A Regional Investigation of Nitrogen Rate Prescription, Hybrid, and Population on Maize Yield and Nitrogen Use

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Introduction

Nitrogen (N), an essential element, is often limiting to plant growth. There is great value in determining the optimum quantity and timing of N application to meet crop needs while minimizing losses. 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. 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 N and is expected to increase NUE. This in-season application also allows for adjustments which can be responsive to actual field and weather conditions which result in varying N needs. 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. 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. Strategies which detect crop N status at early growth stages can also improve NUE. Active crop canopy sensors monitor the N status of the crop, allowing growers to make management decisions that are reactive to actual growing season conditions. The objective of this study was to evaluate these two approaches for determining in-season N rates: Maize-N model and an active crop canopy sensor. 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 study was conducted in 6 fields in 2013. Fields were located in three states: Missouri, Nebraska, and North Dakota. Two experimental sites, in close proximity to each other, were selected in each state. In Missouri, sites were located near Columbia identified as MOBA13 and MOTR13. Nebraska sites were located in central Nebraska near Clay Center (NECC13) and Grand Island (NEMC13). North Dakota sites were located in the eastern part of the state near Arthur (NDAR13) and Valley City (NDVC13). 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. 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 1. Soil series data is shown in Table 2. Select soil fertility values are shown for each site in Table 3.

Table 1: Site productivity potential and agronomic practice arranged by site.

State	Field ID	Site Yield Potential	Row Spacing --meters--	Tillage	Previous Crop
Missouri	**MOTR13**	High	0.76	Field cultivator	Soybeans
	MOBA13	Moderate	0.76	No-till	Soybeans
Nebraska	**NECC13**	High	0.76	Ridge till and cultivate	Soybeans
	NEMC13	Moderate	0.76	Stalk chop	Corn
North Dakota	**NDAR13**	High	0.56	Chisel and field cultivate	Soybeans
	NDVC13	Moderate	0.56	No-till	Wheat

Table 2: Soil series and taxonomic class arranged by site.

Field ID	Soil Series	Taxonomic Class	% Trt Area
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%
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 Coarse-loamy, mixed, superactive, frigid Typic Endoaquolls	37%
NDVC13	Barnes-Svea loams, 0-3%	Fine-loamy, mixed, superactive, frigid Calcic Hapludolls Fine-loamy, mixed, superactive, frigid Pachic Hapludolls	52%
	Swenoda-Barnes complex, 3-6%	Coarse-loamy, mixed, superactive, fridig Pachic Hapludolls Fine-loamy, mixed, superactive, frigid Calcic Hapludolls	48%
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%
	Fonner sandy loam, rarely flooded	Sandy, mixed, mesic Cumulic Haplustolls	18%

Table 3: Select soil fertility values for each site.

Field ID	Organic Matter (%)	P	K	pH	NO_3-N (lbs N/ac 3 ft)
MOTR13	1.90	69 lb/ac **B1P	359 lb/ac	6.8	<20
MOBA13	1.90	27 lb/ac B1P	182 lb/ac	6.8	<20
NDAR13	3.40	5 ppm ***OP	120 ppm	8.0	66 *top 2 feet
NDVC13	3.60	19 ppm OP	160 ppm	6.4	113 *top 2 feet
NECC13	2.8	23 ppm *M3P	428 ppm	6.4	27 *top 2 feet
NEMC13	2.1	29 ppm M3P	212 ppm	7.5	64 *top 2 feet

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

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. Each hybrid was planted at a standard seeding rate and high seeding rate. Hybrids with their drought classifications and low and high seeding rates are reported in Table 4 by site. 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 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. 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.

Table 4: Corn hybrid and planting population arranged by site.

