VARIABILITY IN OBSERVED AND SENSOR BASED ESTIMATED OPTIMUM N RATES IN CORN

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ABSTRACT

Recent research showed that active sensors such as Crop Circle can be used to estimate in-season N requirements for corn. The objective of this research was to identify sources of variability in the observed and Crop Circle-estimated optimum N rates. Field experiments were conducted at two locations for a total of five sites during the 2007 growing season using a randomized complete block design with increasing N rates applied at V6-V8 (N_{V6}) as the treatment factor. Field sites were selected from different landscape positions representing variable soil moisture regimes so as to generate a range of optimum N rates at V6. Corn canopy reflectance was measured using Crop Circle prior to N application at V6. Soil and plant biomass samples were obtained at planting, V6, R1 and physiological maturity. A significant grain yield response to N_{V6} was observed at three of the five sites. The remote sensing model accurately estimated the optimum N_{V6} rates at three of the five sites. Grain yield did not respond to N_{V6} applications at two sites, where the remote sensing model over-estimated the optimum N_{V6} rates. The soil NO_3-N and total N uptake data measured during the growing season indicated that the interactive effect of changes in soil moisture and N availability after the N_{V6} application can influence the accuracy of estimated optimum N_{V6} rates. A better understanding of the soil moisture redistribution to the depth of root zone in relation to landscape position could help in understanding the influence of water stress on the N utilization of corn and thereby improve estimates of in-season N requirements.

Keywords: Crop Circle, Corn, N management, remote sensing, active sensor

INTRODUCTION

Traditional methods of estimating in-season optimum N requirements for corn (*Zea mays* L.) are based on soil testing (Magdoff, 1991), tissue N concentrations (Tyner and Webb, 1946), or chlorophyll concentration or leaf greenness (Varvel et al., 1997). Macy (1936) recognized that the concentration of a nutrient in plant tissue is a function of the sufficiency of that nutrient, and his work laid the foundation for the current ideas regarding use of tissue analysis to diagnose nutrient deficiencies. The leaf opposite and below the primary ear at silking ("ear leaf") frequently is used to determine the N status of corn (Tyner and Webb, 1946). Critical N concentrations in the ear leaf between tasseling and silking range from 26 to 36 g N kg^{-1} in the dry matter (Soltanpour et al., 1995). End-of-season cornstalk N content has been used as an indicator tool for determining N status in corn at harvest (Blackmer and Mallarino, 1996). The relationship between the availability of soil N and NO_3–N concentration of a crop is complex, and it is often difficult to translate observations on tissue NO_3-N concentration into quantitative estimates of N deficiency or excess. In an effort to address these difficulties, total N concentration has been evaluated for its potential as an indicator of the N status of corn. Unfortunately, because total N concentration reaches a plateau with increasing N supply, total N has proved to be an unsuitable indicator for detecting excess N in corn (Cerrato and Blackmer, 1991). These methods are labor intensive, time consuming, and may not be economically feasible for large fields. Remote sensing via aerial film, digital photography, and the use of tractor-mounted active sensors can provide valuable crop information at varying spatial and temporal scales.

The indicators derived from remote sensing either refer to the color of individual leaves (leaf greenness) or to the color of the entire crop (field or canopy greenness). The pigments involved in photosynthesis (chlorophyll) absorb visible light (400–700 nm) selectively. Chlorophyll absorbs mainly blue (~ 450 nm) and red (~ 660 nm) wavelengths and reflects green (~ 550 nm) wavelengths (Lilleseater, 1982). Image-based remote sensing can be used to monitor seasonal variability of soil and crop characteristics such as soil moisture, biomass, crop evapotranspiration, and crop nutrient deficiencies (Blackmer et al., 1996). Remote sensing via aerial color photography has been used to detect N stress in corn (Blackmer and Schepers, 1996; Blackmer et al., 1996), predict corn yield potential and determine N fertilizer requirements for site-specific applications by utilizing green (G) digital counts early in the growing season (Scharf and Lory, 2002). Shanahan et al. (2001) suggested that green normalized difference vegetation index (GNDVI) measured during mid–grain-filling period could be used to produce relative yield maps depicting within-field spatial variability for corn.

