MANAGING NITROGEN IN GRAIN SORGHUM TO MAXIMIZE N USE EFFICIENCY AND YIELD WHILE MINIMIZING PRODUCER RISK

by

ANDREW NEIL TUCKER

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Approved by:

Major Professor
Dr. David B. Mengel

Abstract

Grain Sorghum (*Sorghum bicolor*) is one of the most drought and stress tolerant crops grown in Kansas. For this reason, much of the sorghum is grown in high risk environments where other crops are more likely to fail or be unprofitable. Efficient sorghum cropping systems should not only produce high yields and use inputs such as nitrogen efficiently, but they should also remove as much risk as possible for a successful crop, and give farmers more flexibility in making input decisions.

The price of nitrogen (N) fertilizer has increased substantially in recent years. Current retail prices for commonly used N fertilizers range from $0.88 to $1.50 per kilogram of N in Kansas. Thus, a farmer could easily invest $50-$100 per hectare in N, depending on the rate of N needed and the source used. Practices which allow farmers to assess crop potential as late as possible after planting before applying costly inputs like fertilizer, can increase the potential for a profitable return on those inputs in risky environments. Currently, most sorghum growers routinely apply all the N fertilizer prior to planting, sometimes as much as 6 months prior. The current Kansas State University (KSU) nitrogen recommendation is yield goal based and performs well when the grower is able to predict yield six months or more in advance of harvest. However, yield is quite variable and difficult to predict. Because long range weather and yield predictions are not very reliable, could deferring making N application decisions until later in the season when yield can be more accurately predicted reduce risk? Can the use of active sensors provide a better estimate of yield potential and nitrogen needs sometime after planting? If they can, how late can the decision be made and how best should the fertilizer N be applied?

Several studies were conducted throughout Kansas to look at the effect of N rate, N application timing (pre-plant, side dress, or combinations of the two) and method of application on sorghum yield and N use efficiency. The studies were also designed to examine the potential of using optical sensors to predict optimum N rate for post-planting applications as a means of avoiding the use of soil tests to estimate soil N contributions.

The objectives of this research were:

a. to validate the KSU N fertilizer recommendations for grain sorghum grown in rotation with crops such as soybeans and wheat,

b. to determine the effect of both pre-plant and midseason N applications on the growth and yield potential of grain sorghum, and to determine the optimal timing and method for midseason N applications on grain sorghum, and,

c. to assess the potential of optical sensing of the growing crop to refine N recommendations using in-season applications during the growing season. This thesis will summarize the results from the various experiments we completed to achieve these objectives.

The KSU N fertilizer recommendations for grain sorghum may need some revisions. This research suggests that including coefficients relating to N use efficiency may be necessary to get more accurate N recommendations. Both pre-plant and midseason N applications increased the yield of grain sorghum whenever a response to N was observed. There was no negative effect of applying all the nitrogen midseason at 30-40 days after planting when compared to pre-plant applications. Injecting nitrogen fertilizer below the soil surface had higher yields than other methods of midseason N applications such as surface banding or surface broadcasting, especially when a significant rainfall event did not occur within a few days of application. The optical sensors used in this study were very effective at making N recommendations 30-40 days after planting. These sensors will provide for more accurate N recommendations compared to the current soil test and yield goal method.

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CHAPTER 1 - Nitrogen Management in Grain Sorghum Production: a Review of Current Literature

Introduction

Grain sorghum is an important part of the cropping system and farm economy in Kansas. Of the summer crops routinely grown in the Central Great Plains region, it is the most drought tolerant. Approximately 1.2 million ha of sorghum are currently grown each year by Kansas farmers. While sorghum remains a major crop in Kansas, acreage has dropped recently as many farmers have intensified and diversified their cropping systems. Other equally important factors influencing sorghum acreage include limited options for weed control, especially grasses, the high cost of inputs, including N fertilizer, and the price of sorghum relative to corn, especially in western Kansas.

The majority of sorghum today is grown under dry land conditions, in places where precipitation and stored soil water is inadequate to reliably grow corn. Yields vary from year to year, generally tracking annual variations in rainfall during the growing season. According to the USDA National Agriculture Statistics state average yields for Kansas ranged from 2700-5080 kg/ha within the last five years. With this high variability in yield, and increasing costs of inputs such as fuel and fertilizer, it seems logical that developing fertilization practices that can adjust mid-season to changes in weather and resulting yield potential could enhance profitability for sorghum growers. Being able to delay the final fertilization decisions and investments until 30-40 days after planting, would allow growers to have a better feel for the stored water available and yield potential that year, and the return the grower might obtain from the investment in side-dressed N fertilizer. Thus, fertilizer rates could potentially be adjusted to meet the sorghum crop's need at that time. Several concepts will be discussed in this chapter, including N use efficiency, N recommendation systems, N timing, N placement, and the use of optical crop sensors.

The Concept of N Use Efficiency

Nitrogen use efficiency (NUE), defined as the percent of fertilizer N 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 US (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 and sorghum yield would have dropped by 41 and 19%, respectively, 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, 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. Cassman et al. (2002) discusses these components as well, however, he raises the issue of applying adequate N to maintain a soil N pool for sustainable production. Regardless of how NUE is measured, utilization of applied fertilizer N is generally low.

Agricultural inputs have to be managed efficiently, especially during periods of high dry matter production in 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, soil denitrification, surface runoff, volatilization of ammonia, and leaching of nitrates (Raun and Johnson, 1999). With the exception of N 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. One of the most important is the inability to predict the amount of fertilizer N that should be added to a crop, particularly a crop such as sorghum grown in a high risk environment. With current management practices that emphasize pre-plant N application, poor synchrony between soil N supply and crop demand is another critical factor (Raun and Johnson, 1999; Cassman et al., 2002; Fageria and Baligar, 2005). Poor synchronization can be caused by many 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) 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 contributions to the crop and determine N need.

Nitrogen Recommendation Systems

The current Kansas State University N recommendation for sorghum, 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 sorghum the N recommendation equation is:

N needed in kg/ha = (Yield Goal Mg/ha × 25.5) – (% SOM × 22) +/- Previous Crop Adjustments – Soil Profile Nitrate-N – Manure N – Other N Adjustments.

The problem with this approach is that yield and N provided through mineralization are both strongly impacted by in-season weather. USDA National Agriculture Statistics state average yields for Kansas ranged from 2700-5080 kg/ha over the last five years (2004-2008). This huge variability in yield makes the determination of crop N need very difficult. 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 or sorghum 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 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 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.

The final problem with the current N recommendation for KSU is that it was developed using corn N response data. As with many sorghum N recommendation systems used in the US, the original KSU recommendations were developed using the assumption that sorghum responded like corn to applied N. Most of the underlying relationships upon which the recommendations are based are drawn from work done with corn in Kansas and surrounding states; however, sorghum may not respond to N in exactly the same way as corn. The sorghum we currently are growing appears to be slightly more efficient at extracting N from soils, and in utilizing the N taken up to produce grain. In addition, sorghum is generally planted a month to six weeks later than corn, which can result in sorghum being in position to utilize N mineralized from residues and organic matter more effectively. Having a later planting date allows the soil temperatures to be considerably warmer than when we plant corn. This results in increase microbial activity to allow for N mineralization to occur in synchronization with sorghum growth. As a result, sorghum may well be more efficient in utilizing available N, and inherently need less fertilizer N than corn.

However, the N management practices commonly used on sorghum, together with the fact that a large portion of the sorghum grown utilizes no-tillage production systems (Kastens et al., 2006) may result in lower N use efficiency, and a resulting need for higher N applications. Nitrogen application practices for example have been shown to significantly impact N utilization and crop yield (Bandel et al., 1980; Eckert, 1987; Fox et. Al., 1986; Lamond, 1987; Mengel et al., 1982). For example, a portion of the broadcast surface applications of N as urea-DAP (diammonium phosphates) blends applied in late winter or early spring to wheat stubble, could be immobilized by soil organisms decomposing crop residue. This N may not be released in time to be available for the planted crop, resulting in lower N use efficiency and the need to apply higher rates of N. A better understanding of the relative efficiencies available from different N management practices, would allow growers to select practices which are more efficient and potentially more profitable. With N prices currently at $.88 to $1.40 per kg of N retail in many markets, more efficient N management programs which could save 10 to 20 kg of N or more per ha are very attractive, economically.

N Timing for Sorghum

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 sorghum yield.

Applying no N or minimal N rates at planting, can result in reduced yield potential through inadequate panicle size and reduced seed numbers, particularly in no-till systems. The layer of crop residue on the soil can reduce soil temperature, (Unger, 1978; Thomas et al., 1973) and may sometimes lower nutrient availability in the early part of the growing season (Gordon and Whitney, 1995). Application of starter-band fertilizer N within the rooting zone of the young seedlings has been shown to be efficient and beneficial to the crop (Lamond and Whitney, 1991). In a study in North Central KS, Gordon and Whitney (1995) reported an increase of 18% in the grain yields of sorghum by application of fertilizer N in a starter-band. In tilled systems, starter N responses are not as common, due to more rapid mineralization of crop residues.

The period of rapid vegetative growth and nutrient uptake by sorghum plants begins about 25-30 days after emergence at the six to seven leaf growth stage and continues through pollination and early grain fill (Vanderlip, 1993). Side-dress application of N during the early portions of this period is feasible and could be beneficial for the crop. However, since sorghum is normally grown in low rainfall areas where N loss problems are minimal, this practice is not widely used. Most growers use preplant N applications as their primary N fertilization strategies. Little research could be found comparing the advantages or disadvantages of sidedressing N in sorghum. However the application of N fertilizer after planting to sorghum should not be ignored, particularly in no-till planting systems. Delaying the N rate decision until later in the season, when the impact of weather on the crop and N availability may be better understood, could enhance efficiency and profitability.

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 and 1984; 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. Much less work has been done on N fertilizer management for grain sorghum in no-till cropping systems. However, Lamond and co-workers in Kansas (1991) found similar results of higher yields with knifed UAN than broadcast, with surface bands intermediate in sorghum. Thus, fertilizer placement below the soil surface should be more affective than broadcasting or banding on the soil surface, both in ensuring quick availability and in enhancing N use efficiency.

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 sorghum 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, 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 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, NB). These crop sensors rely on crop reflectance to determine N status in plants.

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, therefore, reflectance measurements that use these wavelengths can 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). The 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. With this information, 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 for land cover, 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, relative 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 was based on results obtained using a SPAD chlorophyll meter to monitor crop N status and applying fertilizer N "as needed" by fertigation. 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's 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 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 in Asia (Hussain et al. 2000). In addition, this study found that the SI approach proved to adapt 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/ha N 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 & 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 a 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 reducing applied N using fertigation by 39 kg ha^{-1} 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 GreenNDVI was well correlated with SPAD readings for corn at V11 and could be used for determining N rates on the go. However, but work done by Osborne et al. (2002) showed that optimum wavelengths for estimating crop biomass, nitrogen concentration, grain yield, and chlorophyll meters 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 GreenNDVI approaches on a large scale basis where large variability in yield exists, and in crops that have a lower biomass production than irrigated corn. Perhaps, the use of a wavelength to get 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 GDD accumulated at time of 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 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% as opposed to traditional fertilizer application methods (Raun et al., 2002). In spring wheat, correlations between sensor data and grain yield have not been near as good as in winter wheat. In addition, correlations between sensor readings and nitrogen uptake have also not been as good. Certain varieties however, 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 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). In sorghum, work has shown that grain yield and NDVI were best correlated at growth stage 3. When INSEY was used it did not improve the correlation and NDVI did not correlate as well with N concentration in the grain at harvest (Moges et al., 2006).

To date, the GreenSeeker sensor is the only active sensor 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 once a leaf area index greater than 2 is met (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. But, is not an issue in lower biomass crops such as wheat, the crop the GreenSeeker was specifically developed for.

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CHAPTER 2 - Response of Sorghum to Preplant and Side-dressed Nitrogen Applications in Kansas

Abstract

Research has shown that most grain sorghum hybrids (*Sorghum bicolor* L. Moench) are more tolerant of water-stress than corn (*Zea mays* L.). As a consequence sorghum is commonly grown in the Central Great Plains region in rotation with winter wheat (*Triticum aestivum* L.) and soybeans (*Glycine max*) in areas and soils where corn does not perform well due to regular drought stress. Sorghum yields vary widely from year to year (USDA-NASS, 2009) following changes in annual rainfall, making traditional pre-plant, yield goal based, N recommendations a challenge.

A series of field experiments were conducted across Kansas from 2006 through 2008 to address this issue. Two simple preliminary field experiments were conducted at Manhattan in 2006 focused on general N fertilization practices. One experiment examined the effect of time of sidedress N application on sorghum and method of sidedress N placement, banded on the surface in contact with residue or banded below the residue, on sorghum yield. A second experiment examined both fertilizer placement and the use of ammonium and calcium thiosulfate additives to liquid N fertilizers as an alternative to subsurface placement. The objective of these experiments was to determine how late N could be applied to sorghum without impacting yield, how that late applied N should be applied for maximum efficiency, and if the use of thiosulfate products added to surface applied UAN could enhance the performance of the surface applied N.

A large multi-site/multi-year study consisting of a factorial combination of pre-plant and side-dress N rates to supply a total of 0-168 kg N ha^{-1} was conducted at several locations over three years. Grain yields obtained at the ten site-year combinations ranged from 630 to 10660 kg

ha^{-1}. Grain sorghum yields were responsive to N at eight of the 10 experiments, with only four responding to more than the initial 34 kg ha^{-1} N rate. Non-responsiveness of grain sorghum yields at the rest of the sites was due to high levels (> 73 kg N ha^{-1}) of soil profile residual nitrate –N and/or drought stress during the growing season.

Introduction

Grain sorghum is an important part of the cropping system and farm economy in Kansas. Of the summer crops routinely grown in this region, sorghum is the most drought tolerant (Kreig, 1988). Approximately 1.2 million ha of sorghum are currently grown each year by Kansas farmers (USDA-NASS, 2009). While sorghum remains a major crop in Kansas, acreage has dropped recently as many farmers have intensified and diversified their cropping systems. Other equally important factors influencing sorghum acreage include limited options for weed control, especially grasses, the high cost of inputs, including nitrogen (N) fertilizer, and the price of sorghum relative to the price of corn, especially in western Kansas (USCP Startegic plan, 2009).

The majority of the sorghum today is grown under dryland conditions, in places where precipitation and stored soil water is inadequate to reliably grow corn. Yields vary from year to year, generally tracking annual variations in rainfall during the growing season. With this high variability in yield, and increasing costs of inputs such as fuel and fertilizer, it seems logical to develop better fertilization practices for sorghum that have the flexibility to adjust N application based on yield potential evaluations made in season. Being able to delay the final N fertilization decisions and investments until 30-40 days after planting, would allow growers to have a better feel for the stored water available and yield potential that year, and greatly increase the return the grower obtains from the investment in side-dressed N fertilizer.

As with many sorghum N recommendation systems used in the US, the original Kansas State University (KSU) recommendations were developed using the assumption that sorghum responded like corn to applied N (D. B. Mengel, personal communication). Most of the underlying relationships upon which the recommendations are based are drawn from work done with corn in Kansas and surrounding states; however, sorghum may not respond to N in exactly the same way as corn. Current sorghum hybrids appear to be slightly more efficient at extracting N from soils than corn, and in utilizing the N taken up to produce grain. In addition, sorghum is generally planted a month to six weeks later than corn, which can result in sorghum being in position to utilize N mineralized from crop residues and organic matter more effectively. As a result, sorghum may well be more efficient in utilizing available N, and inherently need less fertilizer N than corn.

However, the N management practices commonly used on sorghum, together with the fact that much of the sorghum is currently grown utilizing no-tillage (Kastens et al., 2006), may result in low N recovery and a resulting need for higher N applications. For example, a portion of the broadcast surface applications of N as urea applied in late winter or early spring to wheat stubble, could be immobilized by soil organisms decomposing the crop residue. This immobilized N may not be released in time to be available for the planted crop, resulting in lower N use efficiency/recovery and the need to apply higher rates of N to compensate. A better understanding of the relative efficiencies available from different N management practices, would allow growers to select practices which are more efficient and potentially more profitable. With N prices currently at $0.60 to $1.50 per kg of N retail in many markets, more efficient N management programs which could save 10 to 20 kg of N per ha are very attractive and could increase sorghum growers bottom lines.

Having adequate N available to the crop early to ensure high yield potential, and applying late season N in a manner that ensures crop availability are also important. Applying none or minimal N rates at planting, could result in reduced yield potential through inadequate panicle size and reduced seed numbers. The period of rapid growth and nutrient uptake by sorghum plants begins about 25 days after emergence at the six to seven leaf growth stage and continues through early grain fill (Vanderlip, 1993). Side-dress application at the beginning of this period of N uptake period is feasible using standard N application equipment and could be beneficial for the crop, particularly in conditions or locations where N loss is common. However, applying some N fertilizer at planting should not be ignored, especially when the side dressing may be delayed until panicle development.

The layer of crop residue found on the soil surface in no-till production systems can reduce soil temperature, (Unger, 1978; Thomas et al., 1973) and may sometimes lower the nutrient availability in the early part of the growing season (Gordon and Whitney, 1995). Application of starter fertilizer N within the rooting zone of the young seedlings has been shown to be efficient and beneficial to the crop (Lamond and Whitney, 1991). Gordon and Whitney (1995) reported an 18% increase in grain yields by application of fertilizer N in a starter-band.

So a balance of preplant/planting time N and sidedressing must be achieved to ensure optimum yields. Late season N must also be applied in a method that ensures quick availability to the crop. Several studies (Eckert, 1987; Fox and Piekielek, 1987; Fox et al., 1986; Maddux et al., 1984; Bandel et al., 1980 and 1984; Mengel et al., 1982) have examined placement methods for no-tillage corn production in the Corn Belt and Great plains. They all reported application of broadcast UAN-N fertilizer produced lower yields than either injected or subsurface-banded UAN. Surface banded UAN performance was intermediate. Possible N loss mechanisms noted with broadcast UAN by these authors included both ammonia volatilization and immobilization. Much less work has been done on N fertilizer management for grain sorghum in Great Plains cropping systems. However Lamond et al. (1991), reported similar responses to subsurface N applications in no-till sorghum in Kansas as seen with corn in the Corn Belt. Thus, fertilizer placement below the soil surface should be more effective than either broadcasting or banding N fertilizers on the soil/residue surface, both in ensuring quick availability of the fertilizer during periods of dry weather, and in enhancing N use efficiency.

The objectives of this research were to:

a. Confirm the importance of subsurface placement for side dress application of N fertilizers in no-till sorghum, and examine the potential of three products being sold as additives to surface applied UAN that enhance NUE/recovery,
b. To determine the length of the “window” for side dress N on grain sorghum,
c. To determine the optimum N application rate and identify some of the factors which influence N response in sorghum in Kansas. This chapter will summarize the results from experiments conducted to address these objectives. Only results from N responsive N sites will be discussed in detail in this chapter. The results from all experiments, responsive and non-responsive are summarized in the appendix.

Materials and Methods

Three experiments were conducted to confirm the effect of N placement on sorghum yield, to determine the length of the "window" or period of time available to effectively side dress sorghum using standard ground equipment, and to determine the efficacy of some of the products offered for sale in Kansas as tools to enhance the performance of surface applied UAN fertilizer.

In 2006 a timing and method of placement study was conducted at the KSU Agronomy North Farm (39^0 08 02" N lat.; 96^o37 09" W long.), on a Smolan silt loam soil. The study consisted of a no side dress control treatment, and a single rate of 67 kg N ha^{-1} applied as UAN solution either surface banded directly on the residue in the row middles (SB) or coulter banded, injected, approximately 7.5cm deep below the residue in the row middles (CB). The experiment was designed to use three side dress timings, 30, 40 and 50 days after planting. However, the 50 day treatment proved to be too late to be done safely and resulted in unacceptable levels of stalk breakage (>30%) and was abandoned.

The experiment was set in the field using a randomized complete block (RCB) design, with seven treatments and four replications. Individual plots were four rows spaced 76 cm wide and 15 m long. The sorghum was planted May 21, 2006 using Pioneer 84G62 hybrid at a seeding rate of 125,000 seeds ha^{-1}. Starter N fertilizer was applied at a rate of 22 kg ha^{-1} applied with the planter 5cm to the side and 5 cm deep to all treatments including the no side dress control. No additional P or K fertilizer was applied due to high soil tests.

Plots were harvested shortly after physiological maturity, by collecting all the heads from 5.2 m of the middle two rows by hand, and threshed using an Almaco mechanical thresher. A grain sample was collected for each plot to determine grain N content and grain moisture. Yields were corrected to 130 g kg^{-1} moisture. N content of the grain was determined by the KSU Soil Testing Lab.

A second study to evaluate the efficacy of calcium and ammonium thiosulfate compounds as additives to UAN fertilizer solutions to enhance N recovery and yield with surface applied N as compared to injected N was also conducted at the KSU Agronomy Farm in 2006. This study was conducted on an Ivan/Kennebec silt loam soil following soybeans. Eight treatments consisting of a control, and seven side dress N applications were arranged in the field using a RCB design with four reps. Treatments applied were 67 kg N ha^{-1} as broadcast urea, broadcast UAN, broadcast UAN plus 5 or 10% calcium or ammonium thiosulfate and UAN coulter banded or injected below the residue and UAN surface banded directly on the residue covered soil surface. This experiment was no-till planted May 19, 2006 using Pioneer 84G62 sorghum hybrid at a seeding rate of 160,000 seeds ha^{-1} with 22 kg N ha^{-1} applied as starter to all treatments, including the control at planting.

A third study was conducted in 2007, also at the Agronomy Farm on an Ivan/Kennebec soil, to determine the efficacy of the UAN additive Nutrisphere N. In this study ten treatments consisting of a control, 34 and 67 kg N ha^{-1} as UAN SB or CB with and without the addition of labeled rates of Nutrisphere N, and 67 kg N ha^{-1} as urea surface broadcast only. A RCB design with four replications was used. This experiment was no-till planted into corn stubble on June 14, 2007 using the hybrid Dekalb 42-20 at a seeding rate of 127,000 seeds ha^{-1}.

All three studies used plot sizes, cultural practices and measurement techniques as described for experiment one.

In addition to the three experiments focused on N management techniques described above, a large N response study was conducted a total of ten times during 2006, 2007 and 2008 at several locations in Kansas. The purpose of these studies was to determine the variability in N response in sorghum common to Kansas across years and environments. Four studies were conducted in 2006, three in 2007 and three in 2008. Each consisted of a series of N rates applied pre-plant or side dress. In 2006 N rates used were 0, 34, 67, 101, 135 and 168 kg N ha^{-1} applied pre-plant or side dress in factorial combination. These experiments were conducted at the KSU Agronomy Farm on an Ivan/Kennebec silt loam; the NC Kansas Experiment Field near Belleville, Ks ($39^0$48 53"N $97^0$39 29"W) on a Crete silt loam soil; SCK Kansas Experiment Field Partridge Unit ($37^0$58' 02"N $98^0$05' 31"W) on a Funmar/Tabler loam soil; and the Western Kansas Research Center at Tribune ($38^0$28'19" N, $101^0$45'19"W) on a Richfield silt loam.

In 2007 and 2008 only the 0, 34, 67, 101 and 135 kg N ha^{-1} rates in pre-plant and side dress combination were used. The studies in 2007 were conducted at The Agronomy Farm on a Smolan silt loam, Partridge and Tribune on Funmar/Tabler and Richfield soils respectively. In 2008 the studies were conducted at the Agronomy Farm, Partridge and the ECK Experiment Field near Ottawa, KS ($38^0$32'16" N, $95^0$15'15"W) on a Woodson silt loam soil. Significant dates and cultural practices used are summarized in Table 2.1. Plots were arranged in the field at all locations using a RCB design with four replications at all locations except Belleville, where space limited the study to three replications.

Each block of each 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. Sampling was done using a hand probe, and samples consisted of 12 to 15 individual cores composited to form an individual sample. Analysis was done 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).

Flag leaves were collected from each plot and analyzed for total N as indication of N sufficiency. Total N uptake was estimated by collecting the total above ground vegetation in six meters of row prior to harvest, chopping the stover, 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 this by the total amount of biomass produced (stover + grain). Total N uptake was only measured at the Manhattan sites, and the Tribune 2007. All plant analysis was done by the KSU Soil Testing Lab.

Table 2.1 Key cultural practices used at each of the location in the N response studies.

Location	Year	Planting Date	Hybrid	Seeding Rate ha^{-1}	Previous crop	Sidedress date
Agronomy	2006	May 19	P84G62	150,000	Soybean	June 19
Partridge	2006	May 31	P85G46	115,000	Sorghum	July 7
Tribune	2006	June 4	P86G08	75,000	Fallow	July 13
Belleville	2006	May 23	P85G46	127,000	Sorghum	June 20
Agronomy	2007	May 23	DK 42-20	127,000	Wheat	June 27
Partridge	2007	June 13	P85G46	115,000	Wheat	July 25
Tribune	2007	June 1	P86G08	75,000	Wheat	July 10
Agronomy	2008	May 20	DK 54-00	127,000	Wheat	June 26
Partridge	2008	June 5	P85G46	115,000	Wheat	July 15
Ottawa	2008	May 20	P84G62	127,000	Soybeans	July 10

Grain yield was determined at all locations by harvesting 12 m of the middle two rows of each plot using a plot combine. Yields were adjusted to standard 130 g kg^{-1} moisture content. Optimum N rate at each site was determined by running a linear or quadratic regression analysis using EXCEL, choosing the best model as determined by the r2, and solving for the N rate at 100% of yield. Additional statistical analysis was run to analyze differences between treatments that were observed using SAS version 9.1 with proc GLM an alpha of 0.10.

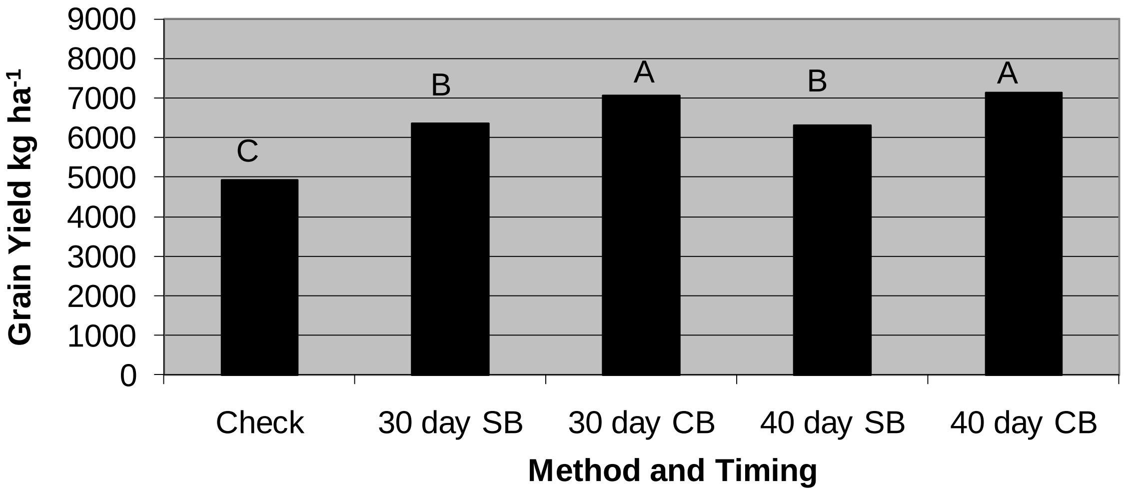
Results and Discussion

Nitrogen timing and method of application study, Agronomy Farm, 2006

The results from the 2006 N timing and method of application study are summarized in Figure 2.1. No significant difference in sorghum yield was seen when N was applied at 30 or 40 days after planting in this study. However the crop had grown tall enough by 50 days that we were not able to side dress using normal ground application equipment without causing a high degree of stalk breakage. This would indicate that farmers could expect to have a “window” of approximately two weeks, from roughly 30 to 45 days to complete side dress applications of N using standard equipment. After approximately 45 days high clearance sprayers would be needed in many cases to safely apply N. The results of this study also confirm the earlier work indicating that placing the N below the surface residue increases N recovery and yield. Yields of both the 30 and 40 day CB treatments were significantly higher than the SB treatments. This reinforces the importance of being able to side dress within that 30 to 45 day window to avoid the inefficiency of surface banding with high clearance sprayers, or cost of specialized high clearance equipment designed to coulter band N in tall crops.

In this study no significant precipitation occurred until between the 30 day N application and 44 days after planting. This may have reduced the effectiveness of the 30 day applications, allowing the 40 day application to perform as well. All plots in this study received 22 kg N ha^{-1} as starter also, which should have supplied enough N to ensure no N stress on the sorghum at early stages of growth. The lower yields obtained with surface banded applications is likely the result of immobilization of N in old sorghum residue and/or ammonia volatilization as noted by Lamond et al. (1991).

Figure 2.1 The Effect of Timing and Method of N Application on Sorghum Grain Yield in 2006.



Thiosulfate product evaluation, Agronomy Farm 2006

In this study a significant response to N was seen, with coulter banded (injected) UAN yielding significantly higher than urea broadcast on the surface of the residue covered soil, or the surface banded UAN with or without the addition of thiosulfate compounds (Table 2.2). Lower yields with broadcast urea and surface banded UAN as compared to injected UAN may have been due to immobilization of N by old sorghum residue or from ammonia volatilization. A significant rainfall event did not occur until 14 days after fertilizer application, creating optimum conditions for volatilization and immobilization of N in decomposing residues. In addition, the fertilizer N from the broadcast urea and surface banded UAN would not have been available for root uptake until after the rain moved it into the soil. Thus, loss of N or positional unavailability for two weeks could both have limited yield. The fact that flag leaf N content and total N uptake were not significantly different between any of the fertilized treatments suggests that positional unavailability could have been responsible for the relatively poor performance of all the surface applied treatments.

The addition of calcium thiosulfate or ammonium thiosulfate to the surface banded UAN applications did not improve N any measure of N uptake, N utilization or grain yield. While these products had been advertised as improving utilization of UAN fertilizers by preventing volatilization of ammonia-N, they did not do so in this study.

Table 2.2 Effect of Method of N Application and the Use of Thiosulfate Products on N Uptake and Grain Yield of Sorghum, Agronomy Farm, 2006.

Treatment	Flag Leaf N Percent N	Grain N Percent N	N Uptake, kg N ha^{-1}	Grain Yield, Kg ha^{-1}
No N Control	1.72c	1.01b	72 b	5210c
Surface Broadcast	2.40b	1.20a	113a	7090ab
Surface Band (SB)	2.38b	1.16a	99a	6840b
SB + 5% Ca Thio	2.36b	1.13a	103a	6590b
SB + 10% Ca Thio	2.32b	1.17a	100a	6550b
SB + 5% NH4 Thio	2.43ab	1.18a	109a	6770b
SB + 10% NH4 Thio	2.28b	1.16a	106a	6900b
CB UAN	2.60a	1.16a	116a	7530a
LSD 0.10	0.18	0.08	16	630

Nutrisphere-N Product Evaluation, 2007

A third N management study with sorghum was conducted in 2007 looking at the effect of N rate (0, 34 and 67 kg N ha^{-1}), method of application (surface vs. coulter banded) with and without the addition of the product called NutriSphere N, a long chain polymer with high negative charge which claims to have effects on nitrification and ammonia volatilization. The results from this study are summarized in Table 2.3.

Table 2.3 Effects of N Rate, Method of Application and the Use of NutriSphere in a Side-dress Application of N on Grain Sorghum, Agronomy Farm, 2007.

Method of N Application	N Applied as sidedress UAN Kg n ha^{-1}	Product applied at sidedressing	Sorghum Yield Kg grain ha^{-1}
None	0	None	4,580
Surface Band	34	None	5,520
Surface Band	34	NutriSphere N	5,390
Coulter Band	34	None	5,270
Coulter Band	34	NutriSphere N	5,580
Surface Band	67	None	6,460
Surface Band	67	NutriSphere N	6,330
Coulter Band	67	None	5,830
Coulter Band	67	NutriSphere N	6,080
LSD 0.10			500

Table 2.3 Continued

Main Effects Due to:

Due to N Rate:	34	5,440b
	67	6,180a
Due to Additive:	None	5,770a
	NutriSphere N	5,850a
Due to Placement:	Surface Band	5,930a
	Coulter Band	5,690a

In this study, a significant rainfall event occurred shortly after side-dress N application, creating conditions where applied N would have been moved quickly into the soil and removing any potential for loss through ammonia volatilization or immobilization. While a significant response to N was seen to the highest rate of 67 kg N ha^{-1}, (22 kg as starter plus 67 applied sidedress) no differences were observed between between methods of application at sidedressing or to the use of the NutriSphere additive with the sidedress N.

These results were to be expected with rainfall effectively incorporating the N and removing any potential for loss through ammonia volatilization or immobilization. This situation occurs frequently and makes the development of hard recommendations on the use of N management practices difficult. The choice of management practices such as method of placement or the use of additives to reduce N loss must consider how frequently conditions conducive to loss will found at a particular site.

Response of Sorghum to N, 2006 to 2008

In the ten large factorial studies designed to determine the response of sorghum to fertilizer N, only eight sites responded to nitrogen fertilizer. Of those eight, four responded only to the initial rate of N, while four responded to higher rates. There are a number of likely reasons that this limited response was seen, including high levels of nitrate-N present at some locations, and drought stress limiting yield and N need at some locations. The results from these studies showing the yield goals used at each location to make N recommendations, yields attained with preplant N applications, the amount of nitrate-N present in the soil profile as measured by a 60 cm soil test, the amount of N recommended by the KSU sorghum N recommendation, the N response observed at that site and the difference between N recommended by soil test and actual response observed are summarized in Table 2.4.

Table 2.4 Soil Based Fertilizer Recommendations for Sites in 2006-2008

Location	Year	Yield Goal kg ha^{-1}	Observed Yield kg ha^{-1}	Recommended N kg N ha^{-1}	Observed N Response kg N ha^{-1}	Recommended vs. Observed Difference kg kg N ha^{-1}
Belleville	2006	6270	6020	45	0	45
Manhattan	2006	8780	9720	86	37	49
Partridge	2006	5020	2010	45	62	-17
Tribune	2006	5020	8030	37	17	20
Manhattan	2007	7530	6840	143	118	25
Partridge	2007	5020	4390	45	22	23
Tribune	2007	5020	4960	59	0	59
Manhattan	2008	8780	8030	112	50	62
Ottawa	2008	5020	4010	73	67	6
Partridge	2008	5020	7720	46	17	29
mean		6150	6170	69	39	30

Using the current KSU N recommendation formula, the average N recommendation for the ten sites was 69 kg N ha^{-1}, ranging from 37 to 143 kg N ha^{-1}. However the average observed N response averaged only 39 kg N ha-1, with a range of 0 to 118 kg N ha^{-1}, with recommendations at nine of the ten sites exceeding the amount actually needed to maximize yield. This would suggest need for reassessing the way N recommendations for sorghum are made in Kansas.

Table 2.4 gives flag leaf N content at bloom, total N uptake by the crop and grain yield as a function of N rate applied, and time of N application at the five most responsive sites. At all five site year combinations, flag leaf N content increased as N rate increased, and tended to be higher at Manhattan and Ottawa when N was applied all sidedress.

Table 2.5 Flag Leaf Nitrogen Concencntration, Total N uptake, and Grain Yield 2006-2008.

Manhattan 2006					
Flag Leaf % N					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	2.29 D	2.57 C	2.68 B	2.84 A	2.6 A
Side-dress	2.46 C	2.57 C	2.82 A	2.72 Ab	2.64 A
Main Effect Rate	2.38 D	2.57 C	2.75 Ab	2.78 A	
N uptake kg ha $^{-1}$					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	109 D	136 C	146 Bc	188 A	145 B
Side-dress	143 C	157 Cb	201 A	175 Ab	169 A
Main Effect Rate	126 D	147 Cd	174 Ab	182 A	
Grain Yield kg ha $^{-1}$					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	8199 C	8647 Bc	8973 B	9948 A	8942 B
Side-dress	9560 A	9560 A	9940 A	9395 A	9614 A
Main Effect Rate	8880 A	9104 A	9457 A	9672 A	
Partridge 2006					
Flag Leaf % N					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	2.06 C	2.28 Bc	2.15 C	2.38 B	2.22 B
Side-dress	2.15 Bc	2.55 A	2.5 A	2.55 A	2.44 A
Main Effect Rate	2.11 B	2.42 A	2.33 A	2.47 A	
Grain Yield kg ha -1					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	1468 Ab	1788 A	1217 Bc	1524 Ab	1499 A
Side-dress	1681 Ab	1800 A	2082 A	1380 B	1736 A
Main Effect Rate	1575 A	1794 A	1650 A	1452 A	

Table 2.5 Continued

Manhattan 2007					
Flag Leaf % N					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	2.23 C	2.33 C	2.3 C	2.47 B	2.33 B
Side-dress	2.27 C	2.49 B	2.46 B	2.66A	2.47 A
Main Effect Rate	2.25 C	2.41 B	2.38 B	2.57 A	
N uptake kg ha $^{-1}$					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	88 C	118 B	122 B	119 B	112 A
Side-dress	90 C	110 B	129 Ab	139 A	117 A
Main Effect Rate	89 C	114 B	126 Ab	129 A	
Grain Yield kg ha $^{-1}$					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	4914 D	5580 C	6210 B	6358 B	5766 A
Side-dress	4552 D	5658 C	6712 Ab	7036 A	5990 A
Main Effect Rate	4733 C	5619 B	6461 A	6697 A	
Manhattan 2008					
Flag Leaf % N					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	2.39 C	2.62 A	2.58 A	2.63 A	2.56 A
Side-dress	2.51 B	2.58 Ab	2.59 Ab	2.63 A	2.58 A
Main Effect Rate	2.45 B	2.60 A	2.59 A	2.63 A	
Grain Yield kg ha $^{-1}$					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	7628 B	8017 B	8064 Ab	8573 A	8071 B
Side-dress	7938 B	8430 Bc	8772 C	9022 Ac	8541 A
Main Effect Rate	7783 B	8224 Ab	8418 A	8798 A	
Ottawa 2008					
Flag Leaf % N					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	2.05 E	2.21 D	2.2 D	2.29 C	2.19 B
Side-dress	2.34 D	2.5 C	2.66 B	2.76 A	2.57 A
Main Effect Rate	2.20 C	2.36 B	2.43 B	2.53 A	
Grain Yield kg ha $^{-1}$					
N Rate kg ha^{-1}	**33.6**	**67.2**	**100.8**	**134.4**	**Main Effect Timing**
Preplant	2709 C	3229 Bc	3430 B	3474 B	3211B
Side-dress	3158 B	3993 A	3930 A	4503 A	3896 A
Main Effect Rate	2934 B	3611 A	3680 A	3989 A	

Yield also tended to be higher when N was applied sidedress than preplant, with the difference in main effects varying from a low of 224 kg ha^{-1} at Manhattan in 2007, to a high of 685 kg ha^{-1} at Ottawa in 2008. This is somewhat surprising as N loss was generally not considered to be a major problem at any of the locations. One possible explanation could be more efficient use of water resulting from delayed N application and reduced vegetative growth.

