NITROGEN MANAGEMENT OF CORN WITH SENSOR TECHNOLOGY

by

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B.S., Kansas State University, 2005
M.S., Kansas State University, 2009

AN ABSTRACT OF A DISSERTATION

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Abstract

Corn (*Zea mays*) is an important cereal crop in Kansas primarily used as livestock feed for cattle in the feedlots, and there has been increased use of corn for ethanol production as well. According to the USDA National Agriculture Statistics approximately 1.7 million hectares of corn is planted each year in Kansas, with an average yield ranging from 5,750-7,750 kg ha^{-1} within the last five years (2005-2009). With this variability in yield and volatility of crop and fertilizer prices over that same period, it seems logical that optimum nitrogen or N rates may vary.

A series of 14 field experiments were conducted across Kansas from 2006 through 2009 to address this issue. Specific experiments included: evaluating optimum N rates from side-dressing nitrogen fertilizer; timing of nitrogen application, pre-plant vs. split applications and normal side-dress V-6-V-9 vs. late side-dress V-14-V-16; N response of corn to a late side-dress of nitrogen fertilizer; and the evaluation of optical sensors for making in season N recommendations.

The specific objectives of this research were to:

a. Determine the optimum N application rate and timing to optimize corn grain yields in different corn producing regions in Kansas.

b. Confirm or revise the current K-State soil test based N recommendation system for corn.

c. Evaluate N management strategies using the GreenSeeker, Crop Circle, and SPAD meter, crop sensors.

d. Develop draft GreenSeeker, Crop Circle, and SPAD sensor algorithms for producers to use.

Grain corn yields were responsive to N at all but 3 sites. Grain yields obtained at the sites ranged from 3,460 to 15,480 kg ha^{-1}. Optimum N rates varied from 0 to 246 kg N ha^{-1}. This work suggests that current K-State N fertilizer recommendations for corn need revisions due to over recommendation of N. Including different coefficients for irrigated and dry land corn along with N recovery terms would create a more accurate N recommendation system that more closely reflects the results obtained in these experiments, and provide a significant improvement over the current system. The optical sensors used in this study were effective at making N recommendations for corn. These sensors can be a valuable tool for producers to use and determine in season N status of corn.

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Major Professor
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CHAPTER 1 - Nitrogen Management in Corn Production: Review of Current Literature

Introduction

Corn (*Zea mays*) is an important cereal crop in Kansas primarily used primarily as livestock feed for cattle in the feedlots, although there has been increased use for ethanol production as well. According to the USDA National Agriculture Statistics approximately 1.7 million hectares of corn are planted each year in Kansas, with an average yield ranging from 5,750-7,750 kg ha^{-1} within the last five years (2005-2009). With this variability in yield, plus volatility of crop price and fertilizer price over this same time period, it seems logical that developing fertilization practices that can adjust fertilizer rates mid-season could enhance profitability and nitrogen use efficiency.

The efficient use of nitrogen (N) fertilizer in corn production is important for maximizing economic returns for producers, and minimizing nitrate leaching. Current fertilizer N management practices for corn have lead to nitrate-N being the most common contaminant found in the surface and ground waters of the eastern Corn Belt region of the U.S. (Schilling, 2002; Steinheimer et al., 1998; CAST, 1999). In addition, the amount of biologically reactive N delivered from the land to coastal waters through the Missouri and Mississippi river systems has increased dramatically over the past century (Turner and Rabalais, 1991), and has been a primary factor in causing oxygen depletion of coast waters (Rabalais, 2002). Many current N management practices have resulted in low N use efficiency (NUE), environmental contamination, and public debate about the use of N fertilizers in crop production. The further development of alternative N management practices that maintain crop productivity, improve

NUE, and minimize environmental impact will be of continued importance to sustain production systems worldwide.

The Concept of N Use Efficiency

Nitrogen use efficiency (NUE), commonly defined as the percent of fertilizer N which is recovered or utilized by a fertilized crop, and is estimated to be only 33% for grain production, and about 45% for forage production in the U.S. (Raun and Johnson, 1999). Yet, according to work by Johnston (2000), N fertilizer use has increased yield more in the past few decades than any other agricultural input. Smith et al., (1990) have reported that corn yields would have decreased by 41%, without N fertilizer application.

Nitrogen use efficiency and/or fertilizer recovery in crop production systems can be computed using many different methods. The components of nitrogen use efficiency, as initially discussed by Moll et al. (1982) include the efficiency of absorption or uptake (Nt/Ns) and the efficiency with which N absorbed is utilized to produce grain (Gw/Nt), where Nt is the total N in the plant at maturity (grain+stover), Ns is the nitrogen supply or rate of fertilizer N applied, and Gw is the grain weight (all expressed in the same units). Using the same components as Moll et al. (1982), Varvel and Peterson (1990) calculated the percent of fertilizer recovery by using the difference method. Here the total N uptake in corn from unfertilized plots is subtracted from the total N uptake in corn from the N fertilized plots, and then divided by the rate of fertilizer N applied. The recovery method accounts for the N being supplied by soil and attempts to focus on fertilizer N only. Cassman et al., (2002) discusses these components of NUE as well, however, they also raises the issue of the need for applying adequate N to maintain a reasonable soil N pool for sustainable production. Regardless of which of these systems or concepts is used to measure NUE, utilization of applied fertilizer N is generally low in current corn production systems.

Agricultural inputs have to be managed efficiently, especially during periods of high dry matter production by the crop to maximize yield and profit, and to minimize environmental consequences (Feinerman et al., 1990). There are a number of potential pathways for N losses from agricultural ecosystems. These include: gaseous plant emissions of ammonia; soil denitrification; surface runoff; volatilization of ammonia; and leaching of nitrates (Raun and Johnson, 1999). With the exception of N fully denitrified to N_2, these pathways all can lead to an increased load of biologically reactive N in the environment (Cassman et al., 2002). Continued low NUE in crops could have a drastic impact on land-use and food supplies worldwide (Frink et al., 1999).

Causes of Low NUE for Current N Management Practices

There are a number of causes for low NUE in crops. Two of the most important are the inability to predict the amount of N available from the soil and consequently the amount of fertilizer N that should be added to a crop, and poor synchrony between N supply and N demand. With current management practices that emphasize pre-plant N fertilizer application there is poor synchrony between soil and fertilizer N supply and crop demand (Raun and Johnson, 1999; Cassman et al., 2002; Fageria and Baligar, 2005). For example pre-plant nitrogen for corn production can result in potential nitrogen loss by leaching or denitrification in some environments before plant uptake, as the majority of N uptake occurs after the V-8 growth stage

(40-50 days after planting). Poor synchronization also can be caused by many other factors including:

a. Applications of N made after the primary uptake periods of the crop;

b. Loss of fertilizer N from the soil applied long before the plant was capable of utilizing it through mechanisms such as leaching or denitrification, particularly from fall or spring preplant applications of fertilizer.

c. Immobilization, runoff, or volatilization losses of pre-plant, surface applied N fertilizers, particularly in high residue management systems.

To increase NUE in crops, several approaches have been taken. These include:

a. Appropriate timing of N application(s) which synchronizes N supply with need, but avoids potential periods of high N loss;

b. Proper placement of the fertilizer in the soil to minimize potential loss from immobilization, runoff or volatilization;

c. The use of specific fertilizer sources or additives to minimize loss through leaching, denitrification or volatilization;

d. The use of crop sensors during appropriate portions of the growing season to better estimate soil contributions to N supply available to the crop and determine additional fertilizer N need.

Nitrogen Recommendation Systems

The current Kansas State University N recommendation for corn, as with many other systems used in the U.S., considers several components to calculate an N recommendation. These components include a yield goal or expected yield term to determine overall N need by the crop, from which expected soil N supply, estimated from mineralization of soil organic matter (SOM) and previous crop residue, and soil profile nitrate-N, is subtracted. The balance is the fertilizer N recommendation. For corn the N recommendation equation is:

N needed in kg ha^{-1} = (Yield Goal Mg ha^{-1} × 25.5) – (g kg^{-1} SOM × 2.2) +/- (Previous Crop Adjustments) – (Soil Profile Nitrate-N) – (Manure N) – (Other N Adjustments).

The problem with this approach is that both yield and N provided through mineralization are strongly impacted by in-season weather. USDA National Agriculture Statistics show average yields for Kansas ranged from 5,750-7,750 kg ha^{-1} over the last five years (2005-2009). This variability in yield makes the determination of crop N need difficult, especially prior to planting. Determining soil N supply is also difficult. While the recommendation system is designed to utilize a profile nitrate-N soil sample to a depth of 0.6 meters, records of the KSU Soil Testing Lab indicate that less than 10% of the samples submitted for corn fertilizer recommendations include a profile sample for N, and only about 20% request soil organic matter tests. As a result the vast majority of the N recommendations made use generalized default values for profile nitrate-N and SOM, significantly reducing the accuracy of the N recommendation. The release of N through mineralization of SOM and crop residue is also quite variable and depends on soil moisture and temperature. If the soil is cool and dry, there will be less release than if the soil is warm and moist throughout the growing season. The other components including manure N and previous crop adjustments also exhibit variability.

Another important factor that is not currently included in the KSU N recommendation is fertilizer recovery or N use efficiency (NUE). Currently NUE or fertilizer recovery, is built into the crop N need coefficient, and assumes a fertilizer recovery of 50%. Considerable research has shown that recovery varies as a function of N rate, fertilizer source used, timing and method of application and many other factors. Thus being able to adjust N rate when using more efficient N management practices, or for sites less prone to N loss would be advantageous as it would reduce N recommended and over fertilization.

N Fertilizer Placement

Nitrogen fertilizers must be applied in a method that ensures a high level of N availability to the crop, and high NUE. Several studies (Eckert, 1987; Fox and Piekielek, 1987; Fox et al., 1986; Maddux et al., 1984; Bandel et al., 1980; Mengel et al., 1982) have examined placement methods for no-tillage corn production. They all reported that broadcast applications of UAN-N (urea-ammoniaum nitrate solutions) produced lower yields than injected or knifed UAN with surface-banded UAN solutions intermediate in performance. Possible N loss mechanisms noted with broadcast UAN includes ammonia volatilization from the urea component of the solution and immobilization of N in the surface residue. Thus, fertilizer placement below the soil surface should be more effective than broadcasting or banding fertilizers on the soil surface, both in ensuring quick availability and in enhancing N use efficiency.

N Fertilizer Timing

Having adequate N available to the crop early to ensure high yield potential, and having adequate N remaining late in the season are both important for optimum corn yield. Applying no N or minimal N rates at planting, can result in reduced yield potential through inadequate ear size and reduced seed numbers. The greater the N deficiency of the site, the earlier N must be applied to obtain maximum grain yields. Maximum yield can still be obtained even when N is applied as late as the R-1 growth stage, provided the level of N deficiency at early stages, when yield potential is fixed, is small. If nitrogen deficiency occurs late, a grain yield response to N fertilizer can still be seen as late as the R-3 growth stage. The magnitude of the response to late season N will be greater if N deficiency is greater, however, maximum grain yields may not be achieved (Binder et al., 2000).

The Use of Optical Crop Sensors

Using the proper timing and placement of fertilizer N does little to enhance efficiency and crop yields if a producer does not know both the amount of N needed by the crop, and N supply available in the soil. Determining N need and N supply is very difficult in any crop because of the large influence of weather on both. In corn production this is especially important as the yield, and subsequent N need can vary widely from year to year. A new tool slowly gaining adoption to help producers determine N need and N supply is the use of optical crop sensors. These crop sensors were developed based on research which has shown that indices based on red/near infrared ratios can be used to estimate leaf area index, green biomass, crop yield potential, and canopy photosynthetic capacity (Araus, 1996). The use of reflectance at 430, 550, 680 nanometers or nm, and near infrared wavelengths > than 780nm have shown potential for assessing N status in wheat (Filella et al., 1995). Recent advances in technology have resulted in instruments that use these concepts to help increase NUE in crops. Some of these instruments that are currently available include: the SPAD Chlorophyll Meter (Konica Minolta, Inc, Tokyo, Japan) the GreenSeeker hand held optical sensor (NTech Industries, Ukiah, CA), and the Crop Circle ACS-210 hand held optical sensor (Holland Scientific, Lincoln, NE). These crop sensors rely on crop reflectance to determine N status in plants, since absorption of photosynthetic wavelengths is related to the concentration of photo pigments and N content. Both the GreenSeeker and Crop Circle are also currently marketed as applicator mounted, on the go systems for variable rate N applications.

Crop reflectance is defined as the ratio of the amount of radiation that is reflected by an individual leaf or leaf canopy to the amount of incident radiation (Shroder et al., 2000). Plants that are dark green in color will typically exhibit very low reflectance and transmittance in the visible region of the spectrum due to strong absorption by photosynthetic tissue and plant pigments (Chappelle et al., 1992). The pigments involved in photosynthesis (chlorophyll a and b) absorb visible light selectively. They absorb mainly the blue and red wavelengths of the visible spectrum, reflecting the green. Therefore, reflectance measurements at these wavelengths can potentially give a good indication of leaf greenness. On the contrary, reflectance and transmittance are usually high in the near-infrared (NIR) region of the spectrum (700-1400 nm) because there is little absorption by the photosynthetic tissue and plant pigments (Gausman, 1974; Gausman 1977; Slaton et al., 2001). Near infrared light is more strongly absorbed by the soil than the crop, so reflectance measurements that use these wavelengths can also provide information on the amount of leaf area relative to the amount of uncovered soil. The color of the crop is not just determined by the color of the leaves. The color of the soil, moistness of the leaves, cloud cover, and temperature can also influence the readings obtained with these sensors. Nonetheless, combinations of reflectance in different wavelengths are used to estimate biophysical characteristics of vegetation. A vegetation index can be derived from reflectance with respect to different wavelengths, which could be a function of chlorophyll content in the leaves, leaf area index, green biomass, or some different background scattering. Several vegetation indexes for this estimation of biophysical characteristics of vegetation stands have been proposed. The Normalized Difference Vegetation Index (NDVI) has shown to be a very good estimator of the fraction of photosynthetically active radiation absorbed (Blackmer et al., 1996a; Osborne et al., 2002; Stone et al., 1996). NDVI is the difference between the NIR and visible reflectance, which may be red, green, or amber, divided by the sum of these two reflectance values. Thus, it seems logical that the use of these real-time crop sensors could have huge potential in agriculture.

Remote sensing previously has been largely used in natural resources management for land cover estimates, biomass estimation, and to note changes in land uses (Deering et al., 1975; Sala et al., 2000; Kogan et al., 2004; Henebry et al., 2005). Within the last decade, attempts have been made to adopt this approach to commercial agriculture with some success. Several studies have shown good relationships between spectral reflectance, chlorophyll content, and N status in green vegetation (Bausch and Duke, 1996; Stone et al., 1996; Blackmer et al., 1996a; Osborne et al., 2002). In addition, other techniques have been developed using the SPAD chlorophyll meter, color photography, or canopy reflectance factors to assess spatial variation in N concentrations across growers' cornfields (Schepers et al., 1992; Blackmer et al., 1993; Blackmer et al., 1994; Blackmer et al., 1996a; Blackmer et al., 1996b; Blackmer and Schepers, 1996; Schepers et al., 1996). The SPAD chlorophyll meter estimates the amount of chlorophyll present in a leaf by clamping the meter over the leaf to receive an indexed chlorophyll content reading (0-99.9). This chlorophyll content is well correlated with nitrogen concentrations in the leaf. The concept of “spoon feeding” N to the crop on an “as needed” basis (Schepers et al., 1995) is intended to enhance the efficiency of N fertilization and reduce the potential for environmental contamination by N in corn production. This strategy is based on results obtained using a SPAD chlorophyll meter to monitor crop N status and applying fertilizer N “as needed” by fertigation, the application of N through irrigation water. With this approach, chlorophyll readings of well fertilized reference strips, normally 1.3 times the normal recommended N rate, are compared to chlorophyll readings where possible fertilizer N is needed. A sufficiency index (SI) is calculated by the following equation: ((SPAD reading of field area/ SPAD reading of reference strip) *100%)). It is believed that when the sufficiency index (SI) is less than 95% that fertilizer N is needed. Using this strategy from V8 to R1, Ritchie et al. (1986) and Varvel et al. (1997) were able to maintain crop yield with less fertilizer N when compared to a uniform rate of 200 kg ha^{-1}.

Although most of the work with the SPAD meter has been done in irrigated corn, research has occurred in other crops. For example, a study in Asia found that a well fertilized reference strip and a chlorophyll meter may be used as an indicator of in-season N status on irrigated rice (Hussain et al., 2000). In addition, this study found that the SI approach proved adaptable to different seasons, soil types, and cultivars. The authors obtained similar yields with less N fertilizer than with fixed N-timing treatments 90% of the time when a threshold SI of 90% was used and 35 kg N ha^{-1} was added whenever the SI dropped below 90%. Another study found that chlorophyll meter readings correlated well with N concentrations in potato leaves in the Netherlands (Vos and Bom, 1993). The use of the SPAD strategy has proven to be highly efficient in N use, but it is not very practical when growers have a large number of hectares to fertilize in a short period of time. In addition, there are problems associated with the sufficiency index related to how much N is really needed. These issues have limited the use of the SPAD meter.

Bausch and Duke (1996) developed an N reflectance index (NRI) from green and NIR reflectance of an irrigated corn crop. The NRI was highly correlated with the SPAD based sufficiency index, and provided rapid assessment of corn plant N status for mapping purposes. A study using the NRI to monitor in-season plant N resulted in a 39 kg ha^{-1} reduction in applied N using fertigation, without reducing grain yield (Bausch and Diker, 2001). With this index being based on the plant canopy instead of individual leaf measurements like the SPAD meter, it has the potential for larger scale applications and direct input into variable rate fertilizer application technology. Shanahan et al. (2003) found that Green NDVI was well correlated with SPAD readings for corn at V11 and could be used for determining N rates on the go. However, work done by Osborne et al. (2002) showed that optimum wavelengths for estimating crop biomass, nitrogen concentration, grain yield, and chlorophyll meter readings shift with growth stage and sampling date, especially when working with N and water stress. Their work found difficulty in assessing crop N need using the NRI and Green NDVI approaches on a large scale basis where large variability in yield exists, and in crops that have a lower biomass production than irrigated corn. They concluded that the use of a wavelength that provided an indicator of field greenness, as well as the use of NIR to get biomass could be a better fit.

Raun et al (2001, 2002) proposed the use of optical sensors for in-season N management in winter wheat fields. Their work was done using the GreenSeeker hand held optical sensor, which uses light emitting diodes (LED) to generate light in the red and near infrared bands (NIR). This method of using light in the red and NIR bands gives not only an indication of plant biomass, but also, an indication of plant greenness. Their approach divides NDVI by Growing Degree Days (GDD), or heat units, accumulated at time of sensing (also called in-season estimate of yield (INSEY)) to estimate top-dress N rates. This in-season method for estimating top-dress N rates is based on yield estimated from early-season sensor data rather than pre-season “yield goals”. The in-season top-dress N rate is estimated by subtracting the projected N uptake for the predicted yield in the sensor area, from the projected N uptake in the non-N limiting reference strip, and then dividing by an efficiency factor. Early work in winter wheat showed that N uptake of winter wheat and NDVI are highly correlated (Stone et al., 1996). Further work has shown that yield potential can be predicted accurately about 50% of the time by the Greenseeker when readings are taken at the Feekes 5 growth stage. When fertilizing wheat based on yield potential and having the ability to apply variable rate fertilizer N, plant N use efficiency was increased by 15 percentage points as opposed to traditional fertilizer application methods (Raun et al., 2002).

In spring wheat, correlations between sensor data and grain yield have not been nearly as good as in winter wheat. In addition, correlations between sensor readings and nitrogen uptake have also not been as good, though certain varieties have had better correlations than others (Osborne et al., 2006). Work in corn, has shown that grain yield and NDVI were best correlated at the V8 growth stage. Categorizing sensor data by GDD did not improve the correlation, however, it did extend the critical sensing window two leaf stages (Teal et al., 2006). A more recent study found that when corn was younger and smaller, the sensor has the ability to detect more soil area in areas of lower yielding plants compared to higher yielding plants. Conversely, at later stages of growth, corn plants were taller which required increased elevation of the sensor, and soil background had a diminished influence on NDVI. This resulted in NDVI explaining

64% of the variation in N uptake at early growth stages. However at later growth stages, NDVI was not as well correlated with N uptake (Freeman et al., 2007).

The GreenSeeker and Crop Circle sensors are currently commercially available for on the go N applications in grain crops. While acceptance has been good, it does have some limitations. One major limitation is that NDVI saturates, or reaches maximum values, once the leaf area index is greater than 2 (Gitelson et al., 1996; Myneni et al, 1997). This presents problems when trying to use this sensor in high biomass production crops such as irrigated corn.

The objectives of this research were:

a. To determine the optimum N application rate and timing to optimize corn grain yields in Kansas.
b. To confirm or revise the current K-State soil test based N recommendation system for corn.
c. To evaluate N management strategies using the GreenSeeker, Crop Circle, and Spad sensors.
d. To develop draft GreenSeeker, Crop Circle, and Spad sensor algorithms for producers to use.

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CHAPTER 2 - Response of Corn to Nitrogen Fertilization in Kansas

Abstract

Corn (*Zea mays*) is an important cereal crop in Kansas used primarily as livestock feed for cattle in the feedlots, although there has been increased use of corn as a feedstock for ethanol production as well in recent years. According to the USDA National Agriculture Statistics, approximately 1.7 million hectares of corn are planted each year in Kansas, with an average yield ranging from 5,750-7,750 kg ha^{-1} over the last five years. With this variability in yield and volatility of crop and fertilizer price over that same period, it seems logical that the economic optimum N rates may vary also.

A series of 14 field experiments were conducted across Kansas from 2006 through 2009 to address this issue. Specific experiments included: evaluating optimum N rates from side-dressing nitrogen fertilizer; timing of nitrogen application, pre-plant vs. split applications and normal side-dress at V-6 toV-9 vs. late side-dress at V-14 to -V-16.

Grain corn yields were responsive to N at all but three sites tested. Grain yields obtained at the sites ranged from 3,460 to 15,480 kg ha^{-1}. Optimum N rates varied from 0 to 246 kg N ha^{-1}. This work suggests that current KSU N fertilizer recommendations for corn need revisions to reduce over fertilization. This research further suggests that including coefficients to separate irrigated and dry land corn, along with the addition of a nitrogen recovery term would create a more accurate N recommendation system and provide a significant improvement over the current system.

Introduction

Corn (*Zea mays*) is an important cereal crop in Kansas primarily used as livestock feed for cattle in the feedlots, and as a feedstock for ethanol production. USDA National Agriculture Statistics show that approximately 1.7 million hectares of corn are planted each year in Kansas, with an average yield ranging from 5,750-7,750 kg ha^{-1} within the last five years (2005-2009). With this variability in yield, plus volatility of crop and fertilizer price over this same time period, it seems logical that developing fertilization practices that would allow farmers to adjust fertilizer rates mid-season could enhance profitability and nitrogen use efficiency.

The efficient use of nitrogen (N) fertilizer in corn production is important for maximizing economic returns for producers, and minimizes nitrogen loss and environmental contamination. Current fertilizer N management practices for corn have lead to nitrate-N being the most common contaminant found in the surface and ground waters of the region (Schilling, 2002; Steinheimer et al., 1998; CAST, 1999). In addition, the amount of biologically reactive N delivered from the Corn Belt area to the Gulf of Mexico coastal waters via the Mississippi River has increased dramatically over the past century (Turner and Rabalais, 1991), and has been a primary factor in causing oxygen depletion of these coastal waters (Rabalais, 2002). Commonly used N management practices have resulted in low N use efficiency (NUE), environmental contamination, and public debate about the use of N fertilizers in crop production. The development of alternative N management practices that maintain crop productivity, improve NUE, and minimize environmental impact will be of continued importance to crop production systems and people worldwide.

Nitrogen use efficiency (NUE), defined as the percent of fertilizer N applied which is recovered or utilized by a fertilized crop, is estimated to be only 33% for grain production, and about 45% for forage production in the U.S. (Raun and Johnson, 1999). Yet, according to work by Johnston (2000), N fertilizer use has increased yield more in the past few decades than any other agricultural input. Smith et al., (1990) reported that corn yields would have decreased by 41%, without N fertilizer application over this same period.

Nitrogen use efficiency and/or N fertilizer recovery by crop production systems can be computed using many different methods. The components of nitrogen use efficiency, as initially discussed by Moll et al. (1982) include the efficiency of absorption or uptake (Nt/Ns) and the efficiency with which absorbed N is utilized to produce grain (Gw/Nt), where Nt is the total N in the plant at maturity (grain+stover), Ns is the nitrogen supply or rate of fertilizer N applied, and Gw is the grain weight (all expressed in the same units). Using the same components as Moll et al. (1982), Varvel and Peterson (1990) calculated the percent of fertilizer recovery by using the difference method. Here the total N uptake in corn from unfertilized plots is subtracted from the total N uptake in corn from the N fertilized plots, and then divided by the rate of fertilizer N applied, as a means of estimating and accounting for the native N supply coming from the soil. Cassman et al. (2002) discusses these components as well, however, they raise the additional issue of supplying adequate N through fertilization to maintain a soil N pool for sustainable production. Regardless of how these methods by which NUE is measured, utilization of applied fertilizer N is generally low.

Agricultural inputs such as fertilizers, have to be managed efficiently, especially during periods of high dry matter production by the crop to maximize yield and profit, and to minimize environmental consequences (Feinerman et al., 1990). Pathways for N losses from agricultural ecosystems include: gaseous plant emissions of ammonia; denitrification; surface runoff; volatilization of ammonia; and leaching of nitrates (Raun and Johnson, 1999). With the exception of N fully denitrified to N_2, the remaining pathways all can lead to an increased load of biologically reactive N in the environment (Cassman et al., 2002). Continued low NUE in crops could have a drastic impact on land-use and food supplies worldwide (Frink et al., 1999).

There are a number of causes for low NUE in crops. Two of the most important are the inability to predict the amount of fertilizer N that should be added to a crop and poor synchrony between N supply and N demand. With current management practices that emphasize pre-plant N application there can be poor synchrony between soil N supply and crop demand (Raun and Johnson, 1999; Cassman et al., 2002; Fageria and Baligar, 2005). For example pre-plant nitrogen for corn production can result in potential nitrogen loss by leaching or denitrification in some environments before the majority of nitrogen uptake occurs, after the V-8 growth stage. Poor synchronization also can be caused by many other factors including:

a. Applications of N made after the primary uptake periods of the crop;

b. Loss of fertilizer N from the soil applied long before the plant was capable of utilizing it through mechanisms such as leaching or denitrification, particularly from fall or spring preplant applications of fertilizer; and

c. immobilization, runoff, or volatilization losses of pre-plant, surface applied N fertilizers, particularly in high residue management systems.

To increase NUE in crops, several approaches have been taken. These include:

a. Appropriate timing of N application(s) to synchronize with need but avoid potential periods of high N loss;

b. Proper placement of the fertilizer to minimize potential loss from immobilization, runoff or volatilization;

c. The use of specific sources or additives to minimize loss through leaching, denitrification or volatilization;

d. The use of crop sensors during appropriate portions of the growing season to better estimate soil N contributions to the crop and determine additional fertilizer N need.

The current Kansas State University N recommendation for corn, as with many other systems used in the U.S., considers several components to calculate an N recommendation. These components include a yield goal or expected yield term to estimate overall N need by the crop, from which expected soil N supply, estimated from mineralization of soil organic matter (SOM) and previous crop residue, and soil profile nitrate-N, is subtracted. The balance is the fertilizer N recommendation. For corn the N recommendation equation is:

N needed in kg ha^{-1} = (Yield Goal Mg ha^{-1} × 28.6) – ((g kg^{-1} SOM × 2.2) +/- (Previous Crop Adjustments) + (Soil Profile Nitrate-N) + (Manure N) + (Other N Adjustments)).

The problem with this approach is that both yield and N provided through mineralization are strongly impacted by in-season weather. USDA National Agriculture Statistics show average yields for Kansas ranged from 5,750-7,750 kg ha^{-1} over the last five years (2005-2009). This variability in yield makes the determination of crop N need difficult especially prior to planting. Determining soil N supply is also difficult. While the recommendation system is designed to utilize a profile nitrate-N soil sample to a depth of 0.6 meters, records of the KSU Soil Testing Lab indicate that less than 10% of the samples submitted for corn fertilizer recommendations include a profile sample for N, and only about 20% request soil organic matter tests. As a result the vast majority of the N recommendations made use generalized default values for profile nitrate-N and SOM, significantly reducing the accuracy of the N recommendation. The release of N through mineralization of SOM and crop residue is also quite variable and depends on soil moisture and temperature. If the soil is cool and dry, there will be less release than if the soil is warm and moist throughout the growing season. The other components including manure N and previous crop adjustments also exhibit considerable variability.

Another component that is not currently included in the KSU N recommendation is fertilizer recovery or N use efficiency (NUE). Currently NUE or fertilizer recovery, is built into the crop N need coefficient, and assumes a fertilizer recovery of 50%. Considerable research has shown that recovery varies as a function of soil, climate, N rate applied, fertilizer source used, timing and method of application and many other factors. Thus, being able to adjust N rate when using more efficient N management practices, or for sites less prone to N loss, would be beneficial.

Nitrogen fertilizers must be applied in a method that ensures a high level of N availability to the crop, and high NUE. Several studies (Eckert, 1987; Fox and Piekielek, 1987; Fox et al., 1986; Maddux et al., 1984; Bandel et al., 1980; Mengel et al., 1982) have examined placement methods for no-tillage corn production. They all reported that broadcast applications of UAN-N (urea-ammoniaum nitrate solutions produced lower yields than injected or knifed UAN with surface-banded UAN solutions intermediate in performance. Possible N loss mechanisms noted with broadcast UAN include ammonia volatilization from the urea component of the solution and immobilization of N in the surface residue. Thus, fertilizer placement below the soil surface should be more effective than broadcasting or banding on the soil surface, both in ensuring quick availability and in enhancing N use efficiency.

Having adequate N available to the crop early to ensure high yield potential, and having adequate N remaining late in the season are both important for optimum corn yield. Applying no N or minimal N rates at planting, can result in reduced yield potential through inadequate ear size and reduced seed numbers. The greater the early N deficiency, the earlier N must be applied to obtain maximum grain yields. Maximum yield can still be obtained, even applying nitrogen as late as the R-1 growth stage, provided the level of N deficiency at early growth stages is small. If nitrogen deficiency becomes present at later stages of growth, a grain yield response can often still be seen with applications made as late as the R-3 growth stage. However, while the magnitude of the N response obtained will be greater as N deficiency becomes more severe, maximum grain yields may not be achieved (Binder et al., 2000). Using the proper timing and placement of fertilizer N does little to enhance efficiency and crop yields if a producer does not know both the amount of N needed by the crop, and N supply available in the soil.

The objectives of this research were:

a. To determine the optimum N application rate and timing to optimize corn grain yields in Kansas.

b. To confirm or revise the current KSU soil test based N recommendation system for corn.

Materials and Methods

A total of 14 site years of data were collected to evaluate the effects of nitrogen rate and nitrogen application timing on grain yield for corn. Research locations were all located in Kansas close to the towns of Colby (2008-2009), Manhattan (2006-2009), Rossville (2007-2009), and Tribune (2007-2009). All experiments were set in the field using a randomized complete block (RCB) design with all treatments being replicated four times. Individual plots were either four or eight rows with rows spaced 76 cm apart and at least 15 m in length. Grain yield was determined at all locations by either hand harvesting 5.25 m of the middle two rows of each plot, and shelling using an Almaco mechanical thresher or by harvesting at least 12 m of the middle two rows of each plot using a plot combine. When starter fertilizer was used it was applied 5 cm to the side of the seed row and 5 cm deep with the planter. Yields were adjusted to standard 155 g kg^{-1} moisture content. Economic optimum N rate at each site was determined by running a linear or quadratic regression analysis using Microsoft Excel, choosing the best model as determined by the adjusted R^2, and solving for the N rate at maximum return to nitrogen at differing price ratios. Additional statistical analyses were run to analyze differences between treatments that were observed using SAS version 9.1 with proc GLM and an alpha of 0.05.

Each block of each main experiment was soil sampled 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 nitrate N when each experiment was initiated. Sampling was done using either a hand probe or a hydraulic probe mounted to a tractor, and samples consisted of 12 to 15 individual cores to form a composite sample. Analysis was performed by the KSU Soil Testing Lab using procedures described in Recommended Chemical Soil Test Procedures for the North Central Region, NCRR Publication no. 221 (1998).

Ear leaves were collected from each plot and analyzed for total N as an indication of N sufficiency at midseason/silking. Total N uptake was estimated by collecting the total above ground vegetation from ten plants at black layer formation, removing the ears and weighing the stover, chopping using a small brush chipper and measuring dry matter and total N on a representative subsample. Nitrogen in the grain was determined by collecting a representative subsample from each plot, drying, grinding, and analyzing for total N. Total N uptake was calculated as the total N content in stover and grain. Harvest index was calculated by taking the amount of grain yield and dividing by the total amount of biomass produced (stover + grain). Total N uptake was measured at the following sites: Colby in 2009, Manhattan in 2006 and 2008, Rossville 2007-2009, and Tribune 2007-2009. All plant analysis was performed by the KSU Soil Testing Lab.

In 2006 a study examining the effect of side-dressed nitrogen rate at the V-8 growth stage was conducted at the KSU Agronomy North Farm (39^0 12’ 51”; 96^0 35’ 29”), on a Kahola silt loam soil. Specific treatments consisted of a no nitrogen check, a pre-plant N application 179 kg N ha^{-1} with an additional 45 kg N ha^{-1} applied as a starter, a starter treatment of 45 kg N ha^{-1}, and starter treatments plus an additional 34-202 kg N ha^{-1} in 34 kg N ha^{-1} increments applied as UAN solution coulter band injected approximately 7.5 cm deep below the residue in the row middles at the V-8 growth stage. This study was no-till planted on April 18, 2006 using Pioneer 33R81 hybrid (Pioneer Hybrids, Johnston, IA) at a seeding rate of 60,500 seeds ha^{-1} into soybean residue from the previous crop year. A starter application of 20 kg P ha^{-1} was applied to all treatments and no additional K fertilizer was applied due to a sufficient soil test.

The study was attempted again in 2007, but weather delays prevented planting in a timely manner so it was not completed. In 2008 the study was completed again at the KSU Agronomy

North Farm on a Kahola silt loam soil. Specific treatments again consisted of a no nitrogen check, a pre-plant N application 179 kg N ha^{-1} with an additional 45 kg N ha^{-1} applied as a starter, a starter treatment of 45 kg N ha^{-1}, and a starter treatments plus an additional 34-202 kg N ha^{-1} in 34 kg N ha^{-1} increments applied as UAN solution coulter banded injected approximately 7.5 cm deep below the residue in the row middles at the V-8 growth stage. This study was no-till planted on April 23 at a seeding rate of 66,690 seeds ha^{-1} into sorghum residue from the previous crop year. Asgrow RX785VT3 (Monsanto, St. Louis, MO) corn was used. A starter application of 20 kg P ha^{-1} was applied to all treatments and no additional K fertilizer was applied due to a sufficient soil test.

In 2007 a three year study was initiated examining the effects of pre-plant N vs. split applied N was conducted at the Kansas River Valley Experiment Field near Rossville (39^0 6' 59"; 95^0 55' 38") on an Eudora silt loam soil and at the Western Kansas Research Center near Tribune (38^0 31' 45"; 101^0 39' 42") on a Ulysses silt loam soil. Both locations had N management strategies involving pre-plant only and split applications. Specific treatments consisted of a starter only treatment of 22 kg N ha^{-1}, total pre-plant N rates of 134, 179, and 224 kg N ha^{-1}, and total split applied N rates of 134, 179, and 224 kg N ha^{-1} where 50% of the N was applied at planting time with the other 50% applied at the V-8 growth stage. All treatments were applied using liquid UAN and injecting it into the soil between the corn rows.

