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A Regional Investigation of In-season Nitrogen Requirement for Maize Using Model and Sensor-based Recommendation Approaches

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A REGIONAL INVESTIGATION OF IN-SEASON NITROGEN REQUIREMENT FOR MAIZE USING MODEL AND SENSOR-BASED RECOMMENDATION APPROACHES

by

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N management for corn can be improved by applying a portion of the total N during the growing season, allowing for adjustments which are responsive to actual field conditions. This study was conducted to evaluate two approaches for determining in-season N rates: Maize-N model and active crop canopy sensor. Various sensor algorithms designed for making in-season N recommendations from crop canopy sensor data were evaluated. The effects of corn hybrid and planting population on recommendations with these two approaches were considered. In a 2-yr study, a total of twelve sites were evaluated over a 3-state region, including sites in Missouri, Nebraska, and North Dakota. In-season N recommendations were generally lower when using the sensor-based approach with Holland and Schepers (2012) algorithm than the model-based approach. This resulted in observed trends of higher partial factor productivity of N and agronomic efficiency for the sensor-based treatments than the model-based treatments. At specific sites, conditions leading to high levels of mineralized N becoming available to the crop during the growing season increased environmental and economic benefit of the sensor-based approach. The optimum N rate was estimated using a linear-plateau model. Compared to the sensor-based approach with the Holland and Schepers algorithm, the model-based

approach more closely estimated the optimum N rate and erred by over-recommending N. Profit loss from the sensor with Holland and Schepers algorithm was greater when considering all sites collectively due to the greater cost of lost yield when N was under-applied, versus the lower cost of excess N when N was over-applied. Two other sensor-based recommendations were also evaluated: Vetsch and Randall (2014) and Missouri USDA-NRCS (2009). Comparing the three sensor-based approaches to the optimum N rate, the Missouri USDA-NRCS algorithm had the closest approximation of optimum N rate and erred by over-recommending N. Mean N rates for the sensor-based algorithms varied greatly, highlighting the importance of the sensor algorithm in overall sensor utility.

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Table of Contents

List of Tables

List of Figures

Chapter 1 : A Review of Current Literature

Introduction

Nitrogen, an essential element, is frequently applied to increase production in crop systems. Plants use N from both indigenous and applied sources. In soil, N exists in many forms, and if not taken up by the crop or immobilized in soil organic nitrogen pools, N can be lost from the cropping system through a variety of pathways (Cassman et al., 2002). These N fertilizer loss pathways include loss from gaseous plant emission, soil denitrification, surface runoff, volatilization, and leaching (Raun and Johnson, 1999; Shanahan et al., 2008). Because of the environmental and economic consequences of N loss, there is great interest in minimizing N losses and improving nitrogen use efficiency (NUE). Overall NUE is concerned with determining the proportion of available N from all sources which is found in plant aboveground biomass. However, NUE is often used more specifically to characterize the recovery of fertilizer N in aboveground crop biomass, rather than recovery of all sources of N (Raun and Johnson, 1999; Shanahan, et al., 2008). In order to identify the N recovered due to fertilizer alone, N recovery of an unfertilized check is subtracted out, therefore eliminating the N uptake attributed to residual and mineralized soil N sources. This chapter provides a review of current literature related to factors contributing to low NUE in corn (*Zea mays* L.) as well as recently proposed methods for improving NUE.

Reasons for Low Nitrogen Use Efficiency

Low NUE has been attributed to several factors including poor synchrony between N fertilizer and crop demand, unaccounted-for spatial variability resulting in varying crop N needs, and temporal variance in crop N needs (Shanahan et al., 2008).

Each of these factors has the potential to contribute to greater nitrogen losses through the previously discussed nitrogen loss pathways. In general, conditions and practices that counter the fundamental nitrogen loss pathways (gaseous plant emission, soil denitrification, surface runoff, volatilization, and leaching) will be expected to increase NUE. To improve NUE, it is critical to determine the appropriate amount and timing of N application for a crop spread over a spatially diverse field. However, it is also important that increased NUE does not result in decreased yield.

Poor Nitrogen Synchrony

It is estimated that 75% of N fertilizer is applied prior to planting (Cassman et al., 2002), which results in high levels of inorganic N, particularly nitrate, in the soil before the stage of rapid crop uptake occurs. Because of this, improvements in NUE can be achieved by attaining greater synchrony between the crop N need and the N which is available to the plant from all sources throughout the growing season (Cassman et al., 2002). Applying a portion of the N fertilizer alongside the growing crop allows fertilizer availability to coincide more closely with the time at which the crop needs the most nitrogen and is expected to increase NUE. The ideal timing of in-season applications is related to the growth stage of the corn plant. Scharf and Lory (2006) suggested fertilizer be applied as close as possible to the period of rapid N uptake, which for corn is approximately between the vegetative growth stages of V9 to V18. Additionally, sidedress applications of N at 26 to 31 days after emergence (V5 to V6) has been found to result in more efficient N fertilizer utilization for many N sources (Fox et al., 1986). This supports the position that N synchrony with crop need can be improved by applying a portion of the total N fertilizer during the growing season as a sidedress application, hence improving fertilizer use efficiency.

Spatial Variability

Spatial variability of soil properties presents further challenges to N management. Nitrogen supplying capacity can vary throughout a field. Mamo et al. (2003), indicated that N mineralization of organic matter (OM) varied spatially within a field. The N fertilizer need by the crop can vary spatially across a field, due to varying soil N mineralization rate and yield potential. Specifically, the economic optimum N rate (EONR) has been found to differ spatially within fields, (Mamo et al., 2003; Scharf et al., 2005) and between fields, (Scharf et al., 2005) due to soil characteristics. Schmidt et al. (2002) found that variability in yield response to N was not consistently related to soil OM content; locations with greater OM content did not consistently require less N to achieve maximum yield. Because the N mineralization potential depends on soil properties such as water content and temperature, N mineralization may vary spatially independent of soil OM content. Therefore, it was suggested that landscape position and its impact on variable hydrology ought to be considered when delineating N management zones rather than soil OM alone. Roberts, et al. (2010) found that there was a wider range of variability in the optimal N rate for alluvial and loess soils than for claypan soils. Additionally, N losses are expected to vary spatially as soil texture and landscape position varies. Low areas subject to ponded water are more prone to N loss due to denitrification, while sandy soils are more prone to N loss due to leaching (Ferguson, 2000).

Traditionally N has been applied at uniform rates throughout a field, regardless of spatially differing N needs within a field. Managing N application based on spatial variability was found to reduce the overall N rate and increase profitability when compared with a uniform N application (Mamo et al., 2003). Variable rate applications of N decrease the risk of overfertilization and underfertilization in different parts of the same field compared with uniform applications. It is therefore important to identify a reliable means of determining these spatially differing N application rates. Ferguson, et al. (2002), compared uniform N applications to variable rate N applications, which were determined using the existing recommendation algorithm of the University of Nebraska produced to support uniform N application (Shapiro et al., 2003). This study did not find the variable N application rates to significantly reduce the total amount of N applied, and it concluded that using the previously developed uniform algorithm may be insufficient for predicting spatial applications of N. For this reason it is critical to develop methods for determining N rate in variable rate N application systems.

Temporal Variability

In addition to the spatial variability component of N management, temporal variations in N response and N mineralization related to environmental factors have also been observed (Mamo et al., 2003). Climate and management interactions cause tremendous year-to-year variation in both crop N requirements and crop yields (Cassman et al., 2002). Together, spatial and temporal variation creates uncertainty as to the optimal N fertilizer rate for any given year (Roberts et al., 2010).

Using Sensors for Determining Nitrogen Need

Chlorophyll Meters

Strategies which detect crop N status at early growth stages have been suggested as a method to improve NUE (Ferguson et al., 2002). Early work focused on the use of chlorophyll meters as a means to detect and correct N deficiency in corn. Blackmer and Schepers (1994) found chlorophyll meters to be more useful in detecting N deficiency than traditional leaf N concentration from plant analysis. One reason for this is that with plant samples, leaf N concentrations continue to increase at very high fertilizer N rates while yields did not. Additionally, the critical N level may vary based on plant hybrid, growth stage and year. Using a sufficiency index (SI) approach where chlorophyll meter readings from a non-limiting N rate were used as a reference area to normalize data makes it possible to compare data across hybrids, locations and sampling dates. Additionally, chlorophyll meters provide instantaneous results whereas data from plant samples are delayed due to laboratory analysis. Blackmer and Schepers concluded that SI generated with chlorophyll meters was highly correlated with grain yield at the R5 growth stage. Blackmer and Scheper (1995) found that at V6, poor relationships were observed between chlorophyll meter readings and yield. This is likely due to environmental differences that affected yield later in the growing season. Relationships between yield and chlorophyll meter readings at R4 or R5 were better than those at V6. It was found that chlorophyll meters were able to distinguish between fertilizer N treatments that resulted in N deficiencies leading to loss of grain yield. Their work further highlighted the importance of using an SI to relate chlorophyll meter readings to a non-N-limiting area in order to eliminate the effect of hybrid, field, and sampling date. Varvel et al. (1997) found that in cases of early severe N stress as detected by chlorophyll sensing, maximum yields were not achieved even with addition of N fertilizer. If the SI at V8 was below 90%, maximum yields were not achieved. However, if SI is maintained between 90 to 100% through early season N fertilization, maximum yields could be attained. Thus far chlorophyll meters were found useful for determining whether N deficiency exists in corn during the growing season. Varvel et al. (2007) used the relationship between chlorophyll meter readings and yield to quantify the amount of N fertilizer needed for an in-season fertilizer application corn application that results in maximum yields. In a 10 year study of corn response to N fertilizer, chlorophyll meter data was collected at specific growing degree days (GDD) for the crop. The GDDs chosen corresponded to approximately the V8, V10, and V12 growth stages. The SI approach was used where readings collected with the chlorophyll meter were compared to data from a well-fertilized area. Using a quadratic model, N fertilizer rate was related to SI and generalized equations were provided for the three thermal times studied. This work represented early attempts to utilize chlorophyll meter readings for determining an in-season N rate to maximize corn yield. Varvel et al. (2007) concluded that the approach should be valid using other instruments such as a crop canopy sensor to collect data for a SI.

Active Canopy Sensors

Active crop canopy sensors have been used to monitor the N status of the crop, allowing growers to make management decisions in reaction to actual growing season conditions. These sensors also have the advantage of being able to cover large areas with good spatial resolution, an improvement over the chlorophyll meter. Additionally, sensors have a desirable temporal resolution. Fields can be sensed frequently, which provides for both the temporal variation that occurs within a growing season and for year-to-year climatic variation. Similar to the chlorophyll meter, active canopy sensors can be effective indicators of in-season crop need because they integrate the conditions and stresses that have already occurred during the early growing season, thus allowing the plant to convey the N availability.

How Active Canopy Sensors Work

Active sensors work by emitting modulated polychromatic light onto the crop canopy and then measuring reflectance from the canopy with photodetectors (Figure 1.1). The modulated light source simultaneously emits visible and near infrared light, which is detected synchronously by sensor electronics (Holland, et al., 2004). This allows the sensor to operate in full sun, under cloud cover, or at night. Unlike passive sensors, which rely on natural sunlight, active sensors do not have limitations due to cloud cover and solar angle. When used to detect plant health, light in both the visible (VIS; 400-700 nm) and near-infrared (NIR; 700-1000) portions of the electromagnetic spectrum are generally measured. Reflectance has been found to be correlated to chlorophyll content, which in turn is correlated to the N status of the vegetation (Thomas and Gausman, 1977). Chlorophyll absorbs strongly in the blue (around 450 nm) and red (around 670 nm) portions of the electromagenetic spectrum, while green light (around 550 nm) is reflected. The visible portion of the spectrum is related to the color and photosynthetic activity of cell organelles such as chloroplasts, while the NIR region of the spectrum is an indication of the internal cellular structure of a plant (Walter-Shea et al., 1991).

Chlorophyll content has been shown to be the most important factor affecting spectral reflectance (Reddy et al., 2001). A positive relationship between the greenness of leaves and the crop N status (Piekielek and Fox, 1992) indicates that it is possible to use canopy reflectance measurements for assessment of crop N needs (Blackmer et al., 1996).

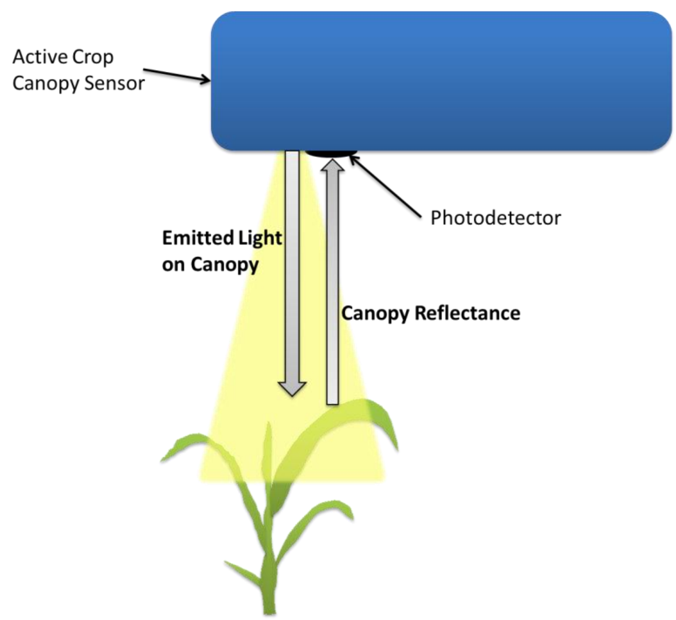

Figure 1.1 Diagram of an active crop canopy sensor.

Vegetation Indices

Reflectance values are often expressed as a vegetation index, such as the normalized difference vegetation index (NDVI), which is used frequently to relate the reflectance of the light energy in the visible and infrared bands of light. Rouse (1974), first proposed this normalized method as follows:

$$\text{NDVI} = \frac{\text{R}_{\text{NIR}} - \text{R}_{\text{RED}}}{\text{R}_{\text{NIR}} + R_{\text{RED}}} \quad (1.1)$$

where

R_{NIR} = near-infrared reflectance

R_{RED} = red reflectance

A positive correlation has been found between chlorophyll levels and NDVI for corn (Reddy et al., 2001). Maximum reflectance in the red region occurs between 660-680 nm and has historically been used to predict chlorophyll content as part of vegetation indices (VI). However, for the red region, saturation occurs at relatively low chlorophyll levels, reducing sensitivity to high chlorophyll contents. The term saturation expresses that readings occur in a narrow range and true differences are overwhelmed by natural variation. The index used for chlorophyll estimation should be one that is maximally sensitive to chlorophyll and is not influenced by other factors. Using slightly shorter or longer wavelengths has proven more useful as higher chlorophyll contents are required to saturate absorptance at these wavelengths (Sims and Gamon, 2002). Reflectance near 700 nm and in the green channel (between 530 to 630 nm) was found to be sensitive to chlorophyll content within a wide range of chlorophyll concentrations. These reflectance values can increase the sensitivity of NDVI to chlorophyll content by approximately five-fold (Gitelson and Merzlyak, 1997). Scharf and Lory (2009) found that the 560 (green) and 710 nm (red edge) wavelengths were among the most sensitive to N stress in leaves. For this reason indices that use these wavelengths would be preferred. The normalized difference red edge (NDRE) index is similar to NDVI, but uses the red edge wavelength in place of the red wavelength.

Solari et al. (2008) used an active sensor to evaluate two VI in comparison with chlorophyll meter readings across two vegetative and two reproductive growth stages. One VI, the chlorophyll index (CI) at 590 nm (Gitelson et al., 2005), was evaluated according to the following formula.

$$\text{CI} = \frac{R_{NIR}}{R_{Green(590\ nm)}} - 1 \qquad (1.2)$$

where

CI = chlorophyll index
R_{NIR} = reflectance in the NIR range (750 to 800 nm)
R_{GREEN} = reflectance at 590 nm

The study also compared the NDVI index as shown in Equation 1.1; however, in place of reflectance in the red band, reflectance at 590 nm was used. This is referred to as the $NDVI_{590}$. The study found CI_{590} to be more sensitive to canopy N status than $NDVI_{590}$. Regardless, the NDVI equation, using several wavelengths is still often used. The $NDVI_{590}$ is also referred to as the Amber Normalized Difference Vegetation Index (ANDVI). Additionally, NDVI which uses the 560 nm wavelength in place of red wavelengths has also been used to detect chlorophyll content and is referred to as the Green Normalized Difference Vegetation Index (GNDVI).

Relating Vegetation Indices to Economic Optimum Nitrogen Rate

Dellinger et al. (2008) sought to determine the relationship between the GNDVI and EONR in order to develop a recommendation for sidedress N. This study found that when no pre-plant N was applied, or when manure was applied, there was a strong relationship between EONR and GNDVI. However, when N fertilizer was applied pre-plant, no relationship between EONR and GNDVI was found suggesting that the use of GNDVI for determining in-season N application rates will be limited to situations where there is little or no fertilizer applied at planting. This is thought to be because the pre-plant fertilizer supplies the crop with enough N fertilizer through the time of sidedress sampling, but not enough to support the plants later in the growing season. Nevertheless, the results suggested that reflectance data collected with an active sensor could be used to direct sidedress N recommendations.

Schmidt et al. (2011) compared several available methods for making N recommendations using an active crop canopy sensor. The ANDVI was the index used for evaluation. Because an algorithm to make N recommendations based on ANDVI did not yet exist, the EONR was used to compare the effectiveness of pre-sidedress nitrate test, chlorophyll meter, and ANDVI. The pre-sidedress soil nitrate test is considered to be one of the better methods currently available for making N recommendations; however, the feasibility of implementing this method for directing in-season, variable rate N applications is limited, as the large number of samples required makes this economically impractical. Additionally, the time required to test these samples means that soil N changes may occur between the time of sample collection and N application. The study found that ANDVI calculated with the use of an active sensor was a slightly better indicator of EONR than pre-sidedress soil nitrate test, and furthermore it is more responsive to spatial and temporal requirements. Additionally, ANDVI collected using an active canopy sensor was found to perform better than the chlorophyll meter as an indicator of EONR. Overall, ANDVI was a more consistent indicator of EONR when compared with the chlorophyll meter or pre-sidedress soil nitrate test.

Using a Sufficiency Index with Active Sensors

Many studies have been done to evaluate the use of sensors to direct N application during the growing season (Dellinger et al., 2008; Kitchen et al., 2010; Schmidt et al., 2011; Shanahan et al., 2008). For sensor information to be useful for calculating optimal N sidedress application rates, algorithms must be used to incorporate sensor reflectance measurements. The algorithms typically require the establishment of an N-rich reference strip within the field, which receives sufficient N application to ensure that N is not limiting (Blackmer et al., 1996; Shanahan et al., 2008). The N-rich reference strip allows sensor data to be normalized, therefore improving correlation by limiting the effects of hybrid, environmental conditions, and diseases (Shanahan et al., 2001) in the same way as with the previously discussed chlorophyll meter. The SI is defined as follows:

$$\mathrm{SI} = \frac{\mathrm{VI}_{\mathrm{Target}}}{\mathrm{VI}_{\mathrm{Reference}}} \tag{1.3}$$

where

VI_{target} is the vegetation index (or measurement) for the sensed crop
$VI_{reference}$ is the vegetation index (or measurement) for the N-rich reference crop

Any number of VI can be used in the calculation of the SI. Sufficiency index values are always expressed from 0 to 1, therefore the number in the denominator must be larger than the number in the numerator. For some VI, this requires the VI of the target and reference crops be switched as with the inverse simple ratio. With the inverse simple ratio, visible reflectance is divided by near infrared reflectance generally resulting in higher values for the target crop than the reference crop.

Roberts et al. (2010) compared sidedress sensor-based N applications to uniform N application rates determined by producers. In order to determine the sensor-based N application rate, a SI was calculated by dividing sensor readings from well-fertilized N-rich reference areas by the sensor reading from the plot area. The study found that in many situations, sensor-based N applications resulted in lower N application rates than producer-determined rates. This resulted in increased yield efficiency (increase in yield per unit of N applied) and higher N fertilizer recovery efficiency (percentage of fertilizer-N recovered in aboveground plant biomass during the growing season). However, at low SI values, the crop health was found to be compromised to the point that additional N could not fully recover yield. Therefore, less N should be recommended as the benefit of application is decreased. As such, adequate early-season N is critical to prevent this compromise of yield. When significant N mineralization during the growing season occurred, sensors were valuable as they took this into account, therefore resulting in increased yield efficiency due to reduced in-season N application.

Algorithm Development for Directing Nitrogen Rates with an Active Sensor

A number of algorithms have been developed to relate sensor-derived crop reflectance data to optimum in-season N rates. Initial sensor-based N rate algorithm development in Nebraska is documented in Solari et al. (2010). This approach is based on a previously developed algorithm for determining crop N need using a chlorophyll meter and correlation between chlorophyll meter and crop canopy sensor readings. The SI approach is used, which can be determined using either the NDVI index or CI. Sufficiency index for NDVI is defined as NDVI of the N limiting crop divided by the

NDVI of a non-N-limiting reference strip. Similarly, SI for CI is defined as CI of the N limiting crop divided by the CI of a non-N-limiting reference strip. Normalizing sensor data to a well-fertilized reference treatment through the use of the SI concept allows for estimation of the crop's ability to respond to applied N. This also serves as a normalization for data to a particular environment. The previously determined quadratic response from SI determined with a SPAD meter to N rate was used as a basis for the algorithm determination. The quadratic model developed for the chlorophyll meter indicated that maximum yield occurred at 179 kg N ha^{-1} and deviated only slightly from year to year. Adjustments were made to make this relationship applicable to sensor derived SI values. The final form of the equation is defined as:

$$Napp = 317\sqrt{0.97 - SI_{sensor}} \quad (1.4)$$

where

Napp = N application rate

SI_{sensor} = sufficiency index calculated by dividing reflectance of a target crop by reflectance of a well-fertilized reference area

0.97 in the equation is the point at which N application is triggered. At values higher than 0.97 response is not expected. This model was developed and validated with data from a specific location and therefore may be limited in its application.

Holland and Schepers (2010) further refined this approach. The goal of their work was to develop and verify a generalized N application model that can be used with contact (e.g. chlorophyll meter) and remotely sensed data. The user can choose which vegetation index they prefer to use to calculate the SI, as discussed previously. Rather than using an estimation of yield potential, which is often used with the mass balance approach to nutrient management, the model allows users to input an optimum N rate (ONR) or EONR. The ONR subtracts the N that has been applied before crop sensing, N credits from the previous crop, manure application, and nitrate in the water to determine the in-season N application rate. Crop N uptake at any given growth stage is estimated based on phenologic information. A compensation term is used to increase the ONR progressively as SI values decrease. The compensation term accounts for both the fertilizer needed for sensed plants to catch up to reference plants and for the N required by the soil microbial community. If the N needs of the soil microbes are not taken into account, crop N will often be limited due to immobilization. The model also incorporates a back-off feature, which reduces the N requirement. At low SI values, N stress is severe enough to reduce yield potential, and therefore N recommendations should be reduced accordingly. This is supported by observations by Kitchen et al. (2010) which indicate that at very low SI values, increases in N fertilizer rates could not profitably increase yields, as low N status in the early growing season resulted in compromised plant health and a loss of yield potential. Two field studies were performed to test the model developed by Holland and Schepers (2010). While they did not quantitatively measure the effectiveness of the model, assumptions of the model were evaluated using crop canopy sensors and chlorophyll meters. The final form of the equation is as follows:

$$N_{APP} = (MZ_i \times N_{OPT} - N_{PreFert} - N_{CRD} + N_{COMP}) \times \sqrt{\frac{(1 - SI)}{\Delta SI}} \qquad (1.5)$$

where

N_{APP} = N rate to be applied
MZ_i = optional management zone scalar based on historical yield or soil sample information
N_{OPT} = EONR or the maximum N rate prescribed by producers
$N_{PreFert}$ = sum of fertilizer N applied before crop sensing and/or in-season N application
N_{CRD} = N credit for the previous season's crop, nitrate in water, or manure application
N_{COMP} = N in excess of N_{OPT} required by the crop under soil-limiting conditions at a given growth stage
SI = Sufficiency index
ΔSI = Difference between where SI equals 1.0 and the point where the response curve intersects the y axis (mathematically, 1-SI(0))

Other algorithm development approaches such as the approach developed by Oklahoma State University are largely based on the traditional method of determining fertilizer N requirements. An expected yield is determined, and typical grain protein content is used to determine the total N uptake expected for this yield. Nitrogen use efficiency and other credits are taken into account. The N fertilizer recommendation is determined by back calculating from the yield goal in a mass balance approach. Raun et al. (2004) provides a summary, update, and justification of the Oklahoma State University algorithm work. The rationale for basing their algorithm on predicted yield is provided. The logic employed is that at any given level of yield for a specific crop, nutrient removal can be estimated. By estimating yield, the nutrient removal rates can be determined, and in-season application rates can then be determined based on expected removal.

Raun et al. (2001) documents initial attempts to develop this N rate prediction algorithm for use on winter wheat. In their research, spectral measurements during the growing season were used to predict potential grain yield for winter wheat. Actual measured grain yield is used as an indicator of the potential grain yield. Red and NIR wavelengths were used along with GDD. The metric used to estimate yield in-season was to sum NDVI from two sensing dates and divide by the GDD that occurred between the first and second sensing. The sensing dates were at Feekes 4 and Feekes 5 growth stages for wheat and by obtaining two sensor readings, a measure of crop development and growing conditions is provided. The first reading establishes a base measurement of crop condition, while the second measurement assesses postdormancy changes. Estimated yield (EY) using this method was found to explain 83% of the variability in measured grain yield. Grain yield goals have long been used to estimate preplant fertilizer N rates. By more closely predicting potential grain yields, adjustments may be made to in-season nutrient applications to reflect early crop development and growing conditions. Therefore, the use of EY was proposed to assist in refining in-season application of fertilizer N based on predicted potential grain yield.

The work by Raun et al. (2001) was expanded upon by Lukina et al. (2001). Lukina et al. (2001) attempted to resolve limitations of the previous work. One noted limitation was that the estimation of yield required data from two independent sensing events. Therefore, a goal was to determine the feasibility of using a single sensor measurement to predict early-season plant N uptake. A different index than previously developed by Raun et al. (2001) was used to relate NDVI to wheat yield. Henceforth this index is termed INSEY which stands for in-season estimate of yield. The approach for determining INSEY was to divide the NDVI measurement from one sensing date at growth stage Feekes 4-6 by the days from planting to sensing. The INSEY index was found to have better correlation ($R^2 = 0.64$) than the previous EY index ($R^2 = 0.53$) with winter wheat grain yield.

Lukina et al. (2001) also laid the framework for the development of an N application rate algorithm. Early season plant N uptake was predicted ($R^2 = 0.75$) using NDVI readings. Grain yield was predicted ($R^2 = 0.64$) using the INSEY and yield relationship that was empirically developed. Percent N in the grain is also predicted based on a relationship with predicted yield level. By combining these three predictions (percent N in the grain, early-season plant N uptake, and wheat grain yield), a procedure was developed to predict N fertilizer application rate. Predicted grain N uptake is calculated by multiplying predicted grain yield by predicted percent N in the grain. The predicted early-season plant N uptake is then subtracted from the predicted grain N uptake. This determines the predicted N deficit. The predicted N deficit is then divided by a factor to account for efficiency. Lukina et al. (2001) suggested an efficiency factor of 0.70 be used, which essentially says that a maximum of 70% efficiency of applied N can be achieved by streamed, top-dressed UAN to wheat applied in-season. This factor can be adjusted to account for differing anticipated efficiencies. The result was that increased N rates were prescribed for areas in the field with high yield potential as indicated by INSEY and reduced N rates are prescribed for areas in the field with lower yield potential. This procedure accounts for the amount of N in the plant at the time of sensing and adjusts N need downward accordingly.

Raun et al. (2002), defined the term YP_0 as predicting grain yield potential with no added fertilization, similar to the term EY in research by Raun et al. (2001). YP_0 was predicted using the INSEY approach by Lukina et al. (2001). A slight modification was made to the denominator of the INSEY equation. Where Lukina et al. (2001) used days from planting to sensing, Raun et al. (2002) redefines GDD to INSEY determination as days from planting to sensing where GDD are greater than 0. Essentially, INSEY is an estimate of biomass produced per GDD, which is correlated to ultimate grain yield. The number of days from planting acts as the normalized divisor. However, potential yield may be altered between the times of sensing to harvest due to adverse conditions and may therefore differ from the actual yield obtained. As later explained in Raun et al. (2004), to correctly predict potential yield, the model development required removing data points outside of one standard deviation to eliminate those sites where adverse conditions negatively impacted yields resulting in actual yields less than yield potential.

In the research by Raun et al. (2002), the previously suggested nitrogen rate algorithm by Lukina et al. (2001) was further modified to include the response index (RI) feature. The RI was developed in order to estimate the potential yield increase that could be achieved with additional N applications during the growing season. This is calculated by dividing NDVI of a non-N-limiting strip by the average NDVI in the remainder of the field. In-season RI was found to be correlated to RI at harvest. The in-season RI accounts for the likelihood of obtaining a response to in-season N and the magnitude of the response to applied N at a given level of YP_0. Response to applied N has been found to be highly variable from year to year. This is because the response to N fertilizer is dependent on the supply of the non-fertilizer N in any given year. By providing a reliable indicator of the RI, the estimation of N requirement for that year should be improved. In general, the higher the RI, the more N will be recommended, and at lower NDVI readings. In Raun et al. (2004)'s work, adjustments made to this portion of the algorithm to "fine-tune" the RI are documented. For example, a cutoff factor is applied so that NDVI values lower than 0.25 do not receive N application as this is the point at which wheat stands are so poor that they will not produce appreciable yields. It was found that the RI was a conservative estimate that has the tendency to underestimate yield potential. To overcome this problem an alternate response index based on potential yield was created, termed RI_{YP}.

The RI is then multiplied by YP_0 to determine the potential yield with added N fertilizer here referred to as $YP_{N.}$ Prediction of percent N in the grain is made using YP_N. Percent N in the grain is then multiplied by YP_N to determine the predicted grain N uptake. Forage N uptake is also predicted using NDVI. By subtracting forage N uptake at the time of sensing from the anticipated end of season N uptake of the grain, N deficit is determined. The N deficit is then divided by an NUE efficiency factor, in this case, set at 0.70. A maximum yield potential (YP_{MAX}) is set to place limits on $YP_{N.}$ In this way the expected yield with nitrogen fertilizer application is set to not exceed biological limits previously documented for specific environments.

In documentation by Raun et al. (2004), an additional adjustment due to the coefficient of variation (CV) was introduced. CV was shown to be correlated with plant population. NDVI is correlated with N uptake, which is the product of N content and plant biomass. Therefore by identifying changes in plant population due to the use of CV, estimations of N uptake can be improved. High CV indicates that plant stands and growth are irregular and therefore the RI will be lower than if the plant stands are uniform, for a given NDVI. Therefore, adjusting RI as a function of CV accounts for the inability for predicted yields to be reached. The yield potential without added N was left independent of CV, while the yield potential with added N was made dependent on CV.

Teal et al. (2006) documented the adaption of this algorithm approach for use in corn. The most effective growth stage for corn grain yield prediction was determined and a corn yield potential prediction equation was generated from actual yields and early season NDVI measurements. The highest coefficient of determination for NDVI and yield was obtained at the V8 growth stage. The INSEY calculated using GDD was used to develop a relationship to actual grain yield and is here referred to as GDD INSEY. Categorizing NDVI measurements by GDD ranging from 800 to 1000 resulted in a significant exponential relationship between grain yield and NDVI, similar to the V8 leaf stage characterization. However, by categorizing NDVI by GDD (800-1000 GDD) the time of sensing was extended by two leaf stages (V7-V9) thereby increasing practicality.

Early work in developing an N recommendation algorithm in Missouri focused on calibrating reflectance measurements to predict EONR (Scharf and Lory, 2009). Measurements were taken on multiple sites with a sensor capable of measuring reflectance in eight wavelength bands. Sites had multiple N rates applied. Yield was collected from each site and grain yield response to N rate was modeled as a quadratic-plateau function. EONR was then calculated for each location using a nitrogen/grain price ratio. Wavelengths were combined in simple ratios and evaluated to determine which ratios were the strongest predictors of EONR. Absolute reflectance values (those not related to reflectance from a non-limiting N reference) were poorly related to EONR;

however, by using a high-N reference area, reliable estimates of ONR were produced. It was determined that visible/NIR ratios (sometimes referred to as the simple inverse ratio (ISR)) relative to the same ratio of a high-N reference area was the strongest predictor of EONR. Of this ratio, the 560/NIR ratio was most strongly related to EONR. It was also noted that when starter fertilizer N was applied, diagnostic errors in N recommendation may occur. This was because the apparent N availability to the plant early in the season did not indicate the season-long availability of N, leading to situations where N could be underdiagnosed.

Later work by Scharf et al. (2011), further refined the N recommendation equation. The relative ratio of 560/NIR suggested by Scharf and Lory (2009) was used in the N rate calculation. The ISR from both the reference crop and target crop were needed to generate a relative ratio. The optimal yield derived from the model was related to the relative ISR. Based on modeled optimal yield and economics, optimal N was derived. Because the differences in spectral properties between N-sufficient and N-stressed corn gets larger as the growth stage advances, the N rate calculation equation was modified for various growth stages. Additionally, it was observed that the relative visible/NIR ratio varied more when measured with the Greenseeker® sensor than with the Crop Circle™ ACS-210. Therefore a mathematic relationship between relative visible/NIR was developed for these two sensors and an N rate equation specific to each sensor was developed. Three variations of the equation were then published based on corn growth stage. A minimum base rate of 55 -65 kg N ha^{-1} is generally recommended even when target corn has the same appearance as the high-N reference corn. A normal range of reflectance readings for N-sufficient corn at various growth stages was found by Sheridan et al. (2012). These values are used to guard against including anomalous readings in an N application algorithm. These limits are applied to ISR values in the application of the Missouri algorithm.

Benefits and Limitations of Active Crop Sensors

Active crop canopy sensors have many benefits. They allow growers to make management decisions that are based on actual growing season conditions, effectively integrating conditions and stresses which have occurred. They also allow for large areas to be covered with good spatial resolution and can immediately supply information needed to direct N application rates. Kitchen et al. (2010) observed that the value of using crop canopy sensors increased as fertilizer cost increased relative to grain price. The study also identified a number of field conditions and scenarios that the researchers believed would cause canopy sensors to be particularly valuable. These include: large within-field soil type variability, recent manure applications, recent conversion from pasture or grassland, corn grown following a legume cover crop, excessive early-season rainfall causing significant loss of preplant N, and recent drought where there may be large N carryover. Crop canopy sensors can also be mounted on the N fertilizer applicator to detect and evaluate the N status of the crop, which provides the information needed to direct N application rates. Kitchen et al. (2010) found crop canopy reflectance to be an effective indicator of optimal N rate in 50% of the fields evaluated.

However, there are limitations to active crop sensor use. Solari et al. (2008) found that both CI_{590} and $NDVI_{590}$ were more highly associated with chlorophyll meter readings in vegetative growth stages than during reproductive growth stages. This was attributed to interference from the tassel during reproductive growth. Additionally, because N tends to concentrate around the ear leaf at initiation and in later growth stages sensor should take measurements beneath higher leaves. However, light emitted from sensors are not able to reach the leaf ear, only the upper canopy. The chlorophyll meter can be positioned on the leaf ear, therefore obtaining different readings of N status than an active sensor can gather. Similarly, Kitchen et al. (2010) found that subtle differences in N status may be more easily detected with chlorophyll meter than with a canopy sensor, which might be related to red NDVI sensor saturation.

At the time of sensing, N may appear to be adequate in plants; however, this does not indicate if enough N is present in the soil to complete the growing season. Changes such as N losses through leaching, volatilization, or denitrification or additions of N through mineralization that may occur in the remainder of the growing season are not accounted for, as they are not yet expressed in the crop. Nitrogen supply, in some cases, may not be adequate to persist beyond the time of sensing. Algorithms developed for crop canopy sensor data are limited in that they cannot approximate the effects of weather on crop health and N availability from the time of sensing until harvest, therefore N recommendations will be imperfect. Additionally, uniform plant distribution is required for accurate sensor assessment of canopy N status. Practically, the time and labor constraints of sensing crops and applying in-season N applications may be a substantial deterrent. This is particularly true for producers which cannot utilize irrigation to apply N or are worried about rainfall at the critical time for sensing and N application which would limit accessibility to the field and delay or prevent the needed N application. Nevertheless, active canopy sensors are a promising precision agriculture technology.

Further development, testing, and refinement of algorithms for translating sensor readings into N fertilizer application rates are needed.

Simulation Models for Determining Nitrogen Need

In addition to remote sensing techniques, simulation models have been identified as a precision management approach which has potential to maximize the synchrony of crop demand for N and fertilizer N supply (Cassman et al., 2002). Models are a method of N management which account for the interactions between management and environmental conditions. Two such models are Maize-N and Adapt-N.

Maize-N was developed to simulate soil N mineralization and N fertilizer recovery (Setiyono et al., 2011). Maize-N builds on the Hybrid-Maize model (Yang et al., 2004), which simulates maize growth and yield based on climate and water supply. Maize N has four components which estimate corn yield potential, soil C and N mineralization, NUE, and yield versus N response. Crop rotation, tillage practices, N fertilizer form and application, as well as N fertilizer and grain prices are taken into account. The model makes use of attainable yield, which is a fraction of total yield potential. A default value of 0.85 is used based on research suggesting that attainable yield levels of 80 to 90% of yield potential can be obtained. The model was validated in experiments in central Nebraska, eastern South Dakota, and western Nebraska and included both irrigated and rainfed systems. The EONR simulated by Maize-N was relatively robust across the different sites. Maize-N is based on relationships that govern N availability and crop demand, and therefore it is speculated that these relationships would hold across many locations and environments. When compared with existing algorithms for determining N from the University of Nebraska-Lincoln, South Dakota State University, Kansas State University, and the University of Missouri, the Maize-N model estimated the EONR with greater accuracy (Setiyono et al., 2011).

It should be noted that when soybean was the previous crop, and when conventional tillage was used, the system was more sensitive to changes in soil organic carbon and attainable yield. A reliable estimate of yield potential is critical as it sets the upper ceiling for yield and N uptake requirements. Determining the yield with no fertilizer is also important because, taken together with the agronomic efficiency, this defines the shape of the N rate to yield function. It is difficult to estimate attainable yields and the yield with no applied fertilizer, for these depend on climate and water availability. Using real-time weather data in addition to long-term weather data may improve the estimate of yield with no applied fertilizer.

The Adapt-N tool is another model developed to determine in-season N recommendation rates for corn (Melkonian et al., 2008). This model was developed specifically for the Northeast region of the USA. Weather is a significant factor in influencing N dynamics as it influences mineralization of N as well as N losses through leaching and denitrification. In particular, the weather in the early growing season has been identified as important for determination of crop N availability. Initially, temperature affects the rate of N mineralization. In cool springs, mineralization is lower, while in warmer springs, more mineralization may be expected. The availability of the early season mineralized N is largely dependent on precipitation. Early growing seasons with wet conditions are subject to higher environmental N losses. Consequently, in years with wet conditions in the early growing season, more N may be required. If this is not accounted for, excess fertilization is likely in years with dry springs, and inadequate fertilization is probable in years with high early season N losses. Adapt-N was developed to improve in-season N recommendations based on simulation of soil N dynamics and maize N uptake. The Precision Nitrogen Management model and near-real time high-resolution climate data are used (Melkonian et al., 2005). The Precision Nitrogen Management model has two components: LEACHN and a maize N uptake, growth, and yield model. LEACHN simulates water and solute transport, and chemical and biological N transformations in the unsaturated soil zone. Outputs of the Precision Nitrogen Management model are simulation of mineralized N and losses through leaching, denitrification, and volatilization, as well as crop N uptake and biomass accumulation. Adapt-N users input information including soil textural class, drainage class, slope, tillage practices, OM content, timing and amounts of previous N inputs, soil nitrate data, crop maturity class, crop density, and tillage and planting dates. Temperature and precipitation data are provided at a 4 x 4 km gridded density. This high-resolution climate data allows for simulation of early-season soil N levels which can improve estimates of sidedress N needs.

Conclusion

Techniques which can address N management in-season, in response to current conditions, and in a spatially appropriate manner hold great promise for reducing over and under-application of N, therefore increasing NUE. For this reason, the continued investigation of the utility of crop canopy sensors and N prediction models is strongly advised.

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Chapter 2 : Interactions of In-season Maize-N-Based and Ground Sensor-Based Nitrogen Management, Hybrid, and Population

Abstract

N management for corn (*Zea mays* L.) can be improved by applying a portion of the total required N in-season, allowing for adjustments which are responsive to actual field conditions. This study was conducted to evaluate two approaches for determining in-season N rates: Maize-N model and active crop canopy sensor. The effects of corn hybrid and planting population on recommendations with these two approaches were considered. In a 2-yr study, a total of twelve sites were evaluated over a 3-state region, including sites in Missouri, Nebraska, and North Dakota. Over all site-years combined, in-season N recommendations were generally lower when using the sensor-based approach than the model-based approach. This resulted in observed trends of higher partial factor productivity of N (PFP_N) and agronomic efficiency (AE) for the sensor-based treatments than the model-based treatments. Overall, yield was better protected by using the model-based approach than the sensor-based approach. For two Nebraska sites in 2012 where high levels of N mineralization were present, the sensor approach appropriately reduced N application, resulting in no decrease in yield and increased profitability when compared with the non-N-limiting reference. This indicates that specific conditions will increase the environmental and economic benefit of the sensor-based approach. Significant population differences in normalized difference red edge (NDRE) reflectance were observed. Using a reference strip of differing plant population than the target crop resulted in N recommendations different from those obtained using a reference strip and target crop of the same population. It is advised that the non-N-

limiting reference strip be of the same plant population as the target crop to which N will be applied.

Introduction

Low nitrogen use efficiency (NUE) has been attributed to several factors including poor synchrony between nitrogen (N) fertilizer and crop demand, unaccounted for spatial variability resulting in varying crop N needs, and temporal variances in crop N needs (Shanahan et al., 2008). It is estimated that 75% of N fertilizer is applied prior to planting (Cassman et al., 2002), which results in high levels of inorganic N, such as nitrate, in the soil before the stage of rapid crop uptake occurs. Because of this, improvements in NUE can be achieved by attaining greater synchrony between the crop N need and the N which is available to the plant from all sources throughout the growing season (Cassman et al., 2002). Applying a portion of the N fertilizer alongside the growing crop allows fertilizer availability to coincide more closely with the time in which the crop needs the most nitrogen and is expected to increase NUE. Spatial variability of soil properties presents further challenges to N management. Nitrogen supplying capacity can vary throughout a field. Mamo et al. (2003), showed that N mineralization of organic matter (OM) varied spatially within a field. Additionally, the N fertilizer need by the crop can vary spatially across a field, due to varying yield potential. Mineralization of N is also dependent on soil water and temperature which vary with landscape position; therefore OM content should not be used as a sole criterion when delineating N management zones (Schmidt et al., 2002). Managing N application based on spatial variability can reduce the overall N rate applied and increase profitability when compared with a uniform N application (Mamo et al., 2003). Variable rate application of N decreases the risk of overfertilization and underfertilization, compared with uniform applications. In addition to the spatial variability component of N management, temporal variations in N response and N mineralization related to environmental factors have also been observed (Mamo et al., 2003). Climate and management interactions cause tremendous year-to-year variation in both crop N requirements and crop yields (Cassman et al., 2002). Together, spatial and temporal variation creates uncertainty as to the optimal N fertilizer quantity for any given year (Roberts et al., 2010). Determining the amount and timing of N needed by the crop over a spatially diverse field is critical for improving NUE.

Strategies which detect crop N status at early growth stages have been suggested as a method to improve NUE (Ferguson et al., 2002). Active crop canopy sensors are available to monitor the N status of the crop, allowing growers to make management decisions that are reactive to actual growing season conditions. Sensors also have the advantage of being able to cover large areas with good spatial resolution. Additionally, sensors have a desirable temporal resolution. Fields can be sensed frequently, therefore providing for the temporal variation that occurs within a growing season as well as year-to-year climatic variation. Sensors can be an effective indicator of in-season crop need as they serve to integrate the conditions and stresses that have already occurred during the early growing season. Crop canopy sensors are designed to detect specific wavelengths of light that are reflected by crop canopies. These wavelengths are then combined to create indices that have been found to be correlated with specific crop conditions of interest. Reflectance values are often expressed as a vegetation index such as the normalized difference vegetation index (NDVI), which relates the reflectance of the light energy in the visible and infrared bands of light. A positive correlation has been found between chlorophyll levels and NDVI for corn (Reddy et al., 2001). Maximum reflectance in the red region occurs between 660-680 nm and has historically been used to predict chlorophyll content as part of vegetation indices. However, for the red region, saturation occurs at low chlorophyll levels, reducing sensitivity to high chlorophyll contents. The index used for chlorophyll estimation should be one that is maximally sensitive to chlorophyll and is not influenced by other factors. For this reason, the NDRE index has been used in place of NDVI.

For sensor information to be useful for calculating optimal N sidedress application rates, algorithms must developed which will incorporate sensor reflectance measurements. The algorithms require the establishment of an N-rich reference strip within the field, which receives sufficient N application to ensure that N is not limiting (Blackmer et al., 1996; Shanahan et al., 2008). The N-rich reference strip allows sensor data to be normalized, therefore improving correlation by limiting the effects of hybrid, environmental conditions, and diseases (Shanahan et al., 2001). A sufficiency index (SI) is then determined as follows:

$$\mathrm{SI} = \frac{\mathrm{VI}_{\mathrm{Sensor}}}{\mathrm{VI}_{\mathrm{Reference}}} \tag{2.1}$$

where

VI_{sensor} is the vegetation index (or measurement) for the sensed crop

$VI_{reference}$ is the vegetation index (or measurement) for the N-rich reference crop

Various algorithms have been developed, to relate sensor-derived data to the amount of N needed. Holland and Schepers (2010) developed a generalized N application model that was used with remotely sensed data in this study, and is here referred to as the Nebraska algorithm. This approach is based on the shape of an N fertilizer response function and the relationship between N rate and in-season crop vegetation index data. Rather than using an estimation of yield potential, which is often used with the mass balance approach to nutrient management, the model uses local or regional data to generate an optimum N rate (ONR) or economic optimum N rate (EONR). Consequently, this method relies on the shape of the fertilizer N response function. Yield by fertilizer N rate is typically defined as a linear or quadratic plateau response function. The plateau is the portion where yield becomes insensitive to further increases in N fertilizer additions. This area is defined in the algorithm as Nopt. Nitrogen which was applied pre-plant and other known N credits are then subtracted from Nopt. Next, a compensation factor is added. The compensation factor is based on the expected NUE of the plant and takes into account the N uptake that has already occurred for the growth stage when the crop is sensed. N uptake is determined based on the previously determined relationship between corn growth stage and relative N uptake. Finally, the resulting value is multiplied by the SI portion of the model. The user can choose which vegetation index they prefer to use to calculate the SI, as discussed previously. This study used the NDRE index. The term ΔSI is used to define the point between a SI of 1 and the point where the response curve intersects the y-axis (SI at N rate of 0 or “check response”). The SI portion of the model essentially predicts the response that can occur due to N fertilizer application based on the relationship between SI and N rate. Therefore, the SI of the sensed crop is used to predict the response compared to non-limiting crops. Additionally, there is an optional and adjustable cutoff feature which accounts for the fact that at some point, plant stress is so great that recovery is not likely, even with large N applications. The final form of the equation is as follows:

$$N_{APP} = (MZ_i \times N_{OPT} - N_{PreFert} - N_{CRD} + N_{COMP}) \times \sqrt{\frac{(1 - SI)}{\Delta SI}} \qquad (2.2)$$

where

N_{APP} = N rate to be applied
MZ_i = optional management zone scalar based on historical yield or soil sample information
N_{OPT} = EONR or the maximum N rate prescribed by producers
$N_{PreFert}$ = sum of fertilizer N applied before crop sensing and/or in-season N application
N_{CRD} = N credit for the previous season's crop, nitrate in water, or manure application
N_{COMP} = N in excess of N_{OPT} required by the crop under soil-limiting conditions at a given growth stage
SI = Sufficiency index
ΔSI = Difference between where SI equals 1.0 and the point where the response curve intersects the y axis (mathematically, 1-SI(0))

In addition to remote sensing techniques, simulation models have been identified as a precision management technique which has potential to maximize the synchrony of crop demand for N and fertilizer N supply (Cassman et al., 2002). Models are a method of N management which account for the interactions between management and environmental conditions. The Maize-N model was developed to estimate economically optimum N fertilizer rates for maize by taking into account soil properties, indigenous soil N supply, local climatic conditions and yield potential, crop rotation, tillage and fertilizer formulation, application method and timing (Setiyono, et al., 2011). The model was validated in experiments in central Nebraska, eastern South Dakota, and western

Nebraska and included both irrigated and rainfed systems. The EONR simulated by Maize-N was relatively robust across the different sites. Maize-N is based on relationships that govern N availability and crop demand, and therefore it is speculated that these relationships would hold across many locations and environments. When compared with existing algorithms for determining N from the University of Nebraska-Lincoln, South Dakota State University, Kansas State University, and the University of Missouri, the Maize-N model estimated the EONR with greater accuracy (Setiyono, et al., 2011).

The objective of this study was to evaluate these two approaches for determining in-season N rates: Maize-N model and sensor with Nebraska algorithm. Utility in predicting N need is evaluated for both approaches over a 3-state region, including sites in Missouri, Nebraska, and North Dakota. Additionally, the study investigated effects of maize hybrid and population on the efficacy of the two N recommendation strategies.

Materials and Methods

Site Locations and Soils

This research was conducted in twelve fields over the course of the 2012 and 2013 growing seasons. Fields were located in three states: Missouri, Nebraska, and North Dakota Figure 2.1. Site selection was based on expected corn yield potential. For each year, a high yield potential and moderate yield potential site was chosen for each state. The lower expected yield site was chosen due to a limiting feature such as drainage, soil texture, or rooting depth. Sites were located in relatively close proximity to each other in order to minimize the impact of weather variability. Row spacing, plot length, tillage practices, and previous crop varied depending on the site. Expected yield potential, previous crop, tillage, and row spacing are shown for each site in Table 2.1. Soil series data is shown in Table 2.2. Select soil fertility values are shown for each site in Table 2.3.

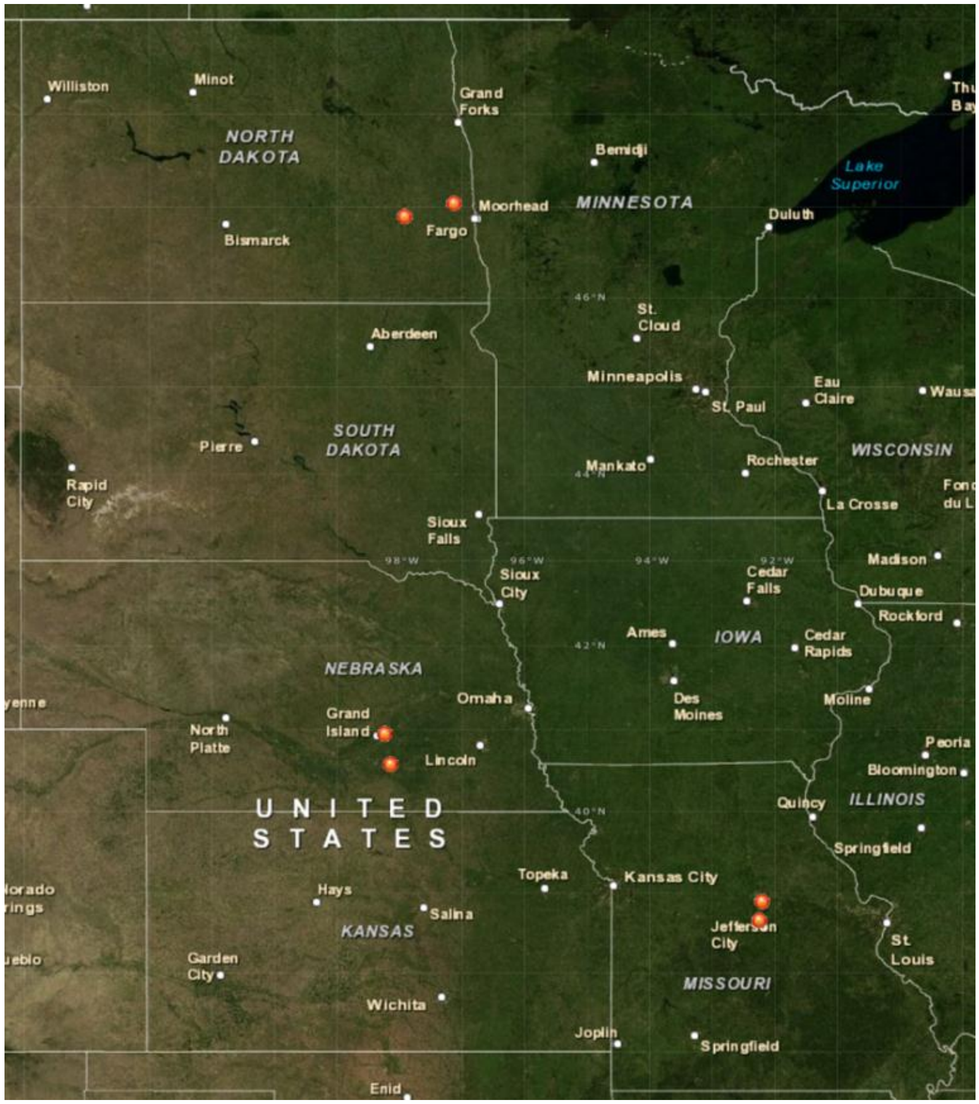

Figure 2.1 Approximate locations of research sites in eastern North Dakota, central Nebraska, and central Missouri in 2013 are indicated by red dot. Locations for 2012 are close in proximity to those shown for 2013.

Table 2.1 Site productivity potential, row spacing, tillage practice, previous crop, and irrigation amount for sites in Missouri (MO), Nebraska (NE), and North Dakota (ND) in 2012 and 2013.

Year	State	Field ID	Site Yield Potential	Row Spacing --meters--	Tillage	Previous Crop	Irrigation Amount --cm--
2012	**Missouri**	**MORO12**	High	0.76	Disk/cultivate	Soybeans	7.6
		MOLT12	Moderate	0.76	Disk/cultivate	Soybeans	7.6
	Nebraska	**NECC12**	High	0.76	Stalk chop	Corn	21.4
		NEMC12	Moderate	0.76	Stalk chop	Corn	24.1
	North Dakota	**NDDN12**	High	0.56	Chisel and field cultivate	Corn	0
		NDVC12	Moderate	0.56	No-till	Wheat	0
2013	**Missouri**	**MOTR13**	High	0.76	Field cultivator	Soybeans	0
		MOBA13	Moderate	0.76	No-till	Soybeans	0
	Nebraska	**NECC13**	High	0.76	Ridge till and cultivate	Soybeans	33.1
		NEMC13	Moderate	0.76	Stalk chop	Corn	13.9
	North Dakota	**NDAR13**	High	0.56	Chisel and field cultivate	Soybeans	0
		NDVC13	Moderate	0.56	No-till	Wheat	0

Table 2.2 Soil series and taxonomic class for research sites in Missouri (MO), North Dakota (ND), and Nebraska (NE).