Potential changes to the KSU sorghum N recommendations.

Making soil test based nitrogen recommendations for sorghum can be challenging. The current K-State nitrogen recommendation for sorghum is given as:

N Rec kg/ha = (Yield Goal Mg/ha × 28.6) – (% SOM × 22.4) – Profile N – Manure N – Other N Adjustments +/- Previous Crop 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 sorghum. Often, when growing sorghum, particularly in the drier regions of the state, 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 precipitation does occur. In addition, our ability to recover applied N may be lower at low yield levels than at higher yield levels, since at low yield levels water is the primary limiting factor, and nitrate N moves to the plant by diffusion (Barber, 1995).

The relationships given in Figures 2.2 and 2.3 show that as yield level increases, the Harvest Index, or the amount of grain produced per given amount of biomass increases expressed as a fraction of total dry matter produced increases (Figure 2.2); and that the amount of N needed per Mg ha^{-1} grain decreases as Harvest Index increases (Figure 2.3).

Figure 2.2 Relationship between Harvest Index and Grain Yield

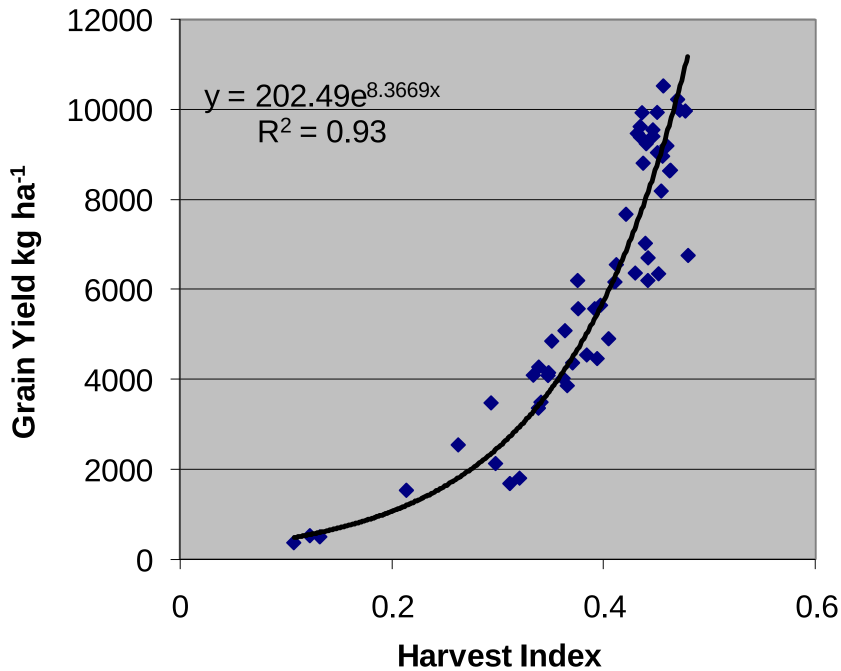
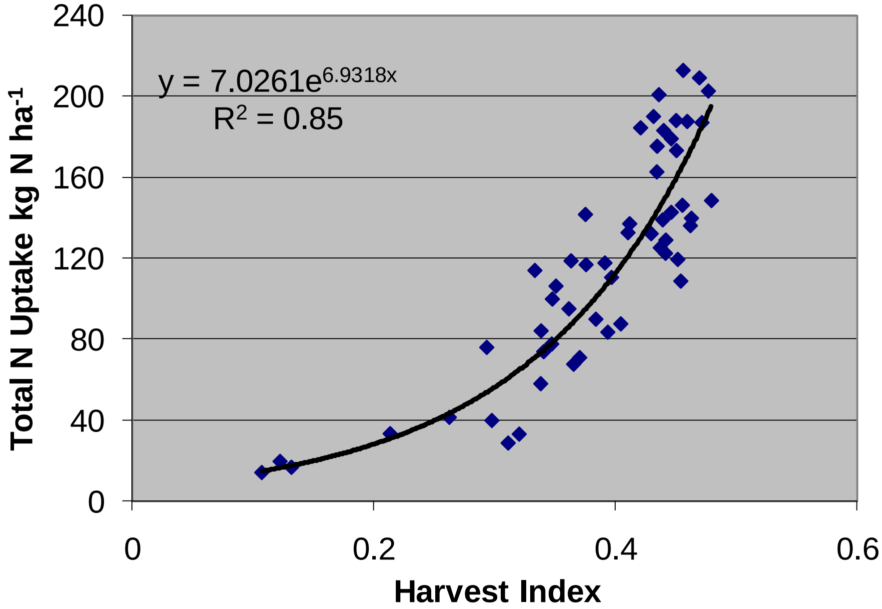


Figure 2.3 Relationship between Harvest Index and Total N Uptake



Thus it appears that a crucial component of the K-State nitrogen recommendation, a term to reflect these two relationships, is missing. This component should be considered as an efficiency term similar to N utilization efficiency as described by Moll et al (1982), or how much nitrogen must be taken up and utilized by the plant at a given yield level. The relationship that should hold true is that as yield potential goes up, so should N use efficiency. Since N is moved into the plant primarily by mass flow, this means that if we have adequate water in the soil profile, and adequate N present, then we can expect higher yields, than if either one of these were limiting. By using the equations representing the relationships shown in Figures 2.2 and 2.3 we can solve for harvest index given a certain yield level and then solve for the amount of N uptake that would occur given that harvest index. Solving for multiple yield levels creates the N use efficiency factors given at different yield levels for side-dress N applications given in Table 2.6.

Table 2.6 Table of Expected Yield, Harvest Index, N uptake, kg N/ 1000 kg grain, and proposed side-dress efficiency factors.

Expected Yield	Harvest Index	N Uptake kg N ha^{-1}	Kg N 1000 kg $grain^{-1}$	Side-dress Efficiency
2490	0.3	56	22.6	0.38
5030	0.384	101	20.0	0.47
7520	0.432	140	18.7	0.57
10,080	0.467	179	17.8	0.66

Using these relationships to modify the existing recommendations, a comparison of the current soil based K-State nitrogen recommendation and a modified soil based K-State nitrogen recommendation which considers N uptake and utilization efficiencies can be calculated (Table 2.7). This table was generated using the same yield goals for each of the sites in the N response experiments, the sites used for the studies and the multiple coefficients and side-dress efficiency factors from Table 2.6. If we use Manhattan 2007 as an example, our yield goal is 7530 kg ha^{-1}, then the N recommendation would be 7530 kg ha^{-1}*18.7 kg N / 1000 kg grain – the soil components (profile NO_3 + o.m. contribution + previous crop adjustment) and divided by the efficiency factor of .57 we would get a N recommendation of 120 kg N ha^{-1}.

Table 2.7 Current and Modified Soil Test Based Fertilizer Recommendations for All Sites Used in the N Response Experiments, in 2006, 2007 and 2008

Location	Year	Yield Goal kg ha^{-1}	Observed Yield kg ha^{-1}	Current KSU N Rec. Kg N ha^{-1}	Modified KSU N. Rec. Kg N ha^{-1}	Observed N Response kg N ha^{-1}	Current minus Observed Difference kg n ha^{-1}	Modified vs. Observed Difference kg N ha^{-1}
Belleville	2006	6270	6020	45	0	0	45	0
Manhattan	2006	8780	9720	86	22	37	49	-15
Partridge	2006	5020	2010	45	0	62	-17	-62
Tribune	2006	5020	8030	37	0	17	20	-17
Manhattan	2007	7530	6840	143	120	118	25	2
Partridge	2007	5020	4390	45	4	22	23	-18
Tribune	2007	5020	4960	59	0	0	59	0
Manhattan	2008	8780	8030	112	66	50	62	16
Ottawa	2008	5020	4010	73	65	67	6	-2
Partridge	2008	5020	7720	46	7	17	29	-10
	Avg.	6150	6170	69	28	39	30	-11

While still not perfect, these modified recommendations are much closer to the actual N response observed than the current recommendations. The current KSU N recommendation for sorghum overestimate N needs an average of 30 kg ha^{-1}, while using the modified recommendations underestimate N needs on average of 11 kg ha^{-1}. A further evaluation of efficiency factors utilizing many additional site years of data and different application products and methods should be done to help determine which efficiency factors will be appropriate. It is important that the KSU recommendations not underestimate N needs for farmers to develop trust and use a modified system.

Conclusions

A series of N management experiments were conducted to establish some basic parameters for efficient side dressing of N fertilizers for sorghum. Some of the key conclusions from these studies were:

1. Nitrogen fertilizer can be successfully applied to sorghum using standard available ground application equipment during a window form approximately 30 to 45 days after planting. Delaying application beyond 45 days increases risk of stalk breakage. This could be overcome at some cost by using high clearance sprayers and surface applying N.
2. As has been demonstrated in corn, coulter injecting N UAN solutions in high residue sorghum production systems is more effective than surface broadcasting UAN. In addition, plants will have quicker access to the applied N, especially when an extended dry period follows application. Surface banding of UAN was generally found to be intermediate in performance to coulter banding and surface broadcasting.
3. While a number of products are currently marketed as additives to enhance the performance of surface applied UAN, the two tested in this research, thiosulfate compounds and Nutrisphere N did not enhance the performance of surface banded UAN. To be fair, the NutriSphere would not have been expected to perform since a significant rainfall event incorporated the surface applied N and negated any potential for the product to enhance performance.

The current KSU sorghum N recommendations were find to overestimate N needs by an average of 30 kg N ha^{-1}, in a series of ten N response studies conducted across Kansas. One issue with the recommendations is a single constant relating the N need per unit of yield, regardless of yield level or expected N use efficiency. By developing relationships to show how N uptake per unit of yield varied with yield level, and how N utilization efficiency varied with yield level, a modified N recommendation was developed. This modified system underestimated N need by approximately 11 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 that delaying the N application decision until later in the growing season to have a better idea of the true yield potential that year, could be significant improvements over the current system used.

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CHAPTER 3 - Using Active Optical Sensors to Manage N Fertilization of Sorghum in Kansas

Abstract

Research in the Central Plains region has shown grain sorghum (*Sorghum bicolor* L. Moench) to be more tolerant of water-stress than corn (*Zea mays* L.) (Kreig, 1988). Sorghum is commonly grown in the region in rotation with winter wheat (*Triticum aestivum* L.) and soybeans (*Glycine max*) in areas and soils where corn does not perform well due to regular drought stress. Sorghum yields vary widely from year to year due to variations in temperature and rainfall (USDA-NASS, 2009) making traditional pre-plant, yield goal based, N recommendations a challenge. The objective of this study was to determine if a sensor based mid-season N recommendation system utilizing a high N reference and sensor based estimates of yield potential and soil N supply, as indicated by plant N content would be more effective.

Thirteen field N response experiments were conducted across Kansas in 2006 to 2008. Specific treatments used consisted of combinations of pre-plant and side-dress N rates supplying a total of 0-168 kg N ha^{-1}. Pre-plant N treatments were applied immediately prior to planting at all locations. Side-dress N treatments were applied 30-40 days after planting. All nitrogen in these studies was applied using either broadcast urea or coulter banded UAN solutions.

Grain yields ranged from 630 to 10,600 kg ha^{-1}. Grain sorghum yields were responsive to applied N at most sites. Non-responsiveness of grain sorghum yields at the remaining sites were mainly due to high levels of soil profile residual nitrate-N (> 73 kg N ha^{-1}), and water stress conditions during the growing season. The sensor based mid-season N recommendation system developed provides a much closer fit to observed N response than the traditional pre-plant N recommendation system.

Introduction

Nitrogen use efficiency (NUE), defined as the percentage of applied N recovered or utilized by the target crop in the United States is estimated to be only 33% for grain production, and about 45% for forage production (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 and sorghum yield would decrease by 41 and 19%, respectively, 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, soil denitrification, surface runoff, volatilization, and leaching (Raun and Johnson, 1999). With the exception of N denitrified to N_2, these pathways 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. To increase NUE in crops several concepts can be used. These include using split or delayed applications of fertilizer N to improve synchrony, and the use of soil testing, or plant analysis to better estimate soil N supply and crop needs.

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 hand held optical sensor (NTech Industries, Ukiah, CA), and the Crop Circle ACS-210 hand held optical sensor (Holland Scientific, Lincoln, NB).

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 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, using 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 is 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 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. 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 a yield potential estimate from early-season sensor data generated from 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% 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 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).

In sorghum, work has showed that grain yield and NDVI were best correlated at growth stage 3. When INSEY was used to normalize readings at other growth stages it did not improve the correlation and NDVI did not correlate as well with N concentration in the grain at harvest (Moges et al., 2006).

The specific objective of this study was to assess the potential for optical sensing systems to estimate mid-season N needs for Grain Sorghum production, and to determine if a sensor based system was more accurate in predicting N response than the traditional yield goal soil test based pre-plant systems.

Materials and Methods

A series of field experiments were conducted from 2005 through 2008 to evaluate the use of optical sensors and the SPAD meter for making in-season N fertilizer recommendations for sorghum. At the Kansas State University Agronomy North Farm (390 08 02” N lat.; 96o37 09” W long.), a long-term continuous sorghum (LTS) site was conducted in 2005, 2006, and 2007 on a Smolan silt loam soil. This study was initiated in 1981 to examine the relative N use efficiency of various fertilizer sources, additives, and methods of application in conventional and no-till sorghum production. Key information on production practices used in this study is summarized in Table 3.1.

Table 3.1 Key cultural practices used in the Long-Term Continuous Sorghum Experiement.

Year	Planting Date	Hybrid	Seeding Rate	Previous crop
2005	June 17	Crop Land	115,000	Sorghum
2006	May 23	P84G62	115,000	Sorghum
2006	May 20	DK 42-20	115,000	Sorghum

From 1981 through 2004, four N rates of 0, 33, 67, and 134 kg N ha^{-1} were used each year, creating high, medium, and low responsive N environments due to differences in mineralizable N, in both no-till and conventional tillage systems. Beginning in 2005 N fertilizer rates of 0, 67, and 134 kg N ha^{-1} were applied within each N response environment and tillage system.

The experimental design used was a split block with three replications, with tillage treatments serving as the main plots, and N environments and N treatments randomized within each main plot as subplots. Soil samples to a depth of 60 cm were taken each spring prior to planting to estimate the residual nitrate available in the soil. NDVI readings were taken twice a week until half-bloom once a week afterwards using a hand-held GreenSeeker sensor in 2005, 2006 and 2007. Similar readings were taken using a Crop Circle hand held sensor in 2007 only. Spad meter readings were taken in 2006 and 2007 at GS-3 and again at flowering.

Flag leaves were collected from each plot and analyzed for total N as an indication of N sufficiency. Total N uptake was estimated by collecting the total above ground vegetation (less the head) in six meters of row prior to harvest, weighing the total mass of vegetation collected wet, chopping the vegetation 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, and grinding, for total N. Total N uptake was calculated as the total N content in vegetation and grain.

Grain yield was estimated by harvesting six meters of the two middle rows of each plot by hand in 2005, and 2006, and machine harvesting the middle two rows of the plots in 2007. Yield was adjusted to 130 g kg^{-1} grain moisture.

In addition to the experiment described above, a large N response study was conducted a total of ten times during 2006, 2007 and 2008 at several locations in Kansas. The purpose of these studies was to determine the variability in N response in sorghum common to Kansas across years and environments and determine if an active sensor based, side-dress application N recommendation would provide a more accurate N recommendation than the current pre-plant based system. Four studies were conducted in 2006, three in 2007 and three in 2008. Each consisted of a series of N rates applied pre-plant, side-dress, or in combination. In 2006 N rates used were 0, 34, 67, 101, 135 and 168 kg N ha^{-1}. These experiments were conducted at the KSU Agronomy Farm on an Ivan/Kennebec silt loam; the NC Kansas Experiment Field near Belleville, Ks (39^{0}48 53”N 97^{0}39 29”W) on a Crete silt loam soil; SCK Kansas Experiment Field Partridge Unit (37^{0}58’ 02”N 98^{0}05’ 31”W) on a Funmar/Tabler loam soil; and the Western Kansas Research Center at Tribune (38^{0}28’19” N, 101^{0}45’19”W) on a Richfield silt loam.

In 2007 and 2008 only the 0, 34, 67, 101 and 135 kg N ha^{-1} rates were used. The studies in 2007 were conducted at The Agronomy Farm on a Smolan silt loam, Partridge and Tribune on Funmar/Tabler and Richfield soils respectively. In 2008 the studies were conducted at the Agronomy Farm, Partridge and the ECK Experiment Field near Ottawa, KS (38^{0}32’16” N, 95^{0}15’15”W) on a Woodson silt loam soil. Significant dates and cultural practices used are summarized in Table 3.2. Plots were arranged in the field using a RCB design with four replications at all locations except Belleville, where space limited the study to three replications.

Each block of each experiment was soil sampled to a depth of 15 cm for pH, available phosphorus (P), exchangeable potassium (K), soil organic matter (SOM), and to a depth of 60 cm for profile nitrate N. Sampling was done using a hand probe, and samples consisted of 12 to 15 individual cores composited to form an individual sample. Analysis was done 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).

Flag leaves were collected from each plot and analyzed for total N as an indication of N sufficiency. Total N uptake was estimated by collecting the total above ground vegetation in six meters of row prior to harvest, chopping the vegetation in a lawn chipper/shredder, 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 this by the total amount of biomass produced (stover + grain). Total N uptake was only measured at the Manhattan sites, and the Tribune 2007. All plant analysis was done by the KSU Soil Testing Lab.

Table 3.2 Key cultural practices used at each of the location in the N response studies.

Location	Year	Planting Date	Hybrid	Seeding Rate	Previous crop	Sidedress date
Agronomy	2006	May 19	P84G62	150,000	Soybean	June 19
Partridge	2006	May 31	P85G46	115,000	Sorghum	July 7
Tribune	2006	June 4	P86G08	75,000	Fallow	July 13
Belleville	2006	May 23	P85G46	127,000	Sorghum	June 20
Agronomy	2007	May 23	DK 42-20	127,000	Wheat	June 27
Partridge	2007	June 13	P85G46	115,000	Wheat	July 25
Tribune	2007	June 1	P86G08	75,000	Wheat	July 10
Agronomy	2008	May 20	DK 54-00	127,000	Wheat	June 26
Partridge	2008	June 5	P85G46	115,000	Wheat	July 15
Ottawa	2008	May 20	P84G62	127,000	Soybeans	July 10

Grain yield was determined at the Agronomy Farm in 2006 and 2008 by hand harvesting five m of the two middle rows of each plot. At all other locations and years yield was determined by harvesting 12 m of the middle two rows of each plot using a plot combine. Yields were adjusted to standard 130 g kg^{-1} moisture content.

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 2006, 2007 and 2008, and Crop Circle amber sensor 2007 and 2008 only. The Crop Circle sensor (ACS-210, Holland Scientific) 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) 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. A response index (RI_{NDVI}) was calculated by taking the NDVI of the highest pre-plant N rate at GS-3 and dividing this by the NDVI of the other treatments. Calculation of response index grain yield (RI_{GY}) 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 were below the optimum N response. In season estimate of yield (INSEY) was determined by taking NDVI divided by the days after planting to sensing.

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. The SPAD meter readings were averaged by plot. A response index (RI_{SPAD}) was calculated by taking the SPAD reading of the highest pre-plant N rate at GS-3 and dividing this by the SPAD reading of the lower N treatments. Calculation of response index grain yield (RI_{GY}) 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 lower N treatments.

Optimum N rate at each site was determined by running 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 an alpha of 0.10.

Results and Discussion

Predicting crop yield and N response from sensor data

2005 Preliminary Results

In 2005, a Long Term Sorghum N response study was used to start collecting sensor data to allow the prediction of crop yield at midseason as a means of establishing overall N need of a sorghum crop, and the relative N supply or responsiveness of a site when compared to a well fertilized reference strip. At the Manhattan LTS site, NDVI measurements were collected using a GreenSeeker hand held sensor between 21 and 49 days after planting and these values were then correlated with final grain yield, using an exponential equation. The relationships found between NDVI at each individual sampling time, and resulting grain yield at harvest resulting from the combination of N mineralized and applied fertilizer N in this experiment are presented in Figures 3.1 through 3.5. As can be clearly seen from these figures, the correlation between NDVI and yield improves as the plant develops, from an R^2 of 0.20 at 21 days to an R^2 of 0.67 at 35 days after planting, then remains relatively constant for the next two weeks.

Figure 3.1 Relationship of NDVI at 21 Days after Planting and Grain Yield in 2005

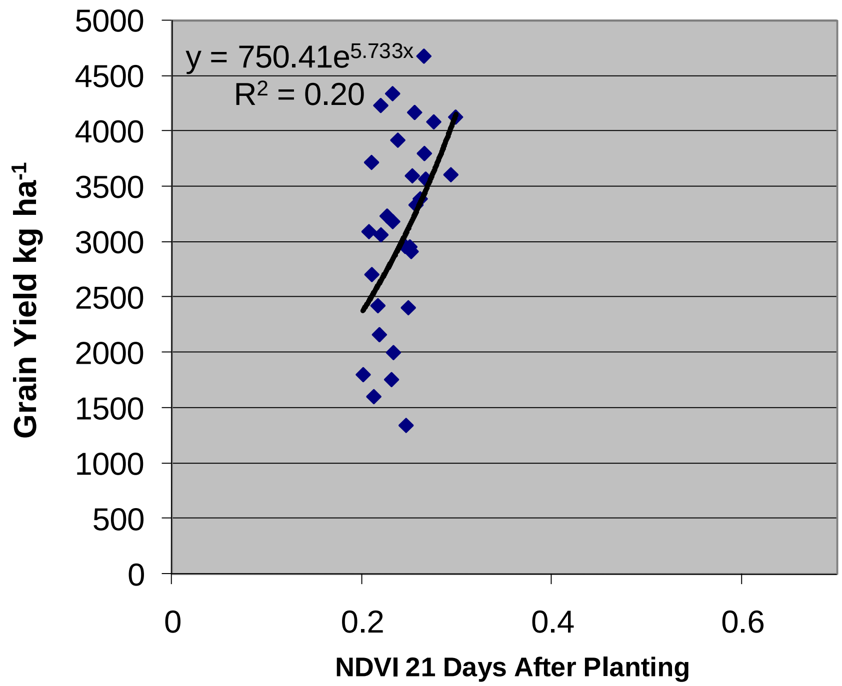


Figure 3.2 Relationship of NDVI at 28 Days after Planting and Grain Yield in 2005

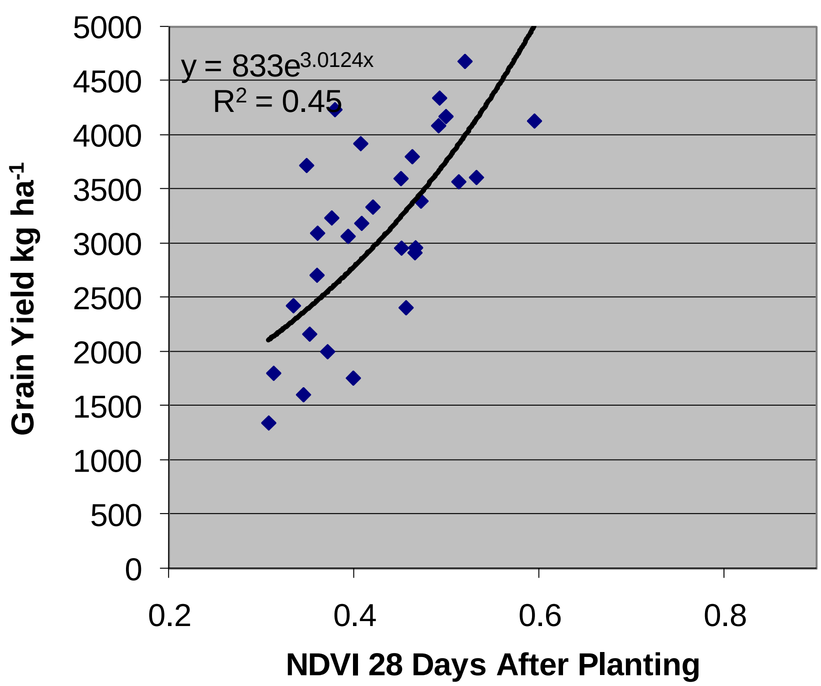


Figure 3.3 Relationship of NDVI at 35 Days after Planting and Grain Yield in 2005

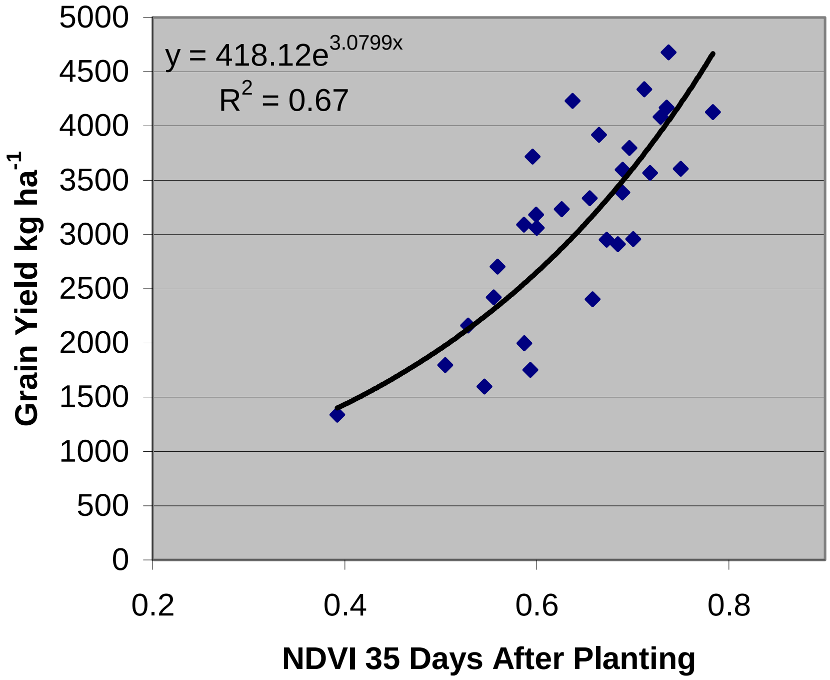


Figure 3.4 Relationship of NDVI at 41 Days after Planting and Grain Yield in 2005

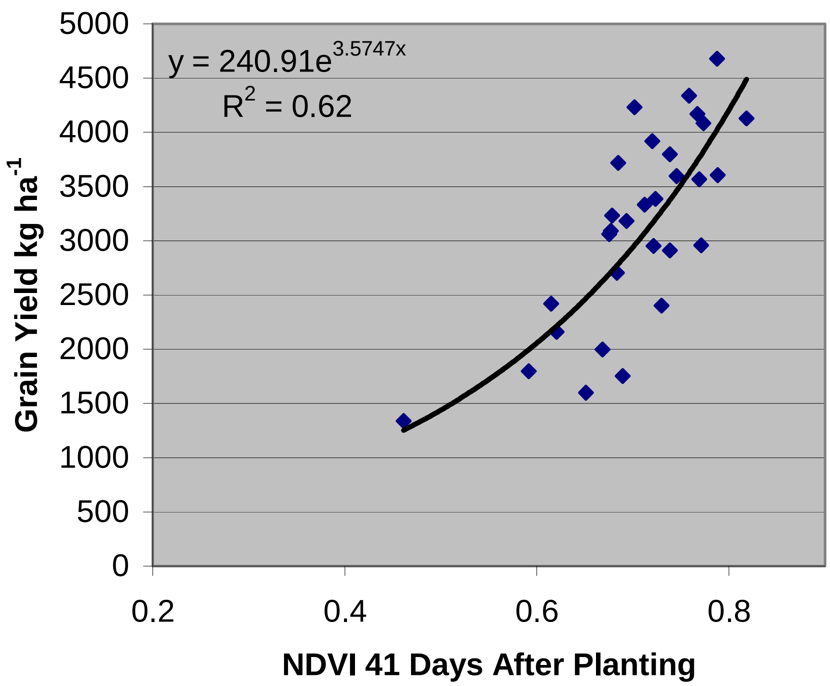
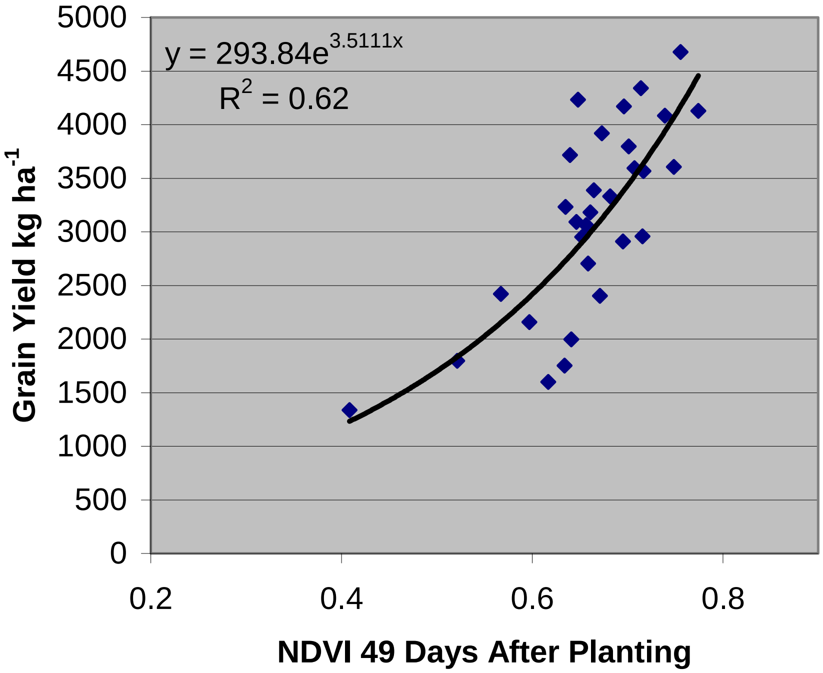


Figure 3.5 Relationship of NDVI at 49 Days after Planting and Grain Yield in 2005



This would indicate a useful yield prediction for the purpose of predicting overall N need of the crop during the two week window of 35 to 49 days after planting. To actually determine which sampling time and resulting yield prediction model to use to establish yield goal for N recommendations, a number of other factors such as the ability to successfully side-dress using available equipment (Figure 2.1), changes in NDVI with time (Figure 3.6), changes in the variance of the NDVI measurement that is encountered (Figure 3.7), and the ability of the sensor to detect differences in greenness resulting from differences in N supply as measured by the response index, RI_{ndvi} (Figure 3.8) should all be considered. When selecting a time to make sensor measurements for the purpose of N recommendations, it was very important to choose a specific period when NDVI readings have reached some base level indicative of near canopy cover, the variance of the measurement is minimal, the native soil supply of N is becoming exhausted and unfertilized plants are beginning to exhibit N stress as compared to well fertilized reference strips and a response index can be calculated which correlates with final yield response, and a time in which side-dressing sorghum is possible economically and without injury to the crop..

Figure 3.6 Effect of Days from Planting to Sensing on NDVI

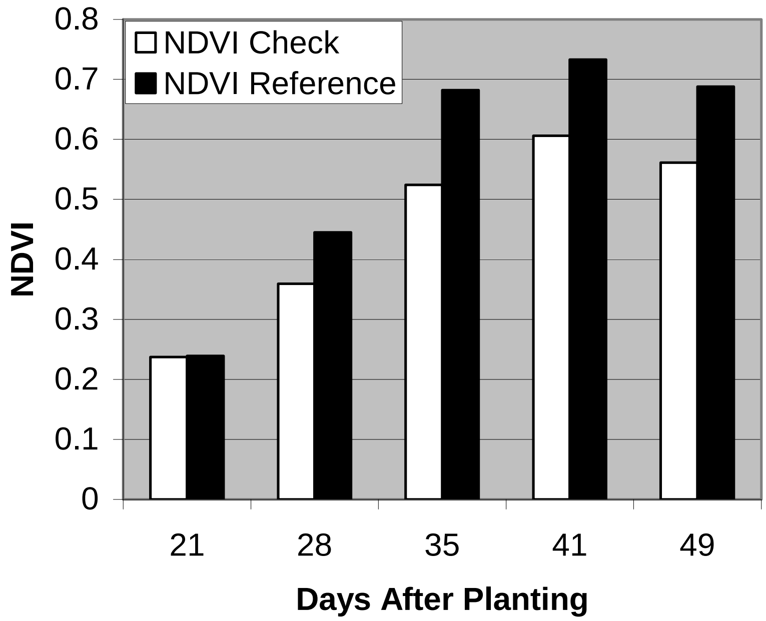


Figure 3.7 Effect of Days from Planting to Sensing on CV of NDVI Measurements

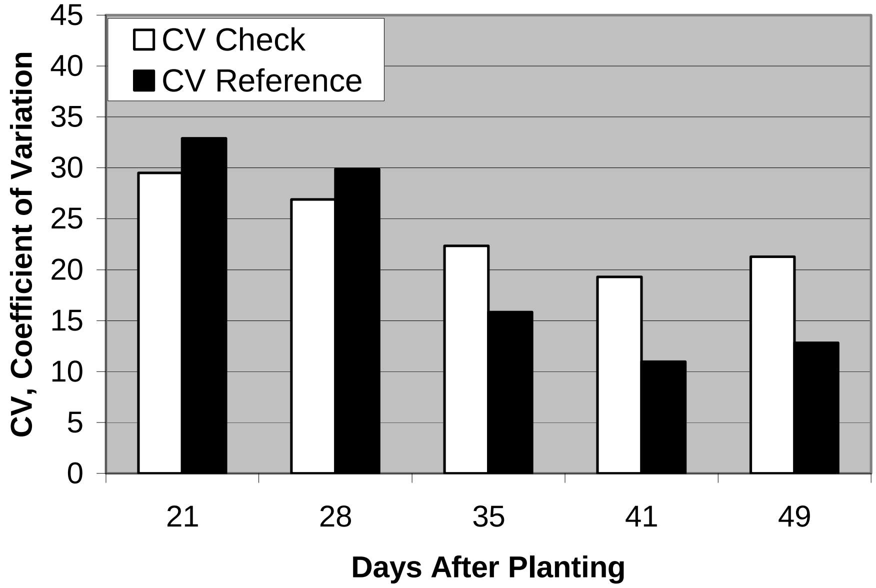
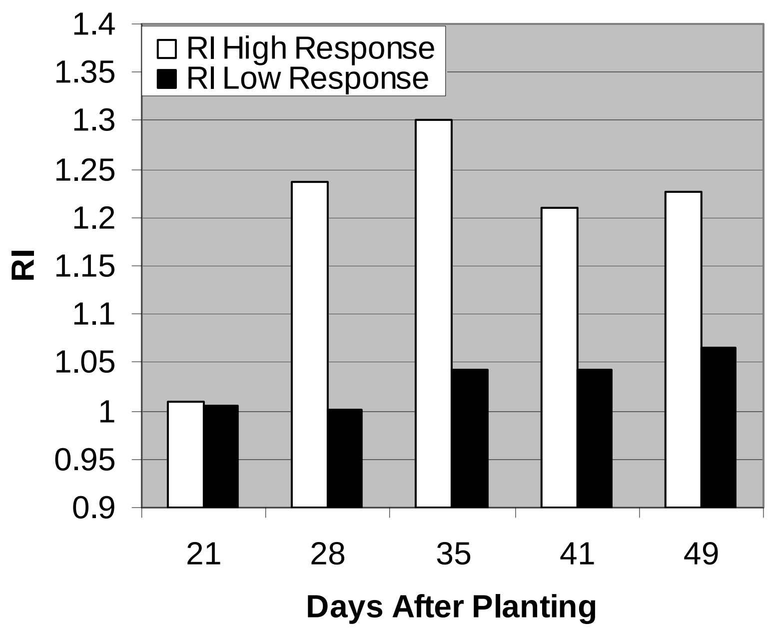


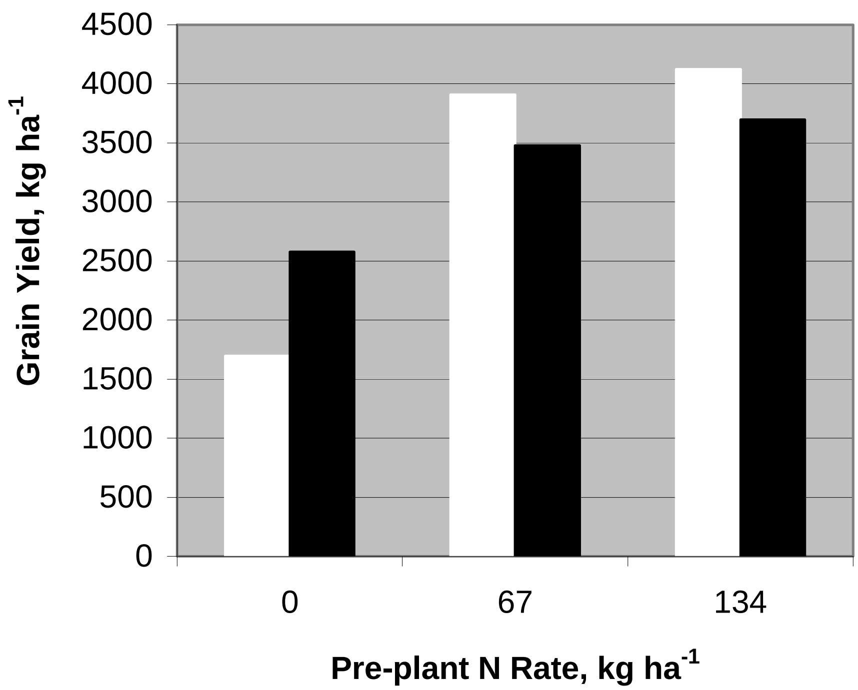
Figure 3.8 Effect of Days from Planting to Sensing on Response Index in 2005



The data presented in the figures above, and Figure 2.1 in Chapter Two showing that side-dressing is feasible during the 30 to 40 day time period, but not at 50 days, suggests that the GreenSeeker sensor has potential for estimating mid-season grain yields for sorghum, and relative greenness as a measure of N need, in the period from 28 to 42 days after planting, with best results likely obtained 35 to 41 days after planting. NDVI, variance, and response index all reached stable values at 35-41 days after planting. This would suggest that the sensor probably has the most potential at this time, which corresponds to the GS-3 growth stage, or approximately the 8 leaf growth stage. The window of opportunity however, is rather small, so expanding the window to allow more flexibility is possible, though variability may increase, and sensitivity may be reduced.