At Rossville soil samples to a depth of 1 m were taken prior to initial treatment application, after each harvest, and then again in the spring prior to planting. This site was supplemental irrigated with sprinkler irrigation to minimize water stress throughout the growing season. Corn was planted in late April (19-21) each year with a target seeding rate of 80,000 seeds ha^{-1} using the DKC 61-69 hybrid (Monsanto, St. Louis, MO). Herbicides were used to control in-season weeds in all plots along with in row cultivation to control volunteer corn. Both preplant residual and post emerge herbicides were used. A starter application of 20 kg P ha^{-1} was applied to all treatments and no additional K fertilizer was applied due to a sufficient soil test. Fall and spring tillage occurred to prepare and warm the seedbed for corn planting the following growing season.

At Tribune, tensiometers were placed at 1.35 and 1.65 m depth in all plots and readings taken approximately weekly during the growing season. Also, porous cup soil solution samplers were placed in each plot at a depth of 1.5 m. However, attempts to collect soil solution samples were unsuccessful because of insufficient soil moisture at that depth, although available water content was above 50%. Soil samples to a depth of 2.4 m were taken prior to initial treatment application and then after each harvest. This site was fully sprinkler irrigated to minimize water stress throughout the growing season. Soil water content was measured throughout the growing season to ensure adequate without excessive irrigation. Corn was planted in early May with a target seeding rate of 80,000 seeds ha^{-1} using the Pioneer 33B54 hybrid. Herbicides were used to control in-season weeds in all plots. A starter application of 20 kg P ha^{-1} was applied to all treatments and no additional K fertilizer was applied due to a sufficient soil test. Fall and spring tillage occurred to prepare and warm the seedbed for corn planting the following growing season.

In 2008 another location was added as a two year study examining the effects of pre-plant N vs. split applied N at the Northwest Kansas Research Center near Colby (39^0 23' 18" ; 101^0 4' 19") on a Keith silt loam soil. Corn was planted in early May with a target seeding rate of 80,000 seeds ha^{-1} using the Pioneer 33H26 hybrid. Herbicides were used to control in-season weeds in all plots. Soil samples to a depth of 1 m were taken prior to initial treatment application, and after the final harvest. This site was flood irrigated to minimize water stress throughout the growing season. A starter application of 20 kg P ha^{-1} was applied to all plots and no additional K fertilizer was applied due to a sufficient soil test. Spring strip tillage occurred to prepare and warm the seedbed for corn planting that growing season.

In 2009 four additional studies were conducted to look at the impact of timing of N application on corn grain yield, N response on corn grain yield applied at the V-16 growth stage, and the response of N application on corn grain yield when it was severely N stressed at the V-16 growth stage. The primary timing study was conducted at the KSU Agronomy North Farm (39^0 12’ 48”; 96^0 35’ 34”), on a Reading silt loam soil. Specific treatments consisted of a starter only treatment of 22 kg N ha^{-1}, and base treatments that had a total of 67 kg N ha^{-1} with an additional 0, 34, 67, or 101 kg N ha^{-1} applied at either the V-8 or V-16 growth stage. There were also two studies conducted to look at N response on corn grain yield applied at the V-16 growth stage. These were conducted on farmer’s fields near St. Mary’s KS (39^0 9’ 40”; 96^0 0’ 14”), on a Rossville silt loam soil and (39^0 8’ 38”; 96^0 0’ 50”), on a Eudora-Bismark silt loam soil. Specific treatments consisted of a pre-plant N application of 78 kg N ha^{-1} with an additional 0, 34, 67, or 101 kg N ha^{-1} applied at the V-16 growth stage. The fourth study was conducted at the Kansas River Valley Experiment Field near Rossville (39^0 6’ 59”; 95^0 55’ 38”) on a Eudora silt loam soil. Specific treatments included a starter only treatment of 22 kg N ha^{-1} with an additional 0, 34, 67, or 101 kg N ha^{-1} applied at the V-16 growth stage. All of these studies were planted in late April at seeding rates of approximately 66,500 seeds ha^{-1} into conventional tilled soil with a previous crop of soybean with the exception of the timing study at Manhattan which was no-till planted into double cropped soybean residue after wheat. The sites on farmer fields and at KRV were supplemental irrigated. A starter application of 20 kg P ha^{-1} was applied to all treatments and no additional K fertilizer was applied due to a sufficient soil test.

Results and Discussion

Side-dressed nitrogen rate study, Agronomy Farm, 2006 and 2008

The results from the 2006 and 2008 studies, conducted at the KSU Agronomy Farm, which were part of a regional project conducted with other universities across the United States, examining the effect of side-dressed nitrogen rate at the V-8 growth stage are summarized in Tables 2.1and 2.2. A significant nitrogen response was seen for total biomass, grain yield, and total N uptake up to a total application of 146 kg N ha^{-1} in 2006. As the total N rate increased beyond that required for maximum yield, the residual N left in the soil after harvest, corn whole plant N concentration, and corn earleaf N concentration increased. There was a trend for higher grain yields past the 146 kg N ha^{-1} rate up to 213 kg N ha^{-1}. Increasing the nitrogen rate past the 146 kg N ha^{-1} rate increased the amount of nitrogen left in the soil profile, which could potentially leach into groundwater. A significant decrease in grain yields occurred at the highest N rate as compared to the 146, 179, and 213 kg N ha^{-1} rate.

Table 2.1 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Agronomy North Farm, 2006.

Pre-plant N	Starter N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
(kg ha^{-1})							(g kg^{-1})			(%)
0	0	0	15290 d	5910 e	102 e	29 e	11.6 bcd	3.8 e	16.6 d	--
0	45	45	16600 cd	7190 d	119 de	28 e	11.4 d	4.2 de	16.7 d	38
0	45	78	18000 bcd	8340 c	138 cd	34 e	11.6 bcd	4.5 cde	20.0 c	46
0	45	112	18380 cb	9360 bc	151 cb	34 e	12.2 abc	4.5 cde	21.1 bc	43
0	45	146	21380 a	10280 ab	174 ab	41 d	11.5 cd	5.2 bcd	21.4 bc	50
0	45	179	19510 ab	10800 a	181 a	53 cd	12.4 ab	5.6 abc	23.2 ab	44
0	45	213	21160 a	11100 a	187 a	81 b	11.8 bcd	5.8 ab	22.5 ab	40
0	45	246	18750 abc	9700 b	179 a	100 a	12.3 ab	6.2 ab	23.9 a	31
224	0	224	20590 ab	10160 ab	194 a	54 c	12.6 a	6.5 a	23.1 ab	41
	Prob > F		0.0014	<.0001	<.0001	<.0001	0.0294	0.0008	<.0001	0.7706
	CV		10.0	7.6	11.4	25.8	4.7	16.2	7.6	36.2
	LSD .05		2755	1016	26	19	0.80	1.20	2.30	NS

In 2008, a significant nitrogen response was seen for total biomass and grain yield to a total application of 249 kg N ha^{-1} the maximum rate used in the study. As the total N rate increased, grain N concentration, corn whole plant N concentration, and corn earleaf N concentration increased. This response in 2008 to a much higher rate of N was likely the result of excessive rainfall in June which resulted in flooding of the site on three separate occasions and created conditions conducive to denitrification.

Table 2.2 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Agronomy North Farm 2008.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Grain N	Stover N	Earleaf N	Plant N Rec.
----------	----------	----------	(kg ha^{-1})	----------	----------	--------	(g kg^{-1})	--------	(%)
0	0	0	7320 e	3460 f	37 e	8.2 c	3.1	15.9 d	--
0	0	45	8990 e	4230 f	45 e	8.4 bc	3.0	16.2 d	19
0	33	78	11100 d	6150 e	65 d	8.6 bc	3.2	18.4 cd	36
0	67	112	12140 cd	6780 de	69 d	8.2 c	3.3	17.7 cd	29
0	101	146	13520 bc	8110 cd	81 d	8.7 bc	3.1	19.4 bc	30
0	134	179	15400 a	10100 ab	110 bc	9.3 bc	4.1	21.4 ab	41
0	168	213	15450 a	10240 ab	109 bc	9.5 b	3.7	21.8 ab	34
0	201	246	16380 a	11640 a	139 a	10.9 a	4.2	22.6 a	41
224	0	224	14940 ab	8840 bc	99 c	9.2 bc	3.7	18.5 cd	28
	Prob > F		<.0001	<.0001	<.0001	<.0001	0.1628	0.0007	0.1529
	CV		9.7	13.8	16.1	7.3	21.0	11.0	35.2
	LSD .05		1811	1159	20	1.0	NS	3.0	NS

A 2006-2008 summary analysis for the Agronomy North Farm location is reported in Table 2.3. A significant nitrogen response for grain yield was seen to 179 kg N ha^{-1}. At this nitrogen rate the nitrogen recovery was 40%.

Table 2.3 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Agronomy North Farm 2006 and 2008.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Grain N	Stover N	Earleaf N	Plant N Rec.
(kg ha^{-1})						(g kg^{-1})			(%)
0	0	0	11300 c	4690 e	70 d	9.9	3.5 c	16.2 d	--
0	0	45	12800 bc	5710 e	82 d	9.9	3.6 c	16.4 d	34
0	33	78	14550 abc	7240 d	102 cd	10.1	3.8 bc	19.2 c	28
0	67	112	15260 ab	8070 cd	110 bcd	10.2	3.9 bc	19.4 c	41
0	101	146	17450 a	9190 bc	128 abc	10.1	4.1 bc	20.4 bc	36
0	134	179	17450 a	10450 ab	145 abc	10.8	4.9 ab	22.3 ab	40
0	168	213	17560 a	10660 a	148 ab	10.6	4.8 ab	22.1 ab	42
0	201	246	18300 a	10660 a	159 a	11.6	5.4 a	23.2 a	37
224	0	224	17760 a	9500 abc	147 ab	10.9	4.9 ab	20.8 bc	36
	Prob > F		0.0023	<.0001	0.0005	0.5365	0.0145	<.0001	0.6209
	CV		23.9	17.0	36.4	16.7	27.4	11.0	39.4
	LSD .05		3780	1440	44	NS	1.2	2.2	NS

Kansas River Valley N Management 2007-2009.

Results from the 2007 of the project at the Kansas River Valley are reported in Table 2.4. A significant nitrogen response was seen for all crop parameters to the first 134 kg N ha^{-1} application. Nitrogen recovery was highest for the 134 kg N ha^{-1} treatment when nitrogen was split applied, as compared with all applied at planting. No differences were seen with all other crop parameters between pre-plant and split applied treatments.

Table 2.4 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Kansas River Valley 2007.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^-[1] in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
----------	----------	----------	($kg\ ha^{-1}$)	----------	----------	----------	----------	($g\ kg^{-1}$)	----------	(%)
0	0	22	13200 b	8290 b	113 b	28	9.7 b	5.4	19.0 b	--
112	0	134	20690 a	13720 a	216 a	46	11.8 a	6.2	28.8 a	77 ab
157	0	179	18280 a	13030 a	199 a	35	11.9 a	6.4	26.7 a	48 c
202	0	224	20740 a	13860 a	236 a	39	12.6 a	6.7	29.4 a	55 bc
45	67	134	19610 a	13970 a	234 a	37	12.8 a	7.3	28.6 a	91 a
67	90	179	19430 a	14030 a	223 a	37	12.4 a	6.5	28.7 a	61 bc
90	112	224	20070 a	13740 a	228 a	47	12.5 a	6.8	27.9 a	52 bc
	Prob > F		0.0041	<.0001	0.0015	0.0506	0.0187	0.1798	0.0048	0.0396
	CV		9.8	6.1	13.1	17.0	7.6	12.1	9.7	23.5
	LSD .05		3300	1410	48	NS	01.6	NS	4.7	27.3
Main Effects Rate		22	13200 b	8290 b	113 b	28 b	9.7 b	5.4 b	19.0 b	NA
		134	20150 a	13840 a	226 a	42 a	12.3 a	6.8 a	28.8 a	84 a
		179	18860 a	13530 a	211 a	36 ab	12.2 a	6.4 a	27.8 a	55 b
		224	20410 a	13800 a	233 a	44 a	12.6 a	6.8 a	28.7 a	53 b
	Prob > F		<.0001	<.0001	<.0001	0.0033	<.0001	0.0115	<.0001	0.0052
	CV		9.1	6.2	13.0	17.3	7.9	11.5	9.1	23.1
	LSD .05		2000	940	31.00	8.00	8.0	1.20	2.30	22.2
Main Effects Timing		Pre-plant	18230	12230	191	37	11.5	6.2	26.0	60
		Split	18100	12510	200	38	11.9	6.5	26.0	68
	Prob > F		0.9181	0.7995	0.7230	0.9639	0.5786	0.3949	0.9904	0.4402
	CV		19.6	21.6	29.6	23.8	13.0	14.5	19.2	32.6
	LSD .05		NS	NS	NS	NS	NS	NS	NS	NS

Results from the 2008 of the project at the Kansas River Valley are reported in Table 2.5. A significant nitrogen response was seen for all crop parameters to the first 134 kg N ha^{-1} while a significant grain yield response was seen to 179 kg N ha^{-1}. Nitrogen recovery was highest for the

134 kg N ha^{-1} treatment when nitrogen was split applied. All crop parameters were similar for pre-plant and split treatments.

Table 2.5 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Kansas River Valley 2008.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
(kg ha^{-1})							(g kg^{-1})			(%)
0	0	22	10010 b	5310 b	58 c	33	8.9 c	3.0 c	12.8 b	--
112	0	134	19060 a	13660 a	165 ab	44	10.6 b	4.7 ab	25.0 a	79
157	0	179	21030 a	14420 a	179 ab	55	10.9 ab	4.5 bc	23.6 a	68
202	0	224	20370 a	14740 a	204 a	56	12.0 a	5.8 a	23.8 a	65
45	67	134	20250 a	13630 a	173 ab	44	11.2 ab	4.3 b	23.3 a	85
67	90	179	19760 a	14780 a	175 ab	42	10.8 b	4.4 b	24.1 a	65
90	112	224	19760 a	14830 a	188 ab	48	11.7 ab	4.5 b	23.2 a	58
	Prob > F		<.0001	<.0001	<.0001	0.3462	0.0016	0.0151	0.0005	0.1142
	CV		8.5	6.6	12.7	26.4	5.8	15.3	10.4	16.4
	LSD .05		2820	1530	37	NS	1.1	1.2	4.1	NS
Main Effects Rate		22	10010 b	5310 c	58 c	33	8.9 c	3.0 b	13.0 b	NA
		134	19660 a	13650 b	169 b	44	10.9 b	4.5 a	24.2 a	82 a
		179	20400 a	14610 a	177 ab	48	10.9 b	4.5 a	23.8 a	66 b
		224	20070 a	14780 a	196 a	52	11.8 a	5.2 a	23.5 a	62 b
	Prob > F		<.0001	<.0001	<.0001	0.0524	<.0001	0.0004	<.0001	0.0117
	CV		8.1	6.2	12.1	25.6	5.3	16.4	9.4	15.1
	LSD .05		1720	910	22	NS	0.7	0.9	2.4	22
Main Effects Timing		Pre-plant	17620	12030	152	47	10.6	4.5	21.3	71
		Split	17450	12140	149	42	10.6	4.1	20.9	69
	Prob > F		0.9328	0.9539	0.9034	0.3396	0.9132	0.3029	0.8529	0.8625
	CV		28.2	36.2	40.9	29.2	12.2	24.8	26.3	20.4
	LSD .05		NS	NS	NS	NS	NS	NS	NS	NS

Results from 2009 at the Kansas River Valley are reported in Table 2.6. During the final year all crop parameters were increased due to nitrogen fertilization, with no difference between pre-plant and split N applications. Nitrogen recovery was highest for the 134 kg N ha^{-1} treatment when nitrogen was split applied while highest grain yields and total N uptake were with 224 kg

N ha^{-1} rate. In addition trends were seen for higher grain yields with split applications at the two lowest N rates.

Table 2.6 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Kansas River Valley 2009.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
(kg ha^{-1})							(g kg^{-1})			(%)
0	0	22	9420 c	5440 c	54 d	31	9.0 c	2.6 b	14.8 b	--
112	0	134	19070 b	12850 b	156 c	47	10.9 b	4.5 a	22.0 a	76
157	0	179	19370 b	13580 ab	164 bc	42	10.9 b	4.8 a	22.0 a	61
202	0	224	21080 a	14690 a	194 a	44	11.7 ab	5.6 a	22.3 a	62
45	67	134	19230 b	13590 ab	163 bc	52	10.8 b	4.9 a	20.4 a	81
67	90	179	19860 ab	14300 a	186 ab	43	11.7 ab	5.7 a	21.9 a	74
90	112	224	20520 ab	14540 a	196 a	52	12.0 a	5.6 a	21.6 a	63
	Prob > F		<.0001	<.0001	<.0001	0.1113	0.0002	0.0054	0.0001	0.0912
	CV		4.9	5.8	10.6	18.3	4.7	16.3	6.1	13.0
	LSD .05		1560	1310	30	NS	0.9	1.4	2.2	NS
Main Effects Rate		22	9420 c	5440 c	54 c	31 b	9.0 c	2.6 c	14.8 b	NA
		134	19150 b	13220 b	159 b	50 a	10.9 b	4.7 b	21.2 a	78 a
		179	19610 b	13940 ab	175 b	43 a	11.3 ab	5.3 ab	21.9 a	67 ab
		224	20800 a	14610 a	195 a	48 a	11.8 a	5.6 a	21.9 a	63 b
	Prob > F		<.0001	<.0001	<.0001	0.0024	<.0001	<.0001	<.0001	0.0287
	CV		4.4	5.9	10.7	17.6	5.0	15.6	6.0	13.2
	LSD .05		920	840	19	9	0.6	0.9	1.5	11
Main Effects Timing		Pre-plant	17240	11640	142	41	10.6	4.4	20.2	66
		Split	17260	11970	150	45	10.9	4.7	19.9	72
	Prob > F		0.992	0.8477	0.7575	0.4200	0.5796	0.5844	0.6830	0.2602
	CV		29.2	34.8	42.1	24.2	11.8	31.5	17.3	15.9
	LSD .05		NS	NS	NS	NS	NS	NS	NS	NS

A 2007-2009 summary analysis for the Kansas River Valley station location is reported in Table 2.7. All crop parameters were again increased by N application. Pre-plant and split applications performed similarly. Nitrogen recovery was highest for the 134 kg N ha^{-1} treatment when nitrogen was split applied. A significant nitrogen response for grain yield was seen to 179 kg N ha^{-1}. There was no statistical difference between pre-plant or split applications.

Table 2.7 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Kansas River Valley 2007-2009.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
(kg ha^{-1})							(g kg^{-1})			(%)
0	0	22	10880 b	6350 c	75 d	31 b	9.2 c	3.6 c	15.5 b	--
112	0	134	19610 a	13410 b	179 c	46 a	11.1 b	5.1 b	25.3 a	77 ab
157	0	179	19560 a	13680 ab	181 c	44 a	11.2 b	5.2 b	24.1 a	59 c
202	0	224	20730 a	14430 a	211 a	46 a	12.1 a	6.0 a	25.2 a	61 c
45	67	134	19700 a	13730 ab	190 bc	44 a	11.6 ab	5.5 ab	24.1 a	86 a
67	90	179	19680 a	14370 a	194 abc	41 a	11.7 ab	5.5 ab	24.9 a	67 bc
90	112	224	20120 a	14370 a	204 ab	49 a	12.1 a	5.6 ab	24.2 a	58 c
	Prob > F		<.0001	<.0001	<.0001	0.0025	<.0001	<.0001	<.0001	0.0006
	CV		8.8	7.5	11.9	20.7	6.0	15.5	10.0	21.4
	LSD .05		1550	920	20	8	0.6	0.8	2.2	14.0
	Main Effects Rate	22	10880 b	6350 c	75 c	31 b	9.2 c	3.7 b	15.5 b	NA
		134	19650 a	13570 b	185 b	45 a	11.4 b	5.3 ab	24.7 a	81 a
		179	19620 a	14030 ab	188 b	42 a	11.5 b	5.4 a	24.5 a	63 b
		224	20430 a	14400 a	208 a	48 a	12.1 a	5.8 a	24.7 a	59 b
	Prob > F		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
	CV		9.1	8.6	12.2	20.6	6.2	15.4	10.3	21.4
	LSD .05		1070	690	13	6	0.5	0.5	1.5	10
	Main Effects Timing	Pre-plant	17690	11970	162	42	10.9	5.0	22.5	66
		Split	17590	12200	166	41	11.1	5.1	22.2	70
	Prob > F		0.9225	0.7817	0.7464	0.8442	0.4548	0.8154	0.7677	0.3795
	CV		24.9	30.0	35.2	25.9	12.0	22.9	21.0	25.9
	LSD .05		NS	NS	NS	NS	NS	NS	NS	NS

Western Kansas N Management 2007-2009.

Results from 2007 at the Western Kansas Research Center are reported in Table 2.8. In the first year of the project at Tribune, total biomass, grain yield, total N uptake, and earleaf N were increased by N applications. A significant nitrogen response was seen to the first 134 kg N ha^{-1}. Nitrogen recovery was highest for the 179 kg N ha^{-1} treatment when nitrogen was applied pre-plant. Grain yields were similar for pre-plant and split N applications.

Table 2.8 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Western Kansas Research Center 2007.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
			(kg ha^{-1})				(g kg^{-1})			(%)
0	0	22	18600 c	10920	158 c	37	11.6	5.1	19.8 b	--
112	0	134	22780 ab	13810	199 ab	29	12.1	5.0	21.3 b	37
157	0	179	25710 a	15480	236 a	59	12.1	6.0	25.3 a	50
202	0	224	22780 ab	13750	204 ab	35	12.6	4.8	24.8 a	23
45	67	134	21360 bc	12690	183 bc	27	11.8	4.9	24.3 a	22
67	90	179	23350 ab	14830	207 ab	48	12.3	4.5	20.4 b	31
90	112	224	24890 ab	15080	233 a	46	12.7	5.3	24.2 a	37
	Prob > F		0.0143	0.0562	0.0079	0.3496	0.6234	0.3766	0.0004	0.3104
	CV		10.7	14.3	13.1	30.2	7.2	17.3	7.4	52.8
	LSD .05		3620	NS	20	NS	NS	NS	2.2	NS
Main Effects Rate		22	18600 b	10920 c	158 c	37	11.6	5.1	19.8 b	NA
		134	22070 a	13250 b	191 b	28	12.0	5.0	22.8 a	30
		179	24530 a	15160 a	221 a	54	12.2	5.2	22.9 a	41
		224	23840 a	14410 ab	219 a	41	12.6	5.0	24.5 a	30
	Prob > F		0.0003	0.0006	0.001	0.3200	0.1031	0.9333	0.0031	0.4397
	CV		11.0	13.6	13.3	42.3	6.5	18.2	10.1	55.2
	LSD .05		2530	1880	27	ns	NS	NS	2.4	NS
Main Effects Timing		Pre-plant	22470	13490	199	42	12.1	5.2	22.8	37
		Split	22050	13380	195	41	12.1	5.0	22.1	31
	Prob > F		0.7322	0.9007	0.7627	0.8442	0.9678	0.4298	0.5195	0.4367
	CV		15.4	18.4	19.1	45.4	7.1	17.4	12.7	55.3
	LSD .05		NS	NS	NS	NS	NS	NS	NS	NS

Results from 2008 at the Western Kansas Research Center are reported in Table 2.9. In the second year of the project at Tribune, total biomass, grain yield, total N uptake, and earleaf N (despite being impacted by hail damage and early season water stress caused by mechanical problems with the irrigation well) were increased by N applications. A significant nitrogen response was seen to 179 kg N ha^{-1} when nitrogen was applied pre-plant. Grain yields were similar for pre-plant and split N applications.

Table 2.9 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Western Kansas Research Center 2008.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Grain N	WP N	Earleaf N	Plant N Rec.
-------------	-------------	------------- (kg ha^{-1})	-------------	-------------	-------------	-------------(g kg^{-1})	-------------	-------------	(%)
0	0	22	11130 c	6650 c	104 d	13.2	5.1	14.2 b	--
112	0	134	14590 ab	9530 b	137 c	12.9	5.0	21.4 a	29
157	0	179	17660 a	11730 a	181 a	13.7	5.8	21.5 a	49
202	0	224	14500 ab	9780 ab	162 abc	14.1	7.4	21.7 a	29
45	67	134	13910 ab	9160 b	137 c	13.4	5.3	21.9 a	29
67	90	179	15180 ab	10350 ab	158 abc	13.6	6.1	22.4 a	34
90	112	224	15860 ab	10540 ab	171 ab	13.7	7.2	22.1 a	33
	Prob > F		0.0143	0.0256	0.0079	0.6234	0.3766	0.0004	0.3104
	CV		10.7	14.3	13.1	7.2	17.3	7.4	52.8
	LSD .05		3620	NS	20	NS	NS	2.2	NS
Main Effects Rate		22	11130 b	6650 b	104 c	13.2	5.1	14.2 b	NA
		134	14250 a	9350 a	137 b	13.2	5.1	21.6 a	30
		179	16420 a	11040 a	170 a	13.7	6.0	22.0 a	41
		224	15180 a	10160 a	167 a	13.9	7.3	21.9 a	30
	Prob > F		0.0002	0.0004	0.001	0.1031	0.9333	0.0027	0.4567
	CV		12.5	15.6	13.3	6.5	18.2	10.1	56.2
	LSD .05		2560	1920	28	NS	NS	2.6	NS
Main Effects Timing		Pre-plant	14470	9420	146	13.5	5.8	19.7	36
		Split	14020	9180	143	13.5	5.9	20.2	32
	Prob > F		0.7322	0.9007	0.7627	0.9678	0.4298	0.5195	0.4367
	CV		15.4	18.4	19.1	7.1	17.4	12.7	55.3
	LSD .05		NS	NS	NS	NS	NS	NS	NS

Results from 2009 at the Western Kansas Research Center are reported in Table 2.10. In the final year of the project at Tribune, total biomass, grain yield, total N uptake, residual, whole plant N, and earleaf N (despite being impacted by slight hail damage) were increased by N applications. A significant nitrogen response was seen to the 179 kg N ha^{-1} rate, especially where nitrogen was applied pre-plant. However, no significant main effects of N timing on grain yields were observed.

Table 2.10 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Western Kansas Research Center 2009.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
----------------------	----------------------	----------------------	(kg ha^{-1})	----------------------	----------------------	----------------------	--------------	(g kg^{-1})	--------------	(%)
0	0	22	13050 c	8580 d	109 c	13	11.0	4.7 c	14.9 d	--
112	0	134	19000 ab	12400 bc	152 bc	47	10.7	4.5 c	19.3 c	38
157	0	179	20850 a	14400 a	186 ab	27	11.4	5.4 bc	21.1 ab	49
202	0	224	20260 ab	13100 abc	199 a	50	12.2	6.9 ab	22.5 a	45
45	67	134	18090 b	12050 c	145 bc	25	10.3	4.9 c	19.9 bc	32
67	90	179	20590 ab	13870 abc	187 ab	43	10.9	6.6 ab	20.7 bc	50
90	112	224	20730 ab	14240 ab	207 a	36	12.1	7.1 a	21.1 ab	49
	Prob > F		0.0001	0.0001	0.0024	0.5261	0.2155	0.0073	<.0001	0.7364
	CV		9.8	10.6	17.9	83.9	10.0	18.9	5.7	44.5
	LSD .05		2750	1990	45	NS	NS	1.6	1.7	NS
Main Effects Rate		22	13050 c	8580 c	109 c	13	11.0 b	4.7 b	14.9 c	NA
		134	18540 b	12220 b	148 b	36	10.5 b	4.7 b	19.6 b	35
		179	20720 a	14130 a	187 a	35	11.1 ab	6.0 a	20.9 a	50
		224	20490 a	13670 a	203 a	43	12.1 a	7.0 a	21.8 a	47
	Prob > F		<.0001	<.0001	<.0001	0.1520	0.0273	0.0001	<.0001	0.2529
	CV		10.1	11.3	17.0	83.4	9.0	17.6	5.8	41.0
	LSD .05		1890	1410	28	NS	1.0	1.0	1.2	NS
Main Effects Timing		Pre-plant	18290	12120	161	34	11.3	5.4	19.4	44
		Split	18110	12180	162	29	11.0	5.8	19.1	44
	Prob > F		0.86	0.9463	0.9824	0.6184	0.5134	0.4020	0.3919	0.9488
	CV		20.9	22.3	29.5	88.6	10.3	25.2	16.1	43.0
	LSD .05		NS	NS	NS	NS	NS	NS	NS	NS

A 2007-2009 summary analysis for Western Kansas Research Center was performed and is reported in Table 2.11. All crop parameters were increased by N application. Pre-plant and split applications performed similarly. A significant nitrogen response was seen to 179 kg N ha^{-1} for corn grain yields. At this site, the 179 kg N ha^{-1} treatment consistently performed better than all other treatments, with higher N uptake, and yield. The question this raises is are these results a reflection of the superiority of that treatment or some residual effect from past work done on the site.

Table 2.11 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Western Kansas Research Center 2007-2009.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
----------	----------	----------	---------- (kg ha^{-1})	----------	----------	----------	----------	----------(g kg^{-1})	----------	(%)
0	0	22	15760 c	8710 c	123 c	13	11.9	5.0 bc	16.3 d	--
112	0	134	20790 ab	11920 b	162 abc	47	11.9	4.8 c	20.7 c	35
157	0	179	23620 a	13870 a	200 a	27	12.4	5.7 ab	21.2 bc	49
202	0	224	21180 ab	12220 ab	187 ab	50	12.9	6.4 ab	23.0 a	32
45	67	134	19650 b	11290 b	154 bc	25	11.9	5.0 bc	22.0 abc	28
67	90	179	21730 ab	13020 a	182 ab	43	12.2	5.7 ab	21.2 bc	38
90	112	224	22630 a	13280 a	202 a	36	12.8	6.5 a	22.4 ab	40
	Prob > F		0.0001	0.0001	0.0024	0.5261	0.2155	0.0073	<.0001	0.7364
	CV		9.3	10.1	17.0	79.7	9.5	18.0	5.4	42.3
	LSD .05		2610	1890	43	NS	NS	1.5	1.6	NS
Main Effects Rate		22	14260 c	8710 c	123 c	13	11.9 b	50. b	16.3 c	NA
		134	18290 b	11610 b	159 b	36	11.9 b	4.9 b	21.3 b	32
		179	20560 a	13440 a	193 a	35	12.3 ab	5.7 ab	21.9 ab	44
		224	19840 ab	12750 ab	196 a	43	12.9 a	6.4 a	22.7 a	36
	Prob > F		<.0001	<.0001	<.0001	0.1520	0.0254	0.0001	<.0001	0.2529
	CV		9.6	10.7	16.2	79.2	8.6	16.7	5.5	40.3
	LSD .05		1800	1340	27	NS	0.9	1.0	1.1	NS
Main Effects Timing		Pre-plant	18410	11680	169	38	12.3	5.5	20.6	39
		Split	18060	11580	167	35	12.2	5.6	20.5	36
	Prob > F		0.86	0.9463	0.9824	0.6184	0.5134	0.4020	0.3919	0.9488
	CV		20.9	22.3	29.5	88.6	10.3	25.2	16.1	43.0
	LSD .05		NS	NS	NS	NS	NS	NS	NS	NS

Northwestern Kansas N Management 2008-2009.

Results from 2008 at the Northwest Kansas Research Center are reported in Table 2.12. All crop parameters were similar among treatments and no nitrogen response for grain yield was seen during the initiation year. This was primarily due to the high soil nitrate levels measured prior to initiation of the study (Appendix table A.21).

Table 2.12 Effect of nitrogen treatment on, grain yield, grain N, and earleaf N concentration, Northwest Kansas Research Center 2008.

Pre-plant N	Side-dress N	Total N	Grain Yield	Grain N	Earleaf N
(kg ha^{-1})				(g kg^{-1})	
0	0	22	11790	13.6	21.4
112	0	134	11980	12.2	23.1
157	0	179	12170	13.0	22.3
202	0	224	11790	14.0	25.0
45	67	134	11850	12.5	23.6
67	90	179	12980	13.7	23.0
90	112	224	13170	13.5	24.5
	Prob > F		0.4044	0.1699	0.3254
	CV		9.2	7.4	9.4
	LSD .05		NS	NS	NS
Main Effects Rate		22	11790	13.6 a	21.4 b
		134	11930	12.4 b	23.4 ab
		179	12580	13.3 a	22.7 b
		224	12500	13.7 a	24.8 a
	Prob > F		0.4074	0.0315	0.0142
	CV		9.3	6.9	8.2
	LSD .05		NS	0.90	1.9
Main Effects Timing		Pre-plant	11910	13.3	22.7
		Split	12690	13.2	23.7
	Prob > F		0.0556	0.9009	0.1982
	CV		8.8	8.0	9.4
	LSD .05		NS	NS	NS

Results from 2009 at the Northwest Kansas Research Center are reported in Table 2.13. In this year of the project at Colby, total biomass, grain yield, total N uptake, residual, whole plant N, and earleaf N (despite being impacted by slight hail damage) were increased by N applications. A significant nitrogen response for grain yield was seen to the first134 kg N ha^{-1}. Grain yields were similar for pre-plant and split N applications.

Table 2.13 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Northwest Kansas Research Center 2009.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Grain N	WP N	Earleaf N	Plant N Rec.
----------	----------	---------- (kg ha^{-1})	----------	----------	----------	----------(g kg^{-1})	----------	----------	(%)
0	0	22	8750 c	4500 b	69 d	11.7	4.1 c	16.7 c	--
112	0	134	17850 ab	9450 a	177 bc	12.2	7.9 ab	23.7 ab	80
157	0	179	18020 ab	10170 a	185 bc	12.5	8.0 ab	24.4 ab	64
202	0	224	18810 ab	10200 a	205 ab	12.8	9.3 a	25.8 a	60
45	67	134	16630 b	9370 a	156 c	12.1	6.8 b	24.4 ab	64
67	90	179	17270 b	9760 a	178 bc	12.8	7.8 ab	22.4 b	61
90	112	224	19830 a	10210 a	222 a	13.2	9.6 a	25.1 ab	68
	Prob > F		<.0001	<.0001	<.0001	0.3788	0.0027	0.0002	0.4573
	CV		8.9	10.7	13.6	7.7	20.5	9.2	22.1
	LSD .05		2200	1440	34	NS	2.3	3.2	NS
Main Effects Rate		22	8750 c	4500 b	69 c	11.7 b	4.2 c	16.7 b	NA
		134	17240 b	9410 a	167 b	12.1 ab	7.3 b	23.4 a	72
		179	17650 b	9960 a	181 b	12.6 a	7.9 ab	24.1 a	62
		224	19320 a	10210 a	214 a	13.0 a	9.4 a	25.5 a	64
	Prob > F		<.0001	<.0001	<.0001	0.0347	<.0001	<.0001	0.3801
	CV		9.9	10.2	14.0	7.2	20.8	9.3	22.1
	LSD .05		1600	900	23	0.9	1.5	2.2	NS
Main Effects Timing		Pre-plant	15860	8580	159	12.3	7.3	22.6	68
		Split	15620	8460	156	12.5	7.1	22.1	64
	Prob > F		0.888	0.9013	0.9060	0.7306	0.7825	0.7453	0.5310
	CV		30.0	31.5	39.5	8.2	35.2	18.8	22.4
	LSD .05		NS	NS	NS	NS	NS	NS	NS

A 2008-2009 summary analysis for the Northwest Kansas Research Center was performed and is reported in table 2.14. All crop parameters were increased by N application. Pre-plant and split applications performed similarly. A significant nitrogen response for grain yield was seen to 134 kg N ha^{-1}.

Table 2.14 Effect of nitrogen treatment on, grain yield, grain N, and earleaf N, Northwest Kansas Research Center 2008-2009.