Field ID	Soil Series	Taxonomic Class	% Trt Area
MORO12	Haymond silt loam, 0-3%	Coarse-silty, mixed, superactive, mesic Dystric Fluventic Eutrudepts	100%
MOLT12	Mexico silt loam, 1-4%, eroded	Fine, smectitic, mesic Vertic Epiaqualfs	100%
MOTR13	Lowmo silt loam, 0-2%, occasionally flooded	Coarse-silty, mixed, superactive, mesic Fluventic Hapludolls	100%
MOBA13	Mexico silt loam, 1-4%, eroded	Fine, smectitic, mesic Vertic Epiaqualfs	95%
	Leonard silt loam, 2-6%, eroded	Fine, smectitic, mesic Vertic Epiaqualfs	5%
NDDN12	Fargo silty clay, 0-1%	Fine, smectitic, frigid Typic Epiaquerts	100%
NDVC12	Barnes loam, 3-6%	Fine-loamy, mixed, superactive, frigid Calcic Hapludolls	100%
NDAR13	Fargo silty clay loam, 0-1%	Fine, smectitic, frigid Typic Epiaquerts	63%
	Glyndon-Tiffany silt loams, 0-2%	Coarse-silty, mixed, superactive, frigid Aeric Calciaqualls	37%
		Coarse-loamy, mixed, superactive, frigid Typic Endoaquolls	
NDVC13	Barnes-Svea loams, 0-3%	Fine-loamy, mixed, superactive, frigid Calcic Hapludolls	52%
		Fine-loamy, mixed, superactive, frigid Pachic Hapludolls	48%
	Swenoda-Barnes complex, 3-6%	Coarse-loamy, mixed, superactive, fridig Pachic Hapludolls	
		Fine-loamy, mixed, superactive, frigid Calcic Hapludolls	
NECC12	Crete silt loam, 0-1%	Fine, smectitic, mesic Pachic udertic Argiustolls	100%
NEMC12	Fonner sandy loam, rarely flooded	Sandy, mixed, mesic Cumulic Haplustolls	80.5%
			19.5%
	Novina sandy loam, rarely flooded	Coarse-loamy, mixed, superactive, mesic Fluvaquentic Haplustolls	
NECC13	Hastings silt loam, 0-1%	Fine, smectitic, mesic Udic Argiustolls	97%
	Hastings silt loam, 1-3%		3%
NEMC13	Alda sandy loam, occasionally flooded	Coarse-loamy, mixed, superactive, mesic Oxyaquic Haplustolls	82%
			18%
	Fonner sandy loam, rarely flooded	Sandy, mixed, mesic Cumulic Haplustolls	

Table 2.3 Select soil fertility mean values for research sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013.

Field ID	Organic Matter (%)	Extractable P mg kg^{-1}	Extractable K mg kg^{-1}	pH	NO_3-N mg kg^{-1} for top 0.6096 m	Irrigation NO_3-N mg kg^{-1}	Seasonal Irrigation cm
MORO12	1.5	44 *B1P	90	7	5.6	-	7.6
MOLT12	2.6	11 B1P	60	5.7	5.3	-	7.6
MOTR13	1.9	29 B1P	150	6.8	2.8†	-	0
MOBA13	1.9	11 mB1P	76	6.8	2.8†	-	0
NDDN12	5.3	32 **OP	600	7.6	6.3	-	0
NDVC12	3.6	10 OP	300	6.3	10.1	-	0
NDAR13	3.4	5 OP	120	8.0	9.2	-	0
NDVC13	3.6	19 OP	160	6.4	15.7	-	0
NECC12	3.9	27 ***M3P	482	6.35	18.3	3.7	21.4
NEMC12	1.7	41 M3P	326	6.65	9.3	8.9	24.1
NECC13	2.8	23 M3P	428	6.4	3.8	3.1	33.1
NEMC13	2.1	29 M3P	212	7.5	8.9	7.4	13.9

**B1P=Bray 1-P Extract, **OP=Olsen Extract, ***M3P=Mehlich-3 Extract,* †=estimated value

The Nebraska sites were fully irrigated in 2012 and 2013. NECC12, NEMC12, and NEMC13 were pivot irrigated. NECC13 was furrow irrigated. In 2012, Missouri sites received limited irrigation. While these sites were originally dryland, drought conditions made irrigation necessary to keep the crop alive. North Dakota sites in 2012 and 2013 and Missouri sites in 2013 were not irrigated. Irrigation time and amounts along with temperatures and precipitation are provided for each site in Appendix A.

Treatments

Each experimental site contained four replications of 16 treatments arranged in a randomized complete block design. Plots in Missouri and Nebraska were 15.24 meters in length with 4 rows per plot. North Dakota plots were 9.14 meters in length and had 6 rows per plot. Two corn hybrids were selected for each site. For Nebraska and Missouri locations, these were differentiated by low drought score (hybrid A) or high drought score (hybrid B). Hybrids for North Dakota were not selected for different drought scores. Additionally, each hybrid was planted at a standard seeding rate and high seeding rate. Hybrids with their drought classification, and low and high seeding rates are reported in Table 2.4 by site. Four N treatments were used: unfertilized check, N-rich reference, sensor-based, and model-based. The unfertilized check received no N application during the study. The N-rich reference received an N quantity that was considered to be non-limiting to yield and varied by site. The sensor-based and model-based treatments each received an initial N application prior to or at planting which also varied based on site. The goal for the initial N rate was that N would not cause unrecoverable stress before the in-season N application. The N-rich reference rate and sensor and model-based initial N rate were determined for each state by a researcher with previous experience in that state. Nitrogen source, timing, quantity, and method of application for the N-rich reference and initial N application for model-based and sensor-based treatments are shown by site in Table 2.5. The sensor-based treatments received an in-season N application which was determined using a sensor and algorithm, and the model-based treatments received an in-season N application which was determined using a model. A representative treatment layout is provided in Figure 2.2.

Table 2.4 Corn hybrid and planting population for evaluation of in-season N application using Maize-N model and crop canopy sensor at sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) sites in 2012 and 2013.

Field ID	**Planting Date**	**Hybrid***		**Planting Population** seeds ha^{-1}	
		A	*B*	*Low Rate*	*High Rate*
MORO12	May 11	Pioneer 33D49	Pioneer 1498	77,601	101,311
MOLT12	May 11	Pioneer 33D49	Pioneer 1498	76,601	101,311
MOTR13	May 23	Pioneer 33D49	Pioneer 1498	76,601	101,311
MOBA13	June 5	Pioneer 33D49	Pioneer 1498	76,601	101,311
NDDN12	April 26	Pioneer 39N99	Pioneer 8906 HR	79,072	103,782
NDVC12	April 26	Pioneer 39N99	Pioneer 8906 HR	79,072	103,782
NDAR13	May 17	Pioneer 39N95 AM	Pioneer 8906 HR	79,072	103,782
NDVC13	May 17	Pioneer 39N95 AM	Pioneer 8906 HR	79,072	103,782
NECC12	May 9	Pioneer 33D49	Pioneer 1498	79,072	103,782
NEMC12	May 10	Pioneer 33D49	Pioneer 1498	79,072	103,782
NECC13	May 13	Pioneer 33D53 AM	Pioneer 1498 AM	79,072	103,782
NEMC13	May 14	Pioneer 33D53 AM	Pioneer 1498 AM	79,072	103,782

* For Nebraska and Missouri sites, hybrid A has a lower drought score and hybrid B has a higher drought score.

Table 2.5 N source, rate, timing, and method of application for N-rich reference treatment and initial N rate for sensor-based and model-based treatments for sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013.

	N-rich reference				Initial sensor based and model based treatments			
Field ID	**Rate kg ha^{-1}**	**Time**	**Source**	**Method**	**Rate kg ha^{-1}**	**Time**	**Source**	**Method**
MORO12	280	May 11	SuperU	Hand broadcast	56	May 11	SuperU	Hand broadcast
MOLT12	280	May 11	SuperU	Hand broadcast	56	May 11	SuperU	Hand broadcast
MOTR13	280	May 23	SuperU	Hand broadcast	56	May 23	SuperU	Hand broadcast
MOBA13	280	June 5	SuperU	Hand broadcast	56	June 5	SuperU	Hand broadcast
NDDN12	224	April 27	Urea	Hand broadcast	0*	--	--	--
NDVC12	224	April 27	Urea	Hand broadcast	0	--	--	--
NDAR13	224	May 15	Ammonium Nitrate	Hand broadcast	0	--	--	--
NDVC13	224	May 15	Ammonium Nitrate	Hand broadcast	0	--	--	--
NECC12	280	March 30	UAN32%	Knifed-in	84	March 30	UAN32%	Knifed-in
NEMC12	268	April 6	UAN32%	Knifed-in	84	April 6	UAN32%	Knifed-in
NECC13	280	April 3	UAN32%	Knifed-in	84	April 3	UAN32%	Knifed-in
NEMC13	268	April 20	UAN32%	Knifed-in	84	April 20	UAN32%	Knifed-in

*No N was applied prior to in-season N application for sensor and model based treatments at North Dakota sites.

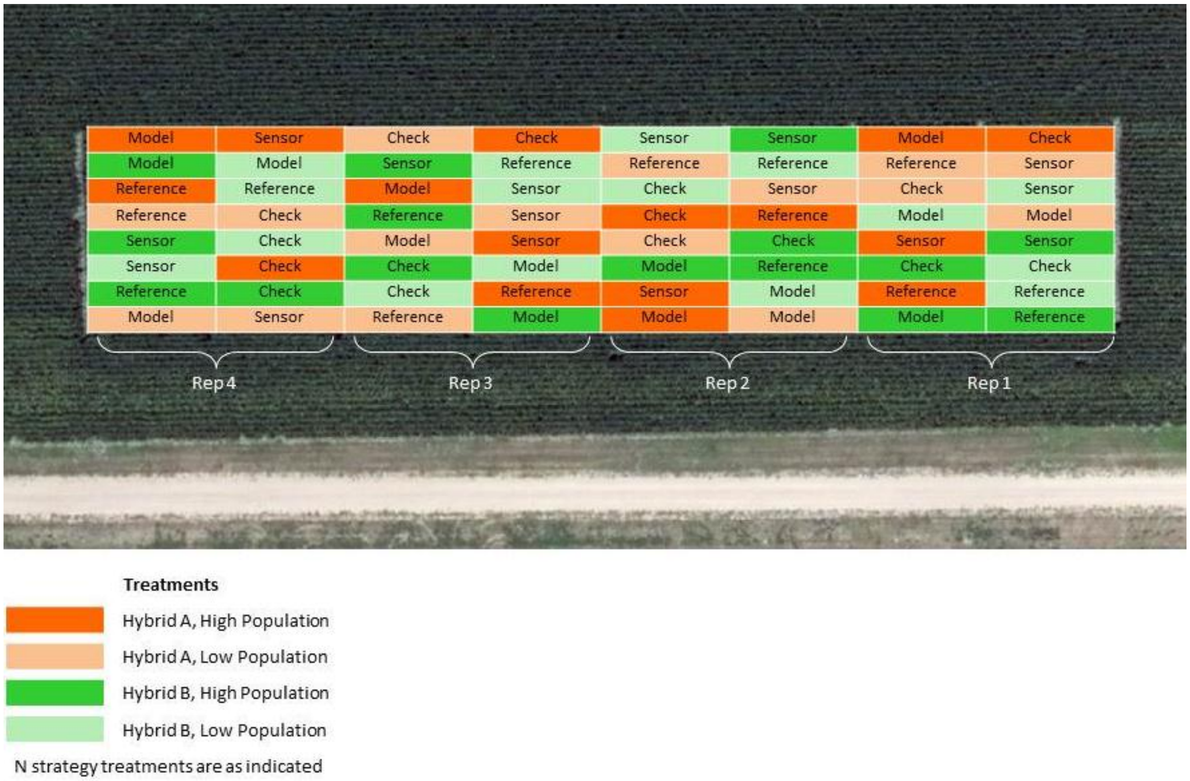

Figure 2.2 Treatment layout of hybrid, plant population and N strategy for a Nebraska site in 2013 (NECC13). Treatments are overlaid on a true-color image.

Implementing the Model Treatments

The in-season N application rates for the model-based treatments were determined using Maize-N: Nitrogen Rate Recommendation for Maize (Yang et al., University of Nebraska – Lincoln, 2008). The Maize-N model was developed to estimate economically optimum N fertilizer rates for maize by taking into account soil properties, indigenous soil N supply, local climatic conditions and yield potential, crop rotation, tillage and fertilizer formulation, and application method and timing. These input values as well as a long-term weather file were entered into the model software. Version 2008.1.0, used for the 2012 growing season, did not have the capability to take into account weather that had occurred in that growing season to determine mineralized N. For 2013, Version 2013.2.0 was used which contains updates to allow the model to utilize current weather data in order to estimate the amount of mineralization of N that had occurred since the last crop. The long-term weather data was then used to predict mineralization of N for the remainder of the season, based on historical trends. Input values and output for Maize-N are provided for each site in Appendix B. Plant population was input into the model as the target seeding rate listed in Table 2.4, except for sites NDDN12 and NDVC12, where stand counts were much lower than the planting rate at the time of in-season N application. At these locations, the plant population input was adjusted to reflect more closely the actual stand. The populations used are noted in input files. A separate iteration of the model was run for each unique hybrid and population treatment combination. The percent of basal N in total N rate was adjusted so that the output value of recommended basal N application was equal to that which was applied initially for the model-based treatments. For consistency, urea ammonium nitrate (28%) was input as the type of fertilizer for basal and in-season N applications. The output recommendations were consequently given for urea ammonium nitrate (28%). This recommendation was then adjusted to apply the same amount of N using the appropriate fertilizer sources for each site. The yield potential, attainable yield, economically optimal N rate for the whole season, and in-season N recommendation are summarized by site and treatment in Table 2.6. It is necessary to note that for site MOTR13, due to an error in N credits applied for the model input values, the economically optimum N rate and in-season N recommendation was incorrectly reduced by 18 kg N ha^{-1}. In-season N was applied using different N sources and methods for each site. Nitrogen for Missouri sites was hand applied using Super-U (46% N). Nebraska sites N was hand applied using UAN (32%). At North Dakota sites, UAN (28%) was applied using a walk behind applicator with streaming drop nozzles that the operator pushed through the field.

Table 2.6 Maize-N generated yield potential, attainable yield, economically optimal N rate, and in-season N recommendation arranged by hybrid and plant population for sites in Missouri (MO), Nebraska (NE), and North Dakota (ND) in 2012 and 2013.

	MORO12			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	13.5	14.8	13.2	14.7
Attainable yield Mg ha^{-1}	11.2	11.2	11.2	11.2
EONR kg N ha^{-1}	173	161	175	163
In-season N rate kg N ha^{-1}	117	105	119	106
	MOLT12			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	13.5	14.8	13.2	14.7
Attainable yield Mg ha^{-1}	9.94	9.94	9.94	9.94
EONR kg N ha^{-1}	135	128	136	129
In-season N rate kg N ha^{-1}	78	72	80	73
	NECC12			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	16.1	17.5	16.0	17.4
Attainable yield Mg ha^{-1}	14.5	14.5	14.5	14.5
EONR kg N ha^{-1}	118	98	121	100
In-season N rate kg N ha^{-1}	34	13	37	16

NEMC12				
	Hybrid A		Hybrid B	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	16.7	18.1	16.5	18.0
Attainable yield Mg ha^{-1}	11.9	11.9	11.9	11.9
EONR kg N ha^{-1}	167	160	169	163
In-season N rate kg N ha^{-1}	83	76	85	78

NDDN12				
	Hybrid A		Hybrid B	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	12.3	12.7	12.8	13.1
Attainable yield Mg ha^{-1}	10.6	10.6	10.6	10.6
EONR kg N ha^{-1}	204	198	197	194
In-season N rate kg N ha^{-1}	204	198	197	194

NDVC12				
	Hybrid A		Hybrid B	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	10.4	12.1	10.8	12.6
Attainable yield Mg ha^{-1}	9.56	9.56	9.56	9.56
EONR kg N ha^{-1}	217	187	205	183
In-season N rate kg N ha^{-1}	217	187	205	183

MOTR13				
	Hybrid A		Hybrid B	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	15.3	14.8	15.3	14.6
Attainable yield Mg ha^{-1}	13.8	13.8	13.8	13.8
EONR kg N ha^{-1}	248	259	249	267
In-season N rate kg N ha^{-1}	192	203	193	211

	MOBA13			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	13.8	15.2	13.7	15.0
Attainable yield Mg ha^{-1}	9.25	9.25	9.25	9.25
EONR kg N ha^{-1}	111	108	112	109
In-season N rate kg N ha^{-1}	55	52	56	53

	NECC13			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	16.3	17.7	16.1	17.5
Attainable yield Mg ha^{-1}	14.5	14.5	14.5	14.5
EONR kg N ha^{-1}	194	175	200	178
In-season N rate kg N ha^{-1}	110	91	115	94

	NEMC13			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	16.9	18.4	16.6	18.1
Attainable yield Mg ha^{-1}	13.2	13.2	13.2	13.2
EONR kg N ha^{-1}	207	197	212	200
In-season N rate kg N ha^{-1}	123	113	128	115

	NDAR13			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	11.9	13.0	11.9	13.0
Attainable yield Mg ha^{-1}	9.94	9.94	9.94	9.94
EONR kg N ha^{-1}	87	77	87	77
In-season N rate kg N ha^{-1}	87	77	87	77

	NDVC13			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
Yield potential Mg ha^{-1}	13.0	14.2	13.0	14.2
Attainable yield Mg ha^{-1}	9.25	9.25	9.25	9.25
EONR kg N ha^{-1}	0	0	0	0
In-season N rate kg N ha^{-1}	0	0	0	0

The Maize-N model was used to determine the model N rates. In 2012, Maize-N Version 2008.1.0 was used which did not take into account in-season weather in determination of predicted N mineralized from soil organic matter. In 2013, Maize-N Version 2013.2.0 was used which contains updates which allow the model to utilize current weather data in order to make an estimation of the amount of N mineralized from soil organic matter. Following the 2013 growing season, Maize-N Version 2008.1.0 and Version 2013.2.0 were evaluated to determine the difference in predicted N mineralization, predicted EONR, and predicted attainable yield generated by the two versions at this affects the in-season N application rate for the Maize-N model treatments (Table 2.7). Generally, Version 2013.2.0 resulted in similar or slightly higher predicted N mineralization from soil organic matter than Version 2008.1.0. Consequently, Version 2013.2.0 resulted in similar or slightly lower predicted EONR than Version 2008.1.0. The two sites in Nebraska in 2012 had the largest difference in predicted N mineralization from soil organic matter and predicted EONR between the two versions of Maize-N. For site NECC12, the predicted N mineralization from soil organic matter was 25 kg N ha^{-1} greater when Version 2013.2.0 was used resulting in a predicted EONR that was 33 to 66 kg N ha^{-1} lower. Similarly, for site NEMC12, the predicted N mineralization from soil organic matter was 11 to 12 kg N ha^{-1} greater when Version 2013.2.0 was used, resulting in a predicted EONR that was 18 to 19 kg N ha^{-1} lower than Version 2008.1.0. By accounting for actual growing season mineralization with Version 2013.2.0 at these two sites, in-season N rates were lowered.

Table 2.7 Comparison of Maize-N Version 2008.1.0 and Version 2013.2.0 in prediction of N mineralization from soil organic matter, EONR, and attainable yield for each hybrid and population at sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013. For the in-season application for model treatments in this study, Version 2008.1.0 was used for 2012 and Version 2013.2.0 was used for 2013.

Site	OM g kg^{-1}	Hybrid	Population	Predicted N mineralization from soil OM kg N ha^{-1}	Predicted EONR kg N ha^{-1}	Predicted Attainable Yield Mg ha^{-1}
				First number is for Maize-N Version 2008.1.0; number in parenthesis is for Maize-N version 2013.2.0		
MORO12	15	A	Low	55 (65)	173 (163)	11.2
		A	High	55 (65)	161 (155)	11.2
		B	Low	55 (65)	175 (165)	11.2
		B	High	55 (65)	163 (152)	11.2
MOLT12	26	A	Low	55 (65)	135 (124)	9.94
		A	High	55 (65)	128 (118)	9.94
		B	Low	55 (65)	136 (126)	9.94
		B	High	55 (65)	129 (119)	9.94
MOTR13	19	A	Low	59 (61)	249 (248)	13.8
		A	High	59 (61)	260 (259)	13.8
		B	Low	59 (59)	250 (249)	13.8
		B	High	59 (59)	268 (267)	13.8
MOBA13	19	A	Low	66 (66)	112 (111)	9.25
		A	High	66 (66)	108 (108)	9.25
		B	Low	65 (66)	113 (112)	9.25
		B	High	65 (66)	109 (109)	9.25
NDDN12	53	A	Low	21 (27)	204 (192)	10.6
		A	High	21 (27)	198 (186)	10.6
		B	Low	21 (27)	197 (185)	10.6
		B	High	21 (27)	194 (182)	10.6
NDVC12	36	A	Low	15 (19)	217 (207)	9.56
		A	High	15 (19)	187 (177)	9.56
		B	Low	15 (19)	205 (196)	9.56
		B	High	15 (19)	183 (173)	9.56
NDAR13	34	A	Low	84 (83)	91 (87)	9.94
		A	High	84 (83)	82 (77)	9.94
		B	Low	84 (83)	91 (87)	9.94
		B	High	84 (83)	82 (77)	9.94
NDVC13	36	A	Low	119 (117)	0 (0)	9.25
		A	High	119 (117)	0 (0)	9.25
		B	Low	119 (117)	0 (0)	9.25
		B	High	119 (117)	0 (0)	9.25
NECC12	39	A	Low	113 (138)	118 (82)	14.5
		A	High	113 (138)	98 (64)	14.5
		B	Low	112 (137)	121 (87)	14.5
		B	High	112 (137)	100 (67)	14.5
NEMC12	17	A	Low	50 (62)	167 (148)	11.9
		A	High	50 (62)	160 (142)	11.9
		B	Low	50 (61)	169 (151)	11.9
		B	High	50 (61)	163 (145)	11.9
NECC13	28	A	Low	98 (100)	196 (194)	14.5
		A	High	98 (100)	177 (175)	14.5
		B	Low	96 (99)	202 (200)	14.5
		B	High	96 (99)	182 (178)	14.5
NEMC13	21	A	Low	67 (68)	210 (207)	13.2
		A	High	67 (68)	198 (197)	13.2
		B	Low	66 (68)	213 (212)	13.2
		B	High	66 (68)	202 (200)	13.2

Implementing the Sensor Treatments

Crop canopy reflectance data was collected from all treatment plots prior to the in-season N fertilizer application of sensor-based and model-based treatments. Data was collected using a RapidSCAN CS-45 Handheld Crop Sensor (Holland Scientific, Lincoln, NE) oriented in the nadir position and at least 0.6 meters above the crop canopy. The sensor is equipped with a modulated light source and three photodetector measurement channels: 670 nm, 730 nm, and 780 nm. Travel speed through the field resulted in collection of approximately one sensor reading every 25 cm. Two rows per plot were scanned, producing one average value from each measurement channel per row. The values generated for each row were then averaged together to create one value for each wavelength per plot. The NDRE was calculated for each plot (Equation 2.3). The SI was then generated by dividing the NDRE from the sensor-based treatment by the corresponding N-rich reference treatment for each replication (Equation 2.4). Sensor-based treatments were paired to N-rich reference treatments with the same hybrid and plant population.

$$\mathrm{NDRE} = \frac{\mathrm{R_{NIR}} - \mathrm{R_{RED\ EDGE}}}{\mathrm{R_{NIR}} + R_{\mathrm{RED\ EDGE}}} \tag{2.3}$$

where

R_{NIR} = near-infrared reflectance (780 nm)
$R_{RED\ EDGE}$ = red edge reflectance (730 nm)

$$\mathrm{SI} = \frac{\text{NDRE of target crop}}{\text{NDRE of N rich reference}} \tag{2.4}$$

Here "target crop" is defined as the sensor-based treatment. The SI was then used in the modified algorithm by Holland and Schepers (2010, modified 2012) to determine an N application rate. In addition to the user providing the SI, this algorithm requires the user to input three other variables: crop growth stage, amount of N fertilizer applied prior to crop sensing and in-season fertilization, and predicted ONR. The date on which the crop was scanned, the date N fertilizer was applied in-season, and the three additional inputs required for the Holland and Schepers algorithm can be found in Table 2.8.

Table 2.8 Scanning and N application date for sensor-based treatments and inputs for the Holland and Schepers sensor algorithm including: growth stage, initial N fertilizer amount, and optimum N rate for sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013.

			-------Inputs for Holland and Schepers algorithm-----		
Field ID	Scanning Date	N Application Date	Growth Stage	Initial N Fertilizer **kg ha^{-1}**	Optimum N Rate **kg ha^{-1}**
MORO12	June 30, 2012	July 2, 2012	V10	56	186
MOLT12	June 29, 2012	June 29, 2012	V11	56	140
MOTR13	June 28, 2013	July 1, 2013	V10	56	194
MOBA13	July 16, 2013	July 16, 2013	V9	56	146
NDDN12	July 2, 2012	July 2, 2012	V9	0	130
NDVC12	July 2, 2012	July 2, 2012	V10	0	81
NDAR13	July 3, 2013	July 3, 2013	V8	0	76
NDVC13	July 3, 2013	July 3, 2013	V8	0	55
NECC12	June 26, 2012	June 26, 2012	V10	84	77
NEMC12	June 26, 2012	June 26, 2012	V9	84	160
NECC13	June 28, 2013	July 1, 2013	V9	84	215
NEMC13	June 28, 2013	July 1, 2013	V8	84	173

The Holland and Schepers algorithm defines the ONR as the EONR or the maximum N rate prescribed by producers. For this study, unless otherwise noted, the ONR was calculated using the algorithm developed by the University of Nebraska-Lincoln for producers in Nebraska applying a uniform rate of N (Shapiro et al., 2003). The algorithm (Equation 2.5) takes into account residual nitrate in the soil, the expected yield, and organic matter present in the soil. The algorithm then subtracts additional sources of N which may be present from legume crops, manure, and nitrate in irrigation water.

$$N\ need\ (lb\ ac^{-1}) =$$

$$35 + (1.2 * EY) - (8 * NO_3\text{-}N\ ppm) - (0.14 * EY * OM) - other\ credits \quad (2.5)$$

where

N need = Nitrogen to apply in lb ac^{-1}
EY = Expected yield for the field
NO_3-N ppm = Residual nitrate in soil
OM = Organic matter in soil
Other credits = sources of N from legume crops, manure, and nitrate in irrigation water

In the case of two North Dakota site years, NDAR13 and NDVC13, the North Dakota N recommendation algorithm was used in place of the University of Nebraska-Lincoln N recommendation algorithm for the determination of ONR. The North Dakota N algorithm is shown below in Equation 2.6.

$$N\ need\ (lb\ ac^{-1}) = (EY * 1.1) - NO_3\text{-}N\ ppm - soy\ credit \quad (2.6)$$

where

N need = Nitrogen to apply in lb ac^{-1}
EY = Expected yield for the field
NO_3-N ppm = Residual nitrate in soil
Soy credit = 40 if soybeans were grown the previous season

There were six site years where the previous crop was soybeans: MORO12, MOLT12, MOTR13, MOBA13, NECC13, and NDAR13. Of these, a soybean credit was only subtracted in the University of Nebraska-Lincoln N recommendation algorithm or North Dakota University N recommendation algorithm for MOTR13, MOBA13, and NDAR13. The University of Nebraska-Lincoln N recommendation algorithm recommends that if N supply from irrigation water is greater than 16.8 kg ha^{-1}, an irrigation credit should be subtracted from the overall N recommendation. Irrigation credits were not subtracted for the Nebraska sites. Sites NECC12, NEMC12, and NECC13 had irrigation water nitrate levels resulting in N supply below 16.8 kg ha^{-1}, therefore no N credit would subtracted according to the algorithm. Site NEMC12 had an N supply from irrigation water of 20.2 kg ha^{-1}, therefore according the University of Nebraska-Lincoln N recommendation algorithm a credit for irrigation water could be subtracted from the overall N recommendation. The calculation of N need to be used as the ONR for the Holland and Schepers algorithm is shown for each site in Table 2.9. The expected yield (EY) required for both the University of Nebraska-Lincoln algorithm and the North Dakota University algorithm was the attainable yield generated using Maize-N: Nitrogen Rate Recommendation for Maize with the same inputs as was done for the model-based treatments at each site (Yang et al., University of Nebraska – Lincoln, 2008). Attainable yield for each site is provided in Table 2.6.

Table 2.9 Calculation of optimum N rate, using university N recommendations for use in the Holland and Schepers sensor algorithm for sensor-based treatments for sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013.

Field ID	**Algorithm calculation for optimum N rate** lb N ac^{-1} from algorithm results	**Optimum N rate** kg ha^{-1}
MORO12	[35 + (1.2 x 178) – (8 x 5.6) – (0.14 x 178 x 1.5)] = 166	186
MOLT12	[35 + (1.2 x 158) – (8 x 5.3) – (0.14 x 158 x 2.6)] = 125	140
MOTR13	[35 + (1.2 x 220) – (8 x 2.8) – (0.14 x 220 x 1.9) - 45] = 173	194
MOBA13	[35 + (1.2 x 147) – (8 x 2.8) – (0.14 x 147 x 1.9) - 20] = 130	146
NDDN12	[35 + (1.2 x 168) – (8 x 6.25) – (0.14 x 168 x 3)] = 116	130
NDVC12	[35 + (1.2 x 152) – (8 x 10.1) – (0.14 x 152 x 3)] = 73	81
NDAR13	(158 x 1.1) – 40 – 66 = 68	76*
NDVC13	(147 x 1.1) – 113 = 49	55*
NECC12	[35 + (1.2 x 231) – (8 x 18.29) – (0.14 x 231 x 3)] = 69	77
NEMC12	[35 + (1.2 x 189) – (8 x 9.34) – (0.14 x 189 x 1.65)] = 143	160
NECC13	[35 + (1.2 x 231) – (8 x 3.75) – (0.14 x 231 x 2.8)] = 192	215
NEMC13	[35 + (1.2 x 210) – (8 x 8.88) – (0.14 x 210 x 2.1)] = 154	173

* Indicates site years where the North Dakota N recommendation algorithm was used in place of the University of Nebraska-Lincoln N recommendation algorithm.

Sufficiency index values for each plot having a sensor-based treatment went into the Holland and Schepers sensor algorithm to produce the N recommendation. These SI values and N recommendations are provided for each plot in Table 2.10. Nitrogen recommended using the Holland and Schepers sensor algorithm was applied to the plots in the same manner and at the same time as the model-based treatments as detailed in section 3.3.

Table 2.10 Sufficiency index generated with NDRE values from the crop canopy sensor and in-season N recommendation determined using the Holland and Schepers sensor algorithm for sensor-based treatments arranged by hybrid and plant population for sites in Missouri (MO), Nebraska (NE), and North Dakota (ND) in 2012 and 2013.

	MORO12			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	---------------------*Sufficiency Index*---------------------			
Rep 1	0.943	0.954	0.843	0.912
Rep 2	0.968	0.955	1.052	1.036
Rep 3	0.953	0.918	0.913	0.834
Rep 4	0.951	0.979	0.928	0.955
	-------------------*In-season N recommendation*------------------ *kg ha^{-1}*			
Rep 1	59	53	106	75
Rep 2	44	52	0	0
Rep 3	54	73	75	110
Rep 4	55	35	67	53
	MOLT12			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	---------------------*Sufficiency Index*---------------------			
Rep 1	0.882	0.932	0.925	0.917
Rep 2	0.909	0.974	0.947	0.962
Rep 3	0.917	0.906	0.956	0.976
Rep 4	0.929	0.964	0.950	0.983
	------------------*In-season -N recommendation*------------------ *kg ha^{-1}*			
Rep 1	61	44	46	49
Rep 2	52	26	38	31
Rep 3	49	53	34	25
Rep 4	45	30	36	20

NECC12				
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	--------------------Sufficiency Index--------------------			
Rep 1	0.994	0.990	0.956	1.020
Rep 2	1.031	0.970	0.999	0.990
Rep 3	1.019	1.046	0.995	0.993
Rep 4	0.981	1.000	1.008	1.061
	------------------In-season N recommendation------------------ *kg ha^{-1}*			
Rep 1	-1	-1	-2	0
Rep 2	0	-1	0	-1
Rep 3	0	0	-1	-1
Rep 4	-1	0	0	0

NEMC12				
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	--------------------Sufficiency Index--------------------			
Rep 1	0.995	1.000	0.980	0.983
Rep 2	0.980	0.987	1.078	1.046
Rep 3	1.147	0.989	0.996	0.996
Rep 4	0.946	0.956	0.958	1.003
	------------------In-season N recommendation------------------ *kg ha^{-1}*			
Rep 1	10	0	20	18
Rep 2	20	16	0	0
Rep 3	0	15	8	9
Rep 4	34	30	29	0

NDDN12				
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	--------------------Sufficiency Index--------------------			
Rep 1	0.598	1.293	1.457	1.566
Rep 2	0.896	1.085	0.819	1.010
Rep 3	0.857	0.796	0.760	0.757
Rep 4	0.624	0.649	0.937	0.701
	------------------In-season N recommendation------------------ *kg ha^{-1}*			
Rep 1	157	0	0	0
Rep 2	80	0	108	0
Rep 3	94	115	126	127
Rep 4	155	151	62	141

	NDVC12			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	--------------------Sufficiency Index--------------------			
Rep 1	0.871	0.863	1.077	1.357
Rep 2	0.837	0.826	0.842	0.946
Rep 3	1.073	0.751	0.847	0.818
Rep 4	0.894	0.971	0.947	0.755
	-------------------In-season N recommendation------------------ *kg ha^{-1}*			
Rep 1	57	59	0	0
Rep 2	65	68	64	36
Rep 3	0	84	63	70
Rep 4	52	26	35	83

	MOTR13			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	--------------------Sufficiency Index--------------------			
Rep 1	0.936	0.954	0.989	0.988
Rep 2	0.990	1.001	1.041	0.907
Rep 3	1.004	1.016	0.965	1.011
Rep 4	0.996	0.944	0.877	0.958
	-------------------In-season N recommendation------------------ *kg ha^{-1}*			
Rep 1	67	56	27	28
Rep 2	26	0	0	83
Rep 3	0	0	48	0
Rep 4	17	62	96	53

	MOBA13			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	--------------------Sufficiency Index--------------------			
Rep 1	0.836	0.860	0.828	0.855
Rep 2	0.791	0.875	0.866	0.868
Rep 3	0.817	0.798	0.818	0.861
Rep 4	0.877	0.797	0.746	0.826
	-------------------In-season N recommendation------------------ *kg ha^{-1}*			
Rep 1	73	67	75	68
Rep 2	85	63	65	65
Rep 3	78	83	78	67
Rep 4	63	83	95	76

NECC13				
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	-------------------***Sufficiency Index***-------------------			
Rep 1	0.992	0.996	0.987	0.981
Rep 2	1.012	0.976	1.014	0.989
Rep 3	0.997	0.987	0.970	0.991
Rep 4	1.000	0.981	0.991	1.000
	------------------***In-season N recommendation***------------------ *kg ha^{-1}*			
Rep 1	21	16	28	34
Rep 2	0	37	0	25
Rep 3	12	27	43	22
Rep 4	4	34	24	6

NEMC13				
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	-------------------***Sufficiency Index***-------------------			
Rep 1	0.956	0.883	0.904	0.871
Rep 2	0.956	0.940	1.081	0.883
Rep 3	0.997	0.929	0.978	0.923
Rep 4	1.044	0.981	0.813	1.009
	------------------***In-season N recommendation***------------------ *kg ha^{-1}*			
Rep 1	35	58	53	62
Rep 2	35	40	0	58
Rep 3	9	45	24	47
Rep 4	0	22	76	0

NDAR13				
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	-------------------***Sufficiency Index***-------------------			
Rep 1	0.805	0.802	0.882	0.805
Rep 2	0.870	0.891	0.929	0.852
Rep 3	0.693	0.831	0.822	0.682
Rep 4	0.859	0.884	0.755	0.816
	------------------***In-season N recommendation***------------------ *kg ha^{-1}*			
Rep 1	64	65	49	64
Rep 2	52	47	38	55
Rep 3	80	59	61	82
Rep 4	54	48	72	62

	NDVC13			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	--------------------Sufficiency Index--------------------			
Rep 1	0.554	0.655	0.697	0.749
Rep 2	0.614	0.621	0.832	0.590
Rep 3	0.693	0.695	0.643	0.646
Rep 4	0.715	0.528	0.618	0.566
	------------------In-season N recommendation------------------ *kg ha^{-1}*			
Rep 1	64	61	57	53
Rep 2	63	63	43	63
Rep 3	58	57	62	61
Rep 4	56	63	63	64

Data Analysis Methods

Normalized difference red edge and SI were collected for the model-based and check treatments at the same times as sensing for implementation of the sensor-based treatments. Here the target crop in the numerator of the SI equation was defined as the model-based treatment or check treatment respectively. Approximately 10 days to 2 weeks following in-season N application, all treatments for 9 of the 12 sites were scanned again using the RapidSCAN CS-45 Handheld Crop Sensor to evaluate canopy reflectance following in-season N application uptake. The NDRE was found for all treatments and the SI was calculated for the sensor-based, model-based, and check treatments. Following physiological maturity, the corn was harvested. In 2012, Nebraska and North Dakota plots were hand harvested and Missouri plots were machine harvested. In 2013, North Dakota plots were hand harvested and Missouri and Nebraska plots were machine harvested. Harvest plant populations were recorded for all sites in 2012 and North Dakota sites in 2013. Barren counts were recorded for 2012 Nebraska sites. Grain samples were collected for determination of percent grain N for Nebraska and Missouri sites in 2012 and Nebraska sites in 2013. Due to uneven irrigation following the in-season N application, MORO12 yield data was considered to be unreliable and was discarded. Recovery of fertilizer N in grain was calculated by taking the difference in grain N content between the fertilized treatment and the check and dividing by the total N application for the fertilized treatment. Partial factor productivity for N was calculated by dividing grain yield by total fertilizer N rate. Agronomic efficiency was calculated by taking the difference in yield between the fertilized treatment and the check and dividing by total N application. The data was analyzed using the GLIMMIX procedure in SAS 9.2 (SAS Institute Inc., Cary, NC). Response variables analyzed include: SI, ΔSI, NDRE, ΔNDRE, yield, partial factor productivity of N, agronomic efficiency, grain recovery of N, and profitability. To analyze response variables, non-significant (α=0.05) interactions were eliminated starting with 3-way interactions of hybrid, N strategy, and plant population, then 2-way interactions, until the final model was obtained. If no interactions were present the final model consisted of the main effects of hybrid, N strategy, and plant population. Mean separation test was done using Fisher's LSD.

Results and Discussion

Crop Canopy Sensor Data

Table 2.11 Significance levels (P≤0.05) for main treatment effects for NDRE and SI at the time of application and following application and change in NDRE and SI between sensing dates for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 (PR>F).

Site	Hybrid	N strategy	Plant population	Hybrid x N strategy	Hybrid x plant population	N strategy x plant population	Hybrid x N strategy x plant population
NDRE main effects at time of application (check, N rich reference, sensor and model treatments included)							
NECC12	0.0001	NS*	0.0039	NS	NS	NS	NS
NEMC12	NS	0.0205	<0.0001	NS	NS	NS	NS
MORO12	NS	<0.0001	NS	NS	NS	NS	NS
MOLT12	0.0003	<0.0001	0.0314	NS	NS	NS	NS
NDDN12	NS	0.0044	0.0245	NS	NS	NS	NS
NDVC12	NS	0.0025	0.0119	NS	NS	NS	NS
NDRE main effects following application (includes N rich reference, sensor and model treatments)							
NECC12	<0.0001	0.0213	0.0435	NS	NS	NS	NS
NEMC12	<0.0001	<0.0001	NS	NS	NS	NS	NS
MORO12	--	--	--	--	--	--	--
MOLT12	--	--	--	--	--	--	--
NDDN12	NS	<0.0001	0.0117	NS	NS	NS	NS
NDVC12	NS	<0.0001	NS	NS	NS	NS	NS
ΔNDRE main effects following in-season N application (includes N rich reference, sensor and model treatments)							
NECC12	0.0709	NS	0.0003	NS	NS	NS	NS
NEMC12	<0.0001	NS	<0.0001	NS	NS	NS	NS
MORO12	--	--	--	--	--	--	--
MOLT12	--	--	--	--	--	--	--
NDDN12	NS	0.0233	NS	NS	NS	NS	NS
NDVC12	NS	NS	0.0084	NS	NS	NS	NS
SI (from NDRE) main effects at time of application (includes N rich reference, sensor and model treatments)							
NECC12	NS	NS	NS	NS	NS	NS	NS
NEMC12	NS	NS	NS	NS	NS	NS	NS
MORO12	NS	0.0049	NS	NS	NS	NS	NS
MOLT12	NS	<0.0001	NS	NS	NS	NS	NS
NDDN12	0.0281	NS	NS	NS	NS	NS	NS
NDVC12	NS	NS	NS	NS	0.0165	NS	NS
SI (from NDRE) main effects following application (includes N rich reference, sensor and model treatments)							
NECC12	0.0320	NS	NS	NS	NS	NS	NS
NEMC12	NS	0.0043	0.0317	NS	NS	NS	NS
MORO12	--	--	--	--	--	--	--
MOLT12	--	--	--	--	--	--	--
NDDN12	NS	NS	NS	NS	NS	NS	NS
NDVC12	NS	0.0327	NS	NS	NS	NS	NS
ΔSI (from NDRE) main effects following application (includes N rich reference, sensor and model treatments)							
NECC12	NS	NS	NS	NS	NS	NS	NS
NEMC12	NS	NS	NS	NS	NS	NS	NS
MORO12	--	--	--	--	--	--	--
MOLT12	--	--	--	--	--	--	--
NDDN12	0.0227	NS	NS	NS	NS	NS	NS
NDVC12	NS	NS	NS	NS	0.0242	NS	NS

**Actual probability level up to 0.05, NS indicates probability level >0.05.*

Table 2.12 Significance levels (P≤0.05) for main treatment effects for NDRE and SI at the time of application and following application and change in NDRE and SI between sensing dates for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2013 (PR>F).

Site	Hybrid	N strategy	Plant population	Hybrid x N strategy	Hybrid x plant population	N strategy x plant population	Hybrid x N strategy x plant population
NDRE main effects at time of application (check, N rich reference, sensor and model treatments included)							
NECC13	<0.0001	<0.0001	<0.0001	NS*	NS	NS	NS
NEMC13	NS	<0.0001	0.0502	0.0161	0.0023	0.0485	NS
MOTR13	<0.0001	<0.0001	0.0009	NS	NS	NS	NS
MOBA13	NS	<0.0001	NS	NS	NS	NS	NS
NDAR13	NS	<0.0001	NS	NS	NS	NS	NS
NDVC13	NS	<0.0001	0.0344	NS	NS	NS	NS
NDRE main effects following application (includes N rich reference, sensor and model treatments)							
NECC13	<0.0001	<0.0001	<0.0001	NS	NS	NS	NS
NEMC13	<0.0001	<0.0001	NS	NS	NS	0.0186	NS
MOTR13	--	--	--	--	--	--	--
MOBA13	<0.0001	<0.0001	NS	NS	NS	NS	NS
NDAR13	0.0275	NS	NS	NS	NS	NS	NS
NDVC13	NS	<0.0001	NS	NS	NS	NS	NS
ΔNDRE main effects following in-season N application (includes N rich reference, sensor and model treatments)							
NECC13	NS	0.0051	NS	0.0008	NS	NS	NS
NEMC13	<0.0001	0.0397	0.0397	0.0176	0.0064	NS	NS
MOTR13	--	--	--	--	--	--	--
MOBA13	<0.0001	<0.0001	NS	NS	NS	NS	NS
NDAR13	NS	<0.0001	NS	NS	NS	NS	NS
NDVC13	NS	<0.0001	NS	NS	NS	NS	NS
SI (from NDRE) main effects at time of application (includes N rich reference, sensor and model treatments)							
NECC13	NS	<0.0001	0.0017	NS	NS	NS	NS
NEMC13	NS	<0.0001	0.0165	NS	NS	NS	NS
MOTR13	NS	<0.0001	NS	NS	NS	NS	NS
MOBA13	NS	<0.0001	NS	NS	NS	NS	NS
NDAR13	NS	NS	NS	NS	NS	NS	NS
NDVC13	NS	NS	NS	NS	NS	NS	NS
SI (from NDRE) main effects following application (includes N rich reference, sensor and model treatments)							
NECC13	0.0036	<0.0001	NS	NS	NS	NS	NS
NEMC13	NS	<0.0001	0.0360	NS	NS	0.0366	NS
MOTR13	--	--	--	--	--	--	--
MOBA13	NS	<0.0001	NS	NS	NS	NS	NS
NDAR13	NS	NS	0.0280	NS	NS	NS	NS
NDVC13	NS	<0.0001	NS	NS	NS	NS	NS
ΔSI (from NDRE) main effects following application (includes N rich reference, sensor and model treatments)							
NECC13	<0.0001	NS	0.0005	NS	NS	NS	NS
NEMC13	NS	NS	0.0492	NS	NS	NS	NS
MOTR13	--	--	--	--	--	--	--
MOBA13	NS	NS	NS	NS	NS	NS	NS
NDAR13	NS	NS	NS	NS	NS	NS	NS
NDVC13	NS	<0.0001	NS	NS	NS	NS	NS

**Actual probability level up to 0.05, NS indicates probability level >0.05.*

Interactions for Sensor Data

Tables of significant interactions and main effects are shown in Table 2.11 and Table 2.12 for NDRE and SI at the time of in-season N application and 10 days to 2 weeks following. Significant interactions of these factors are shown in Figure 2.3 through Figure 2.8 for NDRE and SI (interactions for ΔNDRE and ΔSI not depicted). Many of the interactions for NDRE and SI shown occurred at site NEMC13. At the time of in-season N application, hybrid A had higher NDRE values at the high population than at the low population, while hybrid B had higher NDRE values at the low population than at the high population (Figure 2.4). Further interactions are seen at the time of in-season N application for NEMC13 in Figure 2.3 and Figure 2.5. At the time of application the high population has a greater range of NDRE values, and for both high and low populations, the reference (which received more N) had a higher NDRE value, the sensor and model treatments (which received an intermediate N rate) had an intermediate NDRE value, and the check (which received no N) had the lowest NDRE value (Figure 2.5). Figure 2.6 shows the interaction between these two factors following N application. From these two figures it is seen that a similar relationship between population and N strategy is present at both the initial and follow up sensing date. For both sensing times, the high population had higher NDRE values where N was applied (model, sensor, and reference treatments). Only for the check N strategy does the low population have a higher NDRE. An explanation for this is that in a situation where N is limiting to plant growth, a higher density of plants may negatively impact overall biomass due to more competition for a limiting nutrient, in this case N. Figure 2.7 shows the interaction for

NEMC13 for SI following application for N strategy and plant population. This is similar to what is seen in Figure 2.6, where the low population has a greater SI for the check treatment. Figure 2.8 shows the interaction of SI at the time of application for NDVC12. This interaction is between hybrid and plant population and has an opposite relationship between hybrid and plant population that was observed for NEMC13 for NDRE at the time of application. Overall, no clear trends were seen in these interactions involving NDRE and SI, and furthermore, due to lack of consistently occurring interactions across sites, these relationships are not heavily considered in this discussion. Therefore to further understand trends occurring across sites, the main effects of hybrid, N strategy, and plant population are explored.

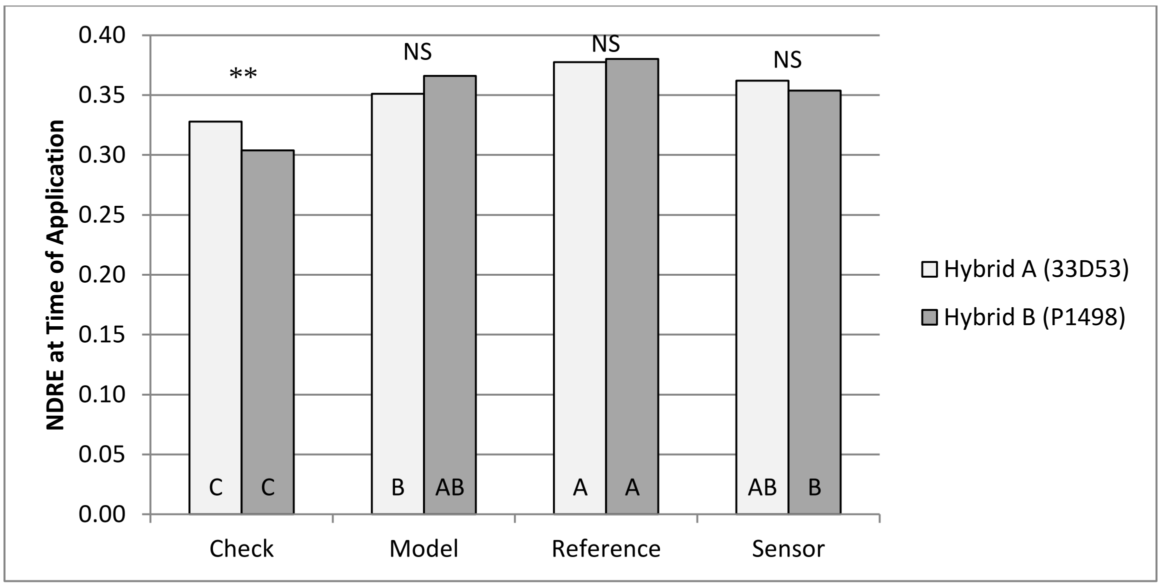

Figure 2.3 Hybrid by N strategy interaction of NDRE at time of application for a site in Nebraska in 2013 (NEMC13). Bars with the same letter are not significantly different at P≤0.05. Significance letters apply within hybrid. Asterisks indicate hybrid significant difference within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

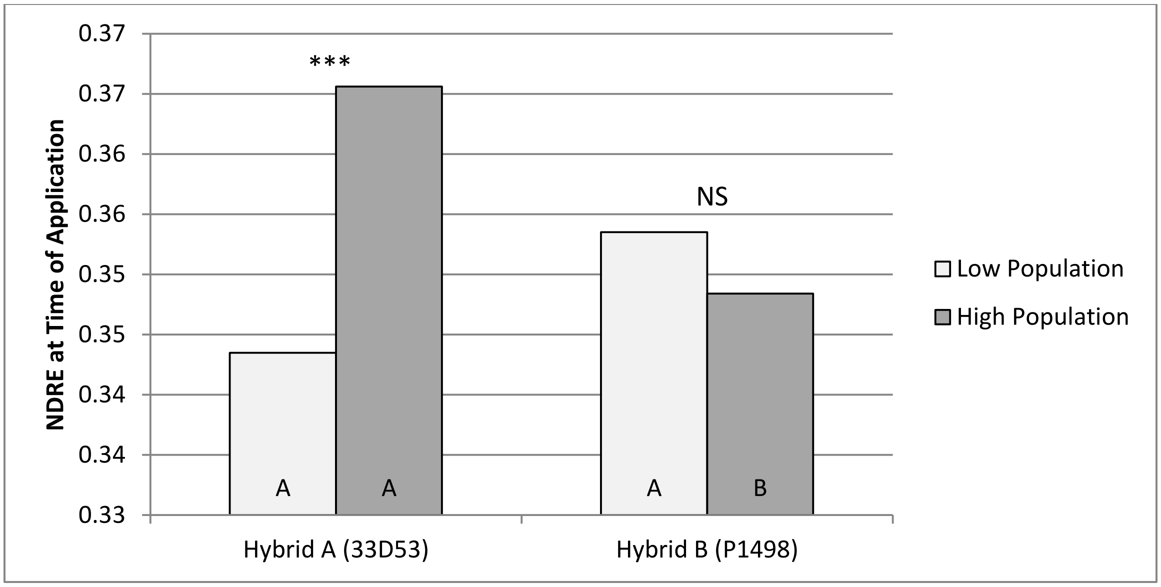

Figure 2.4 Hybrid by plant population interaction of NDRE at time of application for a Nebraska site in 2013 (NEMC13). Bars with the same letter are not significantly different at P≤0.05. Significance letters apply within population. Asterisks indicate population significant difference within hybrid (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

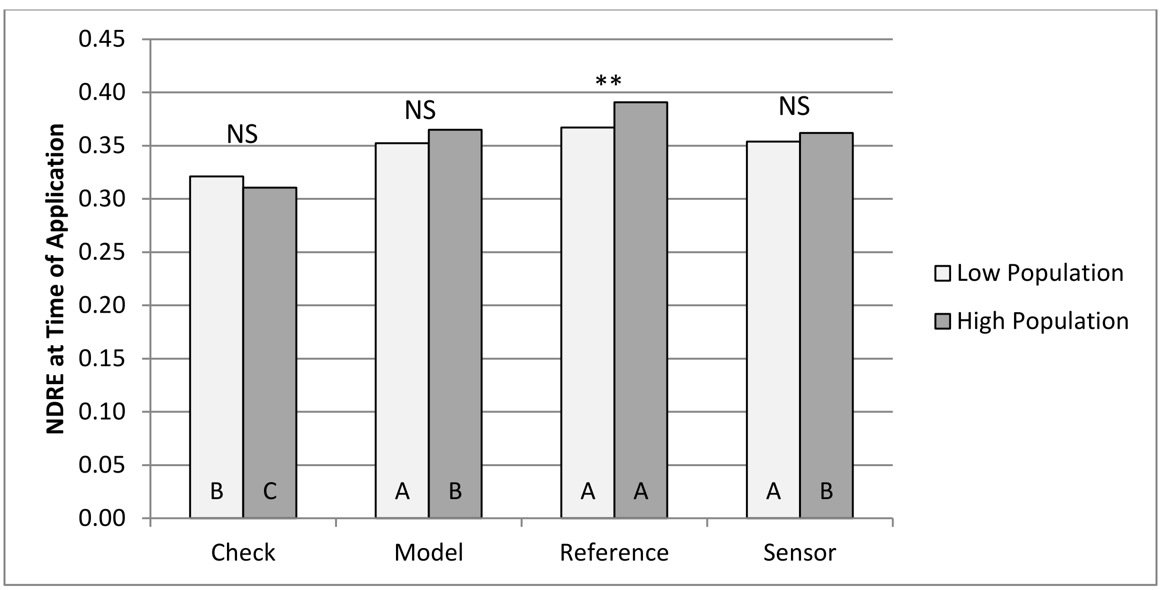

Figure 2.5 N strategy by plant population interaction of NDRE at time of application for a Nebraska site in 2013 (NEMC13). Bars with the same letter are not significantly different at P≤0.05. Significance letters apply within population. Asterisks indicate population significant difference within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

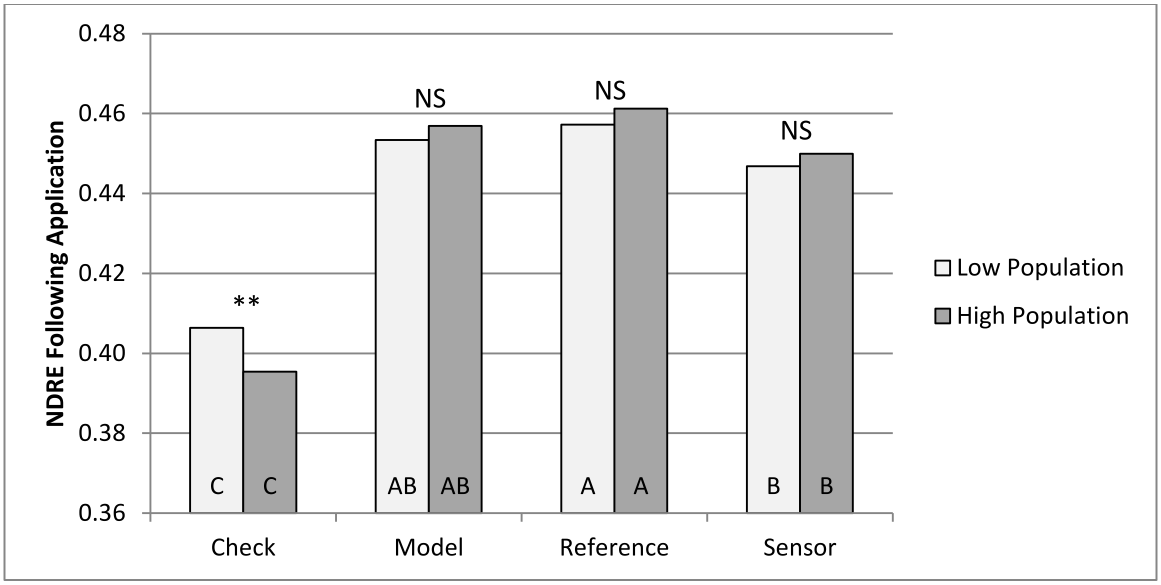

Figure 2.6 N strategy by plant population interaction for NDRE following N application for a Nebraska site in 2013 (NEMC13). Bars with the same letter are not significantly different at P≤0.05. Significance letters apply within population. Asterisks indicate population significant difference within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

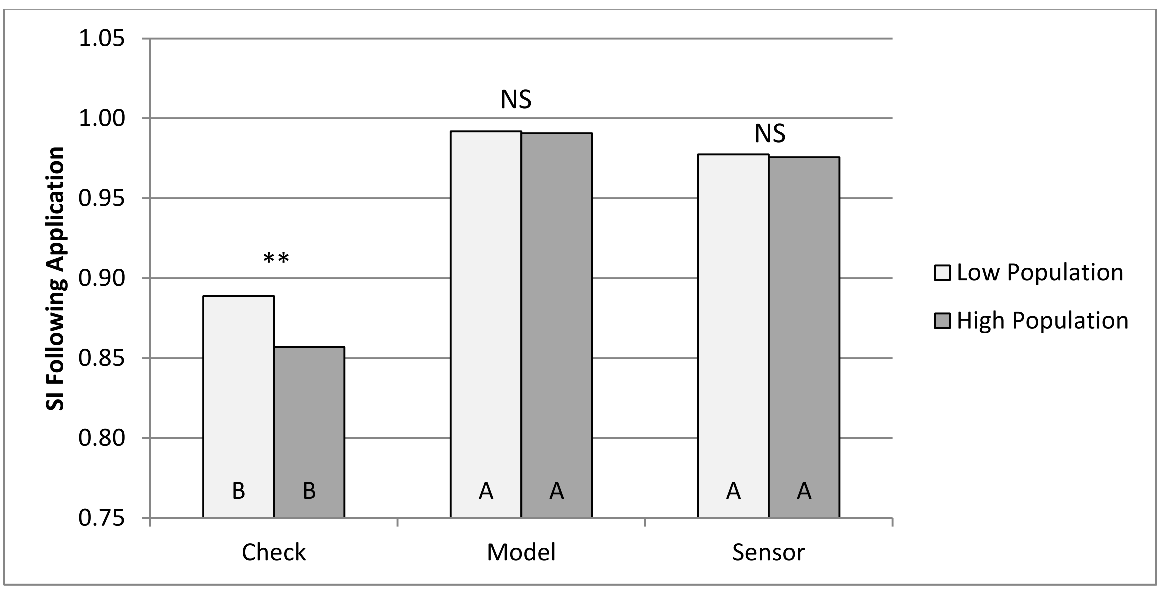

Figure 2.7 N strategy by plant population interaction for SI following N application for a Nebraska site in 2013 (NEMC13). Bars with the same letter are not significantly different at P≤0.05. Significance letters apply within population. Asterisks indicate population significant difference within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

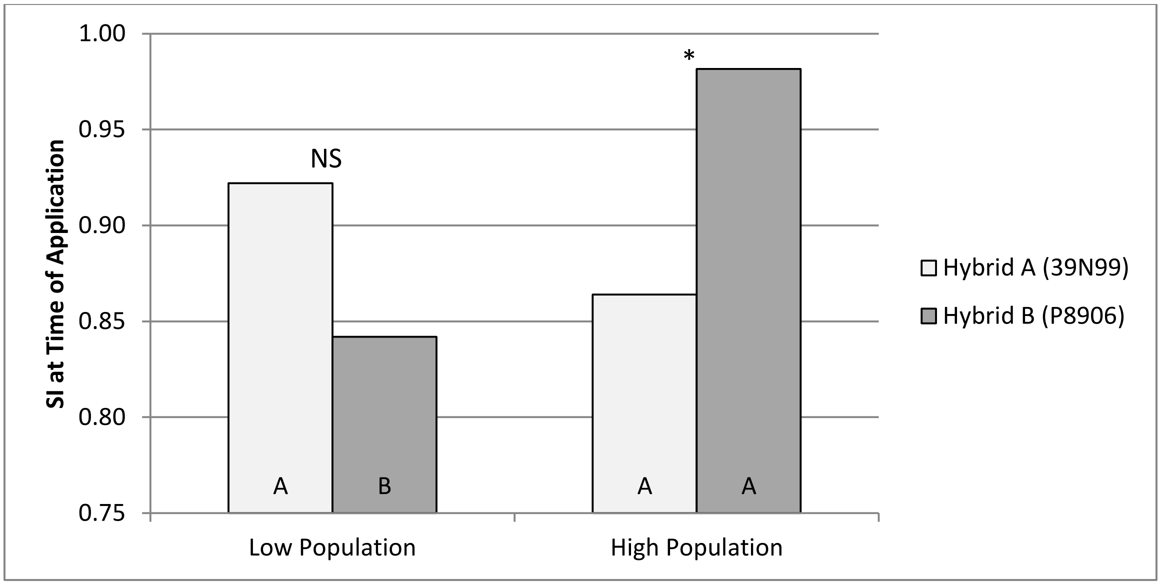

Figure 2.8 Plant population by hybrid interaction for SI at the time of N application for a North Dakota site in 2012 (NDVC12). Bars with the same letter are not significantly different at P≤0.05. Significance letters apply within hybrid. Asterisks indicate hybrid significant difference within population (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

Hybrid Main Effects for Sensor Data

Table 2.13 Hybrid treatment means for NDRE and SI for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 and 2013 where hybrid main effect is significant at P≤0.05.