When looking to expand the sensing period an important aspect to consider is how soon we can we predict an N response. The relationship expressed in Figure 3.8, suggests that in a highly N responsive site we can predict an N response as early as 28 days after planting, allowing a producer to side-dress as early as late GS-2, or the 6 leaf stage. However, if their particular site is only marginally responsive, 35 days after planting may be the earliest sensors can detect a large enough difference in greenness to predict an N response. Figure 3.9 shows the yield response obtained in 2005 on the LTS plots to applied nitrogen fertilizer on plots with moderate and low N mineralization potential and resulting high and marginal response indices.

Figure 3.9 Grain Yield Response to Applied N in areas of Moderate or High Response Indices



2006 Results

The research was expanded to additional sites in 2006, in hopes of obtaining a range of yield potentials and N response conditions. At Manhattan and Tribune, growing conditions were favorable throughout the season, resulting in very good yields, while at Belleville growing conditions were slightly less than favorable, and at Partridge growing conditions were very poor resulting in yields slightly below average and very low, respectively. Based on the preliminary results from the Manhattan LTS 2005 site, the focus in 2006 was on the period from 28 to 42 days after planting and seeing how NDVI measurements related to final grain yield to develop a yield prediction equation and on how quickly the sensor detected differences in greenness as a prediction of N fertilizer need.

At the Belleville and Tribune sites, little or no response to applied N was observed, and NDVI readings value and crop yields were only influenced by spatial variability, and were thus fairly consistent across treatments. At the Hutchinson site, lack of in-season precipitation severely limited yields, however a significant N response was observed. At the Manhattan site, very high yields and a small N response was observed. At the Manhattan LTS site, significant nitrogen responses were observed, and yields were similar to previous years. To account for different sensing times among sites, In Season Estimates of Yield, INSEY (NDVI/Days After Planting) was used to develop a yield potential equation. Data from the no N control plots and those treatments which received pre-plant N only, were used to develop yield potential equations. No side-dress or split N treatments were used. The 2006 equation was developed using an exponential equation to describe the data, sensing data collected at the GS-3 growth stage, adjusted for days after planting using INSEY. The equation developed had R^2 value of 0.92 (Figure 3.10). In addition, the relationship between response index (RI_{NDVI}) at GS-3 and a response index grain yield (RI_{GY}) at harvest was very good, with a R^2 value of 0.93 indicating the differences in greenness present at sensing were strongly related to N response (Figure 3.11).

Figure 3.10 Relationship of INSEY at 35-40 Days after Planting and Grain Yield in 2006

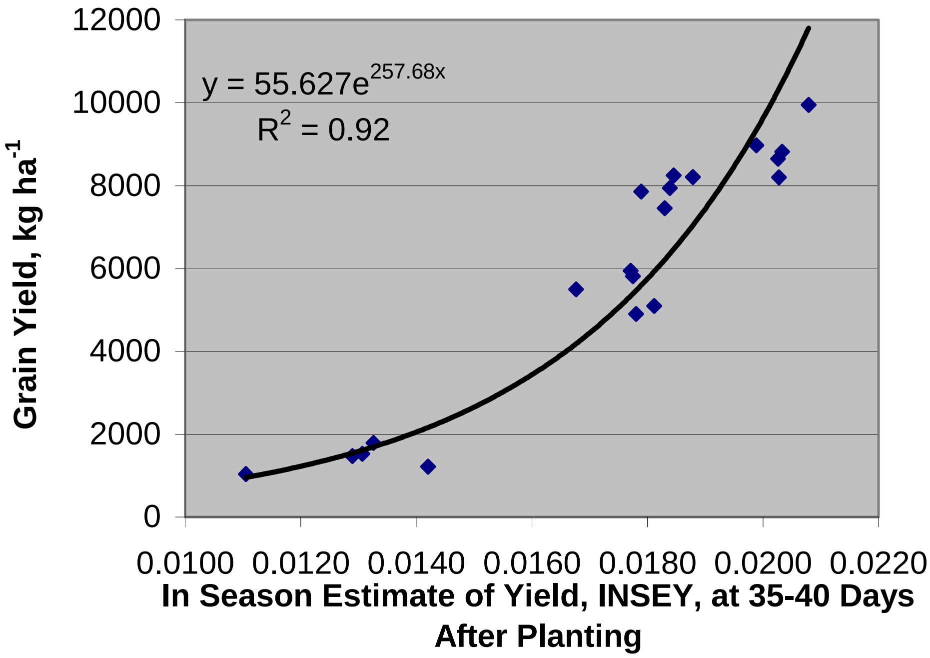
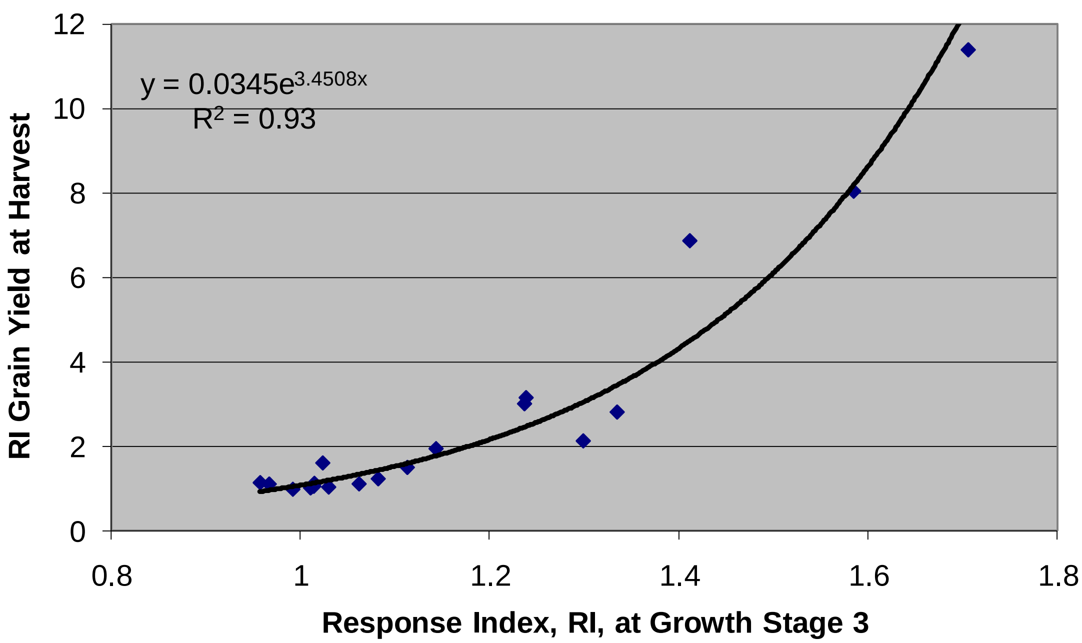


Figure 3.11 Relationship of RI_{NDVI} at GS-3 and RI_{GY} in 2006



2007 Results

At Manhattan and Partridge initial growing conditions were excellent with significant precipitation received during the months of May and June. This resulted in very good early season growth. However, at Partridge, very little rainfall was received in the months of July and August limiting final yield. Yields were good with only a marginal response to N observed. At Manhattan, the rainfall was more consistent throughout the growing season, which allowed for good yields. In addition, a significant response to N was observed. At Tribune, the summer was very dry, early with one significant rainfall event in August, which resulted in higher than expected yields. The contrasts between early and late season growing conditions at two of the three sites resulted in poor predictions of final grain yield from GS-3 sensor data in 2007, with a resulting R^2 of just 0.25 (Figure 3.12). When pooled with the 2005 and 2006 data, the yield prediction equation using GS-3 NDVI and final yield had a R^2 value of 0.74, when INSEY was used at the GS-3 growth stage, and an exponential curve was used to fit the data (Figure 3.13). This was a much lower fit than that obtained from the 2006 data, however, it still provides a useful relationship. The response index (RI_{NDVI}) at GS-3 and response index grain yield (RI_{GY}) relationship in 2007 was still quite good (see figure 3.14). When this data was added to the 2005 and 2006 data this relationship maintained its R^2 value of .93 (see figure 3.15). This indicates that while sensing at early vegetative growth stages may not always be able to provide good predictions of final yield, sensing at GS-3 can do an excellent job of predicting nitrogen responsiveness.

Figure 3.12 Relationship of INSEY at 35-40 Days after Planting and Yield in 2007

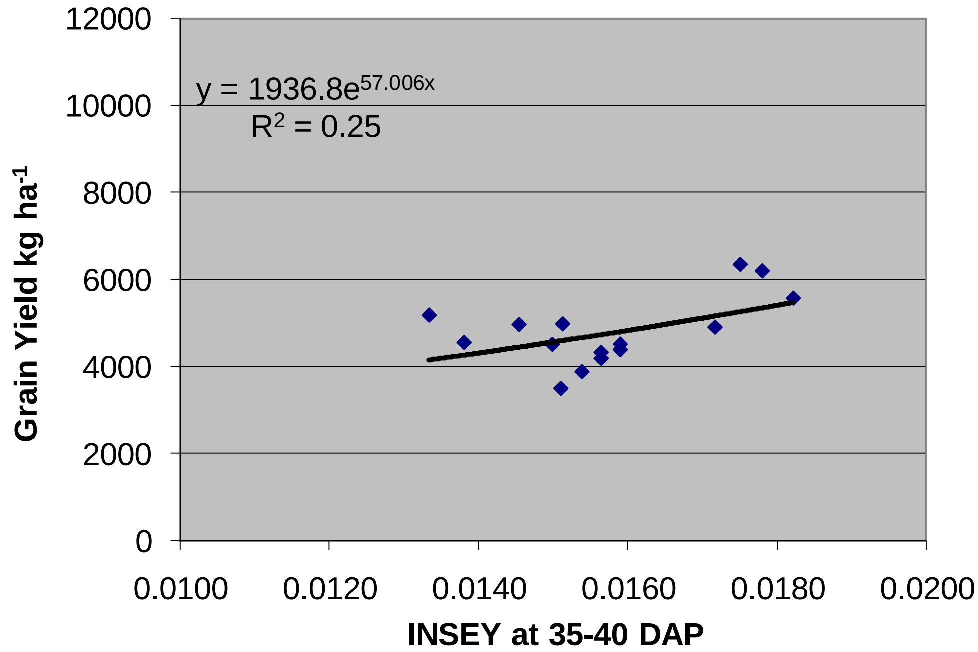


Figure 3.13 Relationship of INSEY at 35-40 Days after Planting and Grain Yield, 2006 and 2007

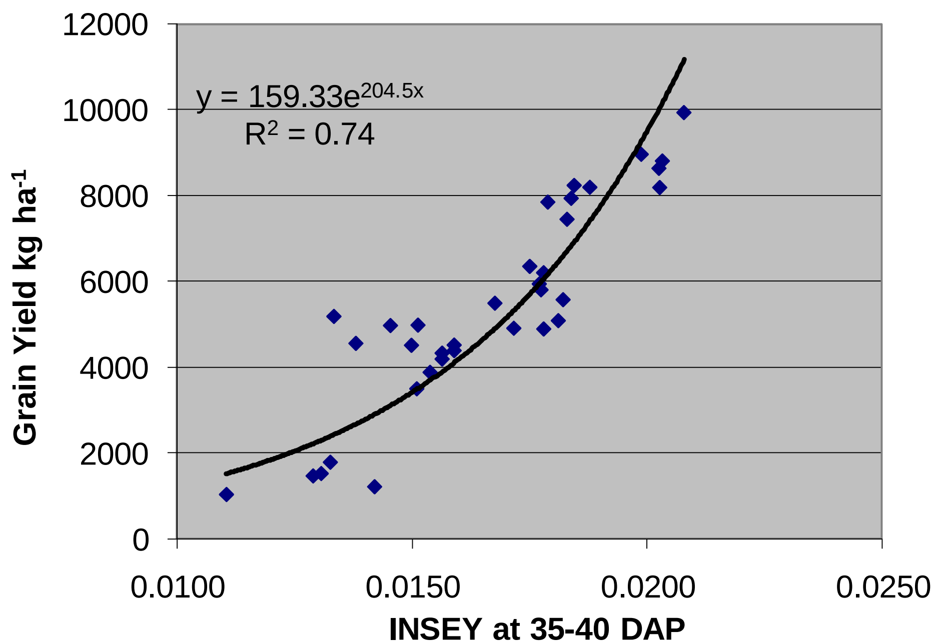


Figure 3.14 Relationship of RI_{NDVI} at GS-3 and RI_{GY} in 2007

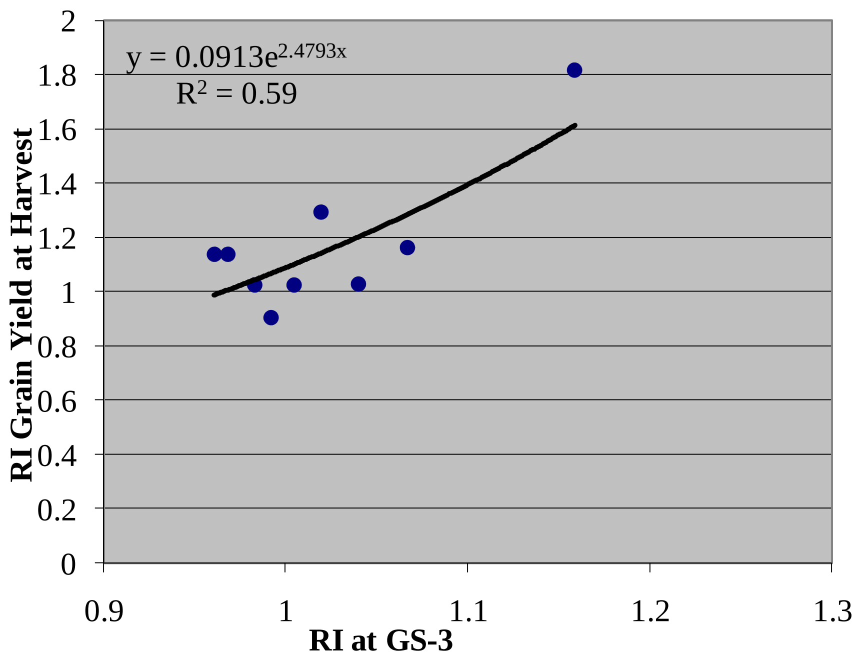
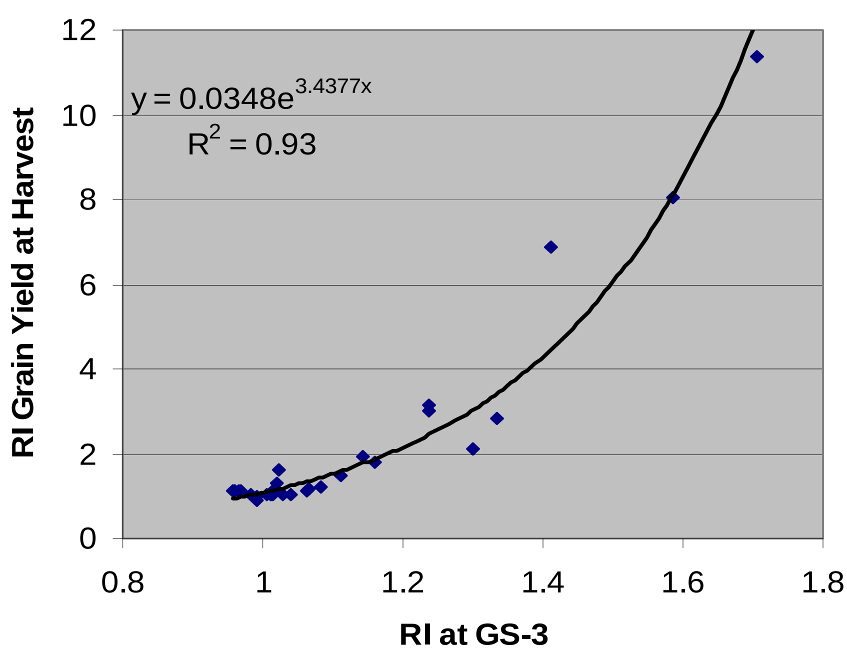


Figure 3.15 Relationship of RI_{NDVI} at GS-3 and RI_{GY}, 2006 and 2007



2008 Results

2008 was a typical Kansas growing season, with Manhattan, and Partridge having excellent growing conditions resulting in good yields, but Ottawa having fair to poor conditions resulting in below average yields for that site. The yield prediction equation for 2008 only produced an excellent relationship between NDVI adjusted for days after planting, INSEY, and grain yield (Figure 3.16). When the NDVI vs grain yield data from 2008 is added to the relationship established with data from 2005 through 2007, a combined yield prediction equation covering a range of conditions with good R^2 (0.76) is developed (Figure 3.17). Adding the 2008 Response Index NDVI vs. Response Index Grain Yield data to similar data from 2005 through 2007 produced an excellent combined relationship with an R^2 of 0.92 indicating the sensor provides a very good estimate of N responsiveness at GS-3 (Figure 3.18). Having established that active sensor technology can be used to predict both yield potential and N response as early as 30 to 40 days planting over a range of environments and growing conditions, it appears highly likely that sensor technology can be very useful in making N rate recommendations for side-dressing N on sorghum.

Figure 3.16 Relationship of NDVI at GS-3 in Sorghum (adjusted for Days from Planting to Sensing, INSEY) and Grain Yield, 2008

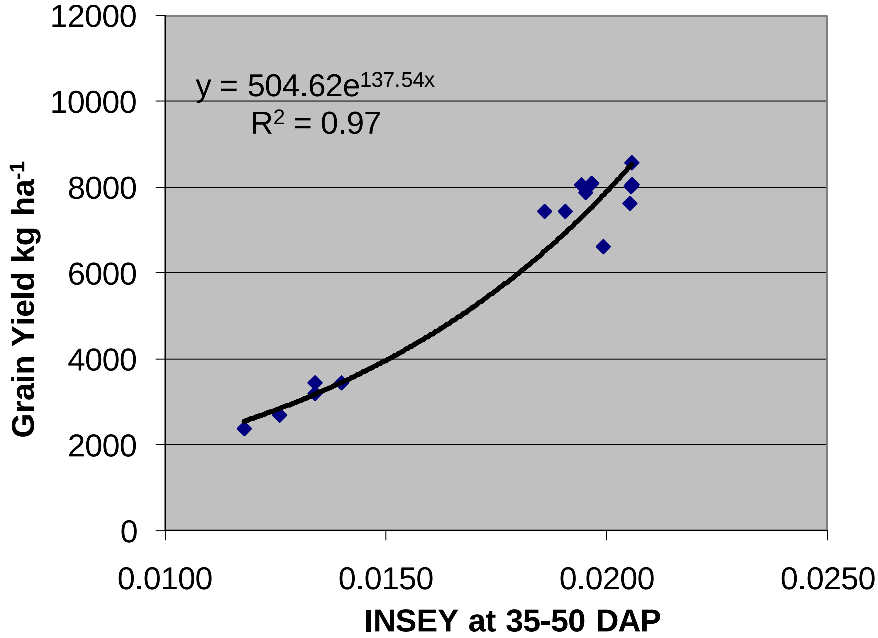


Figure 3.17 Relationship Between NDVI Adjusted for Days from Planting to Sensing INSEY Sensed at GS-3, and Grain Yield, 2005 through 2008

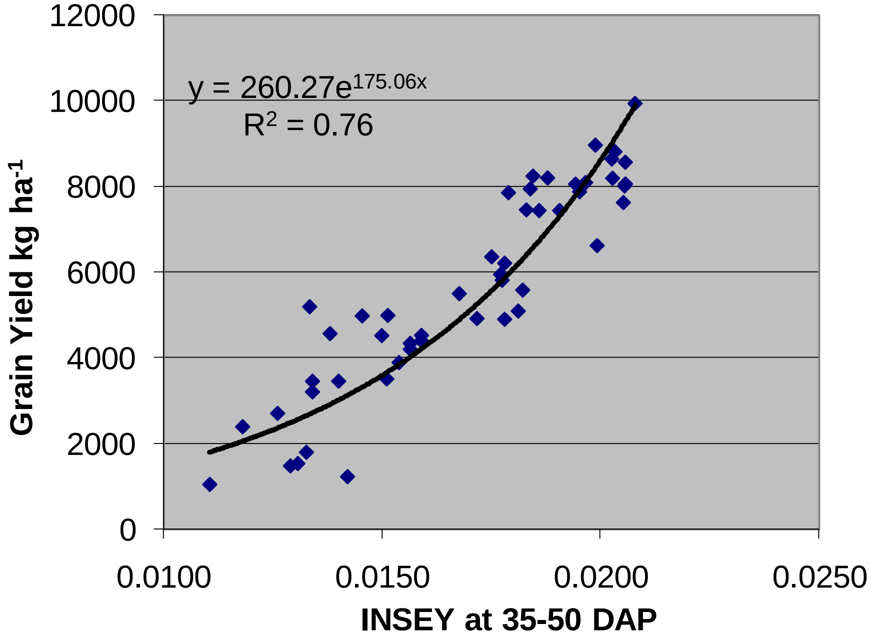
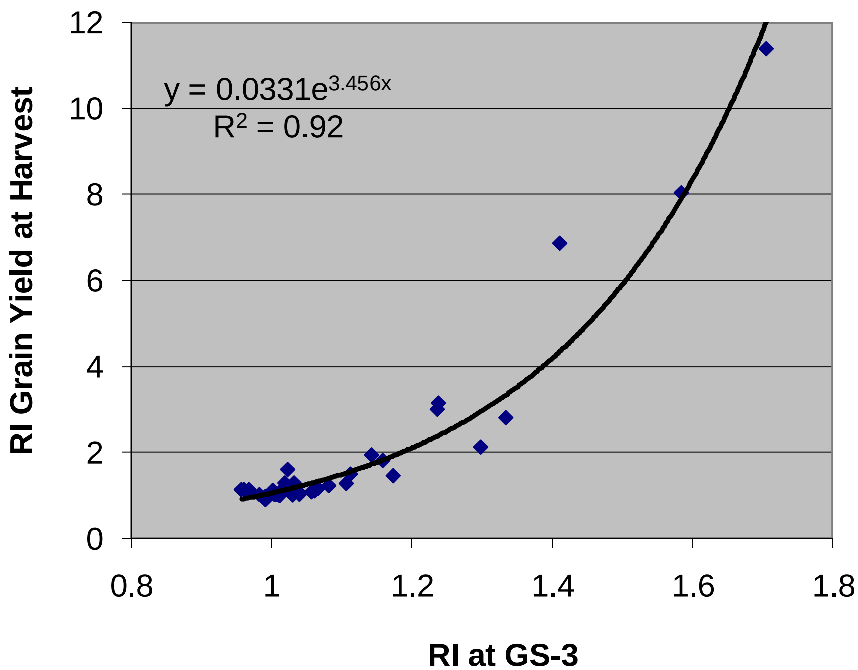


Figure 3.18 Relationship Between Response Index NDVI, RI_{NDVI} and Response Index Grain Yield, RI_{GY}, 2006 to 2008.



Using these relationships to make sensor based, mid-season N recommendations for Sorghum.

Utilizing both the sensor based INSEY yield prediction model (Figure 3.17) developed for the GS-3 growth stage and the N response model based on the relationship between the RI_{NDVI} measured at GS-3 and RIgy at harvest (Figure 3.18), one can calculate the delta yield or response in yield expected in a given field when fertilized at that time. For example, if the reference strip in a field has an NDVI of 0.65 at 35 days after planting, and the bulk field has a mean NDVI of 0.565, then the yield potential of the reference strip, which represents the yield potential of the field if fertilized, can be calculated by dividing 0.65 ($NDVI_{Reference}$) by 35 (time in days after planting that the field was sensed) to obtain $INSEY_{Reference}$. $INSEY_{Reference}$ would then be used in the equation:

Yield kg/ha = 260.27* exp (175.06*INSEY), the equation for the line describing the data in Figure 3.17.

Solving the equation gives the value 6,720 kg ha^{-1} which represents the yield potential of the reference strip, and potentially, the yield potential of the bulk field if adequately fertilized.

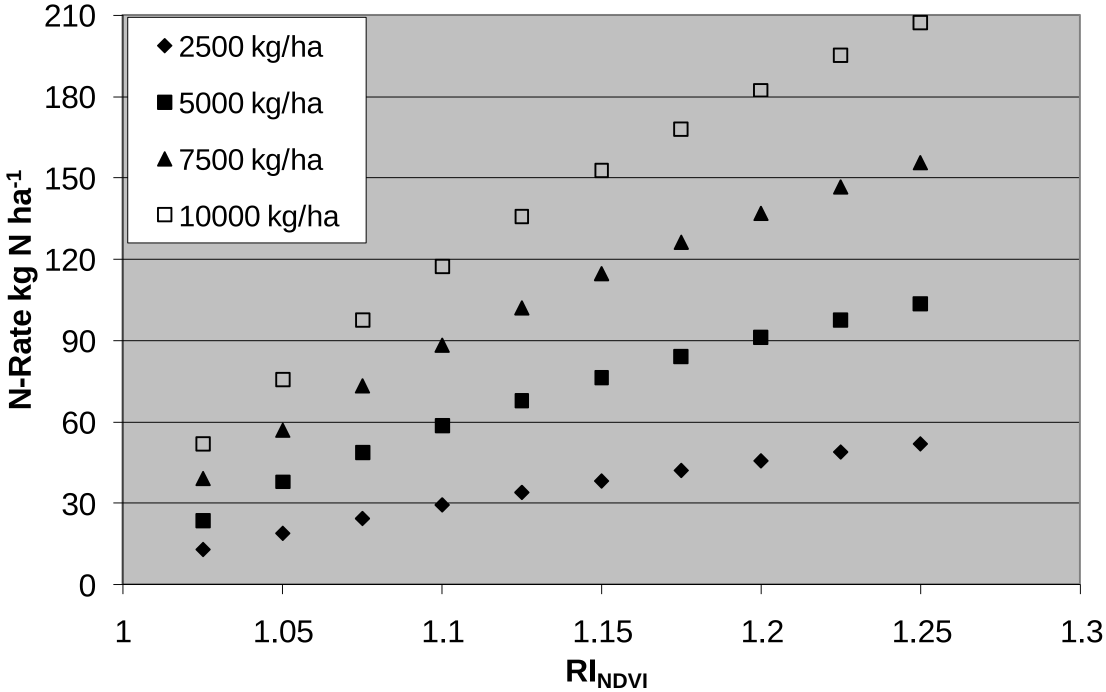
The response index, RI, in this example would be calculated by dividing the NDVI of the reference strip, 0.65, by 0.565, the NDVI of the bulk field. This calculation gives the RI_{NDVI} of the field, or1.15. This RI_{NDVI} would thus translate into a Response Index Grain Yield, RIgy, of 1.76 based on the relationships shown in Figure 3.18. This is done by solving for RIgy in the equation RIgy= .0331*exp (3.456*RI, or 1.15 in this example). By solving for the yield potential and the RIgy, delta yield, or the potential response to fertilizer, can be calculated by taking the yield potential of the reference strip – (the yield potential of the reference strip divided by the RIgy). In our example this would be 6,720 kg ha^{-1} – (6,720/1.76) which equals approximately 2,900 kg ha^{-1}. This would mean that we could a yield of 3,820 kg ha^{-1} with no fertilizer, a response or yield increase of 2,900 kg ha^{-1} if the field were side-dressed with N, resulting in a fertilized yield of 6, 720 kg ha^{-1}.

To calculate the approximate N rate to use for this example, one would take 2,900 kg ha^{-1} * the amount of N needed per 1,000 kg ha^{-1} divided by an efficiency factor. For example if it takes 20 kg N/ 1,000 kg sorghum yield and the normal N use efficiency is 50%, then the recommendation would be 116 kg N/ha (2,900*.02/.5).

Deciding the amount of N needed per 1,000 kg ha^{-1}of yield response, as well as the correct efficiency factor can be difficult. However, the previous chapter (Table 2.-5) provides a summary of potential coefficients and efficiency factors one could use. A further look at Figure 2.4 shows that harvest index peaks at about 0.45 at a yield level of approximately 6,000 kg ha^{-1}. When solving for the amount of N required per 1,000 kg/ha at a harvest index of 0.45 one would get approximately 19 kg N 1,000 kg sorghum yield^{-1}.

By using this value of 19 kg N 1,000 kg sorghum yield^{-1} and efficiency factor of 50% a simplified sensor based nitrogen recommendation system was developed to be used at the GS-3 growth stage. The following graph Figure 3.19, shows how the recommended N rate will change with changes in RI and yield potential. The calculation involved in preparing this graph included solving for delta yield, multiplying delta yield by the 19 kg N 1,000 kg grain^{-1} to get the total amount of N needed, then dividing this amount of N needed by the side-dress efficiency of 50% .

Figure 3.19 Proposed Sensor Based GS-3 N Recommendations for the GreenSeeker Sensor



This proposed N recommendation, when analyzed across experiments conducted in this study, did a very good job of predicting optimal N-response even when unadjusted for fertilizer efficiency (Table 3.3). Problems that were encountered when using these recommendations were that anytime we over estimated yield potential, we over estimated N needs. In addition, using the RI of treatments that had received starter N caused us to under estimate N needs in a very responsive environment. These problems are fairly simple to fix. For example, if the sensor predicts a yield potential higher than what a particular grower would expect, and the weather outlook does not look good, then the producer may decide to cut back on their actual rate of N applied. Also, if a producer does typically apply starter fertilizer, then the producer can include a check strip in their field; by simply turning of the starter fertilizer and using these check areas to calculate their RI. The producer can then subtract off the amount of starter N application from the recommended N-rate. For example, if a producer applied 20 kg N ha^{-1} as starter, and the recommendation says the grower needs to apply 60 kg N ha^{-1}, then the producer should only apply 40 kg N ha^{-1}.

Table 3.3 GreenSeeker GS-3 Recommendations across Sites and Years vs. Observed N Response

Location	Year	Starter kg/ha	Sensor Yield Potential kg/ha Ref. Strip	Observed Yield kg/ha	RI_{NDVI}	Observed N Response kg/ha	Sensor Rec. Unadj. for Efficiency kg/ha	Sensor Rec. Adj. for Efficiency kg/ha
Belleville	2006	0	5960	6020	0.99	0	0	0
Belleville	2006	34	5960	6020	0.99	0	0	0
Manhattan	2006	0	10040	9720	1.02	37	44	37
Manhattan	2006	34	10040	9720	1.01	21	27	23
Partridge	2006	0	3010	2010	1.2	67	60	62
Partridge	2006	34	3010	2010	1.12	40	38	40
Tribune	2006	0	8150	8030	1.02	17	29	27
Tribune	2006	34	8150	8030	0.99	0	0	0
Manhattan	2007	0	6960	6840	1.01	118	120	110
Manhattan	2007	34	6960	6840	1.02	84	39	35
Partridge	2007	0	4830	4390	1.01	22	17	17
Partridge	2007	34	4830	4390	1	0	0	0
Tribune	2007	0	4450	4960	0.99	0	0	0
Tribune	2007	34	4450	4960	0.99	0	0	0
Manhattan	2008	0	9470	8030	1.03	50	59	50
Manhattan	2008	34	9470	8030	1.01	16	23	18
Ottawa	2008	0	3640	4010	1.17	67	60	62
Ottawa	2008	34	3640	4010	1.12	34	43	34
Partridge	2008	0	8780	7720	1.02	17	41	34
Partridge	2008	34	8780	7720	1.01	15	23	20
		Average	6530	6170	1.04	30	31	28

A comparison of how the sensor based recommendation compares to a soil based N fertilizer recommendation is given as table 3-4. In this table the current KSU Soil Test Based N Fertilizer Recommendation is calculated using realistic yield goals for each of the ten sites shown in Table 3.3, adjusted for profile N at planting. We see that the sensor does a considerably better job than Soil Test Based system. The sensor based recommendation comes within an average of 4 kg N ha^{-1} of the actual response that was seen. Unfortunately the current soil based recommendation system over recommends an average of 34 kg N ha^{-1}. A modified soil based system, proposes in Chapter Two provided considerably lower N recommendations, but underestimated actual N needs by an average of 11 kg N ha^{-1} (see Table 2.6).

Table 3.4 Soil vs. Sensor Based N Fertilizer Recommendations

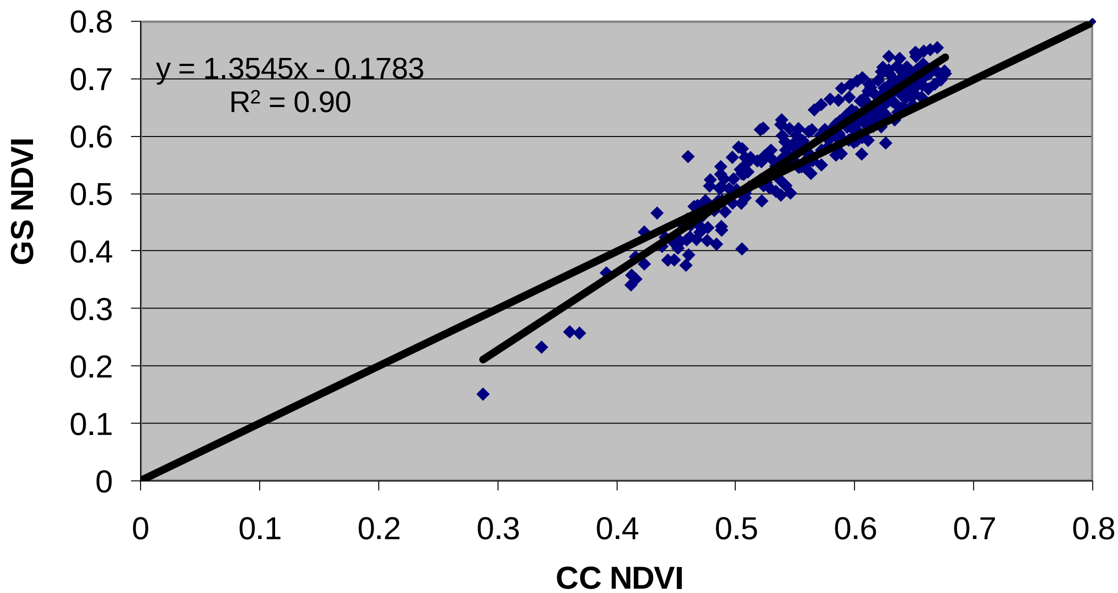
Location	Year	Observed N Response kg N ha^{-1}	Current Soil Based N Rec. kg N ha^{-1}	Sensor N Rec. unadj. for efficiency kg N ha^{-1}	Soil Test vs. Observed Difference kg N ha^{-1}	Sensor vs. Observed Difference kg N ha^{-1}
Belleville	2006	0	45	0	45	0
Manhattan	2006	37	86	44	49	7
Partridge	2006	62	45	60	-17	-2
Tribune	2006	17	37	29	20	12
Manhattan	2007	118	143	120	25	2
Partridge	2007	22	45	17	23	-5
Tribune	2007	0	59	0	59	0
Manhattan	2008	50	112	59	62	9
Ottawa	2008	67	73	60	6	-7
Partridge	2008	17	46	41	29	24
	Avg.	39	69	43	34	4

Sensor Comparisons

There has been little research done on comparing the values obtained from different active sensorssuch as the GreenSeeker and Crop Circle throughout a growing season. The GreenSeeker sensor was developed primarily for use in wheat, while the Crop Circle sensor was developed primarily for use in corn. These two crops exhibit extreme differences in leaf area and biomass. Therefore, differences in the sensors would be expected. In 2007 we had the opportunity to compare the two sensors side by side across a wide range of environments in sorghum. To use these sensors with a common recommendation system, the NDVI values obtained and RI_{NDVI} calculated must be the same, or very close, for the final N recommendations to be the same. Our research found that NDVI values measured and RI_{NDVI} values were different enough to justify developing different recommendations algorithms.