Pre-plant N	Side-dress N	Total N	Grain Yield	Grain N	Earleaf N
--- ($kg\ ha^{-1}$)			---	-----------------------($g\ kg^{-1}$)	-----------------------
0	0	22	8140	12.7	19.1 c
112	0	134	10720	12.2	23.4 ab
157	0	179	11170	12.8	23.4 ab
202	0	224	11000	13.4	25.4 a
45	67	134	10620	12.3	24. ab
67	90	179	11390	13.3	22.7 b
90	112	224	11700	13.4	24.8 ab
	Prob > F		0.0634	0.1210	<.0001
	CV		21.2	8.1	9.8
	LSD .05		NS	NS	2.3
Main Effects Rate		22	8140 b	12.6 b	19.0 c
		134	10670 a	12.6 b	23.7 ab
		179	11270 a	13.0 ab	23.0 b
		224	11350 a	13.4 a	25.1 a
	Prob > F		0.0014	0.0243	<.0001
	CV		24.0	8.1	10.2
	LSD .05		1760	0.7	1.6
Main Effects Timing		Pre-plant	10430	12.8	22.6
		Split	10270	12.8	22.8
	Prob > F		0.8278	0.7983	0.8401
	CV		27.0	8.7	14.4
	LSD .05		NS	NS	NS

Timing of nitrogen application, Agronomy Farm, 2009

The results from the 2009 study examining the effect of timing and rate of nitrogen application conducted at the KSU Agronomy Farm are summarized in Table 2.15. A significant nitrogen response was seen for grain yield, grain N, and earleaf N concentration as nitrogen rates were increased. For the V-10 application timing, grain yield, grain N, and earleaf N concentrations all showed a significant response to the highest N rate of 168 kg N ha^{-1} , while at the V-16 growth stage application timing, grain yield, grain N, and earleaf N concentrations showed a significant response to a total application of 134, 168, and 101 kg N ha^{-1} respectively.

Table 2.15 Effect of nitrogen treatment on corn grain yield grain N and, earleaf N concentration, Agronomy Farm, 2009.

Starter N	V-6 N	V-10 N	V-16N	Total N	Grain Yield	Grain N	Earleaf N
--- (kg ha^{-1})--						----------------(g kg^{-1})----------------	
22	0	0	0	22	5960 f	9.2 e	15.4 c
22	45	0	0	67	8340 e	9.6 de	16.6 c
22	45	34	0	101	9920 d	9.9 cde	17.9 bc
22	45	0	34	101	10410 d	10.2 cd	17.1 bc
22	45	67	0	134	10850 c	10.4 c	19.8 ab
22	45	0	67	134	12040 ab	11.6 b	18.0 bc
22	45	101	0	168	11600 bc	12.1 ab	21.5 a
22	45	0	101	168	12950 ab	12.6 a	17.4 bc
		Prob > F			<.0001	<.0001	0.0056
		CV			7.8	5.4	10.6
		LSD .05			1170	0.85	2.8
	Main Effects Rate			22	5960 d	9.2 d	15.4 b
				67	8340 c	9.5 cd	16.6 b
				101	10170 b	10.1 c	17.5 ab
				134	11450 a	11.0 b	18.9 a
				168	12270 a	12.4 a	19.4 a
		Prob > F			<.0001	<.0001	0.0028
		CV			8.6	5.6	11.9
		LSD .05			840	0.6	2.1
	Main Effects Timing			V-10	10790	10.8	19.7 a
				V-16	11800	11.5	17.5 b
		Prob > F			0.0638	0.2006	0.0140
		CV			11.1	11.1	10.9
		LSD .05			NS	NS	1.7

Late application of nitrogen, Kansas River Valley and on farm trials, 2009

Results from the 4 experiments studying a late application of nitrogen at the V-16 growth stage are reported in table 2.16. For the Kansas River Valley (KRV) and Agronomy North Farm (NF) locations a significant response to nitrogen for grain yield was seen to 101 kg N ha^{-1} and 67 kg N ha^{-1} respectively while the on farm locations (Farm 1 & Farm 2) did not respond to nitrogen fertilization. This was probably primarily due to these on farm locations having a pre-plant N application of at least 78 kg N ha^{-1} which was enough to optimize corn grain yields in this year.

Table 2.16 Late application of nitrogen effects on grain yield, Kansas River Valley, Agronomy North Farm, and on farm trials, 2009.

Location	KRV	NF	Farm 1	Farm 2	KRV	NF	Farm 1	Farm 2
V-16 N		Grain Yield				Grain N		
	---- ($kg\ ha^{-1}$) ----				---- ($g\ kg^{-1}$) ----			
0	6400 c	8340 c	11430	10820	9.8	9.5 c	12.6	12.2
34	8200 bc	10410 b	11180	11200	9.4	10.2 c	12.6	11.5
67	9890 b	12040 a	11860	11310	9.9	11.6 b	12.5	11.8
101	12290 a	12950 a	11310	10880	10.8	12.6 a	12.7	11.7
Prob > F	0.0005	<.0001	0.8955	0.677	0.1021	0.0001	0.8723	0.1702
CV	13.4	6.4	11.5	5.9	6.8	5.1	3.1	3.1
LSD .05	1970	1120	NS	NS	NS	0.9	NS	NS

Economics of Nitrogen Fertilization

With the recent volatility in crop and nitrogen fertilizer prices some economic optimum N rates were calculated for selected sites to see how the cost of nitrogen fertilizer would affect the economic optimum N rate and the yield at that given N rate. The following sites of Kansas River Valley (KRV) 2007-2009, Western Kansas (WKS) 2007-2009, and the Agronomy North Farm (NF) 2008 were chosen for this exercise, as these sites had significant nitrogen response but differing nitrogen recoveries, grain yields, response curve shapes and magnitudes of N response (Figure 2.1). Optimum N rates and grain yields at those N rates are summarized in Table 2.17.

Figure 2.1 Effect of nitrogen rate on corn grain yields for KRV 2007-2009, WKS 2007-2009, and NF 2008.

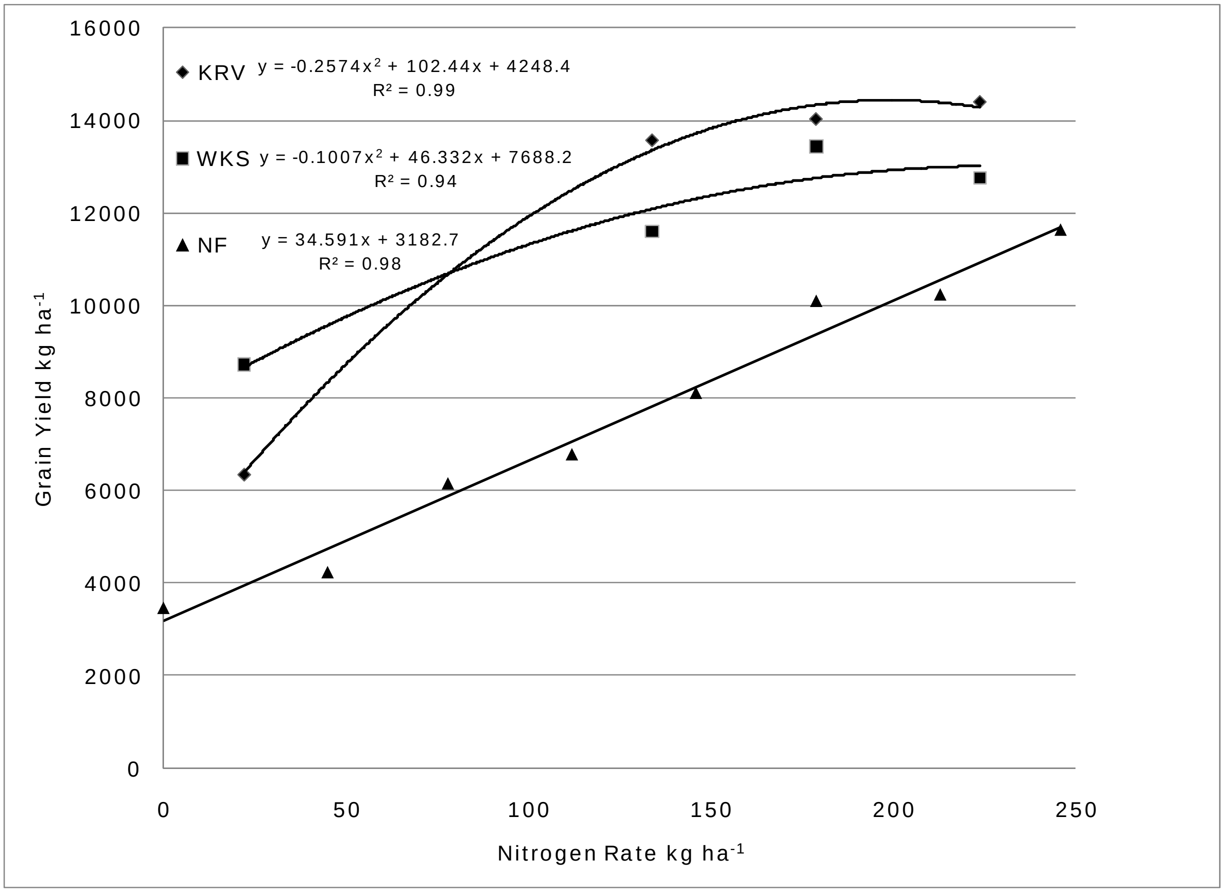

Table 2.17 Effect of grain to nitrogen price ratios on economic optimum N rate and grain yields for KRV 2007-2009, WKS 2007-2009, and NF 2008.

	KRV 2007-2009		WKS 2007-2009		NF 2008	
Grain Nitrogen Price Ratio Price per 100 kg grain : 1kg N fertilizer	Optimum N rate	Grain Yield	Optimum N rate	Grain Yield	Optimum N rate	Grain Yield
	----------	----------	---------- (kg ha^{-1}) ----------	----------	----------	----------
20 to 1	190	14420	206	12940	246	11710
13 to 1	186	14390	196	12890	246	11710
7.3 to 1	172	14250	160	12500	246	11710

When looking at this table it clearly shows that the economic optimum N rate will change depending on the grain to nitrogen price ratios, if the response is defined by a traditional quadratic response as is the case at both the KRV and WKS sites. The difference in response is also increased as the magnitude of N response decreases. As the price of nitrogen fertilizer and corn remains volatile there are some important considerations farmers must realize. If the magnitude of N response is expected to be very large or the response near linear, then the economic optimum N rate is not going to change greatly. But when the magnitude of N response is expected to be small with a non-linear shallow slope then the economic optimum N rate will change more. The response a producer would expect would be influenced by soil N supply and crop need. High profile N tests, or high levels of mineralizable N would suggest limited response. To determine if a producer should expect a large or small response to nitrogen fertilization a profile nitrate test, organic matter content determination and previous crop/management history are necessary. The expected recovery of N, or efficiency of N use will also have a role in the magnitude of expected response. More efficient N fertilization systems, or site sites with low potential for N loss should respond to less N. Including economics into a soil test nitrogen recommendation system may be difficult but in reality as long as farmer tries to use efficient N management practices and applies within 10 kg N ha^{-1} of the economic optimum N rate then the return to nitrogen investment will only differ by a few dollars per hectare.

Potential changes to the KSU corn N recommendations.

Making soil test based nitrogen recommendations for corn can be challenging. The current KSU nitrogen recommendation for corn is given as:

N Rec kg ha^{-1} = (Yield Goal Mg ha^{-1} × 28.6) – ((g kg^{-1} SOM × 2.2) +/- (Previous Crop Adjustments) + (Soil Profile Nitrate-N) + (Manure N) + (Other N Adjustments)).

A review of the first part of the recommendation shows a yield goal times a single coefficient. The use of a single coefficient may not be the best approach for corn for the wide range of yield levels experienced in Kansas. Often, when growing corn, particularly in rain fed systems, we plant utilizing stored soil moisture reserves, and hope to get a precipitation event sometime before grain fill. If a precipitation event does not occur, then we can expect that we will not achieve adequate grain fill, and will be left with a lot of vegetation, but little or no grain. In this situation, it seems logical that the lower yield produced will require more N per Mg ha^{-1} of yield than at higher yield levels when adequate moisture is present. In addition, our ability to recover applied N may be lower at low yield levels than at higher yield levels, since in many cases at low yield levels, water is the primary limiting factor, and nitrate N moves to the plant by mass flow (Barber, 1995). Thus, a higher concentration of nitrate N in the soil solution is required in low rainfall environments than high rainfall environments.

For irrigated corn water as a limiting factor is theoretically removed and therefore corn will have a lower nitrogen requirement per Mg ha^{-1} of yield than in a rain fed system. In addition, the ability to recover applied nitrogen should be higher in an irrigated system as opposed to the rain fed system. To revise the current N recommendation system for corn based off this data it took an average of 14.3 and 16.1 kg N to produce a Mg ha^{-1} of corn grain yield in the irrigated and rain fed systems respectively. In addition, the difference in nitrogen recovery between the irrigated and rain fed systems was 60% and 40% for the irrigated and rain fed systems respectively. Using these average coefficients for N utilization efficiency and N recovery efficiency revised recommendations for N were developed. The revised N recommendation for irrigated corn is:

$$N\ Rec\ kg\ ha^{-1} = [(Yield\ Goal\ Mg\ ha^{-1} \times 14.3) - ((g\ kg^{-1}\ SOM \times 2.2) + (Soil\ Profile\ Nitrate\text{-}N) + (Manure\ N) + (Other\ N\ Adjustments)] / 60\%\ (+/-\ Previous\ Crop\ Adjustments).$$

The revised N recommendation for rain fed corn is:

$$N\ Rec\ kg\ ha^{-1} = [(Yield\ Goal\ Mg\ ha^{-1} \times 16.1) - ((g\ kg^{-1}\ SOM \times 2.2) + (Soil\ Profile\ Nitrate\text{-}N) + (Manure\ N) + (Other\ N\ Adjustments)] / 40\%\ (+/-\ Previous\ Crop\ Adjustments).$$

Using the revised N recommendation formulas, Table 2.18 was developed to compare the current recommendation system with a revised recommendation system using the data from this research. The average observed N response when compared to the current nitrogen recommendation system, the KSU system using default values over estimated N needs by 131 kg N ha^{-1} while the modified nitrogen recommendation system over estimated N needs by 26 kg N ha^{-1}. While this recommendation offers a significant improvement over the current recommendation currently being used, this recommendation will need to be further tested on corn.

Table 2.18 Current and Modified Soil Test Based Fertilizer Recommendations for sites used in the N response experiments in 2006, 2007, 2008, and 2009.

Location	Year	Yield Goal	Observed Yield	Current Rec.	Modified Rec.	Observed N Response	Current minus Observed	Modified minus Observed
		------------------	------------------	------------------	(kg ha^{-1})	------------------	------------------	------------------
KRV	2007	13800	14030	302	175	134	168	41
KRV	2008	13800	14830	318	202	157	161	45
KRV	2009	13800	14690	318	202	179	139	23
WKS	2007	13800	15480	291	157	134	157	23
WKS	2008	13800	11730	316	198	179	137	19
WKS	2009	13800	14400	316	198	179	137	19
NWKS	2008	13800	13170	221	39	0	221	39
NWKS	2009	13800	10210	323	209	157	166	52
Agron	2006	11300	11100	181	168	163	18	5
Agron	2008	11300	11640	251	245	246	5	-1
	Avg.	13300	13130	284	179	153	131	26

Conclusions

In the ten irrigated corn studies conducted for this dissertation, no difference in yield or N response was seen as a result of when N fertilizer was applied. This is contrary to conventional wisdom that suggests side dressing or split application systems are more efficient ways to apply N fertilizers. There are a number of potential reasons why this could occur, but one likely reason is that in a drier environment, particularly in the early parts of the growing season, N loss is minimal. If this lack of response to N timing were to hold over time, this would allow producers more flexibility in applying nitrogen, since applying all the nitrogen pre-plant is the easiest and most cost effective management strategy when yields are very consistent and the irrigation water is managed efficiently to minimize N loss.

However, NUE at some sites was still relatively low, despite a lack of response to delayed application. This may be the fact that N loss is occurring later in Kansas than in the Eastern Cornbelt. Highest monthly rainfall totals tend to be in June in this area, and records indicate precipitation tends to come in large events in summer. This could be leading to N loss through denitrification or leaching later in the season, after most traditional side dress applications are made.

The nitrogen timing studies conducted in 2009 showed that nitrogen can be successfully applied and optimum yields achieved even when N fertilizer is applied late in the growing season. This shows that if there is a slight level of nitrogen stress prior to tassel emergence nitrogen fertilization can be successfully applied to alleviate that stress. Thus if late N loss were to occur, N fertilization could correct the problem.

The current KSU corn N recommendations were found to overestimate N needs by an average of 131 kg N ha^{-1}, in a series of ten N response studies conducted across Kansas. One issue with the current recommendations is a single constant relating the N need per unit of yield, regardless of yield level or expected N use efficiency. By utilizing two constants for irrigated and rain fed corn, plus adding NUE efficiency factors, a modified system greatly improved the recommendations and only overestimated N need by approximately 26 kg N ha^{-1}. While the modified system still has considerable room for improvement, it demonstrates that the constant used in the current system should be modified, and by using nitrogen recovery terms that are commonly observed in those production systems, significant improvements can be made over the current system used.

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CHAPTER 3 - Evaluation of Sensor Based N Management of Corn in Kansas

Abstract

Corn (*Zea mays*) is an important cereal crop in Kansas, primarily used as livestock feed for cattle in the feedlots, although there has been increased use for ethanol production in recent years as well. According to the USDA National Agriculture Statistics approximately 1.7 million hectares of corn is planted each year in Kansas, with an average yield ranging from 5,750-7,750 kg ha^{-1} within the last five years (2005-2009). With this variability in yield and volatility of crop price and fertilizer price, it seems logical that optimum N rates may vary. The objective of this study was to evaluate the use of crop sensor based mid-season N recommendation systems, utilizing a high N reference strip as a control and sensor based estimates of yield potential and soil N supply.

A series of nine field experiments were conducted across Kansas from 2007 through 2009 to evaluate sensor based N recommendations. Specific experiments included evaluating optimum N rates from traditional yield goal and soil test based pre-plant and side dress nitrogen fertilizer recommendations vs. sensor based N recommendation systems. Corn yields were responsive to N at all but 1 of the 9 sites. Yields obtained at the sites ranged from 3,460 to 15,480 kg ha^{-1}. Optimum N rates varied from 0 to 246 kg N ha^{-1}. The sensor based N recommendations used in the study performed well in the majority of experiments, however, there were instances where the sensor based N recommendations underestimated N needs.

Introduction

Nitrogen use efficiency (NUE) is commonly defined as the percentage of applied N recovered or utilized by the target crop. In the United States NUE is estimated to be only 33% for grain production, and about 45% for forage production (Raun and Johnson, 1999). Yet, N fertilizer use has increased crop yield more over the past five decades than any other agricultural input (Johnston, 2000). Smith et al. (1990) suggest that corn yields would decrease by 41% without N fertilizer application. Due to both economic and environmental concerns, agricultural inputs have to be managed efficiently, especially in high production systems (Feinerman et al., 1990).

One of the major reasons for low NUE is loss of applied N from the agricultural system. Pathways for N losses from agriculture ecosystems include: gaseous plant emissions; denitrification; surface runoff; ammonia volatilization; and leaching (Raun and Johnson, 1999). With the exception of N fully denitrified to N_2, these pathways can all lead to an increased load of biologically reactive N into our environment (Cassman et al., 2002). Low NUE in crop production systems could have a drastic impact on land-use and food supplies worldwide if left unaddressed (Frink et al., 1999). A second equally troubling issue is difficulty in estimating soil N supply, particularly prior to planting.

With current management practices that emphasize pre-plant N application there is poor synchrony between soil N supply and crop demand (Raun and Johnson, 1999; Cassman et al., 2002; Fageria and Baligar, 2005). For example pre-plant nitrogen for corn production can result in potential nitrogen loss by leaching or denitrification in some environments prior to plant utilization, since the majority of nitrogen uptake in corn occurs after the V-8 growth stage. Poor synchronization also can be caused by many other factors including:

a. Applications of N made after the primary uptake periods of the crop;

b. Loss of fertilizer N from the soil applied long before the plant was capable of utilizing it through mechanisms such as leaching or denitrification, particularly from fall or early spring preplant applications of fertilizer; and

c. Immobilization, runoff, or volatilization losses of pre-plant, surface applied N fertilizers, particularly in high residue management systems.

To increase NUE in crops, several approaches have been taken. These include:

a. Appropriate timing of N application(s) to synchronize with need but avoid potential periods of high N loss;

b. Proper placement of the fertilizer to minimize potential loss from immobilization, runoff or volatilization;

c. The use of specific sources or additives to minimize loss through leaching, denitrification or volatilization; and

d. The use of crop sensors during appropriate portions of the growing season to better estimate soil contributions to the crop and determine additional fertilizer N need.

The use of crop sensors to provide a rapid estimate of both yield potential and N content of crop plants has the potential to greatly enhance NUE. Early sensor research has shown that indices based on red/near infrared reflectance ratios can provide estimates of leaf area index, green biomass, crop yield, and canopy photosynthetic capacity (Araus, 1996). The use of reflectance at 430, 550, 680 nm, and near infrared wavelengths have shown potential for assessing N status in wheat (Filella et, al. 1995). Recent advances in technology have resulted in instruments that use these concepts specifically to guide N fertilization decisions and help increase NUE in crops. Some of these instruments that rely on crop reflectance at specific wavelengths to determine N status in plants include the SPAD Chlorophyll meter (Konica Minolta Inc, Tokyo, Japan), the GreenSeeker optical sensor (NTech Industries, Ukiah, CA), and the Crop Circle ACS-210 optical sensor (Holland Scientific, Lincoln, NE).

Crop reflectance is defined as the ratio of the radiation of a specific wavelength that is reflected by an individual leaf or leaf canopy to the incident radiation of that wavelength striking the canopy or leaf (Shroder et al., 2000). Plants that are dark green in color will typically exhibit very low reflectance and transmittance in the visible region of the spectrum due to strong absorption of light by photosynthetic tissue and plant pigments (Chappelle et al., 1992). The pigments involved in photosynthesis (chlorophyll a, and b) absorb visible light selectively. These pigments absorb mainly the blue and red wavelengths of the visible spectrum, while reflecting the green fraction. Therefore, reflectance measurements at these blue and red wavelengths can potentially give good indications of leaf greenness. Reflectance and transmittance of light are usually high in the near-infrared (NIR) region of the spectrum (700-1400 nm) because there is little absorption of these wavelengths by the photosynthetic tissue and plant pigments (Gausman, 1974; Gausman 1977; Slaton et al., 2001). A vegetation index can be derived from reflectance with respect to different wavelengths, which could be an indicator of the chlorophyll content of leaves, leaf area index, green biomass, or some other background scattering. The Normalized Difference Vegetation Index (NDVI) has been shown to be a very good estimator of the fraction of photosynthetically active radiation absorbed. The formula for NDVI is:

$$NDVI = (NIR-VIS) / (NIR + VIS),$$

where NIR is the reflectance of a near infrared wavelength and

VIS is the reflectance of a visible wavelength.

The SPAD chlorophyll meter measures the chlorophyll content of a leaf by clamping the meter over the most recently fully developed leaf. An indexed chlorophyll content reading (0-99.9) is provided, measuring the transmittance of two wavelengths of light, 650nm in the visible and 940 nm in the NIR. This chlorophyll reading is well correlated with nitrogen concentrations in the leaf. This meter was used to develop the concept of "spoon feeding" N to the crop on an "as needed" basis through fertigation, or adding N through the irrigation system (Schepers et al., 1995). The intent was enhancing crop yield while maximizing NUE to reduce the potential for environmental contamination by N in irrigated corn production. With this approach, well fertilized reference strips, normally receiving 1.2 to 1.3 times the normal recommended N rate, are strategically placed in the field. Chlorophyll readings are then compared from the reference strip and areas where possible fertilizer N is needed. A sufficiency index (SI) is calculated by the following equation:

SI = (SPAD reading of field area/ SPAD reading reference strip) *100.

It is believed that when the sufficiency index (SI) is less than 100%, additional fertilizer N is needed on the target area. Using this strategy from V8 to R1, Ritchie et al. (1986) and Varvel et al. (1997) were able to maintain crop yield with less fertilizer N when compared to a uniform recommended rate of 200 kg ha^{-1}. The use of the SPAD strategy has proven to be highly efficient in irrigated corn. However it has some limitations in non-irrigated environments where fertigation is not possible. These limits include: being difficult to apply N to a large number of hectares, variably or uniformly, in a short period of time, sampling time to determine how much N is really needed, and receiving adequate moisture to make the N available to the growing crop in non-irrigated production. These issues have limited the use of the SPAD meter in US crop production.

Raun et al., (2001, 2002) proposed the use of active optical sensors for in-season N management in winter wheat fields. Their work was done with the GreenSeeker hand held optical sensor, which uses light emitting diodes (LED) to generate light in the red and near infrared bands (NIR) and also included the use of a reference, or high nitrogen strip or point, in the field. This method of using light in the red and NIR bands gives both an indication of plant biomass, and an indication of plant greenness. Using their approach, one uses the NDVI values generated by the sensor, and the Growing Degree Days (GDD) accumulated at sensing (also called In-Season Yield Estimator (INSEY)) to estimate top-dress N rates. This in-season method for estimating top-dress N rates is based on an estimate of yield potential made from early-season sensor generated plant bio-mass estimates, adjusted for GDD's, rather than a pre-season "yield goal". Thus the impact of plant stand and early growth on yield, in addition to greenness, is considered. The in-season top-dress N rate is calculated by subtracting the projected N uptake for the predicted yield in the sensed area, from the projected N uptake in the non-N limiting reference strip, and then divided by an efficiency factor.

Early work in winter wheat showed that N uptake of winter wheat and NDVI are highly correlated (Stone et al., 1996). Further work done in wheat has shown that yield potential could be accurately predicted 50% of the time by the GreenSeeker when readings were taken at the Feekes 5 growth stage. When fertilizing wheat based on yield potential and having the ability to apply variable rate fertilizer N, plant N use efficiency was increased by more than 15 percentage points when compared to traditional fertilizer application methods (Raun et al., 2002).

In corn, work has shown that grain yield and NDVI were best correlated at the V8 growth stage using an exponential equation. Using the INSEY approach to adjust for early season growing conditions did not improve the correlation; however, it did extend the critical sensing window two leaf stages (Teal et al., 2006). This suggests that using NDVI directly at a specific growth stage would be more accurate for estimating potential grain yield than using an INSEY adjusted NDVI before or after that growth stage, while using INSEY may help extend the critical sensing window.

A more recent study in corn found that when corn was younger and smaller, the sensor has the ability to detect more soil area when sensing areas of lower yielding plants than in areas of higher yielding plants. Conversely, at later stages of growth, corn plants were taller which required increased elevation of the sensor and subsequently soil background had a diminished influence on NDVI. This resulted in NDVI explaining 64% of the variation in N uptake at early growth stages. However, at later growth stages, NDVI was not as well correlated with N uptake (Freeman et al., 2007).

The specific objective of this study was to evaluate optical sensing systems ability to estimate mid-season N needs for corn production using the GreenSeeker, Crop Circle, and SPAD based measurements.

Materials and Methods

A total of nine site years of data were collected to evaluate the effects of nitrogen rate and nitrogen application timing on grain yield for corn. Research locations were all located in Kansas close to the towns of Colby (2008-2009), Manhattan (2006-2009), Rossville (2007-2009), and Tribune (2007-2009). All experiments were set in the field using a randomized complete block (RCB) design with all treatments being replicated four times. Individual plots were either four or eight rows with rows spaced76 cm apart and at least 15 m in length. Grain yield was determined at all locations by either hand harvesting 5.25 m of the middle two rows of each plot, and shelling using an Almaco mechanical thresher or by harvesting at least 12 m of the middle two rows of each plot using a plot combine. When starter fertilizer was used it was applied 5 cm to the side of the seed row and 5 cm deep with the planter. Yields were adjusted to standard 155 g kg^{-1} moisture content. Economic optimum N rate at each site was determined by running a linear or quadratic regression analysis using Microsoft Excel, choosing the best model as determined by the adjusted R^2, and solving for the N rate at maximum return to nitrogen at differing price ratios. Additional statistical analyses were run to analyze differences between treatments that were observed using SAS version 9.1 with proc GLM and an alpha of 0.05.

Each block of each main experiment was soil sampled 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 nitrate N when each experiment was initiated. Sampling was done using either a hand probe or a hydraulic probe mounted to a tractor, and samples consisted of 12 to 15 individual cores to form a composite sample. Analysis was performed by the KSU Soil Testing Lab using procedures described in Recommended Chemical Soil Test Procedures for the North Central Region, NCRR Publication no. 221 (1998).

Ear leaves were collected from each plot and analyzed for total N as indication of N sufficiency at silking. Total N uptake was estimated by collecting the total above ground vegetation of ten plants at maturity, black layer formation, removing the ears, weighing the stalks, chopping the stalks/stover using a lawn chipper-shredder, and measuring dry matter and total N content on a representative subsample. Nitrogen in the grain was determined by collecting a representative subsample from each plot at harvest, drying, grinding, and analyzing for total N. Total N uptake was calculated as the total N content in both the stover and grain. Harvest index was calculated by taking the amount of grain yield and dividing this by the total amount of biomass produced (stover + grain). Total N uptake was measured at the following sites: Colby in 2009, Manhattan in 2008, Rossville 2007-2009, and Tribune 2007-2009. All plant analysis was done by the KSU Soil Testing Lab.

In 2007 a three year study was initiated examining the effects of preplanned pre-plant or split applied N applications vs. sensor based N applications was conducted at the Kansas River Valley Experiment Field near Rossville (39^0 6' 59"; 95^0 55' 38") on an Eudora silt loam and at the Western Kansas Research Center near Tribune (38^0 31' 45"; 101^0 39' 42") on a Ulysses silt loam. In 2008 a third study was added at the Northwest Kansas Research Center near Colby (39^0 23' 18"; 101^0 4' 19") on a Keith silt loam. All locations had ten N management strategies involving pre-plant N only, split applications of N, and variable rate split applications based on active sensor technologies. Specific treatments consisted of a starter only treatment of 22 kg N ha^{-1}, total pre-plant N rates of 134, 179, and 224 kg N ha^{-1}, and total split applied N rates of 134, 179, and 224 kg N ha^{-1} where 50% of the N was applied at planting time with the other 50% applied at the V-8 growth stage. All treatments were applied using liquid urea-ammonium nitrate solutions (UAN) injected it into the soil 8-10 cm deep between the corn rows. In addition three variable rate treatments were used based on recently developed crop sensor technologies (GreenSeeker) and/or a chlorophyll meter. The Rossville and Colby locations had additional treatments using the Crop Circle sensor with and without a chlorophyll meter. With these treatments, a total pre-plant N application of 134 kg N ha^{-1} was used and the optical sensors (GreenSeeker and Crop Circle) were used to estimate yield potential at the V-8 growth stage and apply additional N indicated using the Great Plains corn sensor N rate calculator available on the Oklahoma State University soil fertility website. The chlorophyll meter was used to measure relative greenness of the plot vs. the highest pre-plant N rate plots. When the plot of interest had a relative greenness less than 95% of the reference, an additional 34 kg N ha^{-1} was applied or if less than 90% relative greenness, an additional 67 kg N $ha^{-1}$was applied.

At Rossville soil samples to a depth of 1 m were taken prior to initial treatment application, after each harvest, and then again in the spring prior to planting. This site received supplemental irrigation through a lateral move, overhead sprinkler system to minimize water stress throughout the growing season. Corn was planted in late April (19-21) with a target seeding rate of 80,000 seeds ha^{-1} using the DKC 61-69 hybrid (Monsanto, St. Louis, MO). Herbicides were used to control in-season weeds in all plots along with in row cultivation to control volunteer corn. A starter fertilizer application of 22 kg N and 20 kg P ha^{-1} was applied to all treatments and no additional K fertilizer was applied due to a sufficient soil test. Fall and spring tillage was used to prepare and warm the seedbed for corn planting the following growing season.

At Tribune, tensiometers were placed at 1.35 and 1.65 m depth in all plots and reading taken approximately weekly during the growing season. Also, porous cup soil solution samplers were placed in each plot at a depth of 1.5 m. However, attempts to collect soil solution samples were unsuccessful because of insufficient soil moisture at that depth although available water content was above 50% at that depth. Soil samples to a depth of 2.4 m were taken prior to initial treatment application and then after each harvest. This site received full irrigation using an overhead sprinkler to minimize water stress throughout the growing season. Soil water content was measured throughout the growing season to ensure adequate moisture without excessive irrigation. Corn was planted in early May with a target seeding rate of 80,000 seeds ha^{-1} using the Pioneer 33B54 hybrid (Pioneer Hybrids, Johnston, IA). Herbicides were used to control in-season weeds in all plots. A starter application of 22 kg N and 20 kg P ha^{-1} was applied to all treatments and no additional K fertilizer was applied due to a sufficient soil test. Fall and spring tillage was used to prepare and warm the seedbed for corn planting. At Colby, corn was planted in early May with a target seeding rate of 80,000 seeds ha^{-1} using the Pioneer 33H26 hybrid. Herbicides were used to control in-season weeds in all plots. Soil samples to a depth of 1 m were taken prior to initial treatment application, and after the final harvest. This site was flood irrigated to minimize water stress throughout the growing season with approximately 7 cm of water being applied at each irrigation. A starter application of 22 kg N and 20 kg P ha^{-1} was applied to all treatments and no additional K fertilizer was applied due to a sufficient soil test. Spring strip tillage occurred to prepare and warm the seedbed for corn planting. A one year rain fed location was also used in 2008 as a study examining the effect of side-dressed nitrogen rate at the V-8 growth stage which was conducted at the KSU Agronomy North Farm (39^0 12' 51"; 96^0 35' 29"), on a Kahola silt loam soil. Specific treatments consisted of a no nitrogen check, a pre-plant N application 179 kg N ha^{-1} with an additional 45 kg N ha^{-1} applied as a starter, pre-plant N applications of 90 kg N ha^{-1} with an additional 45 kg N ha^{-1} applied as a starter followed by a variable N at side-dress based off of sensor readings, a starter treatment of 45 kg N ha^{-1}, and a starter treatments plus an additional 34-202 kg N ha^{-1} in 34 kg N ha^{-1} increments applied as UAN solution coulter banded injected approximately 7.5 cm deep below the residue in the row middles at the V-8 growth stage. This study was no-till planted in late April at a seeding rate of 66,500 seeds ha^{-1} with the Asgrow RX785VT3 hybrid (Monsanto, St. Louis, MO) into sorghum residue from the previous crop year. A starter application of 45 kg N and 20 kg P ha^{-1} was applied to all treatments and no additional K fertilizer was applied due to a sufficient soil test.

NDVI and SPAD meter readings were taken throughout the vegetative portion of growth until silking at all locations. The sensors used for this study include the GreenSeeker red sensor and Crop Circle amber sensor. The Crop Circle sensor (ACS-210, Holland Scientific, Lincoln, NE) simultaneously emits light in two bands (visible and NIR) and has a field of view of 32 degrees by 6 degrees. The version of the sensor used in these experiments emits light in amber (590nm ±6nm) and NIR (880nm ±10nm) wavebands from an array of LEDs. The GreenSeeker (Hand-held unit Model 505, NTech Industries, Ukiah, CA) emit light in red (660 ± 15nm) and NIR (770nm ± 15 nm) (NIR). The field of view is approximately constant for heights between 60 and 120 cm above the canopy because of light collimation within the sensor. Both of these sensors calculate NDVI by the following equation: (NIR-Visible) / (NIR+Visible).

To collect these NDVI readings, sensors were positioned approximately 75 cm above the leaf canopy, and walked with the sensor head facing parallel to the row, and directly over the row. The middle two rows of each plot were sensed, and the NDVI values were averaged for the plot, as well as for each treatment.

SPAD meter readings were taken using a Konica-Minolta SPAD meter. The SPAD meter was clamped onto the most recently fully developed leaf with a visible leaf collar of 25 plants within the middle two rows.

Optimum N rate at each site was determined by performing a linear or quadratic regression analysis using EXCEL, choosing the best model as determined by the r^2, and solving for the N rate at 100% of yield. EXCEL was used for all other curve fitting as well. Additional statistical analysis was run to analyze differences between treatments that were observed using SAS version 9.1 with PROC GLM and an alpha value of 0.05.