Although the ability to predict yield could be used to estimate N requirements, a more accurate method may be to use spectral reflectance or radiance to directly measure crop N requirements. Bausch and Duke (1996) observed a near one-to-one relationship between relative Ratio Vegetation Index (ratio of NIR/G of a particular treatment to the NIR/G of a reference area) and the N sufficiency index (ratio of SPAD data for a particular area to the SPAD data for a reference area) and plant tissue total N concentration for corn growth stages between V11 and R4 (Ritchie et al., 1993). Blackmer and Schepers (1995) developed an N sufficiency index (NSI) based on corn chlorophyll meter readings relative to a non-N-limited area to compare N status across fields and for fertigation in the Great Plains. Scharf and Lory (2002) used relative G and Sripada et al. (2006 & 2005) used relative green difference vegetation index (RGDVI) to predict corn optimum sidedress N at V6-V7 and at VT, respectively. More recently Dellinger et al. (2008) showed that Relative Green Normalized Difference Vegetation Index (RGNDVI; Table 1) measured using an active sensor such as Crop Circle (Holland Scientific Inc., Lincoln, NE) was strongly correlated with early in-season N requirements for corn.

From a practical field implementation perspective, the adoption of a remote sensing technique to estimate in-season N requirements would depend in part on the accurate prediction of the requirement resulting in greater profit and/or environmental stewardship via a reduction in N used or an increase in N-use efficiency. To date, there have been very few studies attempting to understand the relationships between availability of soil NO_3–N and corn N uptake during the growing season on the accuracy of estimated in-season optimum N rates using remote sensing. Therefore, the objective of this research was to partially validate the remote sensing-based in-season N requirement estimation model for corn developed by Dellinger et al. (2008) and to identify sources of variability in the observed and estimated optimum N rates at V6.

MATERIALS AND METHODS

Experimental Sites, Design, and Treatments

Field experiments were conducted on two farms in central Pennsylvania during the 2007 growing season for a total of five sites. These included the Bowersox Farm in Mifflinburg (BDS, BMS, and BWS) and Reiner Farm in Klingerstown (KDC and KWC; Table 1). More than one field was selected on each farm to increase the number of data points that could be used to model the relationship between estimated and observed optimum N rates. The distinguishing feature among sites within a farm was landscape position and moisture regime, such that there were sites that were susceptible to relatively dry or wet soil conditions on each farm. The soil classification for each field site is provided in Table 1. Crops grown during the previous year in each field included: soybean [*Glycine max* (L.) Merr.] for BDS, BMS, and BWS or corn for KDC and KWC (Table 1).

A completely randomized block experiment was implemented with four blocks at all five sites. The main-plot factor included seven N treatments applied at V6 (N_{V6}). The N_{V6} treatments were: a check (0 kg ha^{-1} N), 45, 90, 134, 180, 224, and 280 kg ha^{-1} N, broadcast applied as granular ammonium nitrate (NH_4NO_3: 34% N) at all sites except BWS. At BWS the N rates were, 0, 22, 45, 90, 134, 180, and 224 kg ha^{-1} N. Lower N_{V6} rates were applied at BWS because the farmer had inadvertently applied 50 kg ha^{-1} N at planting. Each site had a corresponding ‘reference plot’ that received 280 kg N ha^{-1} as granular NH_4NO_3 at planting, which was used to calculate relative reflectance for the different wavelength bands and various indices. While every attempt was made to accomplish the field activities as close as possible to V6, we acknowledge that the corn may not have been at V6 simultaneously for all the N treatments at any given site.