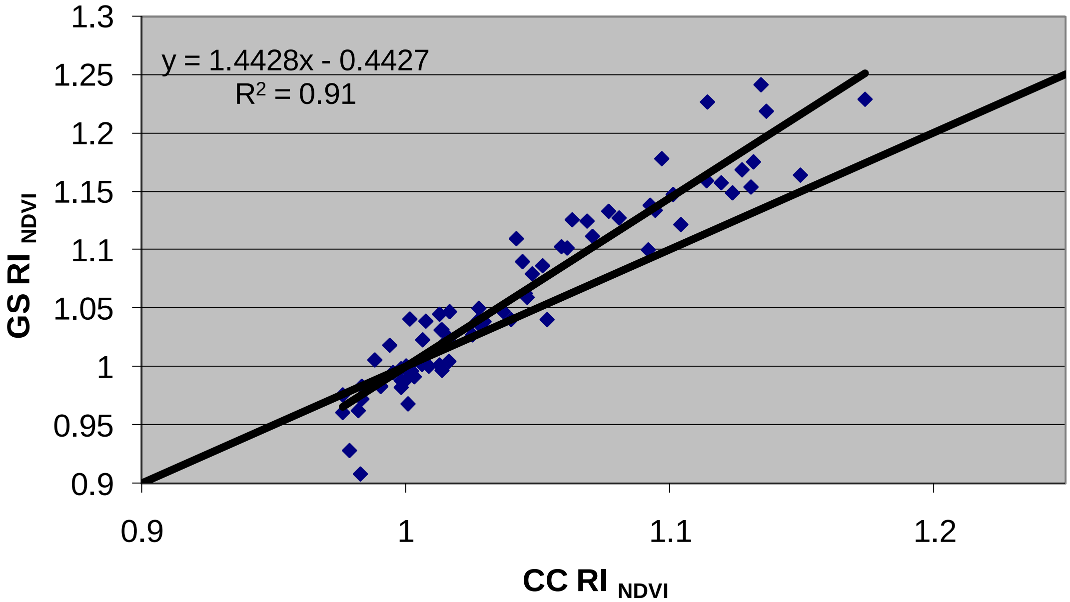
The NDVI values measured over the same field plot areas are shown in Figure 3.20. While the values are highly correlated and their relationship is linear, the slope of theline is clearly not 1. It is clear that at early growth stages on sorghum the GreenSeeker sensor gives lower NDVI values than the CropCircle sensor. That relationship gradually changes, crossing at a NDVI approaching 0.5.

Figure 3.20 Relationship between GS and CC NDVI, and a One to One Line



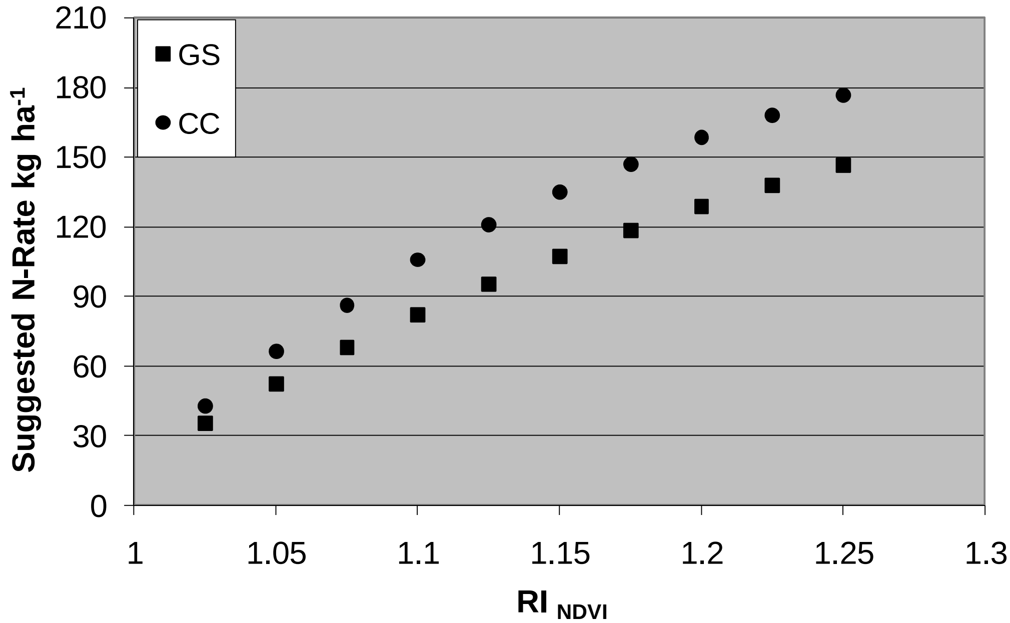
The response index calculated from these same values is shown in Figure 3.21. This figure shows that the RI calculated using NDVI values measured from the GreenSeeker sensor tends to be higher than the RI calculated with NDVI values measured from the same plots using the Crop Circle sensor, and this difference tends to increase with increasing NDVI readings.

Figure 3.21 Relationship between GS RI_{NDVI} and CC RI_{NDVI}, and a One to One Line



These differences in NDVI values and associated calculated RI result in substantial differences in N recommendations, Figure 3.22, if one attempts to use the same algorithm for both sensors. This clearly suggests that differences in the design of the sensors will demand that separate algorithms be developed for their use. Failure to do so could result in significant over or under recommendation of nitrogen fertilizer.

Figure 3.22 Relationship of GS and CC GS-3 Recommendations at 7500 kg ha^{-1} Yield Level



Conclusions

The use of optical sensors to estimate mid-season nitrogen needs in grain sorghum is promising technology. Sensors do an excellent job of predicting yield potential at the GS-3 growth stage when the INSEY concept is used normalize the data for days from planting to sensing. Producer may choose to put limits on yield expectations to further refine this estimated yield potential. The technology will likely require the use of a high N reference strip and, when small amounts starter N fertilizers are applied at planting, a no N check strip, for best results.

The sensor technology seems to work best at the GS-3 growth stage, or about 35 to 50 days after planting. Unfortunately, this only provides a narrow window of opportunity to fertilize the crop. Producers may choose to apply a base level of N on sorghum at planting to minimize risk and maximize yield under different conditions which include:

a. A soil which tested low for available N;

b. When planting in no-till conditions or where soil temperatures have not yet warmed to 20 degrees C;

c. To hasten maturity of the crop;

d. When a producer is concerned about side-dressing 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.

The decision of how to side-dress this nitrogen will depend on a number of variables. However, when a significant rainfall event does not occur shortly after application of N, injected N fertilizer has a greater nitrogen use efficiency than broadcast or surface banded fertilizers. When injecting N fertilizer a method which caused minimal soil disturbance could prevent loss of moisture. The timing of side-dress N application should occur at the GS-3 growth stage. Sidedressing N later than this runs the risk of not being able to get through the field with standard equipment and if significant N stress is present a reduction in yields may occur.

Pre- or at planting N applications seem to reduce the accuracy of the mid-season N recommendations made using sensor technology. Adding a check strip of No pre-plant or at planting N as a correction term is recommended.

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. 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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APPENDIXES

Appendix A. Main Studies from 2006-2008

Table A.1 Data for research site: Long Term Sorghum 2005 Treatment Means

Location	Year	Tillage	Residual kg/ha	Pre-plant N kg/ha	Grain Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
LTS	2005	Conv.	0	0	3017	51	0.41	0.62	NA	NA	0.016	NA	NA	1.09
LTS	2005	Conv.	33.6	0	2910	48	0.42	0.61	NA	NA	0.016	NA	NA	1.09
LTS	2005	Conv.	67.2	0	3719	60	0.42	0.73	NA	NA	0.019	NA	NA	1.10
LTS	2005	Conv.	134.4	0	4309	106	0.40	0.73	NA	NA	0.019	NA	NA	1.35
LTS	2005	Conv.	33.6	67.2	4798	102	0.43	0.69	NA	NA	0.018	NA	NA	1.48
LTS	2005	Conv.	67.2	67.2	4265	115	0.38	0.74	NA	NA	0.019	NA	NA	1.60
LTS	2005	Conv.	134.4	67.2	3851	130	0.36	0.72	NA	NA	0.019	NA	NA	1.80
LTS	2005	Conv.	33.6	134.4	4911	135	0.44	0.72	NA	NA	0.019	NA	NA	1.80
LTS	2005	Conv.	67.2	134.4	4390	155	0.38	0.77	NA	NA	0.020	NA	NA	1.95
LTS	2005	Conv.	134.4	134.4	3889	146	0.38	0.71	NA	NA	0.018	NA	NA	1.99
LTS	2005	No-till	0	0	1543	26	0.35	0.65	NA	NA	0.017	NA	NA	1.06
LTS	2005	No-till	33.6	0	1417	27	0.30	0.65	NA	NA	0.017	NA	NA	1.07
LTS	2005	No-till	67.2	0	2339	43	0.37	0.71	NA	NA	0.018	NA	NA	1.05
LTS	2005	No-till	134.4	0	4221	74	0.41	0.76	NA	NA	0.019	NA	NA	1.15
LTS	2005	No-till	33.6	67.2	3556	75	0.39	0.67	NA	NA	0.017	NA	NA	1.24
LTS	2005	No-till	67.2	67.2	3412	72	0.43	0.75	NA	NA	0.019	NA	NA	1.35
LTS	2005	No-till	134.4	67.2	4591	104	0.42	0.75	NA	NA	0.019	NA	NA	1.47
LTS	2005	No-till	33.6	134.4	3807	100	0.39	0.71	NA	NA	0.018	NA	NA	1.61
LTS	2005	No-till	67.2	134.4	3688	104	0.39	0.73	NA	NA	0.019	NA	NA	1.64
LTS	2005	No-till	134.4	134.4	4397	132	0.39	0.68	NA	NA	0.017	NA	NA	1.79

Table A.2 Data for research site: Long Term Sorghum 2005 Raw Data

Plot	Tillage	Residual kg/ha	pre-plant N kg/ha	Grain Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
115	Conv.	0	0	2823	49.2	0.35	0.65	NA	NA	0.017	NA	NA	0.96
217	Conv.	0	0	3491	54.5	0.40	0.62	NA	NA	0.016	NA	NA	1.07
315	Conv.	0	0	2730	48.4	0.48	0.59	NA	NA	0.015	NA	NA	1.24
116	Conv.	33.6	0	2845	46.0	0.41	0.69	NA	NA	0.018	NA	NA	0.92
215	Conv.	33.6	0	3325	53.6	0.40	0.67	NA	NA	0.017	NA	NA	1.05
311	Conv.	33.6	0	2562	45.1	0.45	0.46	NA	NA	0.012	NA	NA	1.31
114	Conv.	67.2	0	3605	54.8	0.39	0.79	NA	NA	0.020	NA	NA	0.97
212	Conv.	67.2	0	4090	68.7	0.38	0.68	NA	NA	0.018	NA	NA	1.09
314	Conv.	67.2	0	3464	57.0	0.54	0.71	NA	NA	0.018	NA	NA	1.23
120	Conv.	134.4	0	4024	134.4	0.34	0.76	NA	NA	0.019	NA	NA	1.59
219	Conv.	134.4	0	4498	98.8	0.40	0.74	NA	NA	0.019	NA	NA	1.28
320	Conv.	134.4	0	4408	85.1	0.49	0.70	NA	NA	0.018	NA	NA	1.19
113	Conv.	33.6	67.2	5618	118.0	0.40	0.73	NA	NA	0.019	NA	NA	1.38
218	Conv.	33.6	67.2	4861	109.8	0.43	0.74	NA	NA	0.019	NA	NA	1.61
319	Conv.	33.6	67.2	3912	77.3	0.47	0.61	NA	NA	0.016	NA	NA	1.46
111	Conv.	67.2	67.2	4428	121.2	0.36	0.79	NA	NA	0.020	NA	NA	1.45
214	Conv.	67.2	67.2	4535	132.6	0.35	0.75	NA	NA	0.019	NA	NA	1.57
313	Conv.	67.2	67.2	3838	92.1	0.47	0.68	NA	NA	0.017	NA	NA	1.79
112	Conv.	134.4	67.2	4704	126.4	0.40	0.68	NA	NA	0.017	NA	NA	1.52
216	Conv.	134.4	67.2	3531	137.5	0.32	0.77	NA	NA	0.020	NA	NA	1.79
312	Conv.	134.4	67.2	3325	125.2	0.36	0.72	NA	NA	0.018	NA	NA	2.09
117	Conv.	33.6	134.4	5182	140.0	0.40	0.68	NA	NA	0.017	NA	NA	1.68
213	Conv.	33.6	134.4	4561	141.6	0.41	0.77	NA	NA	0.020	NA	NA	1.90
317	Conv.	33.6	134.4	4996	124.2	0.56	0.72	NA	NA	0.019	NA	NA	1.82
118	Conv.	67.2	134.4	3713	150.1	0.34	0.82	NA	NA	0.021	NA	NA	1.97
211	Conv.	67.2	134.4	4877	195.0	0.34	0.77	NA	NA	0.020	NA	NA	1.96
316	Conv.	67.2	134.4	4573	118.4	0.47	0.72	NA	NA	0.019	NA	NA	1.92
119	Conv.	134.4	134.4	3228	144.3	0.31	0.68	NA	NA	0.018	NA	NA	2.00
220	Conv.	134.4	134.4	3779	145.9	0.38	0.69	NA	NA	0.018	NA	NA	2.07
318	Conv.	134.4	134.4	4665	147.8	0.44	0.77	NA	NA	0.020	NA	NA	1.91

Table A.2 Continued

Plot	Tillage	Residual kg/ha	Pre-plant N kg/ha	Grain Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
103	No-Till	0	0	2738	43.2	0.37	0.71	NA	NA	0.018	NA	NA	0.97
209	No-Till	0	0	1675	29.1	0.34	0.62	NA	NA	0.016	NA	NA	1.02
310	No-Till	0	0	210	4.6	0.31	0.61	NA	NA	0.016	NA	NA	1.20
105	No-Till	33.6	0	2984	48.7	0.35	0.71	NA	NA	0.018	NA	NA	0.95
205	No-Till	33.6	0	765	15.6	0.25	0.67	NA	NA	0.017	NA	NA	1.07
305	No-Till	33.6	0	502	16.0	0.18	0.58	NA	NA	0.015	NA	NA	1.19
104	No-Till	67.2	0	2006	35.5	0.38	0.75	NA	NA	0.019	NA	NA	1.10
207	No-Till	67.2	0	3505	65.0	0.41	0.63	NA	NA	0.016	NA	NA	1.05
309	No-Till	67.2	0	1502	28.4	0.30	0.74	NA	NA	0.019	NA	NA	1.00
108	No-Till	134.4	0	4256	72.7	0.43	0.78	NA	NA	0.020	NA	NA	1.07
210	No-Till	134.4	0	3956	64.7	0.44	0.76	NA	NA	0.020	NA	NA	1.16
301	No-Till	134.4	0	4451	85.3	0.38	0.73	NA	NA	0.019	NA	NA	1.22
106	No-Till	33.6	67.2	3305	55.8	0.42	0.67	NA	NA	0.017	NA	NA	1.06
201	No-Till	33.6	67.2	2627	68.6	0.34	0.65	NA	NA	0.017	NA	NA	1.36
308	No-Till	33.6	67.2	4733	99.8	0.42	0.69	NA	NA	0.018	NA	NA	1.30
102	No-Till	67.2	67.2	5514	88.5	0.52	0.80	NA	NA	0.020	NA	NA	1.15
206	No-Till	67.2	67.2	1583	33.4	0.35	0.74	NA	NA	0.019	NA	NA	1.28
303	No-Till	67.2	67.2	3146	93.2	0.36	0.70	NA	NA	0.018	NA	NA	1.63
101	No-Till	134.4	67.2	4756	104.6	0.44	0.76	NA	NA	0.019	NA	NA	1.44
208	No-Till	134.4	67.2	4419	91.6	0.39	0.75	NA	NA	0.019	NA	NA	1.43
307	No-Till	134.4	67.2	4595	117.4	0.42	0.74	NA	NA	0.019	NA	NA	1.55
110	No-Till	33.6	134.4	4802	101.7	0.42	0.74	NA	NA	0.019	NA	NA	1.46
202	No-Till	33.6	134.4	4782	136.8	0.39	0.65	NA	NA	0.017	NA	NA	1.63
302	No-Till	33.6	134.4	1845	60.7	0.33	0.74	NA	NA	0.019	NA	NA	1.76
109	No-Till	67.2	134.4	3745	75.6	0.44	0.74	NA	NA	0.019	NA	NA	1.30
203	No-Till	67.2	134.4	4358	161.9	0.35	0.73	NA	NA	0.019	NA	NA	1.98
306	No-Till	67.2	134.4	2957	74.3	0.39	0.73	NA	NA	0.019	NA	NA	1.64
107	No-Till	134.4	134.4	5249	124.7	0.43	0.77	NA	NA	0.020	NA	NA	1.63
204	No-Till	134.4	134.4	5220	183.8	0.38	0.70	NA	NA	0.018	NA	NA	1.81
304	No-Till	134.4	134.4	2719	86.2	0.37	0.58	NA	NA	0.015	NA	NA	1.92

Table A.3 Data for research site: Long Term Sorghum 2006 Treatment Means

Location	Year	Tillage	Residual kg/ha	Pre-plant N kg/ha	Grain Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
LTS	2006	Conv.	0	0	1813	33.2	0.32	0.45	NA	35.8	0.012	NA	NA	1.08
LTS	2006	Conv.	33.6	0	1693	28.8	0.31	0.49	NA	35.1	0.013	NA	NA	1.08
LTS	2006	Conv.	67.2	0	4472	83.4	0.39	0.63	NA	53.2	0.016	NA	NA	1.22
LTS	2006	Conv.	134.4	0	5093	118.6	0.36	0.60	NA	57	0.015	NA	NA	1.57
LTS	2006	Conv.	33.6	67.2	2139	39.9	0.30	0.54	NA	37.4	0.014	NA	NA	1.00
LTS	2006	Conv.	67.2	67.2	4096	77.6	0.35	0.65	NA	52.3	0.017	NA	NA	1.39
LTS	2006	Conv.	134.4	67.2	4158	99.8	0.35	0.62	NA	56.5	0.016	NA	NA	1.47
LTS	2006	Conv.	33.6	134.4	2553	41.4	0.26	0.60	NA	41.9	0.015	NA	NA	1.05
LTS	2006	Conv.	67.2	134.4	4033	95.0	0.36	0.66	NA	53.3	0.017	NA	NA	1.33
LTS	2006	Conv.	134.4	134.4	4102	113.9	0.33	0.61	NA	57.3	0.016	NA	NA	1.62
LTS	2006	No-till	0	0	376	14.2	0.11	0.38	NA	31.1	0.010	NA	NA	1.31
LTS	2006	No-till	33.6	0	533	19.7	0.12	0.41	NA	31.3	0.011	NA	NA	1.35
LTS	2006	No-till	67.2	0	3870	67.6	0.37	0.68	NA	47.8	0.017	NA	NA	1.05
LTS	2006	No-till	134.4	0	4284	84.1	0.34	0.65	NA	52.5	0.017	NA	NA	1.32
LTS	2006	No-till	33.6	67.2	508	16.8	0.13	0.46	NA	27.1	0.012	NA	NA	1.39
LTS	2006	No-till	67.2	67.2	3371	58.0	0.34	0.63	NA	46	0.016	NA	NA	1.09
LTS	2006	No-till	134.4	67.2	3487	75.9	0.29	0.65	NA	49.6	0.017	NA	NA	1.26
LTS	2006	No-till	33.6	134.4	1543	33.4	0.21	0.52	NA	34.5	0.013	NA	NA	1.27
LTS	2006	No-till	67.2	134.4	4378	70.9	0.37	0.60	NA	50.2	0.015	NA	NA	1.07
LTS	2006	No-till	134.4	134.4	4861	106.2	0.35	0.64	NA	52.6	0.016	NA	NA	1.39

Table A.4 Data for research site: Long Term Sorghum 2006 Raw Data

Plot	Tillage	Residual kg/ha	Pre-plant N kg/ha	Grain Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
115	Conv.	0	0	1886	0.4	0.32	0.42	NA	34.8	0.011	NA	NA	1.00
217	Conv.	0	0	1914	0.3	0.31	0.48	NA	37.6	0.012	NA	NA	0.97
315	Conv.	0	0	1631	0.3	0.31	0.45	NA	34.9	0.012	NA	NA	1.27
116	Conv.	33.6	0	1532	0.3	0.31	0.48	NA	34.2	0.012	NA	NA	0.97
215	Conv.	33.6	0	1930	0.3	0.29	0.47	NA	34.5	0.012	NA	NA	1.02
311	Conv.	33.6	0	1620	0.4	0.32	0.51	NA	36.5	0.013	NA	NA	1.26
114	Conv.	67.2	0	4419	0.5	0.42	0.67	NA	50.5	0.017	NA	NA	1.06
212	Conv.	67.2	0	4473	0.4	0.36	0.61	NA	54.6	0.016	NA	NA	1.27
314	Conv.	67.2	0	4514	0.4	0.39	0.61	NA	54.5	0.016	NA	NA	1.31
120	Conv.	134.4	0	5213	0.4	0.34	0.57	NA	55.8	0.015	NA	NA	1.39
219	Conv.	134.4	0	4876	0.4	0.35	0.64	NA	54.5	0.016	NA	NA	1.59
320	Conv.	134.4	0	5182	0.4	0.37	0.60	NA	60.8	0.015	NA	NA	1.73
113	Conv.	33.6	67.2	1954	0.3	0.23	0.55	NA	37.1	0.014	NA	NA	0.93
218	Conv.	33.6	67.2	2423	0.4	0.34	0.58	NA	38.1	0.015	NA	NA	0.96
319	Conv.	33.6	67.2	2035	0.4	0.32	0.49	NA	36.9	0.013	NA	NA	1.10
111	Conv.	67.2	67.2	3909	0.3	0.30	0.67	NA	48.6	0.017	NA	NA	1.38
214	Conv.	67.2	67.2	4677	0.5	0.41	0.64	NA	54.2	0.016	NA	NA	1.25
313	Conv.	67.2	67.2	3701	0.4	0.32	0.63	NA	54.1	0.016	NA	NA	1.55
112	Conv.	134.4	67.2	4387	0.4	0.34	0.57	NA	55	0.015	NA	NA	1.27
216	Conv.	134.4	67.2	4225	0.4	0.33	0.64	NA	57	0.017	NA	NA	1.53
312	Conv.	134.4	67.2	3868	0.4	0.35	0.65	NA	57.4	0.017	NA	NA	1.61
117	Conv.	33.6	134.4	2534	0.2	0.21	0.56	NA	43	0.014	NA	NA	1.10
213	Conv.	33.6	134.4	2825	0.3	0.28	0.65	NA	40	0.017	NA	NA	0.97
317	Conv.	33.6	134.4	2305	0.3	0.29	0.59	NA	42.6	0.015	NA	NA	1.09
118	Conv.	67.2	134.4	4782	0.4	0.39	0.68	NA	51.5	0.017	NA	NA	1.19
211	Conv.	67.2	134.4	3880	0.4	0.34	0.63	NA	56.6	0.016	NA	NA	1.28
316	Conv.	67.2	134.4	3437	0.4	0.33	0.65	NA	51.7	0.017	NA	NA	1.53
119	Conv.	134.4	134.4	4372	0.4	0.34	0.53	NA	55.8	0.014	NA	NA	1.57
220	Conv.	134.4	134.4	3693	0.3	0.30	0.67	NA	58.5	0.017	NA	NA	1.57
318	Conv.	134.4	134.4	4231	0.4	0.34	0.63	NA	57.6	0.016	NA	NA	1.72

Table A.4 Continued

Plot	Tillage	Residual kg/ha	Pre-plant N kg/ha	Grain Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
103	No-Till	0	0	148	0.1	0.05	0.39	NA	29.8	0.010	NA	NA	1.43
209	No-Till	0	0	553	0.2	0.14	0.39	NA	32.3	0.010	NA	NA	1.06
310	No-Till	0	0	418	0.1	0.11	0.36	NA	31.2	0.009	NA	NA	1.45
105	No-Till	33.6	0	667	0.2	0.14	0.39	NA	30.6	0.010	NA	NA	1.32
205	No-Till	33.6	0	403	0.1	0.09	0.41	NA	32.2	0.011	NA	NA	1.52
305	No-Till	33.6	0	520	0.1	0.13	0.43	NA	31	0.011	NA	NA	1.21
104	No-Till	67.2	0	3774	0.4	0.35	0.69	NA	44.3	0.018	NA	NA	1.20
207	No-Till	67.2	0	3946	0.4	0.37	0.65	NA	49.3	0.017	NA	NA	0.91
309	No-Till	67.2	0	3895	0.4	0.36	0.68	NA	49.7	0.017	NA	NA	1.05
108	No-Till	134.4	0	4151	0.4	0.37	0.61	NA	49.6	0.016	NA	NA	1.21
210	No-Till	134.4	0	5526	0.4	0.35	0.71	NA	55	0.018	NA	NA	1.25
301	No-Till	134.4	0	3167	0.3	0.27	0.64	NA	52.9	0.016	NA	NA	1.50
106	No-Till	33.6	67.2	108	0.0	0.03	0.48	NA	23.2	0.012	NA	NA	1.50
201	No-Till	33.6	67.2	1125	0.2	0.20	0.45	NA	32	0.012	NA	NA	1.09
308	No-Till	33.6	67.2	283	0.1	0.09	0.45	NA	26.2	0.012	NA	NA	1.58
102	No-Till	67.2	67.2	5701	0.4	0.36	0.66	NA	53.5	0.017	NA	NA	1.09
206	No-Till	67.2	67.2	2189	0.3	0.29	0.62	NA	42.2	0.016	NA	NA	1.00
303	No-Till	67.2	67.2	2221	0.3	0.31	0.62	NA	42.2	0.016	NA	NA	1.19
101	No-Till	134.4	67.2	1565	0.2	0.17	0.69	NA	45.2	0.018	NA	NA	1.17
208	No-Till	134.4	67.2	4946	0.3	0.31	0.64	NA	54.8	0.016	NA	NA	1.41
307	No-Till	134.4	67.2	3953	0.4	0.35	0.62	NA	48.9	0.016	NA	NA	1.21
110	No-Till	33.6	134.4	332	0.1	0.06	0.51	NA	29.5	0.013	NA	NA	1.58
202	No-Till	33.6	134.4	1496	0.2	0.20	0.50	NA	35.7	0.013	NA	NA	1.20
302	No-Till	33.6	134.4	2802	0.3	0.30	0.54	NA	38.4	0.014	NA	NA	1.02
109	No-Till	67.2	134.4	3733	0.4	0.33	0.70	NA	47.4	0.018	NA	NA	1.19
203	No-Till	67.2	134.4	5215	0.4	0.37	0.58	NA	52.5	0.015	NA	NA	1.00
306	No-Till	67.2	134.4	4192	0.4	0.39	0.53	NA	50.8	0.014	NA	NA	1.03
107	No-Till	134.4	134.4	4983	0.4	0.37	0.71	NA	48.5	0.018	NA	NA	1.39
204	No-Till	134.4	134.4	5414	0.4	0.35	0.63	NA	55.6	0.016	NA	NA	1.47
304	No-Till	134.4	134.4	4192	0.4	0.31	0.59	NA	53.7	0.015	NA	NA	1.32

Table A.5 Data for research site: Belleville 2006 Treatment Means

Location	Year	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	HI	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
Belleville	2006	0	0	0	5946	NA	NA	0.62	0.62	NA	0.017	0.017	2.56	NA
Belleville	2006	0	33.6	33.6	5526	NA	NA	0.62	0.63	NA	0.017	0.017	2.63	NA
Belleville	2006	0	67.2	67.2	5501	NA	NA	0.66	0.65	NA	0.018	0.018	2.57	NA
Belleville	2006	0	100.8	100.8	5469	NA	NA	0.62	0.62	NA	0.017	0.017	2.64	NA
Belleville	2006	0	134.4	134.4	5494	NA	NA	0.63	0.63	NA	0.017	0.018	2.74	NA
Belleville	2006	33.6	0	33.6	5093	NA	NA	0.63	0.62	NA	0.018	0.017	2.64	NA
Belleville	2006	33.6	33.6	67.2	5469	NA	NA	0.64	0.63	NA	0.018	0.017	2.76	NA
Belleville	2006	33.6	67.2	100.8	6165	NA	NA	0.64	0.63	NA	0.018	0.018	2.91	NA
Belleville	2006	33.6	100.8	134.4	5105	NA	NA	0.64	0.63	NA	0.018	0.018	2.70	NA
Belleville	2006	33.6	134.4	168	5137	NA	NA	0.60	0.62	NA	0.017	0.017	2.88	NA
Belleville	2006	67.2	0	67.2	4898	NA	NA	0.62	0.63	NA	0.017	0.017	2.68	NA
Belleville	2006	67.2	33.6	100.8	5664	NA	NA	0.64	0.64	NA	0.018	0.018	2.74	NA
Belleville	2006	67.2	67.2	134.4	5582	NA	NA	0.62	0.63	NA	0.017	0.017	2.72	NA
Belleville	2006	67.2	100.8	168	6579	NA	NA	0.62	0.62	NA	0.017	0.017	2.82	NA
Belleville	2006	100.8	0	100.8	5814	NA	NA	0.62	0.63	NA	0.017	0.017	2.80	NA
Belleville	2006	100.8	33.6	134.4	6354	NA	NA	0.59	0.61	NA	0.016	0.017	2.81	NA
Belleville	2006	100.8	67.2	168	5570	NA	NA	0.65	0.63	NA	0.018	0.018	2.77	NA
Belleville	2006	134.4	0	134.4	5501	NA	NA	0.59	0.60	NA	0.016	0.017	2.79	NA
Belleville	2006	134.4	33.6	168	5914	NA	NA	0.58	0.60	NA	0.016	0.017	2.89	NA
Belleville	2006	168	0	168	5846	NA	NA	0.61	0.61	NA	0.017	0.017	2.75	NA

Table A.6 Data for research site: Belleville 2006 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
108	0	0	0	4572	NA	NA	0.63	0.61	NA	0.017	0.017	2.64	NA
215	0	0	0	7265	NA	NA	0.59	0.63	NA	0.017	0.018	2.40	NA
304	0	0	0	6005	NA	NA	0.64	0.63	NA	0.018	0.018	2.66	NA
114	0	33.6	33.6	3477	NA	NA	0.58	0.61	NA	0.016	0.017	2.54	NA
209	0	33.6	33.6	6005	NA	NA	0.66	0.65	NA	0.018	0.018	2.72	NA
306	0	33.6	33.6	7097	NA	NA	0.62	0.62	NA	0.017	0.017	2.62	NA
105	0	67.2	67.2	4111	NA	NA	0.67	0.63	NA	0.019	0.017	2.44	NA
201	0	67.2	67.2	4914	NA	NA	0.69	0.67	NA	0.019	0.019	2.57	NA
316	0	67.2	67.2	7475	NA	NA	0.63	0.65	NA	0.017	0.018	2.70	NA
117	0	100.8	100.8	4625	NA	NA	0.58	0.60	NA	0.016	0.017	2.48	NA
207	0	100.8	100.8	5795	NA	NA	0.62	0.62	NA	0.017	0.017	2.67	NA
305	0	100.8	100.8	5998	NA	NA	0.65	0.63	NA	0.018	0.018	2.78	NA
115	0	134.4	134.4	3645	NA	NA	0.56	0.59	NA	0.016	0.016	2.83	NA
216	0	134.4	134.4	6047	NA	NA	0.64	0.64	NA	0.018	0.018	2.54	NA
315	0	134.4	134.4	6787	NA	NA	0.68	0.67	NA	0.019	0.019	2.84	NA
102	33.6	0	33.6	5124	NA	NA	0.61	0.58	NA	0.017	0.016	2.76	NA
218	33.6	0	33.6	5201	NA	NA	0.64	0.62	NA	0.018	0.017	2.54	NA
311	33.6	0	33.6	4950	NA	NA	0.66	0.65	NA	0.018	0.018	2.62	NA
103	33.6	33.6	67.2	4158	NA	NA	0.64	0.60	NA	0.018	0.017	2.75	NA
202	33.6	33.6	67.2	5956	NA	NA	0.65	0.65	NA	0.018	0.018	2.83	NA
303	33.6	33.6	67.2	6299	NA	NA	0.64	0.63	NA	0.018	0.018	2.70	NA
110	33.6	67.2	100.8	4321	NA	NA	0.66	0.62	NA	0.018	0.017	2.88	NA
204	33.6	67.2	100.8	6845	NA	NA	0.62	0.63	NA	0.017	0.018	2.94	NA
308	33.6	67.2	100.8	7341	NA	NA	0.64	0.64	NA	0.018	0.018	2.90	NA
104	33.6	100.8	134.4	4116	NA	NA	0.67	0.62	NA	0.019	0.017	2.69	NA
219	33.6	100.8	134.4	5669	NA	NA	0.62	0.62	NA	0.017	0.017	2.64	NA
313	33.6	100.8	134.4	5537	NA	NA	0.64	0.65	NA	0.018	0.018	2.78	NA
116	33.6	134.4	168	4452	NA	NA	0.56	0.59	NA	0.015	0.016	2.97	NA
213	33.6	134.4	168	6887	NA	NA	0.61	0.63	NA	0.017	0.018	2.90	NA
312	33.6	134.4	168	4064	NA	NA	0.64	0.63	NA	0.018	0.017	2.79	NA

Table A.6 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
120	67.2	0	67.2	4620	NA	NA	0.59	0.61	NA	0.016	0.017	2.76	NA
211	67.2	0	67.2	3901	NA	NA	0.64	0.64	NA	0.018	0.018	2.44	NA
320	67.2	0	67.2	6173	NA	NA	0.64	0.63	NA	0.018	0.018	2.82	NA
109	67.2	33.6	100.8	4148	NA	NA	0.66	0.63	NA	0.018	0.018	2.71	NA
212	67.2	33.6	100.8	6452	NA	NA	0.62	0.63	NA	0.017	0.017	2.75	NA
314	67.2	33.6	100.8	6383	NA	NA	0.66	0.66	NA	0.018	0.018	2.76	NA
113	67.2	67.2	134.4	3519	NA	NA	0.58	0.60	NA	0.016	0.017	2.60	NA
206	67.2	67.2	134.4	5579	NA	NA	0.64	0.63	NA	0.018	0.018	2.76	NA
317	67.2	67.2	134.4	7643	NA	NA	0.63	0.64	NA	0.017	0.018	2.80	NA
101	67.2	100.8	168	6215	NA	NA	0.65	0.60	NA	0.018	0.017	2.85	NA
220	67.2	100.8	168	6166	NA	NA	0.59	0.60	NA	0.016	0.017	2.68	NA
318	67.2	100.8	168	7349	NA	NA	0.63	0.64	NA	0.017	0.018	2.92	NA
106	100.8	0	100.8	3826	NA	NA	0.65	0.62	NA	0.018	0.017	2.71	NA
214	100.8	0	100.8	6677	NA	NA	0.60	0.62	NA	0.017	0.017	3.01	NA
319	100.8	0	100.8	6929	NA	NA	0.62	0.64	NA	0.017	0.018	2.67	NA
119	100.8	33.6	134.4	5817	NA	NA	0.49	0.56	NA	0.014	0.016	2.94	NA
208	100.8	33.6	134.4	6327	NA	NA	0.64	0.63	NA	0.018	0.018	2.81	NA
309	100.8	33.6	134.4	6921	NA	NA	0.63	0.63	NA	0.018	0.018	2.67	NA
107	100.8	67.2	168	3742	NA	NA	0.64	0.63	NA	0.018	0.017	2.70	NA
210	100.8	67.2	168	5949	NA	NA	0.65	0.64	NA	0.018	0.018	2.75	NA
307	100.8	67.2	168	7005	NA	NA	0.66	0.63	NA	0.018	0.018	2.87	NA
111	134.4	0	134.4	5663	NA	NA	0.53	0.56	NA	0.015	0.016	2.75	NA
217	134.4	0	134.4	6131	NA	NA	0.62	0.62	NA	0.017	0.017	2.73	NA
301	134.4	0	134.4	4704	NA	NA	0.61	0.63	NA	0.017	0.017	2.90	NA
118	134.4	33.6	168	5627	NA	NA	0.47	0.53	NA	0.013	0.015	2.80	NA
205	134.4	33.6	168	6795	NA	NA	0.62	0.64	NA	0.017	0.018	2.91	NA
302	134.4	33.6	168	5334	NA	NA	0.64	0.64	NA	0.018	0.018	2.96	NA
112	168	0	168	4488	NA	NA	0.58	0.57	NA	0.016	0.016	2.77	NA
203	168	0	168	5795	NA	NA	0.61	0.64	NA	0.017	0.018	2.71	NA
310	168	0	168	7257	NA	NA	0.66	0.63	NA	0.018	0.018	2.77	NA