Results and Discussion

Rossville Site. Results from 2007 of the project at the Kansas River Valley station are reported in Table 3.1. During the first year of the study, all crop parameters were increased by the first 134 kg N ha^{-1}. The chlorophyll meter indicated a need for supplemental N on only one plot (an additional 34 kg N ha^{-1}), while the GreenSeeker and Crop Circle sensors also indicated a need for supplemental N on one plot as well (an additional 17 kg N ha^{-1}). All measured crop parameters were similar for pre-plant, split, and sensor based N applications.

Table 3.1 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Kansas River Valley 2007.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
(kg ha^{-1})							(g kg^{-1})			(%)
0	0	22	13200 b	8290 b	113 b	28	9.7 b	5.4	19.0 b	--
112	0	134	20690 a	13720 a	216 a	46	11.8 a	6.2	28.8 a	76
157	0	179	18280 a	13030 a	199 a	35	11.9 a	6.4	26.7 a	48
202	0	224	20740 a	13860 a	236 a	39	12.6 a	6.7	29.4 a	55
45	67	134	19610 a	13970 a	234 a	37	12.8 a	7.3	28.6 a	90
67	90	179	19430 a	14030 a	223 a	37	12.4 a	6.5	28.7 a	61
90	112	224	20070 a	13740 a	228 a	47	12.5 a	6.8	27.9 a	52
112	GS	140	18700 a	13250 a	215 a	41	12.5 a	6.8	29.7 a	75
112	CC	140	19580 a	14060 a	212 a	36	11.6 a	6.6	28.0 a	69
112	CH	145	19120 a	13520 a	216 a	41	12.0 a	7.2	27.6 a	74
112	GS + CH	134	19940 a	13450 a	224 a	41	12.0 a	7.2	29.8 a	82
112	CC + CH	134	19140 a	13050 a	202 a	41	11.7 a	6.1	29.9 a	66
	Prob > F		0.0019	<.0001	0.0013	0.2797	0.0220	0.4573	0.0021	0.1657
	CV		8.7	6.3	12.7	19.6	7.1	14.2	9.0	26.1
	LSD .05		2810	1400	45.10	NS	1.4	NS	1.6	NS

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CC=Crop Circle used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

GS+CH=Greenseeker used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

CC+CH=Crop Circle used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

Results from 2008 of the project at the Kansas River Valley station are reported in Table 3.2. During the second year all crop parameters were increased with the first134 kg N ha^{-1} rate, with no additional response found to additional applied N. The chlorophyll meter indicated a need for supplemental N on only one plot (an additional 34 kg N ha^{-1}). The GreenSeeker and Crop Circle sensors also indicated a need for supplemental N for 41 to 63 kg N ha^{-1}. No differences were observed with the crop parameters measured between pre-plant, split, and sensor based N applications.

Table 3.2 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Kansas River Valley 2008.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
(kg ha^{-1})							(g kg^{-1})			(%)
0	0	22	10010 b	5310 b	58 c	32	8.8 d	3.0 d	12.8 b	--
112	0	134	19060 a	13660 a	165 ab	47	10.6 abc	4.7 abc	25.0 a	79
157	0	179	21030 a	14420 a	179 ab	56	10.9 abc	4.5 abc	23.6 a	67
202	0	224	20370 a	14740 a	204 a	67	12.0 a	5.8 a	23.8 a	65
45	67	134	20250 a	13630 a	173 ab	39	11.2 abc	4.3 bc	23.3 a	85
67	90	179	19760 a	14780 a	175 ab	42	10.8 abc	4.4 bc	24.1 a	65
90	112	224	19760 a	14830 a	188 ab	46	11.7 ab	4.5 bc	23.2 a	58
112	GS	175	19080 a	13804 a	172 ab	--	11.3 abc	4.4 bc	23.4 a	65
112	CC	197	20200 a	14960 a	179 ab	--	11.0 abc	4.3 c	22.0 a	61
112	CH	145	18730 a	13480 a	156 b	--	10.5 bc	4.0 cd	24.1 a	70
112	GS + CH	134	20360 a	14340 a	164 b	--	10. cd	4.3 bc	22.7 a	78
112	CC + CH	197	19630 a	14620 a	188 ab	--	11.3 abc	5.5 a	25.0 a	70
	Prob > F		<.0001	<.0001	<.0001	0.3462	0.0180	0.0216	<.0001	0.7710
	CV		7.7	6.8	13.9	22.1	7.8	16.4	9.2	25.9
	LSD .05		2480	1570	39.0	NS	1.4	1.2	3.5	NS

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CC=Crop Circle used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

GS+CH=Greenseeker used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

CC+CH=Crop Circle used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

Results from 2009 of the project at the Kansas River Valley station are given in Table 3.3. During the final year all crop parameters were increased due to nitrogen fertilization, with the intermediate 179 kg N ha^{-1} being optimum. The chlorophyll meter, GreenSeeker, and Crop Circle sensors indicated a need for supplemental N with mean total N applications ranging from 156 to 171 kg N ha^{-1}. All measured crop parameters were similar for pre-plant, split, and sensor based N applications. Trends were seen for higher grain yields with split applications at the two lowest N rates and lower grain yields were seen with the chlorophyll meter only treatment.

Table 3.3 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Kansas River Valley 2009.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
(kg ha^{-1})							(g kg^{-1})			(%)
0	0	22	9420 b	5440 c	54 d	31	9.0 d	2.6 c	14.8 c	--
112	0	134	19070 a	12850 b	156 c	47	10.9 bc	4.5 b	22.0 ab	76
157	0	179	19370 a	13580 ab	164 bc	42	10.9 bc	4.8 ab	22.0 ab	61
202	0	224	21080 a	14690 a	194 ab	44	11.7 abc	5.6 ab	22.3 ab	62
45	67	134	19230 a	13590 ab	163 bc	52	10.8 c	4.9 ab	20.4 b	81
67	90	179	19860 a	14300 ab	186 abc	43	11.7 abc	5.7 ab	21.9 ab	74
90	112	224	20520 a	14540 ab	196 ab	52	12.0 a	5.6 ab	21.6 ab	63
112	GS	171	20190 a	14780 a	190 abc	44	11.6 abc	5.7 ab	22.3 ab	79
112	CC	164	20500 a	15230 a	198 a	55	11.8 ab	6.1 a	21.8 ab	89
112	CH	156	19090 a	13570 ab	168 abc	45	11.2 abc	5.3 ab	22.2 ab	69
112	GS + CH	156	20850 a	14610 ab	186 abc	45	11.4 abc	5.3 ab	20.7 b	92
112	CC + CH	156	20300 a	14080 ab	180 abc	45	11.4 abc	5.2 ab	23.6 a	81
	Prob > F		<.0001	<.0001	<.0001	0.3779	0.0010	0.0130	0.0014	0.5212
	CV		6.6	7.4	12.3	19.1	5.2	15.5	6.3	16.2
	LSD .05		2130	1680	35.0	NS	1.0	1.3	2.3	NS

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CC=Crop Circle used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

GS+CH=Greenseeker used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

CC+CH=Crop Circle used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

A 2007-2009 summary analysis for the Kansas River Valley station location was performed and is reported in Table 3.4. All measured crop parameters were increased by N application. The chlorophyll meter, GreenSeeker, and Crop Circle sensors indicated a need for supplemental N with mean treatment application rates ranging from 138-167 kg N ha^{-1} during the duration of the study. Pre-plant and split applications of N performed similarly while sensor treatments all performed similarly as well. Selected contrasts showed no statistical difference between pre-plant or split applications, nor any differences between pre-plant + split applications when compared to each sensor based treatments. This shows the sensor based treatments performed equally as well as the other treatments with less nitrogen than the 179 kg N ha^{-1} average N rate for the pre-plant and split treatments.

Table 3.4 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Kansas River Valley 2007-2009.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
(kg ha^{-1})							(g kg^{-1})			(%)
0	0	22	10880 c	6350 d	67 d	31 b	9.2 c	3.6 c	15.5 c	--
112	0	134	19610 ab	13410 c	179 c	47 a	11.1 b	5.1 b	25.3 ab	77 ab
157	0	179	19560 ab	13680 bc	181 c	42 ab	11.2 b	5.3 ab	24.1 b	59 c
202	0	224	20730 a	14430 ab	211 a	44 ab	12.1 a	6.0 a	25.2 ab	61 bc
45	67	134	19700 ab	13730 bc	190 bc	52 a	11.6 ab	5.5 ab	24.1 b	85 a
67	90	179	19680 ab	14370 ab	194 abc	43 ab	11.7 ab	5.5 ab	24.9 ab	67 bc
90	112	224	20120 ab	14370 ab	204 ab	52 a	12.1 a	5.6 ab	24.2 ab	58 c
112	GS	162	19320 ab	13940 abc	192 abc	44 ab	11.8 ab	5.6 ab	25.1 ab	73 abc
112	CC	167	20090 ab	14750 a	196 abc	55 a	11.5 ab	5.6 ab	23.9 b	73 abc
112	CH	153	18980 b	13510 bc	180 c	45 ab	11.2 b	5.5 ab	24.7 ab	71 abc
112	GS + CH	138	20380 ab	14130 abc	191 abc	45 ab	11.2 b	5.6 ab	24.4 ab	84 a
112	CC + CH	163	19690 ab	13920 abc	190 bc	45 ab	11.5 ab	5.6 ab	26.2 a	72 abc
	Prob > F		<.0001	<.0001	<.0001	0.0212	<.0001	0.0415	<.0001	0.0149
	CV		7.9	7.5	16.8	21.9	8.0	23.4	15.4	25.7
	LSD .05		1410	940	29.0	8.60	0.9	1.2	3.4	17.0
	Selected Contrasts					P Value if Significant				
	Pre vs. Split		NS	NS	NS	NS	NS	NS	NS	NS
	Pre+Sidedress vs. GS		NS	NS	NS	NS	NS	NS	NS	NS
	Pre+Sidedress vs. CC		NS	0.0159	NS	NS	NS	NS	NS	NS
	Pre+Sidedress vs. CH		NS	NS	NS	NS	NS	NS	NS	NS
	Pre+Sidedress vs. GS+CH		NS	NS	NS	NS	NS	NS	NS	0.0144
	Pre+Sidedress vs. CC+CH		NS	NS	NS	NS	NS	NS	NS	NS

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CC=Crop Circle used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

GS+CH=Greenseeker used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

CC+CH=Crop Circle used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

Tribune Site. Results from 2007 of the project at the Western Kansas Research Center are reported in Table 3.5. In the first year of the project at Tribune, total biomass, grain yield, total N uptake, and earleaf N were increased by N applications. Grain yields were similar for preplant, split, and sensor based N applications. The chlorophyll meter only indicated a need for supplemental N on two plots (an additional 34 kg N ha^{-1} on half of the replications increased total N application 17 kg ha^{-1}). The Greenseeker did not indicate a need for supplemental N above the 134 kg N ha^{-1} applied preplant.

Table 3.5 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Western Kansas Research Center 2007.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
(kg ha^{-1})							(g kg^{-1})			(%)
0	0	22	18600 c	10920 c	158 c	37	11.6	5.1	19.8 c	--
112	0	134	22780 ab	13810 ab	199 ab	29	12.1	5.0	21.3 bc	36
157	0	179	25710 a	15480 a	236 a	59	12.1	6.0	25.3 a	50
202	0	224	22780 ab	13750 ab	204 ab	35	12.6	4.8	24.8 a	23
45	67	134	21360 bc	12690 bc	183 bc	27	11.8	4.9	24.3 a	22
67	90	179	23350 ab	14830 ab	207 ab	48	12.3	4.5	20.4 c	31
90	112	224	24890 ab	15080 ab	233 a	46	12.7	5.3	24.2 a	37
112	GS	134	24620 ab	14660 ab	216 ab	28	12.0	5.3	21.5 bc	52
112	CH	134	24690 ab	15350 a	225 a	45	12.3	5.4	19.6 c	60
112	GS + CH	134	24150 ab	13870 ab	224 a	82	12.0	6.2	23.1 ab	59
	Prob > F		0.0151	0.0274	0.0109	0.5325	0.6977	0.3995	<.0001	0.3017
	CV		10.5	12.4	13.2	45.4	6.3	19.1	7.7	10.1
	LSD .05		3540	2530	40	NS	NS	NS	2.5	NS

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

GS+CH=Greenseeker used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

Results from the 2008 of the project at the Western Kansas Research Center are reported in Table 3.6. In the second year of the project at Tribune, total biomass, grain yield, total N uptake, and earleaf N (despite being impacted by hail damage and early season water stress caused by mechanical problems with the irrigation well) were increased by N applications. Grain yields were similar for preplant, split, and sensor based N applications. Neither the Greenseeker sensor nor the chlorophyll meter indicated a need for supplemental N above the 134 kg N ha^{-1} applied preplant.

Table 3.6 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Western Kansas Research Center 2008.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Grain N	WP N	Earleaf N	Plant N Rec.
(kg ha^{-1})						(g kg^{-1})			(%)
0	0	22	11130 c	6650 c	104 d	13.2	5.1 bc	14.2 b	--
112	0	134	14590 ab	9530 b	137 c	12.9	5.0 c	21.4 a	29
157	0	179	17660 a	11730 a	181 a	13.7	5.8 bc	21.5 a	49
202	0	224	14500 ab	9780 ab	162 abc	14.1	7.4 a	21.7 a	29
45	67	134	13910 ab	9160 b	137 c	13.4	5.3 bc	21.9 a	29
67	90	179	15180 ab	10350 ab	158 abc	13.6	6.1 b	22.4 a	34
90	112	224	15860 ab	10540 ab	171 ab	13.7	7.2 a	22.1 a	33
112	GS	134	14790 ab	9600 ab	143 abc	13.6	5.0 c	20.2 a	35
112	CH	134	15890 ab	10540 ab	157 abc	13.5	5.3 bc	20.4 a	47
112	GS + CH	134	14510 ab	9600 ab	142 abc	13.2	5.6 bc	20.3 a	34
	Prob > F		<.0001	0.012	<.0001	0.778	0.008	<.0001	0.454
	CV		11.5	15.2	14.3	5.8	19.4	7.9	15.2
	LSD .05		3760	2190	30	NS	0.10	2.6	NS

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

GS+CH=Greenseeker used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

Results from 2009 of the project at the Western Kansas Research Center are reported in Table 3.7. In the final year of the project at Tribune, total biomass, grain yield, total N uptake, residual, whole plant N, and earleaf N (despite being impacted by hail damage slightly) were increased by N applications. Grain yields were similar for preplant, split, and sensor based N applications. Both the chlorophyll meter and the GreenSeeker sensor indicated a need for supplemental N with total N application for these treatments ranging from 151to 178 kg N ha^{-1}.

Table 3.7 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Western Kansas Research Center 2009.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
(kg ha^{-1})							(g kg^{-1})			(%)
0	0	22	13050 d	8580 e	109 d	13	11.0	4.7 d	14.9 f	--
112	0	134	19000 abc	12400 cd	152 abc	47	10.7	4.5 d	19.3 bcde	38
157	0	179	20850 a	14400 a	186 ab	27	11.4	5.4 bcd	21.1 ab	45
202	0	224	20260 abc	13100 abcd	199 a	50	12.2	6.9 ab	22.5 a	32
45	67	134	18090 bc	12050 d	145 cd	25	10.3	4.9 d	19.9 bcd	32
67	90	179	20590 ab	13870 abc	187 ab	43	10.9	6.6 abc	20.7 abc	50
90	112	224	20730 a	14240 ab	207 a	36	12.1	7.1 a	21.1 ab	49
112	GS	178	19490 abc	12830 abcd	171 abc	24	11.0	5.8 abcd	18.2 de	40
112	CH	180	17730 c	12200 cd	159 bc	17	11.7	5.2 cd	17.5 e	29
112	GS + CH	151	18580 abc	12440 bcd	156 bc	16	11.2	4.9 d	18.9 cde	34
	Prob > F		<.0001	<.0001	0.0007	0.3494	0.3846	0.0070	<.0001	0.5724
	CV		9.3	9.8	15.9	82.9	10.0	18.9	6.7	41.7
	LSD .05		2530	1800	39	NS	NS	1.5	1.9	NS

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

GS+CH=Greenseeker used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

A 2007-2009 summary analysis for Western Kansas Research Center was performed and is reported in Table 3.8. All measured crop parameters were increased by N application. The chlorophyll meter and GreenSeeker sensors indicated a need for supplemental N above the initial 134 kg of N applied at planting, with treatment mean application rates ranging from 138 to 167 kg N ha^{-1} over the duration of the study. Pre-plant and split applications performed similarly while sensor treatments all performed similar to non-sensor treatments. Selected contrasts showed no statistical difference between pre-plant or split applications, nor any differences between pre-plant + split applications when compared to each sensor based treatments. This shows the sensor based treatments performed equally as well as the other treatments with less nitrogen than the 179 kg N ha^{-1} average N rate for the pre-plant and split treatments.

Table 3.8 Effect of nitrogen treatment on total corn biomass, grain yield, total N uptake, residual nitrogen in the soil, grain N, whole plant N, and earleaf N concentration, and plant nitrogen recovery, Western Kansas Research Center 2007-2009.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual NO_3^{-1} in soil	Grain N	Stover N	Earleaf N	Plant N Rec.
---------- (kg ha^{-1}) ----------							----(g kg^{-1})----			(%)
0	0	22	15760 d	8710 f	123 f	13	11.9 c	5.0 c	16.3 e	--
112	0	134	20790 bc	11920 de	162 bc	47	11.9 c	4.8 c	20.7 c	35
157	0	179	23620 a	13870 a	200 a	27	12.4 abc	5.7 b	22.6 ab	49
202	0	224	21180 bc	12220 cde	187 ab	50	12.9 a	6.4 ab	23.0 a	32
45	67	134	19650 c	11290 e	154 c	25	11.9 c	5.0 c	22.0 abc	28
67	90	179	21730 ab	13020 abc	182 ab	43	12.2 abc	5.7 b	21.2 bc	38
90	112	224	22630 ab	13280 ab	202 a	36	12.8 ab	6.5 a	22.4 ab	40
112	GS	149	21710 ab	12380 bcd	177 b	24	12.2 abc	5.4 bc	20.0 cd	42
112	CH	161	21510 bc	12700 bcd	179 b	17	12.5 abc	5.3 bc	19.1 d	46
112	GS+CH	140	21030 bc	11960 de	174 bc	16	12.2 abc	5.6 b	20.8 c	43
	Prob > F		<.0001	<.0001	<.0001	0.4494	0.0254	0.0080	<.0001	0.4958
	CV		8.4	8.8	14.3	74.6	9.5	17.1	6.1	37.5
	LSD .05		2420	1150	22	NS	0.7	0.8	1.5	NS
	Selected Contrasts					P Value if Significant				
	Pre vs. Split		NS	NS	NS	NS	NS	NS	NS	NS
	Pre+Sidedress vs. GS		NS	NS	NS	NS	NS	NS	NS	NS
	Pre+Sidedress vs. CH		NS	NS	NS	NS	NS	NS	NS	NS
	Pre+Sidedress vs. GS+CH		NS	NS	NS	NS	NS	NS	NS	NS

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

GS+CH=Greenseeker used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

Colby Site. Results from the 2008 of the project at the Northwest Kansas Research Center are reported in Table 3.9. All crop parameters were similar among treatments and no nitrogen response was seen during the initiation year. This was primarily due to the high soil nitrate levels prior to initiation of the study as soil tests indicated 152 kg N ha^{-1} respectively.

Table 3.9 Effect of nitrogen treatment on, grain yield, grain N, and earleaf N, concentration Northwest Kansas Research Center 2008.

Pre-plant N	Side-dress N	Total N	Grain Yield	Grain N	Earleaf N
---------- (kg ha^{-1}) ----------				----------(g kg^{-1})----------	
0	0	22	11790	13.6	21.4 cd
112	0	134	11980	12.2	23.1 abcd
157	0	179	12170	13.0	22.3 bcd
202	0	224	11790	14.0	25.0 a
45	67	134	11850	12.5	23.6 abc
67	90	179	12980	13.7	23.0 abcd
90	112	224	13170	13.5	24.5 ab
112	GS	134	12610	13.0	20.9 d
112	CC	134	12920	13.1	21.2 cd
112	CH	134	11850	12.9	23.5 abc
112	GS + CH	134	11790	13.4	22.1 bcd
112	CC + CH	134	12230	13.2	21.6 cd
	Prob > F		0.6718	0.5332	0.0487
	CV		9.8	7.6	8.0
	LSD .05		NS	NS	2.6

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CC=Crop Circle used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

GS+CH=Greenseeker used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

CC+CH=Crop Circle used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

Results from 2009 of the project at the Northwest Kansas Research Center are reported in Table 3.10. In the final year of the project at Colby, total biomass, grain yield, total N uptake, residual, whole plant N, and earleaf N (despite being impacted by slight hail damage) were all increased by N applications. A significant nitrogen response was seen to the initial 134 kg N ha^{-1} rate. Grain yields were similar for pre-plant, split, and sensor based N applications.

Table 3.10 Effect of nitrogen treatment on corn biomass, grain yield, N uptake, grain N, whole plant N, earleaf N concentrations and plant nitrogen recovery, Northwest Kansas Research Center 2009.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Grain N	WP N	Earleaf N	Plant N Rec.
(kg ha^{-1})						(g kg^{-1})			(%)
0	0	22	8750 d	4500 c	69 d	11.7	4.1 c	16.7 c	--
112	0	134	17850 bc	9450 ab	177 bc	12.2	7.9 ab	23.7 ab	80
157	0	179	18020 abc	10170 a	185 bc	12.5	8.0 ab	24.4 ab	64
202	0	224	18810 ab	10200 a	205 ab	12.8	9.3 a	25.8 a	61
45	67	134	16630 c	9370 ab	156 c	12.1	6.8 b	24.4 ab	65
67	90	179	17270 bc	9760 ab	178 bc	12.8	7.8 ab	22.4 b	61
90	112	224	19830 a	10210 a	222 a	13.2	9.6 a	25.1 ab	68
112	GS	169	17860 bc	8670 ab	169 c	12.0	7.6 ab	24.3 ab	63
112	CC	164	17820 bc	9050 ab	166 c	12.5	6.9 b	24.4 ab	55
112	CH	151	17890 bc	8960 ab	176 bc	12.1	8.2 ab	25.8 a	61
112	GS + CH	197	17650 bc	9210 ab	174 bc	11.8	8.3 ab	23.1 ab	68
112	CC + CH	179	18070 abc	8720 b	171 c	12.4	7.5ab	24.9 ab	63
	Prob > F		<.0001	<.0001	<.0001	0.5107	0.0070	<.0001	0.7577
	CV		7.4	9.7	13.2	7.5	20.8	8.8	25
	LSD .05		1840	1260	33	NS	2.3	0.3	NS

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CC=Crop Circle used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

GS+CH=Greenseeker used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

CC+CH=Crop Circle used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

A 2008-2009 summary analysis for the Northwest Kansas Research Center was performed and is presented in Table 3.11. All crop parameters were increased by N application. The chlorophyll meter, GreenSeeker, and Crop Circle sensors indicated a need for supplemental N with mean application rate ranging from 149 to 166 kg N ha^{-1} during the duration of the study. Pre-plant, split applications and sensor based applications all performed similarly. Selected contrasts showed no statistical difference between pre-plant or split applications, nor any differences between pre-plant + split applications when compared to each sensor based treatments. This shows the sensor based treatments performed equally as well as the other treatments while utilizing less nitrogen than the 179 kg N ha^{-1} average N rate for the pre-plant and split treatments.

Table 3.11 Effect of nitrogen treatment on, grain yield, grain N, and earleaf N concentration, Northwest Kansas Research Center 2008-2009.

Pre-plant N	Side-dress N	Total N	Grain Yield	Grain N	Earleaf N
(kg ha^{-1})				($g\ kg^{-1}$)	
0	0	22	8150	12.7	19.1 c
112	0	134	10720	12.2	23.4 ab
157	0	179	11170	12.8	23.4 ab
202	0	224	11000	13.4	25.4 a
45	67	134	10610	12.3	24. ab
67	90	179	10810	13.3	22.7 b
90	112	224	11690	13.4	24.8 ab
112	GS	152	10640	12.5	22.6 b
112	CC	149	10990	12.8	22.8 b
112	CH	143	10410	12.5	24.7 ab
112	GS + CH	166	10500	12.6	22.6 b
112	CC + CH	157	10480	12.8	23.3 ab
	Prob > F		0.2503	0.3698	<.0001
	CV		20.7	8.2	9.6
	LSD .05		NS	NS	2.2
	Selected Contrasts			P Value if Significant	
	Pre vs. Split		NS	NS	NS
	Pre+Sidedress vs. GS		NS	NS	NS
	Pre+Sidedress vs. CC		NS	NS	NS
	Pre+Sidedress vs. CH		NS	NS	NS
	Pre+Sidedress vs. GS+CH		NS	NS	NS
	Pre+Sidedress vs. CC+CH		NS	NS	NS

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CC=Crop Circle used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

GS+CH=Greenseeker used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

CC+CH=Crop Circle used at 8 leaf stage to determine sidedress N rate plus chlorophyll meter at silking to determine additional in-season N.

Manhattan site. The results from the 2008 study examining the effect of side-dressed nitrogen rate at the V-8 growth stage and some select sensor based treatments conducted at the KSU Agronomy Farm are summarized in Table 3.12. A significant nitrogen response was seen for total biomass, nitrogen uptake and grain yield to a maximum rate of 246 kg N ha^{-1}. As the total N rate increased, grain N concentration, corn whole plant N concentration, and corn earleaf N concentration also increased. At this location the sensor based N treatments performed poorly in comparison to the 246 kg N ha^{-1} treatment. This was primarily due to significant early season N loss from the reference strip resulting in the reference strip plants and sensor based treatments having similar NDVI readings at the V-8 sensing time. This may have been due in part to the plants in the reference strip not being rooted deep enough to have been able to utilize N which had leached deeper in the profile. If these sensor readings would have been taken later in the growing season a difference may have been detected and additional N would have been recommended. At silking, the SPAD meter was able to detect a difference between the reference strip, as the reference strip was able to root down into some of the nitrogen that was leached by significant rainfall events from earlier in the growing season. Addition of nitrogen to the SPAD based treatment was successful in increasing grain yields but yields were still not optimized from this nitrogen application which may have not been high enough or the corn may had suffered too much N stress to fully recover to maximize grain yields.

Table 3.12 Effect of nitrogen treatment on corn biomass, grain yield, N uptake, grain N, whole plant N, earleaf N concentration, and plant nitrogen recovery, Agronomy North Farm 2008.

Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Grain N	WP N	Earleaf N	Plant N Rec.
----------------	----------------	----------------	($kg\ ha^{-1}$)	----------------	----------------	----------------	($g\ kg^{-1}$)	----------------	(%)
0	0	0	7320 e	3460 f	37 e	8.2 c	3.1 d	15.9 d	--
0	0	45	8990 e	4230 f	45 e	8.4 bc	3.0 d	16.2 d	19 c
0	33	78	11100 d	6150 e	65 d	8.6 bc	3.2 cd	18.4 cd	36 ab
0	67	112	12140 cd	6780 de	69 d	8.2 c	3.3 bcd	17.7 cd	29 abc
0	101	146	13520 bc	8110 cd	81 d	8.7 bc	3.1 d	19.4 bc	30 abc
0	134	179	15400 a	10100 ab	110 bc	9.3 bc	4.1 abc	21.4 ab	41 a
0	168	213	15450 a	10240 ab	109 bc	9.5 b	3.7 bcd	21.8 ab	34 ab
0	201	246	16380 a	11640 a	139 a	10.9 a	4.2 ab	22.6 a	41 a
224	0	224	14940 ab	8840 bc	99 c	9.2 bc	3.7 bcd	18.5 cd	28 abc
90	GS	135	12980 c	6710 de	73 d	8.7 bc	3.3 bcd	17.3 cd	27 abc
90	CC	135	12090 cd	6650 de	68 d	8.6 bc	3.1 d	18.0 cd	23 bc
90	CH	202	14830 ab	9160 bc	121 b	11.2a	4.9 a	18.0 cd	42 a
	Prob > F		<.0001	<.0001	<.0001	<.0001	0.0095	0.0003	0.0455
	CV		9.9	14.7	14.4	8.9	19.9	10.7	32.3
	LSD .05		1840	1620	18.	1.1	1.0	2.9	15

GS=Greenseeker used at 8 leaf stage to determine sidedress N rate.

CC=Crop Circle used at 8 leaf stage to determine sidedress N rate.

CH=Chlorophyll meter used at silking to determine in-season N rate.

Conclusions

Sensor based N management of corn proved to be as successful as pre-plant or split nitrogen applications at the Rossville, Tribune, and Colby research locations, producing similar yields while using less nitrogen than the average N rate used for the pre-plant and split applied nitrogen. At the Manhattan location however, the sensor based N treatments grain yields were not optimized when compared to the side-dressed nitrogen treatment which received the highest amount of N. At this location it appears that the reference strip used as a base for sensor measurement was N deficient early on. This points out that just adding large amounts of N at planting may not be adequate to ensure a quality reference strip. The use of products such as controlled release fertilizers or nitrification inhibitors may also be required to ensure a quality reference value for sensor operation.

These results suggest that the sensor technology can be used at the V-8 growth stage in Kansas to make N recommendations for corn. However, if the sensor does not indicate a need for N fertilizer at the V-8 growth stage, then the producer may want to check the corn again at the V-16 growth stage prior to tassel emergence, especially in high N loss situations, such as encountered at Manhattan in 2008, to ensure adequate N is present to optimize yield.

While this limited amount of work suggests that the use of crop sensors in-season can improve N recommendations and reduce N rates, future research will need to be conducted to determine the most efficient management practices for using sensor based N recommendations, how the producer should apply the nitrogen fertilizer, and the timing of the nitrogen application. In addition different sensor based N recommendations may need to be developed to provide better sensor based N recommendations to producers for different N management and cropping management systems.

For those not willing to soil test N prior to planting, the use of sensor technology to estimate soil N contribution would offer an alternative. Also for those producers who wanted to monitor corn growth the use of the sensor technology to document growth would prove to be very useful. Sensor technology could also be used to evaluate growth of different corn hybrids during the growing season.

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CHAPTER 4 - Development of Mid-Season Sensor Based N Recommendations for Corn in Kansas

Abstract

Corn (*Zea mays*) is an important cereal crop grown in Kansas, and primarily used as livestock feed and as a feedstock for ethanol production. USDA National Agriculture Statistics show that approximately 1.7 million hectares of corn is planted each year in Kansas, with an average yield ranging from 5,750-7,750 kg ha^{-1} over the past five years (2005-2009). With this variability in yield and current volatility in crop and fertilizer price as well, it seems logical that optimum N rates may vary from year to year. The N contribution from mineralization of organic N in soils, primarily soil organic matter (SOM) and crop residue also varies widely as it is controlled by many of the same factors which impact yield, such as temperature and rainfall. In addition, the loss of nitrogen from corn fields during the growing season is also difficult to predict. Therefore a research study was initiated to evaluate the use of sensor based mid-season N recommendation systems utilizing a high N reference strip and sensor based estimates of yield potential and soil N supply as a means to improve crop yield and nitrogen fertilizer use efficiency.

A series of field experiments were conducted across Kansas from 2006 through 2009 to assess the potential of developing sensor based N recommendations. Yield prediction equations developed had varying R square values from .40 to .62 with the best relationship between NDVI and grain yield found at the V-8 growth stage. Using sensors to estimate nitrogen responsiveness of corn also had varying results and only performed well at the V-8 growth stage with no-till production sites. However when combining both conventional and no-till sites, nitrogen responsiveness was adequately measured by the sensors at the V-15 growth stage. Using these

relationships, a sensor based N rate calculator will be drafted and tested in the future, similar to current calculators used for sorghum and wheat, to improve the efficiency of nitrogen fertilization of corn in Kansas.

Introduction

Nitrogen use efficiency (NUE), defined as the percentage of applied N recovered or utilized by the target crop is estimated to be only 33% for grain production, and about 45% for forage production in the United States (Raun and Johnson, 1999). Yet, N fertilizer has increased crop yield more over the past five decades than any other agricultural input (Johnston, 2000). Smith et al., (1990) suggest that corn yields would decrease by 41% without N fertilizer application. Due to both economic and environmental concerns, however agricultural inputs have to be managed efficiently, especially in high production systems (Feinerman et al., 1990).

One of the major reasons for low NUE is loss of applied N from the agricultural system. Pathways for N losses from agriculture ecosystems include: gaseous plant emissions; soil denitrification; surface runoff; volatilization, and leaching (Raun and Johnson, 1999). With the exception of N denitrified to N_2, these pathways all can lead to an increased load of biologically reactive N into our environment (Cassman et al., 2002). Low NUE in crop production systems could have a drastic impact on land-use and food supplies worldwide if left unaddressed (Frink et al., 1999).

Two causes for N loss and the low NUE found with current N management practices are poor synchrony between soil N supply and crop demand and the application of more fertilizer N than the crop can use (Raun and Johnson, 1999; Cassman et al., 2002; Fageria and Baligar, 2005). The common practice of making large pre-plant applications of fertilizer N to corn and sorghum is an example of a practice which results in poor synchronization between application and use resulting in low NUE. Since significant amounts of N are not taken up by corn until after the V-6 growth stage, 30-45 days after planting, pre-plant application results in the N fertilizer being stored in the soil for weeks or months, susceptible to N loss. By using split or delayed applications of fertilizer N or by choosing controlled release fertilizers or products such as nitrification inhibitors, to improve synchrony, N loss can be reduced and NUE enhanced.

The use of soil testing, or plant analysis to better estimate soil N supply and crop needs can reduce over application of N and improve NUE also. Unfortunately, very few farmers currently do routine soil N testing. Since much of the N supplied to the crop from the soil each year is the product of microbial decomposition of organic materials and the subsequent mineralization of N, the synchrony of mineralization and crop uptake can also vary Crop sensors have been shown to be able to allow the plant to estimate N supply, removing some of the uncertainty from soil N supply estimates. The use of crop sensors to provide a rapid estimate of both yield potential and N content of crop plants has the potential to greatly enhance NUE by providing more accurate and timely estimates of crop N need. Early sensor research has shown that indices based on red/near infrared reflectance ratios can provide estimates of leaf area index, green biomass, crop yield, and canopy photosynthetic capacity (Araus, 1996). The use of reflectance at 430, 550, 680 nm, and near infrared wavelengths have shown potential for assessing N status in wheat (Filella et al., 1995). Recent advances in technology have resulted in instruments that use these concepts specifically to guide N fertilization decisions and help increase NUE in crops. Some of these instruments that rely on crop reflectance at specific wavelengths to determine N status in plants include the SPAD Chlorophyll meter (Konica Minolta Inc, Tokyo, Japan), the GreenSeeker optical sensor (NTech Industries, Ukiah, CA), and the Crop Circle ACS-210 held optical sensor (Holland Scientific, Lincoln, NE).

Crop reflectance is defined as the ratio of the radiation of a specific wavelength that is reflected by an individual leaf or leaf canopy to the incident radiation of that wavelength striking the canopy or leaf (Shroder et al., 2000). Plants that are dark green in color will typically exhibit very low reflectance and transmittance in the visible region of the spectrum due to strong absorption of light by photosynthetic tissue and plant pigments (Chappelle et al., 1992). The pigments involved in photosynthesis (chlorophyll a, and b) absorb visible light selectively. These pigments absorb mainly the blue and red wavelengths of the visible spectrum, while reflecting the green fraction. Therefore, reflectance measurements at these blue and red wavelengths can potentially give good indications of leaf greenness. Reflectance and transmittance of light are usually high in the near-infrared (NIR) region of the spectrum (700-1400 nm) because there is little absorption by the photosynthetic tissue and plant pigments (Gausman, 1974; Gausman 1977; Slaton et al., 2001). A vegetation index can be derived from reflectance with respect to different wavelengths, which could be an indicator of the chlorophyll content of leaves, leaf area index, green biomass, or some other background scattering. The Normalized Difference Vegetation Index (NDVI) has been shown to be a very good estimator of the fraction of photosynthetically active radiation absorbed. The formula for NDVI is:

$$NDVI = (NIR-VIS) / (NIR + VIS),$$

where NIR is the reflectance of a near infrared wavelength and

VIS is the reflectance of a visible wavelength.