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

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

The model-based treatments used the Maize-N: Nitrogen Recommendation for Maize (Version 2008.1.0, Yang, H.S., et al., University of Nebraska – Lincoln, 2008) software. This model incorporates various user inputted soil properties, agronomic practices, and local weather data to produce the yield potential, attainable yield, and an economic optimum N rate (EONR) recommendation. Separate iterations of the model were run for each hybrid type and planting population at each site. Consequently, up to four unique in-season N recommendations may be returned for each site. 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. The normalized difference red edge index (NDRE) (Equation 1) was calculated for each plot by scanning two rows and averaging the values. The sufficiency index (SI) (Equation 2) was generated by dividing the NDRE from the sensor-based treatment by the NDRE of the N-rich reference treatment which had corresponding hybrids and plant populations.

$$\mathrm{NDRE} = \frac{\mathrm{R_{NIR}} - \mathrm{R_{RED\ EDGE}}}{\mathrm{R_{NIR}} + R_{\mathrm{RED\ EDGE}}} \tag{1}$$

where

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

$$\mathrm{SI} = \frac{\text{NDRE of sensor based treatment}}{\text{NDRE of N rich reference}} \tag{2}$$

The Holland and Schepers modified sensor algorithm (2010, modified 2012) was then used to determine the N application rate. This algorithm uses the SI, crop growth stage, amount of N fertilizer already applied to the sensed crop and the user defined optimum N rate. The optimum N rate for Missouri and Nebraska sites was determined by using the algorithm developed by the University of Nebraska-Lincoln for producers in Nebraska applying a uniform N rate (Equation 3). For North Dakota sites, the North Dakota N recommendation algorithm (Equation 4) was substituted for the University of Nebraska-Lincoln N recommendation algorithm. Of the four sites where the previous crop was soybeans (MOTR13, MOBA13, NECC13, and NDAR13) a soybean credit was only subtracted from three sites. The calculation of N need to be used as the optimum N rate for the Holland and Schepers algorithm is shown for each site in Table 5 and 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. 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 (Version 2008.1.0, Yang, H.S., et al., University of Nebraska – Lincoln, 2008). 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.

$$N\ need\ (lb\ ac^{-1}) = 35 + (1.2 * EY) - (8 * NO_3^{-1} ppm) - (0.14 * EY * OM) - other\ credits \tag{3}$$

where

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

$$N\ need\ (lb\ ac^{-1}) = (EY\ *\ 1.1) - NO_3^{-1} ppm - soy\ credit \tag{4}$$

where

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

Table 5: Calculation of optimum N rate using university N recommendations, for use in the Holland and Schepers sensor algorithm.

Field ID	Algorithm calculation for optimum N rate lb N ac^{-1} from algorithm results	Optimum N rate kg ha^{-1}
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
NDAR13†‡	(158 * 1.1) – 40 – 66 = 68	76
NDVC13†	(147 * 1.1) – 113 = 49	55
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.

Data Analysis Methods

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 and SI were calculated for the sensor-based and model-based treatments. Following physiological maturity, the corn was harvested. North Dakota plots were hand harvested and Missouri and Nebraska plots were machine harvested. Partial factor productivity for N was calculated by dividing 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 Statistical Analysis System (SAS).

Results and Discussion

Nitrogen application for 2013 is summarized for the four N strategies in Figure 1. In-season N rates shown are averaged across plant populations and hybrids. In-season N rates for the model-based treatments were higher than in-season N rates for the sensor-based treatments at 4 of 6 sites.