	Hybrid A	Hybrid B
	NDRE at time of N application	
NECC12	0.4050	0.3957
MOLT12	0.3865	0.3761
NECC13*	0.4387	0.4221
MOTR13	0.3803	0.3654
	NDRE following application	
NECC12	0.4683	0.4538
NEMC12	0.4462	0.4277
NECC13	0.4484	0.4327
NEMC13	0.4549	0.4268
MOBA13	0.4211	0.4062
NDAR13	0.4843	0.4774
	SI at time of N application	
NDDN12	0.8439	1.0361
	SI following application	
NECC12	0.9795	0.9940
NECC13	0.9939	0.9789

**Indicates interaction is present. Graphs of interactions previously provided.*

Hybrid treatment means for NDRE and SI at the time of N application and following N application are provided in Table 2.13 when the hybrid main effect was significant at α=0.05. Where significant, hybrid A has significantly greater NDRE values than hybrid B at the time of N application and following N application (Table 2.13). For Nebraska and Missouri sites a trend can be seen due to the similarity in hybrids used. For both these sites in both years, hybrid B (P1498) had significantly lower NDRE values than hybrid A (either 33D49 or 33D53 which are in the same genetic family). Therefore, for these hybrids there exists a trend suggesting hybrid B (P1498) has lower reflectance values than hybrid A, potentially explained by lower levels of biomass or a different hybrid appearance due to leaf architecture or coloring. Although hybrid B has lower NDRE values than hybrid A, this did not translate into lower yields. When significant differences in yield occur between these two hybrids, hybrid B (P1498) was higher yielding than hybrid A (Table 2.19). The relationship between hybrids and NDRE values is not strongly supported for the North Dakota sites, as only one site had a significant interaction. At NDAR13, hybrid A (39N95) had significantly greater NDRE values than hybrid B (P8906) following N application. The fact that this difference only existed at one of four North Dakota site years suggests that there is not a consistent difference in NDRE values between the hybrids used on North Dakota sites. The SI values at the time of application and following application for the two hybrids do not show a clear trend that would suggest one hybrid has a lower or higher SI. This is expected because the corn sensed for the reference crop in the denominator portion of the SI equation is of the same hybrid as the crop sensed for the numerator target crop portion of the SI equation, therefore differences in reflectance are normalized.

Overall, in some cases, hybrids significantly differed in NDRE determined from active crop canopy sensing. This indicates that it is desirable for the reference strip used for determination of SI to be of the same hybrid as the target crop. The extent of the influence of significantly different NDRE values on the resulting in-season N recommendation was not explored. However, previous work by Sheridan et al., (2012) found that while reflectance differences collected with an active canopy sensor occurred among similar maturing hybrids, they had minimal impact on N fertilizer recommendations. It is suspected that a similar outcome could be expected from this study. It is desirable that hybrid influence on resulting in-season N recommendations be negligible as this would eliminate the need to establish a unique N sufficient reference strip for each hybrid used.

Population Main Effects for Sensor Data

Table 2.14 Population treatment means for NDRE and SI for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 and 2013 where population main effect is significant at P≤0.05.

	Low Population	High Population
	NDRE at time of N application	
NECC12	0.3970	0.4037
NEMC12	0.3481	0.3682
MOLT12	0.3783	0.3843
NDDN12	0.2269	0.2066
NDVC12	0.2925	0.3130
NECC13	0.4268	0.4339
NEMC13*	0.3485	0.3570
MOTR13	0.3681	0.3775
NDVC13	0.2154	0.2278
	NDRE following application	
NECC12	0.4631	0.4590
NDDN12	0.3189	0.3009
NECC13	0.4373	0.4438
	SI at time of N application	
NECC13	0.9835	0.9668
NEMC13	0.9345	0.8866
	SI following application	
NEMC12	0.9886	0.9738
NEMC13*	0.9527	0.9411
NDAR13	1.0082	0.9890

Significant differences in NDRE were frequently seen for the plant population main effect (Table 2.11 and Table 2.12). Population treatment means for NDRE and SI at the time of N application and following N application are provided in Table 2.14 when the population main effect was significant at $\alpha=0.05$. The majority of the time, the high plant population has a higher NDRE at the time of N application (for 8 of 9 sites where population main effect was significant). This is expected as NDRE has been found to be correlated to overall plant biomass, and consequently the higher plant population would have greater plant biomass and therefore higher NDRE values. Following N application, no clear trend was seen in NDRE values related to population (the low plant population had higher NDRE values at two sites and lower NDRE values at one site than the high population). Additionally, for several sites where NDRE was significantly different based on hybrid at the time of application, this relationship no longer existed following N application. It should be noted, however, that NDRE values following application were not collected for two of the sites where NDRE was significantly different due to hybrid at the time of N application, therefore it is unknown whether the significance of population continued for the second sensing date. Because of the lack of clear trend and missing data for the second sensing date, only the significance of population on NDRE at the time of in-season N application is further explored. When examining the relationship between population and SI, the low population has a higher SI than the high population both at the time of N application and following for all sites where this was significant. However, it is noted that the number of sites where a significant difference in SI based on population was much less than the number of sites where NDRE was influenced by population. This is as would be expected, because the SI serves to normalize the sensor readings. Overall, there is evidence that NDRE values may be significantly greater for the high population at the time of N application, and therefore it is important that the reference crop sensed to determine SI is of the same plant population as the target crop.

The magnitude of in-season N recommendations based on significantly different NDRE values at the time of fertilization for varying populations is of interest. Previous work has found that reflectance differences among hybrids had minimal impact on fertilizer N recommendations (Sheridan et al., 2012), therefore having a reference strip of the same hybrid is not critical. However, it is unknown whether reference strips of differing plant populations are similarly unimportant in determination of final in-season N recommendation. Because variable seeding rates are sometimes implemented in commercial crop production, it is important to determine if there is an N recommendation difference if the reference strip is of different plant population than portions of the field which are receiving in-season N applications. Since plant biomass and leaf area index are correlated with crop canopy reflectance, there is reason to believe that population differences may significantly influence vegetation index values, and consequently SI and resulting N recommendation rates. In order to explore this possibility, a SI was generated using NDRE values of the high population treatment for the reference, and low population treatment for the target crop and vice-versa. Population treatments with the same hybrid were used to generate SI, thus reflectance differences based on hybrid are not simultaneously investigated. The SI generated with a reference crop of differing population than the target crop population was then used in the Holland-Schepers sensor algorithm to generate N recommendation rate. This was then compared with the N recommendation for the target crop if the equivalent population treatment was used as a reference. Average N rates when the same population and opposing population were used for the reference and target crop are shown in Table 2.15. The average resulting plot difference in N recommendation from the standard with the same population for target and reference crop is shown in Table 2.16.

Table 2.15 Average plot N rate recommendations generated using SI with NDRE values from the same or different populations of target and reference crops. Fertilizer recommendations for NDRE values were used with Holland-Schepers algorithm for sensor N recommendations. Sites shown in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 and 2013 where significant population main effect differences in NDRE at the time of fertilizing occurred.

Site	Average N rate with matching population kg N ha^{-1}	Average N rate with SI from high population reference and low population target kg N ha^{-1}	Average N rate with SI from low population reference and high population target kg N ha^{-1}
NECC12	0	0	0
NEMC12	13.1	27.7	0
MOLT12	39.2	47.1	29.8
NDDN12	81.8	49.0	109.6
NDVC12	47.1	57.2	35.9
NECC13	21.3	44.8	1.26
MOTR13	34.8	58.3	13.5
NDVC13	59.4	59.4	58.3

Table 2.16 Average plot N rate recommendations differences generated using SI with NDRE values from the same or different populations of target and reference crops. Fertilizer recommendations for NDRE values were used with Holland-Schepers algorithm for sensor N recommendations. Sites shown in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 and 2013 where significant population main effect differences in NDRE at the time of fertilizing occurred.

Site	Average plot N-rate difference if high population reference is used for low population target kg N ha^{-1}	Average plot N-rate difference if low population reference is used for high population target kg N ha^{-1}
NECC12	0	0
NEMC12	12.4	-11.0
MOLT12	2.61	-4.48
NDDN12	-48.2	42.9
NDVC12	14.6	-17.0
NECC13	28.0	-23.5
MOTR13	23.5	-21.3
NDVC13	1.10	-2.73

For some sites, differences in reference population made no difference on the N rate recommended, such as at NECC12. At this site, SI nearly always above 1 because there was no apparent N stress for any treatment, therefore changing population of the reference strip had no effect. For most sites, some difference in N recommendation occurred as a result of using a reference strip with different population of the target crop. In most cases, using a reference of higher population than the target crop resulted in increased N rates recommended. This is as would be expected as the apparent biomass of the higher population reference would be greater, resulting in higher NDRE values and consequently lower SI for use in the N recommendation algorithm. Conversely, using a reference of lower population than the target crop resulted in decreased N recommendation. This is also as expected as the apparent biomass of the lower population reference would be lower, resulting in higher SI values and consequently higher N rates recommended with the algorithm. NDDN12 had an opposite response. At this site, NDRE values of the low plant population treatment were greater than those of the high plant population treatment. Water stress fat NDDN12 at the time of sensing is believed to be the cause of this difference. The high plant population treatment would be expected to have higher water demand than the low plant population treatment and therefore experience greater water stress. Water stress results in decreased reflectance in the NIR region and, as a result, lower NDRE values. Therefore, it is suspected that the high plant population treatment experienced greater water stress resulting in lower NDRE values. Regardless, the response of N rate recommendation based on NDRE was the same at this site as other sites; higher NDRE values for the reference crop produced a lower SI and consequently higher N recommendations and vice-versa.

In many cases the differences in N recommendation rate are marginal and would not be of concern. Additionally, the error associated with the fertilizer applicator may be of greater magnitude than the resulting error in N recommendation based on plant population. However at some sites the N recommendation difference is great enough that it raises concern. It is important to note that the difference of N recommendation rate reported here would be expected to increase as variation in plant population increased. In this study, population differences were at most 24,710 seeds ha^{-1}. The practical significance of these N rate recommendation differences must be evaluated by the producer and be considered in accordance with the level of precision recommendation desired. Producers should be aware that using a higher plant population for the reference strip may result in greater N recommendations, and using a lower plant population for the reference strip may result in lower N recommendations. Those desiring to ensure that N recommendations are not limiting to crop yield should be advised to not use a reference strip of lower plant population than the remainder of the field.

N Strategy Main Effects for NDRE and SI

N strategy was a significant main effect for NDRE and SI at many of the sites (Table 2.11 and Table 2.12). For this reason, NDRE and SI values for all sites are presented graphically regardless of site significance for reported measure (significance is indicated on graphs). NDRE values obtained from the handheld sensor at the time of N application and 10 days to 2 weeks following are shown in Figure 2.9 for the 2012 growing season and Figure 2.10 for the 2013 growing season. The in-season N rate applied for the model-based and sensor-based treatments are shown in point format on the secondary axis for reference.

At all sites, there were no significant differences in NDRE between the model-based and sensor-based treatments at the time of N application Figure 2.9 and Figure 2.10. This was expected, because at this point these treatments had received uniform N application rates. Other differences among N strategy at the initial crop sensing are related to the initial N rates applied. For all cases where the model and sensor based treatments had greater N application than the check treatment (all Nebraska and Missouri sites), the check was significantly lower in NDRE. Similarly, in many cases the reference treatment which received a larger initial N application rate had a significantly higher NDRE than the other N treatments.

Normalized difference red edge values and significance at the second sensing date should be related to the amount of in-season N applied to the sensor and model treatments (i.e. lower N application rates should result in comparatively lower NDRE values, and higher N application rates should result in comparatively higher NDRE values). However, NDRE differences following fertilization may also be attributed to N supplied by the soil, therefore fertilizer N is not the only N source affecting NDRE values. For three site years (MOLT12, MORO12, and MOTR13) no crop canopy sensing following N application was conducted. For the remaining nine sites, three exhibited the expected difference in NDRE based on in-season N application rate. For sites NDVC12, NEMC13, and NDVC13, the treatment that received the lower in-season N application had a significantly lower NDRE at the time of the second sensing. At the remaining six sites there are several plausible explanations as to why this difference was not seen. For NEMC12 and NECC12 high N mineralization was suspected due to warm and moist conditions, and it is therefore likely that N was not limiting for the crop at this point in the growing stage, therefore differences between model and sensor NDRE were not observed. For sites NECC13 and NDAR13, it is less clear why there was no difference in model and sensor treatments at the follow-up sensing. It is probable that N requirements by the plant at that point were met either by N mineralization or applied N. This is further evidenced by the fact that at all four of these sites (NEMC12, NECC12, NECC13, and NDAR13) both model and sensor treatments have NDRE values that are not statistically different than the non-limiting reference, indicating N needs at this point were adequately met. At other sites, model and/or sensor treatments had significantly lower NDRE values than the reference. For MOBA13 the in-season N applications for both the model and sensor treatments, while different, were at this point not resulting in a difference in NDRE values. It was thought that N rates of both treatments were large enough to meet the N need of the crop at that point in the season. At site NDDN12 where large differences in in-season N application between the model and sensor treatments were observed, it is probable that applied N was not sufficiently incorporated into the soil and assimilated in the crop due to inadequate rainfall between the time of in-season application and follow-up sensing (Figure 2.11).

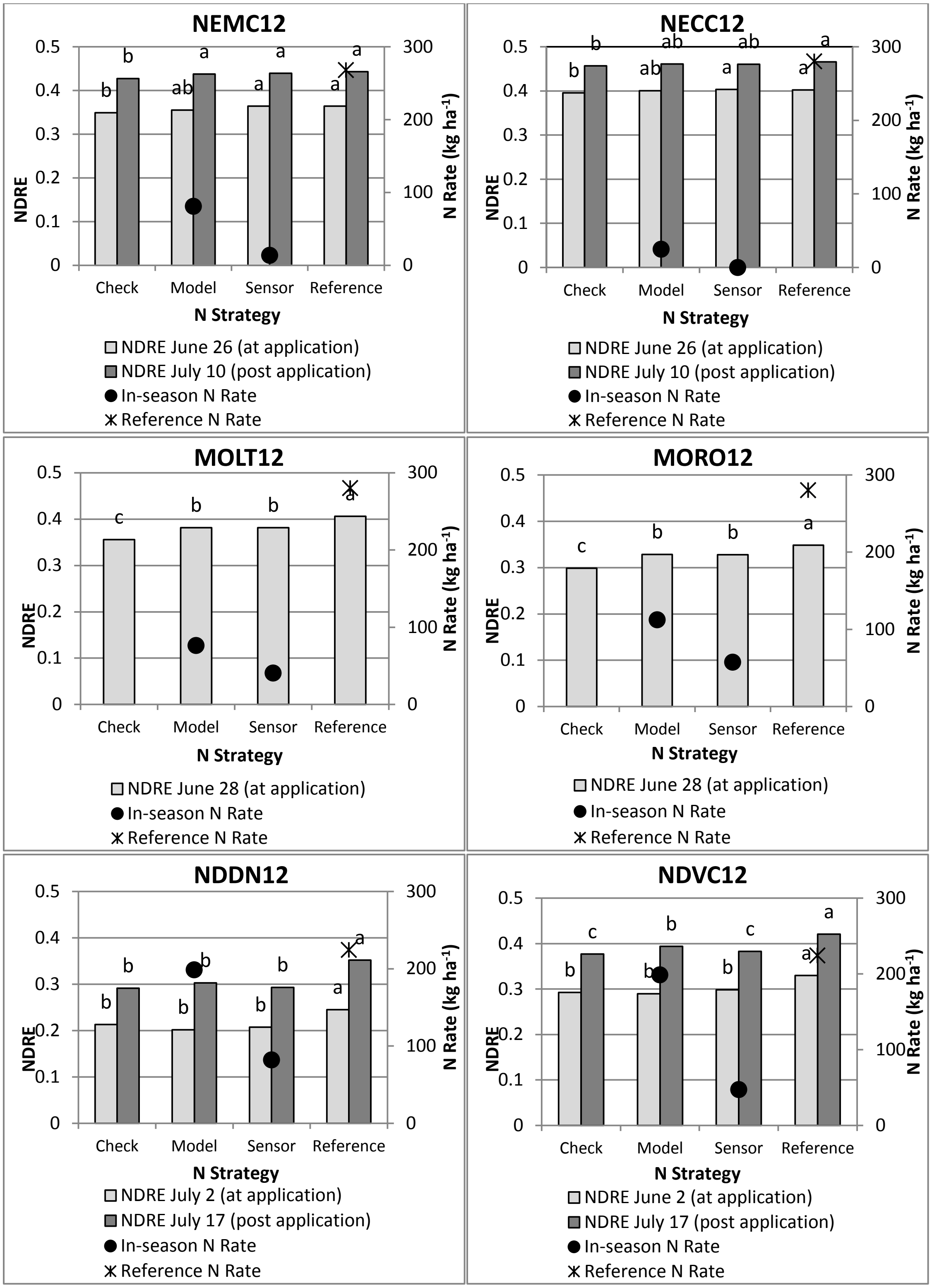

Figure 2.9 NDRE values arranged by N strategy main effect for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012. Mean letters apply within a sensing date. Means with the same letter are not statistically different (P≤0.05). In-season N rates applied to model-based and sensor-based treatments and reference N rate are shown in point format on the secondary axis.

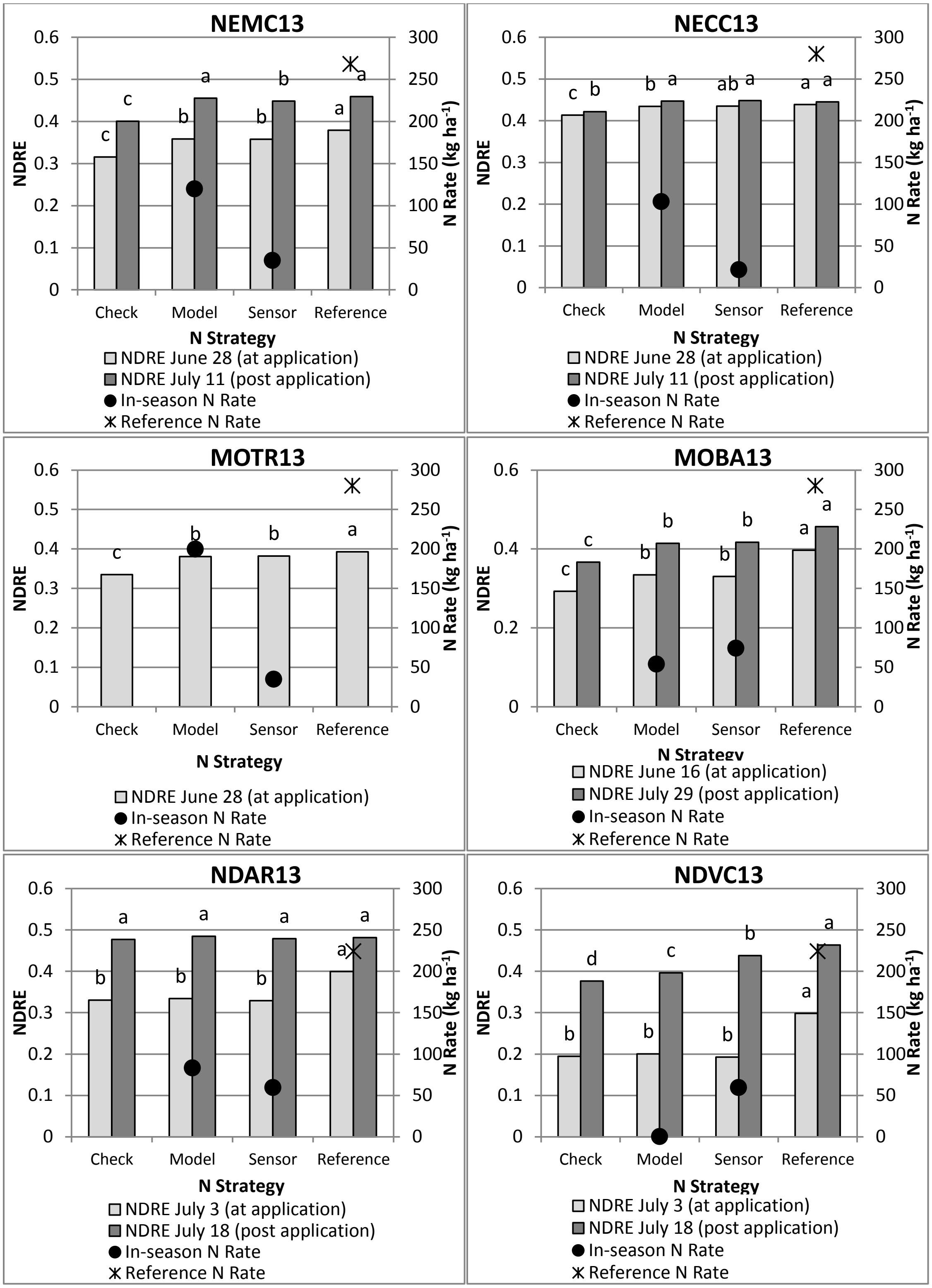

Figure 2.10 NDRE values arranged by N strategy main effect for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2013. Mean letters apply within a sensing date. Means with the same letter are not statistically different (P≤0.05). In-season N rates applied to model-based and sensor-based treatments and reference N rate are shown in point format on the secondary axis.

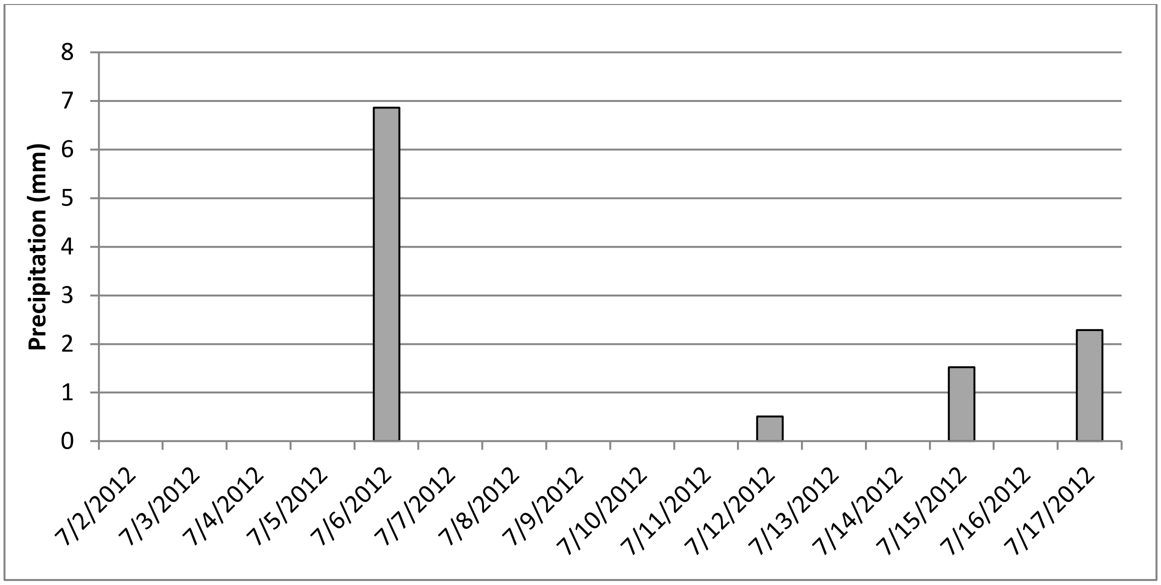

Figure 2.11 Precipitation (mm) for North Dakota site in 2012 (NDDN12) between the first sensing and in-season N application on July 2 and second sensing on July 17.

The change in NDRE between the first and second sensing dates further demonstrates the relationships between N strategies and NDRE (Figure 2.12 and Figure 2.13). By investigating ΔNDRE, the differences that existed prior to N application are accounted for and only the change within a given treatment was examined.

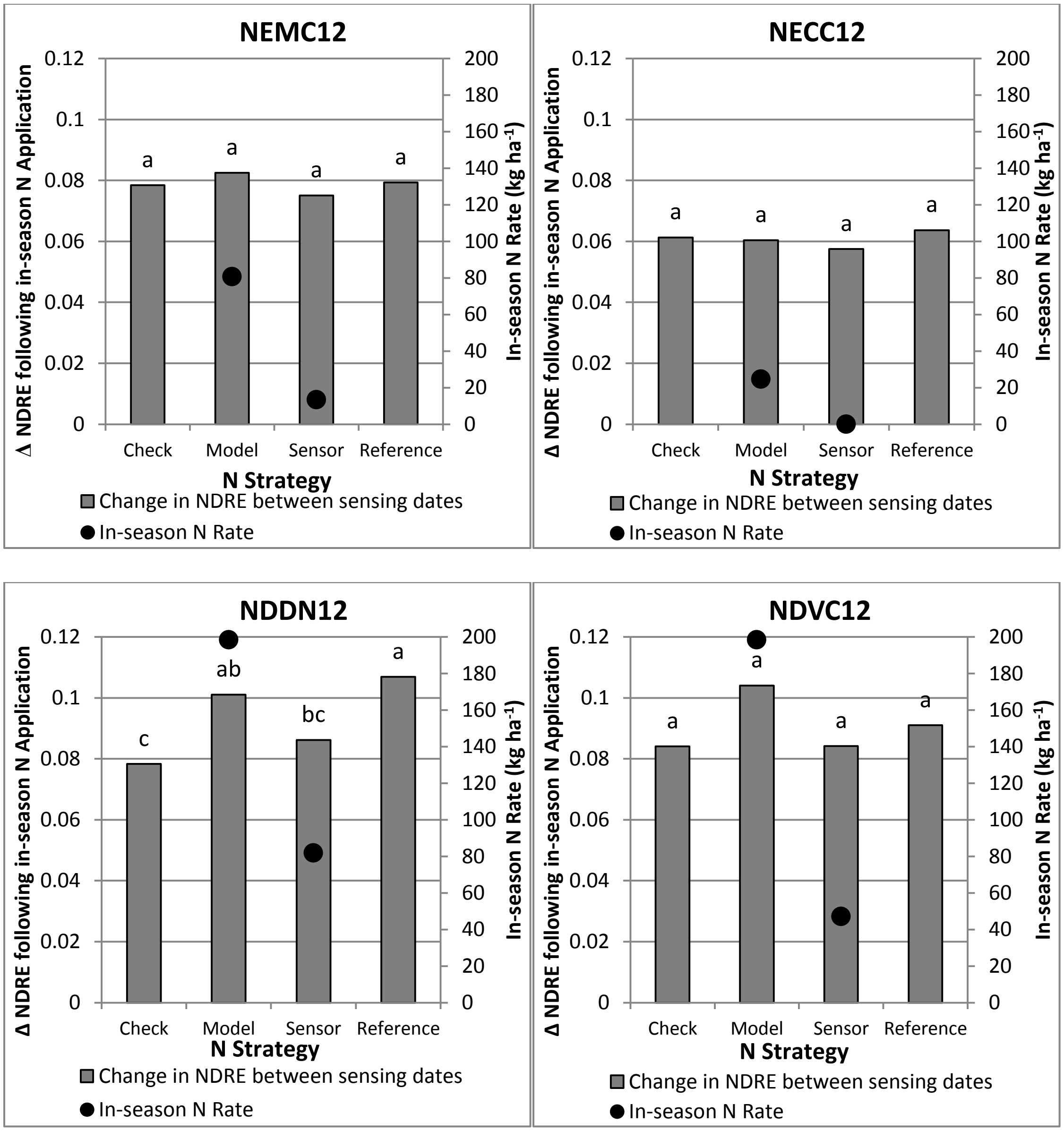

Figure 2.12 Change in NDRE between sensing at application and follow up sensing for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012. Means with the same letter are not statistically different (P≤0.05). In-season N rates applied to model-based and sensor-based treatments are shown in point format on the secondary axis.

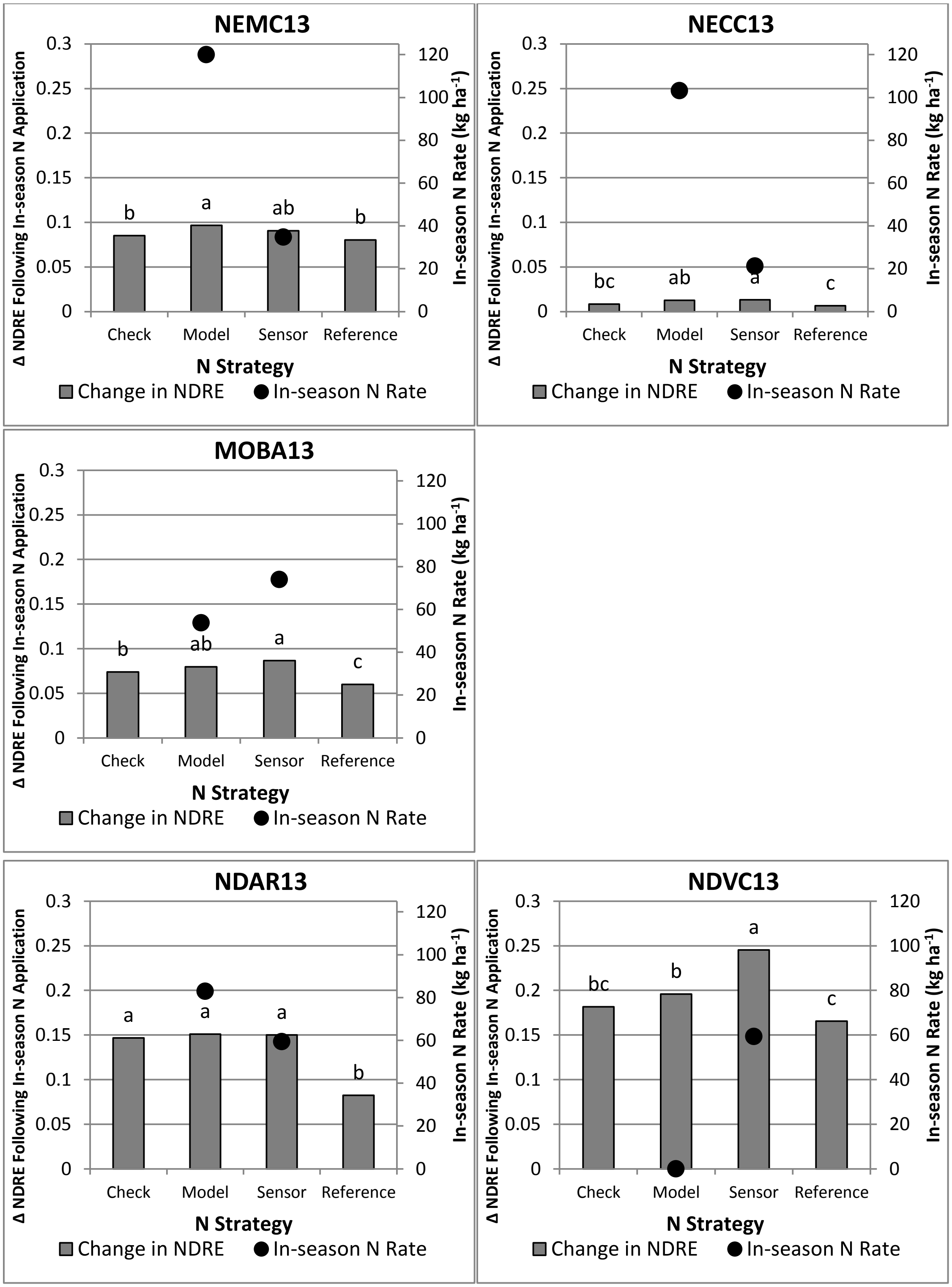

Figure 2.13: **Change in NDRE between sensing at application and follow up sensing for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012. Means with the same letter are not statistically different (P≤0.05). In-season N rates applied to model-based and sensor-based treatments are shown in point format on the secondary axis.**

The SI can also be useful in explaining differences between N strategies based on N application rates. The SI is the ratio of the NDRE of the check, model, or sensor N strategy to the NDRE of the reference N strategy and serves to normalize NDRE values based on location, environment, hybrid, and population differences. SI values for the check, model, and sensor N strategies are provided for both sensing dates where available in Figure 2.14 and Figure 2.15. When SI values are equal to 1, it is expected that N was not limiting (contingent upon reference crop sensed being at maximum NDRE value and non-N-limiting). At the time of in-season N application, there was no difference in SI among model and sensor treatments for any of the sites. There were six sites where the check had a significantly lower SI than the model and sensor and six sites where the check did not have a significantly different SI than the model and sensor. This indicates whether or not the check was experiencing more stress due to lack of initial N application compared to the model and sensor treatments.

It is useful to compare the SI from the first and second sensing for any given site. No comparison can be made for sites MOLT12, MORO12, or MOTR13 due to lack of sensor data. For NEMC12, NECC12, and NECC13, SI values for the model and sensor were very close to 1 at the time of in-season N application and following application, indicating that for these sites, N needs were being adequately met at both points. For NDAR13 and MOBA13, the SI increased from the first sensing date to second sensing date equally for the model and sensor treatments, indicating that N supplied at the in-season application was sufficient for both treatments. However, there were further complexities occurring at NDAR13, where the check which received no in-season or initial N application also increased along with the model and sensor treatment to a similar and non-limiting SI. Therefore, it is believed that at this site, another source of N was being provided to the crop as the check did not respond differently from the model and sensor treatments. It is possible that roots grew down into residual plant-available N or N was mineralized. At NEMC13 and NDVC13 SI increased from the first to second sensing such that at the second sensing, there was a significant difference between the SI of the model and sensor treatments that related to the in-season N application rates. This indicates that for these sites, the treatment (model or sensor) that received the lower N application rate, N was more limiting at the time of the second sensing. Sites NDDN12 and NDVC12 were unique in that for some treatments the SI decreased at the second sensing date. This was particularly true for NDDN12 where all treatments experienced a decrease in SI. It is therefore understood that N was becoming more limiting for these treatments relative to the reference. For this site, this is explained by the lack of rainfall to move in-season N into the soil profile and is consistent with NDRE data explored previously. NDVC12 appears more similar to NEMC13 and NDVC13 where the SI increase was proportional to the N applied in-season. Here the model treatment which received more in-season N has a higher SI at the second sensing date, whereas the sensor treatment which received less in-season N has a lower SI at the second sensing date. It is thought that N was more limiting for the sensor treatment at this site.

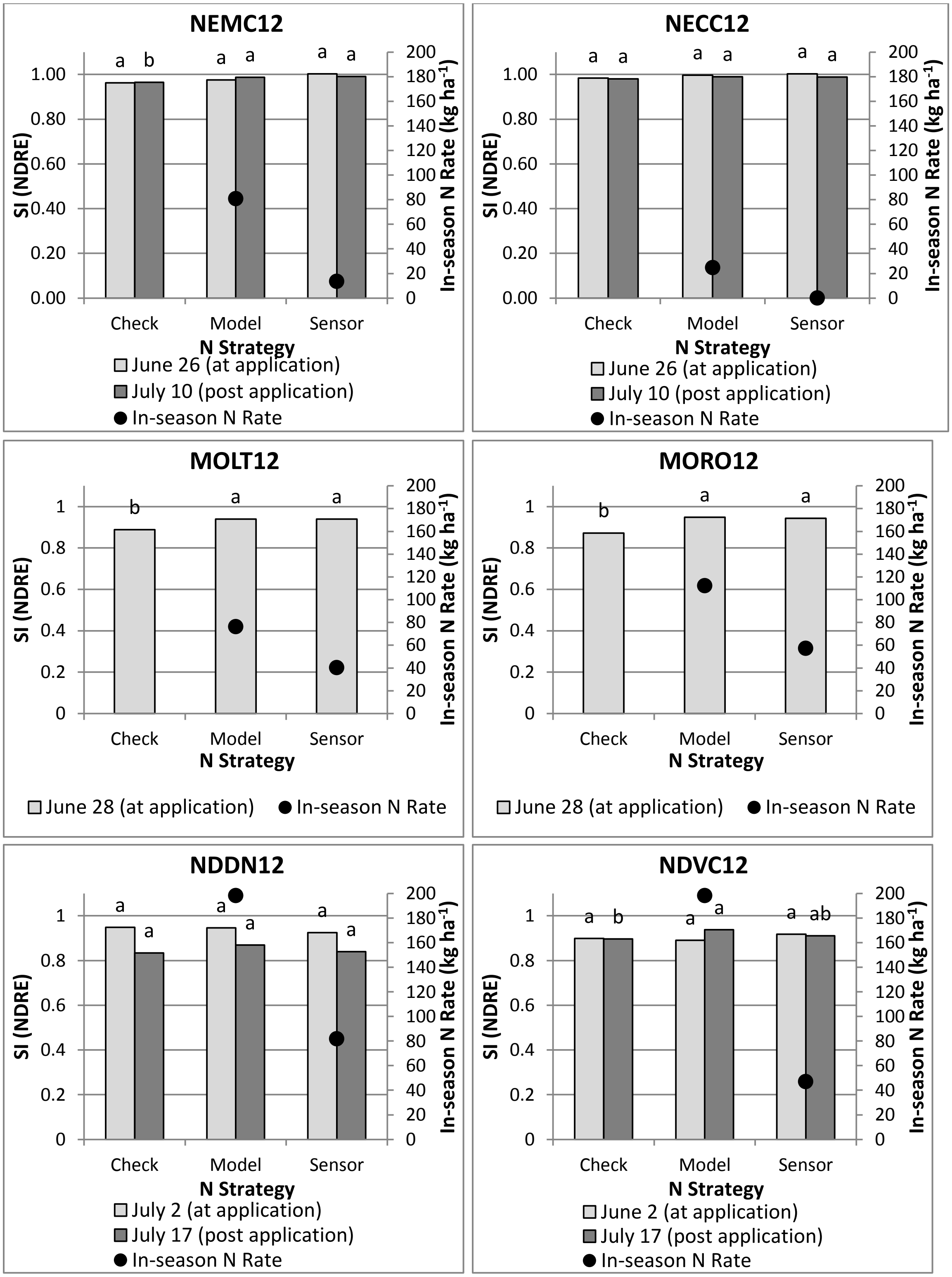

Figure 2.14 SI values arranged by N strategy main effect for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012. Mean letters apply within a sensing date. Means with the same letter are not statistically different (P≤0.05). In-season N rates applied to model-based and sensor-based treatments are shown in point format on the secondary axis.

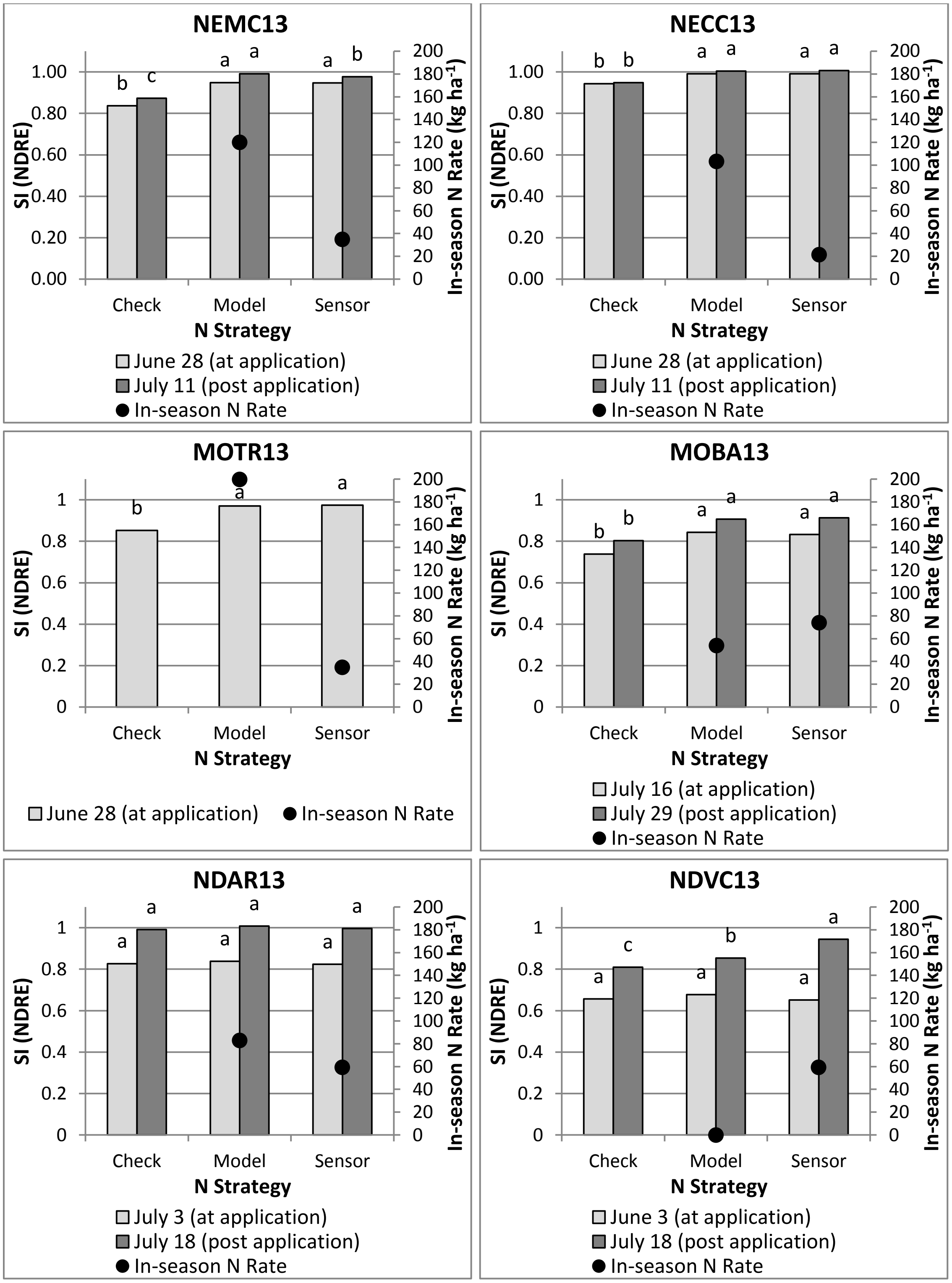

Figure 2.15 SI values arranged by N strategy main effect for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2013. Mean letters apply within a sensing date. Means with the same letter are not statistically different (P≤0.05). In-season N rates applied to model-based and sensor-based treatments are shown in point format on the secondary axis.

It is noteworthy that in some cases, on a replication basis, the reference crop had lower NDRE values than the check, model-based, or sensor-based treatments. This resulted in SI values greater than 1. This is of concern, because the goal of the N reference is to provide a reference where N is not a limiting factor, therefore providing a standard. When the reference crop has lower NDRE readings there is some concern that the highest reference standard available for the field is not being used. This was particularly common on North Dakota sites in 2012 and at NDDN12 in particular where SI values ranged from around 0.6 to 1.6. This large range of SI is somewhat concerning and is thought to be due to poor and sporadic plant stands which obfuscated sensor readings on these sites. Overall, it can be seen that the sites responded differently to N treatments, both initially, and more significantly following N application. In particular, sensor readings from NEMC12, NECC12, and NDDN12 appeared to be unrelated to N application due to N mineralization during the growing season (Nebraska sites) and lack of rainfall to incorporate applied fertilizer N (North Dakota site). Additionally, the response at NDAR13 may be unrelated to N application as the check responded similarly to the model and sensor treatments. It is unclear what the reason for this may be. Sites NEMC13, NDVC13, and NDVC12 showed the most response to N application and the treatment which received more in-season N had a higher NDRE value following application. The treatment which had lower N application experienced reduced SI at the second sensing indicating N was more limiting.

N Application Rates

Nitrogen application for 2012 is summarized for the four N strategies in Figure 2.16. In-season N rates for model and sensor treatments for each site are averaged across hybrid and population treatments at that location. In 2012, for all sites, in-season N rates for the model-based treatments were higher than in-season N rates for the sensor-based treatments. For one site, NECC12, no in-season N application was recommended using the sensor-based approach.

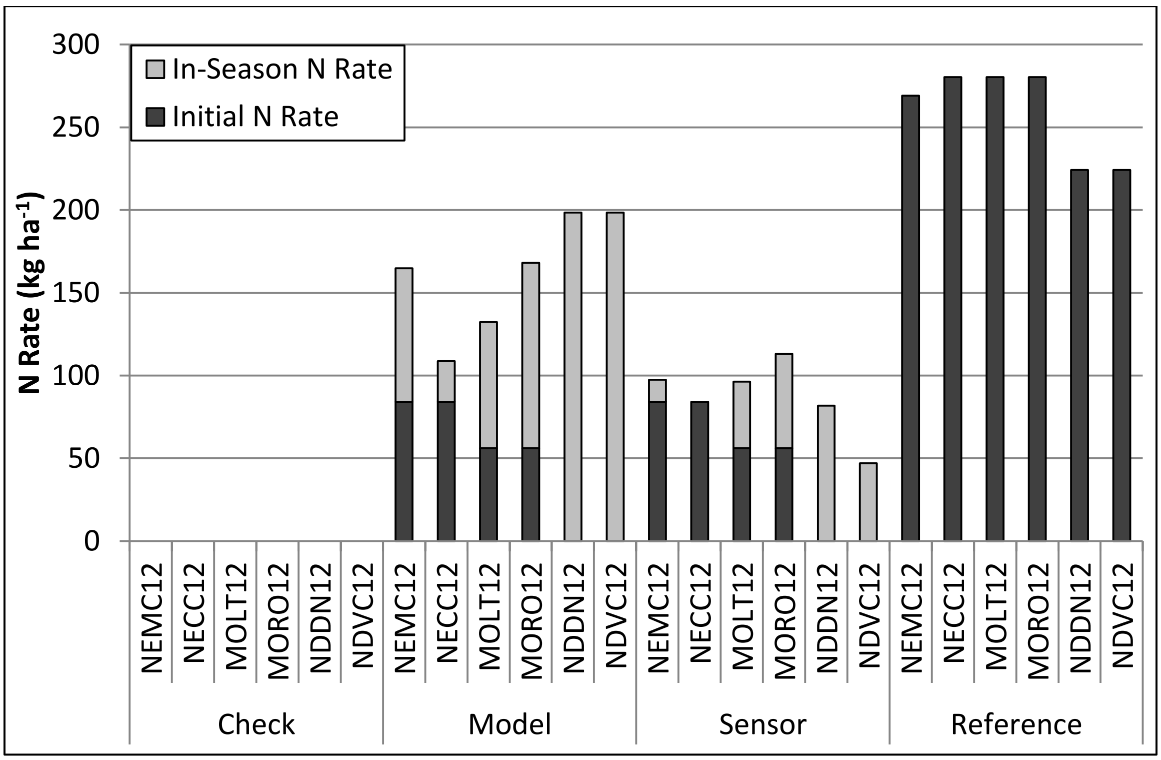

Figure 2.16 N rate applied to sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 arranged by N strategy. Initial and in-season rates are indicated for model-based and sensor-based treatments.

For the sites in 2013, the model-based approach again recommended a higher in-season N application for the majority of the sites (Figure 2.17). However, there were two sites in which a higher in-season N application was recommended by the sensor approach than the model approach. MOBA13 had a higher N recommendation with the sensor approach than with the model approach and NDVC13 had a higher N recommendation using the sensor approach as the model did not recommend any N application at this site. The model approach did not recommend any N application at NDVC13 largely due to high levels of nitrate already present in the soil as evidenced by pre-plant soil tests (Table 2.3). At MOTR13 the in-season N rate for the model approach was erroneously reduced by 18 kg ha^{-1}. This resulted in the total N rate for the model treatments being 25 kg ha^{-1} lower than the N rate for the reference rather than only 7 kg ha^{-1} lower than the reference.