The SPAD chlorophyll meter measures greenness/chlorophyll content of a leaf by clamping the meter over the most recent fully developed leaf. An indexed chlorophyll content reading (0-99.9) is provided, using two wavelengths of light, 650 nm in the visible and 940 nm in the NIR. This chlorophyll reading is well correlated with nitrogen concentrations in the leaf. The meter was used to develop the concept of “spoon feeding” N to the crop on an “as needed” basis through fertigation (or adding N through the irrigation system) (Schepers et al., 1995). The intent is enhancing crop yield while maximizing NUE and minimizing N use, reducing the potential for environmental contamination by N in irrigated corn production. With this approach, well fertilized reference strips, normally receiving 1.2 to 1.3 times the normal recommended N rate, are strategically placed in the field. Chlorophyll readings are then compared from the N rich reference strip and the bulk areas of the field where possible fertilizer N is needed. A sufficiency index (SI) is calculated by the following equation:

SI = (SPAD reading of bulk field area/ SPAD reading reference strip) *100.

It is believed that when the sufficiency index (SI) is less than 100%, additional fertilizer N is needed on the target area. Using this strategy from V8 to R1, Ritchie et al. (1986) and Varvel et al., (1997) were able to maintain crop yield with less fertilizer N when compared to a uniform recommended rate of 200 kg ha^{-1}. The use of the SPAD strategy has proven to be highly efficient in irrigated corn. However it has some limitations in non-irrigated environments where fertigation is not possible. These limits include: availability of high clearance equipment to use for application, time required to variably apply N when growers have a large number of hectares to fertilize in a short period of time, determining how much N is really needed, and sampling time and effort to sample fields. These issues have limited the use of the SPAD meter in US crop production.

Raun et al., (2001, 2002) proposed the use of active optical sensors for in-season N management in winter wheat fields. Their work was done with the GreenSeeker hand held optical sensor, which uses light emitting diodes (LED) to generate light in the red and near infrared bands (NIR) and also included the use of a reference, or high nitrogen strip or point, in the field. This method of using light in the red and NIR bands gives both an indication of plant biomass, and an indication of plant greenness. Using their approach, one uses the NDVI values generated by the sensor, and the Growing Degree Days (GDD) accumulated at sensing (also called In-Season Yield Estimator (INSEY)) to estimate yield potential and top-dress N rates. This in-season method for estimating top-dress N rates is based on a yield potential estimate made from early-season sensor generated plant bio-mass estimates, adjusted for GDD's, rather than a pre-season "yield goal". Thus the impact of plant stand and early growth on yield, in addition to greenness, is considered. The in-season top-dress N rate is calculated by subtracting the projected N uptake for the predicted yield in the sensed area, from the projected N uptake in the non-N limiting reference strip, and then dividing by an efficiency factor.

Early work in winter wheat showed that N uptake of winter wheat and NDVI are highly correlated (Stone et al., 1996). Further work done in wheat has shown that yield potential could be accurately predicted 50% of the time by the GreenSeeker when readings were taken at the Feekes 5 growth stage. When fertilizing wheat based on yield potential and having the ability to apply variable rate fertilizer N, plant N use efficiency was increased by more than 15 percentage points when compared to traditional fertilizer application methods (Raun et al., 2002).

In corn, work in Oklahoma has shown that grain yield and NDVI were best correlated at the V8 growth stage using an exponential equation. Using the INSEY approach to adjust for early season growing conditions did not improve the correlation; however, it did extend the critical sensing window two leaf stages, to V-10 (Teal et al., 2006). This suggests that using NDVI directly at a specific growth stage would be more accurate for estimating potential grain yield than using an INSEY adjusted NDVI before or after that growth stage. However, using INSEY may help extend the critical sensing window.

A more recent study in corn found that when corn was younger and smaller, the sensor has the ability to detect more soil area when sensing areas of lower yielding plants than in areas of higher yielding plants. Conversely, at later stages of growth, corn plants were taller which required increased elevation of the sensor and subsequently soil background had a diminished influence on NDVI. This resulted in NDVI explaining 64% of the variation in N uptake at early growth stages. However, at later growth stages, NDVI was not as well correlated with N uptake (Freeman et al., 2007).

The specific objective of this study was to develop a Kansas specific system to make sensor based N recommendations to estimate mid-season N needs for corn production.

Materials and Methods

A total of 14 site years of data were collected to evaluate the effects of nitrogen rate and nitrogen application timing on grain yield for corn. All research locations were all located in Kansas close to the towns of Colby (2008-2009), Manhattan (2006-2009), Rossville (2007-2009), and Tribune (2007-2009). All experiments were set in the field using a randomized complete block (RCB) design with all treatments being replicated four times. Individual plots were either four or eight rows wide spaced 76 cm apart and at least 15 m in length. Grain yield was determined at all locations by either hand harvesting 5.25 m of the middle two rows of each plot, and shelling using an Almaco mechanical thresher or by harvesting at least 12 m of the middle two rows of each plot using a plot combine. When starter fertilizer was used it was applied 5 cm to the side of the seed row and 5 cm deep with the planter. Yields were adjusted to standard 155 g kg^{-1} moisture content.

In 2006 a study examining the effect of side-dressed nitrogen rate at the V-8 growth stage was conducted at the KSU Agronomy North Farm (39^0 12’ 51”; 96^0 35’ 29”), on a Kahola silt loam soil. The study was duplicated in 2008. Specific treatments consisted of a no nitrogen check, a pre-plant N application 179 kg N ha^{-1} with an additional 45 kg N ha^{-1} applied as a starter, a starter treatment of 45 kg N ha^{-1}, and starter treatments plus an additional 34 to 202 kg N ha^{-1} in 34 kg N ha^{-1} increments applied as UAN solution, coulter band injected approximately 7.5 cm deep below the residue in the row middles at the V-8 growth stage. This study was no-till planted in late April at a seeding rate of 60,500 seeds ha^{-1} into soybean residue from the previous crop year in 2006 with the Pioneer 33R81 hybrid (Pioneer Hybrids, Johnston, IA), and sorghum stubble in 2008 with the Asgrow 785VT3 hybrid (Monsanto, St. Louis, MO). A starter application of 20 kg P ha^{-1} was applied to all treatments with the starter N as a mixture of liquid ammonium polyphosphate and urea-ammonium nitrate.

In 2007 a three year study was initiated examining the effects of pre-plant N vs. split applied N vs. sensor based N was conducted at the Kansas River Valley Experiment Field near Rossville (39^0 6' 59"; 95^0 55' 38") on an Eudora silt loam and at the Western Kansas Research Center near Tribune (38^0 31' 45"; 101^0 39' 42") on a Ulysses silt loam. In 2008 a third study was added at the Northwest Kansas Research Center near Colby (39^0 23' 18"; 101^0 4' 19") on a Keith silt loam. All locations had ten N management strategies involving pre-plant only, split applications, and variable rates based on active sensor technologies. Specific treatments consisted of a starter only treatment of 22 kg N ha^{-1}, total pre-plant N rates of 134, 179, and 224 kg N ha^{-1}, and total split applied N rates of 134, 179, and 224 kg N ha^{-1} where 50% of the N was applied at planting time with the other 50% applied at the V-8 growth stage. All treatments were applied using liquid UAN and injecting it into the soil between the corn rows. In addition three variable rate treatments were used based on recently developed crop sensor technologies (GreenSeeker) and/or a chlorophyll meter. The Rossville and Colby locations had additional treatments using the Crop Circle sensor with and without a chlorophyll meter. With these treatments, a total pre-plant N application of 134 kg N ha^{-1} was used and the optical sensors (GreenSeeker and Crop Circle) were used to estimate yield potential at the V-8 growth stage. Additional N was applied based on the Great Plains corn sensor N rate calculator available on the Oklahoma State University Soil Fertility website. The chlorophyll meter was used to measure relative greenness of the plot vs. the greenness of the highest pre-plant N plots. When the plot of interest had a relative greenness less than 95% an additional 34 kg N ha^{-1} was applied or if less than 90% relative greenness an additional 67 kg N ha^{-1}.

At Rossville soil samples to a depth of 1 m were taken prior to initial treatment application, after each harvest, and then again in the spring prior to planting. This site was supplemental irrigated using an overhead sprinkler minimize water stress throughout the growing season. Corn was planted in late April (19-21) with a target seeding rate of 80,000 seeds ha^{-1} using the DKC 61-69 hybrid (Monsanto, St. Louis, MO) all years. Herbicides were used to control in-season weeds in all plots along with in row cultivation to control volunteer corn. A starter application of 20 kg P ha^{-1} was applied to all treatments in addition to the N starter. Fall and spring tillage occurred to prepare and warm the seedbed for corn planting.

At Tribune, the site was fully irrigated using an overhead sprinkler. To minimize water stress throughout the growing season, tensiometers were placed at 1.35 and 1.65 m depth in all plots and reading taken approximately weekly during the growing season to ensure adequate water without excessive irrigation. Corn was planted in early May with a target seeding rate of 80,000 seeds ha^{-1} with the Pioneer 33B54 hybrid. Herbicides were used to control in-season weeds in all plots. A starter application of 20 kg P ha^{-1} was applied to all treatments in addition to the 22 kg N ha-1 N. Fall and spring tillage occurred to prepare and warm the seedbed for corn planting.

At Colby, corn was planted in early May with a target seeding rate of 80,000 seeds ha^{-1} with the Pioneer 33H26 hybrid. Herbicides were used to control in-season weeds in all plots. Soil samples to a depth of 1 m were taken prior to initial treatment application, and after the final harvest. This site was flood irrigated to minimize water stress throughout the growing season. A starter application of 20 kg P ha^{-1} was applied to all treatments and no additional K fertilizer was applied due to a sufficient soil test. Spring strip tillage occurred to prepare and warm the seedbed for corn planting.

NDVI and SPAD meter readings were taken throughout the growing seasons at all locations. The sensors used for this study include the GreenSeeker red sensor and Crop Circle amber sensor. The Crop Circle sensor (ACS-210, Holland Scientific, Lincoln, NE) simultaneously emits light in two bands (visible and NIR) and has a field of view of 32 degrees by 6 degrees. The version of the sensor used in these experiments emits light in amber (590 nm ±6 nm) and NIR (880 nm ±10 nm) wavebands from an array of LEDs. The GreenSeeker (Hand-held unit Model 505, NTech Industries, Ukiah, CA) emits light in red (660 ± 15 nm) and NIR (770nm ± 15 nm) (NIR). The field of view is approximately constant for heights between 60 and 120 cm above the canopy because of light collimation within the sensor. Both of these sensors calculate NDVI by the following equation: (NIR-Visible) / (NIR+Visible).

To collect these NDVI readings, sensors were positioned approximately 75 cm above the leaf canopy, and walked with the sensor head facing parallel to the row, and directly over the row. The middle two rows of each plot were sensed, and the NDVI values were averaged for the plot, as well as for each treatment. A response index (RI_{NDVI}) was calculated by taking the NDVI of the highest pre-plant N rate at a specific growth stage and dividing this by the NDVI of the other treatments which did not receive any additional N fertilizer. Calculation of response index grain yield (RIGY) was done by taking the grain yield of the highest treatment pre-plant N-Rate and dividing this by the grain yield of the other treatments which received either only starter N fertilizer or pre-plant N fertilizer. In season estimate of yield (INSEY) was determined by taking NDVI divided by the days after planting to sensing or by taking NDVI divided by growing degree units accumulated to sensing date. SPAD meter readings were taken using a Konica-Minolta SPAD meter. The SPAD meter was clamped onto the most recently developed leaf with a visible leaf collar of 25 plants within the middle two rows.

Optimum N rate at each site was determined by performing a linear or quadratic regression analysis using Microsoft EXCEL, choosing the best model as determined by the r^2, and solving for the N rate at 100% of yield. EXCEL was used for all other curve fitting as well. Only the GreenSeeker sensor data was used in this study, due to mechanical problems with the Crop Circle. Where available, Crop circle NDVI values are given in the appendix. Additional statistical analysis was run to analyze differences between treatments that were observed using SAS version 9.1 with proc GLM an alpha of 0.05.

Results and Discussion

Several approaches to building a sensor based recommendation system for corn in Kansas were considered, and will be presented. Regardless of the approach used, the development of a sensor based recommendation system for corn in Kansas appears to be a challenge.

The first approach attempted was to fit a yield prediction equation using NDVI vs. grain yield at several growth stages, and calculate the delta yield or response in yield expected from fertilizer N at that time. This was done by collecting NDVI values of the reference strip and the farmer practice/N treatment, and then comparing the yield differences found between those values. Several yield prediction equations are presented in Figures 4.1, 4.2, and 4.3 which all have R square values of less than 0.50 using the NDVI values of the pre-plant N fertilizer treatments only, which did not receive any additional N. Figure 4.1 shows the relationship between NDVI at V-8/9 and corn grain yield, while Figure 4.2 shows the relationship between NDVI divided by days from planting to sensing (INSEY) vs. corn grain yields, and Figure 4.3 shows the relationship between NDVI divided by growing degree days (base 50) accumulated from planting to sensing vs. corn grain yields. In all three cases yield relationships are not very strong. However, this “total” data set includes sites which had significant hail damage or water stress which would impact the yield prediction equation. The same relationships for sites which were not negatively impacted by hail or drought are given in Figures 4.4, 4.5, and 4.6. In these non-stressed environments, R^2 are all > 0.50, and provide a base relationship to use for estimating yield potential for corn at the V-8,9 growth stage. However, development of a N algorithm depends on a well defined relationship between RI_{NDVI} (response index NDVI) and RI_{GY} (response index of grain yield at harvest). This relationship is given in Figure 4.7 and is a very poor relationship with an R^2 value of 0.26. As with the yield prediction equations, removing the sites which had significant hail damage or water stress improved this relationship. This relationship is given in Figure 4.8 and has a R^2 value of 0.49. Going one step farther and looking at conventional tilled sites and no-till sites separately, while omitting the sites which had significant hail damage or water stress, the relationships are given in Figures 4.9 and 4.10. In the conventional till sites the R^2 value was only 0.17 while it was 0.82 in the no-till sites.

Figure 4.1 Relationship between NDVI sensed at V-8,9, and corn grain yield, 2006-2009, all sites

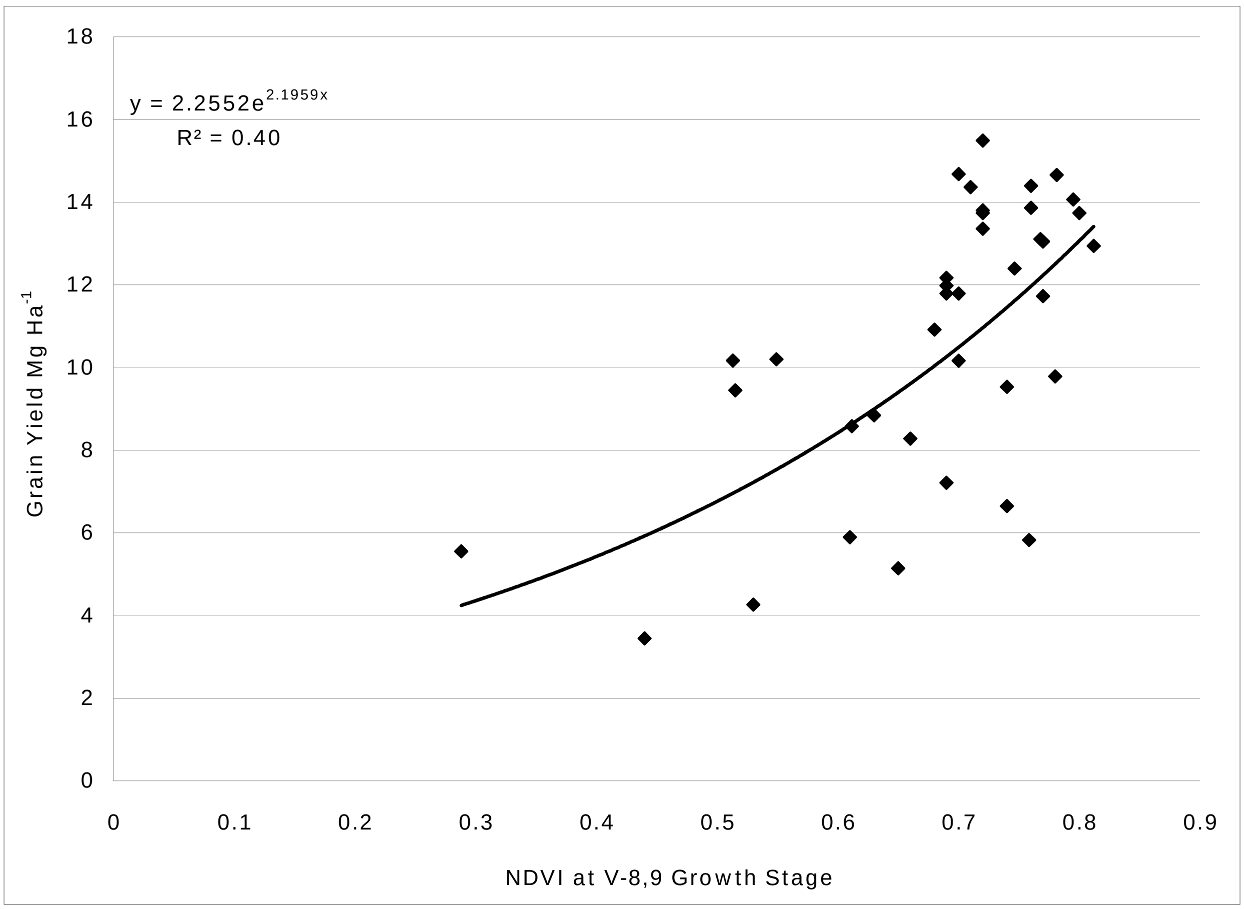


Figure 4.2 Relationship between INSEY at V-8,9, NDVI divided by days from planting to sensing, and corn grain yield, 2006-2009, all sites

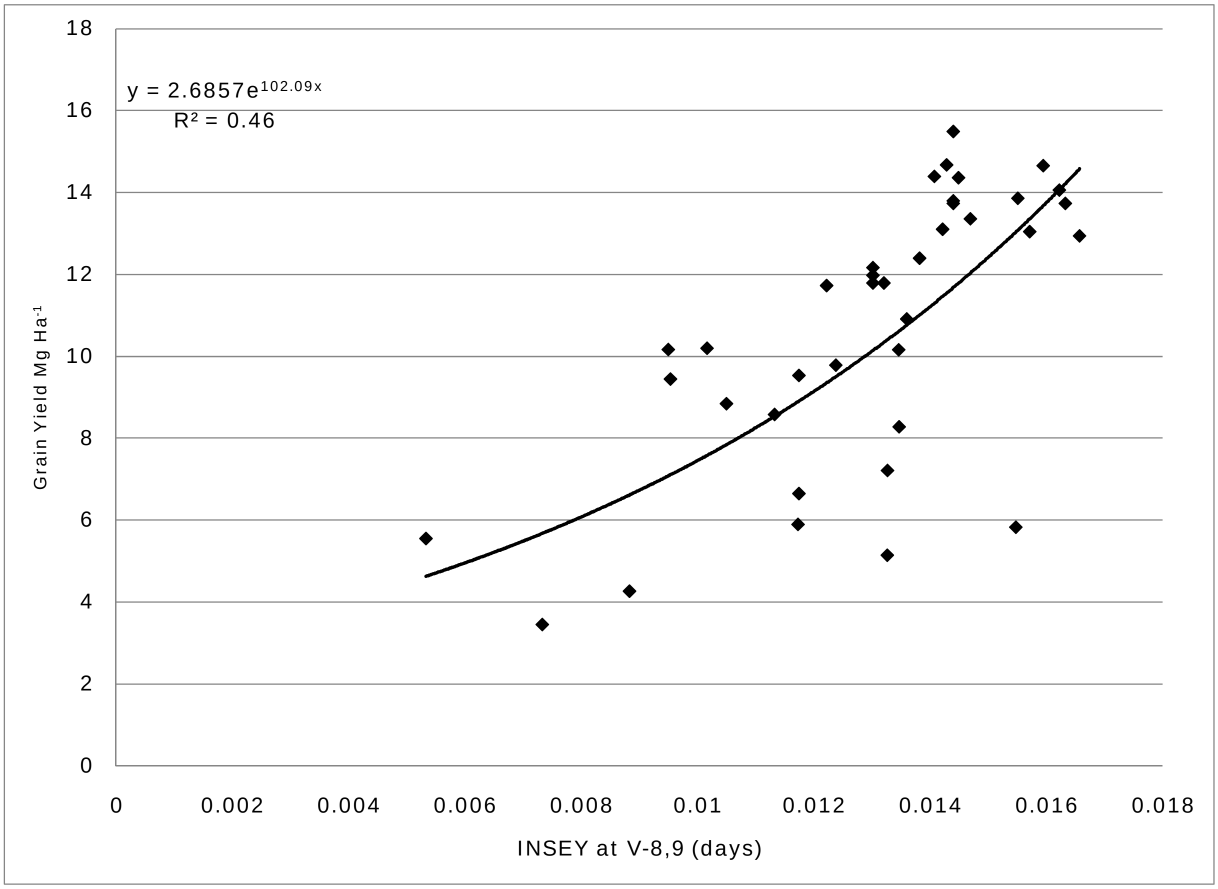


Figure 4.3 Relationship between INSEY at V-8,9, NDVI divided by GDD's base 50 from planting to sensing, and corn grain yield, 2006-2009, all sites

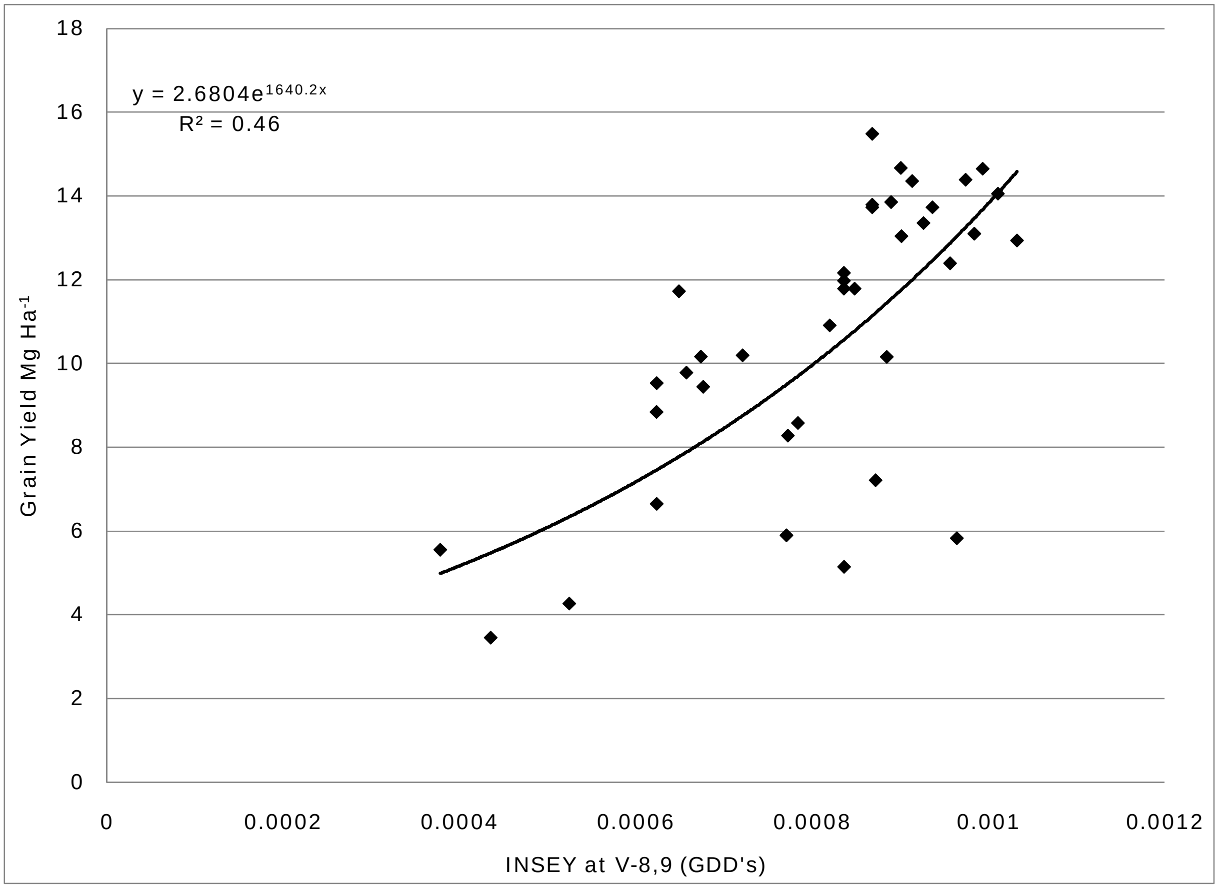


Figure 4.4 Relationship between NDVI sensed at V-8,9, and corn grain yield, 2006-2009, omitting hail and drought sites

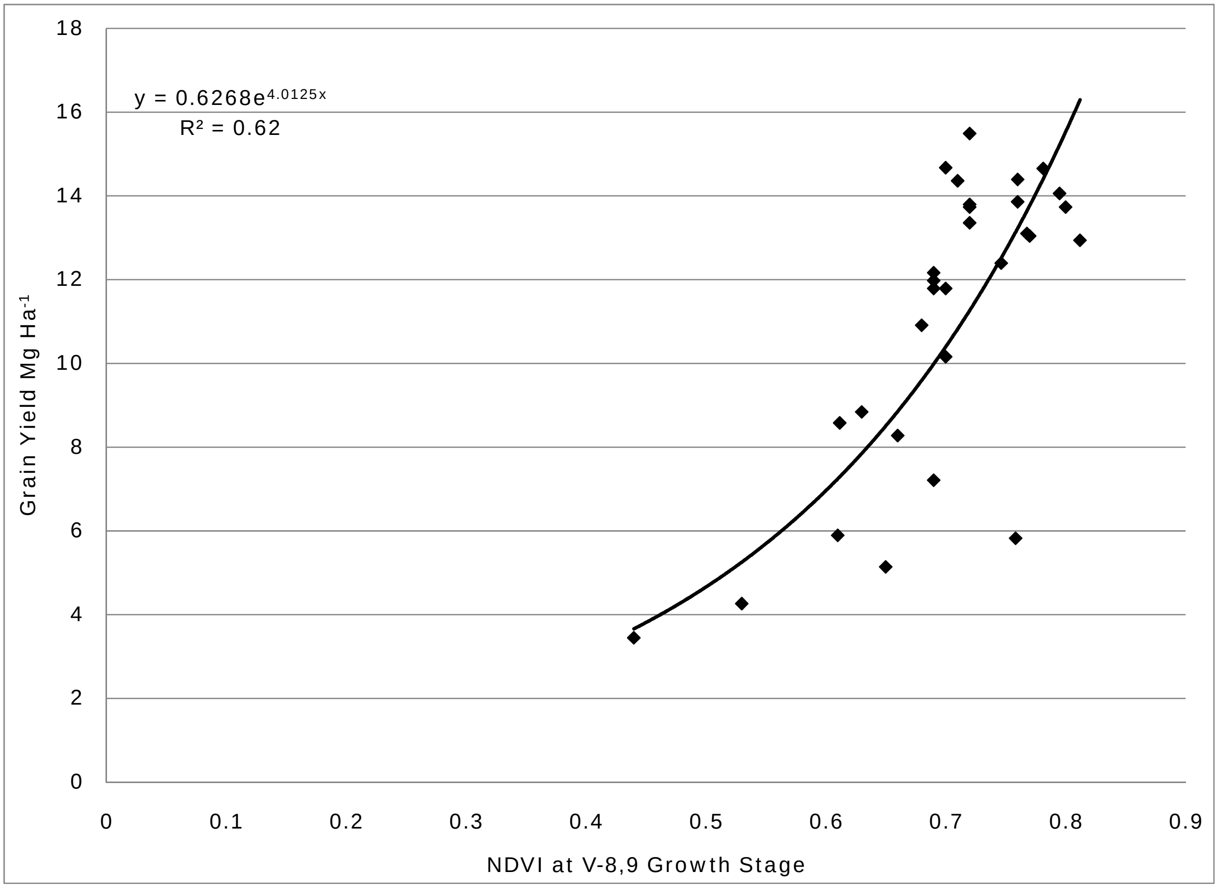


Figure 4.5 Relationship between INSEY at V-8,9, NDVI divided by days from planting to sensing, and corn grain yield, 2006-2009, omitting hail and drought sites

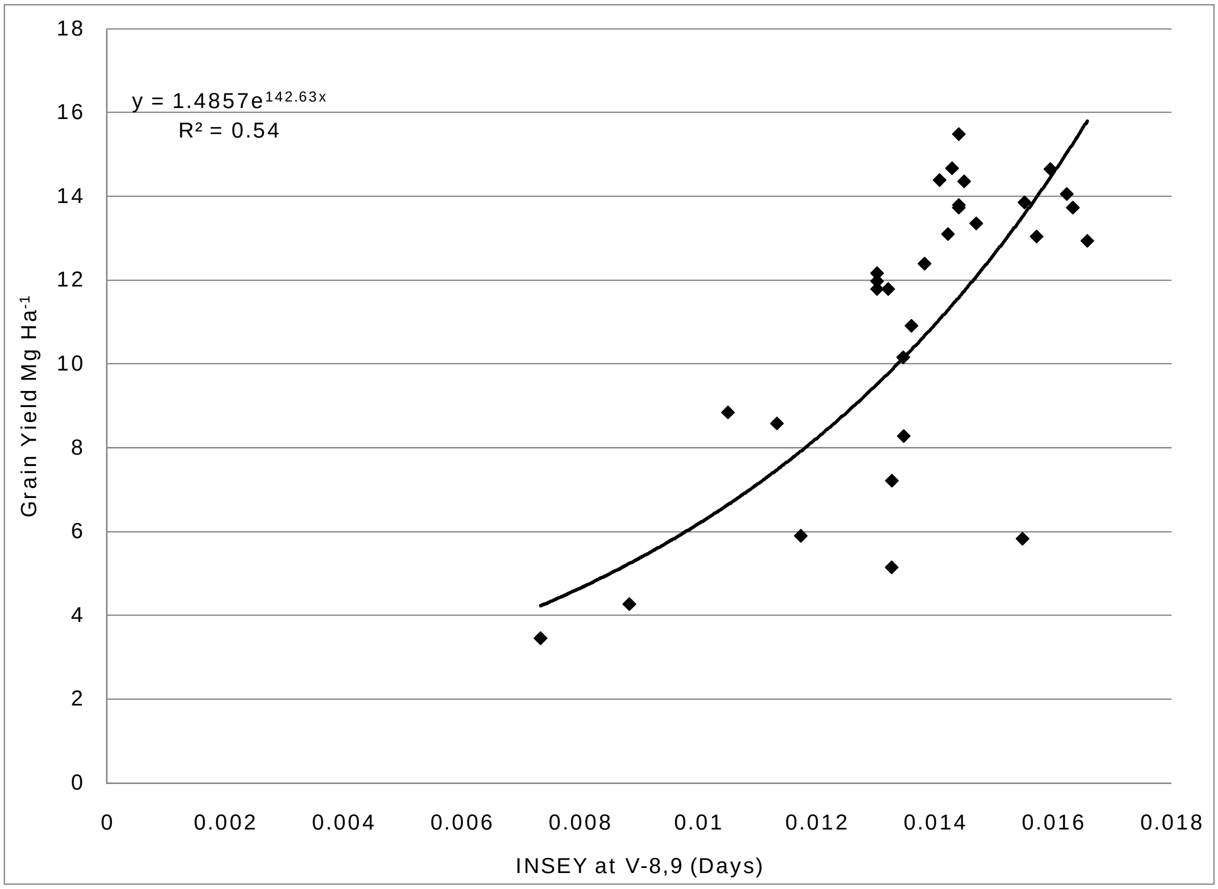


Figure 4.6 Relationship between INSEY at V-8,9, NDVI divided by GDD's base 50 from planting to sensing and corn grain yield, 2006-2009, omitting hail and drought sites

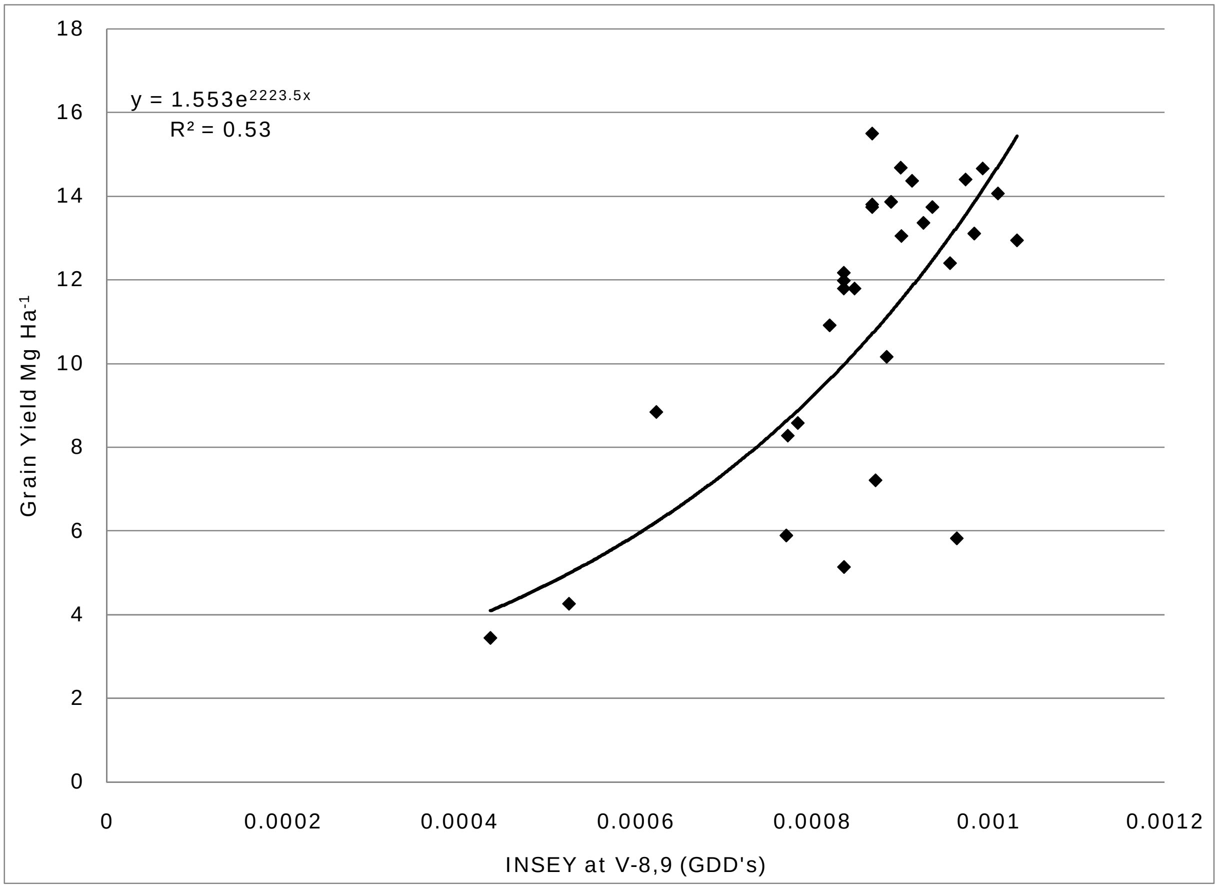


Figure 4.7 Relationship of RI_{NDVI} at V-8,9 growth stage and RI_{GY} at harvest, 2006-2009, all sites