Different corn hybrids were planted (Table 1) at approximately 64,400 – 74,600 seeds ha^{-1} under zero tillage management. The plots were 9.1-m long and 4.6-m (6 rows) wide at all sites. With the exception of N management, the standard management practices corresponding to the region were followed at each site. Fertilizer rates other than N were based on The Pennsylvania State University Agricultural Analytical Services Lab (AASL) soil test results and recommendations (http://www.aasl.psu.edu;verified on April 29, 2008). Pre- and post-emergence herbicides were applied as recommended and weed management was excellent at all sites, except at KWS where there was moderate pressure from Pokeweed (*Phytolacca Americana*).

Table 1. Site, location (nearby town), cultivar, soil classification, and previous crop information for the different field sites during the 2007 growing season.

Site†	Location	Cultivar	Soil classification	Previous crop
BDS	Mifflinburg	Dekalb hybrid ‘DKC 53-54’	Loamy-skeletal, mixed, mesic, Lithic Dystrochrepts	Soybean
BMS	Mifflinburg	Pioneer hybrid ‘36B08’	Fine-loamy, mixed, mesic Typic Fragiaquults	Soybean
BWS	Mifflinburg	Pioneer hybrid ‘36B08’	Fine-loamy, mixed, mesic Aeric Fragiaquults	Soybean
KDC	Klingerstown	Seedway hybrid ‘E-538’	Sandy-skeletal, siliceous, mesic Entic Haplorthods	Corn
KWC	Klingerstown	Dekalb hybrid ‘DKC 54-51’	Coarse-loamy over Sandy-skeletal, mixed, mesic Fluventic Dystrochrepts	Corn

† The first letter indicates the cooperating farm: B = Bowersox, K = Reiner. The second letter indicates the relative moisture regime indicated by: D = dry, M = medium, W = wet. The third letter identifies the previous crop and is indicated by: S = soybean, C = corn.

Soil samples were collected at each site at planting /emergence (VE), V6, V10, R1, and physiological maturity (PM) from the following treatments: 280 kg N ha^{-1} at planting (reference plot), and 0 and 134 kg N ha^{-1} at V6. Soil samples consisted of two to six subsamples taken to a 30-cm depth using a bucket auger or a step tube-type soil probe (10- to 2-cm i.d., respectively) and were collected before N fertilizer was applied at V6. Inorganic N (NO_3-N) was determined by flow injection analysis of 2 *M* KCl extracts (1:5 W/V soil: solution) (Quik Chem Methods; Lachat Instruments, Loveland, CO).

Biomass, Tissue Sampling, and Grain Yield Determination

At all sites, plant biomass samples were collected at V6 and R1 from two 1.0-m sections of row from the same treatments for which soil samples were collected. At PM, plant biomass samples from one 1.0-m section of row were collected from these same treatments. Samples consisted of all the tissue above the soil surface. For each sample, dry biomass was determined by drying the samples at 65°C for 72 h. Samples were ground to pass a 2-mm sieve. Total Kjeldahl N (TKN) was determined by digesting the plant tissue as described by Gallaher et al. (1976) with the following modifications. The TKN was determined by flow injection analysis (QuickChem Method 10-107-06-2-H, Lachat Instruments, Milwaukee, WI). Total N uptake (kg N ha^{-1}) was determined by multiplying dry biomass (kg ha^{-1}) by whole-plant N concentration (g N kg^{-1}). At harvest, grain yield was determined by hand harvesting 7.6 m from two of the four inside rows. Grain yield was adjusted to 155 g kg^{-1} moisture content.