Table A.7 Data for research site: Manhattan 2006 Treatment Means

Location	Year	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
Manhattan	2006	0	0	0	8818	125	0.44	0.80	0.71	46.1	0.020	0.018	2.24	0.97873
Manhattan	2006	0	33.6	33.6	9560	143	0.45	0.81	0.73	46.9	0.020	0.018	2.46	1.10541
Manhattan	2006	0	67.2	67.2	8661	140	0.46	0.78	0.71	44.8	0.020	0.018	2.57	1.24912
Manhattan	2006	0	100.8	100.8	9940	201	0.44	0.82	0.73	46.6	0.020	0.018	2.82	1.36337
Manhattan	2006	0	134.4	134.4	9395	175	0.43	0.78	0.70	47.4	0.020	0.018	2.72	1.41041
Manhattan	2006	33.6	0	33.6	8198	109	0.45	0.79	0.71	47.4	0.020	0.018	2.29	1.05014
Manhattan	2006	33.6	33.6	67.2	9631	163	0.43	0.83	0.74	46.9	0.021	0.018	2.7	1.25231
Manhattan	2006	33.6	67.2	100.8	9998	187	0.47	0.83	0.74	46.6	0.021	0.019	2.91	1.39356
Manhattan	2006	33.6	100.8	134.4	9053	173	0.45	0.79	0.71	46.5	0.020	0.018	2.8	1.41689
Manhattan	2006	33.6	134.4	168	9979	202	0.48	0.81	0.72	48.7	0.020	0.018	3.01	1.48645
Manhattan	2006	67.2	0	67.2	8647	136	0.46	0.78	0.71	49.5	0.020	0.018	2.57	1.25351
Manhattan	2006	67.2	33.6	100.8	9414	179	0.45	0.81	0.73	48.3	0.020	0.018	2.69	1.29538
Manhattan	2006	67.2	67.2	134.4	9251	183	0.44	0.80	0.72	46.6	0.020	0.018	2.86	1.43777
Manhattan	2006	67.2	100.8	168	7683	184	0.42	0.77	0.70	47.7	0.019	0.018	2.91	1.61158
Manhattan	2006	100.8	0	100.8	8973	146	0.46	0.80	0.72	49.2	0.020	0.018	2.68	1.28343
Manhattan	2006	100.8	33.6	134.4	9480	190	0.43	0.82	0.74	49.0	0.021	0.018	2.7	1.41703
Manhattan	2006	100.8	67.2	168	10537	213	0.46	0.82	0.74	47.8	0.021	0.019	3	1.42591
Manhattan	2006	134.4	0	134.4	9947	188	0.45	0.81	0.73	50.1	0.020	0.018	2.84	1.34887
Manhattan	2006	134.4	33.6	168	10236	209	0.47	0.84	0.74	48.7	0.021	0.019	3	1.47942
Manhattan	2006	168	0	168	9204	187	0.46	0.82	0.74	48.9	0.021	0.018	2.84	1.4619

Table A.8 Data for research site: Manhattan 2006 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
108	0	0	0	8772	125.1	0.45	0.79	0.72	44	0.020	0.018	2.34	1.02
215	0	0	0	7588	91.9	0.45	0.78	0.70	45.5	0.020	0.018	2.08	0.87
304	0	0	0	10095	158.4	0.48	0.82	0.72	48.7	0.021	0.018	2.3	1.04
114	0	33.6	33.6	9453	145.6	0.48	0.81	0.72	46.2	0.020	0.018	2.36	1.13
209	0	33.6	33.6	9641	149.1	0.45	0.82	0.74	46.7	0.020	0.018	2.56	1.13
306	0	33.6	33.6	9586	133.1	0.49	0.81	0.74	47.9	0.020	0.018	2.47	1.06
105	0	67.2	67.2	9410	159.5	0.52	0.81	0.72	45.4	0.020	0.018	2.6	1.33
201	0	67.2	67.2	9611	153.9	0.47	0.82	0.73	46	0.020	0.018	2.58	1.22
316	0	67.2	67.2	6961	105.5	0.48	0.72	0.68	43.1	0.018	0.017	2.53	1.20
117	0	100.8	100.8	10270	211.6	0.47	0.82	0.73	46.8	0.021	0.018	2.98	1.41
207	0	100.8	100.8	11010	230.9	0.47	0.81	0.74	45.3	0.020	0.018	2.91	1.30
305	0	100.8	100.8	8538	159.2	0.44	0.82	0.73	47.7	0.021	0.018	2.58	1.38
115	0	134.4	134.4	10832	206.3	0.45	0.82	0.73	47.6	0.021	0.018	2.65	1.42
216	0	134.4	134.4	9843	168.8	0.49	0.77	0.70	47.5	0.019	0.018	2.89	1.36
315	0	134.4	134.4	7510	150.4	0.44	0.75	0.68	47	0.019	0.017	2.63	1.46
102	33.6	0	33.6	8240	121.0	0.46	0.82	0.72	42.9	0.020	0.018	2.39	1.09
218	33.6	0	33.6	7765	93.5	0.48	0.76	0.69	48.5	0.019	0.017	2.22	0.98
311	33.6	0	33.6	8592	111.3	0.51	0.81	0.72	50.8	0.020	0.018	2.26	1.08
103	33.6	33.6	67.2	9052	146.2	0.44	0.83	0.73	45.4	0.021	0.018	2.57	1.20
202	33.6	33.6	67.2	9350	159.9	0.44	0.83	0.74	47	0.021	0.018	2.67	1.24
303	33.6	33.6	67.2	10493	181.3	0.50	0.84	0.74	48.3	0.021	0.019	2.87	1.32
110	33.6	67.2	100.8	10396	171.3	0.52	0.82	0.74	45.7	0.021	0.019	2.86	1.32
204	33.6	67.2	100.8	10231	198.8	0.49	0.83	0.74	46.7	0.021	0.019	2.93	1.41
308	33.6	67.2	100.8	9360	190.5	0.49	0.82	0.74	47.5	0.021	0.019	2.94	1.46
104	33.6	100.8	134.4	9971	185.1	0.47	0.82	0.73	46.6	0.021	0.018	2.88	1.42
219	33.6	100.8	134.4	7703	145.3	0.48	0.75	0.68	47	0.019	0.017	2.83	1.45
313	33.6	100.8	134.4	9484	188.6	0.49	0.80	0.71	45.8	0.020	0.018	2.69	1.39
116	33.6	134.4	168	10680	204.2	0.53	0.81	0.72	47.9	0.020	0.018	2.99	1.48
213	33.6	134.4	168	10090	219.3	0.51	0.81	0.73	50	0.020	0.018	3	1.49
312	33.6	134.4	168	9165	183.8	0.48	0.80	0.71	48.1	0.020	0.018	3.04	1.48

Table A.8 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
120	67.2	0	67.2	9281	145.5	0.51	0.80	0.72	48.9	0.020	0.018	2.55	1.22
211	67.2	0	67.2	10700	163.7	0.49	0.83	0.74	51.2	0.021	0.018	2.69	1.17
320	67.2	0	67.2	5959	98.7	0.47	0.72	0.68	48.3	0.018	0.017	2.48	1.36
109	67.2	33.6	100.8	10311	203.1	0.46	0.83	0.75	46	0.021	0.019	2.67	1.34
212	67.2	33.6	100.8	9985	194.5	0.48	0.81	0.73	49.7	0.020	0.018	2.76	1.24
314	67.2	33.6	100.8	7945	138.9	0.48	0.80	0.70	49.2	0.020	0.017	2.64	1.30
113	67.2	67.2	134.4	10111	206.4	0.48	0.82	0.73	47.8	0.020	0.018	2.86	1.40
206	67.2	67.2	134.4	10431	197.1	0.48	0.82	0.74	44.5	0.020	0.019	2.99	1.35
317	67.2	67.2	134.4	7207	145.2	0.43	0.75	0.69	47.4	0.019	0.017	2.72	1.56
101	67.2	100.8	168	8127	237.1	0.41	0.82	0.73	47.3	0.021	0.018	3.07	1.66
220	67.2	100.8	168	7575	164.6	0.43	0.74	0.69	47.3	0.018	0.017	2.86	1.53
318	67.2	100.8	168	7343	150.8	0.49	0.76	0.68	48.4	0.019	0.017	2.79	1.65
106	100.8	0	100.8	9502	164.1	0.45	0.82	0.74	47.8	0.020	0.018	2.66	1.28
214	100.8	0	100.8	10195	147.5	0.54	0.82	0.74	49.9	0.020	0.018	2.83	1.22
319	100.8	0	100.8	7222	126.4	0.46	0.76	0.68	49.9	0.019	0.017	2.55	1.35
119	100.8	33.6	134.4	9551	178.9	0.44	0.82	0.73	48	0.020	0.018	2.48	1.39
208	100.8	33.6	134.4	10487	202.8	0.46	0.82	0.74	48.9	0.021	0.019	2.9	1.29
309	100.8	33.6	134.4	8401	187.7	0.47	0.82	0.74	50	0.020	0.019	2.73	1.57
107	100.8	67.2	168	11187	216.7	0.48	0.82	0.74	45.6	0.021	0.019	3.02	1.45
210	100.8	67.2	168	10052	199.2	0.48	0.83	0.75	48.7	0.021	0.019	2.99	1.34
307	100.8	67.2	168	10365	222.0	0.49	0.82	0.74	49.2	0.021	0.019	2.99	1.49
111	134.4	0	134.4	10526	205.1	0.51	0.81	0.73	50.1	0.020	0.018	2.83	1.39
217	134.4	0	134.4	9255	155.2	0.47	0.80	0.71	50.6	0.020	0.018	2.84	1.31
301	134.4	0	134.4	10061	203.3	0.46	0.83	0.74	49.5	0.021	0.019	2.86	1.34
118	134.4	33.6	168	9844	179.1	0.52	0.83	0.73	47.9	0.021	0.018	2.96	1.44
205	134.4	33.6	168	10235	207.4	0.48	0.84	0.75	48.3	0.021	0.019	2.99	1.51
302	134.4	33.6	168	10633	240.1	0.50	0.84	0.74	49.9	0.021	0.019	3.06	1.49
112	168	0	168	10007	202.2	0.48	0.82	0.73	48.2	0.021	0.018	2.66	1.36
203	168	0	168	9768	189.9	0.50	0.83	0.74	48.2	0.021	0.019	2.9	1.39
310	168	0	168	7835	169.9	0.48	0.81	0.74	50.3	0.020	0.018	2.95	1.64

Table A.9 Data for research site: Partridge 2006 Treatment Means

Location	Year	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
Partridge	2006	0	0	0	1035	NA	NA	0.45	0.50	44.3	0.012	0.013	2.06	NA
Partridge	2006	0	33.6	33.6	1681	NA	NA	0.49	0.52	48.3	0.013	0.014	2.15	NA
Partridge	2006	0	67.2	67.2	1800	NA	NA	0.46	0.51	48.9	0.012	0.014	2.28	NA
Partridge	2006	0	100.8	100.8	2082	NA	NA	0.44	0.48	48.6	0.012	0.013	2.50	NA
Partridge	2006	0	134.4	134.4	1380	NA	NA	0.45	0.48	48.2	0.012	0.013	2.58	NA
Partridge	2006	33.6	0	33.6	1468	NA	NA	0.50	0.53	46.3	0.013	0.014	2.06	NA
Partridge	2006	33.6	33.6	67.2	1806	NA	NA	0.50	0.54	49.8	0.013	0.014	2.44	NA
Partridge	2006	33.6	67.2	100.8	2471	NA	NA	0.48	0.51	51	0.013	0.014	2.56	NA
Partridge	2006	33.6	100.8	134.4	1769	NA	NA	0.53	0.55	52.2	0.014	0.014	2.54	NA
Partridge	2006	33.6	134.4	168	1524	NA	NA	0.50	0.51	50.3	0.013	0.014	2.58	NA
Partridge	2006	67.2	0	67.2	1788	NA	NA	0.51	0.53	49.1	0.013	0.014	2.55	NA
Partridge	2006	67.2	33.6	100.8	2007	NA	NA	0.54	0.54	49.1	0.014	0.014	2.48	NA
Partridge	2006	67.2	67.2	134.4	2471	NA	NA	0.52	0.54	50.5	0.014	0.014	2.57	NA
Partridge	2006	67.2	100.8	168	1261	NA	NA	0.50	0.51	50	0.013	0.014	2.53	NA
Partridge	2006	100.8	0	100.8	1217	NA	NA	0.56	0.56	48.3	0.015	0.015	2.15	NA
Partridge	2006	100.8	33.6	134.4	1744	NA	NA	0.53	0.54	51	0.014	0.014	2.45	NA
Partridge	2006	100.8	67.2	168	2201	NA	NA	0.55	0.54	48.8	0.014	0.014	2.49	NA
Partridge	2006	134.4	0	134.4	1524	NA	NA	0.52	0.55	50.6	0.014	0.014	2.38	NA
Partridge	2006	134.4	33.6	168	2145	NA	NA	0.53	0.57	50.6	0.014	0.015	2.46	NA
Partridge	2006	168	0	168	1869	NA	NA	0.56	0.59	52.3	0.015	0.016	2.43	NA

Table A.10 Data for research site: Partridge 2006 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
115	0	0	0	599	NA	NA	0.44	0.47	44.2	0.012	0.012	2.39	NA
204	0	0	0	1467	NA	NA	0.45	0.51	45.1	0.012	0.013	2.14	NA
303	0	0	0	1033	NA	NA	0.43	0.49	41.4	0.011	0.013	1.64	NA
109	0	33.6	33.6	1874	NA	NA	0.46	0.51	48.6	0.012	0.013	2.25	NA
206	0	33.6	33.6	1890	NA	NA	0.51	0.54	54.9	0.014	0.014	2.25	NA
313	0	33.6	33.6	1272	NA	NA	0.56	0.54	45	0.015	0.014	1.93	NA
101	0	67.2	67.2	2647	NA	NA	0.45	0.55	47.3	0.012	0.014	2.46	NA
216	0	67.2	67.2	1388	NA	NA	0.41	0.46	51.5	0.011	0.012	2.10	NA
308	0	67.2	67.2	1366	NA	NA	0.53	0.53	47.9	0.014	0.014	2.28	NA
107	0	100.8	100.8	3224	NA	NA	0.47	0.51	52.1	0.012	0.013	2.68	NA
205	0	100.8	100.8	2449	NA	NA	0.44	0.50	51.1	0.012	0.013	2.29	NA
315	0	100.8	100.8	574	NA	NA	0.48	0.49	45.8	0.013	0.013	2.52	NA
116	0	134.4	134.4	1831	NA	NA	0.46	0.50	51.6	0.012	0.013	2.73	NA
215	0	134.4	134.4	1644	NA	NA	0.47	0.50	49.5	0.012	0.013	2.51	NA
317	0	134.4	134.4	656	NA	NA	0.50	0.49	46.3	0.013	0.013	2.49	NA
118	33.6	0	33.6	1521	NA	NA	0.50	0.52	45.8	0.013	0.014	2.26	NA
211	33.6	0	33.6	1334	NA	NA	0.54	0.55	45.6	0.014	0.014	1.96	NA
307	33.6	0	33.6	1543	NA	NA	0.52	0.54	46.3	0.014	0.014	1.97	NA
102	33.6	33.6	67.2	2203	NA	NA	0.46	0.53	48.6	0.012	0.014	2.48	NA
203	33.6	33.6	67.2	1039	NA	NA	0.48	0.51	50.7	0.013	0.013	2.40	NA
304	33.6	33.6	67.2	2173	NA	NA	0.59	0.59	49.5	0.015	0.016	2.46	NA
104	33.6	67.2	100.8	3573	NA	NA	0.49	0.54	53.6	0.013	0.014	2.52	NA
208	33.6	67.2	100.8	2173	NA	NA	0.46	0.48	51.5	0.012	0.013	2.64	NA
302	33.6	67.2	100.8	1659	NA	NA	0.49	0.52	49.3	0.013	0.014	2.51	NA
119	33.6	100.8	134.4	1058	NA	NA	0.49	0.53	54.1	0.013	0.014	2.58	NA
213	33.6	100.8	134.4	2586	NA	NA	0.55	0.56	53.4	0.015	0.015	2.58	NA
309	33.6	100.8	134.4	1662	NA	NA	0.61	0.58	51.5	0.016	0.015	2.47	NA
113	33.6	134.4	168	2129	NA	NA	0.54	0.53	53.6	0.014	0.014	2.62	NA
212	33.6	134.4	168	1848	NA	NA	0.51	0.52	51.3	0.013	0.014	2.66	NA
320	33.6	134.4	168	591	NA	NA	0.53	0.54	51	0.014	0.014	2.45	NA

Table A.10 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
111	67.2	0	67.2	2254	NA	NA	0.57	0.55	50.8	0.015	0.014	2.66	NA
220	67.2	0	67.2	1926	NA	NA	0.48	0.52	49.7	0.013	0.014	2.51	NA
301	67.2	0	67.2	1177	NA	NA	0.54	0.57	47.1	0.014	0.015	2.48	NA
112	67.2	33.6	100.8	2340	NA	NA	0.55	0.54	48.4	0.014	0.014	2.53	NA
214	67.2	33.6	100.8	2159	NA	NA	0.54	0.53	50	0.014	0.014	2.38	NA
311	67.2	33.6	100.8	1520	NA	NA	0.60	0.59	53.5	0.016	0.015	2.53	NA
106	67.2	67.2	134.4	2765	NA	NA	0.52	0.55	52.2	0.014	0.014	2.62	NA
217	67.2	67.2	134.4	2222	NA	NA	0.50	0.52	53.7	0.013	0.014	2.61	NA
305	67.2	67.2	134.4	2430	NA	NA	0.57	0.59	50	0.015	0.016	2.47	NA
120	67.2	100.8	168	1801	NA	NA	0.50	0.48	51.4	0.013	0.013	2.60	NA
218	67.2	100.8	168	1449	NA	NA	0.50	0.52	51.7	0.013	0.014	2.48	NA
319	67.2	100.8	168	530	NA	NA	0.55	0.54	50.7	0.015	0.014	2.51	NA
114	100.8	0	100.8	1468	NA	NA	0.57	0.53	48.3	0.015	0.014	1.94	NA
219	100.8	0	100.8	1763	NA	NA	0.53	0.56	53.4	0.014	0.015	2.41	NA
318	100.8	0	100.8	415	NA	NA	0.61	0.59	42.8	0.016	0.015	2.09	NA
108	100.8	33.6	134.4	2439	NA	NA	0.52	0.55	53.7	0.014	0.014	2.37	NA
209	100.8	33.6	134.4	1407	NA	NA	0.54	0.54	53.1	0.014	0.014	2.51	NA
312	100.8	33.6	134.4	1379	NA	NA	0.57	0.55	51.1	0.015	0.014	2.46	NA
110	100.8	67.2	168	3666	NA	NA	0.57	0.56	53.5	0.015	0.015	2.95	NA
207	100.8	67.2	168	2287	NA	NA	0.50	0.50	46.8	0.013	0.013	2.27	NA
314	100.8	67.2	168	644	NA	NA	0.60	0.55	46.5	0.016	0.015	2.26	NA
117	134.4	0	134.4	1940	NA	NA	0.51	0.53	51.8	0.013	0.014	2.54	NA
201	134.4	0	134.4	767	NA	NA	0.52	0.56	51.4	0.014	0.015	2.26	NA
306	134.4	0	134.4	1877	NA	NA	0.54	0.57	50.7	0.014	0.015	2.34	NA
105	134.4	33.6	168	3300	NA	NA	0.52	0.56	52.6	0.014	0.015	2.59	NA
202	134.4	33.6	168	1660	NA	NA	0.47	0.54	47.8	0.012	0.014	2.32	NA
310	134.4	33.6	168	1465	NA	NA	0.63	0.62	50.5	0.017	0.016	2.46	NA
103	168	0	168	2439	NA	NA	0.52	0.59	50.9	0.014	0.016	2.57	NA
210	168	0	168	2674	NA	NA	0.59	0.61	55.3	0.015	0.016	2.54	NA
316	168	0	168	498	NA	NA	0.62	0.61	53.6	0.016	0.016	2.16	NA

Table A.11 Data for research site: Tribune 2006 Treatment Means

Location	Year	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	HI	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
Tribune	2006	0	0	0	7947	NA	NA	0.64	NA	47.3	0.016	NA	2.05	1.30
Tribune	2006	0	33.6	33.6	8166	NA	NA	0.65	NA	44.7	0.016	NA	2.13	1.34
Tribune	2006	0	67.2	67.2	7702	NA	NA	0.65	NA	44	0.016	NA	2.02	1.37
Tribune	2006	0	100.8	100.8	8047	NA	NA	0.59	NA	42.8	0.015	NA	2.14	1.35
Tribune	2006	0	134.4	134.4	7865	NA	NA	0.60	NA	44.3	0.015	NA	2.16	1.47
Tribune	2006	33.6	0	33.6	8248	NA	NA	0.65	NA	45.2	0.016	NA	2.13	1.45
Tribune	2006	33.6	33.6	67.2	7965	NA	NA	0.68	NA	46.4	0.017	NA	2.10	1.47
Tribune	2006	33.6	67.2	100.8	8342	NA	NA	0.69	NA	46.1	0.017	NA	2.19	1.36
Tribune	2006	33.6	100.8	134.4	8129	NA	NA	0.65	NA	45.6	0.016	NA	2.13	1.46
Tribune	2006	33.6	134.4	168	7827	NA	NA	0.63	NA	45.7	0.016	NA	2.22	1.48
Tribune	2006	67.2	0	67.2	7457	NA	NA	0.64	NA	46.5	0.016	NA	2.15	1.45
Tribune	2006	67.2	33.6	100.8	8260	NA	NA	0.66	NA	45	0.016	NA	2.22	1.46
Tribune	2006	67.2	67.2	134.4	8154	NA	NA	0.64	NA	46	0.016	NA	2.23	1.52
Tribune	2006	67.2	100.8	168	7620	NA	NA	0.66	NA	44.9	0.016	NA	2.19	1.48
Tribune	2006	100.8	0	100.8	7859	NA	NA	0.63	NA	44.4	0.016	NA	2.23	1.46
Tribune	2006	100.8	33.6	134.4	8122	NA	NA	0.67	NA	44.8	0.017	NA	2.30	1.43
Tribune	2006	100.8	67.2	168	8530	NA	NA	0.72	NA	43.5	0.018	NA	2.27	1.54
Tribune	2006	134.4	0	134.4	8204	NA	NA	0.66	NA	45	0.016	NA	2.29	1.51
Tribune	2006	134.4	33.6	168	8254	NA	NA	0.69	NA	46.5	0.017	NA	2.31	1.55
Tribune	2006	168	0	168	8373	NA	NA	0.65	NA	47.1	0.016	NA	2.39	1.52

Table A.12 Data for research site: Tribune 2006 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
108	0	0	0	7562	NA	NA	0.59	NA	44.6	0.017	NA	2.12	1.24
215	0	0	0	6812	NA	NA	0.60	NA	44.6	0.017	NA	2.06	1.30
304	0	0	0	8268	NA	NA	0.70	NA	49.1	0.020	NA	1.94	1.37
403	0	0	0	9156	NA	NA	0.68	NA	50.7	0.019	NA	2.07	1.35
114	0	33.6	33.6	8542	NA	NA	0.61	NA	43.4	0.017	NA	2.28	1.32
209	0	33.6	33.6	7425	NA	NA	0.66	NA	44.5	0.019	NA	2.12	1.34
306	0	33.6	33.6	8363	NA	NA	0.62	NA	43.7	0.018	NA	2.12	1.35
413	0	33.6	33.6	8331	NA	NA	0.71	NA	47.2	0.020	NA	2.00	1.27
105	0	67.2	67.2	8196	NA	NA	0.65	NA	43.1	0.019	NA	2.22	1.50
201	0	67.2	67.2	7254	NA	NA	0.65	NA	47.4	0.019	NA	1.97	1.35
316	0	67.2	67.2	7391	NA	NA	0.65	NA	41.4	0.019	NA	1.90	1.36
408	0	67.2	67.2	7967	NA	NA	0.65	NA	44.2	0.019	NA	1.98	1.32
117	0	100.8	100.8	7678	NA	NA	0.57	NA	45.1	0.016	NA	2.11	1.48
207	0	100.8	100.8	8270	NA	NA	0.58	NA	40.8	0.017	NA	2.30	1.47
305	0	100.8	100.8	7738	NA	NA	0.59	NA	42.7	0.017	NA	1.93	1.46
415	0	100.8	100.8	8500	NA	NA	0.64	NA	42.5	0.018	NA	2.24	1.43
115	0	134.4	134.4	8127	NA	NA	0.55	NA	44.4	0.016	NA	2.33	1.51
216	0	134.4	134.4	8240	NA	NA	0.64	NA	42.7	0.018	NA	2.27	1.41
315	0	134.4	134.4	7425	NA	NA	0.57	NA	42.4	0.016	NA	1.93	1.43
417	0	134.4	134.4	7657	NA	NA	0.64	NA	47.6	0.018	NA	2.13	1.53
102	33.6	0	33.6	8864	NA	NA	0.74	NA	42.5	0.021	NA	2.09	1.46
218	33.6	0	33.6	7657	NA	NA	0.53	NA	42.2	0.015	NA	2.22	1.42
311	33.6	0	33.6	7824	NA	NA	0.58	NA	45.5	0.017	NA	2.15	1.29
407	33.6	0	33.6	8634	NA	NA	0.73	NA	50.5	0.021	NA	2.06	1.38
103	33.6	33.6	67.2	8426	NA	NA	0.70	NA	42.5	0.020	NA	2.13	1.44
202	33.6	33.6	67.2	7329	NA	NA	0.64	NA	47.5	0.018	NA	2.06	1.46
303	33.6	33.6	67.2	7538	NA	NA	0.68	NA	44.9	0.019	NA	2.06	1.46
404	33.6	33.6	67.2	8582	NA	NA	0.68	NA	50.5	0.019	NA	2.16	1.37
110	33.6	67.2	100.8	8594	NA	NA	0.69	NA	46	0.020	NA	2.28	1.53
204	33.6	67.2	100.8	7588	NA	NA	0.72	NA	46.1	0.021	NA	2.16	1.55

Table A.12 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
308	33.6	67.2	100.8	8833	NA	NA	0.70	NA	44.6	0.020	NA	2.04	1.34
402	33.6	67.2	100.8	8363	NA	NA	0.66	NA	47.7	0.019	NA	2.28	1.47
104	33.6	100.8	134.4	8874	NA	NA	0.75	NA	45.1	0.022	NA	2.06	1.54
219	33.6	100.8	134.4	7003	NA	NA	0.52	NA	43.5	0.015	NA	2.27	1.55
313	33.6	100.8	134.4	8655	NA	NA	0.64	NA	44.6	0.018	NA	2.11	1.42
409	33.6	100.8	134.4	7979	NA	NA	0.67	NA	49.1	0.019	NA	2.09	1.41
116	33.6	134.4	168	8479	NA	NA	0.61	NA	44.3	0.018	NA	2.34	1.61
213	33.6	134.4	168	7934	NA	NA	0.66	NA	44.5	0.019	NA	2.22	1.51
312	33.6	134.4	168	8801	NA	NA	0.62	NA	47.1	0.018	NA	2.19	1.42
420	33.6	134.4	168	6097	NA	NA	0.62	NA	47	0.018	NA	2.13	1.57
120	67.2	0	67.2	8101	NA	NA	0.67	NA	47.5	0.019	NA	2.09	1.49
211	67.2	0	67.2	8113	NA	NA	0.70	NA	47.2	0.020	NA	2.24	1.39
320	67.2	0	67.2	5232	NA	NA	0.56	NA	44.8	0.016	NA	2.00	1.50
401	67.2	0	67.2	8373	NA	NA	0.63	NA	46.5	0.018	NA	2.28	1.41
109	67.2	33.6	100.8	8948	NA	NA	0.70	NA	48.1	0.020	NA	2.27	1.46
212	67.2	33.6	100.8	8134	NA	NA	0.64	NA	45.9	0.018	NA	2.40	1.42
314	67.2	33.6	100.8	7341	NA	NA	0.59	NA	40.9	0.017	NA	2.03	1.40
411	67.2	33.6	100.8	8614	NA	NA	0.69	NA	45.1	0.020	NA	2.17	1.48
113	67.2	67.2	134.4	8259	NA	NA	0.62	NA	42.3	0.018	NA	2.44	1.62
206	67.2	67.2	134.4	8164	NA	NA	0.64	NA	47.9	0.018	NA	2.14	1.53
317	67.2	67.2	134.4	7600	NA	NA	0.64	NA	45.5	0.018	NA	2.11	1.48
405	67.2	67.2	134.4	8593	NA	NA	0.67	NA	48.2	0.019	NA	2.22	1.43
101	67.2	100.8	168	8456	NA	NA	0.74	NA	44.6	0.021	NA	2.21	1.47
220	67.2	100.8	168	6083	NA	NA	0.60	NA	41.8	0.017	NA	2.09	1.62
318	67.2	100.8	168	7579	NA	NA	0.61	NA	45	0.017	NA	2.23	1.60
419	67.2	100.8	168	8373	NA	NA	0.69	NA	48.3	0.020	NA	2.21	1.53
106	100.8	0	100.8	8614	NA	NA	0.68	NA	42.1	0.020	NA	2.29	1.51
214	100.8	0	100.8	8250	NA	NA	0.64	NA	43.8	0.018	NA	2.26	1.47
319	100.8	0	100.8	7851	NA	NA	0.63	NA	45.4	0.018	NA	2.20	1.54
418	100.8	0	100.8	6716	NA	NA	0.56	NA	46.2	0.016	NA	2.19	1.54

Table A.12 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
119	100.8	33.6	134.4	7726	NA	NA	0.66	NA	43.7	0.019	NA	2.42	1.60
208	100.8	33.6	134.4	8322	NA	NA	0.59	NA	41.8	0.017	NA	2.16	1.45
309	100.8	33.6	134.4	7675	NA	NA	0.69	NA	44.9	0.020	NA	2.38	1.47
412	100.8	33.6	134.4	8760	NA	NA	0.74	NA	48.7	0.021	NA	2.22	1.46
107	100.8	67.2	168	8447	NA	NA	0.74	NA	47.4	0.021	NA	2.38	1.50
210	100.8	67.2	168	8562	NA	NA	0.67	NA	41.7	0.019	NA	2.41	1.48
307	100.8	67.2	168	8424	NA	NA	0.69	NA	40.6	0.020	NA	2.17	1.41
414	100.8	67.2	168	8676	NA	NA	0.76	NA	44.4	0.022	NA	2.11	1.49
111	134.4	0	134.4	8645	NA	NA	0.69	NA	45.4	0.020	NA	2.52	1.51
217	134.4	0	134.4	7755	NA	NA	0.66	NA	46.2	0.019	NA	2.17	1.55
301	134.4	0	134.4	8122	NA	NA	0.63	NA	44	0.018	NA	2.30	1.53
406	134.4	0	134.4	8280	NA	NA	0.65	NA	44.3	0.019	NA	2.17	1.55
118	134.4	33.6	168	8145	NA	NA	0.61	NA	48.5	0.018	NA	2.41	1.58
205	134.4	33.6	168	7291	NA	NA	0.70	NA	47.4	0.020	NA	2.33	1.54
302	134.4	33.6	168	8456	NA	NA	0.72	NA	43.2	0.021	NA	2.20	1.50
410	134.4	33.6	168	9135	NA	NA	0.73	NA	46.9	0.021	NA	2.31	1.49
112	168	0	168	9468	NA	NA	0.61	NA	46.5	0.017	NA	2.55	1.49
203	168	0	168	7633	NA	NA	0.75	NA	46.4	0.022	NA	2.28	1.56
310	168	0	168	8583	NA	NA	0.60	NA	47.6	0.017	NA	2.38	1.52
416	168	0	168	7812	NA	NA	0.64	NA	47.7	0.018	NA	2.35	1.54

Table A.12 Data for research site: Manhattan 2007 Treatment Means

Location	Year	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
Manhattan	2007	0	0	0	3502	73.8	0.34	0.54	0.55	39.4	0.015	0.015	2.07	1.04
Manhattan	2007	0	33.6	33.6	4552	89.9	0.38	0.51	0.52	41.0	0.014	0.014	2.27	1.08
Manhattan	2007	0	67.2	67.2	5658	110.5	0.40	0.54	0.54	41.3	0.015	0.015	2.49	1.14
Manhattan	2007	0	100.8	100.8	6712	128.9	0.44	0.52	0.54	40.6	0.014	0.015	2.46	1.24
Manhattan	2007	0	134.4	134.4	7036	138.8	0.44	0.55	0.54	39.6	0.015	0.015	2.66	1.31
Manhattan	2007	33.6	0	33.6	4914	87.6	0.40	0.62	0.60	44.4	0.017	0.017	2.23	1.04
Manhattan	2007	33.6	33.6	67.2	5581	116.7	0.38	0.65	0.61	45.3	0.018	0.017	2.36	1.16
Manhattan	2007	33.6	67.2	100.8	6208	141.5	0.38	0.63	0.60	43.4	0.017	0.017	2.53	1.21
Manhattan	2007	33.6	100.8	134.4	6766	148.4	0.48	0.60	0.59	43.6	0.017	0.017	2.68	1.46
Manhattan	2007	67.2	0	67.2	5580	117.6	0.39	0.66	0.63	45.8	0.018	0.017	2.33	1.13
Manhattan	2007	67.2	33.6	100.8	6176	132.5	0.41	0.61	0.59	44.5	0.017	0.016	2.59	1.27
Manhattan	2007	67.2	67.2	134.4	6561	136.9	0.41	0.62	0.61	45.5	0.017	0.017	2.59	1.22
Manhattan	2007	100.8	0	100.8	6210	122.3	0.44	0.64	0.62	45.8	0.018	0.017	2.30	1.18
Manhattan	2007	100.8	33.6	134.4	6375	132.0	0.43	0.63	0.61	46.2	0.017	0.017	2.41	1.29
Manhattan	2007	134.4	0	134.4	6358	119.3	0.45	0.63	0.61	46.6	0.018	0.017	2.47	1.23

Table A.13 Data for research site: Manhattan 2007 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
106	0	0	0	3726	64.8	0.42	0.60	0.59	40.7	0.017	0.016	2.07	1.05
210	0	0	0	3019	69.6	0.25	0.50	0.55	38.2	0.014	0.015	2.09	0.96
302	0	0	0	3630	72.3	0.35	0.57	0.55	38.6	0.016	0.015	2.07	1.01
403	0	0	0	3634	86.7	0.37	0.50	0.51	40.1	0.014	0.014	2.04	1.14
111	0	33.6	33.6	4709	81.0	0.40	0.55	0.55	41.5	0.015	0.015	2.23	1.04
206	0	33.6	33.6	4426	91.4	0.31	0.58	0.55	42.3	0.016	0.015	2.32	1.00
304	0	33.6	33.6	4948	88.4	0.43	0.55	0.56	39.1	0.015	0.015	2.49	1.03
412	0	33.6	33.6	4126	92.6	0.42	0.38	0.42	41.1	0.010	0.012	2.04	1.25
115	0	67.2	67.2	7052	104.3	0.54	0.56	0.54	42.6	0.016	0.015	2.43	1.13
212	0	67.2	67.2	4827	91.6	0.30	0.53	0.53	41.5	0.015	0.015	2.63	1.09
311	0	67.2	67.2	5708	120.6	0.38	0.55	0.57	40.6	0.015	0.016	2.47	1.11
408	0	67.2	67.2	5045	122.6	0.39	0.51	0.52	40.6	0.014	0.015	2.42	1.21
113	0	100.8	100.8	6694	118.7	0.44	0.53	0.54	39	0.015	0.015	2.57	1.18
204	0	100.8	100.8	7160	157.0	0.38	0.54	0.56	42.8	0.015	0.016	2.53	1.29
303	0	100.8	100.8	6202	103.3	0.48	0.51	0.54	41.2	0.014	0.015	2.40	1.13
413	0	100.8	100.8	6793	137.3	0.49	0.49	0.51	39.3	0.014	0.014	2.35	1.36
112	0	134.4	134.4	7291	139.0	0.40	0.55	0.53	39.2	0.015	0.015	2.75	1.17
211	0	134.4	134.4	6786	129.8	0.37	0.59	0.55	40.5	0.016	0.015	2.82	1.26
310	0	134.4	134.4	6593	126.3	0.50	0.50	0.54	39.2	0.014	0.015	2.64	1.29
414	0	134.4	134.4	7473	153.1	0.52	0.55	0.54	39.4	0.015	0.015	2.44	1.50
101	33.6	0	33.6	5169	80.5	0.44	0.63	0.61	44.6	0.018	0.017	2.23	1.04
213	33.6	0	33.6	5579	85.7	0.39	0.59	0.58	45.2	0.017	0.016	2.44	1.02
307	33.6	0	33.6	4799	92.5	0.40	0.69	0.66	44.1	0.019	0.018	2.23	1.01
407	33.6	0	33.6	4110	87.7	0.39	0.55	0.56	43.6	0.015	0.016	2.02	1.08
102	33.6	33.6	67.2	6563	113.0	0.51	0.65	0.60	48.9	0.018	0.017	2.32	1.18
201	33.6	33.6	67.2	4801	99.5	0.30	0.65	0.61	44.3	0.018	0.017	2.30	1.13
301	33.6	33.6	67.2	4990	118.0	0.31	0.68	0.64	43.8	0.019	0.018	2.41	1.18
404	33.6	33.6	67.2	5971	131.3	0.42	0.63	0.60	44.2	0.018	0.017	2.42	1.15
108	33.6	67.2	100.8	6891	121.8	0.45	0.58	0.57	43.9	0.016	0.016	2.61	1.11
202	33.6	67.2	100.8	5731	194.8	0.23	0.64	0.60	44	0.018	0.017	2.71	1.28
305	33.6	67.2	100.8	6279	116.4	0.47	0.63	0.61	43.3	0.018	0.017	2.46	1.27
402	33.6	67.2	100.8	5932	128.2	0.47	0.66	0.62	42.4	0.018	0.017	2.33	1.18