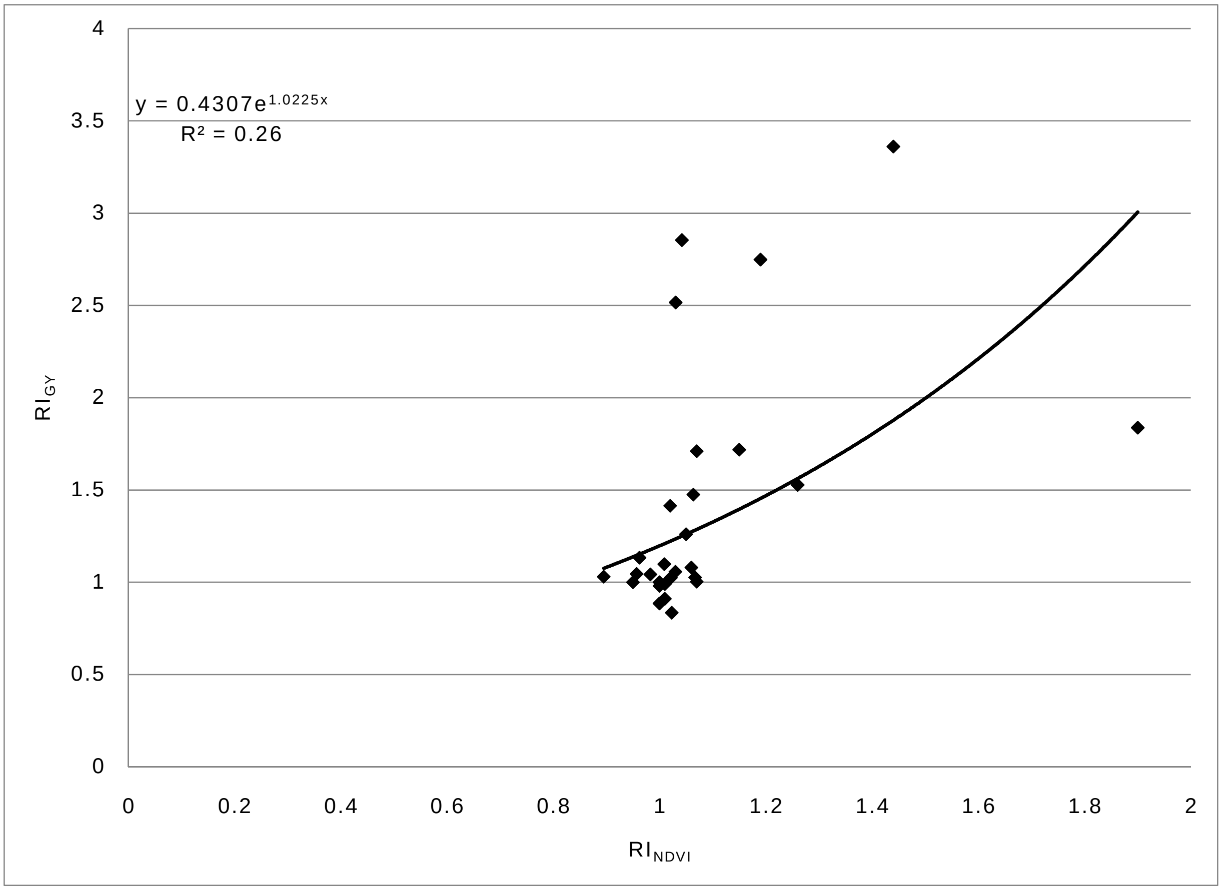


Figure 4.8 Relationship of RI_{NDVI} at V-8,9 Growth Stage and RI_{GY}, 2006-2009, omitting hail and drought sites

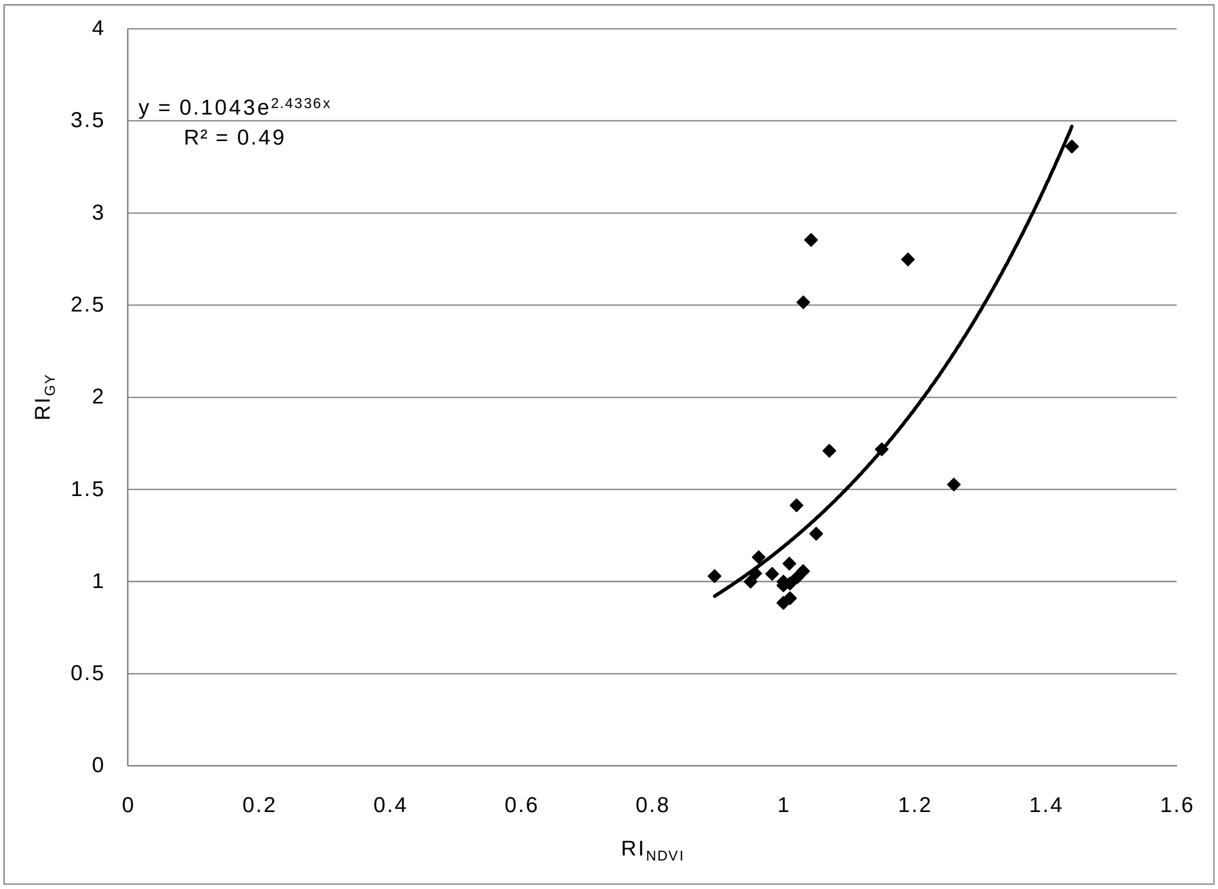


Figure 4.9 Relationship of RI_{NDVI} at V-8,9 Growth Stage and RI_{GY} at harvest in Conventional Tillage, 2007-2009, omitting hail and drought sites.

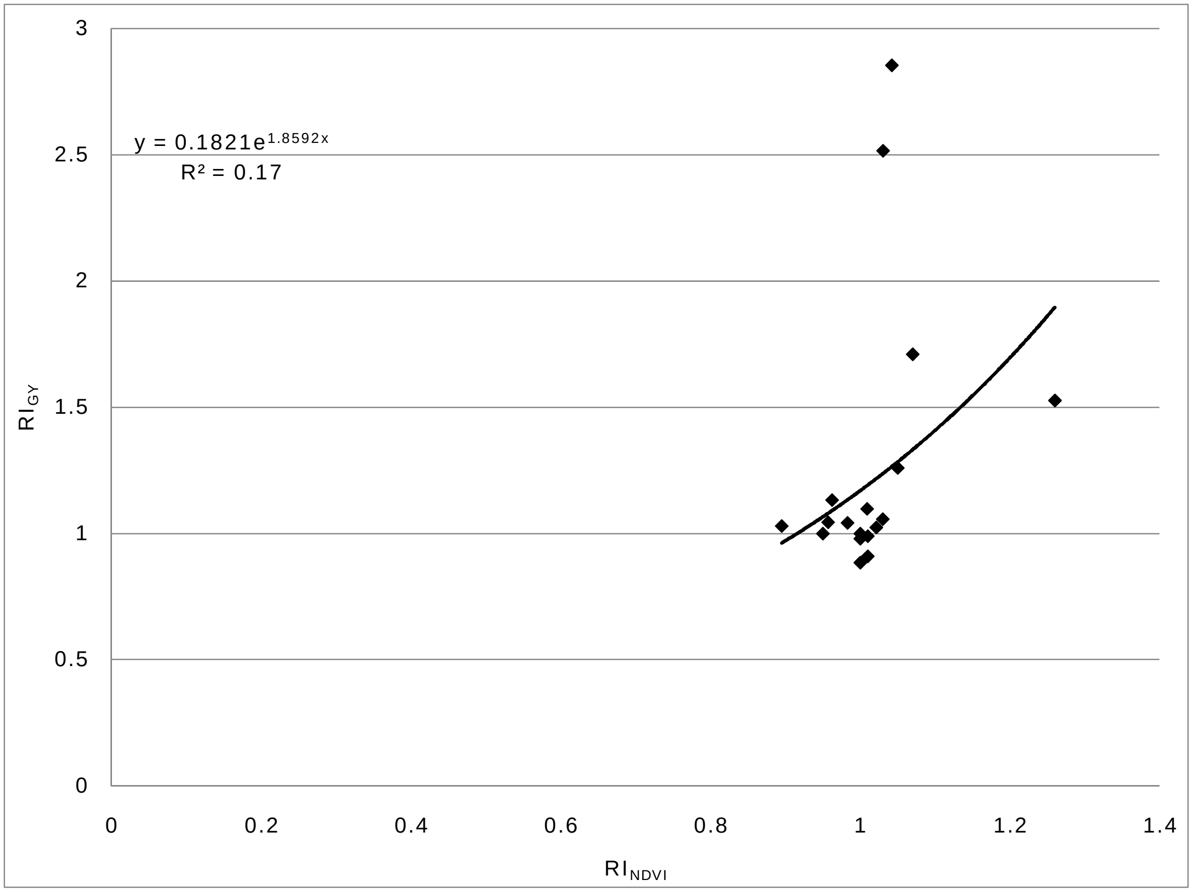
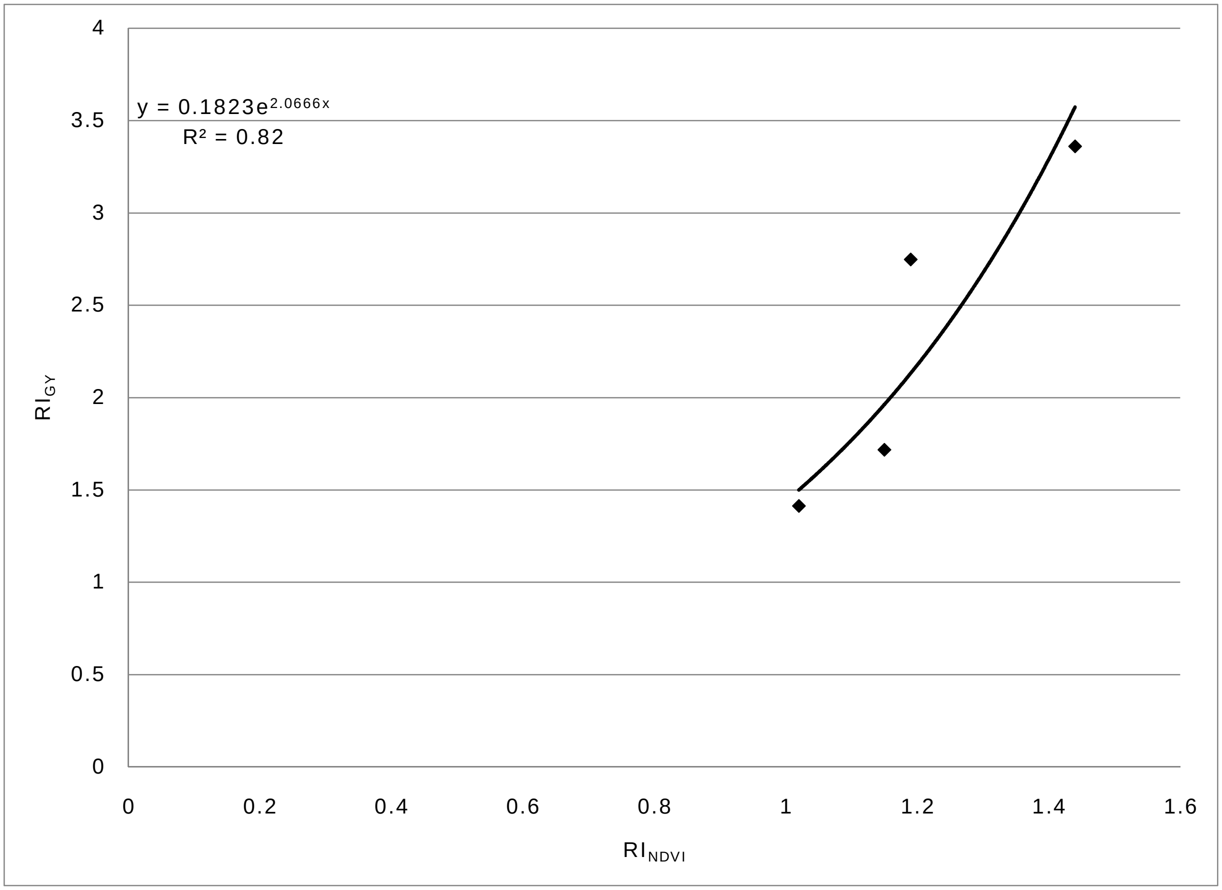


Figure 4.10 Relationship of RI_{NDVI} at V-8,9 Growth Stage and RI_{GY} in No-Till, 2006-2008, omitting hail and drought sites.



An alternative approach to making sensor based N recommendations is just using the sensor to estimate a potential response to nitrogen while ignoring yield potential. This may be a more appropriate approach in corn as the prediction equations identified to date are weak, partly due to the harsh environment common to corn production in Kansas. Making these recommendations requires a well defined relationship between RI_{NDVI} and Delta N needed to achieve 100% yield. The relationship found in this data set is given in Figure 4.11. Using this approach a producer could calculate RI_{NDVI} from sensor measurements from the bulk field and the reference strip in that field and estimate Delta N from that RI_{NDVI} vs. Delta N relationship.

Delta N times an estimated NUE or efficiency factor would then give the N recommendation for the field. Unfortunately this relationship isn't strong for the V-8,9 growth stage using the total data set.. However, separating the conventional till sites and no-till sites, a poor relationship is seen for the conventional till sites while a good relationship is seen for the no-till sites as shown in Figures 4.12 and 4.13.

One significant underlying issue that must be remembered is that only 20-30% of the N that will be used by the crop has been taken up by the V-8,9 growth stage. Thus, many factors can impact uptake of the remaining N including N supply, mineralization rate, water stress, and N loss. So it really should not be surprising that early season sensor use would be relatively unproductive in a typical Kansas environment. There also must be some differences due tillage that explains the difference in performance of the sensors as seen in Figures 4.12 and 4.13. One likely explanation would be the earlier mineralization of soil N due to the mixing and warming of the soil by tillage stimulating soil organic matter mineralization earlier in the season which, together with the application of N in starter fertilizer provides enough nitrogen from soil supply to allow adequate early season growth and sensor readings regardless of N treatment in conventional tillage, but becomes nitrogen deficient later in the growing season.

Waiting to sense until later in the growing season at V-15,16 provides a much better relationship for both conventional till sites and no-till sites as seen in Figures 4.14 and 4.15. While the amount of available data from non-stressed environments is limited, and the large amounts of vegetation limit the range of NDVI values, the high R^2 values (>0.80) suggest a much greater potential for sensors as an N management tool to improve NUE later in the season. One can envision a system whereby a farmer might apply 80% of the normal N needs early in the growing season, and then come back at the V-16 growth stage and "top-off" the N needs of the crop. This approach would be attractive from a risk management perspective also as it would reduce risk of a severe impact on crop yield if the late season N application were delayed or not applied. Since N response is normally defined by a quadratic function, a reduction in 20% of the applied rate would likely result in a 10% or less yield loss.

Figure 4.11 Relationship of RI_{NDVI} at V-8,9 Growth Stage and Delta N, 2006-2009, omitting hail and drought site

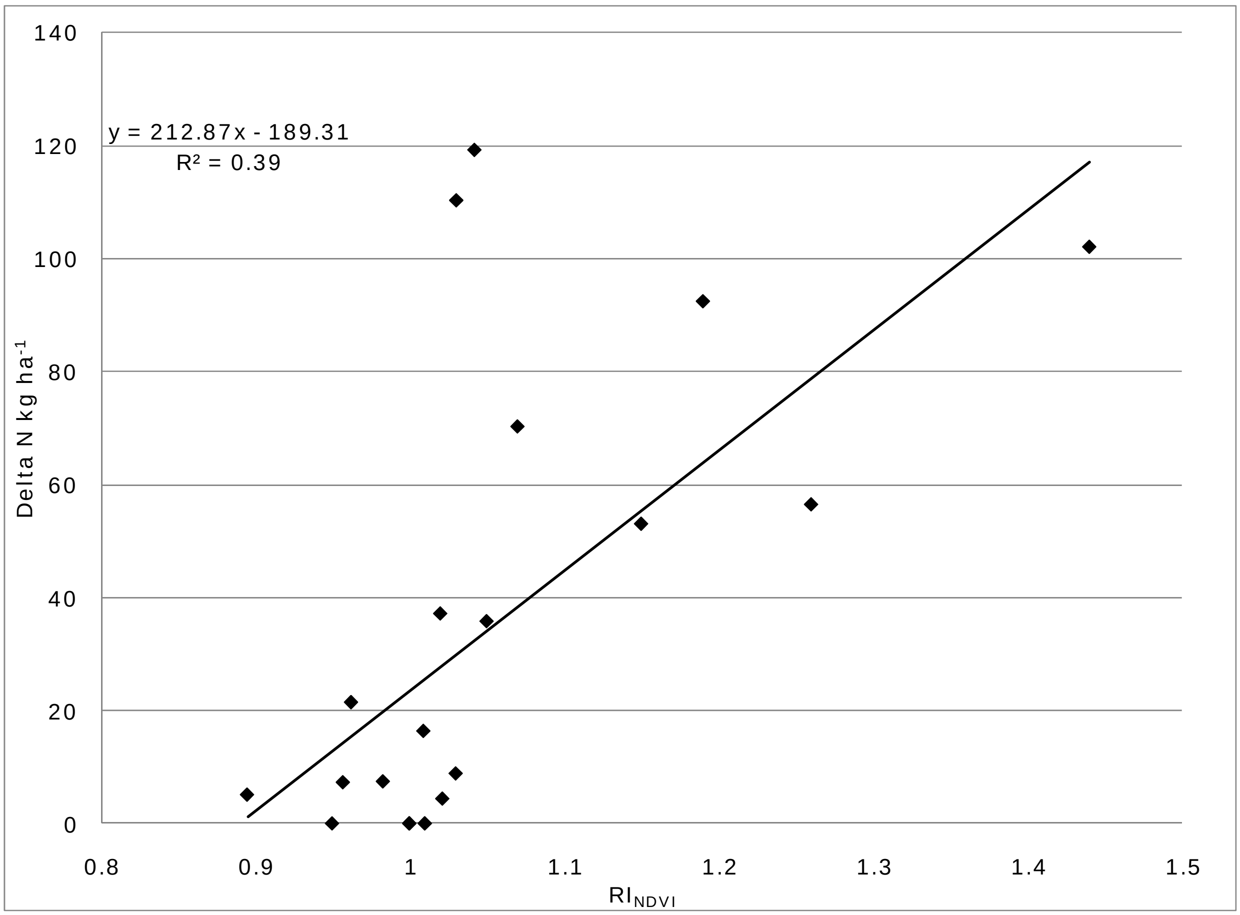


Figure 4.12 Relationship of RI_{NDVI} at V-8,9 Growth Stage and Delta N in Conventional Tillage, 2007-2009, omitting hail and drought sites

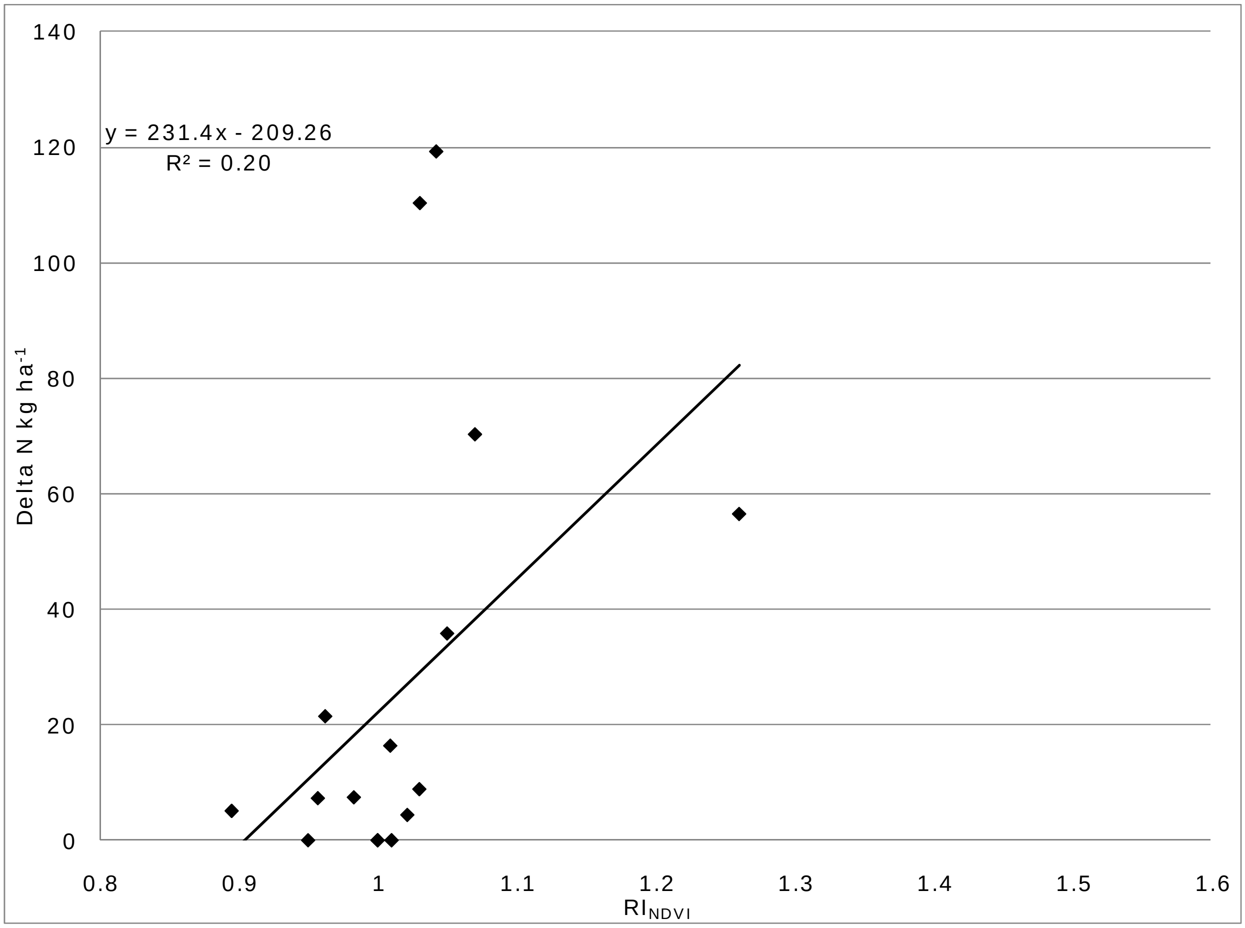


Figure 4.13 Relationship of RI_{NDVI} at V-8,9 Growth Stage and Delta N in No-Till, 2006-2008, omitting hail and drought sites

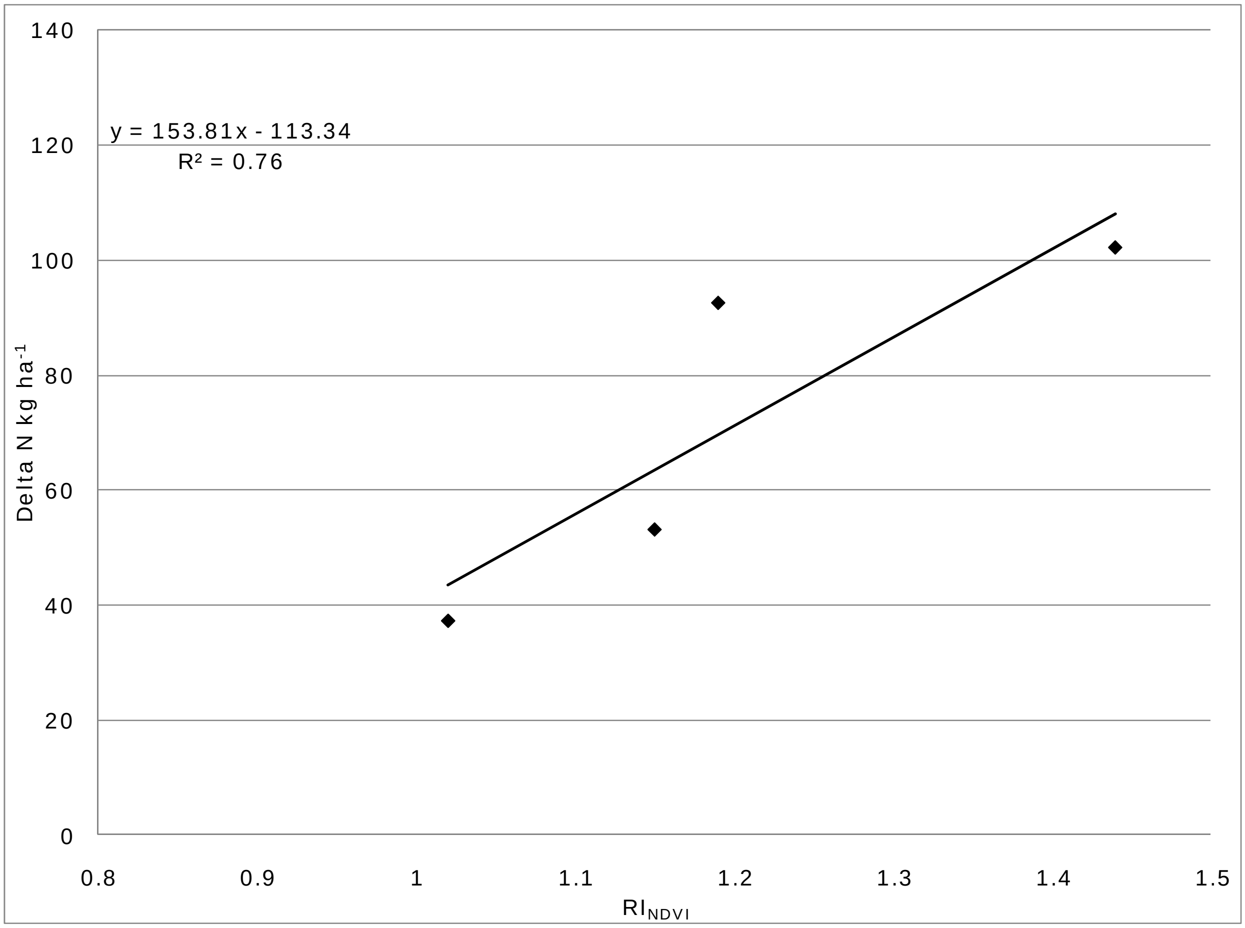


Figure 4.14 Relationship of RI_{NDVI} at V-15,16 Growth Stage and Delta N in Conventional Tillage, 2007-2009, omitting hail and drought sites

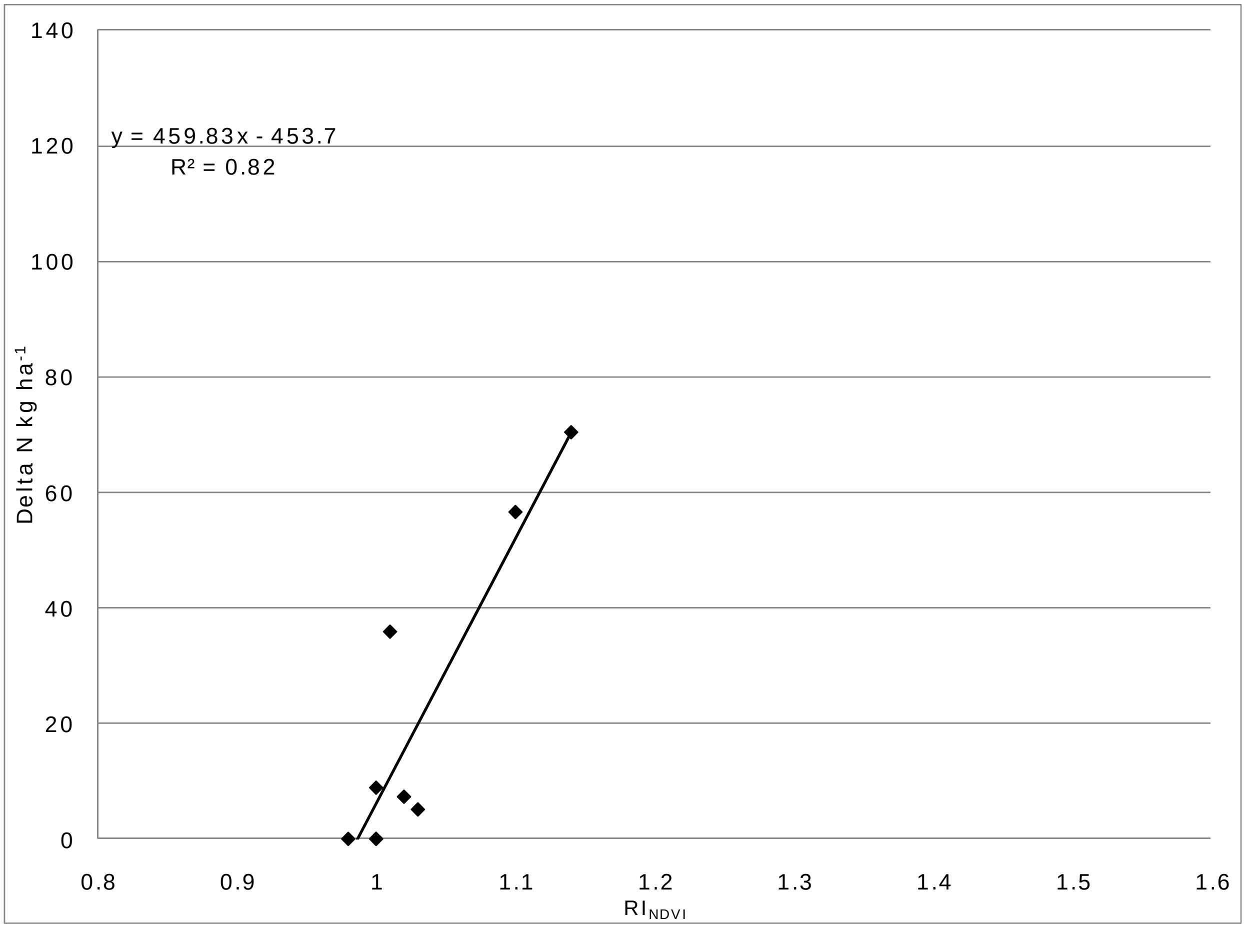
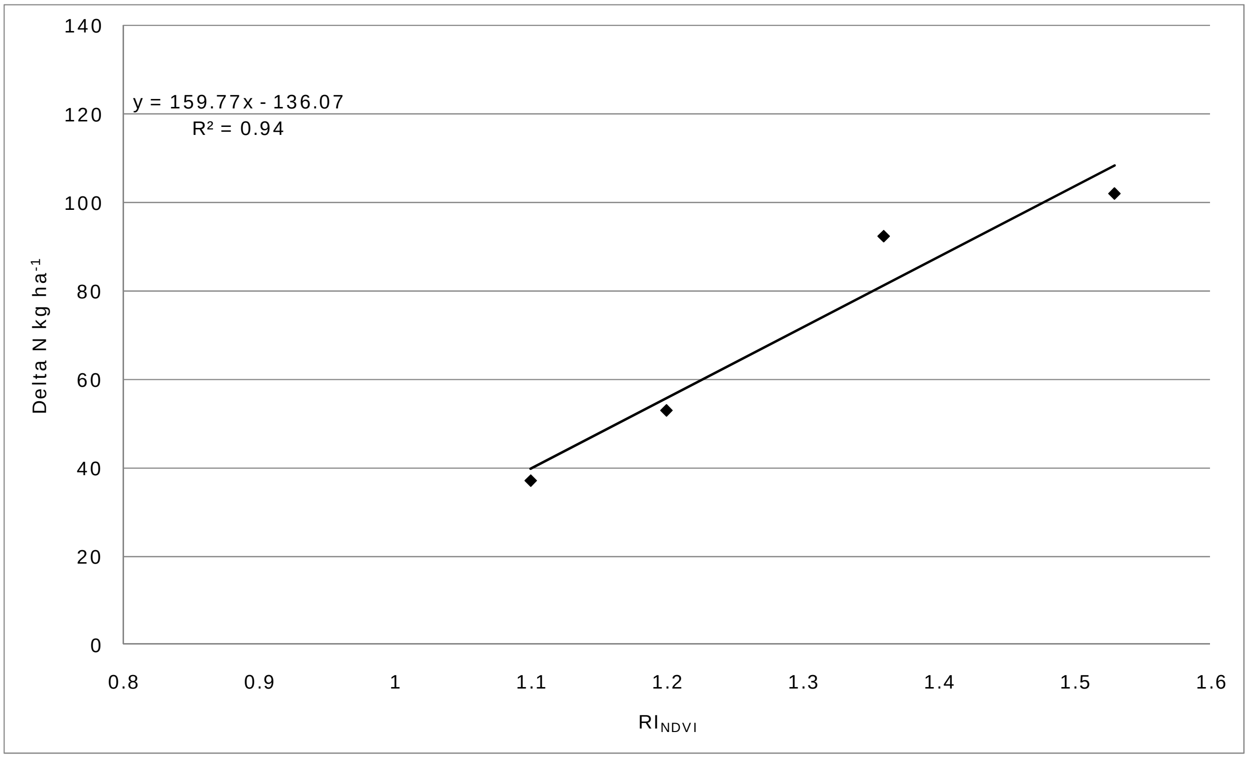


Figure 4.15 Relationship of RI_{NDVI} at V-15,16 Growth Stage and Delta N in No-Till, 2006-2008, omitting hail and drought sites



Conclusions

The use of optical sensors to estimate mid-season nitrogen needs in corn is promising technology. Current sensors can be of some help, but do not do as good a job of predicting nitrogen needs in many fields or environments, unless N is severely limited, when used as early as the V-8 growth stage. But by waiting until the V-15 growth stage performance improves substantially. As currently used, the technology requires the use of a high N reference strip. Care must be made to protect the reference strip from early season N loss.

The results from these studies would indicate that the technology seems to work best at early (V-8) growth stages in environments such as no-till corn, when the plant is N stressed to accentuate N supply differences. Unfortunately, this only provides a narrow window of opportunity to fertilize the crop without the use of high clearance equipment, and producers are unlikely willing to stress corn, and potentially lower yields, to make sensors work early. Therefore it is much more likely that growers would consider adopting a system where the sensors are used at later stages of growth such as at V-16 with high clearance equipment, after they have applied a base level of N on corn at planting to minimize risk and maximize yield. This would be especially true when planting under conditions which include:

a. A soil which tested low for available N;

b. When planting in no-till conditions;

c. When using starter fertilizer to hasten maturity of the crop;

d. When a producer is concerned about the ability to side-dress N in a timely manner;

e. Where a producer only expects a marginal response to N and may choose not to side-dress for various reasons.

Pre- or at planting N applications seem to reduce the ability to differentiate N needs accurately using sensor technology especially early in the growing season at the V-9 growth stage. Adding a check strip of no pre-plant or at planting N as a correction term is recommended to use the sensor technology prior the V-9 growth stage. If producers are going to rely on pre-plant N application of nitrogen and only use the sensor as a tool to fertilize corn as a top off type system it is recommended that they use the technology at the V-15 growth stage or just prior to tassel emergence.