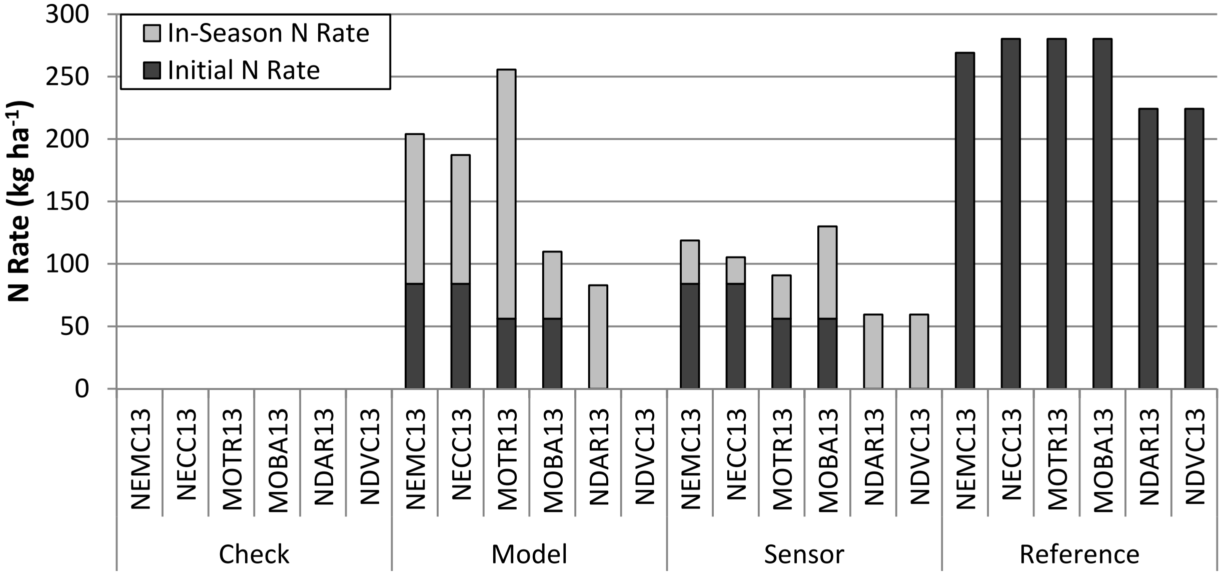

Figure 1: N applied for 2013 arranged by N strategy and site. Initial and in-season N rates are indicated for model-based and sensor-based treatments.

NDRE was obtained using the handheld sensor at the time of N application for all sites, and 10 days to 2 weeks following N application for all sites except MOTR13. Main treatment effects for NDRE at the time of N application and following application are provided in

Table 6. The N strategy main effect is significant for all sites at the time of application and is significant for 4 of 5 sites sensed following application. NDRE values obtained from the handheld sensor at the time of N application and 10 days to 2 weeks following is shown in Figure 2. The change in NDRE for each of the N strategies is shown in Figure 3, arranged by site. The in-season N rate applied for the model-based and sensor-based treatments are shown on the secondary axis. From Figure 3, it is seen that the model has a significantly greater increase in NDRE than the reference at all sites for which data is available. The sensor has a significantly greater increase in NDRE than the reference for 4 of the 5 sites. At all sites, there is a trend that between the model-based and sensor-based treatments, the treatment with the greater N application had a greater increase in NDRE. However, this is only significantly different at NDVC13. This trend would indicate that the applied N is having an effect on the NDRE readings at the date of the second sensing, and the plant is experiencing an increase in NDRE due to added N.

Table 6: Main treatment effects for NDRE at the time of N application and following N application arranged by site (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	0.0542	NS*	00581	NS
NEMC13	NS	<0.0001	0.0502	0.0161	0.0023	0.04845	NS
MOTR13	<0.0001	<0.0001	0.0009	NS	NS	NS	NS
MOBA13	0.0770	<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

