DETERMINING IN-SEASON NITROGEN REQUIREMENTS FOR MAIZE USING MODEL AND SENSOR BASED APPROACHES

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Abstract

There is great value in determining the optimum quantity and timing of nitrogen (N) application to meet crop needs while minimizing losses. Applying a portion of the total N during the growing season allows for adjustments which can be responsive to actual field conditions which result in varying N needs. Two methods of determining in-season N needs were evaluated, a model-based approach and a crop canopy sensor approach. The Maize-N model was developed to estimate the 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. The active crop canopy sensor is responsive to canopy N status during the growing season and when used with high N reference plots, can be used to determine in-season N application rates. Four replications in a randomized complete block design were conducted at each of 6 sites over a 3-state region including Missouri, Nebraska and North Dakota. The model and sensor based approaches were evaluated for yield, nitrogen partial factor productivity, and agronomic efficiency. For all sites, in-season N application rates for model-based treatments exceeded that of sensor-based treatments. Additionally, sensor-based treatments had higher nitrogen use efficiency as seen by partial factor productivity. In a year with high mineralization for Nebraska sites, sensor based application produced higher partial factor productivity of N since the sensor application method required less N and yields were similar between model and sensor based treatments, indicating that in 2012, the sensor-based approach was more responsive to in-season growing conditions.

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 varied spatially within a field. Additionally, 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 sensors have been proposed 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.

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 objective of this study was to evaluate these two approaches for determining in-season N rates: Maize-N model and sensor. 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

This study was conducted in 6 fields in 2012. Fields were located in three states: Missouri, Nebraska, and North Dakota. Two experimental sites per state were selected, located in relatively close proximity to each other in order to minimize weather interactions. In Nebraska, sites were located at the South Central Agricultural Research Laboratory near Clay Center (NE-CC), and in Merrick County, near Grand Island (NE-MC). Missouri sites were both near Columbia, identified as Rollins (MO-RO) and Lone Tree (MO-LT). North Dakota sites were located near Durbin (ND-DN) and Valley City (ND-VC). Site selection was based on expected corn yield potential. 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. Soil information is in Table 1. The experiment was conducted in a randomized complete block design with four replications at each site. Two corn hybrids were used at each location. For Nebraska and Missouri sites, these were characterized by having a low drought score and high drought score. North Dakota hybrids were not selected for different drought scores. Each hybrid was planted at a moderate and high population. Population and drought scores by site are in Table 2. Plots were approximately 50 feet long and 4 rows wide for Nebraska and Missouri. North Dakota plots were 25 feet long and 6 rows wide. Tillage and previous crop varied by location. Pre-plant soil samples for pH, OM, P, K and NO_3-N were obtained for each site (Table 3). Pre-plant, at-planting and in-season N application method and N source varied by state.

Four N treatments were used: unfertilized check, N-rich reference, sensor-based and model-based. All sites had an unfertilized check treatment. Missouri initial N application rates were 50 lbs/ac for the sensor and model-based treatments and 200 lbs/ac for the N-rich reference. Nebraska initial N application rates were 75 lbs/ac for the sensor and model-based treatments and 240 to 250 lbs/ac for the N-rich reference. North Dakota initial N application rates were 0 lbs/ac for the sensor and model-based treatments and 240 to 250 lbs/ac for the N-rich reference. In-season N application was done at V9-V11, depending on location. In-season N application rates for sensor treatments were determined using canopy reflectance data collected from all treatments immediately prior to fertilization. Canopy reflectance data was collected using a RapidSCAN CS-45 Handheld Crop Sensor (Holland Scientific, Lincoln, NE). Two rows per plot were scanned and averaged to generate a value for that plot. The normalized difference red edge index (NDRE) was used to generate a sufficiency index (SI).

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

where

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

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

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

The SI was then used in the modified algorithm by Holland and Schepers (2010, modified 2012) to determine an N application rate. The in-season N application rates for the model treatments were determined using Maize-N: Nitrogen Rate Recommendation for Maize (Version 2008.1.0, Yang, H.S., et al., University of Nebraska – Lincoln, 2008). Model treatment sidedress N was applied at the same date as the sensor treatments. Approximately 10 days to 2 weeks later, plots in Nebraska and North Dakota were scanned again to evaluate canopy reflectance following in-season N application uptake. The SI was also calculated for this sensing date. Canopy reflectance for model treatments was also collected on the same dates that sensor treatments were scanned. Nebraska and North Dakota plots were hand harvested and Missouri plots were machine harvested. Harvest population was recorded at all sites and barren counts were taken in Nebraska. Percent grain N analysis was determined for Nebraska and Missouri plots. 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 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

In-season N recommendations for the model and sensor treatments are summarized in Table 4. Initial and in-season N recommendations for all treatments for all sites are depicted in Figure 1. For all sites, in-season N application for model treatments exceeded that of sensor treatments. For one site, NE – CC, the sensor resulted in no in-season N recommendation.