For those not willing to soil test for N prior to planting, the use of sensor technology to estimate the soil N contribution would offer an alternative. The sensors would also offer a means of addressing in season N loss from leaching or denitrification.

Deciding on which sensor to use should be left up to the producer, however, it is important to use the recommendations that were developed for that sensor only (data not shown). Whichever management decision the grower decides to make, the sensors technology can help aid the farmer in making better nitrogen fertility decisions in the future.

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CHAPTER 5 - Summary and Final Conclusions

In these irrigated corn studies, there was no difference in yield or NUE found due to application timing. This is contrary to responses observed in more humid climates in the Eastern U.S., or where irrigation water application may not have been closely monitored. If this relationship holds, this would allow producers more flexibility in applying nitrogen in these high yielding irrigated systems, as applying all the nitrogen pre-plant may be the easiest and most cost effective management strategy when yields are very consistent and the irrigation water is managed efficiently.

The nitrogen timing study showed that nitrogen can be successfully applied and optimum yields achieved, even when N is applied late in the growing season. This shows that correcting nitrogen stress prior to tassel emergence with nitrogen fertilization can be a successful management tool. In the late timing of nitrogen studies, application of N prior to tassel emergence increased yields even in the severely deficient corn at the Kansas River Valley location confirming this observation. This would suggest that if a producer has N deficient corn that a rescue application of N can be successful to increase grain yields.

In a series of ten N response studies conducted across Kansas the current KSU corn N recommendations were found to overestimate N needs by an average of 131 kg N ha^{-1}. One issue with the recommendations is the use of a single constant relating the N need per unit of yield, regardless of yield level or expected N use efficiency. By utilizing two constants, one for irrigated and one for dryland or rainfed corn, and adding the use separate N use efficiency factors for irrigated and rainfed corn, a proposed modified system overestimated N need by approximately 26 kg N ha^{-1}. While the modified system still has considerable room for improvement, it demonstrates that the single constant used in the current system regardless of yield potential should be modified. The addition of a nitrogen recovery term based on the NUE commonly observed in those systems could also provide significant improvements over the current system used.

Sensor based N management of corn proved to be as successful as pre-plant or split nitrogen applications at the Rossville, Tribune, and Colby research locations, with less nitrogen being applied on average, than used for the pre-plant and split application of N. At the Manhattan 2008 location, sensor based N management of corn at the V-8 growth stage proved to be ineffective as the sensor didn't predict an N response at that growth stage and grain yields were significantly less than those obtained with the side-dressed nitrogen treatment which received the highest amount of N. This was likely due to loss of N from the reference strip. Yields were increased from an application of N at the V-16 growth stage as N was needed as predicted by the SPAD meter.

The use of optical sensors to estimate mid-season nitrogen needs in corn is promising technology. Sensors do an excellent job of predicting nitrogen needs in no-till fields as early as the V-8 growth stage and an even better job at the V-15 growth stage. Unfortunately, in conventional till fields, where higher rates of N mineralization are likely to occur, the sensors predict nitrogen needs poorly at the V-8 growth stage, but do an excellent job later at the V-15 growth stage. The technology will require the use of a high N reference strip for best results.

The sensor technology seems to work best at the V-8 to V-16 growth stage for no-till corn, but only will work well at the V-8 stage for conventional till corn sites if fertilizer N supply is limited to force a differentiation between the bulk field and the reference strip. Unfortunately, this only provides a narrow window of opportunity to fertilize the crop without the use of high clearance equipment. This leads one to conclude that if the sensor technology is used at the V-8 growth stage to guide side dress application, the producer may want to check the corn again at the V-15 growth stage prior to tassel emergence, to ensure it still has adequate N to optimize producer profits.

Future research will need to be conducted to determine the most efficient management practices for using sensor based N recommendations, how the producer should apply the nitrogen fertilizer, and the timing of the nitrogen application. In addition different sensor based N recommendations for different management and cropping management may need to be developed to provide better sensor based N recommendations to producers.

For those not willing to soil test N prior to planting, the use of sensor technology to estimate soil N contribution would offer an alternative. The sensors would also offer a means of addressing in season N loss from leaching or denitrification. Deciding on which sensor to use should be left up to the producer, however, it is important to use the recommendations that were developed for that sensor since NDVI and RI relationships vary. Also for those producers who wanted to monitor corn growth the use of the sensor technology to document growth would prove to be very useful. Sensor technology could also be used to evaluate growth of different corn hybrids during the growing season. Whichever management decision the grower decides to make, the sensors technology can help aid the farmer in making better nitrogen fertility decisions in the future.

Appendix-A Nitrogen Management of Corn with Sensor Technology Raw Data

This appendix contains all raw data collected that may be required to conduct additional analyses in the future. The data are arranged by site location and year.

Manhattan – Agronomy North Farm

Table A.1 Manhattan Regional Trial 2006

Rep	Pre-plant N	Starter N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual	Grain N	WP N	Earleaf N
	-- ($kg\ ha^{-1}$)--							----------- ($g\ kg^{-1}$)-------------		
1	0	0	0	15424	5389	106	27	13.2	3.7	16.7
2	0	0	0	15454	6374	106	33	11.0	4.1	15.8
3	0	0	0	15146	6407	103	21	11.1	4.0	16.0
4	0	0	0	15114	5482	93	33	11.0	3.5	17.8
1	224	0	224	23501	10028	241	65	13.2	7.7	21.3
2	224	0	224	18399	8577	161	69	13.6	4.6	24.7
3	224	0	224	23333	11824	205	46	11.3	6.1	23.4
4	224	0	224	17129	10216	169	35	12.4	6.2	22.8
1	0	45	45	16789	6536	126	39	12.1	4.7	15.3
2	0	45	45	16785	6711	110	31	11.4	3.5	15.4
3	0	45	45	16424	7498	119	20	10.9	4.4	18.4
4	0	45	45	16418	7997	121	21	11.1	4.1	17.7
1	0	45	78	19195	7685	166	38	12.0	6.3	22.7
2	0	45	78	20051	9054	139	38	11.2	3.7	18.1
3	0	45	78	15836	8052	116	38	10.9	4.1	18.8
4	0	45	78	16897	8572	133	22	12.2	3.9	20.2
1	0	45	112	17349	8269	130	34	12.6	3.5	21.4
2	0	45	112	19197	10028	158	49	11.9	4.6	22.6
3	0	45	112	18405	9566	175	26	13.2	5.7	20.4
4	0	45	112	18583	9558	140	27	11.1	4.0	20.1
1	0	45	146	25467	10298	201	54	11.9	5.1	18.9
2	0	45	146	20420	10191	169	41	11.3	5.4	23.7
3	0	45	146	20207	10734	162	38	11.1	4.8	20.9
4	0	45	146	19426	9896	164	30	11.5	5.5	22.2
1	0	45	179	20026	10422	194	76	12.8	6.3	20.8
2	0	45	179	20006	10474	187	75	12.4	6.0	23.7
3	0	45	179	18486	10624	162	85	12.1	4.7	25.3
4	0	45	179	19514	11670	180	86	12.2	5.4	22.9
1	0	45	213	21484	10026	203	91	12.4	6.8	23.2
2	0	45	213	23884	12001	204	32	11.5	5.6	21.7
3	0	45	213	17986	10919	177	50	11.7	6.9	21.7
4	0	45	213	21300	11359	164	39	11.4	4.0	23.3
1	0	45	246	19604	8634	187	101	13.2	6.6	24.9
2	0	45	246	15815	9154	151	112	12.3	5.9	24.0
3	0	45	246	20276	10994	196	117	12.1	6.7	24.3
4	0	45	246	19287	9954	179	67	11.6	6.8	22.2

Table A.2 Manhattan Regional Trial 2006 Sensor Data

Rep	Pre-plant N	Starter N	Total N	GS NDVI V-6	CC NDVI V-6	GS NDVI V-9	CC NDVI V-9	GS NDVI V-16	SPAD V-16
	---------------- (kg ha^{-1})----------------								
1	0	0	0	0.50	0.48	0.61	0.48	0.82	46.8
2	0	0	0	0.51	0.49	0.61	0.49	0.83	45.9
3	0	0	0	0.50	0.49	0.60	0.49	0.80	47.8
4	0	0	0	0.54	0.50	0.62	0.50	0.82	48.5
1	224	0	224	0.58	0.54	0.71	0.54	0.86	63
2	224	0	224	0.57	0.54	0.70	0.54	0.86	60.4
3	224	0	224	0.57	0.54	0.72	0.54	0.85	59.1
4	224	0	224	0.54	0.51	0.69	0.51	0.83	60.9
1	0	45	45	0.57	0.52	0.67	0.52	0.83	53.2
2	0	45	45	0.60	0.55	0.70	0.55	0.82	54.1
3	0	45	45	0.54	0.52	0.67	0.52	0.83	56.1
4	0	45	45	0.62	0.57	0.71	0.57	0.82	54.6
1	0	45	78	0.57	0.52	0.67	0.52	0.84	56.1
2	0	45	78	0.60	0.54	0.71	0.54	0.85	56.3
3	0	45	78	0.57	0.54	0.70	0.54	0.84	56.4
4	0	45	78	0.59	0.54	0.69	0.54	0.83	56.7
1	0	45	112	0.55	0.51	0.68	0.51	0.85	54.8
2	0	45	112	0.61	0.54	0.69	0.54	0.85	56.8
3	0	45	112	0.59	0.55	0.70	0.55	0.84	57.7
4	0	45	112	0.59	0.53	0.68	0.53	0.83	57.6
1	0	45	146	0.57	0.53	0.70	0.53	0.85	55.9
2	0	45	146	0.57	0.53	0.69	0.53	0.85	55.5
3	0	45	146	0.56	0.54	0.67	0.54	0.84	55.7
4	0	45	146	0.61	0.56	0.68	0.56	0.83	55
1	0	45	179	0.61	0.55	0.72	0.55	0.86	55.2
2	0	45	179	0.61	0.54	0.69	0.54	0.85	55.6
3	0	45	179	0.59	0.55	0.70	0.54	0.85	54
4	0	45	179	0.61	0.55	0.69	0.55	0.84	53.1
1	0	45	213	0.55	0.51	0.66	0.51	0.84	56.5
2	0	45	213	0.55	0.51	0.67	0.51	0.86	56.4
3	0	45	213	0.59	0.54	0.68	0.54	0.83	54.7
4	0	45	213	0.58	0.54	0.68	0.54	0.84	55.4
1	0	45	246	0.59	0.53	0.70	0.53	0.85	56.6
2	0	45	246	0.57	0.53	0.69	0.53	0.85	54.1
3	0	45	246	0.60	0.55	0.69	0.55	0.84	55.1
4	0	45	246	0.63	0.56	0.70	0.56	0.84	54.1

Table A.3 Manhattan Regional Trial 2008

Rep	Pre-plant N	Starter N	Total N	Total Biomass	Grain Yield	Total N Uptake	Grain N	WP N	Earleaf N
	-------------------	-------------------	-------------------	(kg ha^{-1})	-------------------	-------------------	----------	(g kg^{-1})	----------
1	0	0	0	6417	4182	38	8.3	3.0	15.4
2	0	0	0	8142	3482	37	7.7	2.8	17.1
3	0	0	0	8151	3121	41	9.3	3.0	17.2
4	0	0	0	6569	3064	32	7.4	3.5	13.8
1	179	45	224	15680	9130	107	9.2	4.4	19.2
2	179	45	224	18139	10908	128	9.4	4.4	17.4
3	179	45	224	14795	8440	96	9.5	3.4	19.4
4	179	45	224	11134	6901	65	8.5	2.7	17.8
1	0	45	45	8911	4402	49	9.3	2.7	16.3
2	0	45	45	10216	4762	45	6.9	2.8	16.9
3	0	45	45	10542	5316	55	7.5	3.6	17.8
4	0	45	45	6273	2464	32	9.7	2.8	13.7
1	0	45	78	12501	6858	78	9.0	3.8	21.2
2	0	45	78	9647	4438	42	7.4	2.4	17.1
3	0	45	78	13522	8436	91	9.1	3.7	17.9
4	0	45	78	8733	4843	50	9.0	2.8	17.4
1	0	45	112	13342	7051	81	8.7	3.8	20.3
2	0	45	112	12814	7010	67	7.9	2.8	19.4
3	0	45	112	12986	7743	77	7.9	3.8	18.1
4	0	45	112	9397	5310	53	8.4	2.9	12.9
1	0	45	146	11941	5734	66	9.2	2.8	16.5
2	0	45	146	15865	9806	89	7.8	2.8	23.0
3	0	45	146	14384	9053	89	8.9	2.7	18.9
4	0	45	146	11896	7841	81	8.9	4.0	19.1
1	0	45	179	16549	10670	142	10.1	6.7	25.5
2	0	45	179	16476	10338	101	8.7	2.9	20.3
3	0	45	179	14964	9668	104	9.2	4.0	21.1
4	0	45	179	13601	9713	93	9.1	2.9	18.5
1	0	45	213	15906	9614	113	9.8	4.1	22.2
2	0	45	213	16573	11059	112	9.2	3.2	22.7
3	0	45	213	16129	11134	121	9.6	4.2	22.7
4	0	45	213	13171	9137	91	9.2	3.3	19.6
1	0	45	246	17816	12177	159	11.8	4.6	27.0
2	0	45	246	17193	11603	140	10.8	4.2	18.4
3	0	45	246	15453	11620	139	11.4	4.0	24.1
4	0	45	246	15052	11139	117	9.7	4.1	20.9
1	89	45	134	15616	7764	85	9.0	2.7	16.4
2	89	45	134	14593	8598	86	7.8	3.8	18.2
3	89	45	134	11152	6326	68	9.1	3.1	16.0
4	89	45	134	10557	4096	55	8.7	3.6	18.3
1	89	45	134	12493	7056	72	8.6	3.0	17.9
2	89	45	134	14973	8430	82	7.5	3.4	20.4
3	89	45	134	11662	6373	69	9.2	3.0	16.8
4	89	45	134	9242	4620	51	9.1	2.8	16.7
1	89	45	202	15656	10643	121	9.9	4.4	19.2
2	89	45	202	17246	10950	128	9.2	5.2	19.8
3	89	45	202	13733	7895	131	13.9	5.2	17.6
4	89	45	202	12680	7136	105	11.9	4.8	15.5

Table A.4 Manhattan Regional Trial 2008 Sensor Data

Rep	Pre-plant N	Starter N	Total N	GS NDVI	CC NDVI	GS NDVI	CC NDVI	SPAD	SPAD
	--------------- (kg ha^{-1})	---------------		V-9	V-9	V-16	V-16	V-9	R-1
1	0	0	0	0.37	0.39	0.47	0.56	31	36.3
2	0	0	0	0.52	0.38	0.53	0.51	30.2	33.4
3	0	0	0	0.49	0.56	0.52	0.58	29.3	38.7
4	0	0	0	0.39	0.47	0.46	0.50	31.7	33.5
1	179	45	224	0.59	0.46	0.69	0.63	41.9	52.7
2	179	45	224	0.70	0.49	0.78	0.71	36.4	53.2
3	179	45	224	0.62	0.58	0.75	0.68	39.8	45.6
4	179	45	224	0.62	0.41	0.69	0.66	44.1	47.5
1	0	45	45	0.49	0.43	0.54	0.59	31.7	39.3
2	0	45	45	0.60	0.44	0.64	0.57	33.5	33.4
3	0	45	45	0.52	0.42	0.60	0.54	32.6	41.6
4	0	45	45	0.53	0.46	0.48	0.51	28	34.1
1	0	45	78	0.41	0.41	0.54	0.60	38.1	44.8
2	0	45	78	0.66	0.44	0.66	0.63	31.9	40.5
3	0	45	78	0.60	0.45	0.69	0.66	35.3	52.9
4	0	45	78	0.57	0.46	0.61	0.58	31.8	38.8
1	0	45	112	0.36	0.43	0.50	0.57	33.7	52.1
2	0	45	112	0.58	0.52	0.66	0.63	34.9	48.3
3	0	45	112	0.54	0.51	0.66	0.65	34.1	46.6
4	0	45	112	0.47	0.41	0.55	0.58	30.4	43.1
1	0	45	146	0.56	0.52	0.64	0.60	33.1	45.6
2	0	45	146	0.59	0.51	0.67	0.64	34.8	53.3
3	0	45	146	0.58	0.49	0.69	0.64	35.1	54.5
4	0	45	146	0.54	0.49	0.63	0.62	33.1	55
1	0	45	179	0.46	0.42	0.60	0.64	38.3	55.6
2	0	45	179	0.63	0.46	0.72	0.68	37.4	51.6
3	0	45	179	0.55	0.41	0.67	0.64	34.6	57.7
4	0	45	179	0.55	0.46	0.63	0.62	36.8	59.5
1	0	45	213	0.55	0.49	0.63	0.61	35.6	54.3
2	0	45	213	0.59	0.42	0.69	0.67	39.4	53.2
3	0	45	213	0.48	0.48	0.60	0.63	36.3	58.4
4	0	45	213	0.52	0.37	0.63	0.61	32.1	57.2
1	0	45	246	0.43	0.37	0.59	0.61	38.1	57.5
2	0	45	246	0.67	0.45	0.77	0.68	34.5	50.8
3	0	45	246	0.58	0.58	0.70	0.68	34	59.9
4	0	45	246	0.51	0.49	0.65	0.63	33.9	59.7
1	89	45	134	0.63	0.49	0.74	0.63	43.6	40.4
2	89	45	134	0.72	0.44	0.78	0.69	35.9	47.5
3	89	45	134	0.63	0.45	0.72	0.68	34.6	43.7
4	89	45	134	0.57	0.55	0.64	0.59	33.4	37.4
1	89	45	134	0.57	0.45	0.68	0.58	41.8	44
2	89	45	134	0.72	0.52	0.80	0.70	39.3	43.7
3	89	45	134	0.63	0.44	0.73	0.67	35.3	42.4
4	89	45	134	0.56	0.42	0.61	0.61	36.7	39.4
1	89	45	202	0.48	0.41	0.63	0.62	40.2	47.3
2	89	45	202	0.74	0.45	0.80	0.70	39.4	46.7
3	89	45	202	0.61	0.44	0.72	0.66	38.7	38.9
4	89	45	202	0.54	0.44	0.65	0.60	38.5	42.1

Table A.5 Manhattan Timing Trial 2009

Rep	Starter N	V-6 N	V-10 N	V-16 N	Total N	Grain Yield	Grain N	Earleaf N
	--- ($kg\ ha^{-1}$)---						------------($g\ kg^{-1}$)------------	
1	22	0	0	0	22	6038	8.6	13.1
2	22	0	0	0	22	5579	9.4	14.9
3	22	0	0	0	22	6514	9.2	18.3
4	22	0	0	0	22	5699	9.5	15.3
1	22	45	0	0	67	8046	9.3	16.9
2	22	45	0	0	67	8895	9.6	15.7
3	22	45	0	0	67	8134	9.8	15.1
4	22	45	0	0	67	8281	9.5	18.6
1	22	45	34	0	101	11195	9.5	17.2
2	22	45	34	0	101	11475	10.3	21.0
3	22	45	34	0	101	8658	10.2	16.5
4	22	45	34	0	101	8368	9.7	16.8
1	22	45	67	0	134	12021	10.1	19.6
2	22	45	67	0	134	9843	9.9	20.1
3	22	45	67	0	134	11403	11.1	18.4
4	22	45	67	0	134	10150	10.5	21.2
1	22	45	101	0	168	11565	11.8	20.5
2	22	45	101	0	168	11909	11.5	24.1
3	22	45	101	0	168	11894	11.7	21.7
4	22	45	101	0	168	11016	13.4	19.8
1	22	45	0	34	101	11766	10.5	16.6
2	22	45	0	34	101	9699	10.5	16.2
3	22	45	0	34	101	9574	10.1	17.1
4	22	45	0	34	101	10586	9.7	18.5
1	22	45	0	67	134	12336	11.3	19.7
2	22	45	0	67	134	12336	13.0	17.5
3	22	45	0	67	134	12622	11.1	19.8
4	22	45	0	67	134	10856	11.1	15.1
1	22	45	0	101	168	13193	12.7	19.3
2	22	45	0	101	168	12941	12.1	16.2
3	22	45	0	101	168	12898	12.8	18.6
4	22	45	0	101	168	12777	12.8	15.3

Rossville - Kansas River Valley

Table A.6 Rossville Irrigated N Study 2007

Rep	Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual	Grain N	WP N	Earleaf N
	----------------------	----------------------	----------	(kg ha^{-1})	----------------------	----------------------	----------	-------------(g kg-1)-------------		
1	0	0	22	11392	7217	85	30	8.2	5.2	14.6
2	0	0	22	13472	8167	118	30	10.3	5.4	22.9
3	0	0	22	14736	9496	136	25	10.6	5.5	19.4
4	0	0	22	11868	7650	104	25	10.4	4.7	33.2
1	112	0	134	18846	13118	212	48	12.9	5.7	28.3
2	112	0	134	20906	14003	223	48	11.9	6.5	27.8
3	112	0	134	22318	14034	213	43	10.6	6.4	30.3
4	112	0	134	16807	13178	179	45	11.3	5.7	33.1
1	157	0	179	16613	13009	183	40	11.4	6.5	28.4
2	157	0	179	19121	12612	204	30	12.5	5.8	31.3
3	157	0	179	19119	13470	211	35	11.8	6.8	20.8
4	157	0	179	20439	14272	239	43	12.4	7.5	34.9
1	202	0	224	23286	14752	281	42	13.4	7.8	28.3
2	202	0	224	20803	13418	223	49	11.7	7.2	30.9
3	202	0	224	18139	13416	206	28	12.7	5.2	29.1
4	202	0	224	19568	14474	215	38	11.2	7.4	33.3
1	45	67	134	19763	14060	251	35	13.6	7.8	27.6
2	45	67	134	20434	14353	253	35	13.0	8.2	30.6
3	45	67	134	18624	13496	201	41	11.7	6.0	27.5
4	45	67	134	13193	7622	123	25	11.5	5.4	25.9
1	67	90	179	20190	14356	235	41	12.6	6.9	24.9
2	67	90	179	17860	13329	203	33	12.4	5.9	32.4
3	67	90	179	20243	14403	230	38	12.3	6.7	28.7
4	67	90	179	14340	9884	164	25	12.7	6.5	25.7
1	90	112	224	18195	12670	201	37	12.1	6.6	25.2
2	90	112	224	22563	14808	262	51	12.8	7.3	30.8
3	90	112	224	19464	13733	222	54	12.6	6.4	27.8
4	90	112	224	16309	12657	186	35	12.0	6.2	30.4
1	112	GS	134	20598	14777	255	54	13.2	7.7	28.6
2	112	GS	134	18996	13450	207	40	12.0	6.3	32.0
3	112	GS	151	16510	11519	184	30	12.3	6.4	28.5
4	112	GS	134	18851	13920	207	30	12.0	5.8	35.2
1	112	CC	151	19419	14270	225	40	12.3	7.1	27.1
2	112	CC	134	19553	13912	207	39	11.9	5.6	27.9
3	112	CC	134	19760	14003	202	30	10.6	7.2	29.1
4	112	CC	246	12687	7461	155	24	13.8	8.2	26.2
1	112	CH	134	20251	14176	246	44	12.7	8.5	22.5
2	112	CH	134	18629	13357	209	52	11.9	7.2	31.9
3	112	CH	168	18484	12951	192	29	11.6	5.9	28.4
4	112	CH	202	17295	12605	189	28	11.8	6.2	19.3
1	112	GS + CH	134	18824	13343	203	42	12.0	5.9	30.9
2	112	GS + CH	134	22450	13823	276	48	13.3	8.8	29.8
3	112	GS + CH	134	18538	13181	192	33	10.8	6.9	28.5
4	112	GS + CH	246	16416	11394	200	29	13.2	7.3	26.5
1	112	CC + CH	134	18746	13396	212	41	13.1	5.1	29.7
2	112	CC + CH	134	19797	12406	203	32	11.5	6.6	28.9
3	112	CC + CH	134	18867	13335	188	52	10.5	6.7	31.2
4	112	CC + CH	179	17777	13055	205	28	12.4	6.6	31.8

Table A.7 Rossville Irrigated N Study Sensor Data 2007

Rep	Pre-plant N	Side-dress	Total N	GS NDVI	CC NDVI	SPAD	GS NDVI	CC NDVI	SPAD
	-----------------(kg ha^{-1})	----------------		-----------------V-9-----------------			-----------------V-16 -----------------		
1	0	0	22	0.64	0.61	51.8	0.64	0.67	46
2	0	0	22	0.60	0.57	46.2	0.70	0.68	48.4
3	0	0	22	0.58	0.55	56.9	0.69	0.68	58.6
4	0	0	22	0.52	0.52	42.1	0.70	0.66	45.6
1	112	0	134	0.74	0.67	61.5	0.79	0.73	61.1
2	112	0	134	0.74	0.66	54.8	0.79	0.72	64.3
3	112	0	134	0.74	0.66	54.4	0.80	0.73	58.6
4	112	0	134	0.66	0.62	55.8	0.65	0.75	56.9
1	157	0	179	0.74	0.67	55.8	0.72	0.74	58.2
2	157	0	179	0.71	0.65	53.9	0.75	0.75	63.7
3	157	0	179	0.61	0.59	57.8	0.79	0.74	56.5
4	157	0	179	0.68	0.64	50.5	0.81	0.75	61.3
1	202	0	224	0.76	0.69	53.9	0.78	0.74	63.5
2	202	0	224	0.70	0.64	50.6	0.78	0.72	61.4
3	202	0	224	0.62	0.57	54.7	0.73	0.74	54.1
4	202	0	224	0.66	0.61	55.6	0.81	0.75	62.1
1	45	67	134	0.67	0.62	53.2	0.72	0.72	60
2	45	67	134	0.69	0.64	49.9	0.76	0.74	61.6
3	45	67	134	0.73	0.65	58.6	0.81	0.74	60.8
4	45	67	134	0.47	0.45	48.1	0.80	0.68	48.5
1	67	90	179	0.73	0.66	49.7	0.76	0.72	61.7
2	67	90	179	0.68	0.64	53.6	0.72	0.74	61
3	67	90	179	0.73	0.67	57.8	0.76	0.75	62.4
4	67	90	179	0.50	0.45	48.8	0.54	0.69	52
1	90	112	224	0.73	0.67	49.8	0.82	0.74	61.2
2	90	112	224	0.73	0.66	53	0.79	0.74	61.8
3	90	112	224	0.76	0.66	53.2	0.82	0.74	61.8
4	90	112	224	0.57	0.52	51.7	0.59	0.73	53.9
1	112	GS	134	0.72	0.66	50.1	0.71	0.73	61.8
2	112	GS	134	0.71	0.65	57.5	0.73	0.74	62.9
3	112	GS	151	0.58	0.55	58.4	0.71	0.72	52.7
4	112	GS	134	0.66	0.62	56.5	0.81	0.74	61.2
1	112	CC	151	0.72	0.66	54.1	0.77	0.74	67.8
2	112	CC	134	0.69	0.64	54.8	0.74	0.74	64.8
3	112	CC	134	0.72	0.64	57.8	0.80	0.74	61.3
4	112	CC	246	0.48	0.48	49.2	0.82	0.68	45.5
1	112	CH	134	0.74	0.66	54.1	0.77	0.73	64.4
2	112	CH	134	0.71	0.66	49.4	0.77	0.74	59.7
3	112	CH	168	0.66	0.62	56.9	0.78	0.75	56.3
4	112	CH	202	0.58	0.56	54	0.57	0.73	54.9
1	112	GS + CH	134	0.74	0.68	56.1	0.80	0.73	63.4
2	112	GS + CH	134	0.72	0.65	51.5	0.77	0.72	59.1
3	112	GS + CH	134	0.72	0.65	56.4	0.80	0.75	58.3
4	112	GS + CH	246	0.53	0.52	45.3	0.81	0.74	60.2
1	112	CC + CH	134	0.73	0.65	52.5	0.76	0.72	60.5
2	112	CC + CH	134	0.71	0.66	53.9	0.80	0.75	62.9
3	112	CC + CH	134	0.66	0.61	58.4	0.80	0.75	58.9
4	112	CC + CH	179	0.67	0.62	56.2	0.76	0.75	58.1

Table A.8 Rossville Irrigated N Study 2008

Rep	Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual	Grain N	WP N	Earleaf N
				(kg ha^{-1})					(g kg-1)	
1	0	0	22	9877	5363	54	19	7.9	3.1	13.0
2	0	0	22	10246	4440	56	45	9.1	3.2	12.0
3	0	0	22	9911	6116	65	35	9.6	2.7	13.5
4	0	0	22	8973	4672	53	32	9.3	3.0	12.8
1	112	0	134	18003	13263	144	36	9.8	4.1	25.4
2	112	0	134	20651	13688	178	48	10.7	5.3	22.0
3	112	0	134	18523	14026	173	48	11.3	4.8	27.6
4	112	0	134	20059	12571	161	57	10.7	4.5	21.1
1	157	0	179	22715	14658	182	50	10.4	4.5	21.9
2	157	0	179	20332	14089	179	56	11.0	4.8	25.8
3	157	0	179	20049	14522	178	58	11.2	4.3	23.0
4	157	0	179	21665	14115	193	60	11.8	4.6	24.6
1	202	0	224	22489	16089	211	71	11.3	5.7	24.4
2	202	0	224	21638	14888	233	49	12.7	7.1	22.4
3	202	0	224	16991	13245	167	47	11.9	4.6	24.5
4	202	0	224	22416	14553	225	100	12.1	6.7	22.6
1	45	67	134	21256	14168	182	53	11.4	4.2	22.3
2	45	67	134	20168	13470	185	31	12.1	4.5	21.0
3	45	67	134	19332	13256	151	48	10.0	4.2	26.7
4	45	67	134	13800	9418	115	25	10.5	4.6	21.2
1	67	90	179	20014	15464	174	40	10.6	4.1	21.2
2	67	90	179	20757	14376	180	44	10.8	4.8	21.2
3	67	90	179	18511	14516	171	41	11.1	4.4	29.8
4	67	90	179	16253	11242	158	43	11.2	6.8	23.2
1	90	112	224	17410	13624	145	26	10.6	2.8	24.6
2	90	112	224	20948	15297	213	52	12.0	6.2	22.3
3	90	112	224	20923	15551	207	66	12.4	4.5	22.8
4	90	112	224	17632	12246	166	38	11.5	5.6	20.9
1	112	GS	168	21281	14592	198	na	11.9	4.9	23.0
2	112	GS	168	18751	14483	162	na	10.4	4.3	23.0
3	112	GS	190	17201	12337	155	na	11.6	4.1	24.1
4	112	GS	202	19845	14866	181	na	11.3	4.4	22.4
1	112	CC	235	21879	15949	196	na	10.8	5.0	23.0
2	112	CC	179	19478	13979	162	na	10.5	4.0	21.4
3	112	CC	179	19254	14968	180	na	11.7	3.7	21.5
4	112	CC	202	15849	10904	146	na	11.8	4.8	19.7
1	112	CH	134	20943	15271	188	na	11.1	4.7	26.3
2	112	CH	134	19309	13338	153	na	10.1	4.0	22.8
3	112	CH	168	15950	11820	128	na	10.2	3.4	23.0
4	112	CH	202	18051	12242	161	na	11.3	5.0	22.0
1	112	GS + CH	134	19897	13836	127	na	7.8	3.8	23.7
2	112	GS + CH	134	21116	14844	197	na	11.7	5.0	20.7
3	112	GS + CH	134	20074	14337	166	na	10.5	4.1	23.6
4	112	GS + CH	179	19883	14158	174	na	11.3	3.9	23.2
1	112	CC + CH	224	20561	15671	194	na	11.4	4.9	24.6
2	112	CC + CH	235	19027	14027	177	na	11.2	5.2	26.6
3	112	CC + CH	134	19311	14161	192	na	11.5	6.5	23.8
4	112	CC + CH	190	19429	13878	179	na	11.7	4.5	26.2

Table A.9 Rossville Irrigated N Study Sensor Data 2008

Rep	Pre-plant N	Side-dress N	Total N	GS NDVI	CC NDVI	GS NDVI	CC NDVI	SPAD	SPAD
	(kg ha^{-1})			V-6		V-9			R-1
1	0	0	22	0.77	0.64	0.81	0.66	34.6	33.8
2	0	0	22	0.75	0.58	0.80	0.68	35	29.4
3	0	0	22	0.70	0.57	0.80	0.65	32.4	32
4	0	0	22	0.64	0.55	0.67	0.62	34.2	30.6
1	112	0	134	0.78	0.68	0.84	0.73	42.4	na
2	112	0	134	0.78	0.67	0.83	0.72	42.9	na
3	112	0	134	0.80	0.66	0.82	0.74	42.1	na
4	112	0	134	0.72	0.62	0.70	0.70	46.3	na
1	157	0	179	0.80	0.68	0.85	0.73	41.4	na
2	157	0	179	0.74	0.64	0.78	0.69	40.9	na
3	157	0	179	0.77	0.55	0.77	0.72	39.2	na
4	157	0	179	0.71	0.55	0.75	0.67	42.6	na
1	202	0	224	0.79	0.67	0.84	0.73	41.1	55.1
2	202	0	224	0.79	0.64	0.82	0.72	37.2	53.7
3	202	0	224	0.68	0.56	0.78	0.67	38.5	54.8
4	202	0	224	0.71	0.55	0.78	0.67	45.8	55.8
1	45	67	134	0.79	0.62	0.81	0.70	38	na
2	45	67	134	0.79	0.59	0.79	0.71	37.2	na
3	45	67	134	0.80	0.55	0.80	0.73	40.9	na
4	45	67	134	0.56	0.49	0.56	0.61	35.5	na
1	67	90	179	0.81	0.66	0.83	0.72	41.3	na
2	67	90	179	0.79	0.65	0.81	0.63	40.9	na
3	67	90	179	0.76	0.61	0.81	0.73	42.7	na
4	67	90	179	0.60	0.51	0.60	0.62	36.1	na
1	90	112	224	0.79	0.67	0.84	0.69	39.6	na
2	90	112	224	0.78	0.61	0.82	0.72	40	na
3	90	112	224	0.77	0.58	0.82	0.73	43	na
4	90	112	224	0.64	0.54	0.64	0.62	35.7	na
1	112	GS	134	0.82	0.65	0.81	0.71	39.5	na
2	112	GS	134	0.77	0.60	0.79	0.72	42.3	na
3	112	GS	151	0.67	0.49	0.76	0.65	38	na
4	112	GS	134	0.72	0.55	0.72	0.69	44.9	na
1	112	CC	151	0.81	0.61	0.83	0.71	39.7	na
2	112	CC	134	0.77	0.66	0.80	0.64	40.6	na
3	112	CC	134	0.80	0.59	0.71	0.73	41.5	na
4	112	CC	246	0.66	0.51	0.78	0.63	37.5	na
1	112	CH	134	0.79	0.63	0.83	0.73	39.9	51
2	112	CH	134	0.79	0.67	0.82	0.62	40.7	48.4
3	112	CH	168	0.73	0.60	0.80	0.72	39.9	52.8
4	112	CH	202	0.63	0.54	0.63	0.64	39.5	50.3
1	112	GS + CH	134	0.79	0.65	0.84	0.72	43.3	52.6
2	112	GS + CH	134	0.79	0.62	0.82	0.72	42.2	48.3
3	112	GS + CH	134	0.79	0.56	0.81	0.73	42.4	52.9
4	112	GS + CH	246	0.71	0.56	0.78	0.66	41.1	55.1
1	112	CC + CH	134	0.80	0.65	0.83	0.72	38.7	54.7
2	112	CC + CH	134	0.77	0.63	0.74	0.70	38.9	55.8
3	112	CC + CH	134	0.79	0.55	0.75	0.71	44.4	51.9
4	112	CC + CH	179	0.69	0.61	0.67	0.68	42.5	52.5