Determination of Observed Optimum Nitrogen Rates

Grain yield response to N_{V6} was modeled as a linear-plateau function using PROC NLIN in SAS (SAS Institute, 1999). If any of the responses that did not fit a linear-plateau function as determined by the significance of the model at $\alpha = 0.05$, then treatment means were compared in PROC GLM using a series of contrasts to determine the optimum N_{V6}. For example, at BMS the mean of treatment 0 kg ha^{-1} was compared to the mean for all other higher treatments (45, 90, 134, 180, 224 and 280 kg ha^{-1}). If there was a significant difference at $\alpha = 0.05$, then the mean for the 45 kg ha^{-1} treatment was compared to the mean for the remaining higher treatments. Likewise, the mean from each subsequent treatment was compared to the mean of all higher treatments. Following this approach, if the mean of any treatment was different from the mean of all remaining higher treatments, then the mean for the next greater treatment not statistically different from the mean of higher treatments was determined as the optimum N rate. In situations where the yield response to fertilizer N was not significant as measured by either of the above methods, the optimum N_{V6} was set equal to zero.

Crop Reflectance Measurements

Corn canopy reflectance was measured immediately before N applications at V6 using a Crop Circle ACS-210 Plant Canopy Reflectance Sensor (Holland Scientific, Inc., Lincoln, NE). The Crop Circle sensor has a modulated polychromatic Light Emitting Diode (LED) array that emits light directed towards the corn canopy in the NIR (880 nm) and Green (590 nm). The portion of emitted light reflected back to the sensor is detected by a silicon photodiode array with a spectral range of 320 nm to 1100 nm. Light signals from ambient light are distinguished by the synchronous modulation and demodulation measurement methodology. The Crop Circle sensor was mounted on a pole and carried at a height of 60 cm above the corn canopy along with a Trimble Pro XRS GPS receiver (Trimble Navigation Ltd, Sunnyvale, CA) and connected to a Trimble TSCe field computer. Corn spectral reflectance measurements were obtained at V6 at the rate of six measurements per second. The geo-referenced corn spectral reflectance data were then exported to ArcMap (Environmental Systems Research Institute, Redlands, CA) for further processing. Areas of interest (AOI) corresponding to each individual plot, excluding a 1-m plot buffer, were identified and included approximately 54 readings for each plot. These measurements were used to extract the mean reflectance representing NIR and G for each individual plot. Using the reflectance measurements for the two individual bands, Relative Green Difference Vegetation Index (RGDVI) was calculated as:

$$\text{RGDVI} = (\text{NIR-Green})_{\text{Plot}} \,/\, (\text{NIR- Green})_{\text{Reference Plot}} \qquad [1]$$

Estimated Optimum N rates at V6

The optimum N_{V6} rates were estimated for each site using the following algorithm developed by Dellinger et al. (2008):

$$\text{Optimum } N_{V6}\ (\text{kg ha}^{-1}) = 1014 + (-988 \times \text{RGDVI}) \qquad [2]$$

$$\text{when RGDVI} < 1.01;$$

$$\text{otherwise equal to zero.}$$

To evaluate the accuracy of this N requirement model, the observed optimum N_{V6} (based on yield response) were plotted against the estimated optimum N_{V6}.

RESULTS AND DISCUSSION

Weather

The weather data were collected from meteorological stations located 1 mile from the experimental plots in Klingerstown and 16 miles southeast of the experimental sites in Mifflinburg. We realize that weather conditions can vary in a distance of 16 miles, however, that was the closest distance where we had facilities to collect weather data. While the total precipitation at both locations was similar during the growing season, with 32.4 cm at Mifflinburg and 31.9 cm at Klingerstown (Table 2), the distribution of precipitation within the growing season varied. From planting to V6, the weather was mild with high precipitation at Mifflinburg while it was warmer with low precipitation at Klingerstown (Table 2). Of the total precipitation during the growing season, approximately 57% of the precipitation was received after V6 N applications at Mifflinburg, while 83% at Klingerstown for the same period.