At the initial sensing, at the time of N application, significant differences in NDRE were present for the N strategy treatment for all sites except NE – CC (Table 5). No sites had a significant difference in NDRE between the model and sensor treatments (Figure 2). For both Nebraska sites the check had a significantly lower NDRE than the sensor and reference. However, the check was not significantly lower than the model for NDRE for these two sites. For both Missouri sites, the check had a significantly lower NDRE than the model, sensor, and reference. Additionally, both the sensor and model treatments had a lower NDRE than the reference. The two North Dakota sites initially had check, model, and sensor treatments with no significant difference in NDRE. The reference for these two sites was significantly higher in NDRE than all other N treatments. Following application, there were still no differences in NDRE between the model and sensor treatments for Nebraska sites. Additionally, neither the model nor the sensor treatments for Nebraska were significantly different than the reference. Missouri sites were not sensed following N application due to time constraints. At North Dakota sites, there were significant differences observed in NDRE following N application. Both sites had sensor and model treatment NDRE values that were significantly lower than the reference NDRE value. At site ND – VC, there was also a difference between the model and sensor treatments, such that the model treatments had a significantly higher NDRE value than the sensor treatments.

Sufficiency index at the time of N application was not significantly different for check, model, or sensor treatments at Nebraska and North Dakota sites (Table 5). For the Missouri sites, the check had a significantly lower SI than the model and sensor treatments (Figure 3). After N application, significant differences in SI with respect to N strategy was seen for sites NE – MC and ND – VC. At NE – MC, the model and sensor treatments had a significantly higher SI than the check. For ND – VC, The model treatment had a significantly higher SI than the check, however, the sensor did not have significantly different SI from the check or the model.

No yield data (and consequently no calculations for agronomic efficiency, partial factor productivity of N, or N grain recovery) is available for MO – RO due to drought conditions which caused a loss of reliable data. At both Nebraska sites and the MO – LT site, the model and sensor treatment yields were statistically the same as the reference (Table 6). Both North Dakota sites had sensor yields that were significantly lower than the reference. However, sensor and model treatments were not significantly different with regard to yield at any site. There were no significant differences between model, sensor, and reference with regard to agronomic efficiency except for site NE – MC. At this site the sensor treatment had a significantly higher agronomic efficiency than both the model and reference treatments. Partial factor productivity of N was correlated with N application strategy for all sites. For all sites, the sensor treatment has a significantly higher NUE as seen by partial factor productivity than the model (Figure 4). Nitrogen use efficiency, measured by recovery of N in grain, was only correlated with N application strategy at the MO – LT site. At this site, the reference has a significantly lower recovery of N in grain than the sensor. There was no significant difference between the sensor and the model for grain N recovery.

Summary

Weather conditions played a large role in study results in 2012. Water stress masked N treatment effects at some sites which were not irrigated, and caused a loss of one Missouri site. The Nebraska sites experienced high rates of mineralization, particularly in March, which resulted in all treatments, including the control, having very high available N. Additionally, leaf curling due to drought stress, and low populations due to soil crusting, likely impacted sensor readings in North Dakota. Because of the weather difficulties experienced, data obtained in the 2013 season will be valuable to validate results. Overall, the sensor approach recommended less N than the model approach for all sites. The lower N recommendation of the sensor, along with non-significantly different yields between the sensor and model treatments, resulted in higher NUE as seen by partial factor productivity. In a year with high N mineralization for site NE – CC, the sensor approach appeared to be more responsive to in-season growing conditions, as no additional in-season N was recommended.

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Table 1. Soil series and taxonomic class arranged by site. Site relative expected productivity is indicated.