Table A.13 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
103	33.6	100.8	134.4	6274	127.1	0.52	0.60	0.61	42.4	0.017	0.017	2.80	1.36
214	33.6	100.8	134.4	7101	120.2	0.51	0.56	0.56	43.8	0.016	0.016	2.94	1.30
308	33.6	100.8	134.4	6419	156.2	0.44	0.62	0.61	44.4	0.017	0.017	2.43	1.55
409	33.6	100.8	134.4	7270	193.7	0.46	0.62	0.60	43.6	0.017	0.017	2.56	1.65
114	67.2	0	67.2	5955	112.4	0.39	0.66	0.63	46.6	0.018	0.017	2.33	1.13
207	67.2	0	67.2	5226	93.7	0.32	0.66	0.62	45.8	0.018	0.017	2.41	1.06
314	67.2	0	67.2	6271	135.2	0.45	0.63	0.62	46	0.018	0.017	2.49	1.26
401	67.2	0	67.2	4869	114.2	0.43	0.67	0.63	44.9	0.019	0.018	2.08	1.08
107	67.2	33.6	100.8	6210	111.1	0.40	0.60	0.57	43.2	0.017	0.016	2.54	1.18
208	67.2	33.6	100.8	6331	133.6	0.34	0.56	0.56	46.7	0.016	0.016	2.74	1.22
309	67.2	33.6	100.8	6337	148.6	0.48	0.62	0.60	45.1	0.017	0.017	2.52	1.39
410	67.2	33.6	100.8	5826	124.0	0.44	0.64	0.62	43.1	0.018	0.017	2.55	1.27
110	67.2	67.2	134.4	6711	118.9	0.41	0.57	0.59	46.2	0.016	0.016	2.64	1.14
203	67.2	67.2	134.4	6777	129.5	0.38	0.60	0.60	45.9	0.017	0.017	2.82	1.26
312	67.2	67.2	134.4	6337	150.8	0.41	0.72	0.67	45.9	0.020	0.019	2.68	1.25
405	67.2	67.2	134.4	6419	141.0	0.45	0.59	0.60	44.1	0.016	0.017	2.21	1.25
105	100.8	0	100.8	7100	107.1	0.58	0.59	0.63	47.1	0.016	0.017	2.42	1.11
209	100.8	0	100.8	6588	116.0	0.37	0.67	0.63	46.4	0.019	0.017	2.45	1.10
313	100.8	0	100.8	6231	156.7	0.42	0.62	0.62	45.1	0.017	0.017	2.40	1.38
415	100.8	0	100.8	4920	102.7	0.43	0.69	0.61	44.4	0.019	0.017	1.95	1.12
104	100.8	33.6	134.4	7084	138.9	0.44	0.62	0.59	47.7	0.017	0.016	2.54	1.31
205	100.8	33.6	134.4	6428	143.4	0.38	0.63	0.63	47.1	0.017	0.018	2.57	1.28
306	100.8	33.6	134.4	5630	127.4	0.43	0.66	0.62	45.6	0.018	0.017	2.45	1.33
411	100.8	33.6	134.4	6358	116.5	0.50	0.61	0.57	44.5	0.017	0.016	2.07	1.24
109	134.4	0	134.4	7185	122.0	0.49	0.64	0.62	46.8	0.018	0.017	2.43	1.23
215	134.4	0	134.4	6937	114.8	0.47	0.66	0.63	46.8	0.018	0.018	2.66	1.27
315	134.4	0	134.4	5727	128.0	0.43	0.60	0.59	47.1	0.017	0.016	2.49	1.28
406	134.4	0	134.4	5585	113.1	0.41	0.62	0.60	45.8	0.017	0.017	2.30	1.15

Table A.14 Data for research site: Partridge 2007 Treatment Means

Location	Year	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
Partridge	2007	0	0	0	3886	NA	NA	0.59	0.56	46	0.015	0.014	2.36	1.35
Partridge	2007	0	33.6	33.6	4409	NA	NA	0.57	0.57	46.5	0.014	0.014	2.34	1.34
Partridge	2007	0	67.2	67.2	3895	NA	NA	0.53	0.53	46.9	0.013	0.013	2.22	1.46
Partridge	2007	0	100.8	100.8	4215	NA	NA	0.60	0.58	47.6	0.015	0.015	2.36	1.57
Partridge	2007	0	134.4	134.4	3562	NA	NA	0.54	0.53	44.5	0.013	0.013	2.20	1.55
Partridge	2007	33.6	0	33.6	4334	NA	NA	0.54	0.54	49.8	0.013	0.013	2.30	1.4
Partridge	2007	33.6	33.6	67.2	4020	NA	NA	0.56	0.56	47.2	0.014	0.014	2.39	1.55
Partridge	2007	33.6	67.2	100.8	4020	NA	NA	0.63	0.59	47.8	0.016	0.015	2.32	1.56
Partridge	2007	33.6	100.8	134.4	4140	NA	NA	0.56	0.55	48.1	0.014	0.014	2.56	1.56
Partridge	2007	67.2	0	67.2	4394	NA	NA	0.62	0.59	48.1	0.015	0.014	2.34	1.53
Partridge	2007	67.2	33.6	100.8	4491	NA	NA	0.59	0.57	50.3	0.015	0.014	2.43	1.54
Partridge	2007	67.2	67.2	134.4	4591	NA	NA	0.59	0.57	49	0.015	0.014	2.44	1.61
Partridge	2007	100.8	0	100.8	4522	NA	NA	0.62	0.59	49.1	0.016	0.015	2.42	1.56
Partridge	2007	100.8	33.6	134.4	3945	NA	NA	0.55	0.56	49.1	0.014	0.014	2.57	1.57
Partridge	2007	134.4	0	134.4	4196	NA	NA	0.50	0.52	46.8	0.012	0.013	2.54	1.58

Table A.15 Data for research site: Partridge 2007 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
114	0	0	0	4317	NA	NA	0.42	0.45	46.8	0.011	0.012	2.48	1.46
208	0	0	0	5221	NA	NA	0.50	0.50	48.6	0.014	0.009	2.69	1.51
301	0	0	0	3158	NA	NA	0.64	0.59	40.2	0.015	0.014	1.94	1.19
410	0	0	0	3975	NA	NA	0.61	0.56	47.7	0.016	0.007	2.32	1.29
108	0	33.6	33.6	4626	NA	NA	0.48	0.50	45.3	0.013	0.010	2.44	1.57
203	0	33.6	33.6	4845	NA	NA	0.69	0.64	47.8	0.016	0.015	2.24	1.26
314	0	33.6	33.6	4940	NA	NA	0.41	0.48	48.2	0.011	0.012	2.73	1.41
405	0	33.6	33.6	3230	NA	NA	0.68	0.62	44.6	0.016	0.015	1.98	1.13
101	0	67.2	67.2	3149	NA	NA	0.69	0.60	44.6	0.016	0.014	2.14	1.39
214	0	67.2	67.2	4252	NA	NA	0.34	0.41	45.1	0.009	0.014	2.69	1.56
305	0	67.2	67.2	3819	NA	NA	0.65	0.62	50.1	0.015	0.014	2.15	1.46
404	0	67.2	67.2	3230	NA	NA	0.65	0.61	48.4	0.015	0.014	1.88	1.43
113	0	100.8	100.8	4762	NA	NA	0.42	0.46	45.9	0.011	0.011	2.33	1.52
205	0	100.8	100.8	4431	NA	NA	0.70	0.65	51.2	0.016	0.015	2.38	1.52
312	0	100.8	100.8	4891	NA	NA	0.50	0.53	46	0.014	0.009	2.47	1.71
415	0	100.8	100.8	3910	NA	NA	0.56	0.55	46.8	0.015	0.008	2.28	1.59
112	0	134.4	134.4	4691	NA	NA	0.41	0.45	49.7	0.011	0.012	2.37	1.72
206	0	134.4	134.4	4527	NA	NA	0.68	0.63	50.3	0.016	0.015	2.40	1.56
302	0	134.4	134.4	1596	NA	NA	0.45	0.45	33.5	0.010	0.011	1.79	1.46
411	0	134.4	134.4	3430	NA	NA	0.61	0.56	44.4	0.017	0.007	2.23	1.48
106	33.6	0	33.6	4118	NA	NA	0.68	0.61	51.5	0.016	0.014	2.33	1.47
202	33.6	0	33.6	3263	NA	NA	0.63	0.59	48.5	0.015	0.014	2.21	1.28
313	33.6	0	33.6	5125	NA	NA	0.42	0.47	51.7	0.011	0.011	2.63	1.44
403	33.6	0	33.6	3694	NA	NA	0.64	0.62	48.2	0.015	0.014	2.02	1.38
109	33.6	33.6	67.2	4973	NA	NA	0.42	0.48	49.9	0.011	0.011	2.47	1.60
213	33.6	33.6	67.2	4710	NA	NA	0.42	0.46	45.8	0.011	0.011	2.44	1.52
303	33.6	33.6	67.2	2944	NA	NA	0.68	0.64	46.4	0.016	0.015	2.17	1.53
414	33.6	33.6	67.2	4572	NA	NA	0.51	0.51	45.9	0.014	0.009	2.47	1.61
104	33.6	67.2	100.8	4152	NA	NA	0.74	0.65	48.8	0.017	0.015	2.15	1.67
201	33.6	67.2	100.8	3690	NA	NA	0.69	0.63	46.7	0.016	0.015	2.23	1.38
307	33.6	67.2	100.8	4142	NA	NA	0.49	0.52	47.7	0.013	0.010	2.46	1.65
408	33.6	67.2	100.8	4101	NA	NA	0.59	0.56	48	0.016	0.007	2.46	1.55

Table A.15 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
110	33.6	100.8	134.4	4995	NA	NA	0.38	0.45	45.5	0.010	0.012	2.71	1.61
212	33.6	100.8	134.4	5088	NA	NA	0.45	0.47	48.6	0.012	0.011	2.66	1.56
311	33.6	100.8	134.4	4630	NA	NA	0.39	0.46	48.5	0.011	0.012	2.52	1.63
412	33.6	100.8	134.4	4111	NA	NA	0.57	0.56	48.5	0.015	0.008	2.35	1.55
103	67.2	0	67.2	3743	NA	NA	0.74	0.63	49.9	0.017	0.015	2.07	1.44
207	67.2	0	67.2	5626	NA	NA	0.52	0.52	46.7	0.014	0.009	2.56	1.53
306	67.2	0	67.2	3844	NA	NA	0.67	0.65	50.9	0.016	0.015	2.25	1.53
413	67.2	0	67.2	4361	NA	NA	0.56	0.55	45	0.015	0.008	2.45	1.58
102	67.2	33.6	100.8	3658	NA	NA	0.74	0.64	50.7	0.017	0.015	2.19	1.45
210	67.2	33.6	100.8	5647	NA	NA	0.44	0.47	47.4	0.012	0.011	2.62	1.50
310	67.2	33.6	100.8	5023	NA	NA	0.47	0.49	49.2	0.013	0.010	2.58	1.55
401	67.2	33.6	100.8	3638	NA	NA	0.71	0.68	54	0.017	0.016	2.34	1.69
105	67.2	67.2	134.4	3549	NA	NA	0.71	0.62	49.5	0.017	0.014	2.38	1.68
204	67.2	67.2	134.4	4856	NA	NA	0.71	0.66	50.7	0.016	0.015	2.36	1.56
309	67.2	67.2	134.4	5208	NA	NA	0.44	0.48	47.8	0.012	0.011	2.66	1.69
406	67.2	67.2	134.4	3642	NA	NA	0.72	0.67	48.8	0.017	0.015	2.35	1.48
107	100.8	0	100.8	4866	NA	NA	0.52	0.53	46.8	0.014	0.009	2.29	1.49
209	100.8	0	100.8	5824	NA	NA	0.47	0.48	48.9	0.013	0.010	2.68	1.56
304	100.8	0	100.8	3605	NA	NA	0.69	0.65	50.4	0.016	0.015	2.22	1.65
409	100.8	0	100.8	4924	NA	NA	0.58	0.56	49.5	0.016	0.007	2.48	1.62
111	100.8	33.6	134.4	5166	NA	NA	0.44	0.49	48.8	0.012	0.011	2.44	1.59
215	100.8	33.6	134.4	4092	NA	NA	0.35	0.42	45.1	0.009	0.013	2.53	1.56
308	100.8	33.6	134.4	4795	NA	NA	0.44	0.49	51.8	0.012	0.011	2.75	1.67
407	100.8	33.6	134.4	3986	NA	NA	0.55	0.56	49.3	0.015	0.008	2.56	1.55
115	134.4	0	134.4	4418	NA	NA	0.38	0.44	47.1	0.010	0.012	2.58	1.69
211	134.4	0	134.4	4865	NA	NA	0.36	0.41	45.2	0.010	0.013	2.65	1.64
315	134.4	0	134.4	5502	NA	NA	0.38	0.46	44	0.010	0.013	2.66	1.49
402	134.4	0	134.4	3132	NA	NA	0.66	0.63	50.3	0.015	0.015	2.28	1.55

Table A.16 Data for research site: Tribune 2007 Treatment Means

Location	Year	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
Tribune	2007	0	0	0	4987	100.1	0.52	0.53	0.50	42.9	0.015	0.014	2.67	1.87
Tribune	2007	0	33.6	33.6	4778	94.4	0.56	0.49	0.48	42.6	0.014	0.014	2.59	1.90
Tribune	2007	0	67.2	67.2	5618	114.1	0.53	0.52	0.49	42.9	0.015	0.014	2.75	1.72
Tribune	2007	0	100.8	100.8	5560	115.3	0.55	0.57	0.51	42.1	0.016	0.015	2.66	1.92
Tribune	2007	0	134.4	134.4	4916	NA	NA	0.48	0.46	43.2	0.014	0.013	2.76	1.91
Tribune	2007	33.6	0	33.6	4562	93.7	0.54	0.48	0.47	42.2	0.014	0.014	2.58	1.85
Tribune	2007	33.6	33.6	67.2	5068	NA	NA	0.58	0.51	43.3	0.017	0.015	2.69	1.94
Tribune	2007	33.6	67.2	100.8	4380	NA	NA	0.53	0.50	42.3	0.015	0.014	2.64	1.92
Tribune	2007	33.6	100.8	134.4	4392	NA	NA	0.54	0.51	42.3	0.015	0.014	2.71	1.99
Tribune	2007	67.2	0	67.2	4977	102.5	0.55	0.51	0.49	45.1	0.015	0.014	2.68	1.83
Tribune	2007	67.2	33.6	100.8	4185	NA	NA	0.43	0.45	44.2	0.012	0.013	2.73	2.01
Tribune	2007	67.2	67.2	134.4	4700	NA	NA	0.50	0.49	44.5	0.014	0.014	2.69	1.99
Tribune	2007	100.8	0	100.8	4516	104	0.53	0.52	0.50	45.3	0.015	0.014	2.64	2.00
Tribune	2007	100.8	33.6	134.4	4863	NA	NA	0.45	0.45	44.9	0.013	0.013	2.84	1.87
Tribune	2007	134.4	0	134.4	5191	NA	NA	0.47	0.47	45.3	0.013	0.013	2.75	2.05

Table A.17 Data for research site: Tribune 2007 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
114	0	0	0	5868	110.8	0.56	0.56	0.50	41.7	0.016	0.014	2.64	1.74
208	0	0	0	5773	111.2	0.58	0.46	0.47	43.2	0.013	0.013	2.82	1.87
301	0	0	0	3387	77.7	0.42	0.53	0.50	43.3	0.015	0.014	2.48	1.98
410	0	0	0	4921	100.8	0.52	0.57	0.52	43.4	0.016	0.015	2.76	1.85
108	0	33.6	33.6	2531	72.0	0.44	0.47	0.47	42.2	0.014	0.013	2.50	2.04
203	0	33.6	33.6	5611	108.0	0.60	0.43	0.47	41.8	0.012	0.013	2.76	1.83
314	0	33.6	33.6	6426	114.4	0.59	0.61	0.52	42.3	0.018	0.015	2.43	1.68
405	0	33.6	33.6	4544	83.4	0.61	0.42	0.44	44.1	0.012	0.013	2.68	1.75
101	0	67.2	67.2	6507	119.2	0.59	0.39	0.42	41	0.011	0.012	2.80	1.71
214	0	67.2	67.2	7591	138.3	0.59	0.58	0.53	43.6	0.016	0.015	2.90	1.73
305	0	67.2	67.2	3961	103.6	0.44	0.62	0.54	43.8	0.018	0.015	2.68	2.10
404	0	67.2	67.2	4412	95.1	0.49	0.51	0.49	43.3	0.015	0.014	2.60	1.94
113	0	100.8	100.8	5740	113.6	0.50	0.55	0.49	41.3	0.016	0.014	2.72	1.75
205	0	100.8	100.8	5760	116.9	0.57	0.49	0.49	44.7	0.014	0.014	2.69	1.87
312	0	100.8	100.8	4083	99.7	0.48	0.61	0.52	40.3	0.017	0.015	2.48	2.11
415	0	100.8	100.8	6656	131.1	0.62	0.61	0.55	41.9	0.018	0.016	2.77	1.87
112	0	134.4	134.4	6103	NA	NA	0.47	0.43	42	0.013	0.012	2.94	1.74
206	0	134.4	134.4	5018	NA	NA	0.45	0.46	41.9	0.013	0.013	2.73	1.94
302	0	134.4	134.4	3713	NA	NA	0.43	0.42	47.1	0.012	0.012	2.69	1.90
411	0	134.4	134.4	4829	NA	NA	0.56	0.51	41.8	0.016	0.015	2.70	2.03
106	33.6	0	33.6	3925	79.0	0.51	0.51	0.49	41.2	0.015	0.014	2.45	1.89
202	33.6	0	33.6	4921	96.1	0.59	0.46	0.46	44.5	0.013	0.013	2.76	1.82
313	33.6	0	33.6	5396	110.1	0.54	0.54	0.50	42.3	0.016	0.014	2.49	1.89
403	33.6	0	33.6	4006	89.7	0.51	0.42	0.45	40.7	0.012	0.013	2.61	2.06
109	33.6	33.6	67.2	3929	NA	NA	0.53	0.49	44.4	0.015	0.014	2.53	2.00
213	33.6	33.6	67.2	6131	NA	NA	0.59	0.54	42	0.017	0.015	2.70	1.90
303	33.6	33.6	67.2	3395	NA	NA	0.57	0.46	41.9	0.016	0.013	2.75	2.06
414	33.6	33.6	67.2	6818	NA	NA	0.63	0.54	44.7	0.018	0.015	2.80	1.78
104	33.6	67.2	100.8	4363	NA	NA	0.49	0.48	40.9	0.014	0.014	2.58	1.96
201	33.6	67.2	100.8	5234	NA	NA	0.51	0.49	41.9	0.015	0.014	2.63	1.75
307	33.6	67.2	100.8	3658	NA	NA	0.58	0.51	43.6	0.017	0.014	2.63	2.10
408	33.6	67.2	100.8	4264	NA	NA	0.53	0.51	42.8	0.015	0.014	2.71	1.92

Table A.17 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
110	33.6	100.8	134.4	3735	NA	NA	0.41	0.44	43	0.012	0.013	2.67	2.01
212	33.6	100.8	134.4	4954	NA	NA	0.60	0.55	41.1	0.017	0.016	2.77	1.98
311	33.6	100.8	134.4	4002	NA	NA	0.53	0.49	42.3	0.015	0.014	2.72	2.07
412	33.6	100.8	134.4	4878	NA	NA	0.61	0.55	42.6	0.018	0.016	2.69	1.92
103	67.2	0	67.2	4454	94.9	0.51	0.42	0.45	43.4	0.012	0.013	2.58	1.97
207	67.2	0	67.2	5861	108.7	0.65	0.56	0.55	45	0.016	0.016	2.80	1.85
306	67.2	0	67.2	3457	91.7	0.44	0.58	0.50	45.2	0.017	0.014	2.52	2.17
413	67.2	0	67.2	6137	114.4	0.59	0.48	0.47	46.7	0.014	0.013	2.81	1.75
102	67.2	33.6	100.8	4182	NA	NA	0.36	0.39	41.9	0.010	0.011	2.75	1.95
210	67.2	33.6	100.8	5050	NA	NA	0.53	0.53	45.5	0.015	0.015	2.79	1.92
310	67.2	33.6	100.8	4412	NA	NA	0.56	0.51	43.6	0.016	0.015	2.64	2.10
401	67.2	33.6	100.8	3096	NA	NA	0.26	0.36	45.9	0.007	0.010	2.75	2.05
105	67.2	67.2	134.4	4042	NA	NA	0.51	0.50	43.1	0.014	0.014	2.52	2.01
204	67.2	67.2	134.4	6487	NA	NA	0.46	0.47	46.1	0.013	0.014	2.80	1.82
309	67.2	67.2	134.4	4119	NA	NA	0.48	0.47	45.6	0.014	0.013	2.79	2.04
406	67.2	67.2	134.4	4151	NA	NA	0.56	0.52	43.2	0.016	0.015	2.65	2.02
107	100.8	0	100.8	3527	96.8	0.47	0.54	0.51	43.4	0.015	0.015	2.47	2.15
209	100.8	0	100.8	6252	122.9	0.62	0.49	0.49	46	0.014	0.014	2.81	1.84
304	100.8	0	100.8	3391	92.7	0.47	0.51	0.48	45	0.015	0.014	2.50	2.14
409	100.8	0	100.8	4894	103.8	0.56	0.56	0.52	46.6	0.016	0.015	2.76	1.95
111	100.8	33.6	134.4	5105	NA	NA	0.52	0.48	44.9	0.015	0.014	2.68	1.84
215	100.8	33.6	134.4	7833	NA	NA	0.48	0.50	44.4	0.014	0.014	2.90	1.65
308	100.8	33.6	134.4	3442	NA	NA	0.23	0.34	44.3	0.007	0.010	3.10	2.02
407	100.8	33.6	134.4	3072	NA	NA	0.54	0.51	46.1	0.015	0.014	2.69	2.14
115	134.4	0	134.4	6043	NA	NA	0.60	0.54	46.3	0.017	0.015	2.65	1.80
211	134.4	0	134.4	4942	NA	NA	0.56	0.53	46.6	0.016	0.015	2.73	2.02
315	134.4	0	134.4	7644	NA	NA	0.55	0.51	42.6	0.016	0.015	2.88	1.83
402	134.4	0	134.4	2134	NA	NA	0.15	0.29	45.7	0.004	0.008	2.73	1.84

Table A.18 Data for research site: Manhattan 2008 Treatment Means

Location	Year	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
Manhattan	2008	0	0	0	6621	NA	NA	0.76	0.65	38.5	0.020	0.017	2.41	1.11
Manhattan	2008	0	33.6	33.6	7938	NA	NA	0.75	0.65	38.7	0.020	0.017	2.51	1.18
Manhattan	2008	0	67.2	67.2	8430	NA	NA	0.76	0.66	39.85	0.020	0.017	2.58	1.28
Manhattan	2008	0	100.8	100.8	8772	NA	NA	0.77	0.67	39.4	0.020	0.018	2.59	1.31
Manhattan	2008	0	134.4	134.4	9022	NA	NA	0.76	0.66	38.75	0.020	0.017	2.63	1.36
Manhattan	2008	33.6	0	33.6	7628	NA	NA	0.78	0.68	40.1	0.021	0.018	2.39	1.15
Manhattan	2008	33.6	33.6	67.2	8182	NA	NA	0.77	0.67	39.8	0.020	0.018	2.54	1.23
Manhattan	2008	33.6	67.2	100.8	8960	NA	NA	0.78	0.68	39.45	0.021	0.018	2.54	1.28
Manhattan	2008	33.6	100.8	134.4	8944	NA	NA	0.78	0.68	40	0.021	0.018	2.69	1.27
Manhattan	2008	67.2	0	67.2	8017	NA	NA	0.78	0.68	40.275	0.021	0.018	2.62	1.19
Manhattan	2008	67.2	33.6	100.8	8367	NA	NA	0.79	0.69	40.975	0.021	0.018	2.65	1.29
Manhattan	2008	67.2	67.2	134.4	9041	NA	NA	0.77	0.67	40.325	0.020	0.018	2.62	1.43
Manhattan	2008	100.8	0	100.8	8064	NA	NA	0.78	0.68	39.575	0.021	0.018	2.58	1.32
Manhattan	2008	100.8	33.6	134.4	8814	NA	NA	0.79	0.69	41.25	0.021	0.018	2.60	1.34
Manhattan	2008	134.4	0	134.4	8573	NA	NA	0.78	0.69	40.975	0.021	0.018	2.63	1.34

Table A.19 Data for research site: Manhattan 2008 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
115	0	0	0	6943	NA	NA	0.76	0.65	38.8	0.019	0.017	2.29	1.08
208	0	0	0	6309	NA	NA	0.73	0.63	38.7	0.019	0.016	2.44	1.03
304	0	0	0	6534	NA	NA	0.78	0.67	39.5	0.020	0.017	2.42	1.27
408	0	0	0	6698	NA	NA	0.76	0.66	37	0.019	0.017	2.48	1.06
114	0	33.6	33.6	7685	NA	NA	0.74	0.63	39	0.019	0.016	2.52	1.14
214	0	33.6	33.6	8614	NA	NA	0.74	0.65	38.4	0.019	0.017	2.64	1.12
308	0	33.6	33.6	7107	NA	NA	0.76	0.66	37.4	0.019	0.017	2.32	1.19
410	0	33.6	33.6	8348	NA	NA	0.76	0.67	40	0.020	0.017	2.55	1.14
107	0	67.2	67.2	8876	NA	NA	0.77	0.66	40	0.020	0.017	2.46	1.17
215	0	67.2	67.2	7889	NA	NA	0.75	0.65	41.5	0.019	0.017	2.81	1.21
314	0	67.2	67.2	8186	NA	NA	0.77	0.66	39.3	0.020	0.017	2.41	1.30
407	0	67.2	67.2	8769	NA	NA	0.76	0.66	38.6	0.019	0.017	2.63	1.26
104	0	100.8	100.8	8206	NA	NA	0.80	0.67	39.6	0.020	0.017	2.51	1.37
210	0	100.8	100.8	9537	NA	NA	0.78	0.67	41	0.020	0.017	2.61	1.25
301	0	100.8	100.8	9805	NA	NA	0.74	0.65	39.1	0.019	0.017	2.68	1.22
411	0	100.8	100.8	7539	NA	NA	0.76	0.67	37.9	0.019	0.017	2.58	1.29
112	0	134.4	134.4	8435	NA	NA	0.78	0.67	38.3	0.020	0.017	2.62	1.29
202	0	134.4	134.4	9538	NA	NA	0.77	0.65	41.2	0.020	0.017	2.65	1.28
315	0	134.4	134.4	8737	NA	NA	0.76	0.65	38.5	0.019	0.017	2.54	1.10
404	0	134.4	134.4	9379	NA	NA	0.74	0.66	37	0.019	0.017	2.72	1.41
109	33.6	0	33.6	7797	NA	NA	0.78	0.68	43.5	0.020	0.017	2.48	1.13
203	33.6	0	33.6	8146	NA	NA	0.78	0.68	41.9	0.020	0.017	2.66	1.21
311	33.6	0	33.6	6860	NA	NA	0.79	0.69	35.4	0.020	0.018	1.93	1.26
412	33.6	0	33.6	7710	NA	NA	0.78	0.68	39.6	0.020	0.017	2.51	1.14
106	33.6	33.6	67.2	8624	NA	NA	0.77	0.66	38.5	0.020	0.017	2.67	1.16
212	33.6	33.6	67.2	8810	NA	NA	0.80	0.70	41.9	0.020	0.018	2.73	1.21
313	33.6	33.6	67.2	7459	NA	NA	0.78	0.69	39.6	0.020	0.018	2.66	1.24
414	33.6	33.6	67.2	7835	NA	NA	0.73	0.65	39.2	0.019	0.017	2.11	1.16

Table A.19 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
108	33.6	67.2	100.8	9379	NA	NA	0.78	0.67	40.3	0.020	0.017	2.44	1.19
201	33.6	67.2	100.8	8888	NA	NA	0.77	0.67	39.2	0.020	0.017	2.48	1.28
309	33.6	67.2	100.8	8370	NA	NA	0.80	0.70	38.6	0.020	0.018	2.59	1.31
406	33.6	67.2	100.8	9203	NA	NA	0.77	0.67	39.7	0.020	0.017	2.64	1.37
103	33.6	100.8	134.4	7889	NA	NA	0.81	0.68	38.8	0.021	0.017	2.64	1.40
206	33.6	100.8	134.4	10102	NA	NA	0.78	0.67	40	0.020	0.017	2.94	1.35
310	33.6	100.8	134.4	8688	NA	NA	0.79	0.69	40	0.020	0.018	2.42	1.37
402	33.6	100.8	67.2	9098	NA	NA	0.76	0.68	41.2	0.019	0.017	2.78	1.60
111	67.2	0	67.2	8331	NA	NA	0.79	0.68	39.8	0.020	0.017	2.56	1.19
209	67.2	0	67.2	7405	NA	NA	0.79	0.70	39.5	0.020	0.018	2.57	1.19
306	67.2	0	67.2	8271	NA	NA	0.76	0.67	41.2	0.020	0.017	2.71	1.34
405	67.2	0	100.8	8060	NA	NA	0.78	0.68	40.6	0.020	0.017	2.65	1.40
113	67.2	33.6	100.8	8399	NA	NA	0.79	0.68	40.9	0.020	0.017	2.62	1.29
204	67.2	33.6	100.8	9346	NA	NA	0.77	0.67	41.5	0.020	0.017	2.69	1.28
312	67.2	33.6	100.8	7099	NA	NA	0.82	0.71	40.5	0.021	0.018	2.53	1.29
403	67.2	33.6	134.4	8624	NA	NA	0.77	0.68	41	0.020	0.018	2.76	1.43
110	67.2	67.2	134.4	9397	NA	NA	0.81	0.69	41.4	0.021	0.018	2.67	1.26
205	67.2	67.2	134.4	9790	NA	NA	0.77	0.67	41.4	0.020	0.017	2.85	1.26
302	67.2	67.2	134.4	8852	NA	NA	0.78	0.68	39.3	0.020	0.018	2.81	1.38
415	67.2	67.2	100.8	8127	NA	NA	0.73	0.65	39.2	0.019	0.017	2.17	1.47
101	100.8	0	100.8	7301	NA	NA	0.81	0.69	37.3	0.021	0.018	2.31	1.25
211	100.8	0	100.8	8429	NA	NA	0.78	0.68	39.1	0.020	0.017	2.81	1.20
303	100.8	0	100.8	8224	NA	NA	0.76	0.68	40.2	0.020	0.017	2.56	1.49
413	100.8	0	134.4	8301	NA	NA	0.77	0.69	41.7	0.020	0.018	2.63	1.30
105	100.8	33.6	134.4	8810	NA	NA	0.81	0.68	39.1	0.021	0.018	2.70	1.25
213	100.8	33.6	134.4	9458	NA	NA	0.77	0.68	42.5	0.020	0.017	2.80	1.29
307	100.8	33.6	134.4	8100	NA	NA	0.79	0.70	41.3	0.020	0.018	2.29	1.41
409	100.8	33.6	134.4	8889	NA	NA	0.77	0.68	42.1	0.020	0.017	2.60	1.42
102	134.4	0	134.4	8592	NA	NA	0.82	0.70	41.8	0.021	0.018	2.44	1.33
207	134.4	0	134.4	8949	NA	NA	0.77	0.67	39.6	0.020	0.017	2.79	1.31
305	134.4	0	134.4	7898	NA	NA	0.78	0.69	42.1	0.020	0.018	2.59	1.37
401	134.4	0	134.4	8852	NA	NA	0.76	0.69	40.4	0.020	0.018	2.71	1.44

Table A.20 Data for research site: Ottawa 2008 Treatment Means

Location	Year	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
Ottawa	2008	0	0	0	2378	NA	NA	0.59	0.56	39.8	0.012	0.011	2.01	1.01
Ottawa	2008	0	33.6	33.6	3158	NA	NA	0.63	0.58	NA	0.013	0.012	2.34	1.03
Ottawa	2008	0	67.2	67.2	3993	NA	NA	0.64	0.58	NA	0.013	0.012	2.50	1.05
Ottawa	2008	0	100.8	100.8	3930	NA	NA	0.53	0.54	NA	0.011	0.011	2.66	1.12
Ottawa	2008	0	134.4	134.4	4503	NA	NA	0.60	0.56	NA	0.012	0.011	2.76	1.20
Ottawa	2008	33.6	0	33.6	2709	NA	NA	0.63	0.59	40.15	0.013	0.012	2.05	1.05
Ottawa	2008	33.6	33.6	67.2	3806	NA	NA	0.67	0.61	NA	0.013	0.012	2.34	1.02
Ottawa	2008	33.6	67.2	100.8	3672	NA	NA	0.62	0.58	NA	0.012	0.012	2.53	1.06
Ottawa	2008	33.6	100.8	134.4	4575	NA	NA	0.65	0.59	NA	0.013	0.012	2.63	1.09
Ottawa	2008	67.2	0	67.2	3229	NA	NA	0.67	0.62	44.6	0.013	0.012	2.21	1.00
Ottawa	2008	67.2	33.6	100.8	3809	NA	NA	0.66	0.60	NA	0.013	0.012	2.40	1.04
Ottawa	2008	67.2	67.2	134.4	4235	NA	NA	0.68	0.61	NA	0.014	0.012	2.54	1.09
Ottawa	2008	100.8	0	100.8	3430	NA	NA	0.67	0.62	46.05	0.013	0.012	2.20	1.02
Ottawa	2008	100.8	33.6	134.4	4610	NA	NA	0.70	0.64	NA	0.014	0.013	2.37	1.05
Ottawa	2008	134.4	0	134.4	3474	NA	NA	0.70	0.64	46.925	0.014	0.013	2.29	1.01

Table A.21 Data for research site: Ottawa 2008 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
115	0	0	0	2383	Na	NA	0.66	0.59	36	0.013	0.012	1.70	0.87
208	0	0	0	2670	Na	NA	0.64	0.57	41.9	0.013	0.011	2.04	1.01
304	0	0	0	2472	Na	NA	0.51	0.54	40.8	0.010	0.011	2.22	1.08
408	0	0	0	1990	Na	NA	0.56	0.54	40.5	0.011	0.011	2.10	1.07
114	0	33.6	33.6	3356	Na	NA	0.69	0.58	NA	0.014	0.012	2.28	1.01
214	0	33.6	33.6	3874	Na	NA	0.69	0.60	NA	0.014	0.012	2.28	1.04
308	0	33.6	33.6	2931	Na	NA	0.56	0.56	NA	0.011	0.011	2.45	1.03
410	0	33.6	33.6	2472	Na	NA	0.57	0.56	NA	0.011	0.011	2.36	1.04
107	0	67.2	67.2	3577	Na	NA	0.67	0.58	NA	0.013	0.012	2.55	1.07
215	0	67.2	67.2	4961	Na	NA	0.67	0.60	NA	0.013	0.012	2.35	1.02
314	0	67.2	67.2	4381	Na	NA	0.68	0.60	NA	0.014	0.012	2.42	1.04
407	0	67.2	67.2	3051	Na	NA	0.54	0.53	NA	0.011	0.011	2.68	1.06
104	0	100.8	100.8	3533	Na	NA	0.54	0.55	NA	0.011	0.011	2.78	1.14
210	0	100.8	100.8	3965	Na	NA	0.54	0.55	NA	0.011	0.011	2.50	1.16
301	0	100.8	100.8	3964	Na	NA	0.50	0.52	NA	0.010	0.010	2.65	1.06
411	0	100.8	100.8	4260	Na	NA	0.54	0.56	NA	0.011	0.011	2.71	1.12
112	0	134.4	134.4	4803	Na	NA	0.63	0.58	NA	0.013	0.012	2.76	1.26
202	0	134.4	134.4	3698	Na	NA	0.58	0.53	NA	0.012	0.011	2.80	1.21
315	0	134.4	134.4	4978	Na	NA	0.65	0.58	NA	0.013	0.012	2.72	1.20
404	0	134.4	134.4	4522	Na	NA	0.55	0.55	NA	0.011	0.011	2.77	1.14
109	33.6	0	33.6	2291	Na	NA	0.62	0.58	37	0.012	0.012	2.08	1.09
203	33.6	0	33.6	2406	Na	NA	0.63	0.57	37.8	0.013	0.011	2.07	1.12
311	33.6	0	33.6	3175	Na	NA	0.67	0.63	43	0.013	0.013	2.02	0.95
412	33.6	0	33.6	2961	Na	NA	0.60	0.59	42.8	0.012	0.012	2.03	1.05
106	33.6	33.6	67.2	4009	Na	NA	0.68	0.61	NA	0.014	0.012	2.41	1.01
212	33.6	33.6	67.2	4009	Na	NA	0.66	0.60	NA	0.013	0.012	2.31	1.02
313	33.6	33.6	67.2	3731	Na	NA	0.67	0.61	NA	0.013	0.012	2.24	0.97
414	33.6	33.6	67.2	3477	Na	NA	0.68	0.61	NA	0.014	0.012	2.40	1.09
108	33.6	67.2	100.8	4401	Na	NA	0.69	0.60	NA	0.014	0.012	2.43	1.04
201	33.6	67.2	100.8	3457	Na	NA	0.62	0.56	NA	0.012	0.011	2.55	1.10
309	33.6	67.2	100.8	3590	Na	NA	0.60	0.57	NA	0.012	0.011	2.64	1.05
406	33.6	67.2	100.8	3239	Na	NA	0.56	0.58	NA	0.011	0.012	2.50	1.04