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

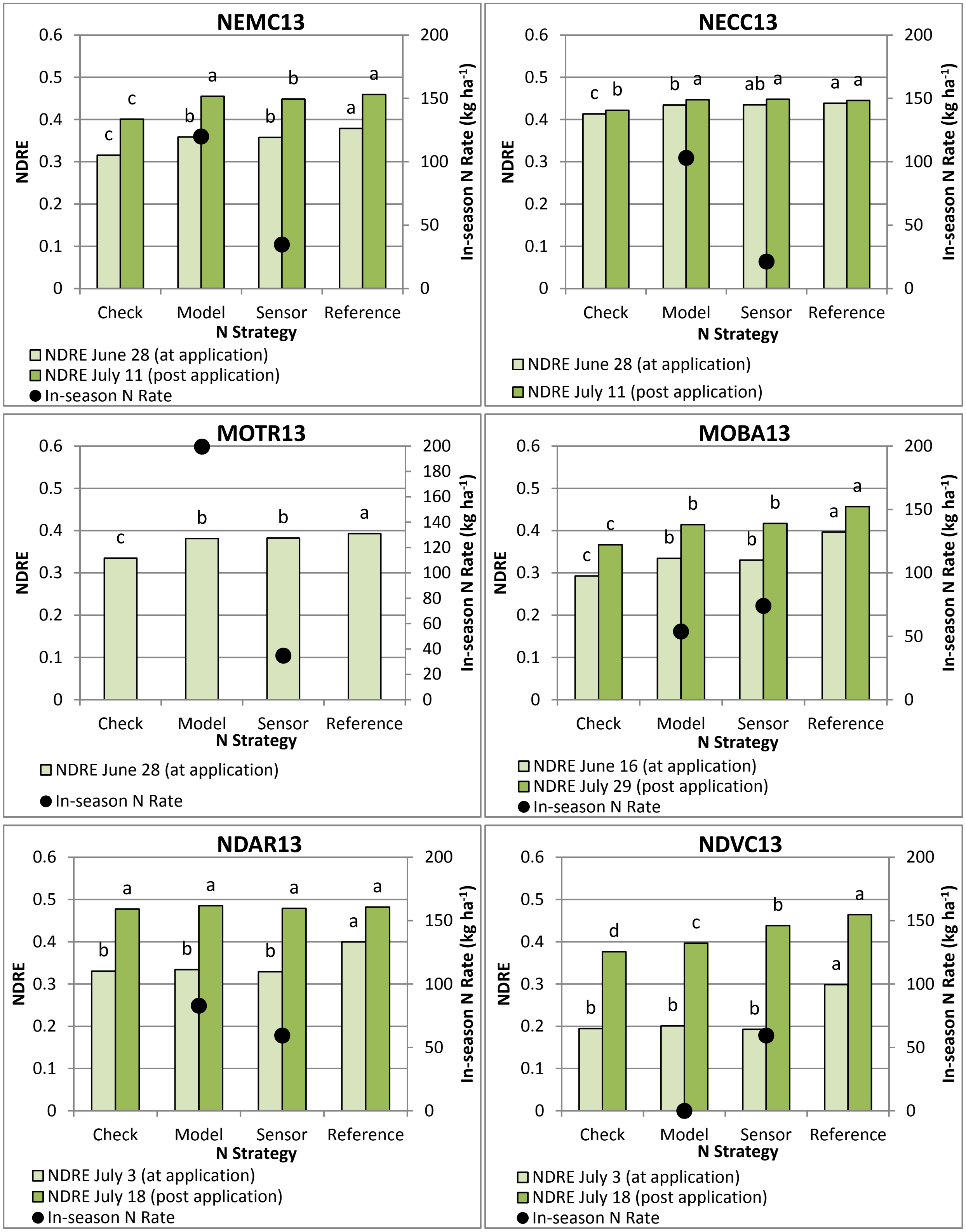

Figure 2: NDRE values arranged by N strategy main effect. Mean letters apply within a sensing date. Means with the same letter are not statistically different (P=0.05). In-season N rates applied to model-based and sensor-based treatments are shown in point format on the secondary axis.