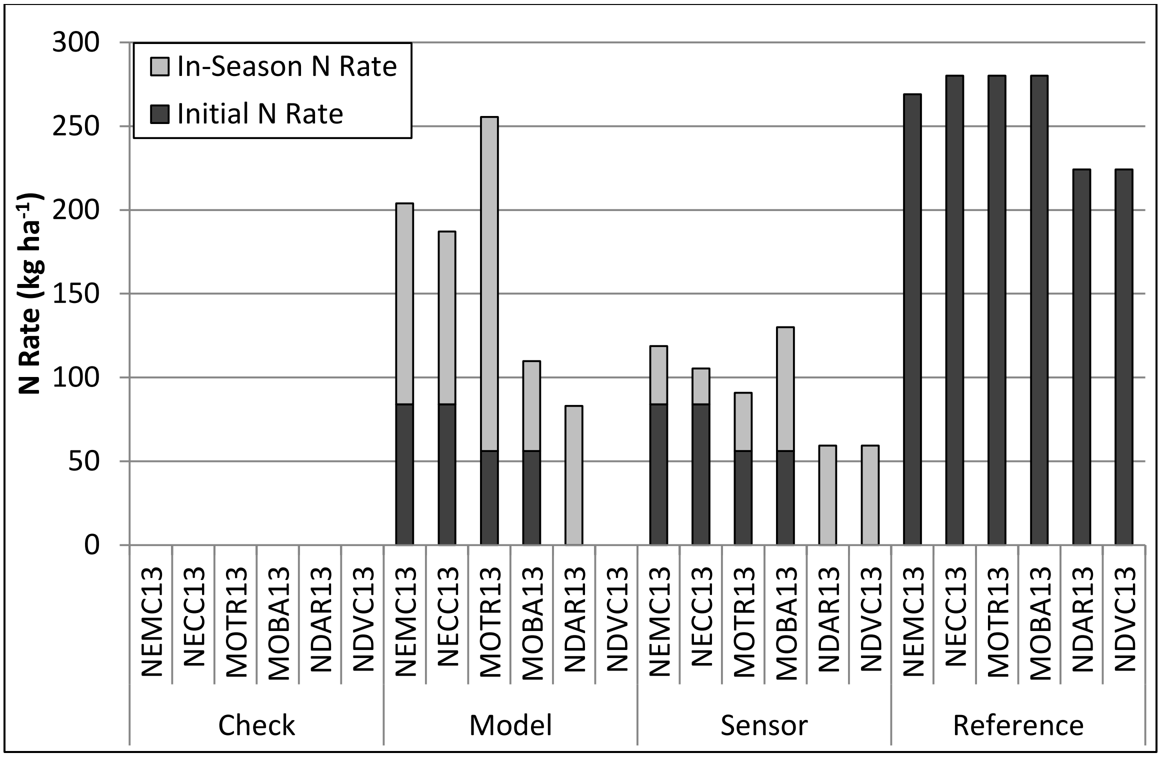

Figure 2.17 N rate applied to sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2013 arranged by N strategy. Initial and in-season rates are indicated for model-based and sensor-based treatments.

To better understand the N rates recommended by the model and sensor approaches, they were compared with N rates that would be recommended using university developed N recommendation algorithms for uniform rate applications. Figure 2.18 shows the N rates recommended by the two N strategies studied along with the university N rate for comparison. For Missouri and Nebraska sites, the University of Nebraska-Lincoln N algorithm was used, and for North Dakota sites, the North Dakota University N algorithm was used for comparison.

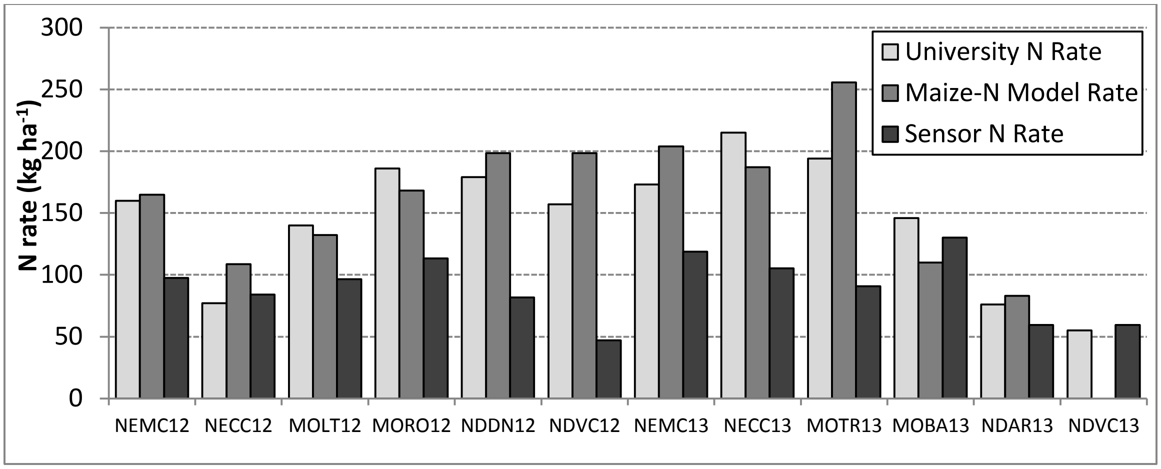

Figure 2.18 N rate comparison for model approach, sensor approach, and university algorithm N rates for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 and 2013.

Yield and NUE Measures

Tables of significant interactions and main effects are shown in Table 2.17 and Table 2.18 for yield and three measures of NUE. Partial factor productivity of N (PFP_N) is defined as the kg of grain per kg of N applied. Agronomic efficiency (AE) is defined as the kg of grain increase from unfertilized to fertilized crop per kg of N applied. The recovery of N in grain is defined as the increase in percent N content in grain from unfertilized to fertilized crop per kg ha^{-1} of N fertilizer applied.

Table 2.17 Significance levels (P≤0.05) for main treatment effects for grain yield, partial factor productivity of N, agronomic efficiency, and grain N recovery for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 (PR>F).

Site	Hybrid	N strategy	Plant population	Hybrid x N strategy	Hybrid x plant population	N strategy x plant population	Hybrid x N strategy x plant population
Main treatment effects on yield (check, N rich reference, sensor and model treatments included)							
NECC12	NS*	NS	NS	NS	NS	NS	NS
NEMC12	<0.0001	0.0010	NS	NS	NS	NS	NS
MORO12	--	--	--	--	--	--	--
MOLT12	0.0005	<0.0001	0.0002	NS	NS	0.0377	NS
NDDN12	NS	0.0273	NS	NS	NS	NS	NS
NDVC12	NS	0.0076	NS	NS	NS	NS	NS
Partial factor productivity of nitrogen main effects (includes N rich reference, sensor and model treatments)							
NECC12	NS	<0.0001	0.0089	NS	NS	0.0041	NS
NEMC12	0.0016	<0.0001	NS	NS	NS	NS	NS
MORO12	--	--	--	--	--	--	--
MOLT12	0.0136	<0.0001	NS	NS	NS	NS	NS
NDDN12	NS	0.0034	NS	NS	NS	NS	NS
NDVC12	NS	<0.0001	NS	NS	NS	NS	NS
Agronomic efficiency main effects (includes N rich reference, sensor and model treatments)							
NECC12	NS	NS	NS	NS	NS	NS	NS
NEMC12	0.0080	0.0022	NS	NS	NS	NS	NS
MORO12	--	--	--	--	--	--	--
MOLT12	NS	0.0014	NS	NS	NS	NS	NS
NDDN12	NS	NS	0.0180	NS	NS	NS	NS
NDVC12	NS	NS	NS	NS	NS	NS	NS
Recovery of nitrogen in grain main effects (includes N rich reference, sensor and model treatments)							
NECC12	NS	NS	NS	NS	NS	NS	NS
NEMC12	NS	NS	NS	NS	NS	NS	NS
MORO12	--	--	--	--	--	--	--
MOLT12	0.0007	0.0382	NS	NS	NS	NS	NS
NDDN12	--	--	--	--	--	--	--
NDVC12	--	--	--	--	--	--	--

**Actual probability level up to 0.05, NS indicates probability level >0.05.*

Table 2.18 Significance levels (P≤0.05) for main treatment effects for grain yield, partial factor productivity of N, agronomic efficiency, and grain N recovery for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2013 (PR>F).

Site	Hybrid	N strategy	Plant population	Hybrid x N strategy	Hybrid x plant population	N strategy x plant population	Hybrid x N strategy x plant population
Main treatment effects on yield (check, N rich reference, sensor and model treatments included)							
NECC13	0.0016	<0.0001	0.0017	NS	NS	NS	NS
NEMC13	NS	<0.0001	NS	0.0019	NS	NS	NS
MOTR13	NS	<0.0001	NS	NS	NS	0.0088	NS
MOBA13	0.0106	<0.0001	0.0003	NS	NS	NS	0.0100
NDAR13	NS	NS	NS	NS	NS	NS	NS
NDVC13	NS	NS	NS	NS	NS	NS	NS
Partial factor productivity of nitrogen main effects (includes N rich reference, sensor and model treatments)							
NECC13	NS	<0.0001	0.0342	NS	0.0323	0.0003	0.0206
NEMC13	NS	<0.0001	NS	NS	NS	NS	NS
MOTR13	NS	<0.0001	NS	NS	NS	NS	NS
MOBA13	NS	<0.0001	NS	NS	NS	NS	NS
NDAR13	NS	<0.0001	NS	NS	NS	NS	NS
NDVC13	NS	<0.0001	NS	NS	NS	NS	NS
Agronomic efficiency main effects (includes N rich reference, sensor and model treatments)							
NECC13	NS	<0.0001	NS	NS	NS	NS	NS
NEMC13	<0.0001	<0.0001	0.0041	NS	NS	NS	NS
MOTR13	NS	<0.0001	NS	NS	NS	NS	NS
MOBA13	NS	<0.0001	NS	NS	NS	NS	NS
NDAR13	NS	NS	NS	NS	NS	NS	NS
NDVC13	NS	0.0417	NS	NS	NS	NS	NS
Recovery of nitrogen in grain main effects (includes N rich reference, sensor and model treatments)							
NECC13	NS	0.0256	0.0138	NS	NS	NS	NS
NEMC13	NS	NS	NS	NS	0.0322	NS	NS
MOTR13							
MOBA13							
NDAR13	--	--	--	--	--	--	--
NDVC13	--	--	--	--	--	--	--

**Actual probability level up to 0.05, NS indicates probability level >0.05.*

Interactions for Yield and NUE measures

All interactions present for yield, PFP_N, AE, and grain N recovery factors are shown in figures below. Interactions relating to yield are shown in Figure 2.19 through Figure 2.23. Overall, no clear trend is apparent in the interaction depicted here. This is in part due to the fact that N strategies depicted are not indicative of N application rate (e.g. model treatments do not always have more N than sensor treatments and relative quantities of N can vary between these treatments). Interactions with partial factor productivity of N are shown in Figure 2.24 through Figure 2.26. Due to lack of conclusive trends in these interactions across site years, the main effects of hybrid, plant population, and N strategy will be explored.

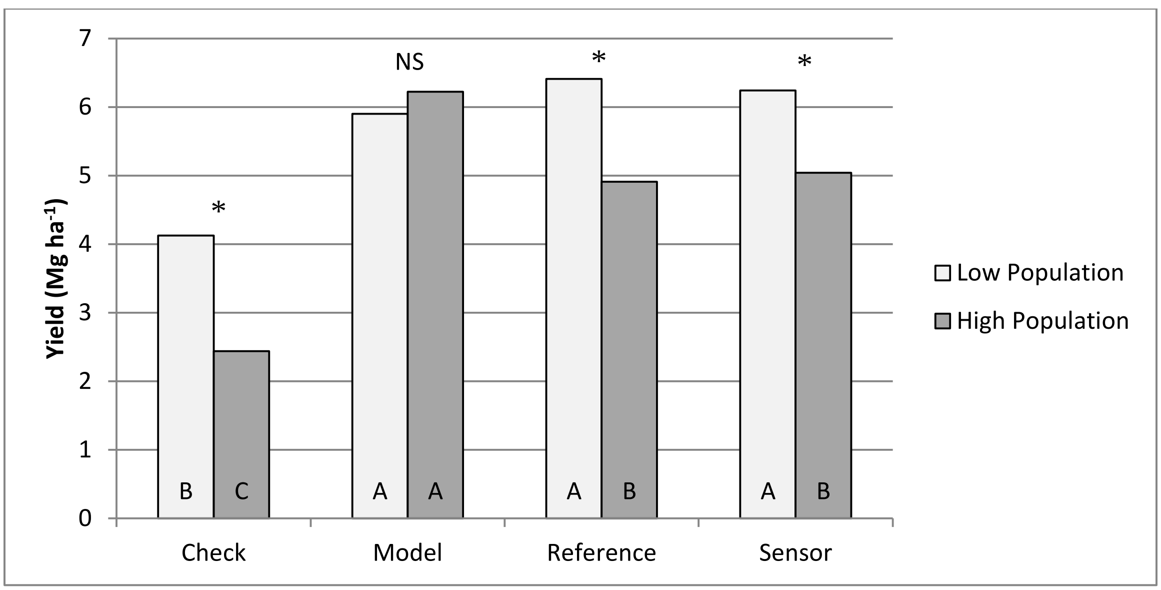

Figure 2.19 N strategy by plant population interaction of yield for a Missouri site in 2012 (MOLT12). Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within plant population. Asterisks indicate population significant difference within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

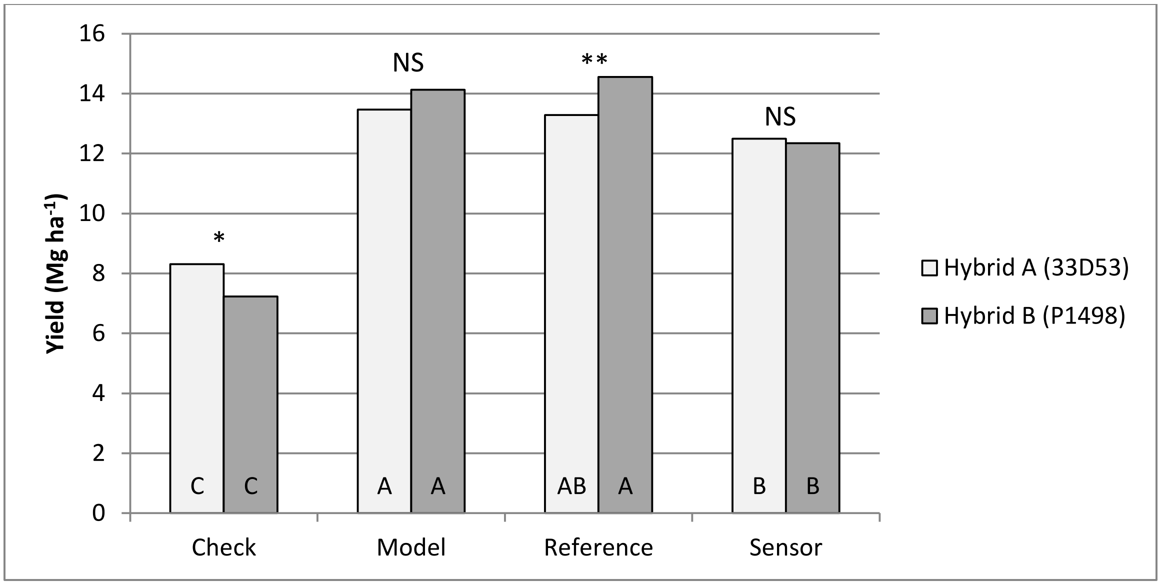

Figure 2.20 N strategy by hybrid interaction of yield for a Nebraska site in 2013 (NEMC13). Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within hybrid. Asterisks indicate hybrid significant difference within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

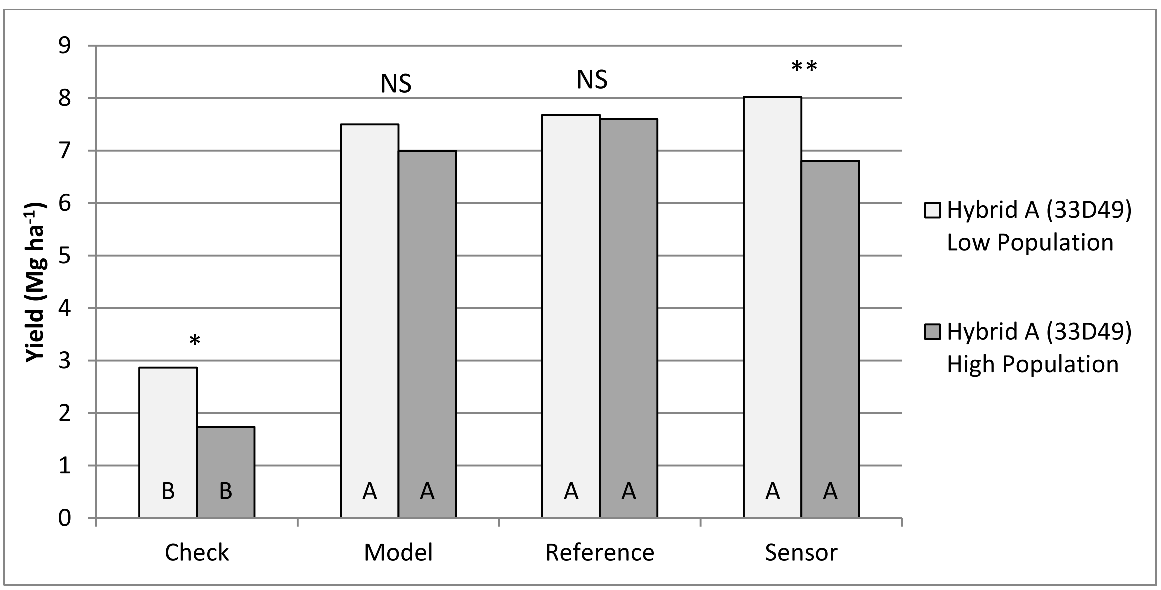

Figure 2.21 N strategy by plant population interaction for hybrid A of yield for a Missouri site in 2013 (MOBA13). Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within population for hybrid A. Asterisks indicate population significant difference for hybrid A within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

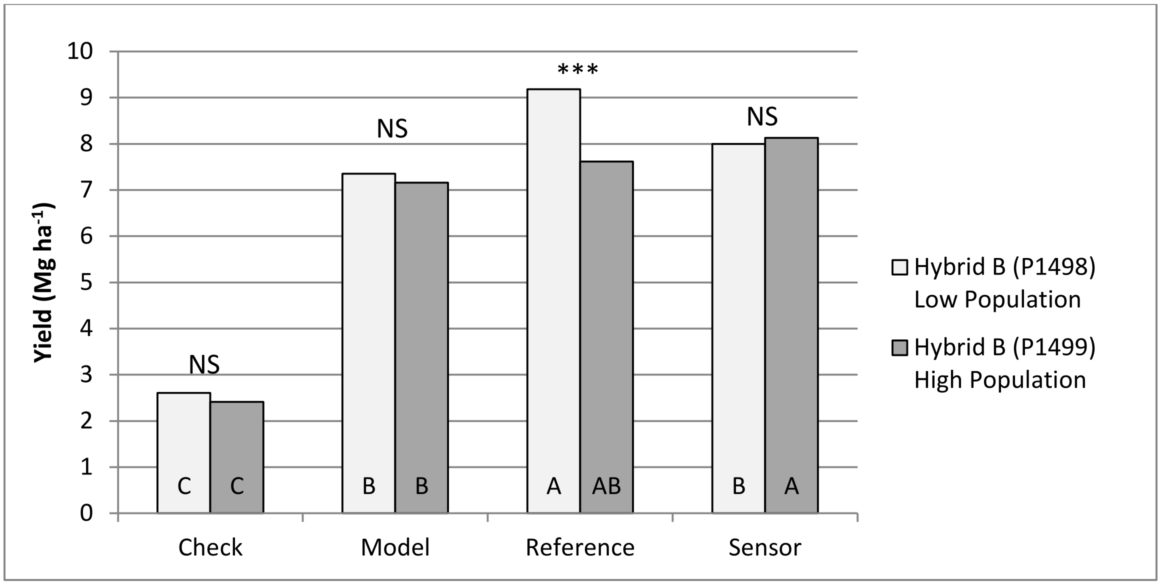

Figure 2.22 N strategy by plant population interaction for hybrid B of yield for a Missouri site in 2013 (MOBA13). Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within population for hybrid B. Asterisks indicate population significant difference for hybrid B within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

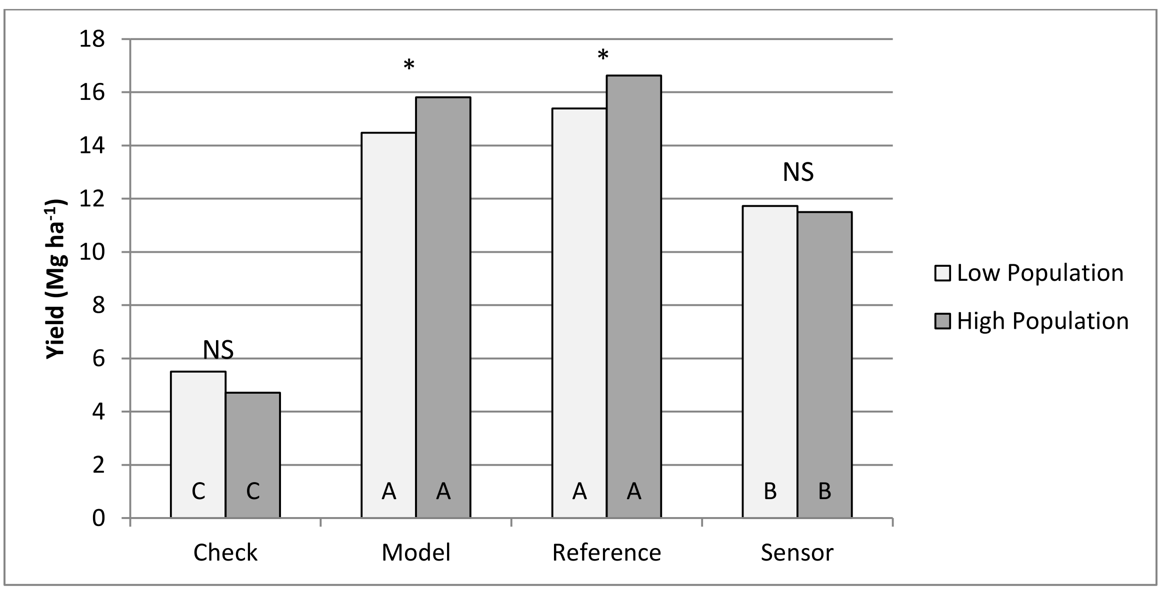

Figure 2.23 N strategy by plant population interaction on yield for a Missouri site in 2013 (MOTR13). Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within population. Asterisks indicate population significant difference within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

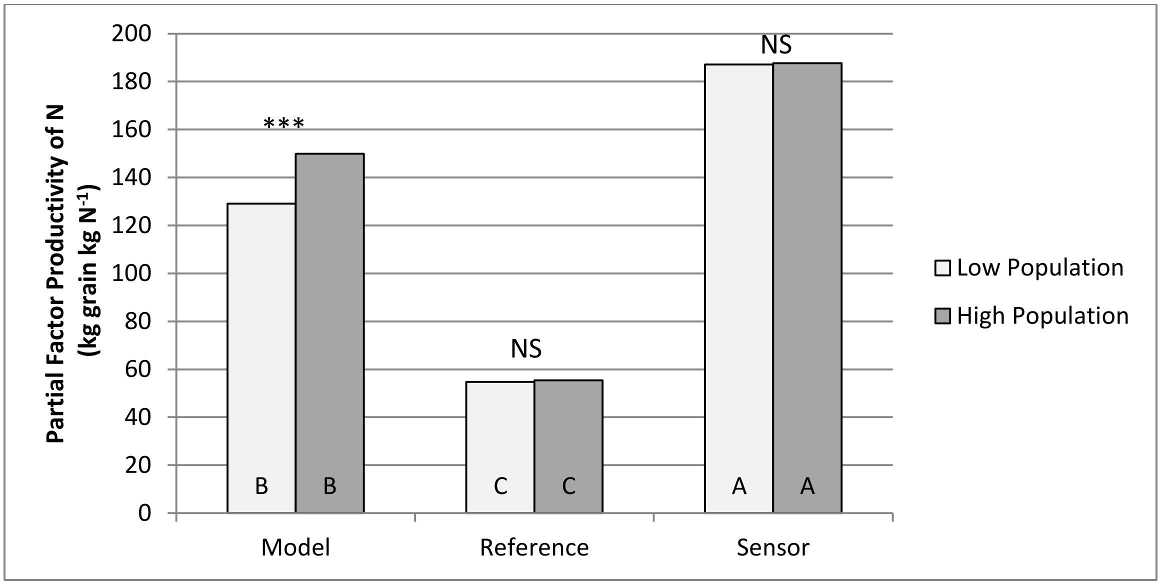

Figure 2.24 N strategy by plant population interaction on partial factor productivity of N for a Nebraska site in 2012 (NECC12). Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within population. Asterisks indicate population significant difference within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

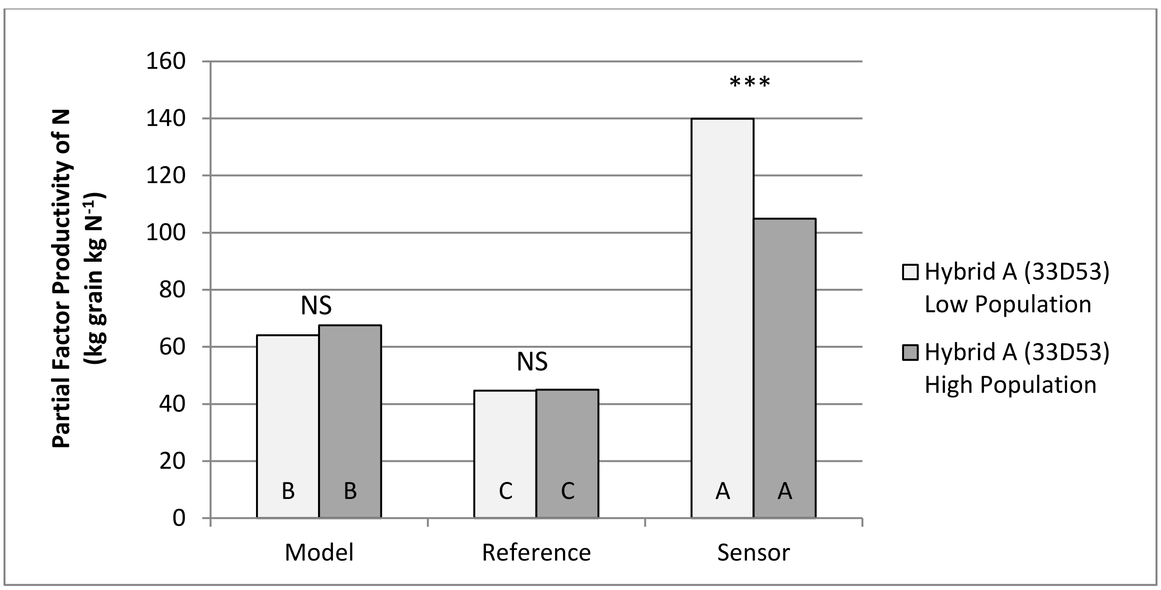

Figure 2.25 N strategy by plant population interaction for hybrid A on partial factor productivity of N for a Nebraska site in 2013 (NECC13). Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within population for hybrid A. Asterisks indicate population significant difference for hybrid A within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

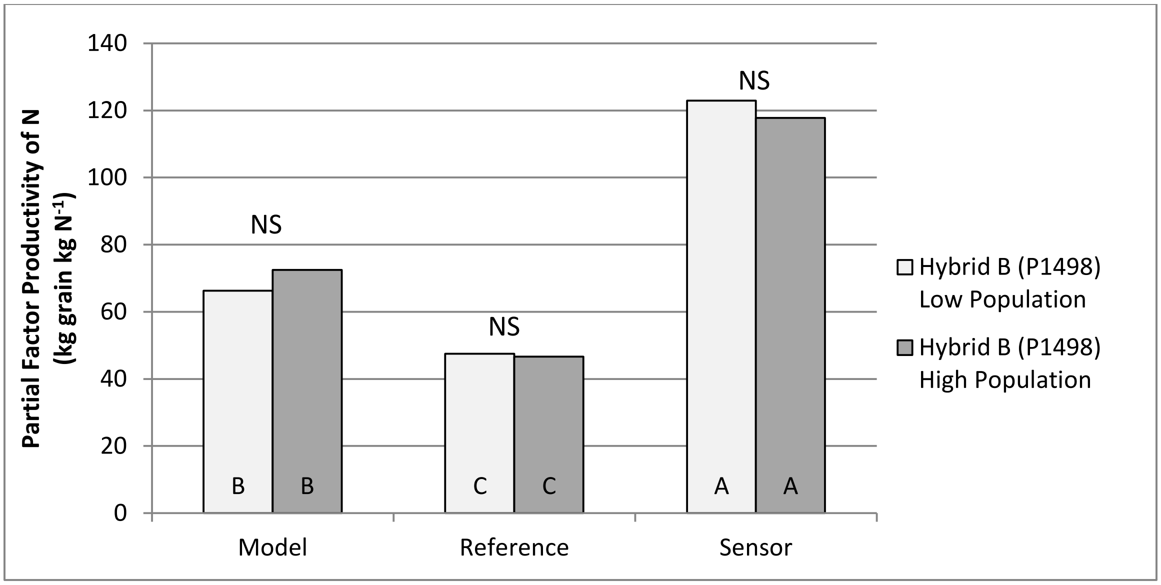

Figure 2.26 N strategy by plant population interaction for hybrid B on partial factor productivity of N for a Nebraska site in 2013 (NECC13). Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within population for hybrid B. Asterisks indicate population significant difference for hybrid B within N strategy (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

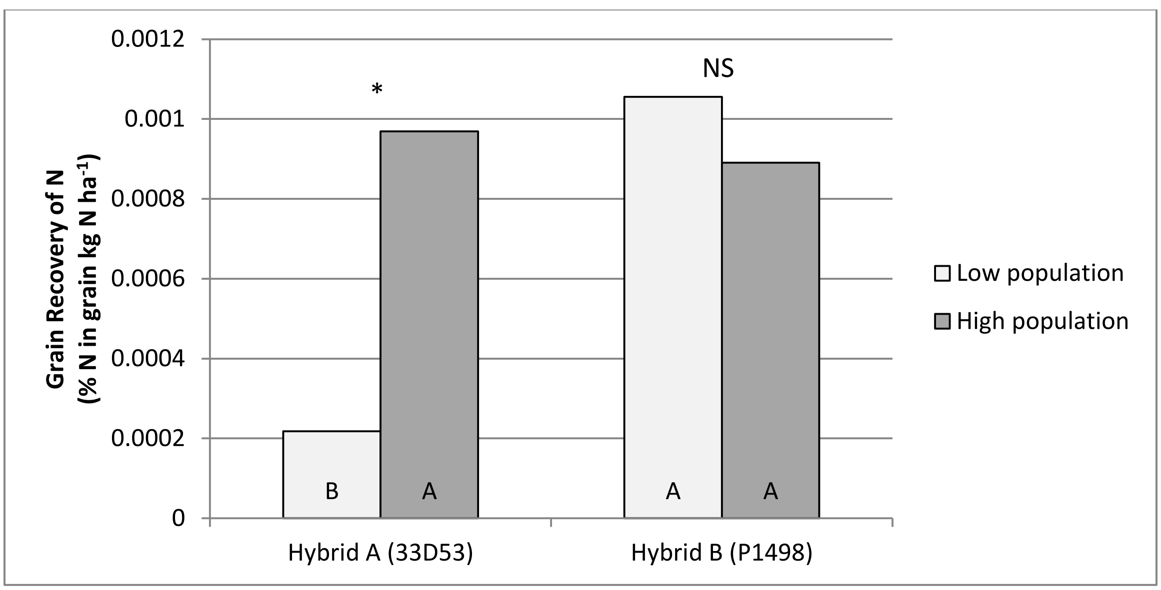

Figure 2.27 Plant population by hybrid interaction on grain N recovery for a Nebraska site in 2013 (NEMC13). Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within population. Asterisks indicate population significant difference within hybrid (*, P≤0.05; **, P≤0.01; ***, P≤0.001).

Hybrid Main Treatment Effects for Yield and NUE

Hybrid treatment means for yield and NUE measures are provided in Table 2.19 when the hybrid main effect was significant at α=0.05. Significant main effects for hybrid were only present at Nebraska and Missouri sites. For yield and all NUE measures shown, hybrid B (P1498) was significantly greater than hybrid A (33D49 and 33D53). Therefore where differences in hybrid exist, it is apparent that hybrid B was higher yielding and more efficient in N use. It is unknown whether the higher yield and NUE for hybrid B is related to its higher drought score. Two of the four sites where yield of hybrid B was higher than yield of hybrid A were fully irrigated; therefore water stress was not a factor for these two sites. As such, no conclusion can be drawn relating the higher yield and NUE of hybrid B to its high drought score. It is noteworthy that although hybrid B was higher yielding, it had significantly lower NDRE values than hybrid A for several sites. Lower NDRE values for hybrid B did not translate into lower yields. It is likely that hybrid differences in NDRE values were more indicative of differences in leaf architecture and hybrid color which were visually observed, rather than in N content and overall plant biomass.

Table 2.19 Hybrid treatment means for yield, partial factor productivity of N, agronomic efficiency, and grain recovery of N for sites in Nebraska (NE) and Missouri (MO) in 2012 and 2013 where hybrid main effect is significant at P≤0.05.

	Hybrid A	Hybrid B
	Yield	
	--------------------------*Mg ha^{-1}*------------------------	
NEMC12	14.4	15.9
MOLT12	4.68	5.64
NECC13	11.7	12.3
MOBA13*	6.15	6.56
	Partial Factor Productivity of N	
	-----------------------*kg grain kg N^{-1}*---------------------	
NEMC12	97.5	112
MOLT12	36.9	46.0
	Agronomic Efficiency	
	-------------*kg grain increase kg N applied^{-1}*---------	
NEMC12	4.71	12.4
NEMC13	26.5	34.3
	Grain Recovery of N	
	---------*Increase in % grain N kg N applied^{-1}*-------	
MOLT12	0.00104	0.00197
NEMC13*	0.000593	0.000972

**Indicates interaction is present. Graphs of interactions previously provided.*

Population Main Treatment Effects for Yield and NUE

Population treatment means for yield and NUE measures are provided in Table 2.20 when the population main effect was significant at α=0.05. The low population treatment was higher yielding than the high population treatment where significant differences occurred. No clear trend was seen in the NUE measures. For sites where PFP_N was significant, the high population treatment was higher one time, and the low population treatment was higher one time. Similarly, for AE the low population treatment was higher in one instance, and the high population treatment was higher in one instance. The high population treatment was consistently higher in grain N recovery.

Table 2.20 Population treatment means for yield, partial factor productivity of N, agronomic efficiency, and grain recovery of N for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 and 2013 where population main effect is significant at P≤0.05.

	Low Population	High Population
	Yield	
	-------------------*Mg ha*$^{-1}$-------------------	
MOLT12 *	5.67	4.65
NECC13	12.3	11.7
MOBA13 *	6.65	6.06
	Partial Factor Productivity of N	
	-----------*kg grain kg N ha*$^{-1}$--------------	
NECC12 *	124	131
NECC13 *	80.9	75.7
	Agronomic Efficiency	
	-------*kg grain increase kg N ha applied*$^{-1}$-------	
NDDN12	17.7	1.9
NEMC13	28.1	32.8
	Grain N Recovery	
	------ *Increase in % grain N kg N ha*$^{-1}$-------	
NECC13	0.00106	0.00153
NEMC13*	0.00064	0.00093

**Indicates interaction is present. Graphs of interactions previously provided.*

N Strategy Main Treatment Effects for Yield and NUE

Main treatment effects of N strategy for grain yield are provided in Table 2.17 and Table 2.18 for years 2012 and 2013 respectively. Figure 2.28 depicts the differences in yield based on N strategy for the 2012 sites. No yield is available for MORO12 due to uneven irrigation resulting in confounding results and loss of data. For the remaining five sites, there is a significant difference in yield due to N strategy at four sites. The model-based and sensor-based treatments were not significantly different in yield at any site. The yield for the model-based approach was not significantly lower than the yield for the reference treatment at any site; however the sensor-based approach was significantly lower in yield than the reference treatment at two of the five sites (NDDN12 and NDVC12). This indicates that at these two North Dakota sites, the model-based approach did a better job of protecting yield compared to the sensor-based approach. Lower than expected yields for MOLT12 were due to drought conditions. High yields for the check treatment at the Nebraska sites are explained by suspected unusually high rates of mineralization of N early in the growing season which reduced response to fertilizer N applied. At these two sites, the sensor-based approach had a lower N rate than the model-based approach, however yield was not significantly different.

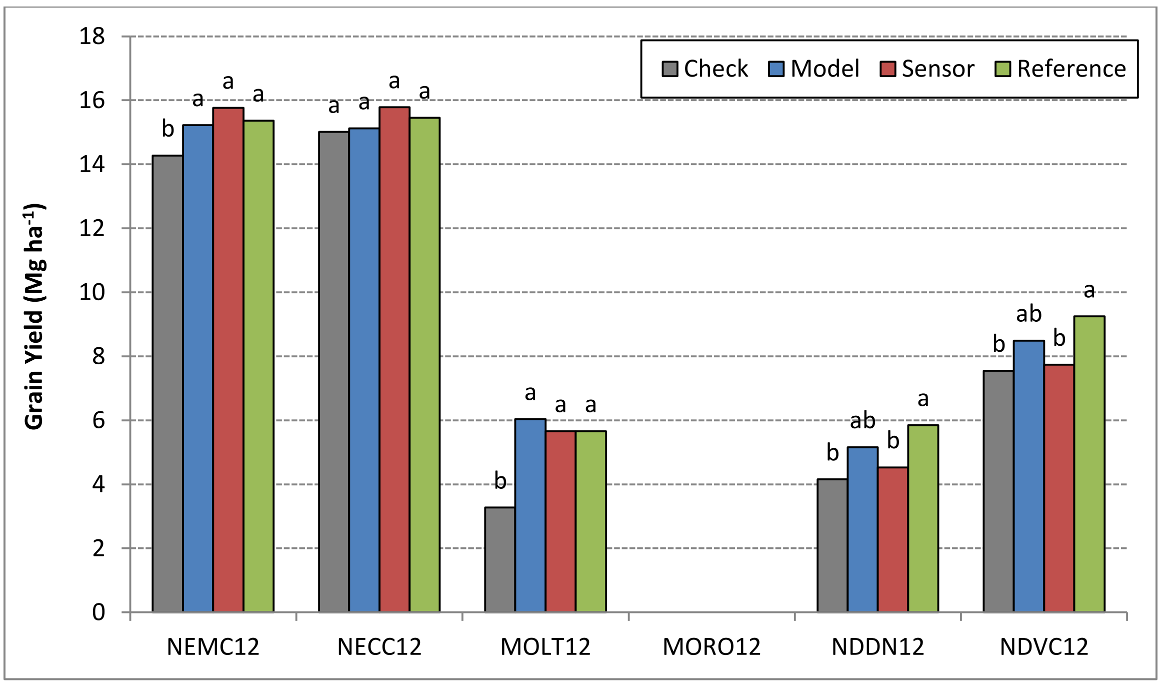

Figure 2.28 Grain yield for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 arranged by N strategy. Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within site.

Grain yield for N strategy main effect of each site in 2013 is shown in Figure 2.29. Lower N rates for model-based and sensor-based treatments contributed to significantly lower yield than reference treatments in four of six sites (two due to model-based approach and two due to sensor-based approach). MOTR13 had exceptionally high yields, such that both the model and sensor N rates limited yield. Sensor-based treatments had a significantly lower yield than model-based treatments at two of the six sites, while model-based treatments had a significantly lower yield than sensor-based treatments at one of the six sites. However, at this site the in-season N rate for the model approach was erroneously reduced by 18 kg ha^{-1}. This resulted in the total N rate for the model treatments being 25 kg ha^{-1} lower than the N rate for the reference rather than only 7 kg ha^{-1} lower than the reference. This difference would likely have resulted in yields for the model treatments being closer to that of the reference. At the North Dakota sites, no significant response to fertilizer N was seen. Factors other than N limited crop production here, therefore reducing the N response. Overall, yield results suggest that the model-based approach better protects yield potential than the sensor-based approach.

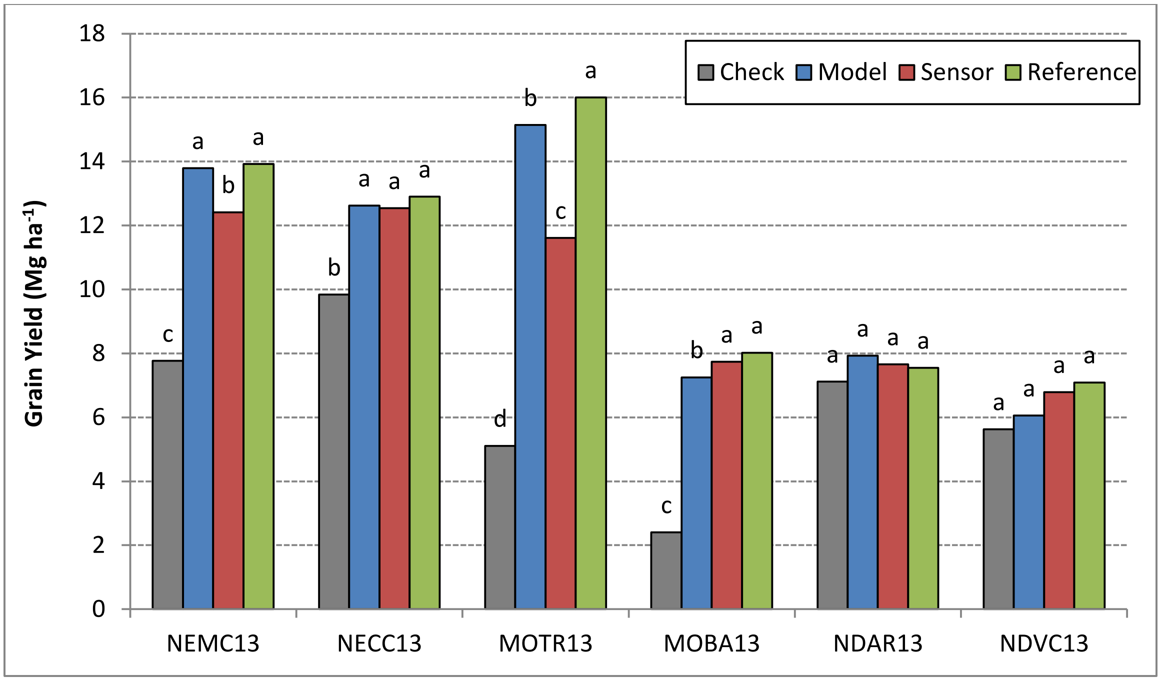

Figure 2.29: Grain yield for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2013 arranged by N strategy. Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within site.

Table 2.17 and Table 2.18 also provide main treatment effects of N strategy for three measures of NUE. There was a significant difference in PFP_N among N strategies at all sites. These differences are represented graphically in Figure 2.30 and Figure 2.31 for 2012 and 2013 respectively. In 2012 where sensor-based treatments had lower in-season N rates, the sensor-based approach had a significantly higher NUE than the model-based approach for all sites, as seen by PFP_N. For Nebraska sites this difference is attributed to high levels of N mineralization resulting in high yields, even for the check treatment which received no N application. The sensor approach appropriately reduced the in-season N recommendation at these sites, while the model did not. It should be noted that the model Version 2008.1.0 was used in 2012, which lacked the capability of estimating anticipated additions of available N due to mineralization by using in-season weather. For site NEMC12, the sensor-based in-season N rate was 14 kg N ha^{-1} while the model-based in-season N rate was 81 kg N ha^{-1}. However, if Maize-N Version 2013.2.0 which uses current season weather for estimation of N mineralization of soil organic matter is used, the in-season N rate is reduced to 62 kg N ha^{-1} (Table 2.7). The use of Version 2013.2.0 would in this case somewhat improve the in-season N recommendation by appropriately lowering the N rate; however, the rate is still higher than the sensor-based rate. For site NECC12, the sensor-based in-season N rate was 0 kg N ha^{-1} while the model-based in-season N rate calculated with Maize-N Version 2008.1.0 was 25 kg N ha^{-1}. Using Version 2013.2.0 for NECC12 results in the in-season N rate being reduced to 0 kg N ha^{-1} (Table 2.7). In this case, the updated version of Maize-N would result in an appropriately reduced in-season N rate that is equal to the N rate prescribed by the sensor-based approach and the PFP_N would be the same as the sensor-based approach in Figure 2.30. In 2013, lower N application resulted in a higher PFP_N for the sensor-based treatment than the model-based treatment at four of five sites and a higher PFP_N for the model-based treatment than the sensor-based treatment for 1 of 5 sites as shown in Figure 2.31 (no comparison can be made for site NDVC13 as the model-based approach recommended no N application).

The relationship between PFP_N shown in Figure 2.30 and Figure 2.31 and total N rate applied shown in Figure 2.16 and Figure 2.17 is noteworthy. The treatments receiving the highest N rates generally have the lowest PFP_N, while the treatments receiving the lowest N rates generally have the highest PFP_N. Therefore the treatment with the highest PFP_N likely has the lowest N rate, and in many cases this resulted in reduced yield when compared to treatments with a higher N rate. For this reason, PFP_N should not be solely considered as an evaluation of the effectiveness of an N strategy. It is important to realize that increasing NUE as measured by PFP_N or other measures while simultaneously reducing yield is an undesirable scenario. Higher NUE as measured by PFP_N or AE is desirable within a context where yield is not negatively impacted.

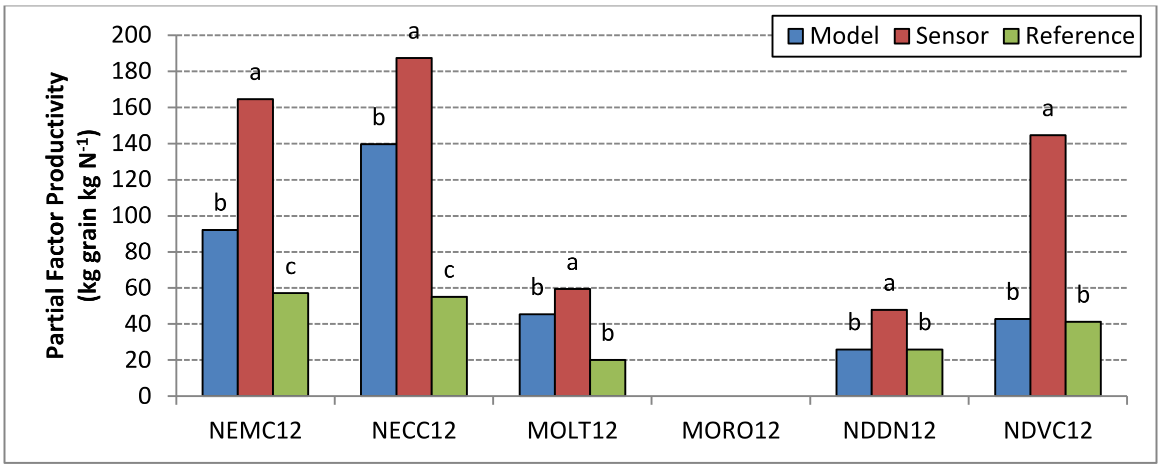

Figure 2.30 Partial factor productivity of N arranged by N strategy for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012. Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within site.

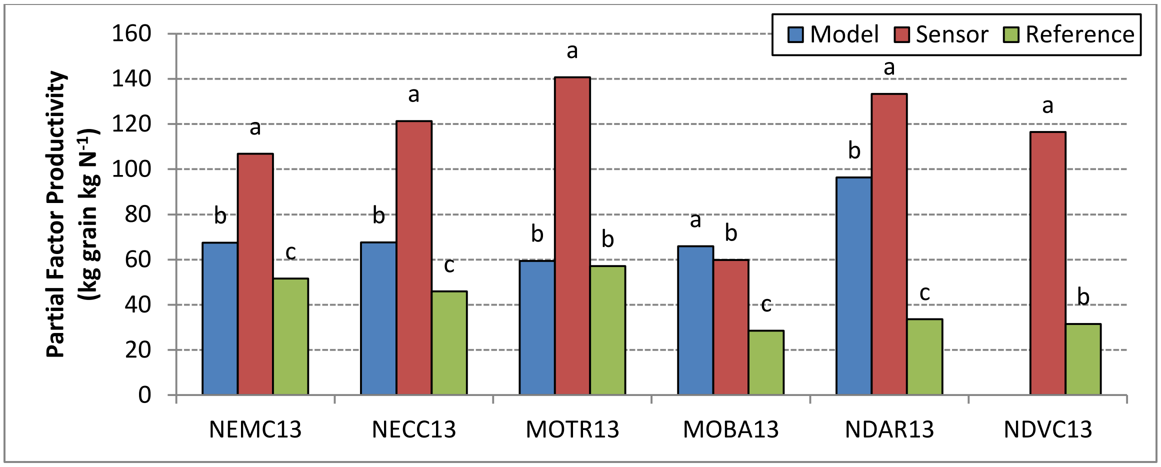

Figure 2.31: Partial factor productivity of N arranged by N strategy for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2013. Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within site.

In 2012, AE was only significantly different due to N strategy at two of five sites with data (NEMC12 and MOLT12). For all sites, agronomic efficiency of the sensor-based approach was higher than that of the model-based approach; however, it was only significantly higher at one of the five sites (Figure 2.32). In 2013, the sensor-based approach had a significantly greater agronomic efficiency than the model-based approach at three sites, and was not significantly different at two sites as seen in Figure 2.33 (as with PFP_N no comparison can be made for NDVC13 as there was no N application for the model-based approach).

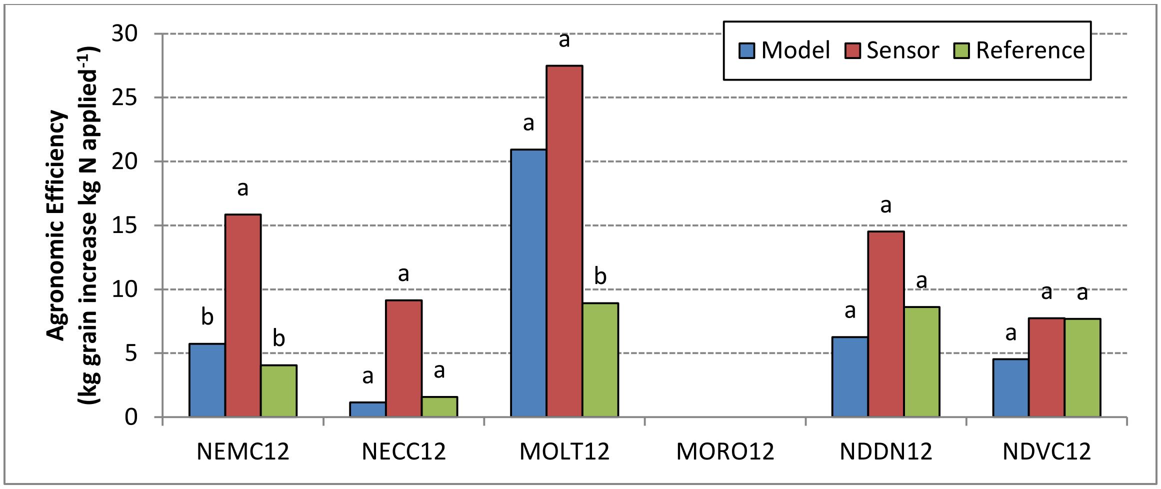

Figure 2.32: Agronomic efficiency arranged by N strategy for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012. Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within site.

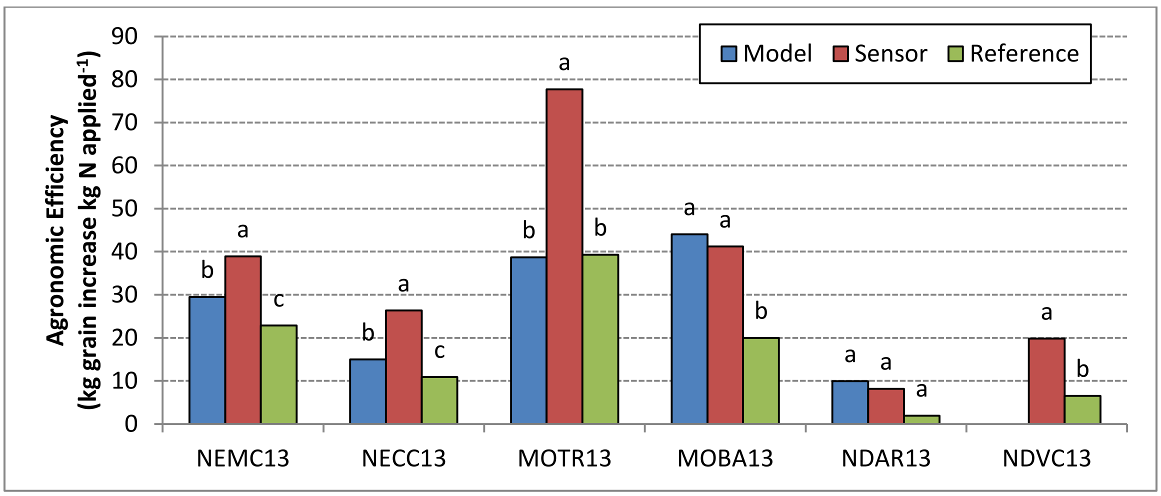

Figure 2.33: Agronomic efficiency arranged by N strategy for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2013. Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within site.

Finally, NUE by recovery of N in grain was only found to be significantly impacted by N strategy for one of three sites tested in 2012 (MOLT12) and one of two sites tested in 2013 (NECC12). Grain recovery of N for these two sites are shown in Figure 2.34. For MOLT12, the sensor-based approach was significantly higher in NUE than the reference, but was not significantly greater than the model-based approach. For NECC13, the sensor-based approach was significantly higher in NUE than both the reference and the model-based approach.

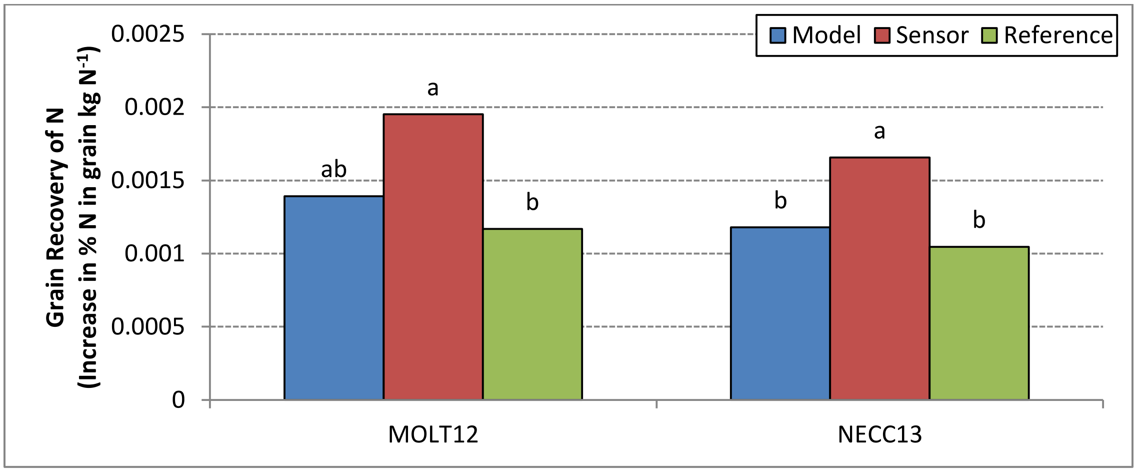

Figure 2.34 Grain recovery of N for sites in Missouri (MO) and Nebraska (NE) in 2012 and 2013 where N strategy main effect is significant. Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within site.