Site	Series	Taxonomic Class	% Trt Area
NE - CC ***High yield potential***	Crete silt loam, 0-1%	Fine, smectitic, mesic Pachic udertic Argiustolls	100%
NE - MC ***Low yield potential***	Fonner sandy loam, rarely flooded	Sandy, mixed, mesic Cumulic Haplustolls	80.5%
	Novina sandy loam, rarely flooded	Coarse-loamy, mixed, superactive, mesic Fluvaquentic Haplustolls	19.5%
MO - RO ***High yield potential***	Haymond silt loam, 0-3%	Coarse-silty, mixed, superactive, mesic Dystric Fluventic Eutrudepts	100%
MO - LT ***Low yield potential***	Mexico silt loam, 1-4%, eroded	Fine, smectitic, mesic Vertic Epiaqualfs	100%
ND - DN ***High yield potential***	Fargo silty clay, 0-1%	Fine, smectitic, frigid Typic Epiaquerts	100%
ND - VC ***Low yield potential***	Barnes loam, 3-6%	Fine-loamy, mixed, superactive, frigid Calcic Hapludolls	100%

Table 2. Hybrid and planting population arranged by site.

Site	Hybrid		Planting Population (seeds per acre)	
	A	*B*	*High*	*Low*
NE – CC	Pioneer 33D49 (LDS)*	Pioneer 1498 (HDS)	42,000	32,000
NE – MC	Pioneer 33D49 (LDS)	Pioneer 1498 (HDS)	42,000	32,000
MO – RO	Pioneer 33D49 (LDS)	Pioneer 1498 (HDS)	41,000	31,000
MO – LT	Pioneer 33D49 (LDS)	Pioneer 1498 (HDS)	41,000	31,000
ND – DN	Pioneer 39N99	Pioneer 8906	42,000	32,000
ND – VC	Pioneer 39N99	Pioneer 8906	42,000	32,000

**LDS=low drought score, HDS=high drought score*

Table 3. Pre-plant soil test values arranged by site. Phosphorus test used is indicated.

Site	Organic Matter	P	K	pH	NO_3-N (lbs N/ac 3 ft)	Irrigation NO_3-N Credit
NE – CC	3.88%	27 ppm *M3P	482 ppm	6.35	132	~10 lbs/ac
NE – MC	1.65%	41 ppm M3P	326 ppm	6.65	68	~24 lbs/ac
MO – RO	1.50%	106 lbs/ac **B1P	217 lbs/ac	7	45	
MO – LT	2.60%	26 lbs/ac B1P	145 lbs/ac	5.7	38	
ND – DN	5.30%	32 ppm ***OP	600 ppm	7.6	45	
ND – VC	3.60%	10 ppm OP	300 ppm	6.3	73	

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

Table 4. Average nitrogen rate in lbs N/acre for sensor and model treatments arranged by site.

	Sensor				Model			
	A,Lpop TRT 3*	*A,Hpop TRT 7*	*B,Lpop TRT 11*	*B,Hpop TRT 15*	*A,Lpop TRT 4*	*A,Hpop TRT 8*	*B,Lpop TRT 12*	*B,Hpop TRT 16*
NE – CC	0	0	0	0	30	12	33	14
NE – MC	14	14	13	6	74	68	76	70
MO – RO	47	47	55	53	104	94	106	95
MO – LT	46	34	34	28	70	64	71	65
ND – DN	108	59	66	60	182	177	176	173
ND – VC	39	53	36	42	194	167	183	163

**A=hybrid A, B=hybrid B, Lpop=low population, Hpop=high population*

Figure 1. Initial and in-season N application rates by N strategy arranged by site.