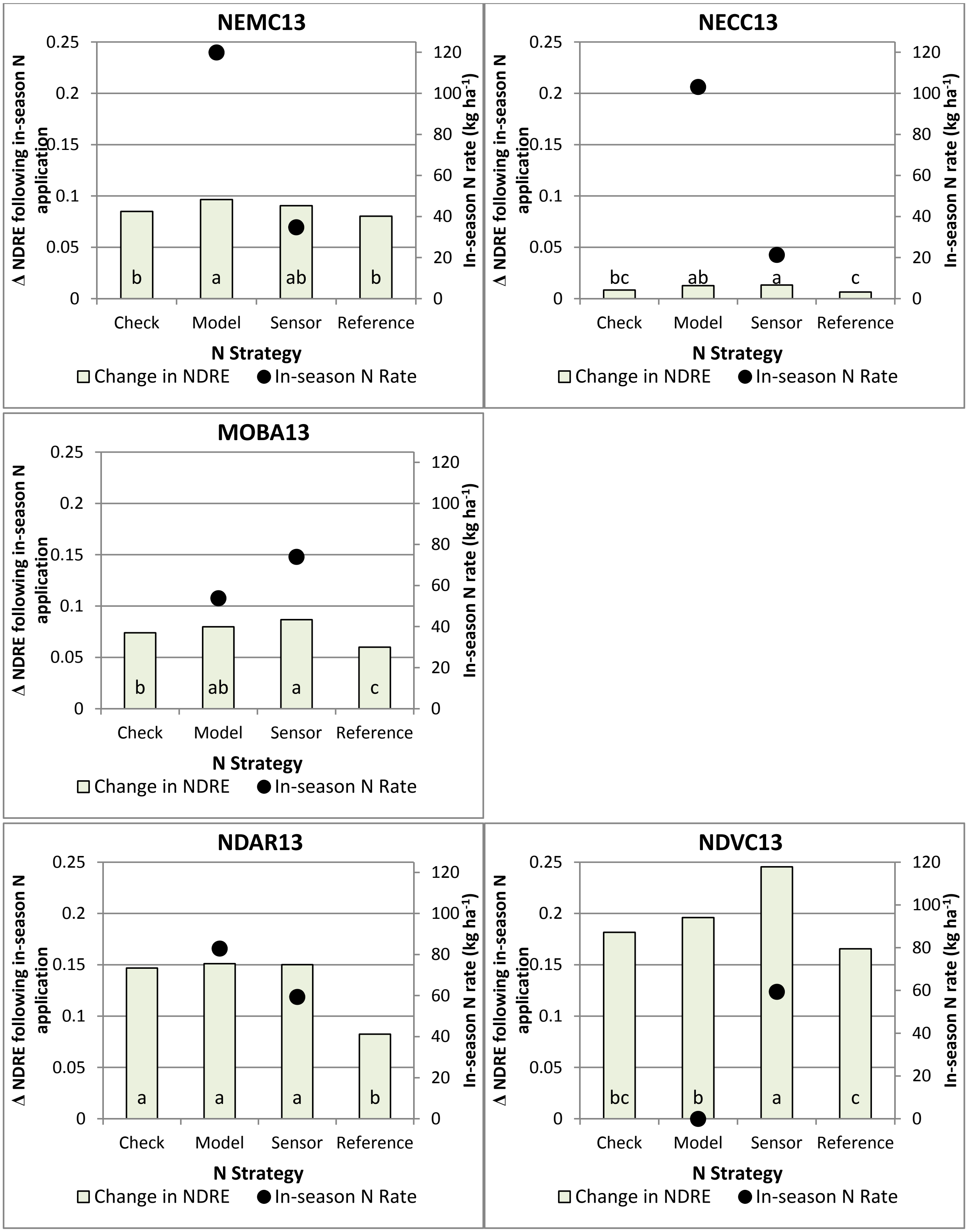

Figure 3: Change in (Δ) NDRE between sensing at application and follow up sensing. Means with the same letter are not statistically different (P=0.05). In-season N rates applied to model-based and sensor-based treatments are shown in point format on the secondary axis.

Grain yield for N strategy main effect of each site is shown in Figure 4. Lower N rates for model-based and sensor-based treatments are believed to contribute to significantly lower yield than reference treatments in 4 of 6 sites (2 due to model-based approach and 2 due to sensor-based approach). Sensor-based treatments had a significantly lower yield than model-based treatments at 2 of the 6 sites, while model-based treatments had a significantly lower yield than sensor-based treatments at 1 of the 6 sites. Overall, yield results suggest that the model-based approach better protects yield than the sensor-based approach.