Overall, when examining these measures of NUE, the sensor approach is consistently higher in NUE than the model approach. This is likely due to the frequently lower N rates recommended by the sensor N strategy than the model N strategy. Sites where NUE was increased and yield was not significantly decreased from that of the reference crop are of particular interest as this is a favorable situation. There were seven sites where the sensor treatment was not significantly lower yielding than the reference and of these seven sites, six had the highest PFP_N of all N strategies (NEMC12, NECC12, MOLT12, NECC13, NDAR13, and NDVC13). In general, this situation occurred where the site was not highly responsive to N applications. This may be due to unpredictable conditions resulting in reduced yield, such as drought, or conditions resulting in N being available from other sources such as through N mineralization. In the case of NEMC12 and NECC12, high N mineralization and lack of conditions contributing to mechanisms of N loss is suspected, resulting in these sites being less responsive to fertilizer N. Similarly, dry conditions resulted in lower yields for MOLT12, NDAR13, and NDVC13, therefore introducing another more limiting factor (water) and reducing N requirements for this site. In these cases, the sensor approach appropriately reduced in-season N application, resulting in increased N fertilizer savings and higher NUE with no significant reduction in potential yield. In the case of NECC13, the reason for reduced N need is less certain, however, a hail event late in the season that resulted in reduced yields may be a factor. In this case, the sensor N recommendation was previous to the hail event; therefore it is unknown whether the N rates recommended by the sensor would have been sufficient if yield loss had not occurred.

There were nine sites where the sensor treatment was not significantly lower yielding than the reference. Of these, none had the highest PFP_N; however, for five of these sites the model treatment is significantly higher in PFP_N than the reference (NEMC12, NECC12, NEMC13, NECC13, and NDAR13). Therefore, it is possible that NUE can be improved to some degree while better protecting yield using the model approach. Site MOTR13 is one where the model clearly better estimated N needs than the sensor. At this site yields were high, such that neither the model nor sensor approach provided enough N to maximize yields. However, the model N recommendation was much closer to approximating N need than the sensor which had severely reduced yields. The effect of this is further seen when examining profitability.

Profitability Analysis

A comparison of profitability across the N strategies was made by assuming corn could be sold for \$0.20 kg^{-1} and that N fertilizer cost \$1.10 kg^{-1}. The yield for each plot was then multiplied by the price it could be sold for and the amount of fertilizer applied to each plot was multiplied by the cost of fertilizer per unit. Fertilizer cost was subtracted from grain price to determine the profit in \$ ha^{-1}. In 2012, there was a significant difference in profitability among N strategies for three of five sites as seen in Table 2.21. The difference between N strategies is further depicted in Figure 2.35. It can be seen that for three of the sites there is no difference in profitability between the model-based and sensor-based treatments. For the two Nebraska sites, the sensor approach was significantly more profitable than the model. This is due to lower in-season N recommendations for the sensor-based N strategy and comparable yields when compared with the model-based approach.

Table 2.21 Significance levels (P≤0.05) for main treatment effects for profitability for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 (PR>F).

Site	Hybrid	N strategy	Plant population	Hybrid x N strategy	Hybrid x plant population	N strategy x plant population	Hybrid x N strategy x plant population
Profit for corn at \$0.20 kg^{-1} and N fertilizer at \$1.10 kg^{-1} (includes N rich reference, sensor and model treatments)							
NECC12	<0.0001	0.0033	NS	NS	NS	NS	NS
NEMC12	<0.0001	0.0041	NS	NS	NS	NS	NS
MORO12	--	--	--	--	--	--	--
MOLT12	0.0002	<0.0001	0.0006	NS	NS	NS	NS
NDDN12	NS	NS	NS	NS	NS	NS	NS
NDVC12	NS	NS	NS	NS	NS	NS	NS

**Actual probability level up to 0.05, NS indicates probability level >0.05.*

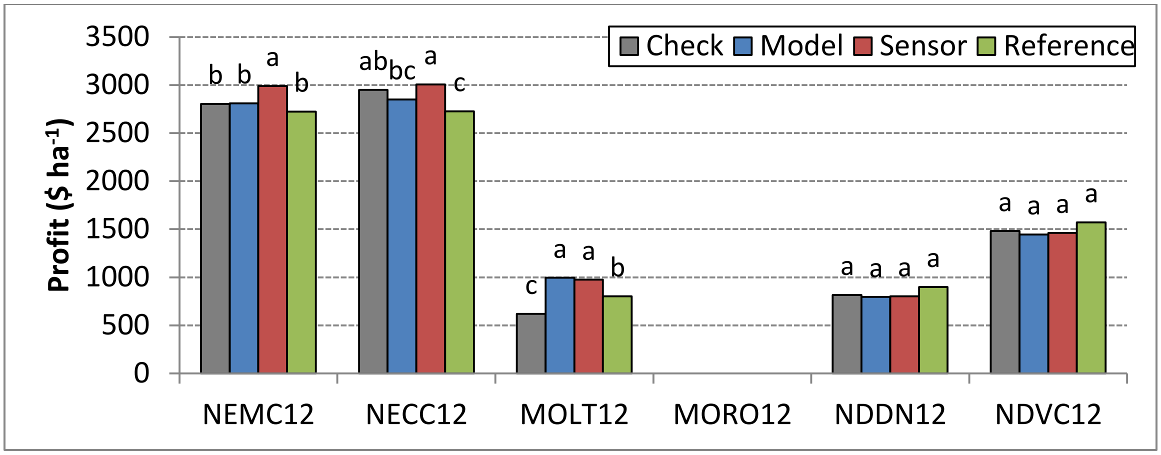

Figure 2.35 Profitability arranged by N strategy (given \$0.20 kg^{-1} corn and \$1.10 kg^{-1} fertilizer) for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012. Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within site.

In 2013, the model-based treatments had a significantly higher profitability than the sensor-based treatments at two of six sites (Figure 2.36). The remaining four sites had no significant differences between the model and sensor treatments. When comparing the sensor-based treatment to the reference, the sensor-based approach had a significantly higher profitability in three of six sites, and a significantly lower profitability in two of six sites. The model-based treatment had a significantly higher profitability compared to the reference in one of six sites, while the reference had a significantly higher profitability than the model-based treatment in one of six sites. A large difference in profitability was seen for MOTR13 due to reduced yields caused by insufficient N availability for both the model and, more substantially for the sensor treatments. Overall, there is not a clear trend for profitability of these varying approaches. However, it should be noted that when considering profitability, the dollar amount that is significant to trigger management changes for a producer is not necessarily the same as what would be considered statistically different.

Table 2.22 Significance levels (P≤0.05) for main treatment effects for profitability for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2013 (PR>F).

Site	Hybrid	N strategy	Plant population	Hybrid x N strategy	Hybrid x plant population	N strategy x plant population	Hybrid x N strategy x plant population
Profit for corn at \$0.20 kg^{-1} and N fertilizer at \$1.10 kg^{-1} (includes N rich reference, sensor and model treatments)							
NECC13	0.0019	<0.0001	0.0023	NS	NS	NS	NS
NEMC13	NS	<0.0001	NS	0.0005	NS	NS	0.0517
MOTR13	NS	<0.0001	NS	NS	NS	0.0091	NS
MOBA13	0.0120	<0.0001	0.0005	NS	NS	NS	0.0106
NDAR13	NS	0.0012	NS	NS	NS	NS	NS
NDVC13	NS	NS	NS	NS	NS	NS	NS

**Actual probability level up to 0.05, NS indicates probability level >0.05.*

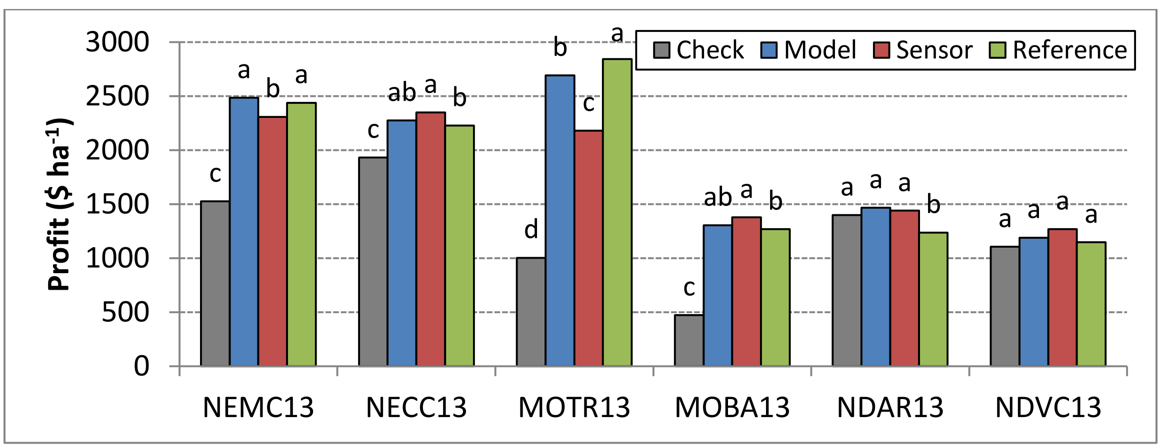

Figure 2.36: Profitability arranged by N strategy (given \$0.20 kg^{-1} corn and \$1.10 kg^{-1} fertilizer) for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2013. Bars with the same letters are not significantly different at P≤0.05. Significance letters apply within site.

Comparison Summary

Table 2.23 and Table 2.24 provide a summary of the differences in measures previously discussed between the model and sensor approaches for years 2012 and 2013 respectively. From this comparison it is clear the sensor performed better at NEMC12 and NECC12 as it recommended lower N rates, had higher yield, greater profit, and greater NUE. At all other sites, greater N application resulted in greater yield, but lower PFP_N. It is therefore less straightforward which method performed better at the remaining sites.

Table 2.23 Mean differences between model and sensor treatments for N input, yield, profit, AE, and PFP_N for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012.

	2012					
	NE-MC	NE-CC	MO-LT	MO-RO	ND-DN	ND-VC
Model- Sensor						
N-Input (kg ha^{-1})	67	25	36	55	117	151
Yield (kg ha^{-1})	-545	-657	377	--	629	755
Profit ($ ha^{-1})	-181*	-157*	21	--	-8	-15
AE (kg grain increase kg N^{-1})	-10*	-8	-7	--	-8	-3
PFP_N (kg grain kg N^{-1})	-4052*	-2681*	-781*	--	-1227*	-5696*

*Indicates significant difference at P≤0.05.

Table 2.24 Mean differences between model and sensor treatments for N input, yield, profit, AE, and PFP_N for sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2013.

	2013					
	NE-MC	NE-CC	MO-TR	MO-BA	ND-AR	ND-VC
Model- Sensor						
N-Input (kg ha^{-1})	85	82	165	-20	24	-59
Yield (kg ha^{-1})	1377*	81	3528*	-485*	270	-735
Profit ($ ha^{-1})	177*	-74	510*	-73	28	-79
AE (kg grain increase kg N^{-1})	-9*	-11*	-39*	3	2	--
PFP_N (kg grain kg N^{-1})	-2202*	-3010*	-4549*	338*	-2076*	--

*Indicates significant difference at P≤0.05.

Conclusions

Hybrid and plant population in some cases had an impact on NDRE determined from active crop canopy sensing. This indicates that it is desirable for the reference strip used for determination of SI to be of the same hybrid and population as the target crop. The extent of the influence of different NDRE values due to hybrid on the resulting in-season N recommendation was not explored, however in previous studies this difference has been found to be minimal (Sheridan, et al., 2012). Population differences in NDRE were explored and magnitude of deviation in N recommendation due to using reference strips of varying population varied based on site. Higher NDRE values for the reference crop at high population produced lower SI and consequently higher N recommendations and vice-versa. In many cases the differences in N recommendation rate are marginal and would not be of concern. However at some sites the N recommendation difference is great enough that it raises concern. N rate variation would be expected to increase as population differences increased within a field. In this study, the population difference between the target and reference crop was at most 24,710 plants ha^{-1}. The practical significance of these N rate recommendation differences must be evaluated by the producer and considered in accordance with the level of precision recommendation desired. Producers should be aware that using a higher plant population for the reference strip may result in greater N recommendations and a lower plant population for the reference strip may result in lower N recommendations. Those desiring to ensure that N recommendations are not limiting to crop yield should be advised to not use a reference strip of lower plant population than the remainder of the field.

The 2012 growing season was characterized by extremely dry growing conditions and warm temperatures early in the season. These conditions played a large role in Nebraska and Missouri sites. While both Missouri sites were initially strictly dryland, drought conditions led to rescue irrigation attempts at both sites following in-season N fertilization. One site (MORO12) experienced variability in irrigation which led to elimination of yield data from this site. The remaining site, MOLT12 experienced reduced yields due to drought conditions. Nebraska sites were irrigated and therefore did not experience the negative impacts of the drought. High levels of solar radiation early in the growing season contributed to warm temperatures and suspected high N mineralization. This resulted in high yields that were independent of N strategy. The sensor approach appropriately accounted for the additional N available to the crop, thereby reducing N application and improving NUE with no detriment to yield or profit. North Dakota sites experienced uneven stands due to wet field conditions at the time of planting. This led to an overall reduction in plant population.

The 2013 growing season was more favorable for crop production. Rainfall was generally adequate. Large quantities of early season rainfall led to planting being delayed until June 5 at one Missouri site, MOBA13. At the other Missouri site, MOTR13, conditions were excellent for corn production and yields high. This resulted in both model and sensor approaches under-recommending N, and experiencing reduced yield, more substantially so for the sensor approach. A dry period in mid-summer at Nebraska sites was compensated for with irrigation. North Dakota sites experienced below average rainfall during the growing season. Low yields at North Dakota sites were indicative of other limiting factors besides N being present.

Over all site years combined, yield is better protected by using the model-based approach than the sensor-based approach with the Holland and Schepers algorithm. However, due to generally lower in-season N recommendations, the sensor-based approach is generally higher in NUE than the model-based approach. No clear trends in profitability were seen. In an ideal situation, N applications would be reduced without sacrificing yield. This clearly was the case for two Nebraska sites in 2012 where the sensor approach appropriately reduced N application. This demonstrates how the sensor approach is unique in its ability to be responsive to in-season growing conditions. The latest version of the model approach has some ability to do this, as N recommendations account for expected mineralization of N that has occurred in that growing season based on in-season weather up to that point. However, the Maize-N model at current does not have the ability to account for N losses through leaching, denitrification, or volatilization.

Another limitation of Maize-N that could be addressed is the input of residual N available in the soil based on soil testing. At present, this input does not account for the distribution of N in the soil profile. This may have been a problem at NDVC13 where large amounts of residual N were reported resulting in no N being recommended using the model approach. However, at the time of in-season N application, the crop visually appeared deficient in N. This may be explained by residual N being located at soil profile depths below that which the crop roots could access or at low profile depths that were quickly moved out of the root zone. This may be better addressed by the model by accounting for the depth that presumed available N is located in the profile.

A potential problem with the sensor algorithm arises when examining the NDRE value used for the reference crop. At times the NDRE value of the reference crop was lower than that of the target crop. This would indicate that the optimal NDRE value was not always being used. It would be desirable for the sensor treatments to be adjusted such that if higher NDRE values were found in areas of the field, this value would be substituted in as the reference NDRE value. This may be potentially addressed by using the virtual reference concept suggested by Holland and Schepers (2013) which uses the 95-percentile value from a vegetation-index histogram to identify the vegetation index of adequately fertilized plants. Because of the influence of the reference crop in generating a SI and in-season N rate, the N received by the reference crop is of great importance. It is necessary that the reference crop be non-N-limiting. Often the quantity of N applied to create a non-N-limiting strip is left to the grower's discretion and experience. One may want to consider calculating the quantity of N for the non-N-limiting strip by using a standard university developed algorithm for uniform N application. The inputs to the university algorithm could be adjusted such that the yield goal input in the algorithm is 5% greater than the highest expected yield on the field. Another option is to use the Maize-N model for determining the N rate for the non-N-limiting strip. Instead of inputting the average yield of the last five years, the grower may want to input a 5% increase of the greatest yield he or she has historically obtained. This would create greater insurance that adequate N would be available for the reference crop, while hopefully keeping the N rates in a reasonable range such that undue environmental impacts are not incurred. However, it is still possible that N losses may occur to the non-N-limiting strip such that it becomes limiting. If this is suspected it may be necessary that additional N is supplied to the non-N-limiting strip.

It is important to keep in mind the restrictions of both approaches. While both approaches have promise, they are similarly limited in that they cannot predict the effects of weather on crop health and N availability from the time of in-season N application until harvest, therefore N recommendations will be imperfect. For the crop canopy sensor approach, at the time of sensing, N may appear to be adequate in plants; however, this does not indicate if enough N is present in the soil to complete the growing season. Changes such as N losses through leaching, volatilization, or denitrification or additions of N through mineralization that may occur in the remainder of the growing season are not accounted for, as they are not yet expressed in the crop. Nitrogen supply, in some cases, may not be adequate to persist beyond the time of sensing. In-season soil sampling may be beneficial in addressing this, as N supply in the soil can be assessed, providing an estimate of the N that is expected to be available to the crop in the remainder of the growing season. Both the model and sensor approaches have merit and may best be utilized when combined. The model has the ability to provide estimates of attainable yield and a starting point for ONR. This is valuable for the sensor approach as most algorithms for sensor-based N recommendations require either an estimate of expected yield or of ONR.

User convenience of these approaches is also necessary to consider. It should be noted that Maize N requires more up-front information, such as residual N be supplied by the operator. Another significant difference between the two approaches is the easy of making spatially variable recommendations. The sensor approach rapidly incorporates spatial variability into its recommendation, while making spatially variable recommendations with the model is cumbersome and involves manually inputting different variables such as OM, residual N, and soil texture. Both approaches are constrained by the user applying in-season N in a narrow window of time, a condition that may limit adoption where rainfall in the early growing season would prevent in-season N applications from occurring.

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Chapter 3 : A Comparison of Optimum Nitrogen Rate to Applied Nitrogen Rates for Model-based and Sensor-based In-season Recommendation Strategies

Abstract

There is great value in determining the optimum N rate (ONR) and N application timing for corn (*Zea mays* L.). Applying a portion of total N during the growing season allows for adjustments which are responsive to actual field conditions. This study was conducted to compare ONR to two approaches for determining in-season N rates: Maize-N model and active crop canopy sensor with the Holland and Schepers (2010, modified 2012) algorithm. In a 2-yr study, a total of twelve sites were evaluated over a 3-state region, including sites in Missouri, Nebraska, and North Dakota. Treatments included two hybrids and two plant populations at each site. Optimal N rate was determined using a linear-plateau model, considering hybrid and population differences ($P \leq 0.05$) for both the linear and plateau parts of the model. When compared to the ONR, the model-based approach more closely estimated ONR than the sensor-based approach when considering all sites collectively. Overall, the model-based approach erred by over-recommending N, while the sensor-based approach erred by under-recommending N. When N recommended by either approach was greater than the ONR, the model-based approach resulted in greater cost due to excess N. When N was under-recommended, the cost of lost yield was greater for the sensor-based approach. At four sites, the sensor-based approach was less profitable than the model-based approach, and at five sites, the model-based approach was less profitable than the sensor-based approach when compared to profit at ONR. Overall, the cost of lost yield was greater than the cost of excess N, therefore there is a financial incentive for producers to err on the side of over-application of N. Net profit of the sensor-based approach was also lower than net profit of the model-based approach when examining all sites combined (difference of \$388 ha^{-1}). This

result is that the model-based approach may be more attractive to producers as there is a lower risk of profit loss when using the sensor-based N recommendation approach.

Introduction

Nitrogen (N), an essential element, is frequently applied to increase production in crop systems. Plants use N from both indigenous and applied sources. In soil, N exists in many forms, and if not taken up by the crop or immobilized in soil organic nitrogen pools, N can be lost from the cropping system through a variety of pathways (Cassman et al., 2002). These N fertilizer loss pathways include loss from gaseous plant emission, soil denitrification, surface runoff, volatilization, and leaching (Raun and Johnson, 1999; Shanahan et al., 2008). Because of the environmental and economic consequences of N loss, there is great interest in minimizing N losses and improving nitrogen use efficiency (NUE). Overall NUE is concerned with determining the proportion of available N from all sources which is found in plant aboveground biomass. However, NUE is often used more specifically to characterize the recovery of fertilizer N in aboveground crop biomass, rather than recovery of all sources of N (Raun and Johnson, 1999; Shanahan et al., 2008). In order to identify the N recovered due to fertilizer alone, N recovery of an unfertilized check is subtracted out, therefore eliminating the N uptake attributed to residual and mineralized soil N sources. This chapter provides a review of current literature related to factors contributing to low NUE in corn as well as recently proposed methods for improving NUE.

Low NUE has been attributed to several factors including poor synchrony between N fertilizer and crop demand, unaccounted for spatial variability resulting in varying crop N needs, and temporal variance in crop N needs (Shanahan et al., 2008). Each of these factors has the potential to contribute to greater nitrogen losses through the previously discussed N loss pathways. In general, conditions and practices that counter the fundamental N loss pathways (gaseous plant emission, soil denitrification, surface runoff, volatilization, and leaching) will be expected to increase NUE.

Active crop canopy sensors are available to monitor the N status of the crop, allowing growers to make management decisions that are reactive to actual growing season conditions, thereby improving NUE. Sensors can be an effective indicator of in-season crop need as they serve to integrate the conditions and stresses that have already occurred during the early growing season. Crop canopy sensors are designed to detect specific wavelengths of light that are reflected by crop canopies. These wavelengths are then combined to create indices that have been found to be correlated with specific crop conditions of interest. Reflectance values are often expressed in vegetation indices such as the commonly used normalized difference vegetation index (NDVI), which is used frequently to relate the reflectance of the light energy in the visible and infrared bands of light. A positive correlation has been found between chlorophyll levels and NDVI for corn (Reddy et al., 2001). Maximum reflectance in the red region occurs between 660-680 nm and has historically been used to predict chlorophyll content as part of vegetation indices. However, for the red region, saturation occurs at low chlorophyll levels, reducing sensitivity to high chlorophyll contents. The index used for chlorophyll estimation should be one that is maximally sensitive to chlorophyll and is not influenced by other factors. Scharf and Lory (2009) found that the 560 (green) and 710 nm (red edge) wavelengths were among the most sensitive to N stress in leaves. For this reason indices that use these wavelengths would be preferred. The normalized difference red edge (NDRE) index is similar to NDVI, but uses the red edge wavelength in place of the red wavelength.

For sensor information to be useful for calculating optimal N sidedress application rates, algorithms must be developed which will incorporate sensor reflectance measurements. The algorithms require the establishment of an N-rich reference strip within the field, which receives sufficient N application to ensure that N is not limiting (Blackmer et al., 1996; Shanahan et al., 2008). The N-rich reference strip allows sensor data to be normalized, therefore improving correlation by limiting the effects of hybrid, environmental conditions, and diseases (Shanahan et al., 2001). A sufficiency index (SI) is then determined as follows:

$$\mathrm{SI} = \frac{\mathrm{VI_{Sensor}}}{\mathrm{VI_{Reference}}} \tag{3.1}$$

where

VI_{sensor} is the vegetation index (or measurement) for the sensed crop
$VI_{reference}$ is the vegetation index (or measurement) for the N-rich reference crop

Various algorithms have been developed, to relate sensor-derived data to the amount of N needed. Holland and Schepers (2010) developed a generalized N application model that was used with remotely sensed data in this study. This approach is based on the shape of an N fertilizer response function and the relationship between N rate and in-season crop vegetation index data. Rather than using an estimation of yield potential, which is often used with the mass balance approach to nutrient management, the model uses a user inputted ONR or economic optimum N rate (EONR). Consequently, this method relies on the shape of the fertilizer N response function. Yield by fertilizer N rate is typically defined as a linear or quadratic plateau response function. The plateau is where yield becomes insensitive to further increases in N fertilizer additions. This area is defined in the algorithm as Nopt. Nitrogen which was applied pre-plant and other known N credits are then subtracted from Nopt. A compensation factor is included which is based on expected NUE and the plant N uptake that has already occurred at the growth stage when the crop is sensed. Nitrogen uptake is determined based on the previously determined relationship between corn growth stage and relative N uptake. The resulting value is multiplied by the SI portion of the model. The user can choose which vegetation index they prefer to use to calculate the SI, as discussed previously. This study used the NDRE index as it includes wavelengths that have been previously found to be more sensitive to chlorophyll content of the plant (Scharf and Lory, 2009). The SI portion of the model essentially predicts the response that can occur due to N fertilizer application based on the relationship between SI and N rate. Therefore, the SI of the sensed crop is used to predict the response of the target crop compared to non-limiting crops. Additionally, there is an optional and adjustable cutoff feature which accounts for the fact that at some point, plant stress is so great that recovery is not likely, even with large N applications. The final form of the equation is as follows:

$$N_{APP} = (MZ_i \times N_{OPT} - N_{PreFert} - N_{CRD} + N_{COMP}) \times \sqrt{\frac{(1 - SI)}{\Delta SI}} \tag{3.2}$$

where

N_{APP} = N rate to be applied
MZ_i = optional management zone scalar based on historical yield or soil sample information
N_{OPT} = EONR or the maximum N rate prescribed by producers
$N_{PreFert}$ = sum of fertilizer N applied before crop sensing and/or in-season N application
N_{CRD} = N credit for the previous season's crop, nitrate in water, or manure application
N_{COMP} = N in excess of N_{OPT} required by the crop under soil-limiting conditions at a given growth stage
SI = Sufficiency index
ΔSI = Difference between where SI equals 1.0 and the point where the response curve intersects the y axis (mathematically, 1-SI(0))

Simulation models have also been identified as a precision management technique which has potential to maximize the synchrony of crop demand for N and fertilizer N supply thereby having potential to increase NUE (Cassman et al., 2002). Models are a method of N management which account for the interactions between management and environmental conditions. The Maize-N model was developed to estimate economically optimum N fertilizer rates for maize by taking into account soil properties, indigenous soil N supply, local climatic conditions and yield potential, crop rotation, tillage and fertilizer formulation, application method and timing (Setiyono, et al., 2011). The model was validated in experiments in central Nebraska, eastern South Dakota, and western Nebraska and included both irrigated and rainfed systems. The EONR simulated by Maize-N was relatively robust across the different sites. Maize-N is based on relationships that govern N availability and crop demand, and therefore it is speculated that these relationships would hold across many locations and environments. When compared with existing algorithms for determining N from the University of Nebraska-Lincoln, South Dakota State University, Kansas State University, and the University of Missouri, the Maize-N model estimated the EONR with greater accuracy (Setiyono, et al., 2011).

The objective of this study was to i) compare the estimated ONR for each site to in-season N rates generated by these two technologies: Maize-N model and sensor reflectance data with the Holland and Schepers algorithm and ii) compare the profitability of these two technologies relative to profitability for the estimated ONR.

Materials and Methods

Experimental Locations and Treatments

The research was carried out at sites in Nebraska, Missouri, and North Dakota over the 2012 and 2013 growing seasons for a total of 12 site-years (Figure 3.1). Each experimental site contained four replications of 16 treatments arranged in a randomized complete block design. The soil types and previously planted crops varied by location. Site characteristics are provided in Table 3.1. Two hybrids were selected for each site, and each hybrid was planted at high and low seeding rates. Hybrids and seeding rates for each site are shown in

Table 3.2. Additionally, there were four N treatments: unfertilized check, N-rich reference, sensor-based, and model-based. The unfertilized check received no nitrogen during the study. The N-rich reference received N at a rate considered to be non-limiting to yield for the site. The N-rich rate was 280 kg ha^{-1} for Missouri sites, 224 kg ha^{-1} for North Dakota sites, and ranged from 268 to 280 kg ha^{-1} for Nebraska sites. The sensor-based and model-based treatments received an initial N rate and an in-season N rate. The initial N rate for sensor-based and model-based treatments was 56 kg ha^{-1} for Missouri sites, 0 kg ha^{-1} for North Dakota sites, and 84 kg ha^{-1} for Nebraska sites. In-season N application for sensor-based and model-based treatments was determined using a crop canopy sensor and corresponding algorithm for the sensor-based treatments, and a model for the model-based treatments.

Figure 3.1 Approximate locations of research sites in eastern North Dakota, central Nebraska, and central Missouri in 2013 are indicated by red dot. Locations for 2012 are close in proximity to those shown for 2013.

Table 3.1 Characteristics of experimental locations including site yield potential, soil texture, predominant soil subgroup, and previous crop.

Year	State	Site ID	Site Yield Potential	Soil Texture†	Predominant soil subgroup	Previous Crop
2012	**Missouri**	**MORO12**	High	SiL	Fluventic Eutrudepts	Soybeans
		MOLT12	Moderate	SiL	Vertic Epiaqualfs	Soybeans
	Nebraska	**NECC12**	High	SiL	Pachic Udertic Argiustolls	Corn
		NEMC12	Moderate	SL	Cumulic Haplustolls	Corn
	North Dakota	**NDDN12**	High	SiCL	Typic Epiaquerts	Corn
		NDVC12	Moderate	L	Calcic Hapludolls	Wheat
2013	**Missouri**	**MOTR13**	High	SiL	Fluventic Hapludolls	Soybeans
		MOBA13	Moderate	SiL	Vertic Epiaqualfs	Soybeans
	Nebraska	**NECC13**	High	SiL	Udic Argiustolls	Soybeans
		NEMC13	Moderate	SL	Oxyaquic Haplustolls	Corn
	North Dakota	**NDAR13**	High	SiLC	Typic Epiaquerts	Soybeans
		NDVC13	Moderate	L	Calcic and Pachic Hapludolls	Wheat

†SiL, silt loam; SL, sandy loam; SiCL, silty clay loam; L, loam

Table 3.2 Corn hybrid and planting population for evaluation of in-season N application using Maize-N model or crop canopy sensor at sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013.

Field ID	Hybrid		Planting Population seeds ha^{-1}	
	A	*B*	*Low Rate*	*High Rate*
MORO12	Pioneer 33D49	Pioneer 1498	76,601	101,311
MOLT12	Pioneer 33D49	Pioneer 1498	76,601	101,311
MOTR13	Pioneer 33D49	Pioneer 1498	76,601	101,311
MOBA13	Pioneer 33D49	Pioneer 1498	76,601	101,311
NDDN12	Pioneer 39N99	Pioneer 8906 HR	79,072	103,782
NDVC12	Pioneer 39N99	Pioneer 8906 HR	79,072	103,782
NDAR13	Pioneer 39N95 AM	Pioneer 8906 HR	79,072	103,782
NDVC13	Pioneer 39N95 AM	Pioneer 8906 HR	79,072	103,782
NECC12	Pioneer 33D49	Pioneer 1498	79,072	103,782
NEMC12	Pioneer 33D49	Pioneer 1498	79,072	103,782
NECC13	Pioneer 33D53 AM	Pioneer 1498 AM	79,072	103,782
NEMC13	Pioneer 33D53 AM	Pioneer 1498 AM	79,072	103,782

The model-based treatments used the Maize-N: Nitrogen Recommendation for Maize (Yang et al., University of Nebraska – Lincoln, 2008) software. This model incorporates various user inputted soil properties, agronomic practices, and local weather data to produce an EONR recommendation. Version 2008.1.0, used for the 2012 growing season, did not have the capability to take into account weather that had occurred in that growing season to determine mineralized N. For 2013, Version 2013.2.0 was used. This version has updates to allow the model to utilize current weather data in order to estimate the amount of mineralization of N that had occurred since the last crop. The long-term weather data is then used to predict mineralization of N for the remainder of the season, based off historical trends. Separate iterations of the model were run for each hybrid and planting population at each site. Consequently, up to four unique in-season N recommendations may be returned for each site. Input values and output for Maize-N are provided for each site in Appendix B. Nitrogen was applied to the model-based treatments in accordance with the recommendation produced by the model.

The sensor-based treatments used crop canopy reflectance data collected using a RapidSCAN CS-45 Handheld Crop Sensor (Holland Scientific, Lincoln, NE). The sensor utilizes a modulated light source and three photodetector channels centered around the 670 nm, 730nm, and 780 nm wavelengths. Normalized difference red edge index (Equation 3.3) was calculated for each plot by scanning the reflectance for the center two rows and averaging the reflectance values obtained.

$$\mathrm{NDRE} = \frac{\mathrm{R_{NIR}} - \mathrm{R_{RED\ EDGE}}}{\mathrm{R_{NIR}} + R_{\mathrm{RED\ EDGE}}} \qquad (3.3)$$

where

R_{NIR} = near-infrared reflectance (780 nm)

$R_{RED\ EDGE}$ = red edge reflectance (730 nm)

The SI was calculated by dividing the NDRE of the sensor-based crop by the NDRE of the N-rich reference treatment which had corresponding hybrids and plant populations for each replication.

The Holland and Schepers modified sensor algorithm (2010, modified 2012) was used to determine the N application rate. This algorithm uses SI, crop growth stage, amount of N fertilizer already applied to the sensed crop, and user defined ONR. The ONR was determined by using the algorithm developed by the University of Nebraska-Lincoln for producers in Nebraska applying a uniform N rate (Shapiro et al., 2003) (Equation 3.4).

$$N\ need\ (lb\ ac^{-1}) =$$

$$35 + (1.2 * EY) - (8 * NO_3\text{-}N\ ppm) - (0.14 * EY * OM) - other\ credits \quad (3.4)$$

where

N need = Nitrogen to apply in lb ac^{-1}
EY = Expected yield for the field
NO_3-N ppm = Residual nitrate in soil
OM = Organic matter in soil
Other credits = sources of N from legume crops, manure, and nitrate in irrigation water

For two North Dakota site years, the North Dakota N recommendation algorithm (Equation 3.5) was substituted for the University of Nebraska-Lincoln N recommendation algorithm.

$$N\ need\ (lb\ ac^{-1}) = (EY\ *\ 1.1) - NO_3\text{-}N\ ppm - soy\ credit \qquad (3.5)$$

where

N need = Nitrogen to apply in lb ac^{-1}
EY = Expected yield for the field
NO_3-N ppm = Residual nitrate in soil
Soy credit = 40 if soybeans were grown the previous season

Of the six sites where the previous crop was soybeans (MORO12, MOLT12, MOTR13, MOBA13, NECC13, and NDAR13) a soybean credit was only subtracted from three sites. Sites from which a soybean credit were removed and sites which used the North Dakota N recommendation algorithm in place of the University of Nebraska – Lincoln algorithm are noted in Table 3.3. The expected yield (EY) required for both university algorithms was generated using Maize-N: Nitrogen Recommendation for Maize with the same inputs as were used in the model-based treatments (Yang et al., University of Nebraska – Lincoln, 2008).

Table 3.3 Calculation of optimum N rate, using university N recommendations for use in the Holland and Schepers sensor algorithm for sensor-based treatments for sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013.

Field ID	Algorithm calculation for optimum N rate lb N ac^{-1} from algorithm results	Optimum N rate kg ha^{-1}
MORO12	[35 + (1.2 x 178) – (8 x 5.6) – (0.14 x 178 x 1.5)] = 166	186
MOLT12	[35 + (1.2 x 158) – (8 x 5.3) – (0.14 x 158 x 2.6)] = 125	140
MOTR13‡	[35 + (1.2 x 220) – (8 x 2.8) – (0.14 x 220 x 1.9) - 45] = 173	194
MOBA13‡	[35 + (1.2 x 147) – (8 x 2.8) – (0.14 x 147 x 1.9) - 20] = 130	146
NDDN12	[35 + (1.2 x 168) – (8 x 6.25) – (0.14 x 168 x 3)] = 116	130
NDVC12	[35 + (1.2 x 152) – (8 x 10.1) – (0.14 x 152 x 3)] = 73	81
NDAR13†‡	(158 * 1.1) – 40 – 66 = 68	76
NDVC13†	(147 * 1.1) – 113 = 49	55
NECC12	[35 + (1.2 x 231) – (8 x 18.29) – (0.14 x 231 x 3)] = 69	77
NEMC12	[35 + (1.2 x 189) – (8 x 9.34) – (0.14 x 189 x 1.65)] = 143	160
NECC13	[35 + (1.2 x 231) – (8 x 3.75) – (0.14 x 231 x 2.8)] = 192	215
NEMC13	[35 + (1.2 x 210) – (8 x 8.88) – (0.14 x 210 x 2.1)] = 154	173

† Indicates site years where the North Dakota N recommendation algorithm was used in place of the University of Nebraska-Lincoln N recommendation algorithm.
‡ Indicates site years where a soybean credit was subtracted.

Sufficiency index values for each plot having a sensor-based treatment went into the Holland and Schepers sensor algorithm to produce the in-season N rate recommendation. Inputs other than SI for the Holland and Schepers algorithm are provided in Table 3.4. Because in-season N application recommendations involved unique SI values for each plot, up to 16 in-season recommendations may be returned for each site. Nitrogen was applied to sensor-based treatments in accordance with recommendations from the Holland and Schepers sensor algorithm.

Table 3.4 Scanning date for sensor-based treatments and inputs for the Holland and Schepers sensor algorithm including: growth stage, initial N fertilizer amount, and optimum N rate for sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013.

		-------Inputs for Holland and Schepers algorithm-------		
Field ID	Scanning Date	Growth Stage	Initial N Fertilizer **kg ha^{-1}**	Optimum N Rate **kg ha^{-1}**
MORO12	June 30, 2012	V10	56	186
MOLT12	June 29, 2012	V11	56	140
MOTR13	June 28, 2013	V10	56	194
MOBA13	July 16, 2013	V9	56	146
NDDN12	July 2, 2012	V9	0	130
NDVC12	July 2, 2012	V10	0	81
NDAR13	July 3, 2013	V8	0	76
NDVC13	July 3, 2013	V8	0	55
NECC12	June 26, 2012	V10	84	77
NEMC12	June 26, 2012	V9	84	160
NECC13	June 28, 2013	V9	84	215
NEMC13	June 28, 2013	V8	84	173

Upon physiological maturity, corn from all plots was harvested. In 2012, Nebraska and North Dakota plots were hand harvested and Missouri plots were machine harvested. In 2013, North Dakota plots were hand harvested and Missouri and Nebraska plots were machine harvested. The total N rate applied by either the model-based or sensor-based treatment was compared to the estimated ONR to determine how these two in-season N recommendations strategies compared.

Estimating Optimum N Rate

In order to compare the sensor-based and model-based approaches to the ONR, an estimation of the ONR for each site-year studied was needed. A number of models have been used to describe the response of corn yield to N fertilizer and therefore can be used to estimate ONR. Cerrato and Blackmer, 1990 compared various models that are often used to describe the corn yield response to N fertilizer relationship. 12 site-years of yield trials were conducted with 10 N rates each. The linear-plateau and quadratic-plateau model both fit yield data equally well when evaluated with the R^2 statistic. Additionally, maximum yield predicted by both the linear-plateau and quadratic-plateau models was similar. Differences arise when comparing predicted EONR for these two models. The linear-plateau approach generally predicted lower economic optimum rates of fertilization than the quadratic-plateau model. It was also noted that with the linear-plateau model, the economic optimum rate of fertilization is independent of the fertilizer-to-corn price ratio. Therefore, at higher price ratios the EONR for the linear-plateau approach shifts closer to the EONR of the quadratic-plateau approach. Furthermore, it is noted that the linear-plateau model has a tendency to overestimate yields in the portion of the response curve close to the EONR. This overestimation of yield therefore results in identification of EONR that are too low. For this study we chose to use the linear-plateau approach as we had a limited number of N rates with which to build the response function. Therefore, unique linear-plateau response curves representing yield as a function of N rate were derived using the N rates and corresponding yields for each site in the study.

The high N reference was assumed non-limiting for N and thus used to generate the plateau portion of the response relationship. Tests of statistical differences ($\alpha = 0.05$) due to plant population and hybrid for the high N reference treatments were determined using the GLM procedure in SAS 9.2 (SAS Institute Inc., Cary, NC). If a significant difference occurred for plant population or hybrid, then individual means for these treatments were used to create separate plateaus, to reflect the different mean values. If no statistically significant differences were found for plant population or hybrid for the high N reference, the overall mean of the high N reference was used to determine the plateau value. For the linear part of the linear-plateau relationship, the N check (no N) and the sensor-based and model-based treatment results were used. The yield of the N check, established the linear model intercept. The model-based and sensor-based N rate and yields were utilized to determine the slope of the function. A SAS stepwise linear regression ($\alpha = 0.05$) was used to test for significant intercept and slope differences, as impacted by plant population and/or hybrid treatments (Appendix C). The procedure allowed for unique linear models to be generated when significant differences occurred with no N and/or with N additions. Optimum N rate for all unique combinations of the linear-plateau models was determined by solving for the joint of the linear-plateau model, as follows:

$$ONR = (plateau - a)/b \tag{3.6}$$

where: a = the linear regression intercept
b = the linear regression slope

The ONR was then compared graphically to actual N applied for both the model-based and sensor-based treatments, to examine which treatment was best at predicting ONR.

Data Analysis Methods

For both the model and sensor N recommendation approaches, a linear regression analysis was performed using the REG procedure in SAS 9.2 (SAS Institute Inc., Cary, NC). The intercept was suppressed from the model statement so that it would be set to 0. R^2 values shown are the adjusted R^2.

Results and Discussion

The ONR values derived using the linear-plateau model are provided for each site in Table 3.5. Where significant differences due to plant population and/or hybrid occurred, ONR was adjusted accordingly. For three sites, MORO12, NDVC12, and NECC12, the ONR was 0 for all treatment combinations (i.e., drought suppressed N fertilizer response), therefore these were not included in the analysis.

Table 3.5 ONR values derived using the linear-plateau model for each site in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013. Where significant differences in hybrid and plant population treatments occurred, unique linear-plateau models were derived resulting in unique ONR values as shown. For three sites, ONR estimated by the linear-plateau model was 0 for all hybrid and plant population combinations, therefore no ONR value is reported for these sites.

	Hybrid A		Hybrid B	
	Low Population	**High Population**	**Low Population**	**High Population**
		ONR --------------------*kg ha^{-1}*--------------------		
MORO12	--	--	--	--
MOLT12	141	73	141	73
MOTR13	245	279	245	279
MOBA13	162	124	162	124
NDDN12	0	0	225	225
NDVC12	0	0	253	253
NDAR13	45	45	45	45
NDVC13	--	--	--	--
NECC12	--	--	--	--
NEMC12	0	0	132	132
NECC13	184	234	138	176
NEMC13	172	172	215	215

Using the linear-plateau estimated ONR, the total N applied by both the model-based and sensor-based treatment approaches can be compared. Figure 3.2 illustrates the relationship between the estimated ONR and the total N rate actually applied. The diagonal line represents the location on the graph where total N applied matches the linear-plateau estimated ONR calculated or y=1x. Points falling below this line are sites where the total N applied was in excess of the optimum, and points falling above this line are sites where the total N applied was less than the optimum. Points at a greater distance from the line indicate further variation from the estimated ONR.

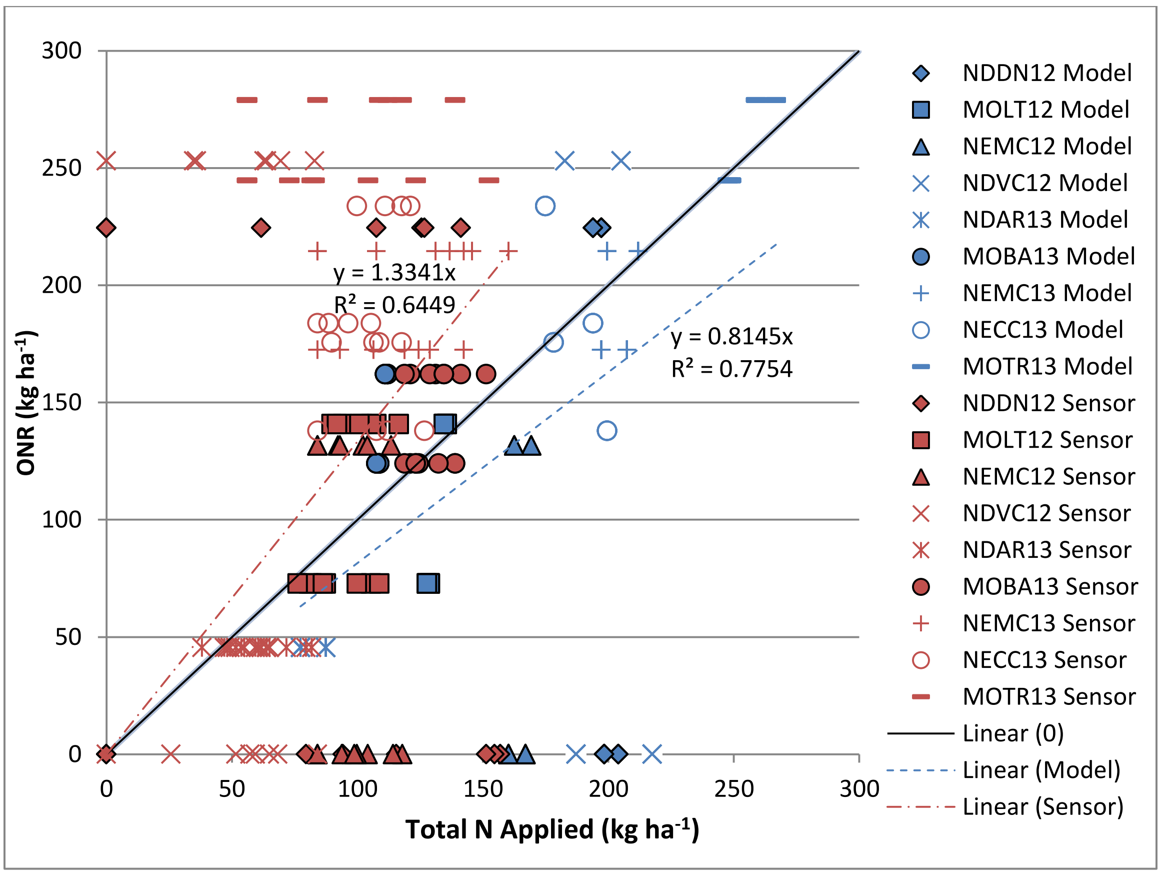

Figure 3.2 ONR derived from linear-plateau model compared to total N applied using model-based approach (blue symbols) and sensor-based approach (red symbols) for sites in Missouri (MO), Nebraska (NE), and North Dakota (ND) where for at least some combination of hybrid and plant population estimated ONR was greater than 0.

When examining the results of this analysis it should be noted that where ONR seeks to determine the N rate needed for maximum yield, EONR seeks to determine the optimum economic N rate, therefore N recommendations of ONR are typically higher than N recommendations for EONR. The sensor-based N recommendation did not include an economic component; therefore the approach would be considered a recommendation of the ONR. In contrast, the Maize-N model requires the input of corn and fertilizer prices, therefore estimating the EONR rather than the ONR. However, changing the input values for economic factors in the model resulted in little to no change in the EONR generated. This is likely due to the EONR being nearly equal to the ONR. For this reason, little discrepancy is anticipated due to comparing ONR versus EONR for the two approaches.

When comparing the model-based and sensor-based approaches, more deviation from the linear-plateau estimated ONR is seen for the sensor-based treatments. This is evidenced by the lower coefficient of determination for the sensor-based approach. For many locations, the sensor-based approach recommended N applications that were much lower than the linear-plateau estimated ONR, resulting in an under application of N and consequential yield loss. Of particular interest are the sites where the sensor-based or model-based approach for N application deviated most strongly from the linear-plateau estimated ONR. In particular, sites NDDN12, NDVC12, MOTR13, and NEMC12 will be examined as they have data points further from the ideal line where linear-plateau estimated ONR is equal to N applied.

Both North Dakota sites in 2012 experienced poor plant stands which likely influenced sensor readings. Estimated ONR derived from the linear-plateau model for sites NDDN12 and NDVC12 were 0 kg N ha^{-1} for hybrid A and 224.5 and 253 kg N ha^{-1} for hybrid B respectively (Table 3.5). From an agronomic perspective this is difficult to accept. It is unlikely that the N requirements for these two hybrids varied that vastly. It is possible that differences in plant stand between the two hybrids would result in a large difference in N need, however, this scenario is unlikely. Stand counts taken for both sites prior to in-season fertilization were largely the same between the hybrids. Therefore it is likely that the estimation of ONR for these sites was inaccurate. This may be in part due to lack of a range of N rates with which to construct the linear plateau. This discrepancy in estimated ONR for sites NDDN12 and NDVC12 accounts for some of the outliers seen in Figure 3.2.

Another source of variation from the linear-plateau estimated ONR is due to lower N recommendations with the sensor approach for site MOTR13 where estimated ONR ranged from 245 to 279 kg N ha^{-1}. MOTR13 was a high yielding site, where yields for the N-rich reference treatment averaged 16 Mg ha^{-1}. An initial N application of 56 kg ha^{-1} was applied to model-based and sensor-based treatments. At the time of in-season application (V10 growth stage), the SI generated by the sensor was greater than 1 for five of the 16 sites, resulting in no N recommendation for those plots. Similarly, seven other plots had SI values above 0.95 as seen in Table 3.6. These high SI values indicate that N stress was not yet apparent in the sensed treatments at the V10 growth stage, as they had NDRE values very similar to the NDRE values of the N-rich reference treatments. However, it is evident that at some point between V10 and crop maturity, N supply to the sensor-based treatments became limiting. Because of this, the sensor-based approach had significantly reduced yields compared to the N-rich reference and model-based treatments ($\alpha = 0.05$) (Table 3.7). A similar incident was noted by Kitchen, et al., (2010). Corn sensed at the V8-V11 growth stage appeared to have sufficient N, however adequate N was not present to meet the crop N need for the full growing season. On the other hand, the model in-season N recommendations ranged from 192 and 211 kg N ha^{-1} (Table 3.6). This N rate still led to a significant reduction in yield compared to the non-N-limiting reference, however, model treatment yields were significantly greater than sensor treatment yields. This would indicate that when N needs are greater than anticipated the sensor does not perform well. This is potentially due to the approach used by the sensor-based N recommendation algorithm which requires the user to provide the ONR which sets the ceiling for N recommendations. If the ONR set by the producer is too low, as in this case, the sensor may severely under-estimate N need. The ONR set for this site was based on a yield goal of 13.8 Mg ha^{-1}; however the sensor treatments only averaged 11.6 Mg ha^{-1}.

Table 3.6 Sufficiency index generated from NDRE collected using the crop canopy sensor and in-season N recommendation generated using the Holland and Schepers algorithm for sensor-based treatments arranged by hybrid and plant population for a Missouri site in 2013 (MOTR13).

	MOTR13			
	Hybrid A		**Hybrid B**	
	Low Population	High Population	Low Population	High Population
	--------------------***Sufficiency Index***--------------------			
Rep 1	0.936	0.954	0.989	0.988
Rep 2	0.990	1.001	1.041	0.907
Rep 3	1.004	1.016	0.965	1.011
Rep 4	0.996	0.944	0.877	0.958
	-------------------***Sensor In-season N recommendation***------------------ *kg ha^{-1}*			
Rep 1	67	56	27	28
Rep 2	26	0	0	83
Rep 3	0	0	48	0
Rep 4	17	62	96	53
	------------------***Model In-season N recommendation***------------------ *kg N ha^{-1}*			
All Reps	192	203	193	211

Table 3.7 Yield and significance for N strategies at a Missouri site in 2013 (MOTR13). Means followed by the same letter are not significantly different at P≤0.05.

MOTR13		
N Strategy	**Yield**	
	Mg ha^{-1}	
Unfertilized check	5.1	d
N- rich reference	16.0	a
Model-based	15.1	b
Sensor-based	11.6	c

Additionally, at site NEMC12, some model based treatments produced over-application of N where the estimated ONR was 0 kg N ha^{-1}. At this location estimated ONR was 0 and 132 kg N ha^{-1} for hybrid A and B, respectively. While it is again unlikely that the linear-plateau estimated ONR actually varied this much based on hybrid, the variation is not as extreme as for previously discussed North Dakota sites. At this site, weather conditions were warm and moist due to irrigation resulting in unexpectedly high presumed levels of N mineralization. Both the sensor and the model approaches recommended N where the ONR was estimated to be 0 kg ha^{-1}, however, the model estimated more N than the sensor therefore leading to greater over-application of N.

It is important to note that conditions which occur between the time of in-season application and harvest cannot be accounted for using either the model or sensor approach. For this reason, outliers which are due to extreme conditions occurring after in-season application should not be considered when seeking to quantify the accuracy of the model or sensor approach in predicting ONR.

It is of interest to determine the cost of additional N over that of the linear-plateau estimated ONR. Where sensor-based and model-based N applications were greater than the estimated ONR, the difference in N cost was calculated using a fertilizer N price of \$1.10 kg^{-1} (Figure 3.3). For all but one site (MOBA13) the model-based approach resulted in a greater cost due to excess N than the sensor-based approach. This is expected as the sensor approach more frequently erred on the side of under-application of N therefore there are less instances of excess N application. Over all the sites combined, the average cost per site of excess N was \$48 ha^{-1} more for the model approach than for the sensor approach. It is also of interest to determine the cost of lost yield when N application was less than the linear-plateau estimated ONR. This was calculated by first determining the difference between the yield at linear-plateau derived ONR and yield from model-based and sensor-based treatments when N application was less than the linear-plateau derived ONR. The cost of the yield difference was then calculated based on a corn grain price of \$0.20 kg^{-1} (Figure 3.4). The cost of lost yield was greater for the sensor-based treatments than the model-based treatments at five of the nine sites. This is expected as the sensor approach erred on the side of under-application of N and would therefore be more likely to experience yield loss than the model approach. Over all the sites combined, the average cost of lost yield per site was \$142 ha^{-1} greater for the sensor approach versus the model approach. The difference in magnitude of the cost of excess N versus the cost of lost yield is of interest. It is apparent that the cost of lost yield is greater than the cost of excess N. This indicates there is a financial incentive for producers to err on the side of over-application of N.

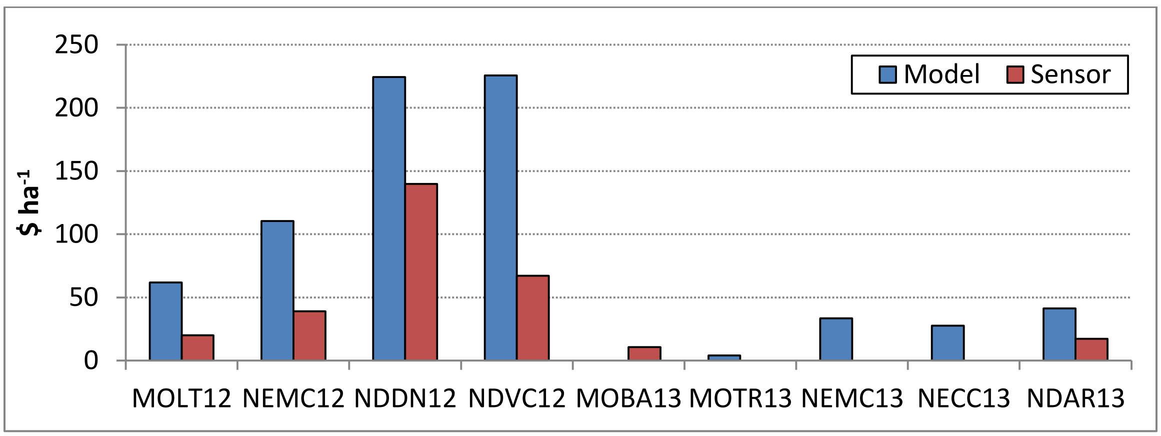

Figure 3.3 Cost of excess N where N application was greater than ONR derived using the linear-plateau model for sites in Missouri (MO), Nebraska (NE), and North Dakota (ND) in 2012 and 2013. Cost calculated using an N fertilizer price of \$1.10 kg^{-1} N.