Grain Yield Response to Nitrogen

Across all the experimental sites grain yields ranged from 2.2 - 8.3 Mg ha^{-1}. Grain yield response to N_{V6} was modeled as a linear plateau and was significant at three of the five experimental sites (Fig 1). Corn grain yield responded to N_{V6} at KWC, KDC, BMS during 2007 (Table 3; Fig 1). The corresponding optimum N_{V6} rates were 94, 64, and 141 kg ha^{-1} for BMS, KDC, and KWC, respectively (Fig 1). At BWS, the lack of response to N_{V6} can probably be attributed to the accidental application of 50 kg ha^{-1} N at planting, and the higher yields attributable to a wetter soil moisture regime during a low rainfall growing season. At BDS, the dry soil moisture regime (based on the landscape position) coupled with the low precipitation resulted in very low yields and probably contributed to the non-responsiveness to N_{V6}. The soil NO_3-N levels measured at V6 at all sites were lower than 21 mg kg^{-1}, the critical level indicating a high probability of response for the PSNT in Pennsylvania (Beegle et al. 2004 & 1999). However, within these five sites, the soil NO_3-N levels at BDS (13.0 mg kg^{-1}) and BWS (13.6 mg kg^{-1}) were numerically higher than BMS (10.0 mg kg^{-1}), KDC (11.4 mg kg^{-1}) and KWS (10.3 mg kg^{-1}). The soil NO_3-N increased from 7.9 and 3.3 mg kg^{-1} to 13.0 and 13.6 mg kg^{-1} from planting to V6 at BDS and BWS respectively (Fig 3A).

Table 2. Air temperature and precipitation during the 2007 growing season at Mifflinburg and Klingerstown in central Pennsylvania.

Growth stage† ‡	Mifflinburg		Klingerstown	
	Air Temp.	Precipitation	Air Temp.	Precipitation
	°C	cm	°C	Cm
Planting – V6	15.3	13.9	18.8	5.4
V6 – V 10	20.5	5.1	21.0	1.5
V10 – R1	22.7	2.3	21.8	6.5
R1 – PM	20.8	11.1	19.5	18.4

† V6 – Six leaf growth stage; V10 - Ten leaf growth stage; R1 – Tasseling; PM - Physiological maturity.

‡Corn was planted on April 14 and May 12 at Mifflinburg and Klingerstown respectively. The V6, V10, R1, and PM growth stages were observed on June 19, July 06, August 01, and October 01, and June 21, July 10, August 2 and October 12 at Mifflinburg and Klingerstown respectively.

Comparison of Estimated and Observed Optimum Nitrogen Rates at V6 (N_{V6})

The estimated optimum N_{V6} rates were calculated using the algorithm developed by Dellinger et al. (2008). The different soil moisture regimes combined with varying crop rotation and soils at these field sites created a range of spectral variability among sites and resulted in a wide range of optimum N_{V6}. The range of estimated optimum N_{V6} was 71 to 152 kg ha^{-1} (Fig 2).

The effectiveness of the remote sensing model to accurate estimate the optimum N_{V6} was evaluated by comparing the estimated and observed optimum N_{V6} with the 1:1 line (Fig 2). In general, the model tended to overestimate optimum N_{V6}. The difference in the estimated and observed optimum N_{V6} was less at sites BMS, KDC, and KWC compared to BDS and BWS, where the difference was 83 and 152 kg ha^{-1} respectively (Fig 2). The contrasting lower and higher yields observed at BDS & BWS, respectively, warrant a more detailed evaluation of the available soil NO_3-N and the corresponding N uptake during the growing season. With BDS and BWS located in dry and wet soil moisture regimes, the possible interaction of soil NO_3-N availability with soil moisture on the N uptake of corn might help us understand the differences in estimated and observed optimum N_{V6} rates.

Table 3. Corn grain yield information for the five research sites during the 2007 growing season.