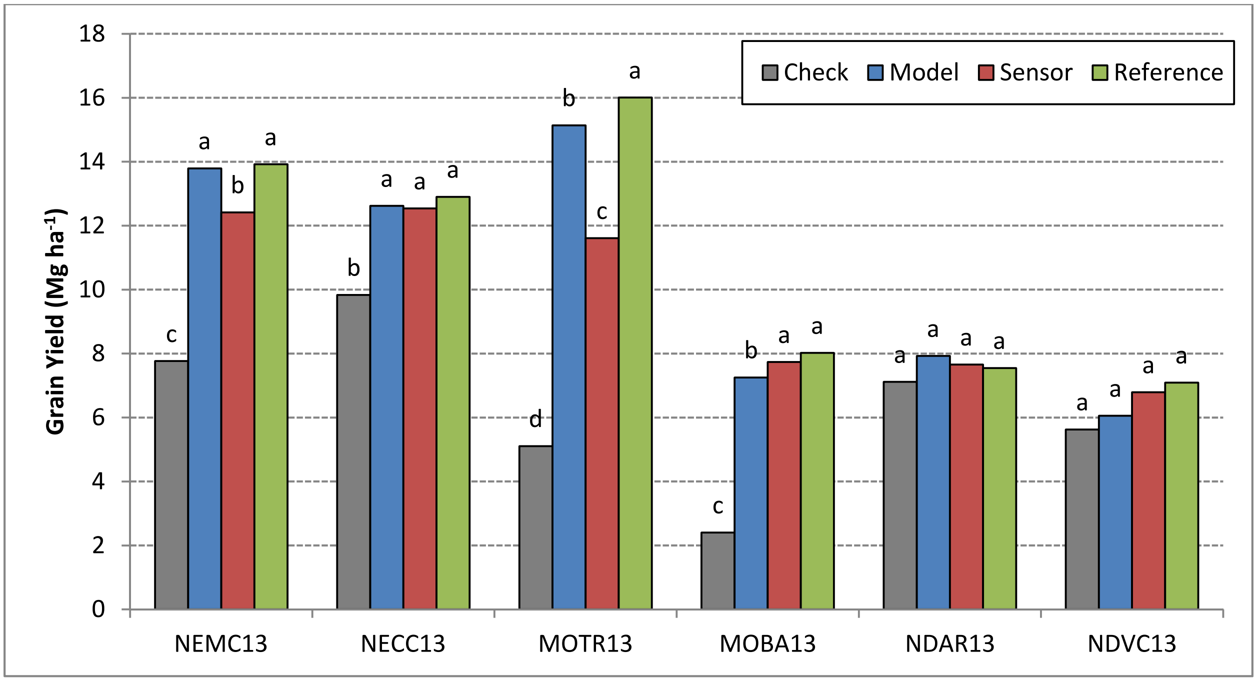

Figure 4: Grain yield arranged by site and N strategy. Bars with the same letters are not significantly different at alpha = 0.05. Significance letters apply within site.

Two measures of nitrogen use efficiency (NUE) were calculated. Partial factor productivity of N is defined as the kg of grain per kg of N applied. Agronomic efficiency is defines as the kg of grain increase from unfertilized to fertilized crop per kg of N applied. Lower N application resulted in a higher partial factor productivity of N for the sensor-based treatment than the model-based treatment at 4 of 5 sites and a higher partial factor productivity of N for the model-based treatment than the sensor-based treatment for 1 of 5 sites as shown in Figure 5 (no comparison can be made for site NDVC13 as the model-based approach recommended no N application). Similarly, the sensor-based approach had a significantly greater agronomic efficiency than the model-based approach at 3 sites, and was not significantly different at 2 sites as seen in Figure 6 (again no comparison can be made for NDVC13 as there was no N application for the model-based approach). Generally, the sensor-based approach provides higher NUE as seen by partial factor productivity of N and agronomic efficiency.