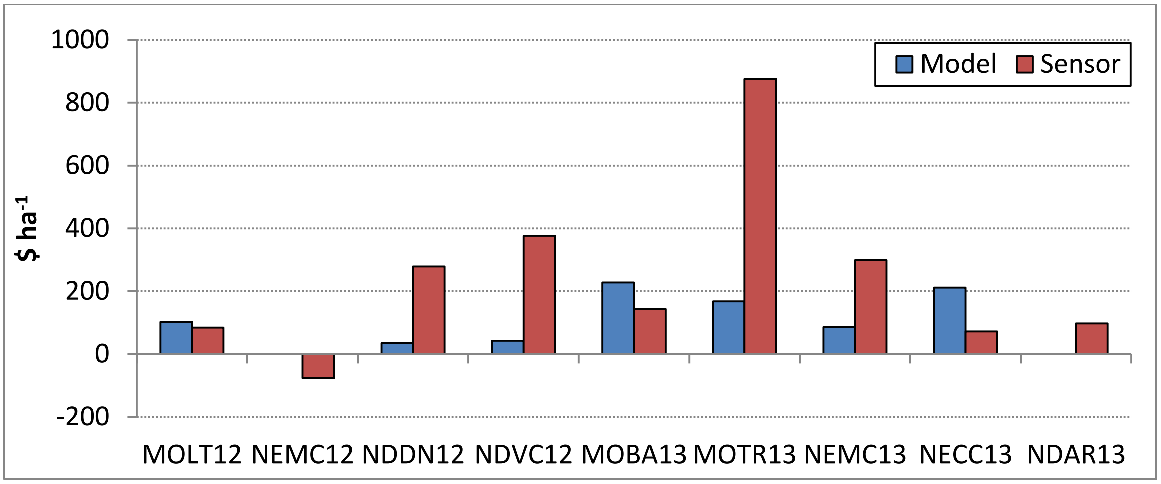

Figure 3.4 Cost of lost yield where N application was less than ONR derived using the linear-plateau model for sites in Missouri (MO), Nebraska (NE), and North Dakota (ND) in 2012 and 2013. Cost of yield calculated using a grain price of \$0.20 kg^{-1}.

Profit of the model-based and sensor-based approaches was calculated and compared to the profit that would be expected if N rate and yield was the optimum calculated. A grain price of \$0.20 kg^{-1} and fertilizer N price of \$1.10 kg^{-1} was used. Results are shown in Figure 3.5. Profitability of the model-based and sensor-based approaches was lower than profitability of estimated ONR in most cases. At four sites, the sensor-based approach was less profitable than the model-based approach, and at five sites, the model-based approach was less profitable than the sensor-based approach. The magnitude of profit lost using the sensor approach at MOTR13 is much greater than for any other site of either approach. Over all the sites combined, on average, the sensor approach achieved \$43 ha^{-1} less profit compared to the model approach. Therefore, when considering cost of excess N, cost of lost yield, and net profit loss together for all sites, the model approach produces a more favorable financial outcome.

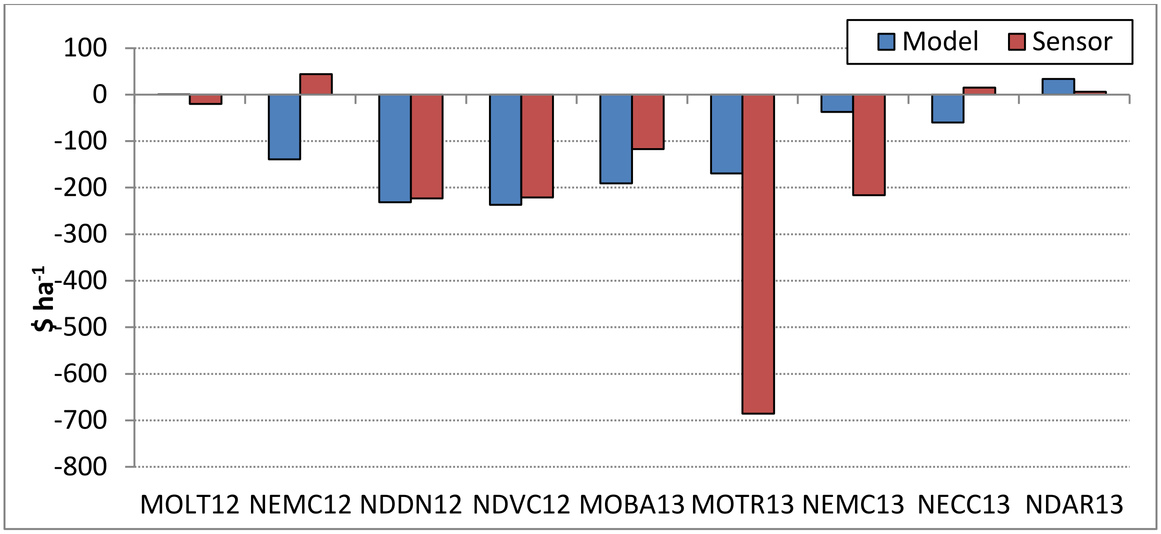

Figure 3.5 Change in net profit for model and sensor based approaches when compared to profit calculated using ONR derived using the linear-plateau model and yield at ONR for sites in Missouri (MO), Nebraska (NE), and North Dakota (ND) in 2012 and 2013. Grain price of \$0.20 kg^{-1} and fertilizer N price of \$1.10 kg^{-1} N was used for profit comparison.

Conclusion

The model-based approach more closely estimated the linear-plateau derived ONR than the sensor-based approach when examining all sites collectively. Additionally, the model-approach recommended N rates that erred on the side of over-application of N, resulting in fewer sites where yield was negatively impacted. For this reason, the model-based approach may be preferable to producers as yield is better protected. However, there are negative environmental implications of over-application of N that cannot be ignored.

When N recommended by the model and sensor approaches was greater than the linear-plateau derived ONR, the model-based approach resulted in greater cost due to excess N, totaling \$435 ha^{-1} more than the cost of excess N for the sensor-based approach for all sites combined. The cost of lost yield when N recommended by the model and sensor approaches was less than the linear-plateau derived ONR was \$1277 ha^{-1} greater for the sensor-based approach than the model-based approach when considering all sites together. Because the overall cost of lost yield is greater than the cost of excess N, there is a financial incentive for producers to err on the side of over-application of N. When comparing net profit of the model-based and sensor-based approaches to profit of the linear-plateau estimated ONR, the sensor-based approach was less profitable than the model-based approach at four sites, and the model-based approach was less profitable than the sensor-based approach at five sites. However, when considering all sites together, the sensor-based approach resulted in a loss of \$388 ha^{-1} more than the model approach. Therefore, when considering cost of excess N, cost of lost yield, and net profit loss together for all sites, the model approach may be more attractive to producers as there is lower risk of losing profit. The N rate recommendation algorithm used with the sensor data in this study was the Holland and Schepers algorithm. The sensor algorithm used for determining the in-season N application rate for the sensor-based approach largely influences the performance. Other algorithms would likely result in differing in-season N recommendations and therefore would be expected to vary in performance.

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Chapter 4 : A Comparison of Sensor-Based Nitrogen Recommendation Algorithms

Abstract

Applying a portion of total N during the growing season allows for adjustments which are responsive to actual field conditions. Various algorithms have been developed to relate active crop canopy sensor reflectance values to recommended N rates for in-season applications in corn (*Zea mays* L.). This study was conducted to compare and evaluate N rates recommended by three sensor-based algorithms (Holland and Schepers, 2012, Vetsch and Randall, 2014, and Missouri USDA-NRCS 2009) and a simulation model (Maize-N). In a 2-yr study, a total of twelve sites were evaluated over a 3-state region, including sites in Missouri, Nebraska, and North Dakota. Treatments included two hybrids and two plant populations at each site. The Maize-N model and Missouri USDA-NRCS algorithm recommended the highest application rates. Mean N rates for the sensor-based algorithms ranged from 63 kg ha^{-1} for Vetsch and Randall to 155 kg ha^{-1} for Missouri USDA-NRCS. When considering data from all sites collectively, the Maize-N model recommendations most closely approximated the ONR (y=0.8145x) and erred by over-recommending N (mean ONR=138 kg N ha^{-1}; mean Maize-N recommendation=170 kg N ha^{-1}). The Missouri USDA-NRCS algorithm had the closest approximation of ONR of the three sensor-based algorithms, with data fitting at y=0.7887x and also erred by over-recommending N. When considering sites based on state, the Missouri algorithm most closely approximated the ONR at Nebraska and Missouri sites. At North Dakota sites all algorithms had low coefficients of determination. The variation in recommended N rates and approximation of ONR highlights the importance of considering the algorithm used with crop canopy sensor data.

Introduction

Low nitrogen use efficiency (NUE) has been attributed to several factors including poor synchrony between N fertilizer and crop demand, unaccounted for spatial variability resulting in varying crop N needs, and temporal variances in crop N needs (Shanahan et al., 2008). It is estimated that 75% of N fertilizer is applied prior to planting (Cassman et al., 2002), which results in high levels of inorganic N, such as nitrate, in the soil before the stage of rapid crop uptake occurs. Because of this, improvements in NUE can be achieved by attaining greater synchrony between the crop N need and the N which is available to the plant from all sources throughout the growing season (Cassman et al., 2002). Applying a portion of the N fertilizer alongside the growing crop allows fertilizer availability to coincide more closely with the time in which the crop needs the most nitrogen and is expected to increase NUE. Spatial variability of soil properties presents further challenges to N management. Nitrogen supplying capacity can vary throughout a field. Research by Mamo et al. (2003), showed that N mineralization of organic matter (OM) varied spatially within a field. Mineralization of N is also dependent on soil water and temperature which vary with landscape position; therefore OM content should not be used as a sole criterion when delineating N management zones (Schmidt et al., 2002). Consequently, the N fertilizer need can vary spatially across a field. Managing nitrogen application based on spatial variability has been found to reduce the overall N rate applied and increase profitability when compared with a uniform N application (Mamo et al., 2003). Variable rate application of N decreases the risk of overfertilization and underfertilization, as can occur with uniform applications. In addition to the spatial variability component of N management, temporal variations in N response and N mineralization related to environmental factors have also been observed (Mamo et al., 2003). Climate and management interactions cause tremendous year-to-year variation in both crop N requirements and crop yields (Cassman et al., 2002). Together, spatial and temporal variation creates uncertainty as to the optimal N fertilizer quantity for any given year (Roberts et al., 2010). Determining the amount and timing of N needed by the crop over a spatially diverse field is critical for improving NUE.

Strategies which detect crop N status at early growth stages have been suggested as a method to improve NUE (Ferguson, et al., 2002). Active crop canopy can monitor the N status of the crop, allowing growers to make management decisions that are reactive to actual growing season conditions. Sensors can be an effective indicator of in-season crop need as they serve to integrate the conditions and stresses that have already occurred during the early growing season. Crop canopy sensors are designed to detect specific wavelengths of light that are reflected by crop canopies. These wavelengths are then combined to create indices that have been found to be correlated with specific crop conditions of interest. Reflectance values are often expressed in vegetation indices such as the commonly used normalized difference vegetation index (NDVI), which is used frequently to relate the reflectance of the light energy in the visible and infrared bands of light. A positive correlation has been found between chlorophyll levels and NDVI for corn (Reddy et al., 2001). Maximum reflectance in the red region occurs between 660-680 nm and has been used to predict chlorophyll content as part of vegetation indices. However, for the red region, saturation occurs at low chlorophyll levels, reducing sensitivity to high chlorophyll contents. The index used for chlorophyll estimation should be one that is maximally sensitive to chlorophyll and is not influenced by other factors. For this reason the normalized difference red edge (NDRE) index has been used in place of NDVI.

For sensor information to be useful for calculating optimal N sidedress application rates, algorithms must developed which will incorporate sensor reflectance measurements. The algorithms require the establishment of an N-rich reference strip within the field, which receives sufficient N application to ensure that N is not limiting (Blackmer et al., 1996; Shanahan et al., 2008). The N-rich reference strip allows sensor data to be normalized, therefore improving correlation by limiting the effects of hybrid, environmental conditions, and diseases (Shanahan et al., 2001). A sufficiency index (SI) is then determined as follows:

$$\mathrm{SI} = \frac{\mathrm{VI}_{\mathrm{Sensor}}}{\mathrm{VI}_{\mathrm{Reference}}} \tag{4.1}$$

where

VI_{sensor} is the vegetation index (or measurement) for the sensed crop
$VI_{reference}$ is the vegetation index (or measurement) for the N-rich reference crop

Various algorithms have been developed, to relate sensor-derived data to the amount of N needed. In addition to remote sensing techniques, simulation models have been identified as a precision management technique which has potential to maximize the synchrony of crop demand for N and fertilizer N supply (Cassman et al., 2002). Models are a method of N management which account for the interactions between management and environmental conditions. Three university developed algorithms and the simulation model are described below.

Nebraska Algorithm

Holland and Schepers (2010) developed a generalized N application model that was used with remotely sensed data in this study, and is here referred to as the Nebraska algorithm. This approach is based on the shape of an N fertilizer response function and the relationship between N rate and in-season crop vegetation index data. Rather than using an estimation of yield potential, which is often used with the mass balance approach to nutrient management, the model uses local or regional data to generate an optimum N rate (ONR) or economic optimum N rate (EONR). Consequently, this method relies on the shape of the fertilizer N response function. Where yield becomes insensitive to further increases in N fertilizer additions is defined in the algorithm as Nopt. Nitrogen which was applied pre-plant and other known N credits are subtracted from Nopt. A compensation factor based on the expected NUE of the plant and N uptake that has already occurred for the growth stage when the crop is sensed is incorporated. The user can choose which vegetation index they prefer to use to calculate the SI. The term ΔSI is used to define the point between a SI of 1 and the point where the response curve intersects the y-axis (SI at N rate of 0 or "check response"). The SI portion of the model essentially predicts the response that can occur due to N fertilizer application based on the relationship between SI and N rate. There is an optional and adjustable cutoff feature which accounts for the fact that at some point, plant stress is so great that recovery is not likely, even with large N applications. The final form of the equation is as follows:

$$N_{APP} = (MZ_i \times N_{OPT} - N_{PreFert} - N_{CRD} + N_{COMP}) \times \sqrt{\frac{(1 - SI)}{\Delta SI}} \quad (4.2)$$

where

N_{APP} = N rate to be applied
MZ_i = optional management zone scalar based on historical yield or soil sample information
N_{OPT} = EONR or the maximum N rate prescribed by producers
$N_{PreFert}$ = sum of fertilizer N applied before crop sensing and/or in-season N application
N_{CRD} = N credit for the previous season's crop, nitrate in water, or manure application
N_{COMP} = N in excess of N_{OPT} required by the crop under soil-limiting conditions at a given growth stage
SI = Sufficiency index
ΔSI = Difference between where SI equals 1.0 and the point where the response curve intersects the y axis (mathematically, 1-SI(0))

Minnesota Algorithm

The University of Minnesota algorithm (Vetsch and Randall, 2014) utilizes the same approach as an Oklahoma State University developed algorithm; however, local Minnesota field data was used in place of Oklahoma data to adapt the algorithm to the region (J. Vetsch, personal communication, 2014). The approach is largely based on the traditional method of determining fertilizer N requirements. An expected yield is determined, and typical grain protein content is used to determine the total N uptake expected for this yield. N use efficiency and other credits are taken into account. The N fertilizer recommendation is determined by back calculating from the yield goal. The logic employed is that at any given level of yield for a specific crop, nutrient removal can be estimated. By estimating yield, the nutrient removal rates can be determined, and in-season application rates can then be determined based on the expected removal. Raun et al. (2001) documents initial attempts to develop this N rate prediction algorithm for use on winter wheat. Wheat yield was related to NDVI to produce an in-season estimate of yield (INSEY). INSEY is essentially an estimate of biomass produced per day and was found to be correlated to grain yield. The number of growing degree days (GDD) from planting acts as the normalized divisor. Early season plant N uptake was predicted using NDVI readings. Percent N in the grain is also predicted based on a relationship with predicted yield level. By combining these three factors (percent N in the grain, early-season plant N uptake, and wheat grain yield) N fertilizer application rate is predicted (Lukina et al., 2001). The predicted early-season plant N uptake is then subtracted from the predicted grain N uptake. This determines the predicted N deficit. The predicted N deficit is then divided by a factor to account for efficiency. The result is that increased N rates are prescribed for areas in the field with high yield potential as indicated by INSEY and reduced N rates are prescribed for areas in the field with lower yield potential. This procedure accounts for the amount of N in the plant at the time of sensing and adjusts N need downward accordingly.

Later modifications further refined the algorithm. The grain yield potential with no added fertilization (YP_0) is predicted using the INSEY (Lukina et al., 2001). In research by Raun et al. (2002), the algorithm was further modified to include the response index (RI) feature. The RI was developed in order to estimate the potential yield increase that could be achieved with additional N applications during the growing season. This is calculated by dividing NDVI of a non-N-limiting strip by the average NDVI in the remainder of the field. The in-season RI accounts for the likelihood of obtaining a response to in-season N and the magnitude of the response to applied N at a given level of YP_0. A cutoff factor is applied so that NDVI values lower than 0.25 do not receive N application as this is the point at which wheat stands are so poor that they will not produce appreciable yields. The RI is then multiplied by YP_0 to determine the potential yield with added N fertilizer here referred to as YP_N. YP_N is used to predict percent N in the grain. Percent N in the grain is then multiplied by YP_N to determine the predicted grain N uptake. Forage N uptake is also predicted using NDVI. But subtracting the forage N uptake at the time of sensing from the anticipated end of season N uptake of the grain, N deficit is determined. The N deficit is then divided by an NUE efficiency factor, in this case, set at 0.70. A YP_{MAX} is set to place limits on YP_N. In this way the expected yield with nitrogen fertilizer application is set to not exceed biological limits previously documented for specific environments.

Teal et al. (2006) documents the adaption of this algorithm approach for use in corn. To do this, the most effective growth stage for corn grain yield prediction was determined and a corn yield potential prediction equation was generated from actual yields and early season NDVI measurements. The highest coefficient of determination for NDVI and yield was obtained at the V8 growth stage. INSEY calculated using GDD was used to develop a relationship to actual grain yield and is here referred to as GDD INSEY. Categorizing NDVI measurements by GDD ranging from 800 to 1000 resulted in a significant exponential relationship between grain yield and NDVI, similar to the V8 leaf stage characterization. However, by categorizing NDVI by GDD (800-1000 GDD) the time of sensing is extended by two leaf stages (V7-V9) thereby increasing practicality.

Missouri Algorithm

Early work in developing an N recommendation algorithm in Missouri focused on calibrating reflectance measurements to predict EONR (Sharf and Lory, 2009). Measurements were taken on multiple sites with a sensor capable of measuring reflectance in eight wavelength bands. Sites had multiple N rates applied. Yield was collected from each site and grain yield response to N rate was modeled as a quadratic-plateau function. EONR was then calculated for each location using a nitrogen/grain price ratio. Wavelengths were combined in simple ratios and evaluated to determine which ratios were the strongest predictors of EONR. Absolute reflectance values (those not related to reflectance from a non-N-limiting reference) were poorly related to EONR, however, by using a high-N reference area, reliable estimates of ONR were produced. It was determined that visible/NIR ratios (sometimes referred to as the simple inverse ratio (ISR)) relative to the same ratio of a high-N reference area was the strongest predictor of EONR. Of this ratio, the 560/NIR ratio was most strongly related to EONR. It was also noted that when starter fertilizer N was applied, errors may occur. This was because the apparent N availability to the plant early in the season did not indicate the season long availability of N, leading to situations where N could be underdiagnosed.

Later work by Scharf et al. (2011) further refined the N recommendation equation. The relative ratio of 560/NIR suggested by Scharf and Lory (2009) was used in the N rate calculation. The ISR from both the reference crop and target crop were needed to generate a relative ratio. The optimal yield derived from the model was related to the relative ISR. Based on modeled optimal yield and economics, optimal N was derived. Because the differences in spectral properties between N-sufficient and N-stressed corn gets larger as the growth stage advances, the N rate calculation equation was modified for various growth stages. Additionally, it was observed that the relative visible/NIR ratio varied more when measured with the Greenseeker® sensor than with the Crop Circle™ ACS-210. Therefore a mathematic relationship between Relative visible/NIR was developed for these two sensors and an N rate equation specific to each sensor was developed. Three variations of the equation were published based on corn growth stage. These equations are shown below for the Crop Circle™ ACS-210 in Table 4.1 and are found in Missouri USDA-NRCS (2009).

The Missouri N rate equation allows for minimum and maximum N rates to be selected by the producer. A minimum base rate of 55 -65 kg N ha^{-1} is generally recommended, even when target corn has the same appearance as the high-N reference corn. A normal range of reflectance readings for N-sufficient corn at various growth stages was found by Sheridan et al. (2012). These values are used to guard against including anomalous readings in an N application algorithm. These limits are applied to ISR values in the application of the Missouri algorithm and are also provided for the Crop Circle™ ACS-210 in Table 4.1.

Table 4.1 Missouri equations for calculating N rates for corn from Crop Circle™ ACS-210 sensor readings (adapted from Missouri USDA-NRCS, (2009)).

Corn Growth Stage	**N Rate Equation (kg ha^{-1})**	**Upper value for $ratio_{reference}$**
V6-V7	$\left(370 \times \frac{ratio_{target}}{ratio_{reference}}\right) - 303$	0.37
V8-V10	$\left(280 \times \frac{ratio_{target}}{ratio_{reference}}\right) - 224$	0.25
≥V11	$\left(269 \times \frac{ratio_{target}}{ratio_{reference}}\right) - 235$	0.20

Maize-N Model

The Maize-N model was developed to estimate EONR for maize (Setiyono et al., 2011). Maize-N builds on the Hybrid-Maize model (Yang et al., 2004), which simulates maize growth and yield based on climate and water supply. Maize N has four components which estimate corn yield potential, soil C and N mineralization, NUE, and yield versus N response. Maize-N takes into account soil properties, indigenous soil N supply, local climatic conditions and yield potential, crop rotation, tillage and fertilizer formulation, application method and timing. The model was validated in experiments in central Nebraska, eastern South Dakota, and western Nebraska and included both irrigated and rainfed systems. The EONR simulated by Maize-N was relatively robust across the different sites. Maize-N is based on relationships that govern N availability and crop demand, and therefore it is speculated that these relationships would hold across many locations and environments. When compared with existing algorithms for determining N rate from the University of Nebraska-Lincoln, South Dakota State University, Kansas State University, and the University of Missouri, the Maize-N model estimated the EONR with greater accuracy (Setiyono et al., 2011). Version 2008.1.0, used for the 2012 growing season, did not have the capability to take into account weather that had occurred in that growing season to determine mineralized N. For 2013, Version 2013.2.0 was used. This version has updates to allow the model to utilize current weather data in order to estimate the amount of mineralization of N that had occurred since the last crop.

The objective of this study was to i) compare N recommendation rates of three sensor-based algorithms (Nebraska, Minnesota, and Missouri) and a simulation model

(Maize-N) and ii) evaluate the relationship between these recommended N rates and the agronomic ONR.

Materials and Methods

Site Description and Treatments

Twelve sites were chosen in Nebraska, Missouri, and North Dakota for the 2012 and 2013 growing seasons (Table 4.2). Each experimental site contained four replications of 16 treatments arranged in a randomized complete block design. Two hybrids were selected for each site, and each hybrid was planted at a high and low seeding rate (Table 4.3).

Table 4.2 Characteristics of research sites and cropping information including site yield potential, predominant soil subgroup, tillage practices, and previous crop.

Year	State	Site ID	Site Yield Potential	Predominant soil subgroup	Tillage	Previous Crop
2012	**Missouri**	**MORO12**	High	Fluventic Eutrudepts	Disk/cultivate	Soybeans
		MOLT12	Moderate	Vertic Epiaqualfs	Disk/cultivate	Soybeans
	Nebraska	**NECC12**	High	Pachic Udertic Argiustolls	Stalk chop	Corn
		NEMC12	Moderate	Cumulic Haplustolls	Shred, stalk chop	Corn
	North Dakota	**NDDN12**	High	Typic Epiaquerts	Chisel, field cultivate	Corn
		NDVC12	Moderate	Calcic Hapludolls	No-till	Wheat
2013	**Missouri**	**MOTR13**	High	Fluventic Hapludolls	Field cultivator	Soybeans
		MOBA13	Moderate	Vertic Epiaqualfs	No-till	Soybeans
	Nebraska	**NECC13**	High	Udic Argiustolls	Ridge till, cultivate	Soybeans
		NEMC13	Moderate	Oxyaquic Haplustolls	Stalk chop	Corn
	North Dakota	**NDAR13**	High	Typic Epiaquerts	Chisel, field cultivate	Soybeans
		NDVC13	Moderate	Calcic and Pachic Hapludolls	No-till	Wheat

Table 4.3 Planting date and hybrid and plant population treatments for evaluation of in-season N application for sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013.

	Planting Date	**Hybrid**		**Planting Population** seeds ha^{-1}	
Site ID		*A*	*B*	*Low Rate*	*High Rate*
MORO12	11 May	Pioneer 33D49	Pioneer 1498	76,601	101,311
MOLT12	11 May	Pioneer 33D49	Pioneer 1498	76,601	101,311
MOTR13	23 May	Pioneer 33D49	Pioneer 1498	76,601	101,311
MOBA13	5 June	Pioneer 33D49	Pioneer 1498	76,601	101,311
NDDN12	26 April	Pioneer 39N99	Pioneer 8906 HR	79,072	103,782
NDVC12	26 April	Pioneer 39N99	Pioneer 8906 HR	79,072	103,782
NDAR13	17 May	Pioneer 39N95 AM	Pioneer 8906 HR	79,072	103,782
NDVC13	17 May	Pioneer 39N95 AM	Pioneer 8906 HR	79,072	103,782
NECC12	9 May	Pioneer 33D49	Pioneer 1498	79,072	103,782
NEMC12	10 May	Pioneer 33D49	Pioneer 1498	79,072	103,782
NECC13	13 May	Pioneer 33D53 AM	Pioneer 1498 AM	79,072	103,782
NEMC13	14 May	Pioneer 33D53 AM	Pioneer 1498 AM	79,072	103,782

Four N treatments were implemented: unfertilized check, N-rich reference, sensor-based, and model-based. The unfertilized check received no nitrogen during the study. The N-rich reference received N in a quantity that was considered to be non-limiting to yield for the individual site. The N-rich rate was 280 kg ha^{-1} for Missouri sites, 224 kg ha^{-1} for North Dakota sites, and ranged from 268 to 280 kg ha^{-1} for Nebraska sites. The sensor-based and model-based treatments received an initial N rate and an in-season N rate. The initial N rate for sensor-based and model-based treatments was 56 kg ha^{-1} for Missouri sites, 0 kg ha^{-1} for North Dakota sites, and 84 kg ha^{-1} for Nebraska sites.

Crop canopy reflectance data was collected using a RapidSCAN CS-45 Handheld Crop Sensor (Holland Scientific, Lincoln, NE). The sensor utilizes a modulated light source and three photodetector channels centered around the 670 nm, 730nm, and 780 nm wavelengths. Reflectance data was collected for all treatments at V8-V11 growth stages by positioning the sensor in the nadir position over the center of the row and was calculated for each plot as an average of the reflectance values for the middle two rows.

In-season N applications were applied to both model-based and sensor-based treatments at the time of crop canopy sensing. In-season N applications were applied to sensor-based and model-based treatments using recommendations from the Holland and Schepers sensor algorithm (Holland and Schepers, 2010) and Maize-N: Nitrogen Recommendation for Maize model (Yang et al., University of Nebraska – Lincoln, 2008) respectively. Upon physiological maturity, corn from all plots was harvested. In 2012, Nebraska and North Dakota plots were hand harvested and Missouri plots were machine harvested. In 2013, North Dakota plots were hand harvested and Missouri and Nebraska plots were machine harvested.

Estimating Optimum N Rate

In order to make an estimation of the agronomic ONR, a linear-plateau response curve representing yield as a function of N rate was derived using the N rates and corresponding yields from this study. Unique linear-plateau relationships were created for each site.

The high N reference was assumed non-limiting for N and thus used to generate the plateau portion of the response relationship. Tests of statistical differences ($\alpha = 0.05$) due to plant population and hybrid for the high N reference treatments were determined using the GLM procedure in Statistical Analysis System (SAS). If a significant difference in plateau yield occurred for plant population or hybrid, then individual means for these treatments were used to create separate plateaus, to reflect the different mean values. If no statistically significant differences were found for plant population or hybrid for the high N reference, the overall mean of the high N reference was used to determine the plateau value. For the linear part of the linear-plateau relationship, the N check (no N), and the sensor-based and model-based treatment results were used. The yield of the N check, established the linear model intercept. The model-based and sensor-based N rate and yields were utilized to determine the slope of the function. A SAS stepwise linear regression ($\alpha = 0.05$) was used to test for significant intercept and slope differences, as impacted by plant population and/or hybrid treatments. The procedure allowed for unique linear models to be generated when significant differences occurred with no N and/or with N additions. Optimum N rate for all unique combinations of the linear-plateau models was determined by solving for the joint of the linear-plateau model, as follows:

$$ONR = (plateau - a)/b \tag{4.3}$$

where: a = the linear regression intercept
b = the linear regression slope

Using this approach ONR was determined for 9 of the 12 sites, including 3 sites from each state. For the remaining 3 sites, a reliable estimate of ONR could not be determined.

The same set of sensor data collected during the growing season was then used to calculate in-season N recommendation rates using three sensor-based algorithms. N recommendation rates for the three algorithms and the Maize-N model were compared. The linear-plateau derived ONR was then compared graphically to N recommendations for the three algorithms and Maize-N model to examine which treatment was best at predicting ONR.

Implementing the Nebraska Algorithm

The Nebraska algorithm requires a SI be calculated by dividing the vegetation index of the target crop by the vegetation index of the reference crop. The NDRE index was calculated for each plot using sensor data (Equation 4.4). Sensor-based treatments were paired to N-rich reference treatments with the same hybrid and plant population.

$$\mathrm{NDRE} = \frac{\mathrm{R_{NIR}} - \mathrm{R_{RED\ EDGE}}}{\mathrm{R_{NIR}} + R_{\mathrm{RED\ EDGE}}} \tag{4.4}$$

where

R_{NIR} = near-infrared reflectance (780 nm)
$R_{RED\ EDGE}$ = red edge reflectance (730 nm)

The SI was then used in the modified algorithm by Holland and Schepers (2010, modified 2012) to determine an N application rate for each replication. In addition to the user providing the SI, this algorithm requires the user input three other variables: crop growth stage, amount of N fertilizer applied prior to crop sensing and in-season fertilization, and a user-predicted ONR. For this study, for 10 of the sites, the ONR was calculated using the soil test-based algorithm developed by the University of Nebraska-Lincoln for producers in Nebraska applying a uniform rate of N (Shapiro et al., 2003). The algorithm (Equation 4.5) takes into account residual nitrate in the soil, the expected yield, and organic matter present in the soil. The algorithm then subtracts additional sources of N which may be present from legume crops, manure, and nitrate in irrigation water.

$N\ need\ (lb\ ac^{-1}) =$

$$35 + (1.2 * EY) - (8 * NO_3\text{-}N\ ppm) - (0.14 * EY * OM) - other\ credits \quad (4.5)$$

where

N need = Nitrogen to apply in lb ac^{-1}
EY = Expected yield for the field
NO_3-N ppm = Residual nitrate in soil
OM = Organic matter in soil
Other credits = sources of N from legume crops, manure, and nitrate in irrigation water

In the case of two North Dakota site years, NDAR13 and NDVC13, the North Dakota N recommendation algorithm was used in place of the University of Nebraska-Lincoln N recommendation algorithm for the determination of the user-predicted ONR. The North Dakota N algorithm is shown below in Equation 4.6.

$$N\ need\ (lb\ ac^{-1}) = (EY * 1.1) - NO = NO_3\text{-}N\ ppm - soy\ credit \quad (4.6)$$

where

N need = Nitrogen to apply in lb ac^{-1}
EY = Expected yield for the field
NO3-N ppm = Residual nitrate in soil
Soy credit = 40 if soybeans were grown the previous season

There were six site years where the previous crop was soybeans: MORO12, MOLT12, MOTR13, MOBA13, NECC13, and NDAR13. Of these, a soybean credit was only subtracted in the University of Nebraska-Lincoln N recommendation algorithm or North Dakota University N recommendation algorithm for MOTR13, MOBA13, and NDAR13. The calculation of ONR for use in the Holland and Schepers algorithm is shown for each site in Table 4.4. The expected yield (EY) required for both the University of Nebraska-Lincoln algorithm and the North Dakota University algorithm was the attainable yield

(Y_a) generated using Maize-N: Nitrogen Rate Recommendation for Maize (Yang et al., University of Nebraska – Lincoln, 2008).

Table 4.4 Calculation of optimum N rate, using university N recommendations for use in the Holland and Schepers sensor algorithm for sensor-based treatments for sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013.

Field ID	Algorithm calculation for optimum N rate lb N ac^{-1} from algorithm results	Optimum N rate kg ha^{-1}
MORO12	[35 + (1.2 x 178) – (8 x 5.6) – (0.14 x 178 x 1.5)] = 166	186
MOLT12	[35 + (1.2 x 158) – (8 x 5.3) – (0.14 x 158 x 2.6)] = 125	140
MOTR13	[35 + (1.2 x 220) – (8 x 2.8) – (0.14 x 220 x 1.9) - 45] = 173	194
MOBA13	[35 + (1.2 x 147) – (8 x 2.8) – (0.14 x 147 x 1.9) - 20] = 130	146
NDDN12	[35 + (1.2 x 168) – (8 x 6.25) – (0.14 x 168 x 3)] = 116	130
NDVC12	[35 + (1.2 x 152) – (8 x 10.1) – (0.14 x 152 x 3)] = 73	81
NDAR13	(158 * 1.1) – 40 – 66 = 68	76*
NDVC13	(147 * 1.1) – 113 = 49	55*
NECC12	[35 + (1.2 x 231) – (8 x 18.29) – (0.14 x 231 x 3)] = 69	77
NEMC12	[35 + (1.2 x 189) – (8 x 9.34) – (0.14 x 189 x 1.65)] = 143	160
NECC13	[35 + (1.2 x 231) – (8 x 3.75) – (0.14 x 231 x 2.8)] = 192	215
NEMC13	[35 + (1.2 x 210) – (8 x 8.88) – (0.14 x 210 x 2.1)] = 154	173

* Indicates site years where the North Dakota N recommendation algorithm was used in place of the University of Nebraska-Lincoln N recommendation algorithm.

Sufficiency index values for each plot having a sensor-based treatment went into the Holland and Schepers sensor algorithm to produce the N recommendation. Inputs other than SI for the Holland and Schepers algorithm are provided in Table 4.5.

Table 4.5 Scanning date for sensor-based treatments and inputs for the Holland and Schepers sensor algorithm including: growth stage, initial N fertilizer amount, and optimum N rate for sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013.

		-------Inputs for Holland and Schepers algorithm-------		
Field ID	Scanning Date	Growth Stage	Initial N Fertilizer **kg ha^{-1}**	Optimum N Rate **kg ha^{-1}**
MORO12	June 30, 2012	V10	56	186
MOLT12	June 29, 2012	V11	56	140
MOTR13	June 28, 2013	V10	56	194
MOBA13	July 16, 2013	V9	56	146
NDDN12	July 2, 2012	V9	0	130
NDVC12	July 2, 2012	V10	0	81
NDAR13	July 3, 2013	V8	0	76
NDVC13	July 3, 2013	V8	0	55
NECC12	June 26, 2012	V10	84	77
NEMC12	June 26, 2012	V9	84	160
NECC13	June 28, 2013	V9	84	215
NEMC13	June 28, 2013	V8	84	173

Implementing the Minnesota Algorithm

The Minnesota algorithm requires inputs of GDD from the time of planting till sensing, the NDVI of the target and reference crop, and a maximum yield for the region. The NDVI was calculated using sensor data as previously described. Sensor-based treatments were paired to N-rich reference treatments with the same hybrid and plant population. The algorithm uses NDVI values to generate the RI. Maximum yield for the region was determined using the Y_a generated using Maize-N: Nitrogen Rate Recommendation for Maize (Yang et al., University of Nebraska – Lincoln, 2008). Expected grain price and fertilizer cost were also required by the algorithm. A grain price of \$0.25 kg^{-1} was used in 2012 and \$0.22 kg^{-1} was used in 2013. An N fertilizer price of \$1.59 kg^{-1} was used in 2012, and \$1.48 kg^{-1} was used in 2013. GDD and maximum yield values are provided in Table 4.6.

Table 4.6 Scanning date for sensor-based treatments and inputs for the Minnesota sensor algorithm including: GDD and maximum yield for sites in Missouri (MO), North Dakota (ND), and Nebraska (NE) in 2012 and 2013.

		------------Inputs for Minnesota algorithm-----------	
Field ID	Scanning Date	GDDs	Maximum Yield for Region **Mg ha^{-1}**
MORO12	June 30, 2012	1254	11.2
MOLT12	June 29, 2012	1216	9.9
MOTR13	June 28, 2013	827	13.8
MOBA13	July 16, 2013	1063	9.2
NDDN12	July 2, 2012	1029	10.6
NDVC12	July 2, 2012	846	9.6
NDAR13	July 3, 2013	789	9.9
NDVC13	July 3, 2013	677	9.2
NECC12	June 26, 2012	994	14.5
NEMC12	June 26, 2012	1021	11.9
NECC13	June 28, 2013	943	14.5
NEMC13	June 28, 2013	968	13.2

Implementing the Missouri Algorithm

The ISR of the target and reference crop were collected using the crop canopy sensor. Sensor-based treatments were paired to N-rich reference treatments with the same hybrid and plant population. The Missouri algorithm is calibrated for specific sensor use, and was developed to estimate N rate based on sensor reflectance values collected with a Crop Circle™ ACS-210 or GreenSeeker®. The Crop Circle™ ACS-210 measures reflectance at 590 and 880 nm. In this study, reflectance was collected with a RapidSCAN CS-45 Handheld Crop Sensor (Holland Scientific, Lincoln, NE) which measures reflectance at 670, 730, and 780 nm. To utilize the equation developed for the Crop Circle™ ACS-210, an adjustment factor was applied to the ISR values. The adjustment factor was derived from the relationship between ISR values between these two sensors (K.A. Sudduth, unpublished data, 2014). The linear adjustment equation is as follows:

$$Y = 1.0272x + 0.0643 \quad (4.4)$$

where: x = ISR values from RapidSCAN CS-45 Handheld Crop Sensor
y = expected ISR value if using Crop Circle™ ACS-210

The equation designed for the Crop Circle™ ACS-210 were then used. Three variations of the equation are available and are to be selected based on corn growth stage. The upper value for the reference ISR value is found in Table 4.1 for each growth stage. An upper value for the target crop was also applied to data and was set at 0.4 as values greater than this have been found to be from areas with few or no corn plants (Kitchen, et al., 2010). The adjusted ISR was used with the equation appropriate to the crop growth stage as seen in Table 4.1.

Implementing the Maize-N Model

The in-season N application rates for the model-based treatments were determined using Maize-N: Nitrogen Rate Recommendation for Maize (Yang et al., University of Nebraska – Lincoln, 2008) Software Version 2008.1.0 was used for the 2012 growing season, and Version 2013.2.0, which includes an added N mineralization component, was used for the 2013 growing season. No sensor data was involved in the implementation of the Maize-N model. Inputs required for the Maize-N model include information about soil properties, indigenous soil N supply, local climatic conditions and yield potential, crop rotation, tillage and fertilizer formulation, and application method and timing. These input values as well as a long-term weather file were entered into the model software. For the 2012 growing season, the model did not have the capability to take into account weather that had occurred in that growing season to estimate mineralized N. For 2013, changes were made allowing the model to utilize current weather data in order to estimate the amount of mineralization of N that had occurred since the last crop. The long-term weather data was then used to predict mineralization of N for the remainder of the season, based on historical trends. Input values and output for Maize-N are provided for each site in Appendix B.

Data Analysis Methods

For all N recommendation approaches a linear regression analysis was performed using the REG procedure in SAS 9.2 (SAS Institute Inc., Cary, NC). The intercept was suppressed from the model statement so that it would be set to 0. R^2 values shown are the adjusted R^2.

Results and Discussion

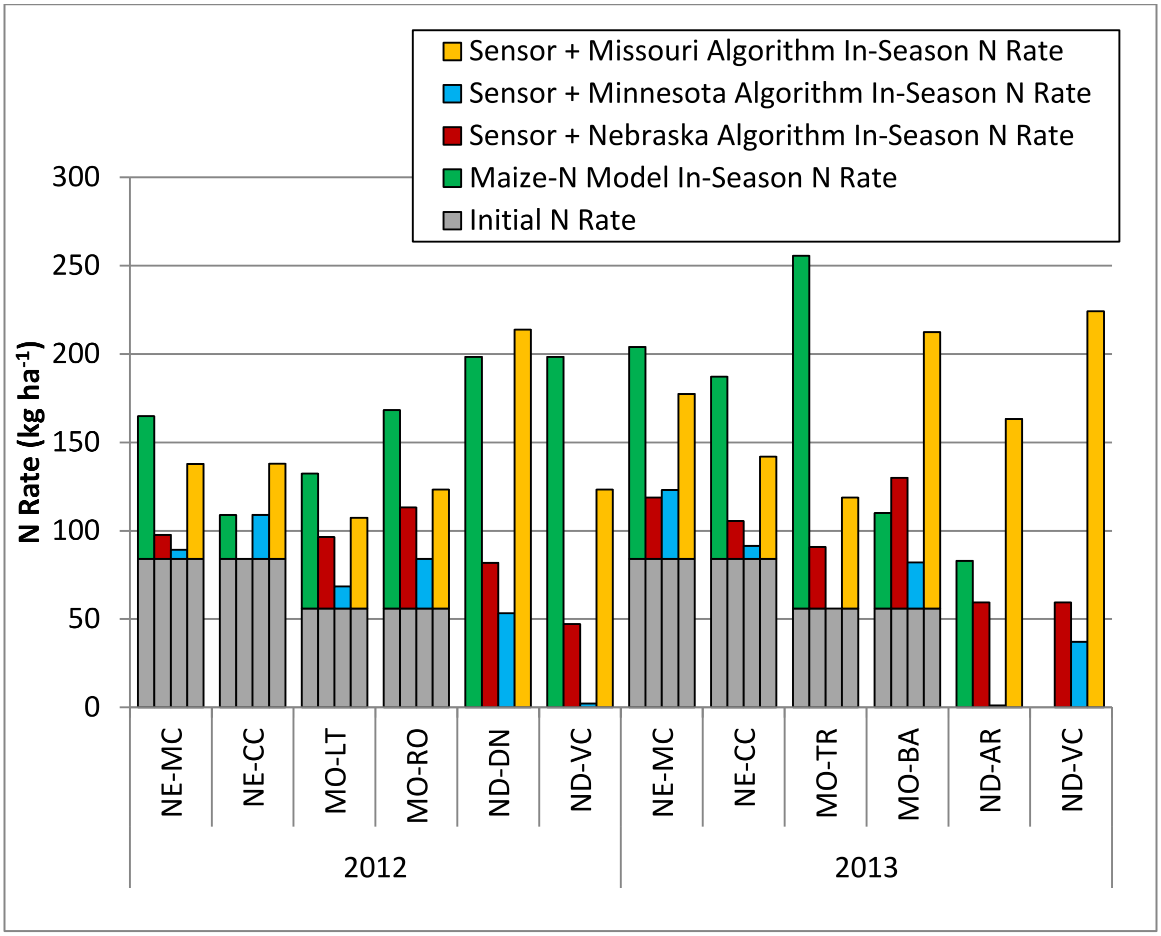

Figure 4.1 Initial and in-season N recommendation rates derived using three sensor-based algorithms (Missouri, Minnesota, and Nebraska) and a simulation model (Maize-N) at sites in Nebraska (NE), Missouri (MO), and North Dakota (ND) in 2012 and 2013.

Table 4.7 Mean, minimum, and maximum N rates for the three sensor-based algorithms (Nebraska, Minnesota, and Missouri) and a simulation model (Maize-N) and the ONR estimation using the linear-plateau model for all sites in Missouri, North Dakota, and Nebraska combined.

	Mean N Rate kg ha^{-1}	Minimum N Rate kg ha^{-1}	Maximum N Rate kg ha^{-1}
Linear-plateau derived ONR	138	0	279
Maize-N	170	77	267
Nebraska Algorithm	92	0	160
Minnesota Algorithm	63	0	162
Missouri Algorithm	155	31	273

The varying N recommendation rates generated by the four approaches evaluated are provided in Figure 4.1. Values reported represent the average N application rate for each site using each of the N recommendation approaches. For sensor-based approaches, this involves an average of 16 N recommendations per site (only sensor-based treatments were evaluated). The Maize-N model and Missouri algorithm recommended the highest application rates. For seven of twelve site years, the Maize-N model recommended the highest N application rate. For the remaining five site years, the Missouri algorithm had the highest N recommendation. The Minnesota algorithm recommended the lowest N application rates at ten of the twelve site years. Mean, minimum, and maximum N rates recommended by each approach across all sites together are provided in Table 4.7 along with the mean, minimum, and maximum estimated ONR from the linear-plateau model.

A comparison of each approach to the ONR derived from the linear-plateau model is made in Figure 4.2 through Figure 4.5. Algorithm approaches have individual replication points plotted rather than mean values for each treatment. This is because unique N rates were generated for each replication of a given treatments. For the model approach, N rates for each treatment are the same across replications therefore fewer data points are visible on the graphs. The solid 1:1 line through each graph represents the ideal N rate, where the recommended N is equal to that of the linear-plateau estimated ONR or y=1x. Data points falling above and left of this line are instances where N was under-recommended, while data points falling below and to the right of this line are occasions where N was over-recommended. A linear regression of the data points with an intercept of 0 was fit and is depicted with a dashed line on each graph. Points falling on the x-axis are of interest as these points are sites where N was recommended but linear-plateau estimated ONR was 0 kg ha^{-1}. This occurred for data from NDDN12, NDVC12, and NEMC12. At the North Dakota sites, poor plant stands were observed which may be the cause of no response to N fertilizer. For the Nebraska site, high mineralization of N during the 2012 growing season is likely the cause of the lack of response to N fertilizer for these points. When evaluating data from all sites, the Maize-N model most closely approximates the linear-plateau estimated ONR (y=0.8145x) and erred on the side of over-recommendation of N (mean ONR=138 kg N ha^{-1}; mean Maize-N recommendation = 170 kg N ha^{-1}). The Missouri algorithm is the next closest, with data fitting a line at y=0.7887x, and thus erring on the side of over-recommendation of N. The Nebraska algorithm was also fairly close to 1, with a regression of y=1.3341x, and a better coefficient of determination than the Missouri algorithm. Both the Maize-N model and Nebraska algorithm were designed to be robust independent of geographic location, therefore it is not surprising that these two approaches performed well when considering data from all sites collectively.

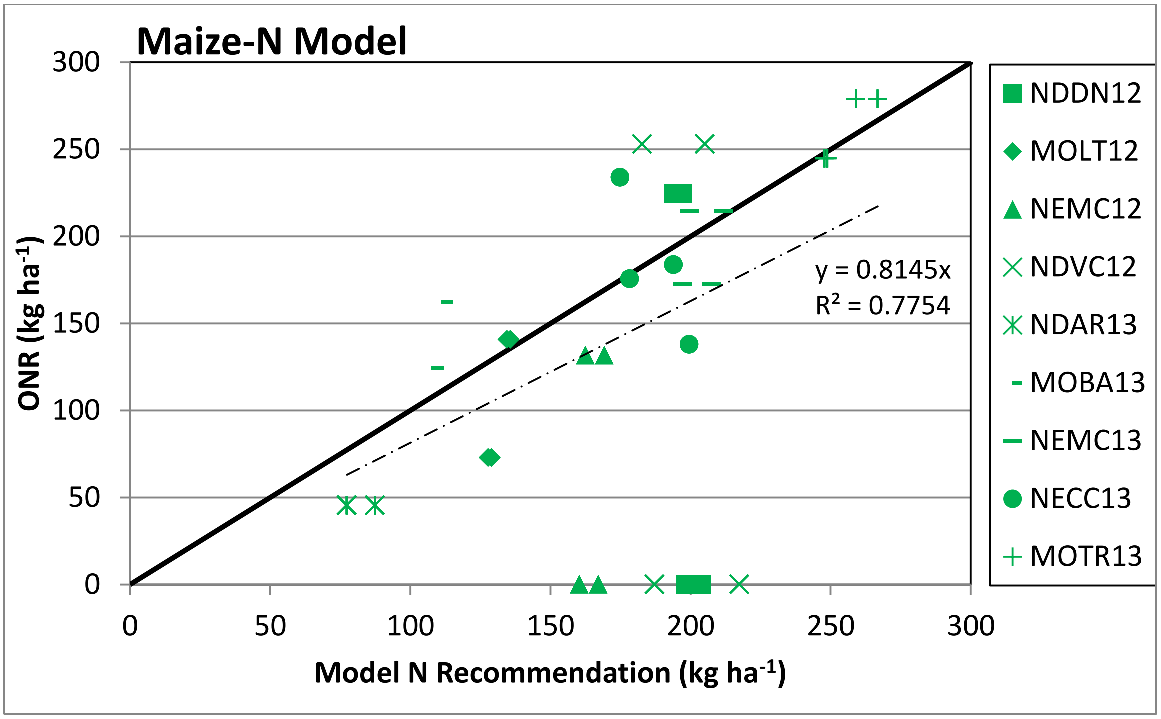

Figure 4.2 Comparison of ONR derived using the linear-plateau model to N recommendation generated using the Maize-N model for all sites in North Dakota (ND), Missouri (MO), and Nebraska (NE) where ONR for at least some combination of hybrid and plant population was greater than 0.

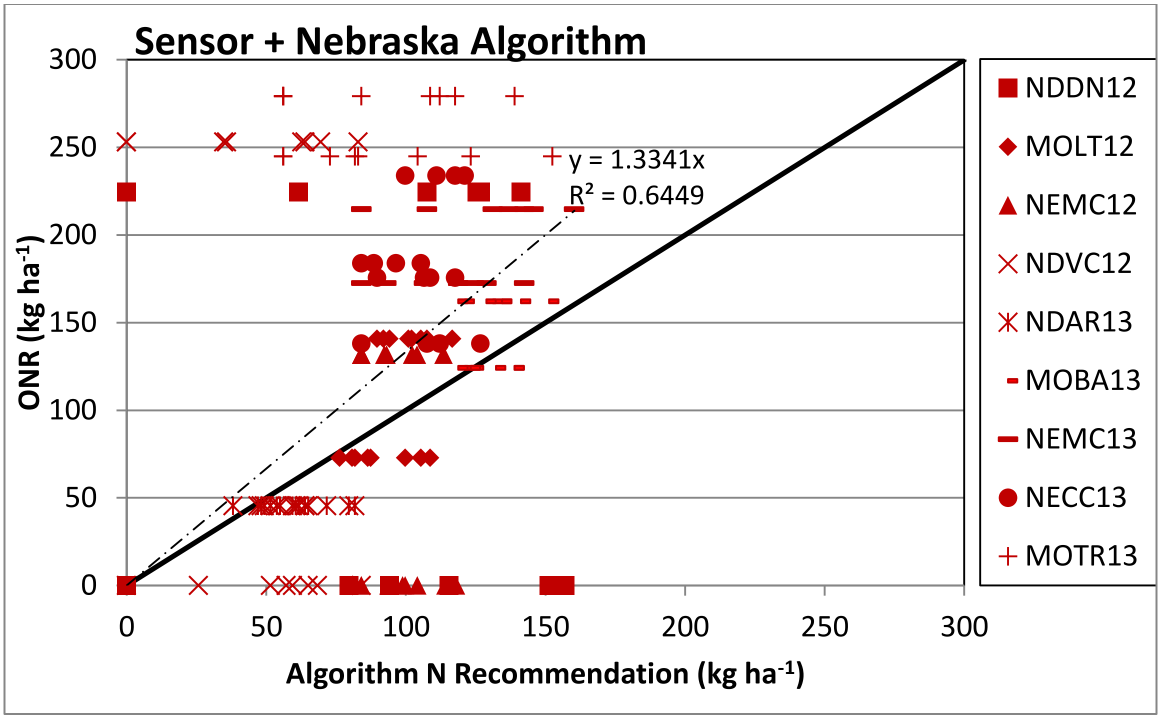

Figure 4.3 Comparison of ONR derived using the linear-plateau model to N recommendation generated using sensor data with the Nebraska algorithm for all sites in North Dakota (ND), Missouri (MO), and Nebraska (NE) where ONR for at least some combination of hybrid and plant population was greater than 0.

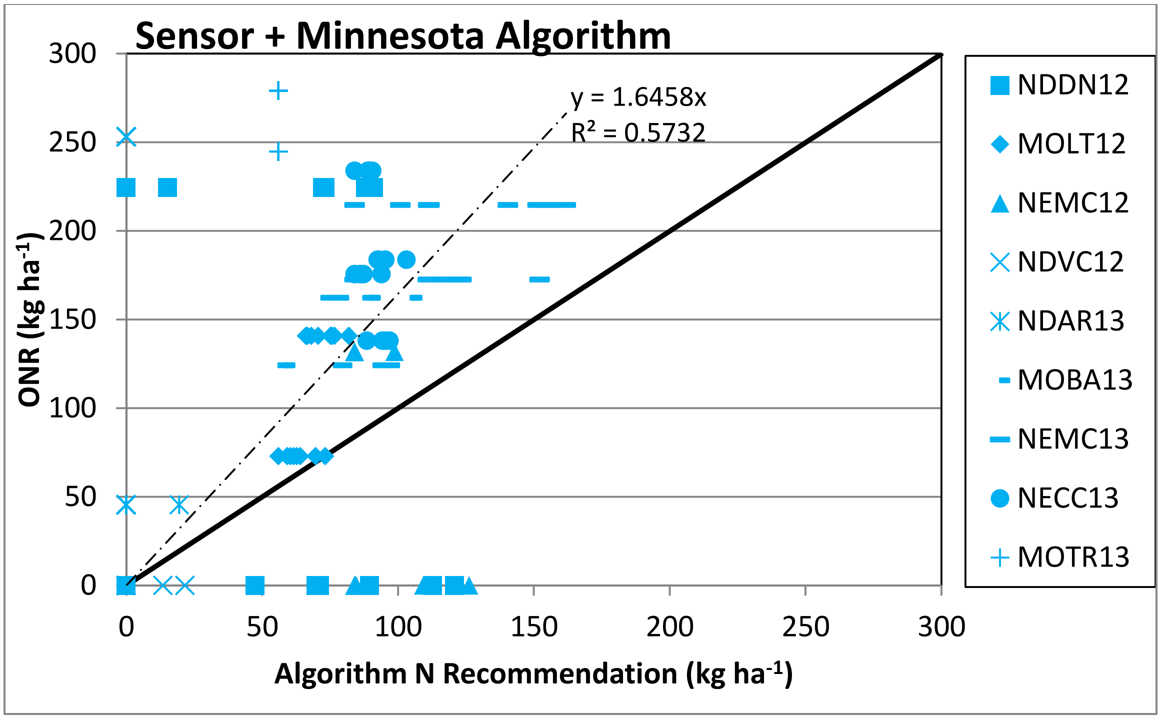

Figure 4.4 Comparison of ONR derived using the linear-plateau model to N recommendation generated using sensor data with the Minnesota algorithm for all sites in North Dakota (ND), Missouri (MO), and Nebraska (NE) where ONR for at least some combination of hybrid and plant population was greater than 0.