Site	KWC	KDC	BDS	BMS	BWS
Response to N at V6	Yes	Yes	No	Yes	No
Average yield (Mg ha^{-1})	6.2	5.1	2.6	7.0	7.3
Optimum N rate at V6 (kg ha^{-1}) (refer to Fig 1.)	141	64	0	94	0
Yield at Optimum N rate (Mg ha^{-1})	6.9	5.5	2.6	7.4	6.8
Yield at Zero N (Mg ha^{-1})	4.6	3.1	2.8	5.8	6.8
Yield at 134 kg ha^{-1} at V6 (Mg ha^{-1})	7.4	5.5	2.2	6.8	7.3
Yield at 280 kg/ha at planting (Mg ha^{-1})	8.0	4.4	2.6	7.7	7.4

In general, when N was not applied at planting nor at V6 the soil NO_3-N levels were as expected, increasing slightly from planting to V6 and then decreasing to PM (Fig 3A). The only exception to this is BWS, where there was a slight increase in soil NO_3-N between V10 to R1. When 134 kg ha^{-1} N was applied at V6, the soil NO_3-N levels increased from V6 - R1 and then decreased by PM (Fig 3B). The decrease between R1 and PM corresponds with a period when the crop accumulates a lot of N in the biomass (Fig. 4A). Soil NO_3-N levels at PM were lowest for BMS, the site which had the highest total N uptake (Fig 3B & Fig 4B). When all the N was applied at planting (280 kg ha^{-1}) there was a huge spike in soil NO_3-N levels from planting to V6, and decreased to V10 and later growth stages, with the exception of BDS, where the soil NO_3-N levels increased from V6 to V10 (Fig 3C). This deviation from the general trend could be due to sampling error in the field where the sample might have been collected from a localized spot in the field that received N applications.