Table A.21 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
103	33.6	100.8	134.4	4205	Na	NA	0.70	0.60	NA	0.014	0.012	2.68	1.12
206	33.6	100.8	134.4	4622	Na	NA	0.60	0.58	NA	0.012	0.012	2.64	1.10
310	33.6	100.8	134.4	5062	Na	NA	0.62	0.60	NA	0.012	0.012	2.58	1.06
402	33.6	100.8	67.2	4417	Na	NA	0.69	0.59	NA	0.014	0.012	2.63	1.07
111	67.2	0	67.2	3610	Na	NA	0.68	0.62	45.2	0.014	0.012	2.31	1.01
209	67.2	0	67.2	3115	Na	NA	0.64	0.61	44.9	0.013	0.012	2.24	1.02
306	67.2	0	67.2	3187	Na	NA	0.69	0.63	42.8	0.014	0.013	2.14	0.99
405	67.2	0	100.8	3001	Na	NA	0.67	0.61	45.5	0.013	0.012	2.14	1.00
113	67.2	33.6	100.8	3848	Na	NA	0.69	0.61	NA	0.014	0.012	2.36	1.11
204	67.2	33.6	100.8	3930	Na	NA	0.64	0.60	NA	0.013	0.012	2.50	1.07
312	67.2	33.6	100.8	3944	Na	NA	0.65	0.61	NA	0.013	0.012	2.34	0.98
403	67.2	33.6	134.4	3513	Na	NA	0.67	0.59	NA	0.013	0.012	2.41	1.01
110	67.2	67.2	134.4	4018	Na	NA	0.71	0.63	NA	0.014	0.013	2.48	1.16
205	67.2	67.2	134.4	4714	Na	NA	0.68	0.63	NA	0.014	0.013	2.47	1.07
302	67.2	67.2	134.4	4200	Na	NA	0.70	0.59	NA	0.014	0.012	2.65	1.04
415	67.2	67.2	100.8	4013	Na	NA	0.64	0.59	NA	0.013	0.012	2.59	1.10
101	100.8	0	100.8	2965	Na	NA	0.71	0.64	44	0.014	0.013	2.05	1.15
211	100.8	0	100.8	4250	Na	NA	0.70	0.64	50	0.014	0.013	2.26	1.00
303	100.8	0	100.8	3018	Na	NA	0.67	0.61	42.2	0.013	0.012	2.27	0.95
413	100.8	0	134.4	3485	Na	NA	0.61	0.60	48	0.012	0.012	2.20	0.98
105	100.8	33.6	134.4	4311	Na	NA	0.67	0.63	NA	0.013	0.013	2.55	1.03
213	100.8	33.6	134.4	4826	Na	NA	0.72	0.64	NA	0.014	0.013	2.23	1.10
307	100.8	33.6	134.4	5056	Na	NA	0.74	0.64	NA	0.015	0.013	2.37	1.02
409	100.8	33.6	134.4	3586	Na	NA	0.67	0.62	NA	0.013	0.012	2.36	1.03
102	134.4	0	134.4	2981	Na	NA	0.74	0.65	43.1	0.015	0.013	2.23	1.01
207	134.4	0	134.4	4659	Na	NA	0.75	0.66	50.5	0.015	0.013	2.37	1.05
305	134.4	0	134.4	4185	Na	NA	0.66	0.63	48.6	0.013	0.013	2.34	0.94
401	134.4	0	134.4	2458	Na	NA	0.63	0.60	45.5	0.013	0.012	2.22	1.05

Table A.22 Data for research site: Partridge 2008 Treatment Means

Location	Year	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N
Partridge	2008	0	0	0	7441	NA	NA	0.73	0.63	44.6	0.019	0.016	2.58
Partridge	2008	0	33.6	33.6	7740	NA	NA	0.73	0.63	NA	0.019	0.016	2.63
Partridge	2008	0	67.2	67.2	7969	NA	NA	0.73	0.63	NA	0.019	0.016	2.78
Partridge	2008	0	100.8	100.8	7720	NA	NA	0.72	0.63	NA	0.018	0.016	2.78
Partridge	2008	0	134.4	134.4	8062	NA	NA	0.74	0.63	NA	0.019	0.016	2.77
Partridge	2008	33.6	0	33.6	7441	NA	NA	0.74	0.64	46.7	0.019	0.016	2.65
Partridge	2008	33.6	33.6	67.2	8066	NA	NA	0.74	0.64	NA	0.019	0.016	2.68
Partridge	2008	33.6	67.2	100.8	8098	NA	NA	0.76	0.65	NA	0.019	0.017	2.67
Partridge	2008	33.6	100.8	134.4	7911	NA	NA	0.75	0.63	NA	0.019	0.016	2.76
Partridge	2008	67.2	0	67.2	7881	NA	NA	0.76	0.63	47.6	0.020	0.016	2.64
Partridge	2008	67.2	33.6	100.8	8203	NA	NA	0.77	0.67	NA	0.020	0.017	2.79
Partridge	2008	67.2	67.2	134.4	8102	NA	NA	0.75	0.66	NA	0.019	0.017	2.72
Partridge	2008	100.8	0	100.8	8061	NA	NA	0.76	0.66	49.7	0.019	0.017	2.74
Partridge	2008	100.8	33.6	134.4	8215	NA	NA	0.75	0.66	NA	0.019	0.017	2.75
Partridge	2008	134.4	0	134.4	8096	NA	NA	0.77	0.66	49.5	0.020	0.017	2.70

Table A.23 Data for research site: Partridge 2008 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
115	0	0	0	7289	NA	NA	0.74	0.64	43	0.019	0.017	2.54	1.40
208	0	0	0	7397	NA	NA	0.75	0.65	43.6	0.019	0.017	2.52	1.30
304	0	0	0	6811	NA	NA	0.69	0.62	43.1	0.018	0.016	2.50	1.37
408	0	0	0	8265	NA	NA	0.71	0.62	48.7	0.018	0.016	2.78	1.48
114	0	33.6	33.6	8424	NA	NA	0.75	0.64	NA	0.019	0.016	2.67	1.33
214	0	33.6	33.6	7281	NA	NA	0.75	0.65	NA	0.019	0.017	2.61	1.36
308	0	33.6	33.6	7557	NA	NA	0.73	0.66	NA	0.019	0.017	2.57	1.46
410	0	33.6	33.6	7698	NA	NA	0.68	0.58	NA	0.017	0.015	2.67	1.40
107	0	67.2	67.2	7747	NA	NA	0.72	0.62	NA	0.018	0.016	2.84	1.39
215	0	67.2	67.2	7885	NA	NA	0.74	0.64	NA	0.019	0.016	2.80	1.26
314	0	67.2	67.2	7678	NA	NA	0.73	0.64	NA	0.019	0.016	2.64	1.40
407	0	67.2	67.2	8564	NA	NA	0.72	0.62	NA	0.019	0.016	2.84	1.53
104	0	100.8	100.8	7698	NA	NA	0.72	0.61	NA	0.018	0.016	2.70	1.44
210	0	100.8	100.8	7716	NA	NA	0.74	0.64	NA	0.019	0.016	2.69	1.47
301	0	100.8	100.8	7329	NA	NA	0.73	0.66	NA	0.019	0.017	2.81	1.48
411	0	100.8	100.8	8135	NA	NA	0.68	0.61	NA	0.017	0.016	2.90	1.47
112	0	134.4	134.4	8643	NA	NA	0.77	0.64	NA	0.020	0.016	2.80	1.54
202	0	134.4	134.4	7838	NA	NA	0.75	0.64	NA	0.019	0.016	2.80	1.53
315	0	134.4	134.4	7778	NA	NA	0.72	0.60	NA	0.018	0.015	2.75	1.36
404	0	134.4	134.4	7987	NA	NA	0.73	0.63	NA	0.019	0.016	2.74	1.61
109	33.6	0	33.6	7876	NA	NA	0.78	0.66	45.6	0.020	0.017	2.45	1.47
203	33.6	0	33.6	7141	NA	NA	0.77	0.64	48.2	0.020	0.016	2.60	1.40
311	33.6	0	33.6	7428	NA	NA	0.76	0.67	46.6	0.019	0.017	2.71	1.40
412	33.6	0	33.6	7320	NA	NA	0.67	0.59	46.4	0.017	0.015	2.85	1.23
106	33.6	33.6	67.2	8256	NA	NA	0.73	0.64	NA	0.019	0.016	2.67	1.30
212	33.6	33.6	67.2	8076	NA	NA	0.76	0.66	NA	0.020	0.017	2.50	1.39
313	33.6	33.6	67.2	7805	NA	NA	0.75	0.63	NA	0.019	0.016	2.68	1.57
414	33.6	33.6	67.2	8127	NA	NA	0.70	0.61	NA	0.018	0.016	2.86	1.49
108	33.6	67.2	100.8	8245	NA	NA	0.75	0.63	NA	0.019	0.016	2.61	1.32
201	33.6	67.2	100.8	7838	NA	NA	0.78	0.70	NA	0.020	0.018	2.63	1.59
309	33.6	67.2	100.8	8195	NA	NA	0.76	0.63	NA	0.019	0.016	2.60	1.30
406	33.6	67.2	100.8	8115	NA	NA	0.74	0.65	NA	0.019	0.017	2.86	1.50

Table A.23 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Yield kg/ha	Total N Uptake kg/ha	Harvest Index	GS NDVI	CC NDVI	SPAD	GS INSEY	CC INSEY	Flag Leaf % N	Grain % N
103	33.6	100.8	134.4	7747	NA	NA	0.72	0.62	NA	0.019	0.016	2.70	1.56
206	33.6	100.8	134.4	7736	NA	NA	0.76	0.62	NA	0.019	0.016	2.71	1.38
310	33.6	100.8	134.4	7977	NA	NA	0.75	0.62	NA	0.019	0.016	2.71	1.53
402	33.6	100.8	67.2	8185	NA	NA	0.76	0.66	NA	0.020	0.017	2.93	1.63
111	67.2	0	67.2	8375	NA	NA	0.77	0.56	46.5	0.020	0.014	2.70	1.39
209	67.2	0	67.2	7636	NA	NA	0.78	0.66	47.1	0.020	0.017	2.55	1.45
306	67.2	0	67.2	7397	NA	NA	0.75	0.62	47.8	0.019	0.016	2.62	1.47
405	67.2	0	100.8	8116	NA	NA	0.75	0.68	49.1	0.019	0.018	2.69	1.54
113	67.2	33.6	100.8	8773	NA	NA	0.77	0.65	NA	0.020	0.017	2.79	1.64
204	67.2	33.6	100.8	8474	NA	NA	0.77	0.69	NA	0.020	0.018	2.69	1.38
312	67.2	33.6	100.8	7329	NA	NA	0.77	0.67	NA	0.020	0.017	2.89	1.49
403	67.2	33.6	134.4	8235	NA	NA	0.77	0.68	NA	0.020	0.017	2.80	1.57
110	67.2	67.2	134.4	8414	NA	NA	0.77	0.64	NA	0.020	0.016	2.58	1.47
205	67.2	67.2	134.4	7827	NA	NA	0.75	0.66	NA	0.019	0.017	2.85	1.46
302	67.2	67.2	134.4	7805	NA	NA	0.75	0.68	NA	0.019	0.018	2.59	1.60
415	67.2	67.2	100.8	8364	NA	NA	0.71	0.66	NA	0.018	0.017	2.85	1.47
101	100.8	0	100.8	8028	NA	NA	0.79	0.70	49.5	0.020	0.018	2.55	1.48
211	100.8	0	100.8	7827	NA	NA	0.77	0.67	49.2	0.020	0.017	2.74	1.40
303	100.8	0	100.8	7995	NA	NA	0.77	0.65	50.6	0.020	0.017	2.69	1.44
413	100.8	0	134.4	8394	NA	NA	0.71	0.62	49.4	0.018	0.016	3.01	1.43
105	100.8	33.6	134.4	8056	NA	NA	0.76	0.64	NA	0.020	0.016	2.75	1.50
213	100.8	33.6	134.4	8364	NA	NA	0.78	0.65	NA	0.020	0.017	2.73	1.49
307	100.8	33.6	134.4	8245	NA	NA	0.76	0.68	NA	0.019	0.017	2.62	1.47
409	100.8	33.6	134.4	8195	NA	NA	0.72	0.65	NA	0.018	0.017	2.89	1.35
102	134.4	0	134.4	8534	NA	NA	0.77	0.67	48	0.020	0.017	2.65	1.57
207	134.4	0	134.4	8086	NA	NA	0.77	0.64	49.6	0.020	0.016	2.71	1.44
305	134.4	0	134.4	8235	NA	NA	0.75	0.63	50.9	0.019	0.016	2.59	1.46
401	134.4	0	134.4	7528	NA	NA	0.78	0.71	49.3	0.020	0.018	2.85	1.50

Appendix B. Method, Timing, and Product Studies 2006-2008

Table B.1 Data for research site: Manhattan 2006 Treatment Means

Location	Year	Method	Timing	Yield kg/ha	Grain N %
Manhattan	2006	NA	NA	4923	1.04
Manhattan	2006	CB	30 day	6598	1.32
Manhattan	2006	SB	30 day	6347	1.22
Manhattan	2006	CB	40 day	7131	1.37
Manhattan	2006	SB	40 day	6303	1.24

Table B.2 Data for research site: Manhattan 2006 Raw Data

Plot	Method	Timing	Yield kg/ha	Grain N%
104	SB	30 day	6261	1.44
205	SB	30 day	6274	1.10
301	SB	30 day	6503	1.13
103	CB	30 day	6333	1.58
203	CB	30 day	6571	1.25
305	CB	30 day	6891	1.13
102	SB	40 day	5813	1.18
206	SB	40 day	5823	1.22
304	SB	40 day	7274	1.31
106	CB	40 day	6986	1.48
201	CB	40 day	7425	1.33
303	CB	40 day	6982	1.31
105	NA	NA	4972	1.11
202	NA	NA	5135	0.91
306	NA	NA	4639	1.09

Table B.2 Data for research site: Manhattan 2006 Treatment Means

Location	Year	Method	Product	Yield kg/ha	Grain % N
Manhattan	2006	NA	NA	5193.2	1.02
Manhattan	2006	SB	Urea	7081.09	1.2
Manhattan	2006	CB	UAN	7526.4	1.19
Manhattan	2006	SB	UAN	6805.12	1.16
Manhattan	2006	SB	UAN + 5%Ca Thio	6554.24	1.13
Manhattan	2006	SB	UAN + 10% Ca Thio	6510.34	1.17
Manhattan	2006	SB	UAN + 5% NH4 Thio	6798.85	1.18
Manhattan	2006	SB	UAN + 10% NH4 Thio	6905.47	1.16

Table B.3 Data for research site Manhattan 2006 Raw Data

Plot	Method	Product	Yield kg/ha	Grain % N
107	NA	NA	4174	1.00
203	NA	NA	4428	0.93
304	NA	NA	5566	1.00
408	NA	NA	6604	1.13
102	SB	Urea	7316	1.34
204	SB	Urea	6805	1.11
307	SB	Urea	6739	1.17
403	SB	Urea	7470	1.17
104	CB	UAN	7854	1.22
202	CB	UAN	7244	1.13
305	CB	UAN	7936	1.18
402	CB	UAN	7083	1.21
106	SB	UAN	6875	1.15
207	SB	UAN	6705	1.17
302	SB	UAN	6907	1.16
405	SB	UAN	6735	1.15
105	SB	UAN + 5%Ca Thio	6219	1.24
206	SB	UAN + 5%Ca Thio	6492	1.10
301	SB	UAN + 5%Ca Thio	6651	1.10
404	SB	UAN + 5%Ca Thio	6856	1.09
108	SB	UAN + 10% Ca Thio	6025	1.08
205	SB	UAN + 10% Ca Thio	6240	1.12
303	SB	UAN + 10% Ca Thio	7018	1.29
401	SB	UAN + 10% Ca Thio	6769	1.17
103	SB	UAN + 5% NH4 Thio	7184	1.26
201	SB	UAN + 5% NH4 Thio	6209	1.13
308	SB	UAN + 5% NH4 Thio	7018	1.14
406	SB	UAN + 5% NH4 Thio	6789	1.19
101	SB	UAN + 10% NH4 Thio	6907	1.20
208	SB	UAN + 10% NH4 Thio	6778	1.12
306	SB	UAN + 10% NH4 Thio	6413	1.06
407	SB	UAN + 10% NH4 Thio	7514	1.26

Table B.3 Data for research site: Manhattan 2007 Treatment Means

Location	Year	Method	Product	N Rate kg/ha	Yield kg/ha
Manhattan	2007	NA	NA	0	4578
Manhattan	2007	SB	UAN	33.6	5445
Manhattan	2007	CB	UAN	33.6	5420
Manhattan	2007	SB	UAN	67.2	6415
Manhattan	2007	CB	UAN	67.2	5959
Manhattan	2007	SB	Urea	67.2	6330

Table B.4 Data for research site: Manhattan 2007 Raw Data

Plot	Method	Product	N Rate kg/ha	Yield kg/ha
107	NA	NA	0.0	4676
207	NA	NA	0.0	4554
308	NA	NA	0.0	4754
407	NA	NA	0.0	4328
110	SB	UAN	33.6	5816
202	SB	UAN	33.6	5266
303	SB	UAN	33.6	5649
410	SB	UAN	33.6	5333
108	SB	UAN + Nutrisphere	33.6	5686
204	SB	UAN + Nutrisphere	33.6	5316
307	SB	UAN + Nutrisphere	33.6	5002
405	SB	UAN + Nutrisphere	33.6	5489
104	CB	UAN	33.6	5087
210	CB	UAN	33.6	5069
304	CB	UAN	33.6	5724
404	CB	UAN	33.6	5071
103	CB	UAN + Nutrisphere	33.6	5580
209	CB	UAN + Nutrisphere	33.6	4744
306	CB	UAN + Nutrisphere	33.6	5606
403	CB	UAN + Nutrisphere	33.6	6475
105	SB	UAN	67.2	6575
203	SB	UAN	67.2	5799
301	SB	UAN	67.2	7362
408	SB	UAN	67.2	6136
102	SB	UAN + Nutrisphere	67.2	6185
201	SB	UAN + Nutrisphere	67.2	6076
302	SB	UAN + Nutrisphere	67.2	6539
402	SB	UAN + Nutrisphere	67.2	6646
106	CB	UAN	67.2	6344
205	CB	UAN	67.2	5458
310	CB	UAN	67.2	5801
406	CB	UAN	67.2	5635
109	CB	UAN + Nutrisphere	67.2	5897
206	CB	UAN + Nutrisphere	67.2	6945
305	CB	UAN + Nutrisphere	67.2	6130
409	CB	UAN + Nutrisphere	67.2	5459
101	SB	Urea	67.2	6394
208	SB	Urea	67.2	6199
309	SB	Urea	67.2	6034
401	SB	Urea	67.2	6692

Appendix C. Additional Sensor Data 2005-2008

Table C.1 Sensor Data for research site Long Term Sorghum 2005 Raw Data

Plot	Tillage	Residual kg/ha	Pre-plant N kg/ha	Planting Date	INSEY 7/8/05	INSEY 7/12/05	INSEY 7/15/05	INSEY 7/20/05	INSEY 7/22/05	INSEY 7/25/05	INSEY 7/28/05
115	Conv.	0	0	6/17/2005	0.010	0.012	0.012	0.019	0.016	0.015	0.016
217	Conv.	0	0	6/17/2005	0.010	0.012	0.013	0.017	0.015	0.015	0.015
315	Conv.	0	0	6/17/2005	0.010	0.010	0.011	0.016	0.014	0.014	0.014
116	Conv.	33.6	0	6/17/2005	0.011	0.012	0.014	0.019	0.017	0.016	0.017
215	Conv.	33.6	0	6/17/2005	0.011	0.012	0.013	0.019	0.017	0.016	0.016
311	Conv.	33.6	0	6/17/2005	0.012	0.010	0.011	0.014	0.011	0.011	0.011
114	Conv.	33.6	67.2	6/17/2005	0.012	0.014	0.016	0.021	0.019	0.018	0.018
212	Conv.	33.6	67.2	6/17/2005	0.012	0.015	0.017	0.021	0.020	0.018	0.018
314	Conv.	33.6	67.2	6/17/2005	0.010	0.010	0.012	0.017	0.016	0.015	0.015
120	Conv.	33.6	134.4	6/17/2005	0.010	0.012	0.014	0.018	0.017	0.016	0.016
219	Conv.	33.6	134.4	6/17/2005	0.013	0.012	0.018	0.023	0.021	0.019	0.019
320	Conv.	33.6	134.4	6/17/2005	0.012	0.013	0.017	0.021	0.020	0.018	0.018
113	Conv.	67.2	0	6/17/2005	0.013	0.016	0.019	0.023	0.021	0.020	0.019
218	Conv.	67.2	0	6/17/2005	0.010	0.010	0.012	0.019	0.017	0.016	0.017
319	Conv.	67.2	0	6/17/2005	0.012	0.012	0.015	0.020	0.019	0.018	0.017
111	Conv.	67.2	67.2	6/17/2005	0.014	0.014	0.019	0.023	0.021	0.020	0.019
214	Conv.	67.2	67.2	6/17/2005	0.012	0.013	0.016	0.021	0.020	0.019	0.018
313	Conv.	67.2	67.2	6/17/2005	0.011	0.011	0.013	0.019	0.018	0.017	0.017
112	Conv.	67.2	134.4	6/17/2005	0.014	0.018	0.021	0.024	0.022	0.020	0.020
216	Conv.	67.2	134.4	6/17/2005	0.012	0.012	0.017	0.022	0.020	0.019	0.019
312	Conv.	67.2	134.4	6/17/2005	0.012	0.013	0.016	0.021	0.019	0.018	0.018
117	Conv.	134.4	0	6/17/2005	0.011	0.013	0.018	0.023	0.020	0.019	0.019
213	Conv.	134.4	0	6/17/2005	0.013	0.014	0.017	0.022	0.020	0.018	0.018
317	Conv.	134.4	0	6/17/2005	0.010	0.011	0.014	0.020	0.018	0.017	0.017
118	Conv.	134.4	67.2	6/17/2005	0.010	0.012	0.013	0.018	0.017	0.016	0.017
211	Conv.	134.4	67.2	6/17/2005	0.013	0.014	0.018	0.023	0.021	0.020	0.019
316	Conv.	134.4	67.2	6/17/2005	0.011	0.011	0.015	0.021	0.019	0.018	0.018
119	Conv.	134.4	134.4	6/17/2005	0.010	0.011	0.013	0.018	0.016	0.016	0.017
220	Conv.	134.4	134.4	6/17/2005	0.011	0.013	0.015	0.019	0.017	0.017	0.017
318	Conv.	134.4	134.4	6/17/2005	0.012	0.012	0.018	0.023	0.021	0.019	0.019

Table C.1 Continued

Plot	Tillage	Residual kg/ha	Pre-plant N kg/ha	Planting Date	INSEY 7/8/05	INSEY 7/12/05	INSEY 7/15/05	INSEY 7/20/05	INSEY 7/22/05	INSEY 7/25/05	INSEY 7/28/05
103	No-Till	0	0	6/17/2005	0.011	0.013	0.013	0.018	0.016	0.016	0.017
209	No-Till	0	0	6/17/2005	0.012	0.012	0.013	0.016	0.015	0.015	0.015
310	No-Till	0	0	6/17/2005	0.010	0.013	0.011	0.014	0.014	0.013	0.015
105	No-Till	33.6	0	6/17/2005	0.012	0.010	0.013	0.017	0.016	0.016	0.017
205	No-Till	33.6	0	6/17/2005	0.011	0.011	0.013	0.016	0.016	0.015	0.016
305	No-Till	33.6	0	6/17/2005	0.013	0.011	0.015	0.016	0.015	0.014	0.014
104	No-Till	33.6	67.2	6/17/2005	0.010	0.011	0.011	0.015	0.015	0.015	0.016
207	No-Till	33.6	67.2	6/17/2005	0.012	0.013	0.015	0.017	0.016	0.016	0.016
309	No-Till	33.6	67.2	6/17/2005	0.014	0.015	0.016	0.018	0.018	0.017	0.017
108	No-Till	33.6	134.4	6/17/2005	0.013	0.014	0.016	0.018	0.018	0.018	0.018
210	No-Till	33.6	134.4	6/17/2005	0.012	0.013	0.014	0.017	0.016	0.016	0.016
301	No-Till	33.6	134.4	6/17/2005	0.015	0.012	0.019	0.020	0.019	0.019	0.018
106	No-Till	67.2	0	6/17/2005	0.012	0.013	0.014	0.018	0.017	0.017	0.018
201	No-Till	67.2	0	6/17/2005	0.012	0.011	0.014	0.015	0.015	0.014	0.015
308	No-Till	67.2	0	6/17/2005	0.014	0.014	0.017	0.020	0.019	0.019	0.018
102	No-Till	67.2	67.2	6/17/2005	0.014	0.015	0.019	0.021	0.021	0.020	0.019
206	No-Till	67.2	67.2	6/17/2005	0.012	0.013	0.015	0.018	0.018	0.018	0.018
303	No-Till	67.2	67.2	6/17/2005	0.012	0.013	0.016	0.018	0.017	0.017	0.017
101	No-Till	67.2	134.4	6/17/2005	0.013	0.013	0.014	0.017	0.016	0.017	0.018
208	No-Till	67.2	134.4	6/17/2005	0.013	0.013	0.017	0.019	0.019	0.018	0.018
307	No-Till	67.2	134.4	6/17/2005	0.013	0.013	0.017	0.020	0.019	0.018	0.018
110	No-Till	134.4	0	6/17/2005	0.012	0.013	0.015	0.020	0.019	0.018	0.019
202	No-Till	134.4	0	6/17/2005	0.015	0.016	0.018	0.021	0.021	0.019	0.019
302	No-Till	134.4	0	6/17/2005	0.013	0.016	0.015	0.018	0.018	0.017	0.018
109	No-Till	134.4	67.2	6/17/2005	0.013	0.013	0.014	0.018	0.019	0.018	0.018
203	No-Till	134.4	67.2	6/17/2005	0.012	0.014	0.016	0.020	0.019	0.018	0.018
306	No-Till	134.4	67.2	6/17/2005	0.012	0.014	0.015	0.018	0.018	0.018	0.018
107	No-Till	134.4	134.4	6/17/2005	0.013	0.013	0.017	0.020	0.020	0.019	0.019
204	No-Till	134.4	134.4	6/17/2005	0.012	0.012	0.015	0.018	0.017	0.017	0.017
304	No-Till	134.4	134.4	6/17/2005	0.010	0.011	0.011	0.014	0.013	0.014	0.014

Table C.2 Sensor Data for research site Long Term Sorghum 2006 Raw Data

Plot	Tillage	Residual kg/ha	Pre-plant N kg/ha	Planting Date	INSEY 6/12/06	INSEY 6/27/06	INSEY 7/19/06	SPAD 7/19/06
115	Conv.	0	0	5/23/2006	0.008976	0.010833	0.013425	34.8
217	Conv.	0	0	5/23/2006	0.009768	0.012387	0.014324	37.6
315	Conv.	0	0	5/23/2006	0.010501	0.011548	0.011677	34.9
116	Conv.	33.6	0	5/23/2006	0.009912	0.012266	0.01354	34.2
215	Conv.	33.6	0	5/23/2006	0.009094	0.012063	0.014006	34.5
311	Conv.	33.6	0	5/23/2006	0.011316	0.013193	0.012743	36.5
114	Conv.	33.6	67.2	5/23/2006	0.011113	0.017177	0.016663	50.5
212	Conv.	33.6	67.2	5/23/2006	0.01081	0.015761	0.016594	54.6
314	Conv.	33.6	67.2	5/23/2006	0.011121	0.015535	0.016231	54.5
120	Conv.	33.6	134.4	5/23/2006	0.011194	0.014541	0.016503	55.8
219	Conv.	33.6	134.4	5/23/2006	0.010508	0.016359	0.016856	54.5
320	Conv.	33.6	134.4	5/23/2006	0.011631	0.015496	0.016182	60.8
113	Conv.	67.2	0	5/23/2006	0.009913	0.014212	0.01491	37.1
218	Conv.	67.2	0	5/23/2006	0.010014	0.014807	0.015057	38.1
319	Conv.	67.2	0	5/23/2006	0.010872	0.012658	0.013844	36.9
111	Conv.	67.2	67.2	5/23/2006	0.011032	0.017128	0.016692	48.6
214	Conv.	67.2	67.2	5/23/2006	0.010631	0.016375	0.01644	54.2
313	Conv.	67.2	67.2	5/23/2006	0.012599	0.016157	0.016392	54.1
112	Conv.	67.2	134.4	5/23/2006	0.009912	0.014568	0.016471	55
216	Conv.	67.2	134.4	5/23/2006	0.010717	0.016506	0.016853	57
312	Conv.	67.2	134.4	5/23/2006	0.013052	0.016566	0.016599	57.4
117	Conv.	134.4	0	5/23/2006	0.011537	0.014403	0.015219	43
213	Conv.	134.4	0	5/23/2006	0.011045	0.016555	0.015555	40
317	Conv.	134.4	0	5/23/2006	0.012061	0.015199	0.015082	42.6
118	Conv.	134.4	67.2	5/23/2006	0.010194	0.017479	0.016933	51.5
211	Conv.	134.4	67.2	5/23/2006	0.010795	0.016264	0.016621	56.6
316	Conv.	134.4	67.2	5/23/2006	0.013506	0.016711	0.016584	51.7
119	Conv.	134.4	134.4	5/23/2006	0.009751	0.013671	0.01626	55.8
220	Conv.	134.4	134.4	5/23/2006	0.012892	0.017286	0.01614	58.5
318	Conv.	134.4	134.4	5/23/2006	0.012058	0.016275	0.016482	57.6

Table C.2 Continued

Plot	Tillage	Residual kg/ha	Pre-plant N kg/ha	Planting Date	INSEY 6/12/06	INSEY 6/27/06	INSEY 7/19/06	SPAD 7/19/06
103	No-Till	0	0	5/23/2006	0.008292	0.010064	0.013231	29.8
209	No-Till	0	0	5/23/2006	0.008551	0.0101	0.013324	32.3
310	No-Till	0	0	5/23/2006	0.007336	0.009281	0.01247	31.2
105	No-Till	33.6	0	5/23/2006	0.008	0.010065	0.013496	30.6
205	No-Till	33.6	0	5/23/2006	0.008447	0.010564	0.012762	32.2
305	No-Till	33.6	0	5/23/2006	0.008412	0.011067	0.012823	31
104	No-Till	33.6	67.2	5/23/2006	0.010453	0.017801	0.017129	44.3
207	No-Till	33.6	67.2	5/23/2006	0.009214	0.016654	0.017151	49.3
309	No-Till	33.6	67.2	5/23/2006	0.010333	0.017497	0.016873	49.7
108	No-Till	33.6	134.4	5/23/2006	0.009064	0.015683	0.017332	49.6
210	No-Till	33.6	134.4	5/23/2006	0.011765	0.018235	0.016962	55
301	No-Till	33.6	134.4	5/23/2006	0.009218	0.016305	0.01735	52.9
106	No-Till	67.2	0	5/23/2006	0.008233	0.012342	0.01352	23.2
201	No-Till	67.2	0	5/23/2006	0.009215	0.011612	0.014428	32
308	No-Till	67.2	0	5/23/2006	0.00838	0.011598	0.012801	26.2
102	No-Till	67.2	67.2	5/23/2006	0.010257	0.016887	0.016915	53.5
206	No-Till	67.2	67.2	5/23/2006	0.009893	0.01588	0.016119	42.2
303	No-Till	67.2	67.2	5/23/2006	0.009457	0.015963	0.016451	42.2
101	No-Till	67.2	134.4	5/23/2006	0.009812	0.017739	0.017508	45.2
208	No-Till	67.2	134.4	5/23/2006	0.011592	0.016493	0.017068	54.8
307	No-Till	67.2	134.4	5/23/2006	0.009417	0.01594	0.017336	48.9
110	No-Till	134.4	0	5/23/2006	0.008858	0.013128	0.01493	29.5
202	No-Till	134.4	0	5/23/2006	0.008783	0.012873	0.014907	35.7
302	No-Till	134.4	0	5/23/2006	0.00936	0.013787	0.015739	38.4
109	No-Till	134.4	67.2	5/23/2006	0.011054	0.017985	0.016704	47.4
203	No-Till	134.4	67.2	5/23/2006	0.009516	0.014866	0.01684	52.5
306	No-Till	134.4	67.2	5/23/2006	0.009057	0.01355	0.016663	50.8
107	No-Till	134.4	134.4	5/23/2006	0.010699	0.018119	0.017405	48.5
204	No-Till	134.4	134.4	5/23/2006	0.010751	0.016094	0.017208	55.6
304	No-Till	134.4	134.4	5/23/2006	0.009417	0.015053	0.017288	53.7

Table C.3 Sensor Data for research site Belleville 2006 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Planting Date	INSEY 6/28/06	INSEY 7/6/07	Spad 7/17/06
108	0	0	0	5/22/2006	0.017	0.016	50.7
215	0	0	0	5/22/2006	0.017	0.017	49.6
304	0	0	0	5/22/2006	0.018	0.016	52
102	0	33.6	33.6	5/22/2006	0.017	0.017	51
218	0	33.6	33.6	5/22/2006	0.018	0.017	51.7
311	0	33.6	33.6	5/22/2006	0.018	0.017	53.9
114	0	67.2	67.2	5/22/2006	0.016	0.016	53.2
209	0	67.2	67.2	5/22/2006	0.018	0.017	52.6
306	0	67.2	67.2	5/22/2006	0.017	0.016	52.5
120	0	100.8	100.8	5/22/2006	0.016	0.016	51.5
211	0	100.8	100.8	5/22/2006	0.018	0.017	51.3
320	0	100.8	100.8	5/22/2006	0.018	0.016	49.8
105	0	134.4	134.4	5/22/2006	0.019	0.017	53
201	0	134.4	134.4	5/22/2006	0.019	0.017	51.8
316	0	134.4	134.4	5/22/2006	0.017	0.016	52.9
103	33.6	0	33.6	5/22/2006	0.018	0.017	49.5
202	33.6	0	33.6	5/22/2006	0.018	0.016	55.6
303	33.6	0	33.6	5/22/2006	0.018	0.016	53.7
106	33.6	33.6	67.2	5/22/2006	0.018	0.017	56.5
214	33.6	33.6	67.2	5/22/2006	0.017	0.016	51.7
319	33.6	33.6	67.2	5/22/2006	0.017	0.016	53
117	33.6	67.2	100.8	5/22/2006	0.016	0.016	53.9
207	33.6	67.2	100.8	5/22/2006	0.017	0.016	54.1
305	33.6	67.2	100.8	5/22/2006	0.018	0.017	53.5
110	33.6	100.8	134.4	5/22/2006	0.018	0.017	51.2
204	33.6	100.8	134.4	5/22/2006	0.017	0.016	53.7
308	33.6	100.8	134.4	5/22/2006	0.018	0.017	52.2
109	33.6	134.4	168	5/22/2006	0.018	0.017	52.1
212	33.6	134.4	168	5/22/2006	0.017	0.017	51.5
314	33.6	134.4	168	5/22/2006	0.018	0.017	53.8

Table C.3 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Planting Date	INSEY 6/28/06	INSEY 7/6/07	Spad 7/17/06
111	67.2	0	67.2	5/22/2006	0.015	0.016	52.9
217	67.2	0	67.2	5/22/2006	0.017	0.016	57.1
301	67.2	0	67.2	5/22/2006	0.017	0.016	54
115	67.2	33.6	100.8	5/22/2006	0.016	0.016	48.7
216	67.2	33.6	100.8	5/22/2006	0.018	0.017	52.4
315	67.2	33.6	100.8	5/22/2006	0.019	0.016	52.6
104	67.2	67.2	134.4	5/22/2006	0.019	0.017	51.7
219	67.2	67.2	134.4	5/22/2006	0.017	0.017	53.8
313	67.2	67.2	134.4	5/22/2006	0.018	0.017	55.1
113	67.2	100.8	168	5/22/2006	0.016	0.016	52.4
206	67.2	100.8	168	5/22/2006	0.018	0.017	51.8
317	67.2	100.8	168	5/22/2006	0.017	0.016	52.3
119	100.8	0	100.8	5/22/2006	0.014	0.015	50.4
208	100.8	0	100.8	5/22/2006	0.018	0.016	50.7
309	100.8	0	100.8	5/22/2006	0.018	0.016	49.1
112	100.8	33.6	134.4	5/22/2006	0.016	0.017	52.5
203	100.8	33.6	134.4	5/22/2006	0.017	0.016	55.4
310	100.8	33.6	134.4	5/22/2006	0.018	0.016	51
116	100.8	67.2	168	5/22/2006	0.015	0.016	55.2
213	100.8	67.2	168	5/22/2006	0.017	0.016	50.8
312	100.8	67.2	168	5/22/2006	0.018	0.016	51.9
101	134.4	0	134.4	5/22/2006	0.018	0.017	52.9
220	134.4	0	134.4	5/22/2006	0.016	0.016	54.7
318	134.4	0	134.4	5/22/2006	0.017	0.016	50.9
107	134.4	33.6	168	5/22/2006	0.018	0.016	52.9
210	134.4	33.6	168	5/22/2006	0.018	0.017	49.1
307	134.4	33.6	168	5/22/2006	0.018	0.017	50.4
118	168	0	168	5/22/2006	0.013	0.014	55.7
205	168	0	168	5/22/2006	0.017	0.016	54.6
302	168	0	168	5/22/2006	0.018	0.017	51.7