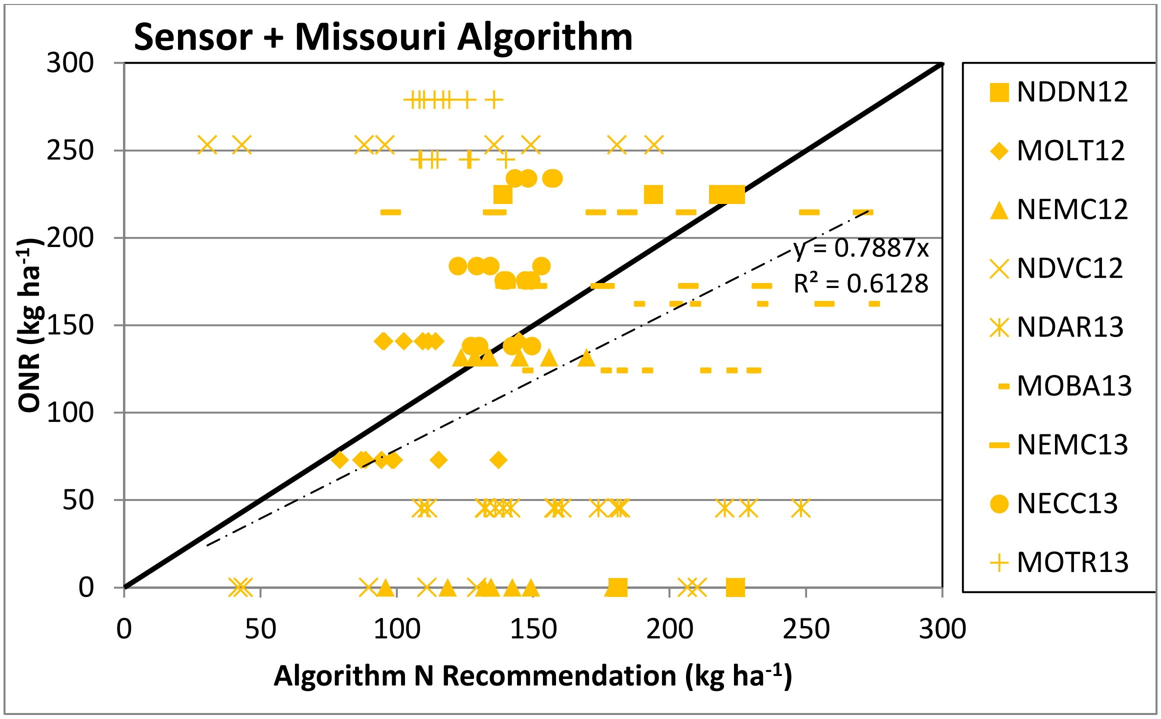

Figure 4.5 Comparison of ONR derived using the linear-plateau model to N recommendation generated using sensor data with the Missouri algorithm for all sites in North Dakota (ND), Missouri (MO), and Nebraska (NE) where ONR for at least some combination of hybrid and plant population was greater than 0.

Because the Minnesota and Missouri algorithms are empirically-derived algorithms designed to be applied in a specific geographic location, it is of interest to evaluate whether these algorithms better approximated the linear-plateau derived ONR for the regions for which they were developed. The Nebraska algorithm and Maize-N model are mechanistically-derived approaches; therefore they should respond equally well in any region. By evaluating all the N recommendation approaches by state, approaches which are best for each location can be determined. Figure 4.6, Figure 4.7, and Figure 4.8 evaluate each approach using only the data from the sites in Nebraska, Missouri, and North Dakota respectively.

For the Nebraska sites, the Missouri algorithm most closely approximated the linear-plateau derived ONR with a reasonable coefficient of determination (Figure 4.6). The Maize-N model also performed well, with a fairly close approximation of the linear-plateau derived ONR and a higher coefficient of determination. The Maize-N model and Nebraska algorithm performed similarly at Nebraska sites alone as for all sites combined.

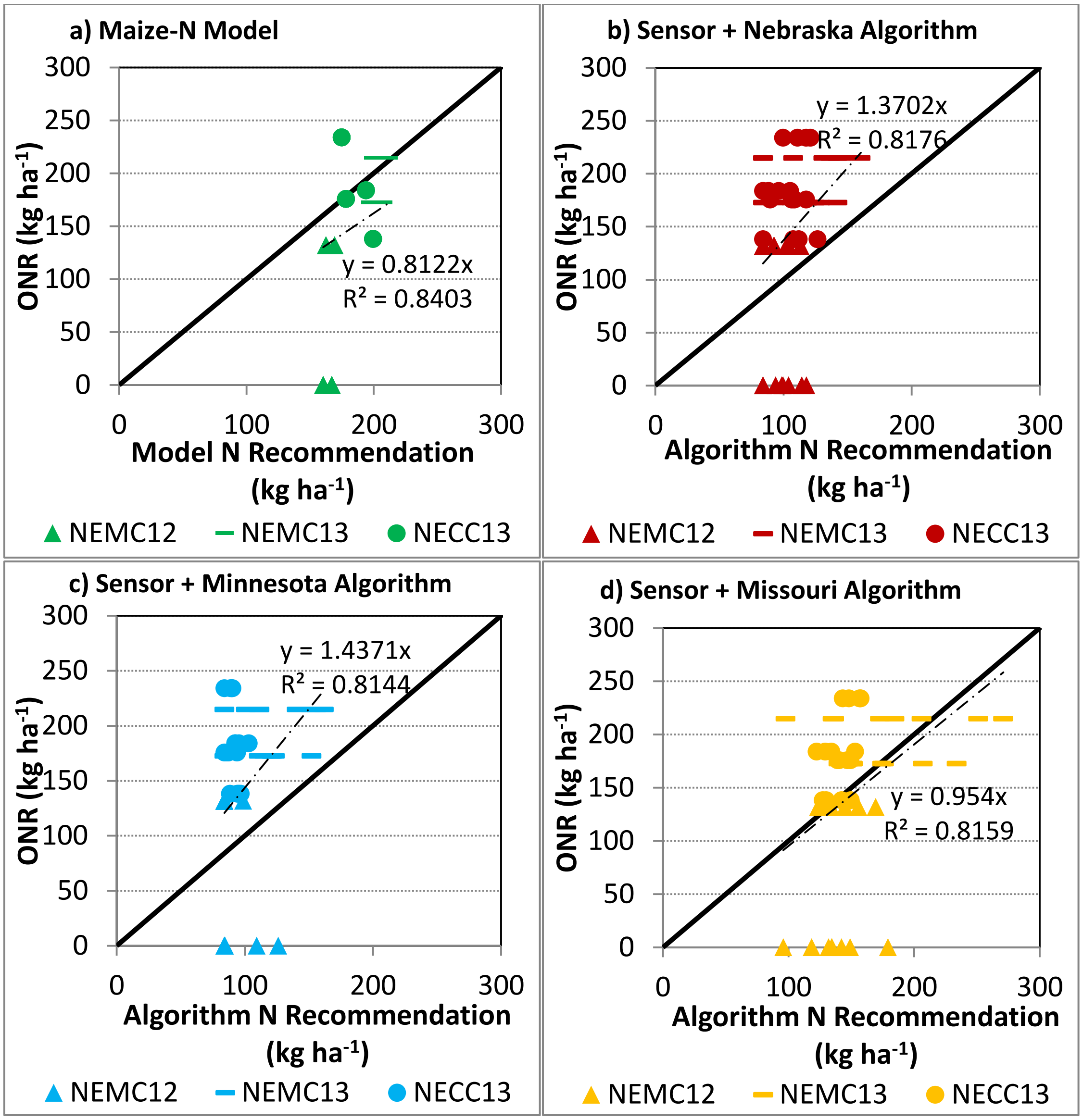

Figure 4.6 Comparison of ONR derived using the linear-plateau model to N recommended by (a) Maize-N model; (b) Nebraska algorithm; (c) Minnesota algorithm; (d) Missouri algorithm for Nebraska (NE) sites in 2012 and 2013.

For Missouri sites, the Maize-N model and Missouri algorithm performed similarly, with linear regression lines fitting close to the optimum (Figure 4.7). However, the Maize-N model had a notably higher coefficient of determination than the Missouri algorithm. For all approaches combined, the trend was for N to be under-recommended. The linear regression of the Minnesota algorithm shows that N recommendations were furthest off of the optimum with recommendations erring on the side of under-recommendation of N.

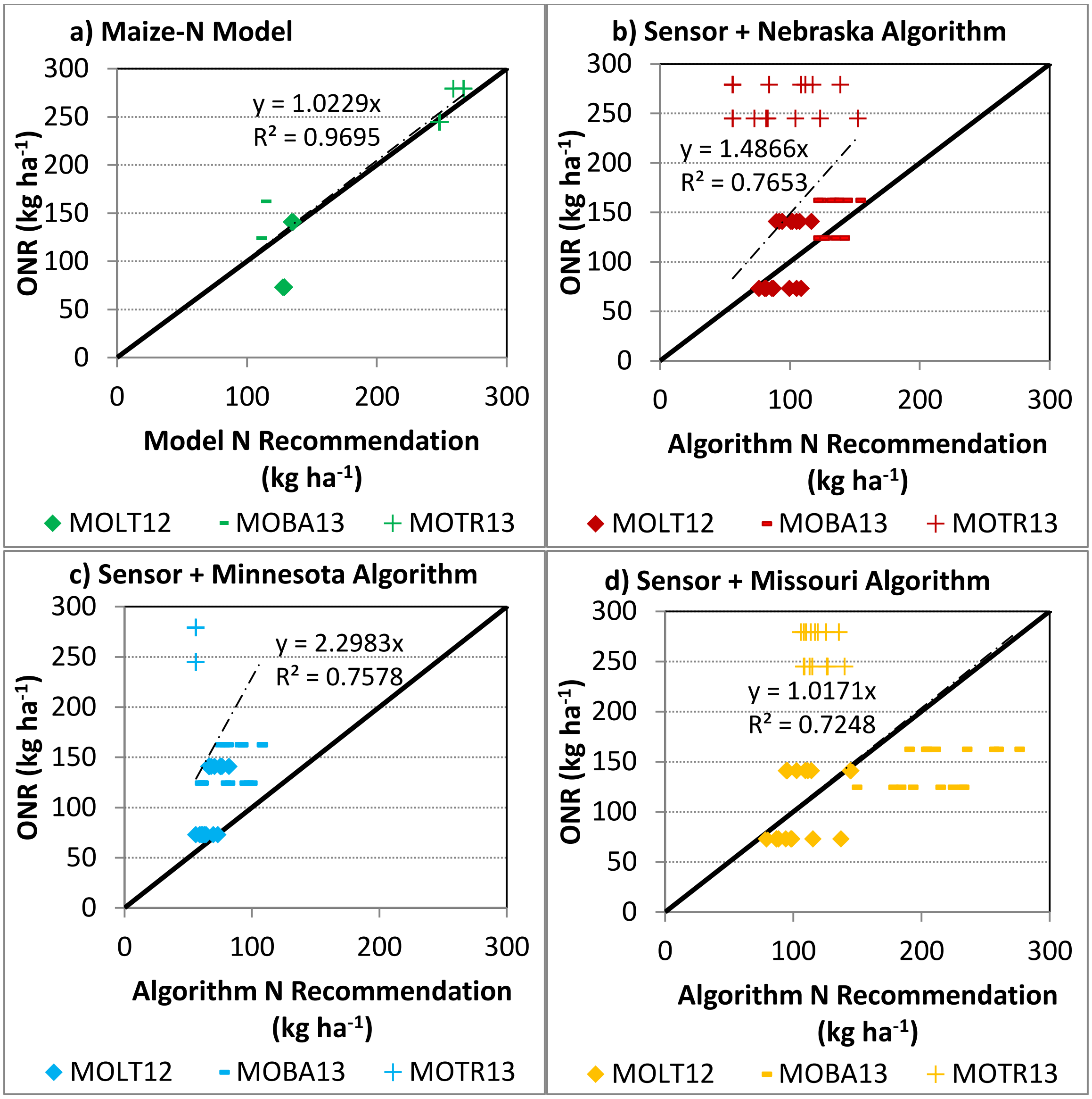

Figure 4.7 Comparison of ONR derived using the linear-plateau model to N recommended by (a) Maize-N model; (b) Nebraska algorithm; (c) Minnesota algorithm; (d) Missouri algorithm for Missouri (MO) sites in 2012 and 2013.

Coefficients of determination for the linear regression were much lower at North Dakota sites than for Missouri and Nebraska sites (Figure 4.8). Here the linear regression for the Missouri algorithm most closely achieved optimal N recommendations. However, the coefficient of determination is low, indicating that there is scatter in the data which creates individual N recommendations further from the optimum. For all approaches, there was a trend of over-recommending N. This may be due in part to the lack of N response for some of the treatments at two of the North Dakota sites. In general, North Dakota sites lack an approach that fits the data well (e.g. has a high coefficient of determination) and closely approximates the linear-plateau derived ONR. It should be noted that North Dakota sites did not have an initial N application prior to in-season application as seen in Figure 4.1. This is likely a confounding factor influencing response to N.

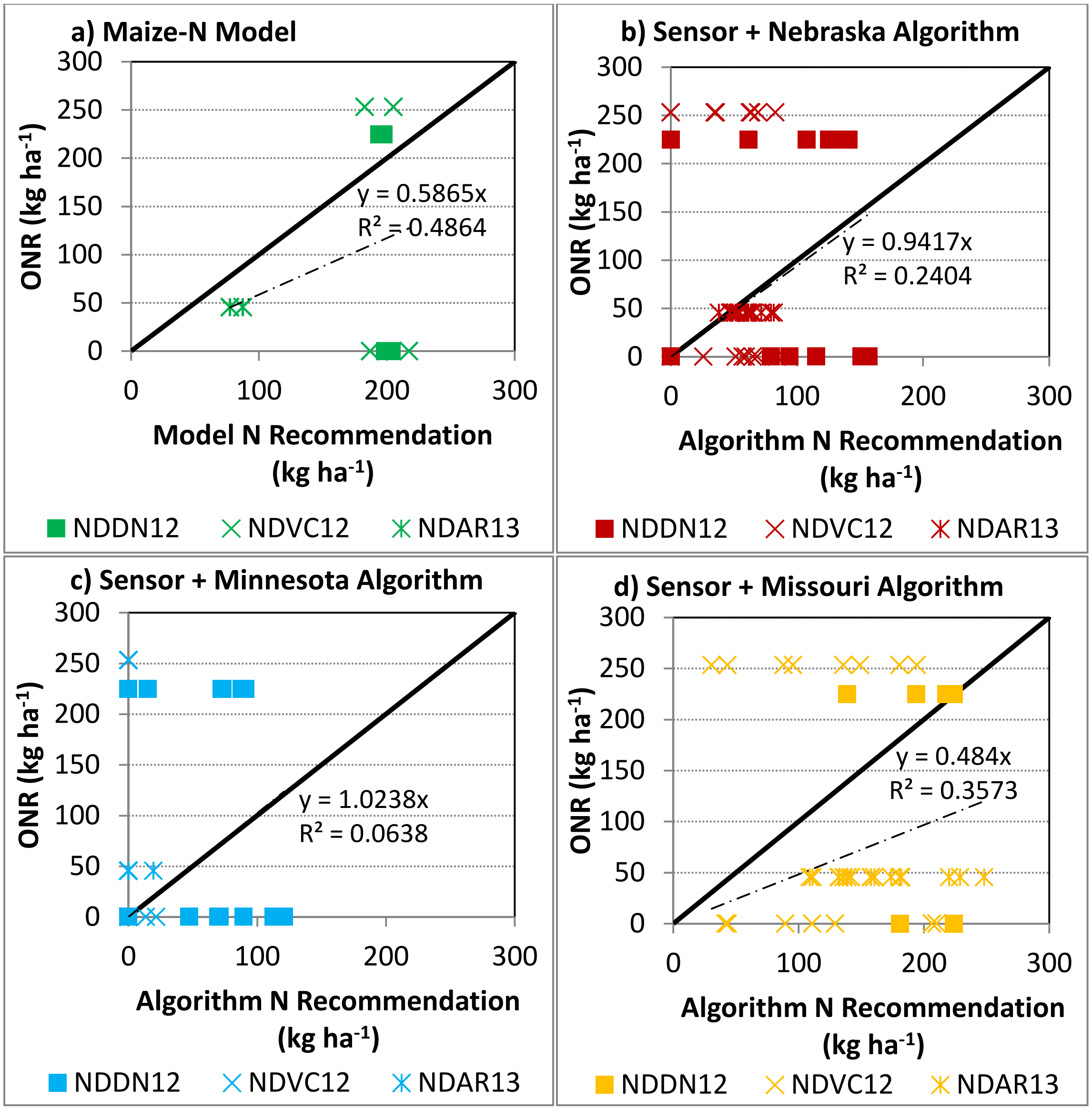

Figure 4.8 Comparison of ONR derived using the linear-plateau model to N recommended by (a) Maize-N model; (b) Nebraska algorithm; (c) Minnesota algorithm; (d) Missouri algorithm for North Dakota (ND) sites in 2012 and 2013.

When evaluating the N recommendation approaches, close approximation of the linear-plateau derived ONR (y=1x) and a high coefficient of determination are desirable. These values are found for each site and all sites combined for the four N recommendation approaches in Table 4.8. The Maize-N model performed well overall and at the Nebraska and Missouri sites individually. It was weaker at the North Dakota sites. The Nebraska algorithm made N recommendations closest to the linear-plateau derived ONR at Nebraska sites, however, it was fairly consistent for all sites. The Minnesota algorithm had a tendency to under-recommend N at all sites and was not a good choice for the Missouri sites. It performed best on North Dakota sites, which are the most geographically proximal to the region for which the algorithm was created. This Missouri algorithm performed particularly well for the Nebraska and Missouri sites but was weaker at the North Dakota sites.

Table 4.8 Linear regression equations, coefficient of determination, and significance (PR>F) are shown for each N rate recommendation approach (three sensor-based algorithms and one simulation model) for all sites combined and for sites from each state (Nebraska, Missouri, and North Dakota) independently.

	Maize-N Model	Nebraska Algorithm	Minnesota Algorithm	Missouri Algorithm
All Sites	y=0.81x R^2 = 0.7754 <0.0001	y=1.33x R^2 = 0.6449 <0.0001	y=1.65x R^2 = 0.5732 <0.0001	y=0.79x R^2 = 0.6101 <0.0001
Nebraska Sites	y=0.81x R^2 = 0.8403 <0.0001	y=1.37x R^2 = 0.8176 <0.0001	y=1.44x R^2 = 0.8144 <0.0001	y=0.95x R^2 = 0.8159 <0.0001
Missouri Sites	y=1.02x R^2 = 0.9695 <0.0001	y=1.49x R^2 = 0.7653 <0.0001	y=2.30x R^2 = 0.7578 <0.0001	y=1.02x R^2 = 0.7248 <0.0001
North Dakota Sites	y=0.59x R^2 = 0.4864 <0.0001	y=0.94x R^2 = 0.2404 0.0002	y=1.02x R^2 = 0.0638 0.0443	y=0.48x R^2 = 0.3573 <0.0001

The variation among the three sensor-based algorithms in N recommendations and ability to closely approximate ONR highlights the importance of carefully considering and selecting the algorithm to be used to generate in-season N rates with crop canopy sensor data. While the Missouri algorithm performed well at Nebraska and Missouri sites, it is not recommended for use in North Dakota. Similarly, the Minnesota algorithm did not perform well at the Nebraska and Missouri sites. The algorithm that is selected should be one that provides a close approximation of the ONR (y=1x) and a high coefficient of determination for the location in which it will be used. Empirically derived algorithms are not recommended for use outside of the region for which they were developed without validating their applicability to the specific region in which they will be used.

The correlation of each approach to the linear-plateau derived ONR and to each other was also evaluated (Table 4.9). When comparing each approach to the estimated ONR, the Maize-N model has the strongest correlation. Other algorithms are not strongly correlated with estimated ONR. It is also noted that the Minnesota and Nebraska algorithm are strongly correlated to each other. This is somewhat difficult to explain as the approaches for generating N recommendations for the Minnesota and Nebraska algorithms are largely divergent.

Table 4.9 Pearson Correlation Coefficients and significance for ONR derived using the linear-plateau model and four N recommendation approaches (three sensor-based algorithms and one simulation model.

	Nebraska Algorithm	Minnesota Algorithm	Missouri Algorithm	Maize-N Model
ONR	0.13081	0.20731*	-0.08643	0.50346***
Nebraska Algorithm		0.78211***	0.39177***	0.00487
Minnesota Algorithm			0.23951*	0.20824
Missouri Algorithm				-0.16201

*Indicates significance at the 0.05 probability level.
**Indicates significance at the 0.01 probability level.
***Indicates significance at the 0.0001 probability level

Conclusion

This evaluation highlights the importance of considering the sensor based N recommendation algorithm used with crop canopy data. Empirically derived algorithms designed for use in a specific location are not recommended for use outside of the region for which they were developed without first testing their applicability. When considering linear regression fit and coefficient of determination for the three sensor-based algorithms, the Missouri algorithm was the best choice for both the Nebraska and Missouri sites. For North Dakota sites, due to low coefficients of determination for all algorithms, none of the algorithms tested here would be recommended. Lack of initial N application prior to in-season N application at these sites may be responsible for low performance of the algorithms tested. Further testing of these algorithms at a larger number of sites in North Dakota is recommended, as two of the three sites tested here did not consistently show a response to N. Additionally, other algorithms should be explored or developed for this region to attempt to find one where N recommendations more reliably approximate the linear-plateau derived ONR.

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Appendix A.

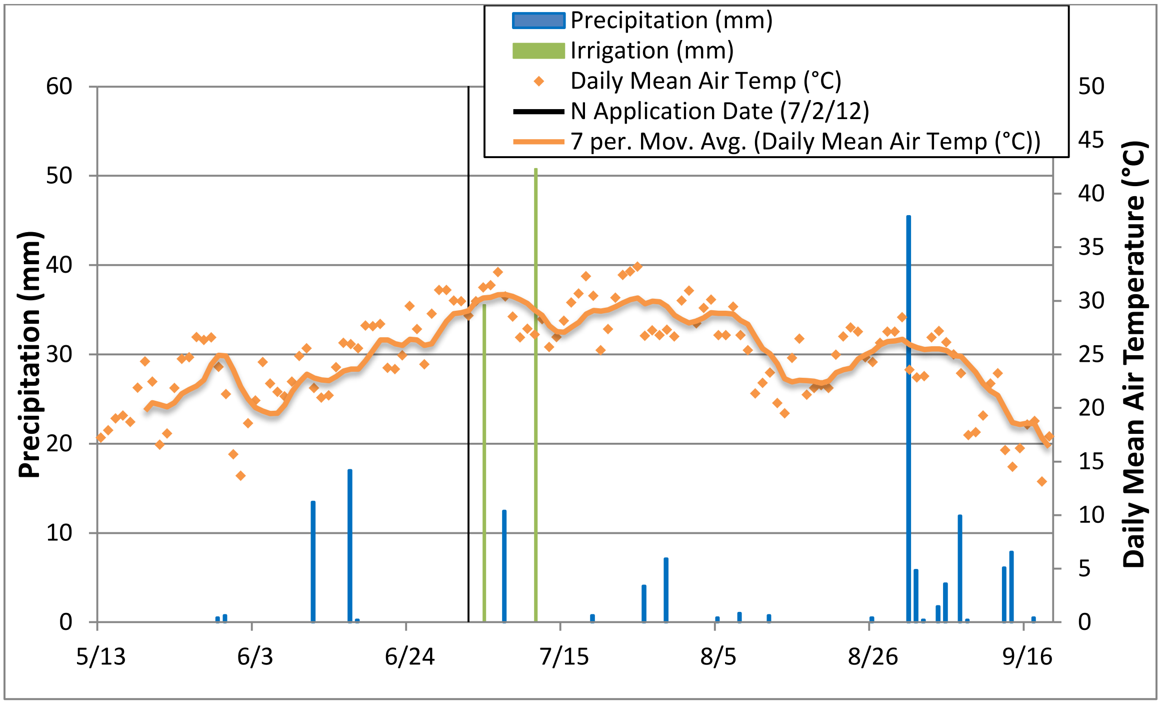

Figure A.1 Weather data for MORO12.

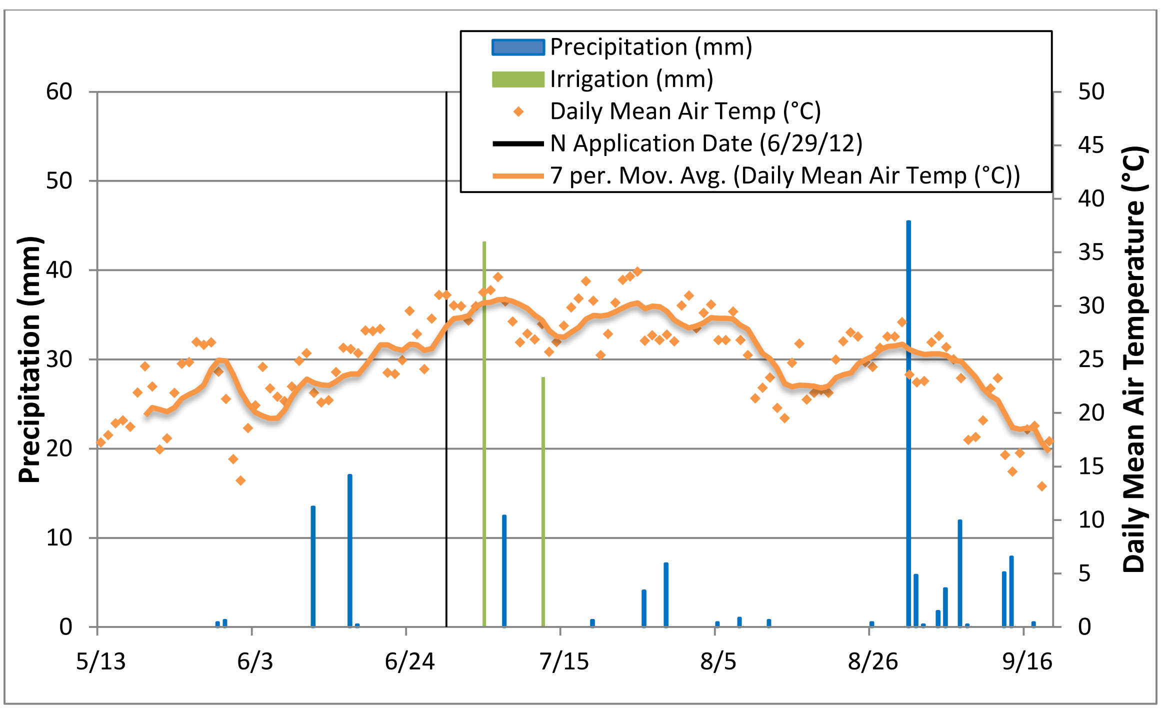

Figure A.2 Weather data for MOLT12.

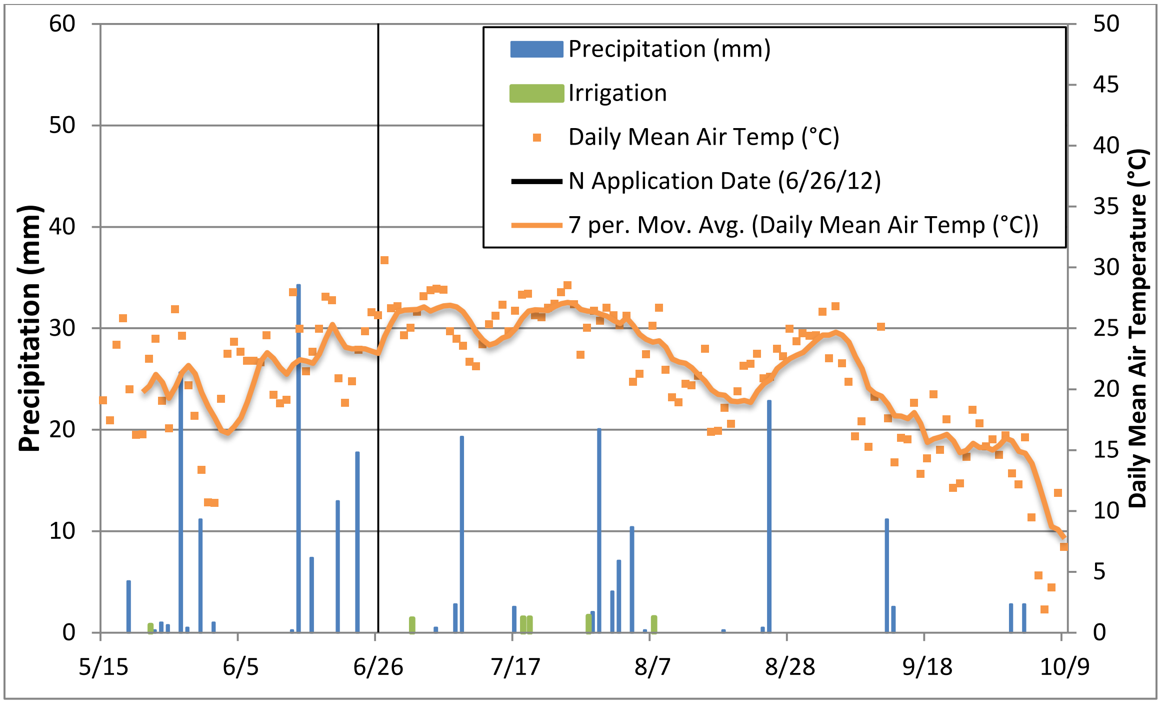

Figure A.3 Weather data for NECC12.

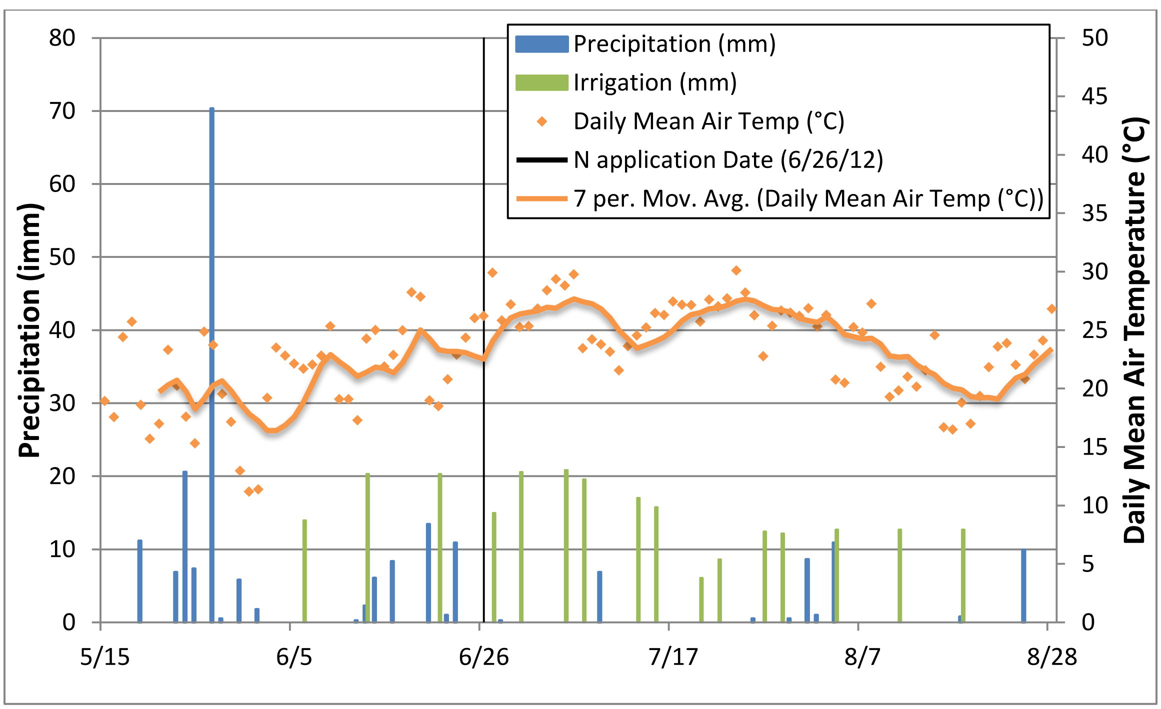

Figure A.4 Weather data for NEMC12.

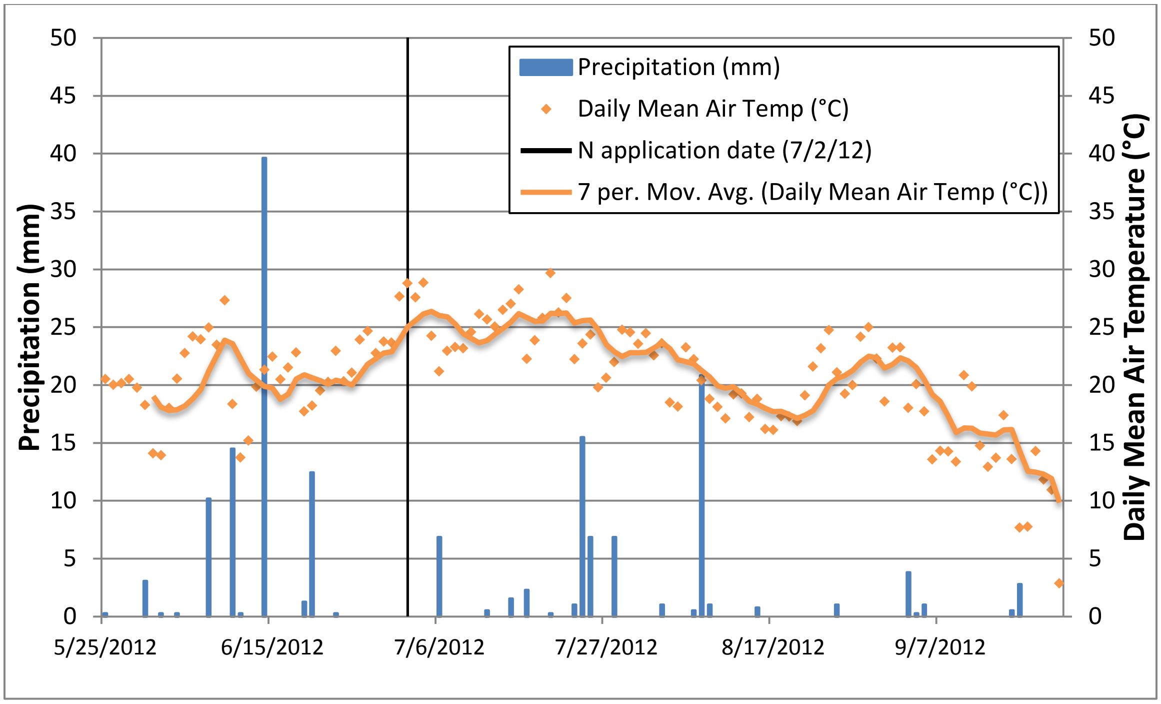

Figure A.5 Weather data for NDDN12.

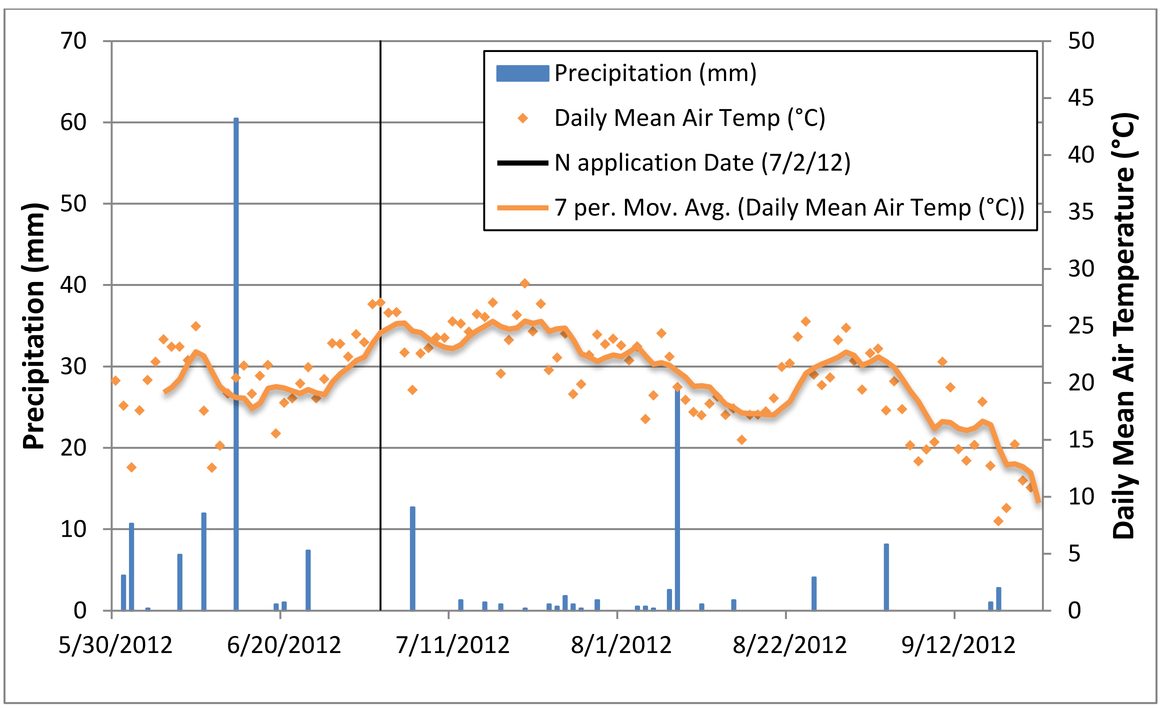

Figure A.6 Weather data for NDVC12.

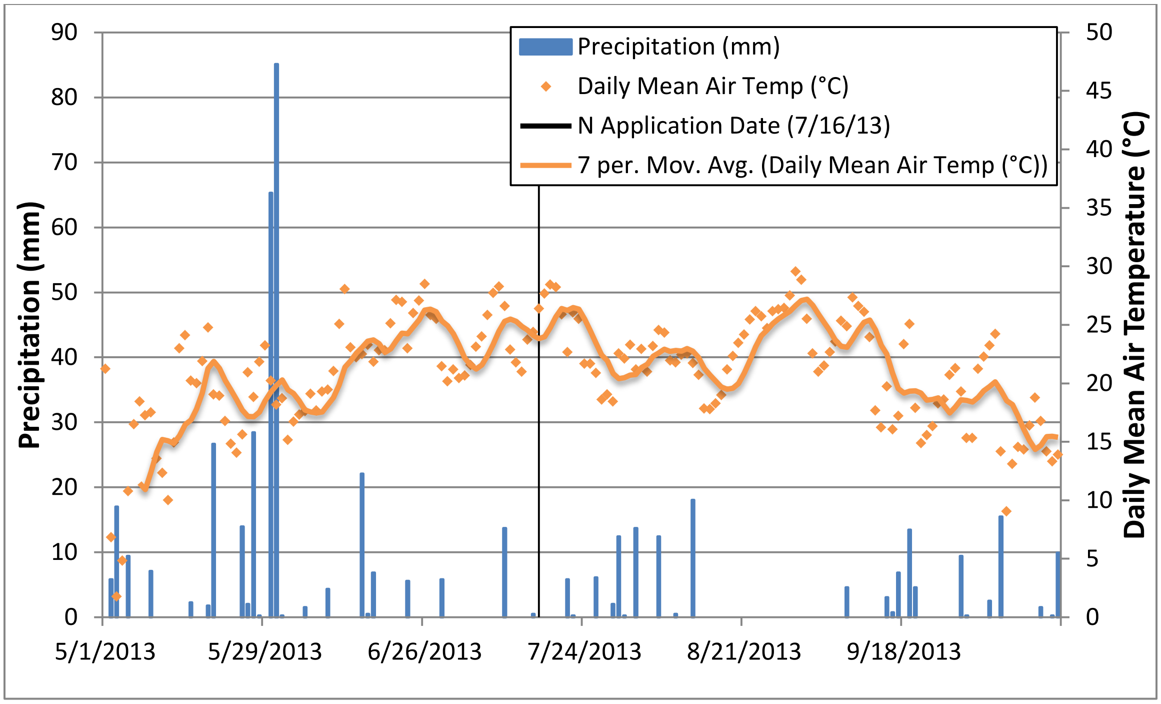

Figure A.7 Weather data for MOBA13.

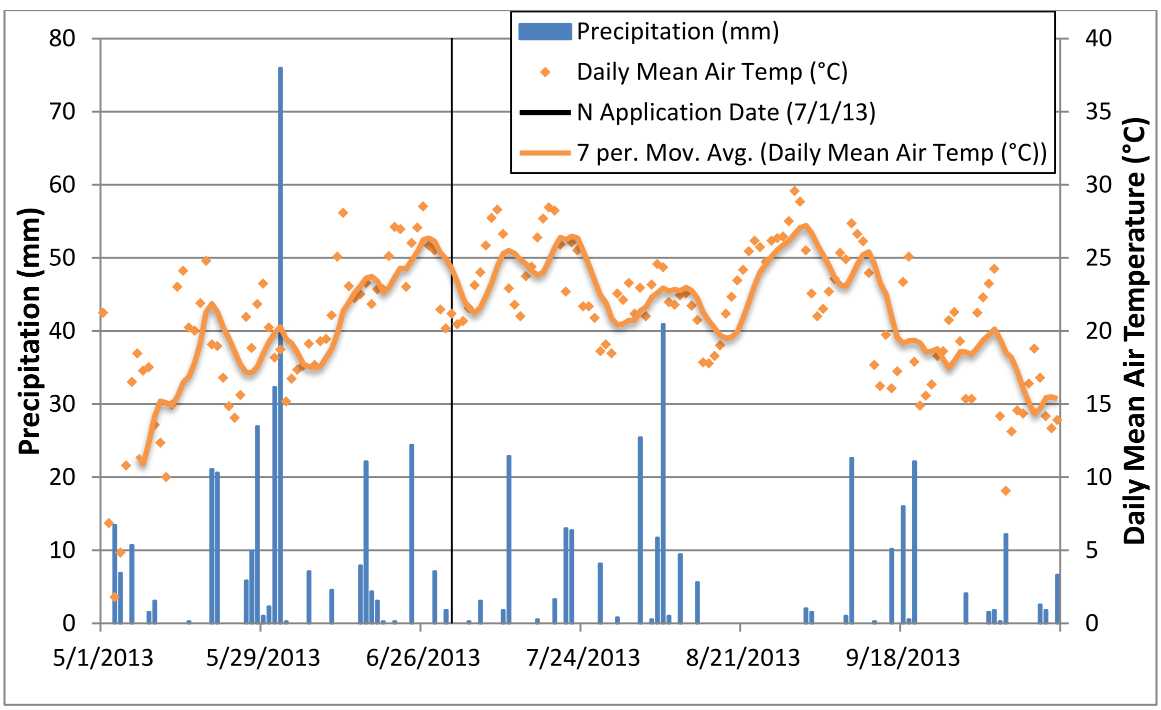

Figure A.8 Weather data for MOTR13.

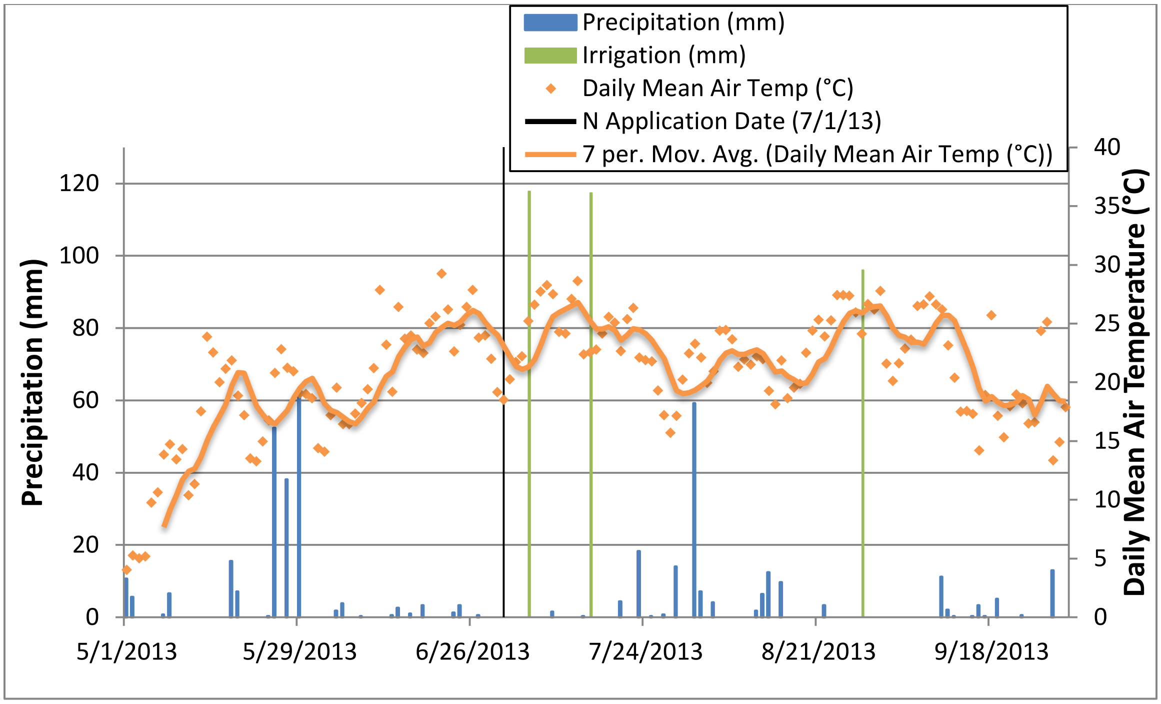

Figure A.9 Weather data for NECC13.

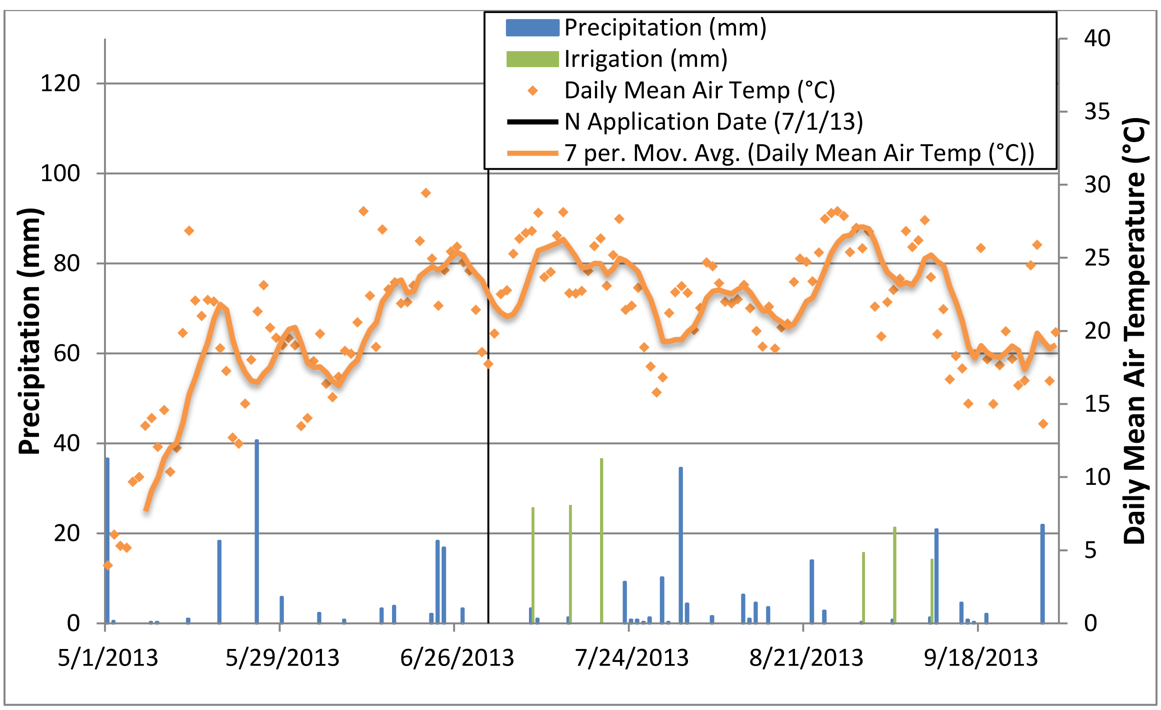

Figure A.10 Weather data for NEMC13.

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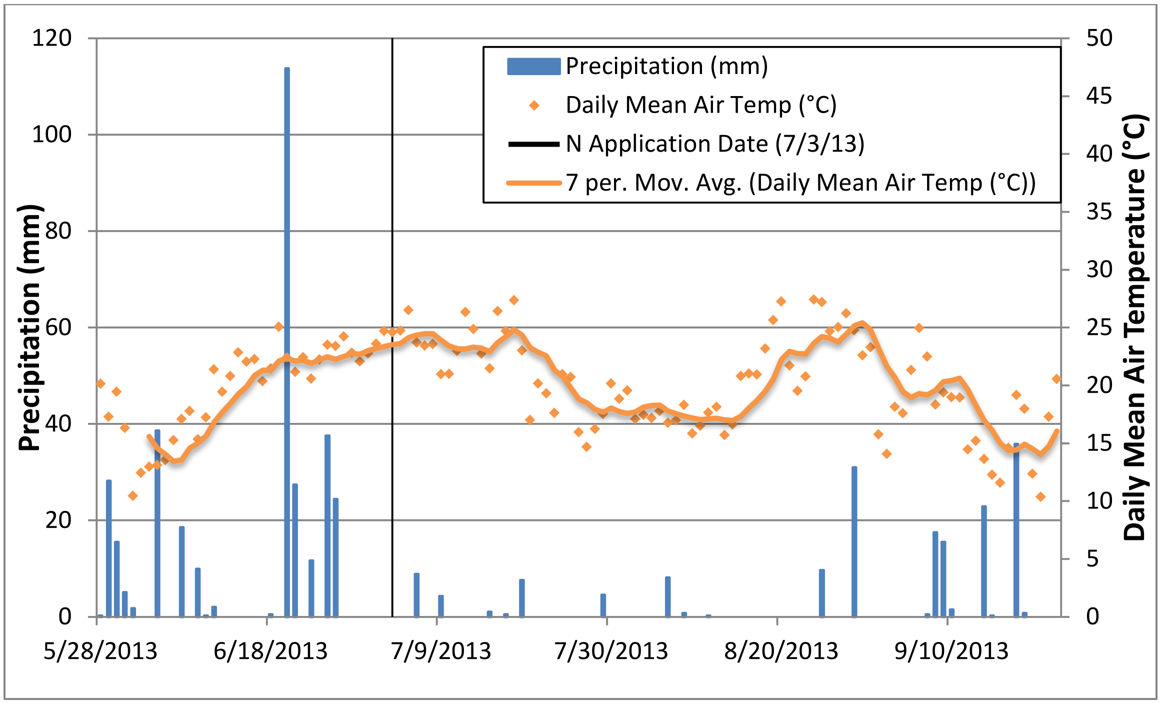

Figure A.11 Weather data for NDAR13.

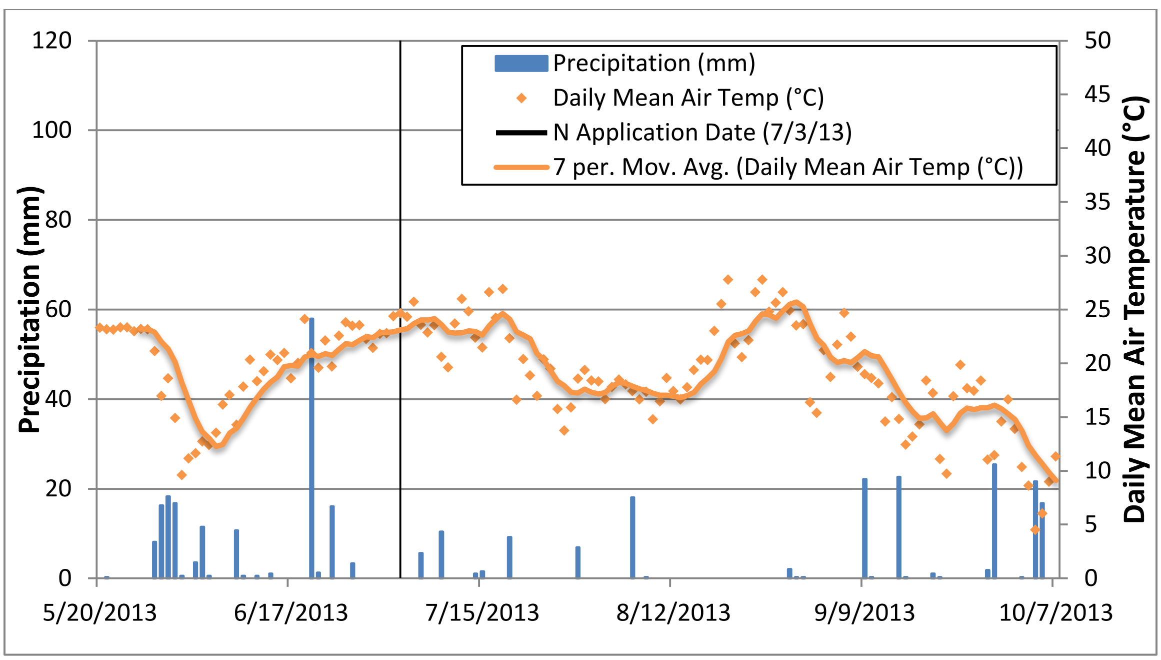

Figure A.12 Weather data for NDVC13.

Appendix B.

Table B.1 User input settings for MORO12. Hybrid relative maturity and planting population varied based on treatment as indicated.

MORO12		
USER INPUT SETTINGS		
Weather Data		
Weather file	Columbia, Mo.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	115*	
Date of planting	2nd week of May	
Plant population	31**	x1000/acre
Price of maize	6.4	/bu
Average yield of last 5 years	170	bu/acre
Last Crop		
Type of crop	Soybean	
Economic yield	50	bu/acre
Time of maturity	2nd half of Sept	
Amount of residues left in the field	All	
Type of N fertilizer aplpied (1)	Anhydrous ammonia	
Amount of N fertilizer aplpied (1)	0	lb N/acre
Tillage		
Type of tillage	Reduced tillage	
Time of tillage operation	1st half of April	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton
% of basal N in total N rate	32.5	%
Time of basal application	2nd half of April	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton

Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	0	lb N/acre
Properties of Top-Soil		
Soil carbon content	1	%
Soil texture	Loam	
Soil bulk density	1.3	g/cm3
Soil acidity	Neutral	
Manuring		
Not applied		
Measured Soil Nitrate to 1 m Depth		
Amount	45	lb N/acre
Time of soil sampling	1st half of May	

* Relative maturity of 115 days was used for hybrid A treatments, and relative maturity of 114 days was used for hybrid B treatments.
** Plant population of 31 was used for low population treatments, and plant population of 41 was used for high population treatments.

Table B.2 Maize-N output for MORO12 hybrid A, low population.