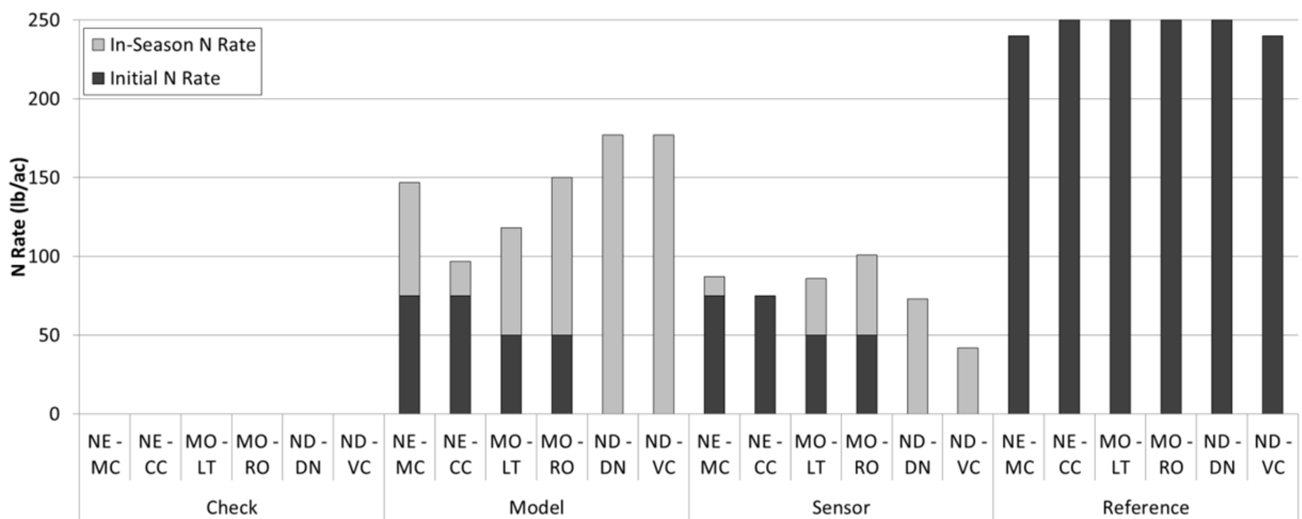


Table 5: Main treatment effects for NDRE at the time of N application, NDRE after N application, SI calculated using NDRE at the time of N application, and SI calculated using NDRE after N application arranged by site (PR>F).

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)							
NE – CC	0.0001	NS*	0.0039	NS	NS	NS	NS
NE – MC	NS	0.0205	<0.0001	NS	NS	NS	NS
MO – RO	NS	<0.0001	NS	NS	NS	NS	NS
MO – LT	0.0003	<0.0001	0.0314	NS	NS	NS	NS
ND – DN	NS	0.0044	0.0245	NS	NS	NS	NS
ND – VC	NS	0.0025	0.0119	NS	NS	NS	NS
NDRE main effects following application (includes N rich reference, sensor and model treatments)							
NE – CC	<0.0001	0.0213	0.0435	NS	NS	NS	NS
NE – MC	<0.0001	<0.0001	NS	NS	NS	NS	NS
MO – RO	--	--	--	--	--	--	--
MO – LT	--	--	--	--	--	--	--
ND – DN	NS	<0.0001	0.0117	NS	NS	NS	NS
ND – VC	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)							
NE – CC	NS	NS	NS	NS	NS	NS	NS
NE – MC	NS	NS	NS	NS	NS	NS	NS
MO – RO	NS	0.0049	NS	NS	NS	NS	NS
MO – LT	NS	<0.0001	NS	NS	NS	NS	NS
ND – DN	0.0281	NS	NS	NS	NS	NS	NS
ND – VC	NS	NS	NS	NS	0.0165	NS	NS
SI (from NDRE) main effects following application (includes N rich reference, sensor and model treatments)							
NE – CC	0.0320	NS	NS	NS	NS	NS	NS
NE – MC	NS	0.0043	0.0317	NS	NS	NS	NS
MO – RO	--	--	--	--	--	--	--
MO – LT	--	--	--	--	--	--	--
ND – DN	NS	NS	NS	NS	NS	NS	NS
ND – VC	NS	0.0327	NS	NS	NS	NS	NS

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

Figure 2. NDRE at the time of application and following application for N treatments arranged by site.