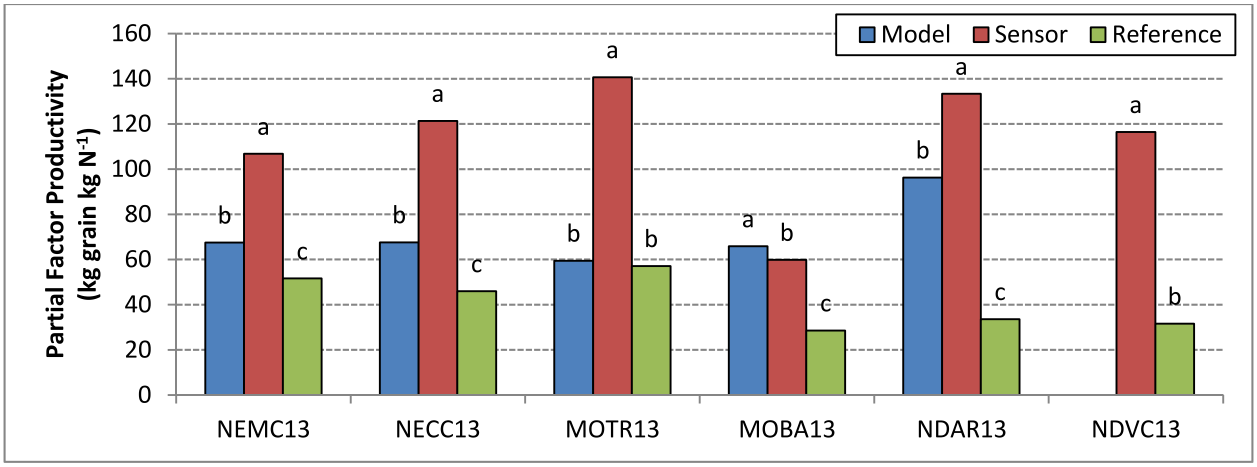

Figure 5: Partial factor productivity of N arranged by N strategy for each site. Bars with the same letters are not significantly different at alpha = 0.05. Significance letters apply within site.

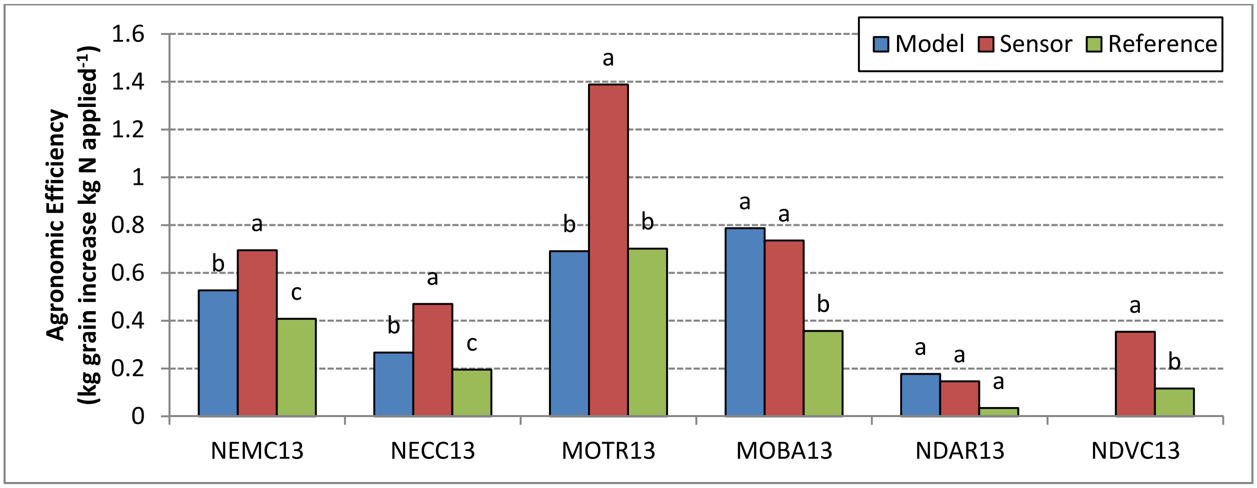

Figure 6: Agronomic efficiency arranged by N strategy for each site. Bars with the same letters are not significantly different at alpha = 0.05. Significance letters apply within site.