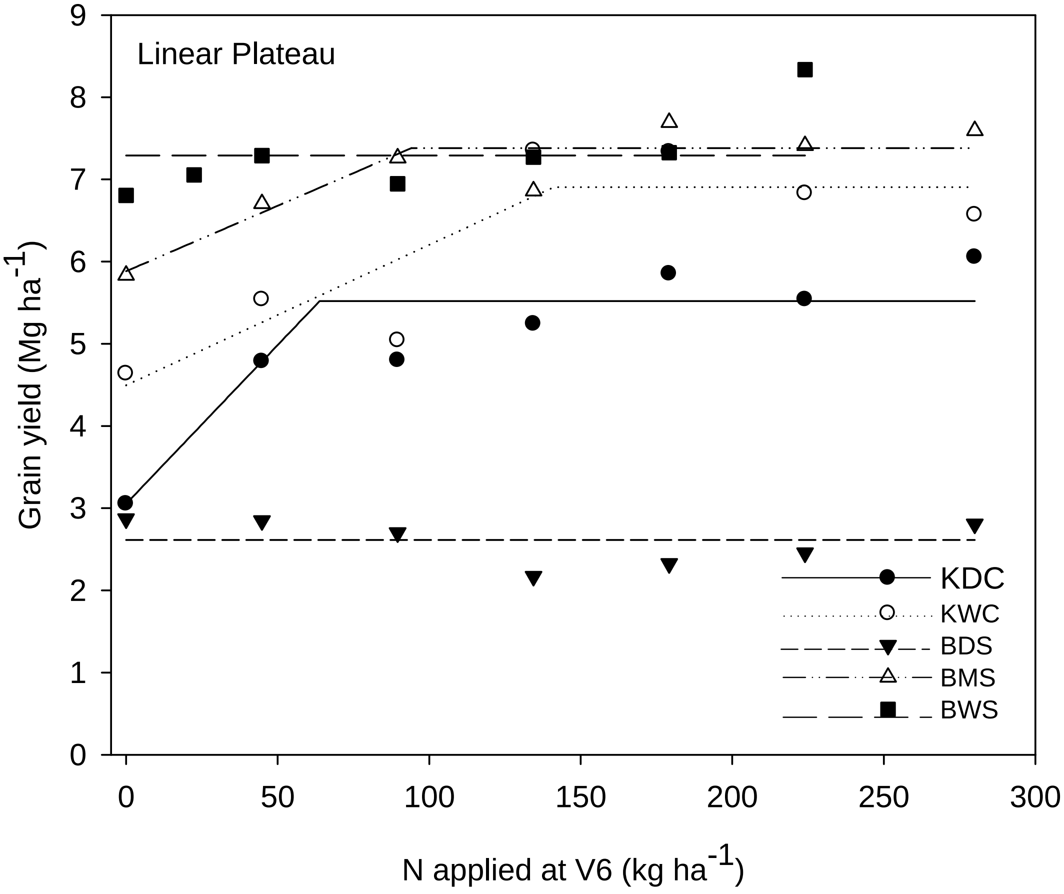

Fig 1. Linear-plateau fit of corn grain yield response to N applied at V6 (N_{V6}) at each site during 2007. Each point is the mean of four replicates.

Compared to applying the entire N at planting, applying N at V6 based on the remote sensing model, yield either increased or remained the same under dry soil moisture regimes (Table 3).Under wet soil moisture regimes, there is an increase yield by applying the entire N at planting compared to applying N at V6 based on the remote sensing model. However, these increases in yield were accompanied by a corresponding decrease in the total N uptake (Table 3; Fig 4B; Fig 4C). Site BWS received an additional 50 kg ha^{-1} at planting resulting in increase N uptake both early and late in the season compared to the other sites (Fig 4A).

At sites BMS, KDC and KWC the remote sensing model estimated the optimum N_{V6} that were very similar to the observed optimum N_{V6} rates (Fig 2). At these sites the soil NO_3-N levels and the total N uptake pattern of corn followed expected trends with decreasing soil NO_3-N availability from V6 to PM for the control treatment and increasing soil N availability from planting to PM when N was applied at V6 (Fig 3A). When N was applied at V6, the total N uptake was higher at BMS which had the higher yields for control treatment among BMS, KDC, and KWC. When N was applied at V6 or when entire N was applied at planting BMS had the highest N uptake with corresponding higher yields (Fig 4B; Fig 4C).