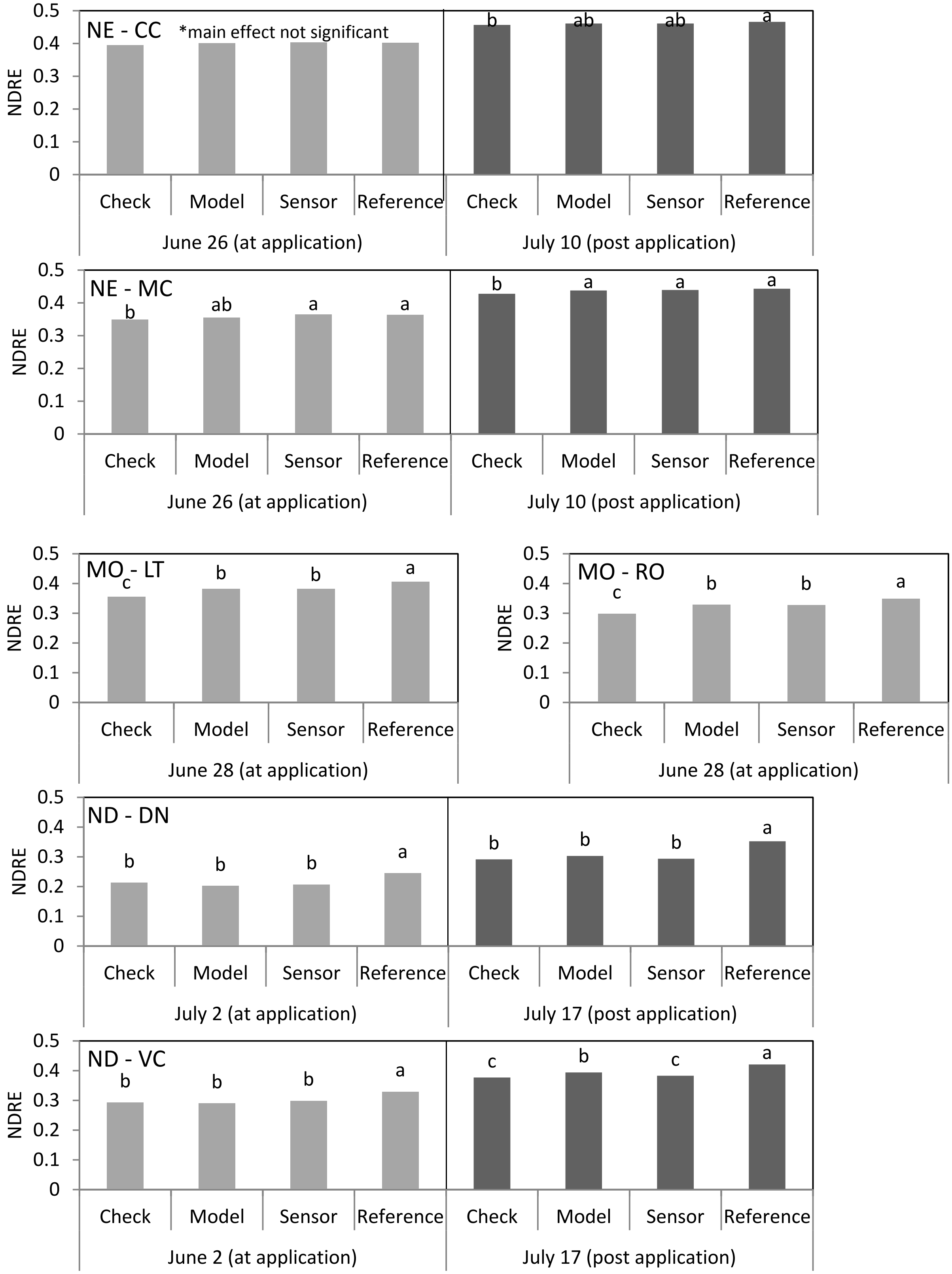


Figure 3. SI calculated using NDRE at the time of application and following application for N treatments arranged by site.