An analysis of profitability was done with a $5.00 corn price and $0.50 N fertilizer price. In 2013, the model-based treatments had a significantly higher profitability than the sensor-based treatments at 2 of 6 sites (Figure 7). The remaining 4 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 3 of 6 sites, and a significantly lower profitability in 2 of 6 sites. The model-based treatment had a significantly higher profitability when compared to the reference in 1 of 6 sites, while the reference had a significantly higher profitability than the model-based treatment in 1 of 6 sites. Overall, there is not a clear trend for profitability of these varying approaches.

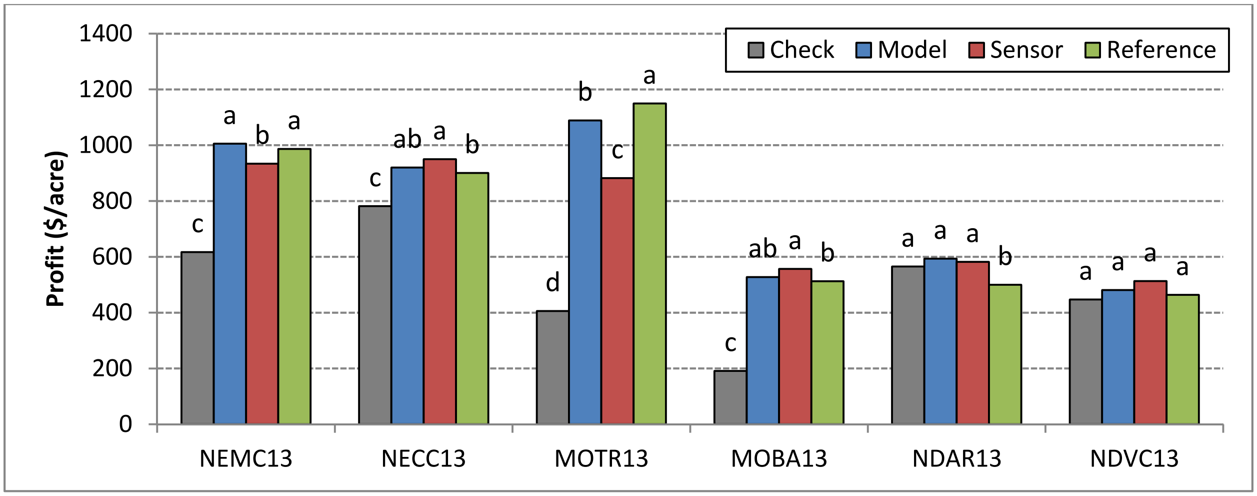

Figure 7: Profitability arranged by N strategy for each site. Bars with the same letters are not significantly different at alpha = 0.05. Significance letters apply within site.

Conclusion

Overall, it appears that the yield is better protected by using the model-based approach than the sensor-based approach. However, the sensor-based approach is generally higher in NUE than the model-based approach. No clear trends in profitability were seen. Further analysis is being done to assess whether the model-based or sensor-based approach more closely estimated the optimum N rate.

Publications

Data from this study was presented at the North-Central Extension-Industry Soil Fertility Conference in Des Moines, IA and at the ASA, CSSA, and SSSA International Annual Meetings in Tampa, FL.

Stevens, L.J., R.B. Ferguson, D.W. Franzen, N.R. Kitchen. 2013. Determining In-season nitrogen requirements for maize using model and sensor based approaches. In: Proceedings of the 43rd North Central Extension-Industry Soil Fertility Conference, Holiday Inn Airport, Des Moines, IA, 20-21 November 2013. P. 157-168.

Stevens, L.J., R.B. Ferguson, D.W. Franzen, N.R. Kitchen. 2013. Determining In-season nitrogen requirements for maize using model and sensor based approaches. Poster presented at ASA, CSSA, and SSSA International Annual Meetings, Tampa, FL, 3-6 November 2013.