MORO12 Output – Hybrid A, Low Planting Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	154	(±28) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	179	(±32) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	372	(±67) lb fertilizer/acre
N fertilizer cost per acre	111	(±20) /acre
Fertilizer recovery efficiency (RE)	0.58	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	58	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	34	lb maize/lb fertilizer-N
Yield potential (Yp)	214	(±22) bu/acre
Attainable yield (Ya)	178	(±19) bu/acre
Yield without N fertilizer (Y0)	85	(±9) bu/acre
N uptake from indigenous sources	65	lb/acre
contribution from carryover-N	3	lb N/acre
contribution from SOM mineralization	49	lb N/acre
contribution from crop residues mineralization	13	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.3 Maize-N output for MORO12 hybrid A, high population.

MORO12 Output – Hybrid A, High Planting Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	144	(±23) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	178	(±29) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	337	(±54) lb fertilizer/acre
N fertilizer cost per acre	104	(±17) /acre
Fertilizer recovery efficiency (RE)	0.58	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	62	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	36	lb maize/lb fertilizer-N
Yield potential (Yp)	236	(±21) bu/acre
Attainable yield (Ya)	178	(±16) bu/acre
Yield without N fertilizer (Y0)	85	(±8) bu/acre
N uptake from indigenous sources	65	lb/acre
contribution from carryover-N	3	lb N/acre
contribution from SOM mineralization	49	lb N/acre
contribution from crop residues mineralization	13	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.4 Maize-N output for MORO12 hybrid B, low population.

ROMO12 – Hybrid B, Low Planting Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	156	(±29) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	179	(±33) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	380	(±71) lb fertilizer/acre
N fertilizer cost per acre	113	(±21) /acre
Fertilizer recovery efficiency (RE)	0.58	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	58	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	33	lb maize/lb fertilizer-N
Yield potential (Yp)	210	(±23) bu/acre
Attainable yield (Ya)	178	(±19) bu/acre
Yield without N fertilizer (Y0)	85	(±9) bu/acre
N uptake from indigenous sources	65	lb/acre
contribution from carryover-N	3	lb N/acre
contribution from SOM mineralization	49	lb N/acre
contribution from crop residues mineralization	13	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.5 Maize-N output for MORO12 hybrid B, high population.

MORO12 – Hybrid B, High Planting Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	145	(±24) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	179	(±30) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	340	(±57) lb fertilizer/acre
N fertilizer cost per acre	105	(±17) /acre
Fertilizer recovery efficiency (RE)	0.58	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	62	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	36	lb maize/lb fertilizer-N
Yield potential (Yp)	233	(±22) bu/acre
Attainable yield (Ya)	178	(±17) bu/acre
Yield without N fertilizer (Y0)	85	(±8) bu/acre
N uptake from indigenous sources	65	lb/acre
contribution from carryover-N	3	lb N/acre
contribution from SOM mineralization	49	lb N/acre
contribution from crop residues mineralization	13	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.6 User input settings for MOLT12. Hybrid relative maturity and planting population varied based on treatment as indicated.

MOLT12		
USER INPUT SETTINGS		
Weather Data		
Weather file	Columbia, Mo.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	115*	
Date of planting	2nd week of May	
Plant population	31**	x1000/acre
Price of maize	6.4	/bu
Average yield of last 5 years	150	bu/acre
Last Crop		
Type of crop	Soybean	
Economic yield	40	bu/acre
Time of maturity	2nd half of Sept	
Amount of residues left in the field	All	
Type of N fertilizer applied (1)	Anhydrous ammonia	
Amount of N fertilizer applied (1)	0	lb N/acre
Tillage		
Type of tillage	Reduced tillage	
Time of tillage operation	1st half of April	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton
% of basal N in total N rate	41.5	%
Time of basal application	2nd half of April	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton
Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	0	lb N/acre

Properties of Top-Soil		
Soil carbon content	1	%
Soil texture	Loam	
Soil bulk density	1.3	g/cm3
Soil acidity	Acid	
Manuring		
Not applied		
Measured Soil Nitrate to 1 m Depth		
Amount	38.4	lb N/acre
Time of soil sampling	1st half of May	

* Relative maturity of 115 days was used for hybrid A treatments, and relative maturity of 114 days was used for hybrid B treatments.

** Plant population of 31 was used for low population treatments, and plant population of 41 was used for high population treatments.

Table B.7 Maize-N output for MOLT12 hybrid A, low population.

MOLT12 – Hybrid A, Low Planting Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	120	(±23) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	177	(±35) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	250	(±49) lb fertilizer/acre
N fertilizer cost per acre	86	(±17) /acre
Fertilizer recovery efficiency (RE)	0.59	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	62	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	37	lb maize/lb fertilizer-N
Yield potential (Yp)	214	(±22) bu/acre
Attainable yield (Ya)	158	(±16) bu/acre
Yield without N fertilizer (Y0)	79	(±8) bu/acre
N uptake from indigenous sources	61	lb/acre
contribution from carryover-N	1	lb N/acre
contribution from SOM mineralization	49	lb N/acre
contribution from crop residues mineralization	11	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.8 Maize-N output for MOLT12 hybrid A, high population.

MOLT12 – Hybrid A, High Planting Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	114	(±20) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	179	(±31) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	228	(±39) lb fertilizer/acre
N fertilizer cost per acre	82	(±14) /acre
Fertilizer recovery efficiency (RE)	0.59	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	65	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	38	lb maize/lb fertilizer-N
Yield potential (Yp)	236	(±21) bu/acre
Attainable yield (Ya)	158	(±14) bu/acre
Yield without N fertilizer (Y0)	80	(±7) bu/acre
N uptake from indigenous sources	61	lb/acre
contribution from carryover-N	1	lb N/acre
contribution from SOM mineralization	49	lb N/acre
contribution from crop residues mineralization	11	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.9 Maize-N output for MOLT12 hybrid B, low population.

MOLT12 – Hybrid B, Low Planting Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	121	(±24) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	177	(±36) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	254	(±51) lb fertilizer/acre
N fertilizer cost per acre	87	(±18) /acre
Fertilizer recovery efficiency (RE)	0.58	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	62	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	36	lb maize/lb fertilizer-N
Yield potential (Yp)	210	(±23) bu/acre
Attainable yield (Ya)	158	(±17) bu/acre
Yield without N fertilizer (Y0)	79	(±9) bu/acre
N uptake from indigenous sources	61	lb/acre
contribution from carryover-N	1	lb N/acre
contribution from SOM mineralization	49	lb N/acre
contribution from crop residues mineralization	11	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.10 Maize-N output for MOLT12 hybrid B, high population.

MOLT12 – Hybrid B, High Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	115	(±21) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	178	(±32) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	232	(±42) lb fertilizer/acre
N fertilizer cost per acre	83	(±15) /acre
Fertilizer recovery efficiency (RE)	0.59	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	65	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	38	lb maize/lb fertilizer-N
Yield potential (Yp)	233	(±22) bu/acre
Attainable yield (Ya)	158	(±15) bu/acre
Yield without N fertilizer (Y0)	80	(±8) bu/acre
N uptake from indigenous sources	61	lb/acre
contribution from carryover-N	1	lb N/acre
contribution from SOM mineralization	49	lb N/acre
contribution from crop residues mineralization	11	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.11 User input settings for NECC12. Hybrid relative maturity and planting population varied based on treatment as indicated.

NECC12		
USER INPUT SETTINGS		
Weather Data		
Weather file	Clay Center (SC), NE.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	115*	
Date of planting	2nd week of May	
Plant population	32**	x1000/acre
Price of maize	6.4	/bu
Average yield of last 5 years	220	bu/acre
Last Crop		
Type of crop	Corn	
Economic yield	246	bu/acre
Time of maturity	2nd half of Sept	
Amount of residues left in the field	All	
Type of N fertilizer applied (1)	Anhydrous ammonia	
Amount of N fertilizer applied (1)	172	lb N/acre
Type of N fertilizer applied (2)	Ammonium polyphosphate	
Amount of N fertilizer applied (2)	93	lb N/acre
Tillage		
Type of tillage	Reduced tillage	
Time of tillage operation	1st half of April	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton
% of basal N in total N rate	71.5	%
Time of basal application	2nd half of April	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton
Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	10	lb N/acre

Properties of Top-Soil		
Soil carbon content	2.25	%
Soil texture	Loam	
Soil bulk density	1.3	g/cm3
Soil acidity	Neutral	
Manuring		
Not applied		
Measured Soil Nitrate to 1 m Depth		
Amount	131	lb N/acre
Time of soil sampling	2nd half of April	

* Relative maturity of 115 days was used for hybrid A treatments, and relative maturity of 114 days was used for hybrid B treatments.

** Plant population of 32 was used for low population treatments, and plant population of 42 was used for high population treatments.

Table B.12 Maize-N output for NECC12 hybrid A, low population.

NECC12 – Hybrid A, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	105	(±43) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	268	(±111) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	107	(±44) lb fertilizer/acre
N fertilizer cost per acre	76	(±31) /acre
Fertilizer recovery efficiency (RE)	0.60	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	46	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	27	lb maize/lb fertilizer-N
Yield potential (Yp)	256	(±32) bu/acre
Attainable yield (Ya)	231	(±28) bu/acre
Yield without N fertilizer (Y0)	180	(±22) bu/acre
N uptake from indigenous sources	147	lb/acre
contribution from carryover-N	45	lb N/acre
contribution from SOM mineralization	101	lb N/acre
contribution from crop residues mineralization	-6	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	8	lb N/acre

Table B.13 Maize-N output for NECC12 hybrid A, high population.

NECC12 – Hybrid A, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	87	(±41) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	267	(±125) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	43	(±20) lb fertilizer/acre
N fertilizer cost per acre	63	(±29) /acre
Fertilizer recovery efficiency (RE)	0.6 0	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	52	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	31	lb maize/lb fertilizer-N
Yield potential (Yp)	279	(±34) bu/acre
Attainable yield (Ya)	231	(±28) bu/acre
Yield without N fertilizer (Y0)	183	(±22) bu/acre
N uptake from indigenous sources	147	lb/acre
contribution from carryover-N	45	lb N/acre
contribution from SOM mineralization	101	lb N/acre
contribution from crop residues mineralization	-6	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	8	lb N/acre

Table B.14 Maize-N output for NECC12 hybrid B, low population.

NECC12 - Hybrid B, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	108	(±44) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	268	(±109) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	118	(±48) lb fertilizer/acre
N fertilizer cost per acre	78	(±32) /acre
Fertilizer recovery efficiency (RE)	0.60	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	45	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	27	lb maize/lb fertilizer-N
Yield potential (Yp)	254	(±32) bu/acre
Attainable yield (Ya)	231	(±29) bu/acre
Yield without N fertilizer (Y0)	179	(±22) bu/acre
N uptake from indigenous sources	147	lb/acre
contribution from carryover-N	45	lb N/acre
contribution from SOM mineralization	100	lb N/acre
contribution from crop residues mineralization	-6	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	8	lb N/acre

Table B.15 Maize-N output for NECC12 hybrid B, high population.

NECC12 – Hybrid B, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	89	(±41) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	267	(±124) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	51	(±24) lb fertilizer/acre
N fertilizer cost per acre	64	(±30) /acre
Fertilizer recovery efficiency (RE)	0.6 0	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	51	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	31	lb maize/lb fertilizer-N
Yield potential (Yp)	277	(±34) bu/acre
Attainable yield (Ya)	231	(±29) bu/acre
Yield without N fertilizer (Y0)	182	(±23) bu/acre
N uptake from indigenous sources	147	lb/acre
contribution from carryover-N	45	lb N/acre
contribution from SOM mineralization	100	lb N/acre
contribution from crop residues mineralization	-6	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	8	lb N/acre

Table B.16 User input settings for NEMC12. Hybrid relative maturity and planting population varied based on treatment as indicated.

NEMC12		
USER INPUT SETTINGS		
Weather Data		
Weather file	Central City, NE.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	115*	
Date of planting	2nd week of May	
Plant population	32**	x1000/acre
Price of maize	6.4	/bu
Average yield of last 5 years	180	bu/acre
Last Crop		
Type of crop	Corn	
Economic yield	180	bu/acre
Time of maturity	2nd half of Sept	
Amount of residues left in the field	All	
Type of N fertilizer applied (1)	Anhydrous ammonia	
Amount of N fertilizer applied (1)	243	lb N/acre
Tillage		
Type of tillage	Reduced tillage	
Time of tillage operation	1st half of April	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton
% of basal N in total N rate	50.25	%
Time of basal application	2nd half of April	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton
Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	24	lb N/acre
Properties of Top-Soil		
Soil carbon content	1	%
Soil texture	Sandy	

Soil bulk density	1.3	g/cm3
Soil acidity	Neutral	
Manuring		
Not applied		
Measured Soil Nitrate to 1 m Depth		
Amount	67	lb N/acre
Time of soil sampling	2nd half of April	

* Relative maturity of 115 days was used for hybrid A treatments, and relative maturity of 114 days was used for hybrid B treatments.

** Plant population of 32 was used for low population treatments, and plant population of 42 was used for high population treatments.

Table B.17 Maize-N output for NEMC12 hybrid A, low population.

NEMC12 – Hybrid A, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	149	(±37) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	268	(±67) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	265	(±66) lb fertilizer/acre
N fertilizer cost per acre	108	(±27) /acre
Fertilizer recovery efficiency (RE)	0.47	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	62	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	29	lb maize/lb fertilizer-N
Yield potential (Yp)	266	(±30) bu/acre
Attainable yield (Ya)	189	(±21) bu/acre
Yield without N fertilizer (Y0)	111	(±12) bu/acre
N uptake from indigenous sources	85	lb/acre
contribution from carryover-N	25	lb N/acre
contribution from SOM mineralization	45	lb N/acre
contribution from crop residues mineralization	-5	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	19	lb N/acre

Table B.18 Maize-N output for NEMC12 hybrid A, high population.

NEMC12 – Hybrid A, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	143	(±37) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	269	(±69) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	243	(±63) lb fertilizer/acre
N fertilizer cost per acre	103	(±27) /acre
Fertilizer recovery efficiency (RE)	0.47	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	65	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	30	lb maize/lb fertilizer-N
Yield potential (Yp)	288	(±33) bu/acre
Attainable yield (Ya)	189	(±22) bu/acre
Yield without N fertilizer (Y0)	111	(±13) bu/acre
N uptake from indigenous sources	85	lb/acre
contribution from carryover-N	25	lb N/acre
contribution from SOM mineralization	45	lb N/acre
contribution from crop residues mineralization	-5	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	19	lb N/acre

Table B.19 Maize-N output for NEMC12 hybrid B, low population.

NEMC12 – Hybrid B, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	151	(±37) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	269	(±67) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	269	(±67) lb fertilizer/acre
N fertilizer cost per acre	109	(±27) /acre
Fertilizer recovery efficiency (RE)	0.47	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	62	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	29	lb maize/lb fertilizer-N
Yield potential (Yp)	263	(±30) bu/acre
Attainable yield (Ya)	189	(±21) bu/acre
Yield without N fertilizer (Y0)	110	(±12) bu/acre
N uptake from indigenous sources	85	lb/acre
contribution from carryover-N	25	lb N/acre
contribution from SOM mineralization	45	lb N/acre
contribution from crop residues mineralization	-5	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	19	lb N/acre

Table B.20 Maize-N output for NEMC12 hybrid B, high population.

NEMC12 – Hybrid B, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/25/2012		
Economically optimal N rate (EONR) of fertilizer	145	(±37) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	268	(±69) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	248	(±63) lb fertilizer/acre
N fertilizer cost per acre	104	(±27) /acre
Fertilizer recovery efficiency (RE)	0.47	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	64	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	30	lb maize/lb fertilizer-N
Yield potential (Yp)	285	(±32) bu/acre
Attainable yield (Ya)	189	(±22) bu/acre
Yield without N fertilizer (Y0)	111	(±13) bu/acre
N uptake from indigenous sources	85	lb/acre
contribution from carryover-N	25	lb N/acre
contribution from SOM mineralization	45	lb N/acre
contribution from crop residues mineralization	-5	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	19	lb N/acre

Table B.21 User input settings for NDDN12. Hybrid relative maturity and planting population varied based on treatment as indicated.

NDDN12		
USER INPUT SETTINGS (setting file: Durbin, ND.stg)		
Weather Data		
Weather file	Fargo, ND.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	87*	
Date of planting	4th week of April	
Plant population	32**	x1000/acre
Price of maize	6.4	/bu
Average yield of last 5 years	160	bu/acre
Last Crop		
Type of crop	Corn	
Economic yield	80	bu/acre
Time of maturity	2nd half of Sept	
Amount of residues left in the field	All	
Type of N fertilizer applied (1)	Urea (liquid)	
Amount of N fertilizer applied (1)	265	lb N/acre
Type of N fertilizer applied (2)	Ammonium sulfate	
Amount of N fertilizer applied (2)	82	lb N/acre
Tillage		
Type of tillage	Reduced tillage	
Time of tillage operation	1st half of April	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton
% of basal N in total N rate	0	%
Time of basal application	2nd half of April	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton
Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	0	lb N/acre

Properties of Top-Soil		
Soil carbon content	3	%
Soil texture	Clay	
Soil bulk density	1.2	g/cm3
Soil acidity	Alkaline	
Manuring		
Not applied		
Measured Soil Nitrate to 1 m Depth		
Amount	45	lb N/acre
Time of soil sampling	1st half of April	

* Relative maturity of 87 days was used for hybrid A treatments, and relative maturity of 89 days was used for hybrid B treatments.

** Plant population of 32 was used for low population treatments, and plant population of 35 was used for high population treatments.

Table B.22 Maize-N output for NDDN12 hybrid A, low population.

NDDN12 – Hybrid A, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2012		
Economically optimal N rate (EONR) of fertilizer	182	(±33) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	649	(±117) lb fertilizer/acre
N fertilizer cost per acre	131	(±24) /acre
Fertilizer recovery efficiency (RE)	0.51	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	58	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	30	lb maize/lb fertilizer-N
Yield potential (Yp)	195	(±22) bu/acre
Attainable yield (Ya)	168	(±19) bu/acre
Yield without N fertilizer (Y0)	72	(±8) bu/acre
N uptake from indigenous sources	55	lb/acre
contribution from carryover-N	37	lb N/acre
contribution from SOM mineralization	19	lb N/acre
contribution from crop residues mineralization	-1	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.23 Maize-N output for NDDN12 hybrid A, high population.

NDDN12 – Hybrid A, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2012		
Economically optimal N rate (EONR) of fertilizer	177	(±32) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	632	(±115) lb fertilizer/acre
N fertilizer cost per acre	128	(±23) /acre
Fertilizer recovery efficiency (RE)	0.51	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	59	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	30	lb maize/lb fertilizer-N
Yield potential (Yp)	202	(±23) bu/acre
Attainable yield (Ya)	168	(±19) bu/acre
Yield without N fertilizer (Y0)	72	(±8) bu/acre
N uptake from indigenous sources	55	lb/acre
contribution from carryover-N	37	lb N/acre
contribution from SOM mineralization	19	lb N/acre
contribution from crop residues mineralization	-1	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.24 Maize-N output for NDDN12 hybrid B, low population.

NDDN12 – Hybrid B, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2012		
Economically optimal N rate (EONR) of fertilizer	176	(±35) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	630	(±126) lb fertilizer/acre
N fertilizer cost per acre	127	(±25) /acre
Fertilizer recovery efficiency (RE)	0.51	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	60	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	31	lb maize/lb fertilizer-N
Yield potential (Yp)	203	(±25) bu/acre
Attainable yield (Ya)	168	(±21) bu/acre
Yield without N fertilizer (Y0)	72	(±9) bu/acre
N uptake from indigenous sources	55	lb/acre
contribution from carryover-N	37	lb N/acre
contribution from SOM mineralization	19	lb N/acre
contribution from crop residues mineralization	-1	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.25 Maize-N output for NDDN12 hybrid B, high population.

NDDN12 – Hybrid B, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2012		
Economically optimal N rate (EONR) of fertilizer	173	(±35) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	616	(±124) lb fertilizer/acre
N fertilizer cost per acre	125	(±25) /acre
Fertilizer recovery efficiency (RE)	0.51	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	61	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	31	lb maize/lb fertilizer-N
Yield potential (Yp)	209	(±26) bu/acre
Attainable yield (Ya)	168	(±21) bu/acre
Yield without N fertilizer (Y0)	72	(±9) bu/acre
N uptake from indigenous sources	55	lb/acre
contribution from carryover-N	37	lb N/acre
contribution from SOM mineralization	19	lb N/acre
contribution from crop residues mineralization	-1	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.26 User input settings for NDVC12. Hybrid relative maturity and planting population varied based on treatment as indicated.

NDVC12		
USER INPUT SETTINGS		
Weather Data		
Weather file	Fargo, ND.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	87*	
Date of planting	4th week of April	
Plant population	24**	x1000/acre
Price of maize	6.4	/bu
Average yield of last 5 years	145	bu/acre
Last Crop		
Type of crop	Wheat	
Economic yield	60	bu/acre
Time of maturity	2nd half of Sept	
Amount of residues left in the field	All	
Type of N fertilizer applied (1)	Anhydrous ammonia	
Amount of N fertilizer applied (1)	85	lb N/acre
Tillage		
Type of tillage	No-till	
Time of tillage operation	1st half of April	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton
% of basal N in total N rate	0	%
Time of basal application	2nd half of April	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	405	/ton
Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	0	lb N/acre
Properties of Top-Soil		
Soil carbon content	2	%
Soil texture	Sandy	

Soil bulk density	1.3	g/cm3
Soil acidity	Neutral	

Manuring
Not applied

Measured Soil Nitrate to 1 m Depth

Amount	73	lb N/acre
Time of soil sampling	1st half of April	

* Relative maturity of 87 days was used for hybrid A treatments, and relative maturity of 89 days was used for hybrid B treatments.

** Plant population of 24 was used for low population treatments, and plant population of 31 was used for high population treatments.

Table B.27 Maize-N output for NDVC12 hybrid A, low population.

NDVC12 – Hybrid A, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/30/2012		
Economically optimal N rate (EONR) of fertilizer	194	(±37) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	692	(±131) lb fertilizer/acre
N fertilizer cost per acre	140	(±26) /acre
Fertilizer recovery efficiency (RE)	0.46	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	53	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	24	lb maize/lb fertilizer-N
Yield potential (Yp)	165	(±20) bu/acre
Attainable yield (Ya)	152	(±18) bu/acre
Yield without N fertilizer (Y0)	69	(±8) bu/acre
N uptake from indigenous sources	53	lb/acre
contribution from carryover-N	40	lb N/acre
contribution from SOM mineralization	13	lb N/acre
contribution from crop residues mineralization	-1	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.28 Maize-N output for NDVC12 hybrid A, high population.

NDVC12 – Hybrid A, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/30/2012		
Economically optimal N rate (EONR) of fertilizer	167	(±32) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	596	(±114) lb fertilizer/acre
N fertilizer cost per acre	120	(±23) /acre
Fertilizer recovery efficiency (RE)	0.46	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	61	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	28	lb maize/lb fertilizer-N
Yield potential (Yp)	193	(±22) bu/acre
Attainable yield (Ya)	152	(±17) bu/acre
Yield without N fertilizer (Y0)	69	(±8) bu/acre
N uptake from indigenous sources	53	lb/acre
contribution from carryover-N	40	lb N/acre
contribution from SOM mineralization	13	lb N/acre
contribution from crop residues mineralization	-1	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.29 Maize-N output for NDVC12 hybrid B, low population.

NDVC12 – Hybrid B, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/30/2012		
Economically optimal N rate (EONR) of fertilizer	183	(±39) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	655	(±141) lb fertilizer/acre
N fertilizer cost per acre	132	(±28) /acre
Fertilizer recovery efficiency (RE)	0.46	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	56	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	25	lb maize/lb fertilizer-N
Yield potential (Yp)	172	(±23) bu/acre
Attainable yield (Ya)	152	(±20) bu/acre
Yield without N fertilizer (Y0)	69	(±9) bu/acre
N uptake from indigenous sources	53	lb/acre
contribution from carryover-N	40	lb N/acre
contribution from SOM mineralization	13	lb N/acre
contribution from crop residues mineralization	-1	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.30 Maize-N output for NDVC12 hybrid B, high population.

NDVC12 – Hybrid B, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/30/2012		
Economically optimal N rate (EONR) of fertilizer	163	(±35) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	583	(±124) lb fertilizer/acre
N fertilizer cost per acre	118	(±25) /acre
Fertilizer recovery efficiency (RE)	0.46	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	62	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	28	lb maize/lb fertilizer-N
Yield potential (Yp)	200	(±25) bu/acre
Attainable yield (Ya)	152	(±19) bu/acre
Yield without N fertilizer (Y0)	70	(±9) bu/acre
N uptake from indigenous sources	53	lb/acre
contribution from carryover-N	40	lb N/acre
contribution from SOM mineralization	13	lb N/acre
contribution from crop residues mineralization	-1	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.31 User input settings for MOTR13. Hybrid relative maturity and planting population varied based on treatment as indicated.

MOTR13		
USER INPUT SETTINGS		
Weather Data		
Weather file	Columbia 6,28,13.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	115*	
Date of planting	3rd week of May	
Plant population	31**	x1000/acre
Price of maize	5.65	/bu
Average yield of last 5 years	210	bu/acre
Last Crop		
Type of crop	Soybean	
Economic yield	40	bu/acre
Time of maturity	2nd half of Sept	
Amount of residues left in the field	A quarter	
Type of N fertilizer applied (1)	Urea ammonium nitrate (UAN 32%)	
Amount of N fertilizer applied (1)	0	lb N/acre
Tillage		
Type of tillage	Reduced tillage	
Time of tillage operation	1st half of May	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
% of basal N in total N rate	23	%
Time of basal application	2nd half of May	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	20	lb N/acre
Properties of Top-Soil		
Soil carbon content	1.1	%

Soil texture	Loam	
Soil bulk density	1.3	g/cm3
Soil acidity	Neutral	

Manuring
Not applied

Measured Soil Nitrate to 1 m Depth
Not measured

* Relative maturity of 115 days was used for hybrid A treatments, and relative maturity of 114 days was used for hybrid B treatments.

** Plant population of 31 was used for low population treatments, and plant population of 41 was used for high population treatments.

Table B.32 Maize-N output for MOTR13 hybrid A, low population.

MOTR13 – Hybrid A, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	221	(±37) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	182	(±30) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	608	(±101) lb fertilizer/acre
N fertilizer cost per acre	148	(±25) /acre
Fertilizer recovery efficiency (RE)	0.58	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	54	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	31	lb maize/lb fertilizer-N
Yield potential (Yp)	243	(±26) bu/acre
Attainable yield (Ya)	220	(±23) bu/acre
Yield without N fertilizer (Y0)	97	(±10) bu/acre
N uptake from indigenous sources (using current season weather data)	74	lb/acre
contribution from carryover-N	0	lb N/acre
contribution from SOM mineralization	54	lb N/acre
contribution from crop residues mineralization	5	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	16	lb N/acre

Table B.33 Maize-N output for MOTR13 hybrid A, high population.

MOTR13 – Hybrid A, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	231	(±33) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	181	(±26) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	642	(±92) lb fertilizer/acre
N fertilizer cost per acre	155	(±22) /acre
Fertilizer recovery efficiency (RE)	0.58	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	52	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	30	lb maize/lb fertilizer-N
Yield potential (Yp)	236	(±22) bu/acre
Attainable yield (Ya)	220	(±20) bu/acre
Yield without N fertilizer (Y0)	97	(±9) bu/acre
N uptake from indigenous sources (using current season weather data)	74	lb/acre
contribution from carryover-N	0	lb N/acre
contribution from SOM mineralization	54	lb N/acre
contribution from crop residues mineralization	5	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	16	lb N/acre

Table B.34 Maize-N output for MOTR13 hybrid B, low population.

MOTR13 – Hybrid B, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	222	(±40) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	174	(±31) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	618	(±111) lb fertilizer/acre
N fertilizer cost per acre	149	(±27) /acre
Fertilizer recovery efficiency (RE)	0.58	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	54	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	31	lb maize/lb fertilizer-N
Yield potential (Yp)	243	(±28) bu/acre
Attainable yield (Ya)	220	(±25) bu/acre
Yield without N fertilizer (Y0)	96	(±11) bu/acre
N uptake from indigenous sources (using current season weather data)	74	lb/acre
contribution from carryover-N	0	lb N/acre
contribution from SOM mineralization	53	lb N/acre
contribution from crop residues mineralization	5	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	16	lb N/acre

Table B.35 Maize-N output for MOTR13 hybrid B, high population.

MOTR13 – Hybrid B, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	238	(±36) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	179	(±27) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	673	(±103) lb fertilizer/acre
N fertilizer cost per acre	160	(±24) /acre
Fertilizer recovery efficiency (RE)	0.58	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	51	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	29	lb maize/lb fertilizer-N
Yield potential (Yp)	232	(±23) bu/acre
Attainable yield (Ya)	220	(±22) bu/acre
Yield without N fertilizer (Y0)	96	(±10) bu/acre
N uptake from indigenous sources (using current season weather data)	74	lb/acre
contribution from carryover-N	0	lb N/acre
contribution from SOM mineralization	53	lb N/acre
contribution from crop residues mineralization	5	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	16	lb N/acre

Table B.36 User input settings for MOBA13. Hybrid relative maturity and planting population varied based on treatment as indicated.

MOBA13		
USER INPUT SETTINGS		
Weather Data		
Weather file	Columbia 7,14,13 for Bay.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	115*	
Date of planting	1st week of June	
Plant population	31**	x1000/acre
Price of maize	5.65	/bu
Average yield of last 5 years	140	bu/acre
Last Crop		
Type of crop	Soybean	
Economic yield	20	bu/acre
Time of maturity	2nd half of Sept	
Amount of residues left in the field	A quarter	
Type of N fertilizer applied (1)	Anhydrous ammonia	
Amount of N fertilizer applied (1)	0	lb N/acre
Tillage		
Type of tillage	No-till	
Time of tillage operation	1st half of May	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
% of basal N in total N rate	50	%
Time of basal application	1st half of June	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	0	lb N/acre
Properties of Top-Soil		
Soil carbon content	1.1	%

Soil texture	Loam	
Soil bulk density	1.32	g/cm3
Soil acidity	Neutral	

Manuring
Not applied

Measured Soil Nitrate to 1 m Depth
Not measured

* Relative maturity of 115 days was used for hybrid A treatments, and relative maturity of 114 days was used for hybrid B treatments.

** Plant population of 31 was used for low population treatments, and plant population of 41 was used for high population treatments.

Table B.37 Maize-N output for MOBA13 hybrid A, low population.

MOBA13 – Hybrid A, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 7/15/2013		
Economically optimal N rate (EONR) of fertilizer	99	(±24) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	177	(±42) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	177	(±42) lb fertilizer/acre
N fertilizer cost per acre	66	(±16) /acre
Fertilizer recovery efficiency (RE)	0.58	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	65	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	38	lb maize/lb fertilizer-N
Yield potential (Yp)	220	(±26) bu/acre
Attainable yield (Ya)	147	(±17) bu/acre
Yield without N fertilizer (Y0)	80	(±9) bu/acre
N uptake from indigenous sources (using current season weather data)	61	lb/acre
contribution from carryover-N	0	lb N/acre
contribution from SOM mineralization	59	lb N/acre
contribution from crop residues mineralization	2	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.38 Maize-N output for MOBA13 hybrid A, high population.

MOBA13 – Hybrid A, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 7/15/2013		
Economically optimal N rate (EONR) of fertilizer	96	(±22) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	178	(±41) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	164	(±37) lb fertilizer/acre
N fertilizer cost per acre	64	(±15) /acre
Fertilizer recovery efficiency (RE)	0.59	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	67	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	39	lb maize/lb fertilizer-N
Yield potential (Yp)	242	(±26) bu/acre
Attainable yield (Ya)	147	(±16) bu/acre
Yield without N fertilizer (Y0)	80	(±9) bu/acre
N uptake from indigenous sources (using current season weather data)	61	lb/acre
contribution from carryover-N	0	lb N/acre
contribution from SOM mineralization	59	lb N/acre
contribution from crop residues mineralization	2	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.39 Maize-N output for MOBA13 hybrid B, low population.

MOBA13 – Hybrid B, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 7/15/2013		
Economically optimal N rate (EONR) of fertilizer	100	(±24) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	179	(±42) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	179	(±42) lb fertilizer/acre
N fertilizer cost per acre	67	(±16) /acre
Fertilizer recovery efficiency (RE)	0.58	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	64	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	38	lb maize/lb fertilizer-N
Yield potential (Yp)	218	(±25) bu/acre
Attainable yield (Ya)	147	(±17) bu/acre
Yield without N fertilizer (Y0)	80	(±9) bu/acre
N uptake from indigenous sources (using current season weather data)	61	lb/acre
contribution from carryover-N	0	lb N/acre
contribution from SOM mineralization	59	lb N/acre
contribution from crop residues mineralization	2	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.40 Maize-N output for MOBA13 hybrid B, high population.

MOBA13 – Hybrid B, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 7/15/2013		
Economically optimal N rate (EONR) of fertilizer	97	(±22) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	180	(±40) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	166	(±37) lb fertilizer/acre
N fertilizer cost per acre	65	(±15) /acre
Fertilizer recovery efficiency (RE)	0.59	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	66	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	39	lb maize/lb fertilizer-N
Yield potential (Yp)	239	(±26) bu/acre
Attainable yield (Ya)	147	(±16) bu/acre
Yield without N fertilizer (Y0)	80	(±9) bu/acre
N uptake from indigenous sources (using current season weather data)	61	lb/acre
contribution from carryover-N	0	lb N/acre
contribution from SOM mineralization	59	lb N/acre
contribution from crop residues mineralization	2	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.41 User input settings for NECC13. Hybrid relative maturity and planting population varied based on treatment as indicated.

NECC13		
USER INPUT SETTINGS		
Weather Data		
Weather file	clay center 6,28,13.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	115	
Date of planting	2nd week of May	
Plant population	32	x1000/acre
Price of maize	5.65	/bu
Average yield of last 5 years	220	bu/acre
Last Crop		
Type of crop	Soybean	
Economic yield	70	bu/acre
Time of maturity	1st half of Sept	
Amount of residues left in the field	All	
Type of N fertilizer applied (1)	Ammonium polyphosphate	
Amount of N fertilizer applied (1)	110	lb N/acre
Tillage		
Type of tillage	Reduced tillage	
Time of tillage operation	2nd half of June	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
% of basal N in total N rate	43	%
Time of basal application	1st half of April	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	8.4	lb N/acre
Properties of Top-Soil		
Soil carbon content	1.6	%
Soil texture	Loam	

Soil bulk density	1.5	g/cm3
Soil acidity	Neutral	
Manuring		
Not applied		
Measured Soil Nitrate to 1 m Depth		
Amount	27	lb N/acre
Time of soil sampling	2nd half of March	

* Relative maturity of 115 days was used for hybrid A treatments, and relative maturity of 114 days was used for hybrid B treatments.

** Plant population of 32 was used for low population treatments, and plant population of 42 was used for high population treatments.

Table B.42 Maize-N output for NECC13 hybrid A, low population.

NECC13 – Hybrid A, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	173	(±43) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	266	(±66) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	353	(±88) lb fertilizer/acre
N fertilizer cost per acre	116	(±29) /acre
Fertilizer recovery efficiency (RE)	0.59	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	52	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	31	lb maize/lb fertilizer-N
Yield potential (Yp)	259	(±32) bu/acre
Attainable yield (Ya)	231	(±28) bu/acre
Yield without N fertilizer (Y0)	136	(±17) bu/acre
N uptake from indigenous sources (using current season weather data)	107	lb/acre
contribution from carryover-N	-5	lb N/acre
contribution from SOM mineralization	89	lb N/acre
contribution from crop residues mineralization	16	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	7	lb N/acre

Table B.43 Maize-N output for NECC13 hybrid A, high population.

NECC13 – Hybrid A, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	156	(±41) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	267	(±70) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	290	(±76) lb fertilizer/acre
N fertilizer cost per acre	104	(±27) /acre
Fertilizer recovery efficiency (RE)	0.59	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	57	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	34	lb maize/lb fertilizer-N
Yield potential (Yp)	282	(±34) bu/acre
Attainable yield (Ya)	231	(±28) bu/acre
Yield without N fertilizer (Y0)	137	(±17) bu/acre
N uptake from indigenous sources (using current season weather data)	107	lb/acre
contribution from carryover-N	-5	lb N/acre
contribution from SOM mineralization	89	lb N/acre
contribution from crop residues mineralization	16	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	7	lb N/acre

Table B.44 Maize-N output for NECC13 hybrid B, low population.

NECC13 – Hybrid B, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	178	(±43) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	268	(±65) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	369	(±90) lb fertilizer/acre
N fertilizer cost per acre	119	(±29) /acre
Fertilizer recovery efficiency (RE)	0.59	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	51	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	30	lb maize/lb fertilizer-N
Yield potential (Yp)	256	(±31) bu/acre
Attainable yield (Ya)	231	(±28) bu/acre
Yield without N fertilizer (Y0)	135	(±16) bu/acre
N uptake from indigenous sources (using current season weather data)	106	lb/acre
contribution from carryover-N	-5	lb N/acre
contribution from SOM mineralization	88	lb N/acre
contribution from crop residues mineralization	16	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	7	lb N/acre

Table B.45 Maize-N output for NECC13 hybrid B, high population.

NECC13 – Hybrid B, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	159	(±41) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	268	(±68) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	302	(±77) lb fertilizer/acre
N fertilizer cost per acre	107	(±27) /acre
Fertilizer recovery efficiency (RE)	0.59	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	57	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	33	lb maize/lb fertilizer-N
Yield potential (Yp)	279	(±34) bu/acre
Attainable yield (Ya)	231	(±28) bu/acre
Yield without N fertilizer (Y0)	136	(±16) bu/acre
N uptake from indigenous sources (using current season weather data)	106	lb/acre
contribution from carryover-N	-5	lb N/acre
contribution from SOM mineralization	88	lb N/acre
contribution from crop residues mineralization	16	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	7	lb N/acre

Table B.46 User input settings for NEMC13. Hybrid relative maturity and planting population varied based on treatment as indicated.

NEMC13		
USER INPUT SETTINGS		
Weather Data		
Weather file	grand island 6,28,13.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	115*	
Date of planting	2nd week of May	
Plant population	32**	x1000/acre
Price of maize	5.65	/bu
Average yield of last 5 years	200	bu/acre
Last Crop		
Type of crop	Corn	
Economic yield	200	bu/acre
Time of maturity	2nd half of Sept	
Amount of residues left in the field	Three quarters	
Type of N fertilizer aplpied (1)	Urea ammonium nitrate (UAN 32%)	
Amount of N fertilizer aplpied (1)	547	lb N/acre
Tillage		
Type of tillage	Reduced tillage	
Time of tillage operation	1st half of May	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
% of basal N in total N rate	40	%
Time of basal application	2nd half of April	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	20	lb N/acre
Properties of Top-Soil		
Soil carbon content	1.2	%

Soil texture	Sandy	
Soil bulk density	1.5	g/cm3
Soil acidity	Neutral	
Manuring		
Not applied		
Measured Soil Nitrate to 1 m Depth		
Amount	64	lb N/acre
Time of soil sampling	2nd half of March	

* Relative maturity of 115 days was used for hybrid A treatments, and relative maturity of 114 days was used for hybrid B treatments.

** Plant population of 32 was used for low population treatments, and plant population of 42 was used for high population treatments.

Table B.47 Maize-N output for NEMC13 hybrid A, low population.

NEMC13 – Hybrid A, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	185	(±42) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	265	(±61) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	397	(±91) lb fertilizer/acre
N fertilizer cost per acre	124	(±28) /acre
Fertilizer recovery efficiency (RE)	0.47	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	60	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	28	lb maize/lb fertilizer-N
Yield potential (Yp)	269	(±30) bu/acre
Attainable yield (Ya)	210	(±23) bu/acre
Yield without N fertilizer (Y0)	118	(±13) bu/acre
N uptake from indigenous sources (using current season weather data)	91	lb/acre
contribution from carryover-N	19	lb N/acre
contribution from SOM mineralization	61	lb N/acre
contribution from crop residues mineralization	-6	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	16	lb N/acre

Table B.48 Maize-N output for NEMC13 hybrid A, high population.

NEMC13 – Hybrid A, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	176	(±43) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	270	(±66) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	357	(±87) lb fertilizer/acre
N fertilizer cost per acre	118	(±29) /acre
Fertilizer recovery efficiency (RE)	0.47	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	63	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	29	lb maize/lb fertilizer-N
Yield potential (Yp)	293	(±34) bu/acre
Attainable yield (Ya)	210	(±24) bu/acre
Yield without N fertilizer (Y0)	118	(±14) bu/acre
N uptake from indigenous sources (using current season weather data)	91	lb/acre
contribution from carryover-N	19	lb N/acre
contribution from SOM mineralization	61	lb N/acre
contribution from crop residues mineralization	-6	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	16	lb N/acre

Table B.49 Maize-N output for NEMC13 hybrid B, low population.

NEMC13 – Hybrid B, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	189	(±41) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	270	(±59) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	405	(±88) lb fertilizer/acre
N fertilizer cost per acre	127	(±27) /acre
Fertilizer recovery efficiency (RE)	0.47	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	59	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	28	lb maize/lb fertilizer-N
Yield potential (Yp)	264	(±28) bu/acre
Attainable yield (Ya)	210	(±23) bu/acre
Yield without N fertilizer (Y0)	117	(±13) bu/acre
N uptake from indigenous sources (using current season weather data)	90	lb/acre
contribution from carryover-N	19	lb N/acre
contribution from SOM mineralization	61	lb N/acre
contribution from crop residues mineralization	-6	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	16	lb N/acre

Table B.50 Maize-N output for NEMC13 hybrid B, high population.

NEMC13 – Hybrid B, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 6/29/2013		
Economically optimal N rate (EONR) of fertilizer	178	(±40) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	267	(±61) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	369	(±84) lb fertilizer/acre
N fertilizer cost per acre	119	(±27) /acre
Fertilizer recovery efficiency (RE)	0.47	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	62	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	29	lb maize/lb fertilizer-N
Yield potential (Yp)	288	(±31) bu/acre
Attainable yield (Ya)	210	(±23) bu/acre
Yield without N fertilizer (Y0)	118	(±13) bu/acre
N uptake from indigenous sources (using current season weather data)	90	lb/acre
contribution from carryover-N	19	lb N/acre
contribution from SOM mineralization	61	lb N/acre
contribution from crop residues mineralization	-6	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	16	lb N/acre

Table B.51 User input settings for NDVC13. Hybrid relative maturity and planting population varied based on treatment as indicated.

NDVC13		
USER INPUT SETTINGS		
Weather Data		
Weather file	fingal for valley city 6,30,13.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	89*	
Date of planting	3rd week of May	
Plant population	32**	x1000/acre
Price of maize	5.65	/bu
Average yield of last 5 years	140	bu/acre
Last Crop		
Type of crop	Wheat	
Economic yield	70	bu/acre
Time of maturity	2nd half of Aug	
Amount of residues left in the field	Three quarters	
Type of N fertilizer applied (1)	Anhydrous ammonia	
Amount of N fertilizer applied (1)	95	lb N/acre
Tillage		
Type of tillage	No-till	
Time of tillage operation	1st half of May	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
% of basal N in total N rate	0	%
Time of basal application	2nd half of May	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	0	lb N/acre
Properties of Top-Soil		
Soil carbon content	2.1	%

Soil texture	Sandy	
Soil bulk density	1.55	g/cm3
Soil acidity	Neutral	
Manuring		
Not applied		
Measured Soil Nitrate to 1 m Depth		
Amount	113	lb N/acre
Time of soil sampling	1st half of May	

* Relative maturity of 89 days was used for hybrid A treatments, and relative maturity of 89 days was used for hybrid B treatments.

** Plant population of 32 was used for low population treatments, and plant population of 42 was used for high population treatments.

Table B.52 Maize-N output for NDVC13 hybrid A and B, low population.

NDVC13 – Hybrid A and B, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 7/1/2013		
Economically optimal N rate (EONR) of fertilizer	0	(±41) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	0	(±146) lb fertilizer/acre
N fertilizer cost per acre	0	(±0) /acre
Fertilizer recovery efficiency (RE)	0.46	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	0	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	0	lb maize/lb fertilizer-N
Yield potential (Yp)	207	(±47) bu/acre
Attainable yield (Ya)	147	(±34) bu/acre
Yield without N fertilizer (Y0)	155	(±36) bu/acre
N uptake from indigenous sources (using current season weather data)	130	lb/acre
contribution from carryover-N	28	lb N/acre
contribution from SOM mineralization	104	lb N/acre
contribution from crop residues mineralization	-2	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.53 Maize-N output for NDVC13 hybrid A and B, high population.

NDVC13 – Hybrid A and B, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 7/1/2013		
Economically optimal N rate (EONR) of fertilizer	0	(±37) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	0	(±134) lb fertilizer/acre
N fertilizer cost per acre	0	(±0) /acre
Fertilizer recovery efficiency (RE)	0.46	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	0	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	0	lb maize/lb fertilizer-N
Yield potential (Yp)	225	(±54) bu/acre
Attainable yield (Ya)	147	(±35) bu/acre
Yield without N fertilizer (Y0)	158	(±38) bu/acre
N uptake from indigenous sources (using current season weather data)	130	lb/acre
contribution from carryover-N	28	lb N/acre
contribution from SOM mineralization	104	lb N/acre
contribution from crop residues mineralization	-2	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.54 User input settings for NDAR13. Hybrid relative maturity and planting population varied based on treatment as indicated.

NDAR13		
USER INPUT SETTINGS		
Weather Data		
Weather file	prosper for arthur 6,30,13.wth (locally measured)	
The Maize Crop		
Maize hybrid relative maturity (days)	89	
Date of planting	3rd week of May	
Plant population	32	x1000/acre
Price of maize	5.65	/bu
Average yield of last 5 years	150	bu/acre
Last Crop		
Type of crop	Soybean	
Economic yield	45	bu/acre
Time of maturity	2nd half of Sept	
Amount of residues left in the field	A quarter	
Type of N fertilizer aplpied (1)	Anhydrous ammonia	
Amount of N fertilizer aplpied (1)	0	lb N/acre
Tillage		
Type of tillage	Plow/disk	
Time of tillage operation	2nd half of Oct	
Nitrogen Fertilizer Management		
Type of fertilizer for basal application	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
% of basal N in total N rate	0	%
Time of basal application	2nd half of May	
Type of fertilizer for in-season applications	Urea ammonium nitrate (UAN 28%)	
N content of the fertilizer	28	%
Price of the fertilizer	376	/ton
Number of in-season doses	1	
User-imposed overall fertilizer recover efficiency	N/A	
N from irrigation water	0	lb N/acre
Properties of Top-Soil		
Soil carbon content	2	%
Soil texture	Clay	

Soil bulk density	1.5	g/cm3
Soil acidity	Alkaline	
Manuring		
Not applied		
Measured Soil Nitrate to 1 m Depth		
Amount	66	lb N/acre
Time of soil sampling	1st half of May	

* Relative maturity of 89 days was used for hybrid A treatments, and relative maturity of 89 days was used for hybrid B treatments.

** Plant population of 32 was used for low population treatments, and plant population of 42 was used for high population treatments.

Table B.55 Maize-N output for NDAR13 hybrid A and B, low population.

NDAR13 – Hybrid A and B, Low Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 7/1/2013		
Economically optimal N rate (EONR) of fertilizer	78	(±82) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	280	(±291) lb fertilizer/acre
N fertilizer cost per acre	52	(±55) /acre
Fertilizer recovery efficiency (RE)	0.51	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	52	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	27	lb maize/lb fertilizer-N
Yield potential (Yp)	189	(±58) bu/acre
Attainable yield (Ya)	158	(±48) bu/acre
Yield without N fertilizer (Y0)	120	(±37) bu/acre
N uptake from indigenous sources (using current season weather data)	96	lb/acre
contribution from carryover-N	17	lb N/acre
contribution from SOM mineralization	74	lb N/acre
contribution from crop residues mineralization	5	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Table B.56 Maize-N output for NDAR13 hybrid A and B, high population.

NDAR13 – Hybrid A and B, High Plant Population		
Maize-N' recommendation of nitrogen (N) fertilizer rate for maize		
Date: 7/1/2013		
Economically optimal N rate (EONR) of fertilizer	69	(±80) lb N/acre
N fertilizer rates:		
Basal application (Urea ammonium nitrate (UAN 28%))	0	(±0) lb fertilizer/acre
In-season applications (Urea ammonium nitrate (UAN 28%))	248	(±285) lb fertilizer/acre
N fertilizer cost per acre	47	(±53) /acre
Fertilizer recovery efficiency (RE)	0.5 1	lb N-uptake/lb N-applied
Physiological efficiency of N-uptake from fertilize (PE)	57	lb maize/lb N-uptake
Agronomic efficiency of fertilizer-N (AE)	29	lb maize/lb fertilizer-N
Yield potential (Yp)	207	(±64) bu/acre
Attainable yield (Ya)	158	(±49) bu/acre
Yield without N fertilizer (Y0)	121	(±38) bu/acre
N uptake from indigenous sources (using current season weather data)	96	lb/acre
contribution from carryover-N	17	lb N/acre
contribution from SOM mineralization	74	lb N/acre
contribution from crop residues mineralization	5	lb N/acre
contribution from manure	0	lb N/acre
contribution from irrigation water	0	lb N/acre

Appendix C.

SAS code for estimation of ONR by linear-plateau.

```
proc import out= yieldall
                  datafile= "C:\Users\S-LSTEVE10\Google Drive\Grad
School\Summaries\EONR by Linear Plateau\Combined_for_lin_plat.xlsx"
                  DBMS=EXCEL Replace;
                  *variables:  year site  plot  trt   rep   hyb
      drtscr      plntpop     nstrat      ininrate inseasn  totn Yield;
                  run;
* need to get a block term;
Data yieldall; set yieldall;
 if plot < 200 then block =1;
 if plot > 200 and plot < 300 then block =2;
 if plot > 300 and plot < 400 then block =3;
 if plot > 400 then block = 4;
 run;

* 1.   get means for N reference;
Data yieldref; set yieldall;
if nstrat ne 'Reference' then delete;
run;
proc sort data=yieldref; by year site;
run;

proc means data=yieldref noprint; by year site;
      class drtscr plntpop;
      var yield;
      output out=meanref mean=;
  run;
* clean up mean dataset and prepare for transposing;
 data meanref2; set meanref;
if _Freq_ = 16 then drtscr = 'all';
if _Freq_ = 16 then plntpop = 64;
if drtscr = '' then drtscr = '_';
if plntpop = . then plntpop = 0;
drop _Type_ _FREQ_;
            run;

* change the means from within a column to multiple columns;
Proc transpose data= meanref2 out=meanref3;
by year site;
id drtscr plntpop;
var Yield;
run;




* 2.  test to see if Reference treatments are different by hyb and
population- for plateau of linear plateau model;
```

```
title 'Nitrogen Rich Reference Results';
proc glm data=yieldref outstat = refstats; by year site;
 class block drtscr plntpop;
 model yield = block drtscr plntpop drtscr*plntpop;
      contrast 'pop within high DroughtScore' plntpop -1 1
drtscr*plntpop -1 1 0 0;
        contrast 'pop within low DroughtScore' plntpop -1 1
drtscr*plntpop 0 0 -1 1;
            lsmeans drtscr plntpop drtscr*plntpop;
run;

Data refstats; set refstats;
drop ss F _Name_ ;
if _Type_= 'SS1' then delete;
if _Type_ = 'ERROR' then delete;
if _Source_ ='block' then delete;
run;

Proc transpose data= refstats out=refstats2;
by year site;
id _Type_ _Source_;
var Prob;
run;


Data mean_and_refstats;
      merge meanref3 refstats2 ; by year site;
      run;

      *step 3-regression work;


data modsen2; set yieldall;
if nstrat = 'Reference' then delete;
if drtscr = 'Low' then HDS = 0;
if drtscr = 'High' then HDS = 1;
if plntpop = 32 then HighPop = 0;
if plntpop = 42 then HighPop = 1;
TN=totN;
N_HDS = TN*HDS;
N_HighPop = TN*HighPop;
HDS_HighPop= HDS*HighPop;
run;

*linear regression;

title 'Stepwise with linear on N included';
Proc reg data=modsen2 outest = regstat; by year site;
  model yield = TN HighPop HDS N_HDS N_HighPop HDS_HighPop / selection
= stepwise sle = .05 sls =.05;
  run;

data regstat; set regstat;
drop yield;
run;
```

```
*'combining 3 datasets: mean of regression stats, plateau mean and
plateau (N reference) stats;
data allcombined;
merge yieldall regstat mean_and_refstats; by year site;
drop F14 _MODEL_ _TYPE_ _DEPVAR_ _RMSE_;
run;


* significant plateau determinations;
data allcombined2; set allcombined;
plateau = all64;
 if SS3drtscr_plntpop <= 0.05 then do;
    if CONTRASTpop_within_high_Drou <=0.05 then do;
            if plntpop = 42 then plateau = High42;
            if plntpop = 32 then plateau = High32; end;
      if CONTRASTpop_within_low_Droug <=0.05 then do;
            if plntpop = 42 then plateau = Low42;
            if plntpop = 32 then plateau = Low32; end; end;
  else do;
      if SS3drtscr <= 0.05 then do;
            if drtscr = 'High' then plateau = High0;
            if drtscr = 'Low' then plateau = Low0; end;
      if SS3plntpop <= 0.05 then do;
            if plntpop = 42 then plateau = _42;
            if plntpop = 32 then plateau = _32; end; end;
run;

* Slope and intercept calculation from regression and then combine with
significant plateau values;
Data allcombined3; set allcombined2;
 * these "if" statements are needed because the output of the stepwise
regression gives missing values if a parameter is not included in the
model;
      if Highpop = . then Highpop = 0;
      if HDS = . then HDS = 0;
      if HDS_HighPop = . then HDS_HighPop = 0;
      if TN = . then TN = 0;
      if N_HDS = . then N_HDS = 0;
      if N_Highpop = . then N_Highpop = 0;

* only interested in sensor and model at this point, so remove the
other;
      if nstrat= 'Reference' then delete;
      if nstrat= 'Check' then delete;

* the meat of the ONR calcuation is here;
      if drtscr = 'Low' and plntpop = 32 then do;
            b = Intercept;
            a = TN; end;
      if drtscr = 'Low' and plntpop = 42 then do;
            b = Intercept + HighPop;
            a = TN + N_Highpop; end;
      if drtscr = 'High' and plntpop = 32 then do;
            b = Intercept + HDS;
            a = TN + N_HDS; end;
      if drtscr = 'High' and plntpop = 42 then do;
            b = Intercept + HighPop + HDS;
```

```
            a = TN + N_Highpop + N_HDS; end;

* cleanup for when ONR will not be solvable;
      if a = 0 then do;
                  ONR = 0; end;
            else do;
                  ONR = (plateau-b)/a; end;
      if ONR < 0 then ONR = 0;
    if ONR = 0 then  Percent_of_ONR = 0;
    if ONR > 0 then Percent_of_ONR = (totN-ONR)/ONR*100 ;
      *maybe could also do on absolute basis as follows (shows
deviation from ORN);
      off = totN - ONR;
      run;


* analysis of variance on ONR;
title 'effect of Sensor and Model on percent ONR';
proc glm data=allcombined3; by year site;
 class block nstrat;
 model Percent_of_ONR = block nstrat;
 model off = block nstrat;
            lsmeans nstrat;
run;
Proc gplot data = allcombined3;
  plot ONR*totN = nstrat;
  plot off*totN = nstrat;
run;
```