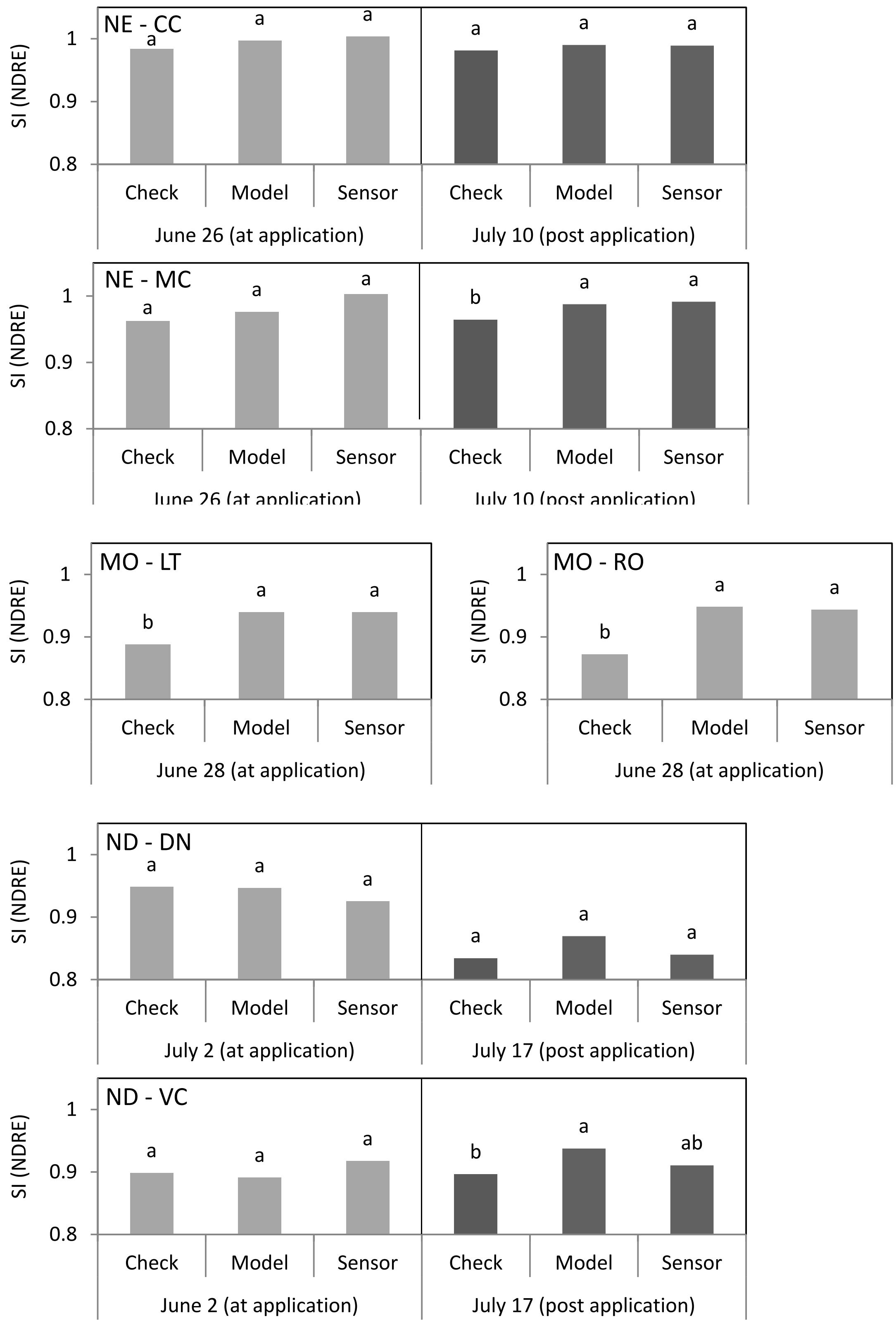
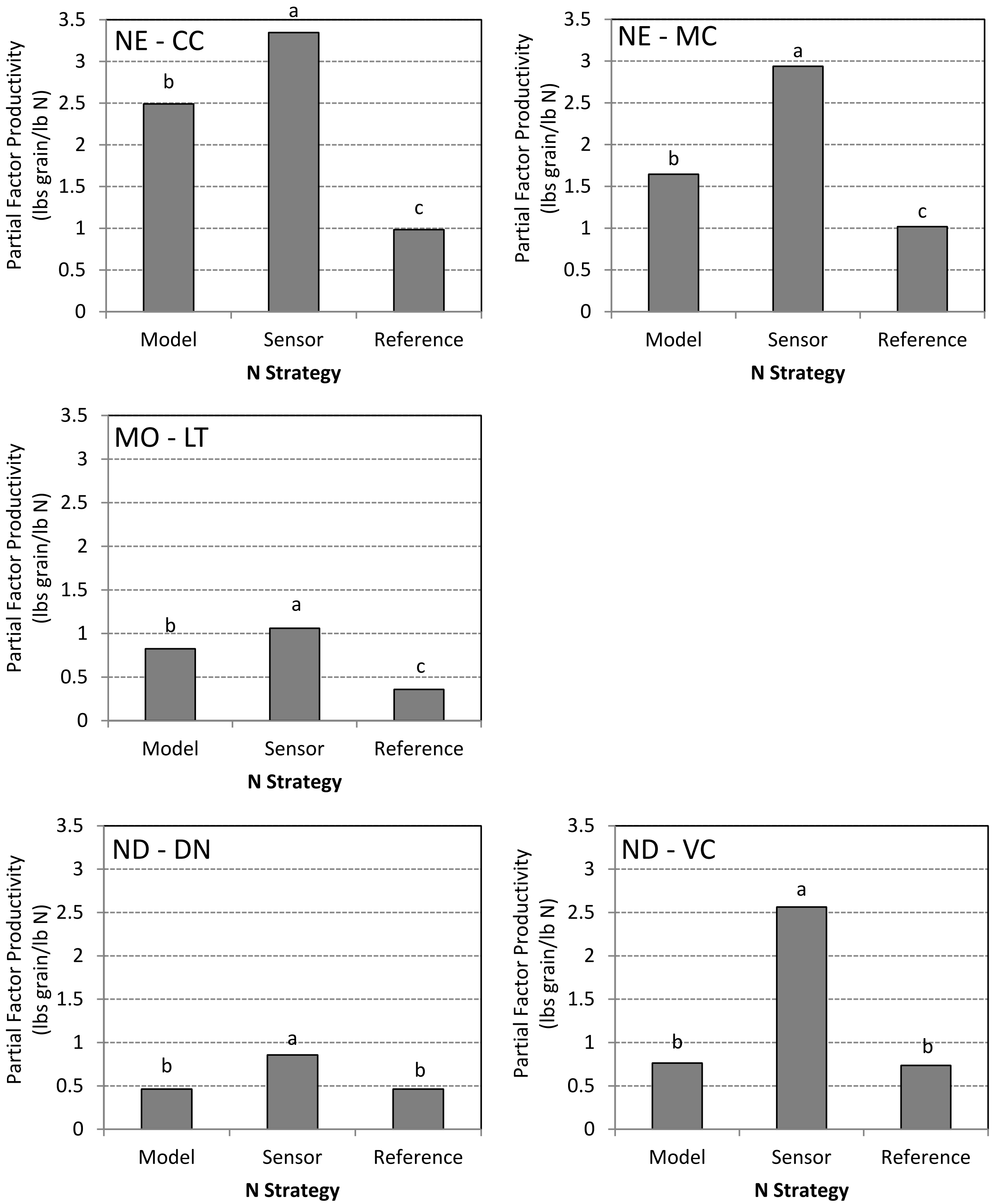