Table A.10 Rossville Irrigated N Study 2009

Rep	Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual	Grain N	WP N	Earleaf N
	(kg ha^{-1})							(g kg-1)		
1	0	0	22	8465	4778	51	33	9.5	2.9	13.3
2	0	0	22	9513	5771	54	40	8.8	2.3	15.1
3	0	0	22	10289	5772	57	21	8.7	2.6	16.0
4	0	0	22	11383	6986	71	31	9.4	2.9	14.0
1	112	0	134	18272	13961	158	39	10.9	4.5	22.2
2	112	0	134	19015	12588	145	55	10.8	3.6	21.0
3	112	0	134	19912	11996	165	47	11.0	5.5	22.7
4	112	0	134	19268	13223	162	40	11.4	4.3	18.8
1	157	0	179	18361	13262	145	48	10.3	4.1	20.0
2	157	0	179	19739	12892	153	39	10.6	4.2	23.3
3	157	0	179	20011	14591	193	39	11.8	6.2	22.4
4	157	0	179	20851	15497	209	58	11.8	7.1	22.6
1	202	0	224	19754	14541	179	46	11.4	5.2	23.8
2	202	0	224	22317	14509	207	52	12.1	5.8	21.9
3	202	0	224	21175	15020	195	34	11.5	5.7	21.2
4	202	0	224	21481	14558	215	47	12.7	6.5	23.5
1	45	67	134	19251	13839	166	58	10.6	5.6	19.9
2	45	67	134	19157	13105	158	49	11.1	4.4	21.6
3	45	67	134	19275	13815	164	49	10.9	4.8	19.8
4	45	67	134	15557	9574	129	34	11.0	5.4	20.0
1	67	90	179	19001	14603	184	39	11.9	5.7	22.4
2	67	90	179	19759	13969	188	44	11.9	6.0	22.1
3	67	90	179	20805	14331	186	47	11.5	5.3	21.0
4	67	90	179	18538	12979	159	39	11.3	4.6	21.6
1	90	112	224	17793	13486	155	39	11.2	4.2	20.1
2	90	112	224	20722	14322	198	54	11.9	6.2	22.9
3	90	112	224	23045	15807	235	62	12.9	6.5	21.7
4	90	112	224	19107	13583	184	38	12.0	6.1	20.4
1	112	GS	168	20625	16131	215	64	12.8	5.8	23.8
2	112	GS	179	21965	15347	203	44	11.4	6.2	21.9
3	112	GS	168	17969	12851	153	23	10.7	5.1	21.3
4	112	GS	134	19616	14338	167	51	11.4	3.9	21.9
1	112	CC	168	21018	15976	204	61	12.0	5.6	20.7
2	112	CC	190	20540	14850	202	54	12.0	6.3	23.9
3	112	CC	134	19929	14879	189	50	11.4	6.2	20.7
4	112	CC	202	17813	12674	156	26	11.7	4.2	18.7
1	112	CH	168	19306	15124	193	49	11.9	6.1	23.7
2	112	CH	202	20051	14294	168	49	10.5	5.1	21.6
3	112	CH	134	17916	11284	144	37	11.1	4.5	21.5
4	112	CH	168	19070	12876	174	34	11.9	5.5	22.5
1	112	GS + CH	168	20690	14516	193	48	11.5	6.2	21.4
2	112	GS + CH	134	22091	14520	187	45	11.1	5.3	19.9
3	112	GS + CH	134	19771	14791	179	42	11.7	4.4	20.7
4	112	GS + CH	190	19486	14518	191	31	11.7	6.5	22.9
1	112	CC + CH	168	20573	14470	190	49	11.7	5.7	25.5
2	112	CC + CH	168	19347	13336	164	48	11.1	4.8	24.1
3	112	CC + CH	134	20980	14446	185	39	11.4	5.2	21.1
4	112	CC + CH	168	19821	15175	197	31	12.6	5.0	21.3

Table A.11 Rossville Irrigated N Study Sensor Data 2009

Rep	Pre-plant N	Side-dress N	Total N	GS NDVI	CC NDVI	GS NDVI	CC NDVI	SPAD	SPAD
	----------------(kg ha^{-1})	----------------		----------V-6----------		--------------V-9--------------			R-1
1	0	0	22	0.60	0.56	0.81	0.57	47.6	39.3
2	0	0	22	0.54	0.52	0.76	0.57	47.5	41
3	0	0	22	0.48	0.50	0.74	0.56	49	37
4	0	0	22	0.46	0.47	0.72	0.55	49.3	40.3
1	112	0	134	0.59	na	0.82	0.61	na	na
2	112	0	134	0.57	na	0.82	0.61	na	na
3	112	0	134	0.58	na	0.82	0.62	na	na
4	112	0	134	0.52	na	0.78	0.60	na	na
1	157	0	179	0.61	na	0.84	0.61	na	na
2	157	0	179	0.59	na	0.81	0.62	na	na
3	157	0	179	0.44	na	0.75	0.57	na	na
4	157	0	179	0.51	na	0.77	0.60	na	na
1	202	0	224	0.57	0.54	0.82	0.61	54.1	57.9
2	202	0	224	0.56	0.54	0.82	0.61	55.8	56.8
3	202	0	224	0.46	0.48	0.75	0.59	55.1	55.5
4	202	0	224	0.45	0.49	0.74	0.58	55.7	54.1
1	45	67	134	0.58	na	0.82	0.60	na	na
2	45	67	134	0.54	na	0.79	0.59	na	na
3	45	67	134	0.60	na	0.82	0.62	na	na
4	45	67	134	0.39	na	0.69	0.55	na	na
1	67	90	179	0.56	na	0.81	0.60	na	na
2	67	90	179	0.47	na	0.77	0.59	na	na
3	67	90	179	0.54	na	0.80	0.61	na	na
4	67	90	179	0.41	na	0.70	0.55	na	na
1	90	112	224	0.65	na	0.86	0.62	na	na
2	90	112	224	0.53	na	0.80	0.61	na	na
3	90	112	224	0.63	na	0.83	0.63	na	na
4	90	112	224	0.44	na	0.73	0.57	na	na
1	112	GS	134	0.57	na	0.83	0.61	na	na
2	112	GS	134	0.54	na	0.78	0.60	na	na
3	112	GS	151	0.44	na	0.72	0.57	na	na
4	112	GS	134	0.52	na	0.79	0.61	na	na
1	112	CC	151	0.58	0.55	0.83	0.61	na	na
2	112	CC	134	0.47	0.49	0.76	0.59	na	na
3	112	CC	134	0.56	0.52	0.80	0.61	na	na
4	112	CC	246	0.35	0.42	0.63	0.51	na	na
1	112	CH	134	0.55	na	0.81	0.60	na	54.2
2	112	CH	134	0.51	na	0.78	0.59	na	54.1
3	112	CH	168	0.46	na	0.76	0.59	na	55.9
4	112	CH	202	0.45	na	0.75	0.57	na	53
1	112	GS + CH	134	0.57	na	0.83	0.60	na	58.4
2	112	GS + CH	134	0.56	na	0.80	0.60	na	54
3	112	GS + CH	134	0.60	na	0.82	0.62	na	55.9
4	112	GS + CH	246	0.38	na	0.69	0.55	na	51.4
1	112	CC + CH	134	0.56	0.53	0.83	0.60	na	54.7
2	112	CC + CH	134	0.57	0.55	0.82	0.63	na	55.8
3	112	CC + CH	134	0.54	0.52	0.80	0.60	na	51.9
4	112	CC + CH	179	0.48	0.49	0.76	0.59	na	52.5

Table A.12 Rossville and On-Farm Trials V-16 Nitrogen Application 2009

Location	KRV	Farm 1	Farm 2	KRV	Farm 1	Farm 2
V-16 N		Grain Yield			Grain N	
-- ($kg\ ha^{-1}$) --				-------------------------------- ($g\ kg^{-1}$) --------------------------------		
0	5713	11070	11531	9.4	12.4	13.1
0	6846	13404	10632	10.2	12.4	12.2
0	7618	9830	10295	9.7	12.6	11.8
0	5436	11397	10820	9.9	12.8	11.4
34	8167	11166	12249	10.2	12.5	11.6
34	8465	13017	10459	9.1	13.1	11.7
34	8493	9875	10708	9.3	11.9	11.2
34	7676	10681	11375	9.1	12.9	11.5
67	12188	13691	10836	11.0	12.3	11.9
67	9009	12744	12087	9.1	13.3	12.2
67	9777	12095	11728	9.7	11.7	11.3
67	8604	8898	10571	9.6	12.5	11.8
101	13846	14013	11077	10.2	13.1	12.3
101	14004	11713	11118	11.4	12.6	11.5
101	10893	9742	11067	10.1	12.3	11.6
101	10398	9784	10273	11.3	12.7	11.4

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Table A.13 Tribune Irrigated N Study 2007

Rep	Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual	Grain N	WP N	Earleaf N
	------------------	------------------	------------------	(kg ha^{-1})	------------------	------------------	------------------	---(g kg-1)	---	---
1	0	0	22	18840	12225	180	na	13.0	4.4	23.5
2	0	0	22	21104	12331	177	na	11.7	5.2	17.8
3	0	0	22	15815	8895	123	na	10.4	5.7	19.7
4	0	0	22	18633	10218	150	na	11.4	5.1	18.0
1	112	0	134	21373	14241	205	na	12.4	5.4	24.1
2	112	0	134	21407	11456	216	na	13.7	6.4	22.4
3	112	0	134	23581	13739	152	na	10.2	2.7	19.7
4	112	0	134	24771	15800	222	na	11.9	5.3	19.1
1	157	0	179	23995	16019	232	na	11.7	6.5	24.2
2	157	0	179	26730	17203	249	na	11.8	5.9	27.6
3	157	0	179	27831	16496	262	na	13.4	5.5	23.8
4	157	0	179	24280	12197	202	na	11.6	5.9	25.7
1	202	0	224	22956	14126	210	na	12.2	5.0	24.8
2	202	0	224	18914	11613	188	na	13.0	5.9	27.9
3	202	0	224	22539	13405	180	na	12.3	3.4	22.6
4	202	0	224	26728	15846	239	na	12.7	4.7	23.8
1	45	67	134	20912	12596	206	na	12.8	6.0	28.3
2	45	67	134	19828	12636	177	na	12.1	4.5	23.3
3	45	67	134	22727	11890	171	na	10.3	5.4	22.7
4	45	67	134	21958	13627	180	na	12.1	3.7	22.8
1	67	90	179	27530	18543	252	na	12.7	3.9	23.2
2	67	90	179	19531	12175	191	na	12.6	5.9	20.2
3	67	90	179	21769	12704	160	na	10.8	3.9	18.6
4	67	90	179	24581	15907	223	na	12.9	4.2	19.5
1	90	112	224	21928	13101	205	na	12.3	5.5	25.5
2	90	112	224	24192	16194	265	na	13.8	6.4	25.8
3	90	112	224	24329	13889	202	na	12.5	4.0	23.5
4	90	112	224	29110	17115	260	na	12.2	5.2	21.8
1	112	GS	134	22892	13696	213	na	13.0	4.7	22.2
2	112	GS	134	27341	15285	246	na	12.4	5.9	22.0
3	112	GS	134	23791	14676	198	na	11.0	5.5	21.7
4	112	GS	134	24473	14997	209	na	11.7	5.2	20.1
1	112	CH	134	25892	15221	235	na	12.6	5.1	21.7
2	112	CH	168	24328	15241	224	na	12.5	5.3	21.2
3	112	CH	134	23560	14498	205	na	11.9	5.3	16.3
4	112	CH	168	24984	16435	237	na	12.3	5.9	19.0
1	112	GS + CH	134	19997	12222	184	na	11.9	5.5	21.7
2	112	GS + CH	134	22682	12894	215	na	12.7	5.9	26.2
3	112	GS + CH	134	28379	14524	270	na	10.8	8.6	20.4
4	112	GS + CH	134	25533	15825	225	na	12.7	4.7	24.1

Table A.14 Tribune Irrigated N Study Sensor Data 2007

Rep	Pre-plant N	Side-dress N	Total N	GS NDVI	CC NDVI	GS NDVI	CC NDVI	SPAD	SPAD
	---------------(kg ha^{-1})---------------			----------V-6---------		-----------------V-16----------------			R-1
1	0	0	22	0.49	0.51	0.83	0.72	52	61.2
2	0	0	22	0.51	0.52	0.80	0.68	48.5	51.7
3	0	0	22	0.42	0.47	0.71	0.61	33.1	49.7
4	0	0	22	0.43	0.48	0.80	0.68	45.7	52
1	112	0	134	0.55	0.56	0.83	0.70	53.9	64
2	112	0	134	0.41	0.50	0.80	0.69	56.3	63.1
3	112	0	134	0.53	0.55	0.83	0.71	55.9	60.7
4	112	0	134	0.50	0.52	0.84	0.72	57.5	59.3
1	157	0	179	0.41	0.47	0.81	0.71	51.8	61.6
2	157	0	179	0.55	0.56	0.84	0.72	56.3	60.9
3	157	0	179	0.52	0.55	0.84	0.72	64.1	57.8
4	157	0	179	0.34	0.43	0.83	0.71	48.5	56
1	202	0	224	0.46	0.50	0.83	0.71	52.9	62.7
2	202	0	224	0.42	0.47	0.82	0.71	51.2	63.8
3	202	0	224	0.52	0.54	0.83	0.70	63	59.3
4	202	0	224	0.39	0.46	0.83	0.72	60.2	56.5
1	45	67	134	0.57	0.54	0.84	0.71	54.9	58.3
2	45	67	134	0.54	0.53	0.83	0.72	56.4	57.8
3	45	67	134	0.50	0.56	0.83	0.71	57.5	55.2
4	45	67	134	0.55	0.52	0.84	0.73	59.1	59.2
1	67	90	179	0.50	0.52	0.83	0.72	57.6	63.1
2	67	90	179	0.59	0.59	0.83	0.71	60.5	62.4
3	67	90	179	0.46	0.51	0.83	0.71	55.1	56.8
4	67	90	179	0.51	0.53	0.84	0.73	61	56
1	90	112	224	0.47	0.51	0.84	0.71	53.8	57.9
2	90	112	224	0.49	0.50	0.83	0.71	40.7	61.1
3	90	112	224	0.47	0.55	0.84	0.72	66.7	60.7
4	90	112	224	0.54	0.53	0.84	0.73	58.8	55.2
1	112	GS	134	0.47	0.54	0.80	0.69	57.6	60.6
2	112	GS	134	0.54	0.55	0.84	0.72	51.9	59
3	112	GS	134	0.55	0.55	0.84	0.72	58	58.7
4	112	GS	134	0.49	0.52	0.84	0.72	52.3	56.6
1	112	CH	134	0.52	0.56	0.83	0.72	54	61.4
2	112	CH	168	0.53	0.56	0.83	0.72	57.5	60.5
3	112	CH	134	0.43	0.48	0.82	0.70	51.5	67.8
4	112	CH	168	0.50	0.47	0.83	0.71	59.3	53.5
1	112	GS + CH	134	0.45	0.48	0.82	0.71	48.6	55
2	112	GS + CH	134	0.48	0.52	0.81	0.70	52.7	59.6
3	112	GS + CH	134	0.55	0.56	0.84	0.71	57.7	60.9
4	112	GS + CH	134	0.48	0.51	0.83	0.71	47.1	62.1

Table A.15 Tribune Irrigated N Study 2008

Rep	Pre-plant N	Side-dress N	Total N	Grain Yield	Earleaf N	GS NDVI	SPAD	SPAD
----------	----------	(kg ha^{-1})	----------	----------	(g kg^{-1})	V-9	V-9	R-1
1	0	0	22	8580	16.5	0.69	47.5	47.5
2	0	0	22	8610	12.9	0.72	47.5	47.5
3	0	0	22	4469	13.4	0.76	41.1	41.1
4	0	0	22	4903	14.1	0.79	40.7	40.7
1	112	0	134	10473	21.5	0.77	na	na
2	112	0	134	7218	22.1	0.60	na	na
3	112	0	134	10139	21.6	0.80	na	na
4	112	0	134	10354	20.2	0.76	na	na
1	157	0	179	12047	21.6	0.78	na	na
2	157	0	179	13255	20.3	0.74	na	na
3	157	0	179	11364	21.9	0.75	na	na
4	157	0	179	10266	22.1	0.80	na	na
1	202	0	224	12024	22.1	0.80	49.4	49.4
2	202	0	224	8547	21.0	0.82	50.6	50.6
3	202	0	224	8378	21.0	0.76	49.3	49.3
4	202	0	224	10225	22.8	0.76	47.1	47.1
1	45	67	134	9141	20.9	0.76	na	na
2	45	67	134	9357	21.0	0.74	na	na
3	45	67	134	7533	25.0	0.83	na	na
4	45	67	134	10501	20.8	0.72	na	na
1	67	90	179	11069	24.2	0.68	na	na
2	67	90	179	9604	22.9	0.84	na	na
3	67	90	179	10092	21.4	0.78	na	na
4	67	90	179	10655	20.9	0.78	na	na
1	90	112	224	10328	18.9	0.76	na	na
2	90	112	224	10220	23.8	0.76	na	na
3	90	112	224	8942	22.7	0.80	na	na
4	90	112	224	12620	22.9	0.81	na	na
1	112	GS	134	7572	18.2	0.77	na	na
2	112	GS	134	9515	19.1	0.75	na	na
3	112	GS	134	10288	20.7	0.73	na	na
4	112	GS	134	11115	22.6	0.80	na	na
1	112	CH	134	10263	19.6	0.75	na	48
2	112	CH	168	9556	23.7	0.79	na	49.9
3	112	CH	134	12112	17.7	0.84	na	56.4
4	112	CH	168	10167	20.5	0.81	na	58.1
1	112	GS + CH	134	8151	19.1	0.79	na	51.1
2	112	GS + CH	134	8589	23.2	0.66	na	47.5
3	112	GS + CH	134	10934	18.0	0.80	na	55.8
4	112	GS + CH	134	10589	21.0	0.82	na	53

Table A.16 Tribune Irrigated N Study 2009

Rep	Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual	Grain N	WP N	Earleaf N
	------------- (kg ha^{-1}) -------------							-------------(g kg-1)-------------		
1	0	0	22	18490	11889	166	11	12.4	5.0	17.5
2	0	0	22	12035	9366	101	14	10.8	3.7	15.2
3	0	0	22	9441	5397	68	14	10.0	4.6	13.2
4	0	0	22	12245	7669	100	13	10.6	5.4	13.5
1	112	0	134	22000	14074	181	26	10.9	5.1	21.6
2	112	0	134	19153	13053	165	135	12.2	3.7	19.4
3	112	0	134	17355	11380	124	12	9.5	4.3	17.4
4	112	0	134	17505	11081	136	15	10.2	5.0	18.8
1	157	0	179	19460	13927	179	32	11.8	5.3	22.3
2	157	0	179	20850	13972	186	28	11.7	5.2	20.2
3	157	0	179	21608	14626	190	24	11.2	5.5	20.9
4	157	0	179	21494	15054	190	23	11.0	5.7	20.8
1	202	0	224	21592	13810	210	62	11.5	7.6	22.6
2	202	0	224	17668	11425	148	29	12.0	4.0	22.4
3	202	0	224	20961	12908	200	82	12.3	6.6	23.4
4	202	0	224	20799	14276	238	27	12.8	9.5	21.7
1	45	67	134	20932	14148	216	42	12.5	7.5	22.4
2	45	67	134	16580	10397	111	26	9.8	3.2	18.6
3	45	67	134	16375	10632	124	15	10.3	4.3	17.4
4	45	67	134	18459	13027	128	15	8.6	4.4	21.0
1	67	90	179	20314	13695	157	32	8.8	6.3	20.8
2	67	90	179	20655	13845	204	107	12.3	6.8	21.2
3	67	90	179	19331	12541	159	13	10.2	5.8	21.1
4	67	90	179	22060	15407	227	22	12.1	7.6	19.8
1	90	112	224	20433	14479	207	55	12.1	7.2	22.1
2	90	112	224	19997	13747	203	32	11.9	7.8	21.5
3	90	112	224	20527	14286	194	28	11.7	6.1	19.7
4	90	112	224	21945	14425	223	28	12.5	7.3	20.9
1	112	GS	134	23576	14132	213	28	11.1	6.9	20.2
2	112	GS	190	17722	12816	151	22	11.4	3.9	18.0
3	112	GS	202	19338	12301	161	26	10.3	6.0	17.2
4	112	GS	185	17318	12078	160	20	11.3	6.3	17.4
1	112	CH	134	18987	12247	167	22	11.6	5.4	20.5
2	112	CH	202	17712	11156	156	11	11.3	6.0	16.4
3	112	CH	202	17380	13382	159	16	11.6	4.5	17.0
4	112	CH	185	16830	12017	156	21	12.2	4.8	16.0
1	112	GS + CH	134	18224	12422	184	18	12.8	6.4	22.7
2	112	GS + CH	134	18948	12898	124	16	8.8	3.5	19.3
3	112	GS + CH	202	18556	11164	165	14	12.3	5.4	14.4
4	112	GS + CH	134	18590	13294	153	17	10.9	4.1	19.2

Table A.17 Tribune Irrigated N Study Sensor Data 2009

Rep	Pre-plant N	Side-dress N	Total N	GS NDVI	CC NDVI	SPAD	CC Red NDVI	CC Red Edge NDVI	SPAD
	---------------(kg ha^{-1})---------------			---------------V-9---------------			-------------------------V-T-------------------------		
1	0	0	22	0.66	0.52	44.2	0.62	0.27	47.9
2	0	0	22	0.56	0.45	48.9	0.51	0.20	45.1
3	0	0	22	0.57	0.46	42.6	0.58	0.24	34.5
4	0	0	22	0.66	0.49	48.3	0.65	0.28	41.2
1	112	0	134	0.75	0.59	na	0.65	0.33	na
2	112	0	134	0.76	0.59	na	0.61	0.27	na
3	112	0	134	0.76	0.59	na	0.65	0.29	na
4	112	0	134	0.72	0.56	na	0.69	0.32	na
1	157	0	179	0.73	0.58	na	0.70	0.33	na
2	157	0	179	0.77	0.61	na	0.65	0.32	na
3	157	0	179	0.80	0.61	na	0.70	0.35	na
4	157	0	179	0.74	0.57	na	0.69	0.35	na
1	202	0	224	0.74	0.59	49.5	0.67	0.32	55.3
2	202	0	224	0.78	0.60	53.1	0.64	0.32	56.4
3	202	0	224	0.79	0.62	55	0.60	0.29	57.9
4	202	0	224	0.77	0.59	54.2	0.69	0.35	55.8
1	45	67	134	0.75	0.59	na	0.62	0.30	na
2	45	67	134	0.69	0.53	na	0.60	0.27	na
3	45	67	134	0.73	0.56	na	0.66	0.32	na
4	45	67	134	0.73	0.56	na	0.70	0.33	na
1	67	90	179	0.70	0.54	na	0.66	0.33	na
2	67	90	179	0.77	0.61	na	0.62	0.31	na
3	67	90	179	0.71	0.56	na	0.60	0.29	na
4	67	90	179	0.74	0.57	na	0.68	0.33	na
1	90	112	224	0.74	0.58	na	0.69	0.35	na
2	90	112	224	0.71	0.56	na	0.67	0.34	na
3	90	112	224	0.78	0.61	na	0.62	0.30	na
4	90	112	224	0.74	0.58	na	0.68	0.33	na
1	112	GS	134	0.76	0.60	na	0.60	0.28	na
2	112	GS	190	0.74	0.55	na	0.56	0.23	na
3	112	GS	202	0.73	0.57	na	0.67	0.32	na
4	112	GS	185	0.74	0.56	na	0.68	0.31	na
1	112	CH	134	0.68	0.55	52.1	0.66	0.32	57.4
2	112	CH	202	0.68	0.52	50.8	0.62	0.28	47
3	112	CH	202	0.78	0.59	55.8	0.58	0.25	51.3
4	112	CH	185	0.74	0.59	54.6	0.66	0.29	49.7
1	112	GS + CH	134	0.69	0.54	na	0.65	0.32	53.8
2	112	GS + CH	134	0.73	0.58	na	0.62	0.29	57.5
3	112	GS + CH	202	0.79	0.61	na	0.67	0.31	50.1
4	112	GS + CH	134	0.75	0.58	na	0.63	0.29	53.4

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Table A.18 Colby Irrigated N Study 2008

Rep	Pre-plant N	Side-dress N	Total N	Grain Yield	Grain N	Earleaf N	GS NDVI	CC NDVI	SPAD	SPAD
	--------------------------(kg ha^{-1})--------------------------				--------(g kg^{-1})--------		------------V-8------------		V-15	V-T
1	0	0	22	13685	15.1	21.4	0.74	na	56.5	56
2	0	0	22	13657	13.0	21.9	0.61	na	55	58.6
3	0	0	22	10467	14.0	23.2	0.47	na	53.6	58
4	0	0	22	9351	12.1	19.2	0.56	na	53.1	46.5
1	112	0	134	12520	14.0	24.6	0.67	na	na	na
2	112	0	134	12198	13.3	23.1	0.56	na	na	na
3	112	0	134	11097	10.5	23.8	0.35	na	na	na
4	112	0	134	12107	11.1	21.0	0.63	na	na	na
1	157	0	179	13892	14.0	21.0	0.60	na	na	na
2	157	0	179	11328	13.4	25.0	0.66	na	na	na
3	157	0	179	12728	12.2	22.5	0.43	na	na	na
4	157	0	179	10692	12.4	20.8	0.56	na	na	na
1	202	0	224	13674	14.4	28.8	0.65	0.63	56	61
2	202	0	224	13812	13.0	25.0	0.55	0.59	59.1	58.1
3	202	0	224	9642	14.4	22.5	0.56	0.51	53.7	56.8
4	202	0	224	10097	14.2	23.7	0.51	0.56	58.5	56
1	45	67	134	14650	14.7	22.5	0.61	na	na	na
2	45	67	134	12182	13.1	24.9	0.49	na	na	na
3	45	67	134	10510	10.7	25.9	0.25	na	na	na
4	45	67	134	10136	11.6	21.2	0.61	na	na	na
1	67	90	179	14245	13.6	19.1	0.65	na	na	na
2	67	90	179	13356	13.5	22.0	0.61	na	na	na
3	67	90	179	11492	13.8	27.6	0.46	na	na	na
4	67	90	179	12937	13.7	23.3	0.65	na	na	na
1	90	112	224	14891	13.1	23.3	0.71	na	na	na
2	90	112	224	11954	14.4	25.2	0.59	na	na	na
3	90	112	224	13444	12.9	23.8	0.37	na	na	na
4	90	112	224	12476	13.5	25.7	0.64	na	na	na
1	112	GS	134	12545	13.8	20.4	0.61	na	na	na
2	112	GS	134	13577	13.2	23.6	0.54	na	na	na
3	112	GS	134	11865	13.1	20.3	0.56	na	na	na
4	112	GS	134	12330	11.9	19.2	0.63	na	na	na
1	112	CC	134	13474	13.9	20.3	0.60	0.62	na	na
2	112	CC	134	14181	14.3	21.1	0.56	0.58	na	na
3	112	CC	134	12482	12.4	21.8	0.37	0.47	na	na
4	112	CC	134	11506	11.7	21.7	0.63	0.61	na	na
1	112	CH	134	13407	14.6	24.1	0.54	na	na	60.7
2	112	CH	134	11082	13.3	25.5	0.66	na	na	58
3	112	CH	134	11352	14.5	23.0	0.49	na	na	59.3
4	112	CH	134	11653	9.2	21.5	0.62	na	na	54.9
1	112	GS + CH	134	12180	14.2	23.1	0.61	na	na	61
2	112	GS + CH	134	15546	14.7	22.0	0.55	na	na	61
3	112	GS + CH	134	8599	13.0	21.5	0.19	na	na	56.4
4	112	GS + CH	134	10765	11.5	22.1	0.46	na	na	57.6
1	112	CC + CH	134	13914	13.8	22.8	0.61	0.60	na	60.2
2	112	CC + CH	134	12469	14.2	21.2	0.67	0.63	na	60.8
3	112	CC + CH	134	11321	12.4	22.5	0.38	0.49	na	56.8
4	112	CC + CH	134	11249	12.3	19.8	0.61	0.60	na	56.7

Table A.19 Colby Irrigated N Study 2009

Rep	Pre-plant N	Side-dress N	Total N	Total Biomass	Grain Yield	Total N Uptake	Residual	Grain N	WP N	Earleaf N
	(kg ha^{-1})							(g kg^{-1})		
1	0	0	22	9521	5611	73	na	12.5	3.0	15.9
2	0	0	22	6698	4382	57	na	13.0	3.0	14.8
3	0	0	22	12497	5733	116	na	11.2	8.0	20.5
4	0	0	22	6294	2260	31	na	10.0	2.6	15.4
1	112	0	134	17331	10415	194	na	13.5	8.8	21.2
2	112	0	134	20838	11096	215	na	12.1	8.8	24.8
3	112	0	134	18311	9711	191	na	12.7	8.6	25.4
4	112	0	134	14913	6575	107	na	10.5	5.2	23.4
1	157	0	179	18118	10866	200	na	13.2	8.8	23.3
2	157	0	179	20058	10328	197	na	10.9	9.0	24.3
3	157	0	179	18168	10197	200	na	13.0	9.2	22.8
4	157	0	179	15747	9279	142	na	12.9	5.1	27.1
1	202	0	224	18819	10864	227	na	13.7	10.6	23.6
2	202	0	224	18418	10118	175	na	12.1	7.3	29.0
3	202	0	224	19116	10345	217	na	13.1	9.9	24.8
4	202	0	224	18889	9473	201	na	12.4	9.3	25.8
1	45	67	134	17736	10726	175	na	12.8	6.8	23.6
2	45	67	134	17207	10131	179	na	12.8	8.0	27.9
3	45	67	134	16342	10014	165	na	12.8	7.2	25.4
4	45	67	134	15217	6594	106	na	9.9	5.2	20.8
1	67	90	179	15624	10041	143	na	12.9	4.8	17.9
2	67	90	179	17908	9727	197	na	13.0	9.3	23.4
3	67	90	179	18799	9976	205	na	13.2	9.0	23.5
4	67	90	179	16769	9303	166	na	12.0	8.0	24.7
1	90	112	224	20428	8950	233	na	12.7	10.7	25.1
2	90	112	224	20039	10368	232	na	12.8	10.6	25.5
3	90	112	224	20169	11196	231	na	13.1	10.1	26.3
4	90	112	224	18695	10343	192	na	14.1	6.9	23.6
1	112	GS	168	19518	10644	199	na	13.2	7.6	23.8
2	112	GS	179	17687	8370	131	na	10.6	5.3	24.0
3	112	GS	168	18851	9676	180	na	12.6	7.3	25.6
4	112	GS	134	15393	6013	164	na	11.6	10.1	23.9
1	112	CC	168	20000	10114	195	na	13.6	6.9	25.1
2	112	CC	190	17620	8983	152	na	13.0	5.3	22.4
3	112	CC	134	18000	9270	170	na	11.3	8.1	27.1
4	112	CC	202	15647	7830	145	na	12.0	7.2	23.1
1	112	CH	168	18225	9503	181	na	12.6	7.9	23.6
2	112	CH	202	19511	10434	205	na	11.4	9.8	26.9
3	112	CH	134	17864	8906	158	na	11.4	7.0	26.5
4	112	CH	168	15965	6982	157	na	12.9	8.0	26.0
1	112	GS + CH	168	17475	9816	190	na	13.3	8.6	23.2
2	112	GS + CH	134	18826	9000	176	na	12.1	7.5	19.1
3	112	GS + CH	134	18483	10740	202	na	11.4	10.5	23.9
4	112	GS + CH	190	15821	7309	127	na	10.3	6.6	26.2
1	112	CC + CH	168	17780	9214	167	na	12.6	7.0	26.2
2	112	CC + CH	168	20372	9538	195	na	13.3	7.2	24.1
3	112	CC + CH	134	18282	9762	191	na	11.8	9.3	25.6
4	112	CC + CH	168	15862	6387	129	na	11.7	6.3	23.7

Table A.20 Colby Irrigated N Study Sensor Data 2009

Re	Pre-plant	Side-dress	Total N	GS	CC	SPAD	CC Red	CC Red Edge	SPAD
	(kg ha^{-1})			V-8			V-T		
1	0	0	22	0.26	0.31	33.4	0.44	0.19	34.5
2	0	0	22	0.25	0.31	41.7	0.43	0.17	36.5
3	0	0	22	0.34	0.35	39.2	0.57	0.27	47.1
4	0	0	22	0.30	0.34	40	0.46	0.18	35.4
1	112	0	134	0.54	0.51	na	0.65	0.33	na
2	112	0	134	0.50	0.46	na	0.64	0.32	na
3	112	0	134	0.52	0.49	na	0.66	0.33	na
4	112	0	134	0.50	0.50	na	0.67	0.34	na
1	157	0	179	0.56	0.49	na	0.65	0.34	na
2	157	0	179	0.48	0.46	na	0.68	0.34	na
3	157	0	179	0.50	0.47	na	0.65	0.33	na
4	157	0	179	0.51	0.50	na	0.66	0.34	na
1	202	0	224	0.57	0.52	54.1	0.64	0.34	55.4
2	202	0	224	0.54	0.49	51.4	0.69	0.36	58.9
3	202	0	224	0.57	0.51	51.3	0.65	0.34	52.7
4	202	0	224	0.52	0.49	49.4	0.67	0.34	52.8
1	45	67	134	0.39	0.41	na	0.59	0.26	na
2	45	67	134	0.46	0.43	na	0.62	0.30	na
3	45	67	134	0.44	0.43	na	0.65	0.33	na
4	45	67	134	0.49	0.48	na	0.63	0.31	na
1	67	90	179	0.39	0.40	na	0.58	0.28	na
2	67	90	179	0.38	0.39	na	0.62	0.30	na
3	67	90	179	0.45	0.43	na	0.65	0.33	na
4	67	90	179	0.47	0.47	na	0.63	0.32	na
1	90	112	224	0.47	0.43	na	0.63	0.32	na
2	90	112	224	0.47	0.45	na	0.66	0.34	na
3	90	112	224	0.53	0.47	na	0.66	0.34	na
4	90	112	224	0.53	0.50	na	0.66	0.34	na
1	112	GS	168	0.51	0.48	na	0.65	0.33	na
2	112	GS	179	0.44	0.45	na	0.65	0.32	na
3	112	GS	168	0.62	0.53	na	0.62	0.31	na
4	112	GS	134	0.50	0.48	na	0.65	0.32	na
1	112	CC	168	0.47	0.47	na	0.65	0.33	na
2	112	CC	190	0.46	0.43	na	0.59	0.30	na
3	112	CC	134	0.48	0.46	na	0.71	0.35	na
4	112	CC	202	0.55	0.52	na	0.66	0.34	na
1	112	CH	168	0.55	0.51	55.4	0.68	0.35	51.2
2	112	CH	202	0.47	0.43	54.3	0.63	0.31	54.1
3	112	CH	134	0.55	0.50	50.3	0.62	0.31	50.5
4	112	CH	168	0.62	0.54	51.5	0.67	0.34	52.8
1	112	GS + CH	168	0.59	0.53	na	0.66	0.34	47.3
2	112	GS + CH	134	0.38	0.39	na	0.59	0.29	52.1
3	112	GS + CH	134	0.45	0.45	na	0.66	0.34	52.8
4	112	GS + CH	190	0.51	0.47	na	0.65	0.33	48.4
1	112	CC + CH	168	0.48	0.47	na	0.67	0.35	54.6
2	112	CC + CH	168	0.39	0.41	na	0.61	0.31	55.1
3	112	CC + CH	134	0.42	0.41	na	0.68	0.34	49.2
4	112	CC + CH	168	0.52	0.46	na	0.65	0.33	51.7

Table A.21 Initial Soil Test Results for Main Studies 2006-2008

Site	Year	Previous Crop	Tillage	Profile NO3	Organic Matter	P Concentration	K Concentration
				kg ha^{-1}	----------------------------mg kg^{-1}----------------------------		
Manhattan	2006	Soybean	No-till	15	23	9	178
Rossville	2007	Corn	Conventional	49	17	14	151
Tribune	2007	Corn	Conventional	56	20	34	650
Manhattan	2008	Sorghum	No-till	32	24	17	235
Colby	2008	Corn	Conventional	152	17	66	711