Table C.4 Sensor Data for research site Manhattan 2006 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Planting Date	INSEY 6/9/06	INSEY 6/14/06	INSEY 6/19/06	INSEY 6/27/06	INSEY 7/5/06	INSEY 7/18/06	Spad 7/18/06
108	0	0	0	5/19/2006	0.015	0.019	0.023	0.020	0.018	0.017	52.8
215	0	0	0	5/19/2006	0.016	0.019	0.023	0.020	0.017	0.017	51.9
304	0	0	0	5/19/2006	0.017	0.021	0.025	0.021	0.018	0.017	54.2
114	0	33.6	33.6	5/19/2006	0.016	0.019	0.024	0.020	0.018	0.017	57.6
209	0	33.6	33.6	5/19/2006	0.016	0.020	0.024	0.020	0.018	0.017	56.3
306	0	33.6	33.6	5/19/2006	0.016	0.021	0.024	0.020	0.018	0.017	57.2
105	0	67.2	67.2	5/19/2006	0.015	0.018	0.023	0.020	0.018	0.017	59.4
201	0	67.2	67.2	5/19/2006	0.015	0.019	0.023	0.020	0.018	0.017	58.4
316	0	67.2	67.2	5/19/2006	0.014	0.016	0.020	0.018	0.017	0.017	53.6
117	0	100.8	100.8	5/19/2006	0.016	0.020	0.024	0.021	0.018	0.017	56.7
207	0	100.8	100.8	5/19/2006	0.015	0.019	0.024	0.020	0.018	0.017	57.4
305	0	100.8	100.8	5/19/2006	0.017	0.021	0.024	0.021	0.018	0.017	58.4
115	0	134.4	134.4	5/19/2006	0.016	0.019	0.024	0.021	0.018	0.017	58.5
216	0	134.4	134.4	5/19/2006	0.015	0.019	0.023	0.019	0.017	0.017	58.4
315	0	134.4	134.4	5/19/2006	0.015	0.018	0.021	0.019	0.017	0.017	56.9
102	33.6	0	33.6	5/19/2006	0.016	0.020	0.024	0.020	0.018	0.017	55.4
218	33.6	0	33.6	5/19/2006	0.015	0.017	0.022	0.019	0.017	0.017	53.3
311	33.6	0	33.6	5/19/2006	0.018	0.020	0.024	0.020	0.017	0.017	57.2
103	33.6	33.6	67.2	5/19/2006	0.017	0.021	0.023	0.021	0.018	0.017	54.4
202	33.6	33.6	67.2	5/19/2006	0.015	0.020	0.024	0.021	0.018	0.017	58.6
303	33.6	33.6	67.2	5/19/2006	0.016	0.021	0.025	0.021	0.018	0.017	59.3
110	33.6	67.2	100.8	5/19/2006	0.016	0.020	0.024	0.021	0.018	0.017	57.5
204	33.6	67.2	100.8	5/19/2006	0.014	0.020	0.024	0.021	0.018	0.017	57.4
308	33.6	67.2	100.8	5/19/2006	0.017	0.021	0.025	0.021	0.018	0.017	60.3
104	33.6	100.8	134.4	5/19/2006	0.015	0.019	0.023	0.021	0.018	0.017	61.1
219	33.6	100.8	134.4	5/19/2006	0.014	0.017	0.022	0.019	0.017	0.017	58.6
313	33.6	100.8	134.4	5/19/2006	0.016	0.020	0.023	0.020	0.017	0.017	60.4
116	33.6	134.4	168	5/19/2006	0.015	0.018	0.023	0.020	0.018	0.017	57.6
213	33.6	134.4	168	5/19/2006	0.016	0.019	0.024	0.020	0.018	0.017	56.7
312	33.6	134.4	168	5/19/2006	0.017	0.020	0.024	0.020	0.018	0.017	58.4

Table C.4 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Planting Date	INSEY 6/9/06	INSEY 6/14/06	INSEY 6/19/06	INSEY 6/27/06	INSEY 7/5/06	INSEY 7/18/06	Spad 7/18/06
120	67.2	0	67.2	5/19/2006	0.015	0.019	0.024	0.020	0.017	0.017	56.1
211	67.2	0	67.2	5/19/2006	0.018	0.021	0.025	0.021	0.018	0.017	56
320	67.2	0	67.2	5/19/2006	0.013	0.015	0.020	0.018	0.017	0.017	54.6
109	67.2	33.6	100.8	5/19/2006	0.018	0.022	0.025	0.021	0.018	0.017	55.8
212	67.2	33.6	100.8	5/19/2006	0.015	0.019	0.024	0.020	0.018	0.017	57.1
314	67.2	33.6	100.8	5/19/2006	0.017	0.020	0.024	0.020	0.017	0.017	57.7
113	67.2	67.2	134.4	5/19/2006	0.017	0.021	0.024	0.020	0.018	0.017	58.5
206	67.2	67.2	134.4	5/19/2006	0.017	0.020	0.024	0.020	0.018	0.017	56.4
317	67.2	67.2	134.4	5/19/2006	0.014	0.017	0.022	0.019	0.017	0.017	57.4
101	67.2	100.8	168	5/19/2006	0.017	0.021	0.025	0.021	0.018	0.017	60.9
220	67.2	100.8	168	5/19/2006	0.013	0.016	0.021	0.018	0.017	0.017	60.5
318	67.2	100.8	168	5/19/2006	0.015	0.017	0.022	0.019	0.017	0.017	58.8
106	100.8	0	100.8	5/19/2006	0.017	0.021	0.024	0.020	0.018	0.017	57.5
214	100.8	0	100.8	5/19/2006	0.018	0.021	0.024	0.020	0.018	0.017	58.4
319	100.8	0	100.8	5/19/2006	0.014	0.018	0.022	0.019	0.017	0.017	60.2
119	100.8	33.6	134.4	5/19/2006	0.017	0.020	0.025	0.020	0.018	0.017	56.4
208	100.8	33.6	134.4	5/19/2006	0.017	0.021	0.025	0.021	0.018	0.017	59.4
309	100.8	33.6	134.4	5/19/2006	0.018	0.021	0.025	0.020	0.018	0.017	58.9
107	100.8	67.2	168	5/19/2006	0.017	0.021	0.025	0.021	0.018	0.017	59.4
210	100.8	67.2	168	5/19/2006	0.017	0.021	0.025	0.021	0.018	0.017	58.4
307	100.8	67.2	168	5/19/2006	0.017	0.021	0.024	0.021	0.018	0.017	59.2
111	134.4	0	134.4	5/19/2006	0.017	0.020	0.024	0.020	0.018	0.017	57.4
217	134.4	0	134.4	5/19/2006	0.016	0.019	0.024	0.020	0.017	0.017	56.2
301	134.4	0	134.4	5/19/2006	0.018	0.023	0.025	0.021	0.018	0.017	59.7
118	134.4	33.6	168	5/19/2006	0.018	0.021	0.025	0.021	0.018	0.017	57.7
205	134.4	33.6	168	5/19/2006	0.017	0.022	0.025	0.021	0.018	0.017	58.9
302	134.4	33.6	168	5/19/2006	0.018	0.022	0.025	0.021	0.018	0.017	59.6
112	168	0	168	5/19/2006	0.017	0.021	0.024	0.021	0.018	0.017	59.2
203	168	0	168	5/19/2006	0.016	0.020	0.025	0.021	0.018	0.017	58.1
310	168	0	168	5/19/2006	0.018	0.021	0.025	0.020	0.017	0.017	56.5

Table C.5 Sensor Data for research site Partridge 2006 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Planting Date	INSEY 7/7/06	INSEY 7/20/06	Spad 7/20/06
115	0	0	0	5/31/2006	0.012	0.012	44.2
204	0	0	0	5/31/2006	0.012	0.013	45.1
303	0	0	0	5/31/2006	0.011	0.012	41.4
109	0	33.6	33.6	5/31/2006	0.012	0.014	48.6
206	0	33.6	33.6	5/31/2006	0.014	0.014	54.9
313	0	33.6	33.6	5/31/2006	0.015	0.014	45
101	0	67.2	67.2	5/31/2006	0.012	0.014	47.3
216	0	67.2	67.2	5/31/2006	0.011	0.013	51.5
308	0	67.2	67.2	5/31/2006	0.014	0.013	47.9
107	0	100.8	100.8	5/31/2006	0.012	0.015	52.1
205	0	100.8	100.8	5/31/2006	0.012	0.013	51.1
315	0	100.8	100.8	5/31/2006	0.013	0.012	45.8
116	0	134.4	134.4	5/31/2006	0.012	0.014	51.6
215	0	134.4	134.4	5/31/2006	0.012	0.015	49.5
317	0	134.4	134.4	5/31/2006	0.013	0.013	46.3
118	33.6	0	33.6	5/31/2006	0.013	0.014	45.8
211	33.6	0	33.6	5/31/2006	0.014	0.014	45.6
307	33.6	0	33.6	5/31/2006	0.014	0.012	46.3
102	33.6	33.6	67.2	5/31/2006	0.012	0.015	48.6
203	33.6	33.6	67.2	5/31/2006	0.013	0.013	50.7
304	33.6	33.6	67.2	5/31/2006	0.015	0.015	49.5
104	33.6	67.2	100.8	5/31/2006	0.013	0.015	53.6
208	33.6	67.2	100.8	5/31/2006	0.012	0.014	51.5
302	33.6	67.2	100.8	5/31/2006	0.013	0.013	49.3
119	33.6	100.8	134.4	5/31/2006	0.013	0.014	54.1
213	33.6	100.8	134.4	5/31/2006	0.015	0.015	53.4
309	33.6	100.8	134.4	5/31/2006	0.016	0.014	51.5
113	33.6	134.4	168	5/31/2006	0.014	0.015	53.6
212	33.6	134.4	168	5/31/2006	0.013	0.015	51.3
320	33.6	134.4	168	5/31/2006	0.014	0.014	51

Table C.5 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Planting Date	INSEY 7/7/06	INSEY 7/20/06	Spad 7/20/06
111	67.2	0	67.2	5/31/2006	0.015	0.015	50.8
220	67.2	0	67.2	5/31/2006	0.013	0.014	49.7
301	67.2	0	67.2	5/31/2006	0.014	0.014	47.1
112	67.2	33.6	100.8	5/31/2006	0.014	0.015	48.4
214	67.2	33.6	100.8	5/31/2006	0.014	0.015	50
311	67.2	33.6	100.8	5/31/2006	0.016	0.014	53.5
106	67.2	67.2	134.4	5/31/2006	0.014	0.015	52.2
217	67.2	67.2	134.4	5/31/2006	0.013	0.015	53.7
305	67.2	67.2	134.4	5/31/2006	0.015	0.015	50
120	67.2	100.8	168	5/31/2006	0.013	0.014	51.4
218	67.2	100.8	168	5/31/2006	0.013	0.016	51.7
319	67.2	100.8	168	5/31/2006	0.015	0.014	50.7
114	100.8	0	100.8	5/31/2006	0.015	0.014	48.3
219	100.8	0	100.8	5/31/2006	0.014	0.015	53.4
318	100.8	0	100.8	5/31/2006	0.016	0.014	42.8
108	100.8	33.6	134.4	5/31/2006	0.014	0.015	53.7
209	100.8	33.6	134.4	5/31/2006	0.014	0.014	53.1
312	100.8	33.6	134.4	5/31/2006	0.015	0.014	51.1
110	100.8	67.2	168	5/31/2006	0.015	0.015	53.5
207	100.8	67.2	168	5/31/2006	0.013	0.014	46.8
314	100.8	67.2	168	5/31/2006	0.016	0.015	46.5
117	134.4	0	134.4	5/31/2006	0.013	0.014	51.8
201	134.4	0	134.4	5/31/2006	0.014	0.014	51.4
306	134.4	0	134.4	5/31/2006	0.014	0.014	50.7
105	134.4	33.6	168	5/31/2006	0.014	0.015	52.6
202	134.4	33.6	168	5/31/2006	0.012	0.014	47.8
310	134.4	33.6	168	5/31/2006	0.017	0.015	50.5
103	168	0	168	5/31/2006	0.014	0.015	50.9
210	168	0	168	5/31/2006	0.015	0.015	55.3
316	168	0	168	5/31/2006	0.016	0.015	53.6

Table C.6 Sensor Data for research site Manhattan 2007 Raw Data

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Planting Date	GS INSEY 6/27/07	GS INSEY 7/3/07	CC INSEY 6/27/07	CC INSEY 7/3/07	Spad 6/28/07	Spad 7/5/07
108	0	0	0	5/23/2007	0.017	0.016	0.016	0.014	40.7	38.2
215	0	0	0	5/23/2007	0.014	0.013	0.015	0.013	38.2	38.8
304	0	0	0	5/23/2007	0.016	0.014	0.015	0.014	38.6	39.3
403	0	0	0	5/23/2007	0.014	0.014	0.014	0.013	40.1	41.1
114	0	33.6	33.6	5/23/2007	0.015	0.016	0.015	0.014	41.5	44.7
209	0	33.6	33.6	5/23/2007	0.016	0.016	0.015	0.014	42.3	43.1
306	0	33.6	33.6	5/23/2007	0.015	0.015	0.015	0.014	39.1	43.3
413	0	33.6	33.6	5/23/2007	0.010	0.012	0.012	0.011	41.1	45.3
105	0	67.2	67.2	5/23/2007	0.016	0.016	0.015	0.014	42.6	46.6
201	0	67.2	67.2	5/23/2007	0.015	0.014	0.015	0.014	41.5	44.5
316	0	67.2	67.2	5/23/2007	0.015	0.016	0.016	0.014	40.6	45.6
408	0	67.2	67.2	5/23/2007	0.014	0.014	0.015	0.013	40.6	41.4
117	0	100.8	100.8	5/23/2007	0.015	0.015	0.015	0.013	39	45.3
207	0	100.8	100.8	5/23/2007	0.015	0.016	0.016	0.014	42.8	46
305	0	100.8	100.8	5/23/2007	0.014	0.015	0.015	0.014	41.2	46.3
415	0	100.8	100.8	5/23/2007	0.014	0.014	0.014	0.013	39.3	46.9
115	0	134.4	134.4	5/23/2007	0.015	0.016	0.015	0.015	39.2	46.1
216	0	134.4	134.4	5/23/2007	0.016	0.015	0.015	0.015	40.5	44.5
315	0	134.4	134.4	5/23/2007	0.014	0.015	0.015	0.015	39.2	45.9
417	0	134.4	134.4	5/23/2007	0.015	0.014	0.015	0.015	39.4	45.7
102	33.6	0	33.6	5/23/2007	0.018	0.017	0.017	0.015	44.6	45.6
218	33.6	0	33.6	5/23/2007	0.017	0.015	0.016	0.015	45.2	44.1
311	33.6	0	33.6	5/23/2007	0.019	0.017	0.018	0.016	44.1	44.1
407	33.6	0	33.6	5/23/2007	0.015	0.015	0.016	0.014	43.6	42.7
103	33.6	33.6	67.2	5/23/2007	0.018	0.018	0.017	0.016	48.9	46.2
202	33.6	33.6	67.2	5/23/2007	0.018	0.017	0.017	0.015	44.3	45.1
303	33.6	33.6	67.2	5/23/2007	0.019	0.017	0.018	0.016	43.8	45.5
404	33.6	33.6	67.2	5/23/2007	0.018	0.016	0.017	0.015	44.2	44.9
110	33.6	67.2	100.8	5/23/2007	0.016	0.017	0.016	0.014	43.9	44.7
204	33.6	67.2	100.8	5/23/2007	0.018	0.017	0.017	0.015	44	45.5
308	33.6	67.2	100.8	5/23/2007	0.018	0.017	0.017	0.016	43.3	46.4
402	33.6	67.2	100.8	5/23/2007	0.018	0.017	0.017	0.015	42.4	46.7

Table C.6 Continued

Plot	Pre-plant N kg/ha	Side-dress N kg/ha	Total N Applied kg/ha	Planting Date	GS INSEY 6/27/07	GS INSEY 7/3/07	CC INSEY 6/27/07	CC INSEY 7/3/07	Spad 6/28/07	Spad 7/5/07
104	33.6	100.8	134.4	5/23/2007	0.017	0.017	0.017	0.015	42.4	46.5
219	33.6	100.8	134.4	5/23/2007	0.016	0.015	0.016	0.015	43.8	43.3
313	33.6	100.8	134.4	5/23/2007	0.017	0.017	0.017	0.015	44.4	49.1
409	33.6	100.8	134.4	5/23/2007	0.017	0.016	0.017	0.015	43.6	49.2
116	33.6	134.4	168	5/23/2007	0.018	0.017	0.017	0.015	46.6	45.4
213	33.6	134.4	168	5/23/2007	0.018	0.017	0.017	0.015	45.8	45.8
312	33.6	134.4	168	5/23/2007	0.018	0.017	0.017	0.015	46	47.3
420	33.6	134.4	168	5/23/2007	0.019	0.016	0.018	0.015	44.9	44.8
120	67.2	0	67.2	5/23/2007	0.017	0.017	0.016	0.015	43.2	44.4
211	67.2	0	67.2	5/23/2007	0.016	0.015	0.016	0.015	46.7	45.9
320	67.2	0	67.2	5/23/2007	0.017	0.016	0.017	0.015	45.1	50
401	67.2	0	67.2	5/23/2007	0.018	0.016	0.017	0.015	43.1	45.8
109	67.2	33.6	100.8	5/23/2007	0.016	0.017	0.016	0.016	46.2	47.8
212	67.2	33.6	100.8	5/23/2007	0.017	0.017	0.017	0.014	45.9	48.1
314	67.2	33.6	100.8	5/23/2007	0.020	0.018	0.019	0.016	45.9	49.5
411	67.2	33.6	100.8	5/23/2007	0.016	0.017	0.017	0.015	44.1	48.3
113	67.2	67.2	134.4	5/23/2007	0.016	0.017	0.017	0.016	47.1	46.6
206	67.2	67.2	134.4	5/23/2007	0.019	0.017	0.017	0.016	46.4	44.7
317	67.2	67.2	134.4	5/23/2007	0.017	0.017	0.017	0.015	45.1	47.8
405	67.2	67.2	134.4	5/23/2007	0.019	0.016	0.017	0.015	44.4	43.6
101	67.2	100.8	168	5/23/2007	0.017	0.018	0.016	0.016	47.7	47.2
220	67.2	100.8	168	5/23/2007	0.017	0.017	0.018	0.016	47.1	46.2
318	67.2	100.8	168	5/23/2007	0.018	0.018	0.017	0.016	45.6	49.2
419	67.2	100.8	168	5/23/2007	0.017	0.016	0.016	0.015	44.5	46.8
106	100.8	0	100.8	5/23/2007	0.018	0.018	0.017	0.015	46.8	47.4
214	100.8	0	100.8	5/23/2007	0.018	0.017	0.018	0.016	46.8	49
319	100.8	0	100.8	5/23/2007	0.017	0.016	0.016	0.015	47.1	50
418	100.8	0	100.8	5/23/2007	0.017	0.017	0.017	0.015	45.8	46.6

Appendix D. Soil Data at Main Study Sites 2005-2008

Table D.1 Soil Data for research site: Long Term Sorghum 2005 Raw Data

Plot	Tillage	Residual kg/ha	Pre-plant N kg/ha	NO3 kg/ha	NH4 kg/ha	% S.O.M	P mg/ha	K mg/kg	pH
115	Conv.	0	0	31.1	NA	2.3	18	279	6.5
217	Conv.	0	0	32.1	NA	2.4	20	243	6.5
315	Conv.	0	0	40.6	NA	2.3	13	285	6.3
116	Conv.	33.6	0	37.1	NA	2.5	15	275	6.5
215	Conv.	33.6	0	48.2	NA	2.8	15	303	6.6
311	Conv.	33.6	0	43.5	NA	2.6	15	245	6.3
113	Conv.	33.6	67.2	43.9	NA	NA	NA	NA	NA
218	Conv.	33.6	67.2	39.7	NA	NA	NA	NA	NA
319	Conv.	33.6	67.2	37.9	NA	NA	NA	NA	NA
117	Conv.	33.6	134.4	20.8	NA	NA	NA	NA	NA
213	Conv.	33.6	134.4	34.5	NA	NA	NA	NA	NA
317	Conv.	33.6	134.4	58.5	NA	NA	NA	NA	NA
114	Conv.	67.2	0	36.1	NA	NA	NA	NA	NA
212	Conv.	67.2	0	41.9	NA	NA	NA	NA	NA
314	Conv.	67.2	0	43.5	NA	NA	NA	NA	NA
111	Conv.	67.2	67.2	40.3	NA	2.9	19	254	6.6
214	Conv.	67.2	67.2	57.4	NA	2.4	12	265	6.6
313	Conv.	67.2	67.2	52.6	NA	2.5	11	289	6.2
118	Conv.	67.2	134.4	43.2	NA	NA	NA	NA	NA
211	Conv.	67.2	134.4	43.4	NA	NA	NA	NA	NA
316	Conv.	67.2	134.4	45.0	NA	NA	NA	NA	NA
120	Conv.	134.4	0	96.9	NA	NA	NA	NA	NA
219	Conv.	134.4	0	75.5	NA	NA	NA	NA	NA
320	Conv.	134.4	0	55.0	NA	NA	NA	NA	NA
112	Conv.	134.4	67.2	67.1	NA	NA	NA	NA	NA
216	Conv.	134.4	67.2	69.8	NA	NA	NA	NA	NA
312	Conv.	134.4	67.2	81.1	NA	NA	NA	NA	NA

Table D.1 Continued

Plot	Tillage	Residual kg/ha	Pre-plant N kg/ha	NO3 kg/ha	NH4 kg/ha	% S.O.M	P mg/ha	K mg/kg	pH
119	Conv.	134.4	134.4	60.8	NA	2.3	6	195	6.1
220	Conv.	134.4	134.4	81.4	NA	2.5	7	281	6.1
318	Conv.	134.4	134.4	39.4	NA	3.1	15	280	6.2
103	No-Till	0	0	26.1	NA	2.5	25	223.0	6.9
209	No-Till	0	0	20.8	NA	2.6	26	308	6.6
310	No-Till	0	0	22.1	NA	2.5	32	254	6.5
105	No-Till	33.6	0	27.1	NA	2.5	17	188.0	6.9
205	No-Till	33.6	0	35.3	NA	2.9	19	286	6.4
305	No-Till	33.6	0	30.2	NA	2.9	25	354	6.2
106	No-Till	33.6	67.2	26.1	NA	NA	NA	NA	NA
201	No-Till	33.6	67.2	28.5	NA	NA	NA	NA	NA
308	No-Till	33.6	67.2	27.9	NA	NA	NA	NA	NA
110	No-Till	33.6	134.4	23.7	NA	NA	NA	NA	NA
202	No-Till	33.6	134.4	23.9	NA	NA	NA	NA	NA
302	No-Till	33.6	134.4	31.4	NA	NA	NA	NA	NA
104	No-Till	67.2	0	37.6	NA	NA	NA	NA	NA
207	No-Till	67.2	0	37.1	NA	NA	NA	NA	NA
309	No-Till	67.2	0	27.4	NA	NA	NA	NA	NA
102	No-Till	67.2	67.2	39.4	NA	2.7	20	197.0	6.6
206	No-Till	67.2	67.2	25.6	NA	2.6	15	264	6.3
303	No-Till	67.2	67.2	37.3	NA	3.3	14	277	6.4
109	No-Till	67.2	134.4	30.0	NA	NA	NA	NA	NA
203	No-Till	67.2	134.4	48.2	NA	NA	NA	NA	NA
306	No-Till	67.2	134.4	31.3	NA	NA	NA	NA	NA
108	No-Till	134.4	0	40.2	NA	NA	NA	NA	NA
210	No-Till	134.4	0	55.8	NA	NA	NA	NA	NA
301	No-Till	134.4	0	68.5	NA	NA	NA	NA	NA
101	No-Till	134.4	67.2	74.4	NA	NA	NA	NA	NA
208	No-Till	134.4	67.2	33.2	NA	NA	NA	NA	NA
307	No-Till	134.4	67.2	70.2	NA	NA	NA	NA	NA
107	No-Till	134.4	134.4	38.1	NA	2.7	8	203.0	6.2
204	No-Till	134.4	134.4	68.7	NA	2.5	13	129	5.9
304	No-Till	134.4	134.4	61.6	NA	3.0	12	371	6.1

Table D.2 Soil Data for research site: Long Term Sorghum 2006 Raw Data

Plot	Tillage	Residual kg/ha	Pre-plant N kg/ha	NO3 kg/ha	NH4 kg/ha	% S.O.M	P mg/ha	K mg/kg	pH
115	Conv.	0	0	32.9	40.6	2.3	18	279	6.5
217	Conv.	0	0	35.8	66.5	2.4	20	243	6.5
315	Conv.	0	0	32.0	89.8	2.3	13	285	6.3
116	Conv.	33.6	0	32.4	48.6	2.5	15	275	6.5
215	Conv.	33.6	0	35.8	64.1	2.8	15	303	6.6
311	Conv.	33.6	0	32.9	94.0	2.6	15	245	6.3
113	Conv.	33.6	67.2	34.6	63.0	NA	NA	NA	NA
218	Conv.	33.6	67.2	36.3	54.2	NA	NA	NA	NA
319	Conv.	33.6	67.2	47.8	68.2	NA	NA	NA	NA
117	Conv.	33.6	134.4	53.1	35.2	NA	NA	NA	NA
213	Conv.	33.6	134.4	49.0	33.4	NA	NA	NA	NA
317	Conv.	33.6	134.4	40.6	63.2	NA	NA	NA	NA
114	Conv.	67.2	0	37.3	46.1	NA	NA	NA	NA
212	Conv.	67.2	0	62.4	27.8	NA	NA	NA	NA
314	Conv.	67.2	0	30.7	86.4	NA	NA	NA	NA
111	Conv.	67.2	67.2	34.2	63.3	2.9	19	254	6.6
214	Conv.	67.2	67.2	33.1	62.5	2.4	12	265	6.6
313	Conv.	67.2	67.2	46.2	78.1	2.5	11	289	6.2
118	Conv.	67.2	134.4	48.8	56.0	NA	NA	NA	NA
211	Conv.	67.2	134.4	53.8	40.3	NA	NA	NA	NA
316	Conv.	67.2	134.4	37.9	73.1	NA	NA	NA	NA
120	Conv.	134.4	0	78.0	30.7	NA	NA	NA	NA
219	Conv.	134.4	0	46.8	62.4	NA	NA	NA	NA
320	Conv.	134.4	0	46.5	44.6	NA	NA	NA	NA
112	Conv.	134.4	67.2	48.6	52.9	NA	NA	NA	NA
216	Conv.	134.4	67.2	68.3	57.6	NA	NA	NA	NA
312	Conv.	134.4	67.2	44.3	113.5	NA	NA	NA	NA
119	Conv.	134.4	134.4	116.9	39.4	2.3	6	195	6.1
220	Conv.	134.4	134.4	76.8	67.7	2.5	7	281	6.1
318	Conv.	134.4	134.4	75.5	37.3	3.1	15	280	6.2

Table D.2 Continued

Plot	Tillage	Residual kg/ha	Pre-plant N kg/ha	NO3 kg/ha	NH4 kg/ha	% S.O.M	P mg/ha	K mg/kg	pH
103	No-Till	0	0	78.7	27.7	2.5	25	223	6.9
209	No-Till	0	0	27.6	57.5	2.6	26	308	6.6
310	No-Till	0	0	26.4	89.6	2.5	32	254	6.5
105	No-Till	33.6	0	28.7	37.5	2.5	17	188	6.9
205	No-Till	33.6	0	25.2	67.8	2.9	19	286	6.4
305	No-Till	33.6	0	23.8	71.2	2.9	25	354	6.2
106	No-Till	33.6	67.2	63.6	45.8	NA	NA	NA	NA
201	No-Till	33.6	67.2	61.0	39.0	NA	NA	NA	NA
308	No-Till	33.6	67.2	41.8	57.7	NA	NA	NA	NA
110	No-Till	33.6	134.4	34.7	52.6	NA	NA	NA	NA
202	No-Till	33.6	134.4	40.3	37.5	NA	NA	NA	NA
302	No-Till	33.6	134.4	34.6	82.1	NA	NA	NA	NA
104	No-Till	67.2	0	46.6	49.1	NA	NA	NA	NA
207	No-Till	67.2	0	41.4	39.5	NA	NA	NA	NA
309	No-Till	67.2	0	32.0	85.5	NA	NA	NA	NA
102	No-Till	67.2	67.2	75.3	41.4	2.7	20	197	6.6
206	No-Till	67.2	67.2	47.6	37.3	2.6	15	264	6.3
303	No-Till	67.2	67.2	35.7	90.5	3.3	14	277	6.4
109	No-Till	67.2	134.4	51.6	37.9	NA	NA	NA	NA
203	No-Till	67.2	134.4	54.3	34.4	NA	NA	NA	NA
306	No-Till	67.2	134.4	29.9	99.5	NA	NA	NA	NA
108	No-Till	134.4	0	89.2	32.9	NA	NA	NA	NA
210	No-Till	134.4	0	54.3	40.7	NA	NA	NA	NA
301	No-Till	134.4	0	34.9	90.6	NA	NA	NA	NA
101	No-Till	134.4	67.2	61.2	56.3	NA	NA	NA	NA
208	No-Till	134.4	67.2	50.2	33.9	NA	NA	NA	NA
307	No-Till	134.4	67.2	45.0	74.3	NA	NA	NA	NA
107	No-Till	134.4	134.4	40.0	69.7	2.7	8	203	6.2
204	No-Till	134.4	134.4	93.1	24.7	2.5	13	129	5.9
304	No-Till	134.4	134.4	25.0	94.2	3.0	12	371	6.1

Table D.3 Soil Data for main study sites: 2006-2008

Location	Year	Tillage	Previous Crop	NO3 kg/ha	NH4 kg/ha	S.O.M.	P mg/ha	K mg/kg	pH
Belleville	2006	No-Till	Sorghum	85.0	47.2	2.2	40	343	5.5
Manhattan	2006	No-Till	Soybeans	75.2	41.1	2.0	35	249	6.9
Partridge	2006	No-Till	Sorghum	69.0	36.1	1.3	31	276	5.6
Tribune	2006	No-Till	Fallow Sorghum	83.9	28.3	1.0	63	593	7.6
Manhattan	2007	No-Till	Fallow Wheat	18.6	43.2	2.4	17	331	5.9
Partridge	2007	No-Till	Wheat Cover Crop	53.8	32.3	2.0	33	290	5.5
Tribune	2007	No-Till	Fallow Wheat	48.7	32.9	1.6	46	643	7.2
Manhattan	2008	No-Till	Soybeans	34.7	35.3	2.2	13	225	6.7
Ottawa	2008	No-Till	Double Crop Soybeans	33.6	34.3	2.1	15	150	6.0
Partridge	2008	No-Till	Wheat Cover Crop	52.6	31.1	2.0	44	342	5.3

Appendix E. Weather Data at Study Sites 2005-2008

Table E.1 Weather Data for research site: Long Term Sorghum 2005

Location	Year	Month	Average Temperature (C)	Precipitation (mm)
Manhattan	2005	Nov-Mar	2.9	141
Manhattan	2005	April	12.9	40
Manhattan	2005	May	17.8	36
Manhattan	2005	June	24.6	301
Manhattan	2005	July	25.6	50
Manhattan	2005	August	24.8	141
Manhattan	2005	September	22.2	91
Manhattan	2005	October	13.7	79
			Totals:	879

Table E.2 Weather Data for research site: Long Term Sorghum and Manhattan 2006

Location	Year	Month	Average Temperature (C)	Precipitation (mm)
Manhattan	2006	Nov-Mar	3.3	90
Manhattan	2006	April	15.0	70
Manhattan	2006	May	18.6	73
Manhattan	2006	June	23.9	37
Manhattan	2006	July	27.2	94
Manhattan	2006	August	26.0	283
Manhattan	2006	September	17.5	51
Manhattan	2006	October	12.3	64
			Totals:	672

Table E.3 Weather Data for research site: Belleville 2006

Location	Year	Month	Average Temperature (C)	Precipitation (mm)
Belleville	2006	Nov-Mar	1.5	69
Belleville	2006	April	14.1	52
Belleville	2006	May	18.3	81
Belleville	2006	June	24.1	43
Belleville	2006	July	26.4	136
Belleville	2006	August	24.9	128
Belleville	2006	September	17.3	71
Belleville	2006	October	11.2	31
			Totals:	612

Table E.4 Weather Data for research site: Partridge 2006

Location	Year	Month	Average Temperature (C)	Precipitation (mm)
Partridge	2006	Nov-Mar	3.6	30
Partridge	2006	April	16.1	49
Partridge	2006	May	19.3	116
Partridge	2006	June	24.7	78
Partridge	2006	July	28.0	43
Partridge	2006	August	26.9	76
Partridge	2006	September	19.0	17
Partridge	2006	October	13.6	30
			Totals:	439

Table E.5 Weather Data for research site: Tribune 2006

Location	Year	Month	Average Temperature (C)	Precipitation (mm)
Tribune	2006	Nov-Mar	2.4	6
Tribune	2006	April	14.1	1
Tribune	2006	May	17.3	2
Tribune	2006	June	23.1	69
Tribune	2006	July	25.9	43
Tribune	2006	August	23.8	48
Tribune	2006	September	16.6	7
Tribune	2006	October	11.0	96
			Totals:	274

Table E.6 Weather Data for research site: Manhattan 2007

Location	Year	Month	Average Temperature (C)	Precipitation (mm)
Manhattan	2007	Nov-Mar	4.4	201
Manhattan	2007	April	12.2	94
Manhattan	2007	May	20.0	302
Manhattan	2007	June	23.3	150
Manhattan	2007	July	26.1	119
Manhattan	2007	August	28.3	56
Manhattan	2007	September	22.2	51
Manhattan	2007	October	16.1	112
			Totals:	1082

Table E.7 Weather Data for research site: Partridge 2007

Location	Year	Month	Average Temperature (C)	Precipitation (mm)
Partridge	2007	Nov-Mar	3.3	234
Partridge	2007	April	10.0	74
Partridge	2007	May	18.9	264
Partridge	2007	June	22.8	185
Partridge	2007	July	25.6	23
Partridge	2007	August	28.3	43
Partridge	2007	September	21.1	66
Partridge	2007	October	15.0	81
			Totals:	970

Table E.8 Weather Data for research site: Tribune 2007

Location	Year	Month	Average Temperature (C)	Precipitation (mm)
Tribune	2007	Nov-Mar	0.6	168
Tribune	2007	April	8.3	84
Tribune	2007	May	16.1	28
Tribune	2007	June	21.1	36
Tribune	2007	July	25.0	13
Tribune	2007	August	26.1	84
Tribune	2007	September	21.1	18
Tribune	2007	October	13.9	3
			Totals:	434

Table E.9 Weather Data for research site: Manhattan 2008

Location	Year	Month	Average Temperature (C)	Precipitation (mm)
Manhattan	2008	Nov-Mar	1.7	183
Manhattan	2008	April	10.0	58
Manhattan	2008	May	17.2	122
Manhattan	2008	June	23.3	305
Manhattan	2008	July	25.6	130
Manhattan	2008	August	23.9	117
Manhattan	2008	September	19.4	137
Manhattan	2008	October	16.1	112
			Total:	1163

Table E.10 Weather Data for research site: Ottawa 2008

Location	Year	Month	Average Temperature (C)	Precipitation (mm)
Ottawa	2008	Nov-Mar	2.2	213
Ottawa	2008	April	11.7	69
Ottawa	2008	May	18.3	137
Ottawa	2008	June	23.3	198
Ottawa	2008	July	26.1	86
Ottawa	2008	August	24.4	142
Ottawa	2008	September	18.9	198
Ottawa	2008	October	12.2	170
			Totals:	1214

Table E.11 Weather Data for research site: Partridge 2008

Location	Year	Month	Average Temperature (C)	Precipitation (mm)
Partridge	2008	Nov-Mar	2.2	97
Partridge	2008	April	10.6	71
Partridge	2008	May	17.8	150
Partridge	2008	June	23.9	137
Partridge	2008	July	26.1	58
Partridge	2008	August	24.4	58
Partridge	2008	September	19.4	140
Partridge	2008	October	13.3	119
			Totals:	828

Appendix F. SAS Example

All statistical analysis used in this thesis was done using SAS version 9.1. An example of the program input is given below to determine all mean separations.

```
data Name of study;
OPTIONS LS=80 PS=48;
INPUT Block Timing Method Yield;
CARDS;
1	1	1	6261
2	1	1	6274
3	1	1	6503
1	1	2	6523
2	1	2	6571
3	1	2	6891
1	2	1	5813
2	2	1	5823
3	2	1	5958
1	2	2	6986
2	2	2	7425
3	2	2	6982
RUN;
PROC GLM;
CLASS Block Timing Method;
MODEL Yield =Block Timing Method timing*method;
means timing/lsd ALPHA=0.05;
means method/lsd alpha=.05;
means timing*method/lsd alpha=.05;
RUN;QUIT;
```