Table 6: Main treatment effects for yield, partial factor productivity of nitrogen, agronomic efficiency, and nitrogen use efficiency arranged by site (PR>F).

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
Main treatment effects on yield (check, N rich reference, sensor and model treatments included)							
NE – CC	NS*	NS	NS	NS	NS	NS	NS
NE – MC	<0.0001	0.0010	NS	NS	NS	NS	NS
MO – RO	--	--	--	--	--	--	--
MO – LT	0.0004	<0.0001	0.0003	NS	NS	NS	NS
ND – DN	NS	0.0273	NS	NS	NS	NS	NS
ND – VC	NS	0.0076	NS	NS	NS	NS	NS
Partial factor productivity of nitrogen main effects (includes N rich reference, sensor and model treatments)							
NE – CC	NS	<0.0001	0.0089	NS	NS	0.0041	NS
NE – MC	0.0016	<0.0001	NS	NS	NS	NS	NS
MO – RO	--	--	--	--	--	--	--
MO – LT	0.0136	<0.0001	NS	NS	NS	NS	NS
ND – DN	NS	0.0034	NS	NS	NS	NS	NS
ND – VC	NS	<0.0001	NS	NS	NS	NS	NS
Agronomic efficiency main effects (includes N rich reference, sensor and model treatments)							
NE – CC	NS	NS	NS	NS	NS	NS	NS
NE – MC	0.0080	0.0022	NS	NS	NS	NS	NS
MO – RO	--	--	--	--	--	--	--
MO – LT	NS	0.0014	NS	NS	NS	NS	NS
ND – DN	NS	NS	0.0061	NS	0.0400	NS	NS
ND – VC	NS	NS	NS	NS	NS	NS	NS
Recovery of nitrogen in grain main effects (includes N rich reference, sensor and model treatments)							
NE – CC	NS	NS	NS	NS	NS	NS	NS
NE – MC	NS	NS	NS	NS	NS	NS	NS
MO – RO	--	--	--	--	--	--	--
MO – LT	0.0007	0.0382	NS	NS	NS	NS	NS
ND – DN	--	--	--	--	--	--	--
ND – VC	--	--	--	--	--	--	--

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

Figure 4: Partial factor productivity of nitrogen by treatment, for all six sites.



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