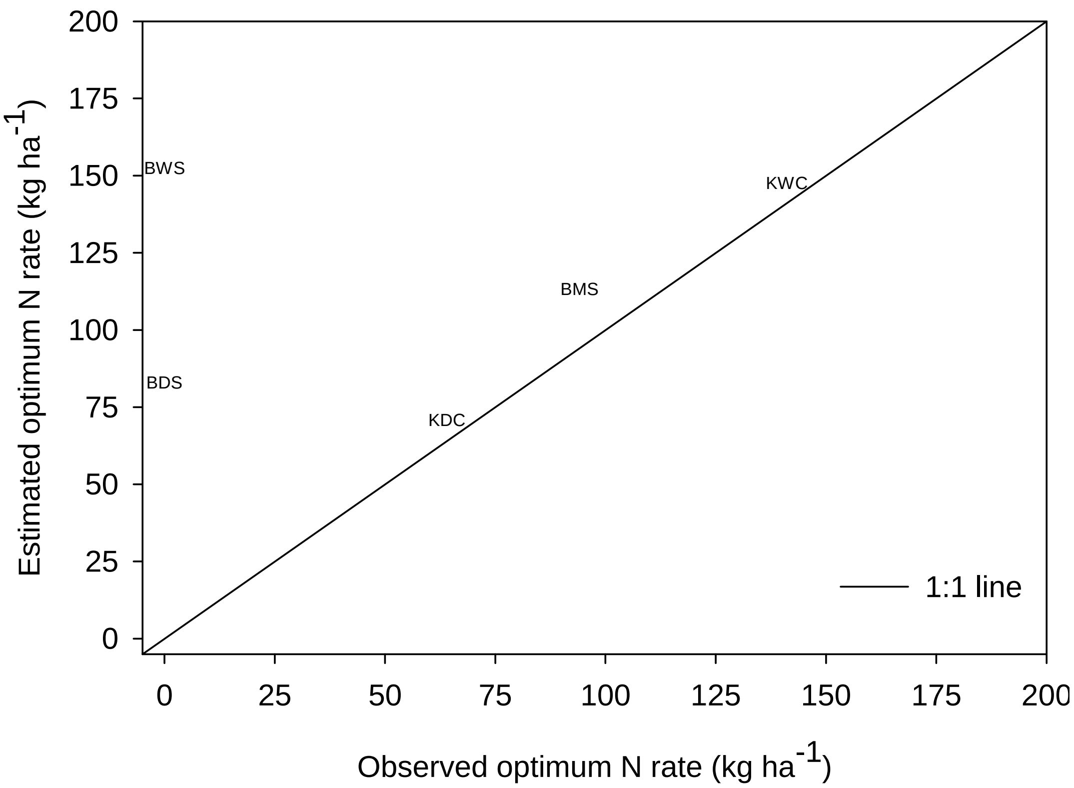

Fig 2. Relationship between the estimated optimum N rates at V6 (N_{V6}) using the model developed by Dellinger et al. (2008) and the observed optimum N_{V6} rates during 2007.

The remote sensing model overestimated the N_{V6} requirements at BDS and BWS. The model estimated optimum N_{V6} rates of 83 and 152 kg ha^{-1}, respectively, while the observed optimum N_{V6} rates were 0 kg ha^{-1} (Fig 2). At BDS, the soil NO_3-N was 7.9 mg kg^{-1} at planting and increased to 13.0 and 135 mg kg^{-1} at V6, when there was 0 and 280 kg ha^{-1} N applied at planting, respectively. The total N uptake was similar when 134 kg ha^{-1} N was applied at V6 or when 280 kg ha^{-1} was applied at planting, with similar yields at 2.6 Mg ha^{-1}. These results illustrate the merit of applying N as a split application at V6 rather than applying all the N at planting, especially during a low rainfall growing season. The combination of high temperature and low precipitation and the dry soil moisture regime (Table 2) at BDS, resulted in lower utilization of the available soil NO_3-N, evident with the high soil NO_3-N levels from V6 to R1 and decreasing by PM (Fig 3) and the corresponding slow increase in N uptake from V6 to R1 and the rapid N uptake from R1 to PM (Fig 4).

In contrast, site BWS is a site with a wetter soil moisture regime. At this site the farmer accidentally applied 50 kg ha^{-1} N at planting. The model developed by Dellinger et al. (2008) was developed for situations that did not receive any commercial fertilizer at planting, so the model may not be appropriate for this specific site. The soil NO_3-N values at V6 were 13.6 mg kg^{-1} indicating a high probability for N response. Even though the soil NO_3-N levels from planting to V6 were relatively high, the mild temperatures and high precipitation during the same period could have resulted in unfavorable conditions for efficient N utilization resulting in high estimated N requirements by the remote sensing model. For the control treatment, total N uptake was higher at BWS, indicating the effect of the extra N application planting. Furthermore, even with the higher N applied at planting and the resulting higher N uptake, the yield increase was modest at 0.1 Mg ha^{-1} (Table 3).

CONCLUSIONS

This study evaluated the potential causes for the variability in estimated optimum N_{V6} rates using remote sensing and those observed in the field. The remote sensing based model estimated the optimum N_{V6} rates similar to those observed in the field at three of the five sites where it was tested and over predicted at a site that was in a dry soil moisture regime with low precipitation and a wet site that had very high late season N uptake. The weather from the time of split N application to PM plays a very critical role in the accuracy of the in-season N estimates. A better understanding of the soil moisture redistribution to the depth of root zone will help in understanding the influence of water stress on the N utilization of corn and thereby should improve estimates of in-season N requirements.

NOTES

Trade or manufacturers' names mentioned in the paper are for information only and do not constitute endorsement, recommendation, or exclusion by the USDA-ARS.

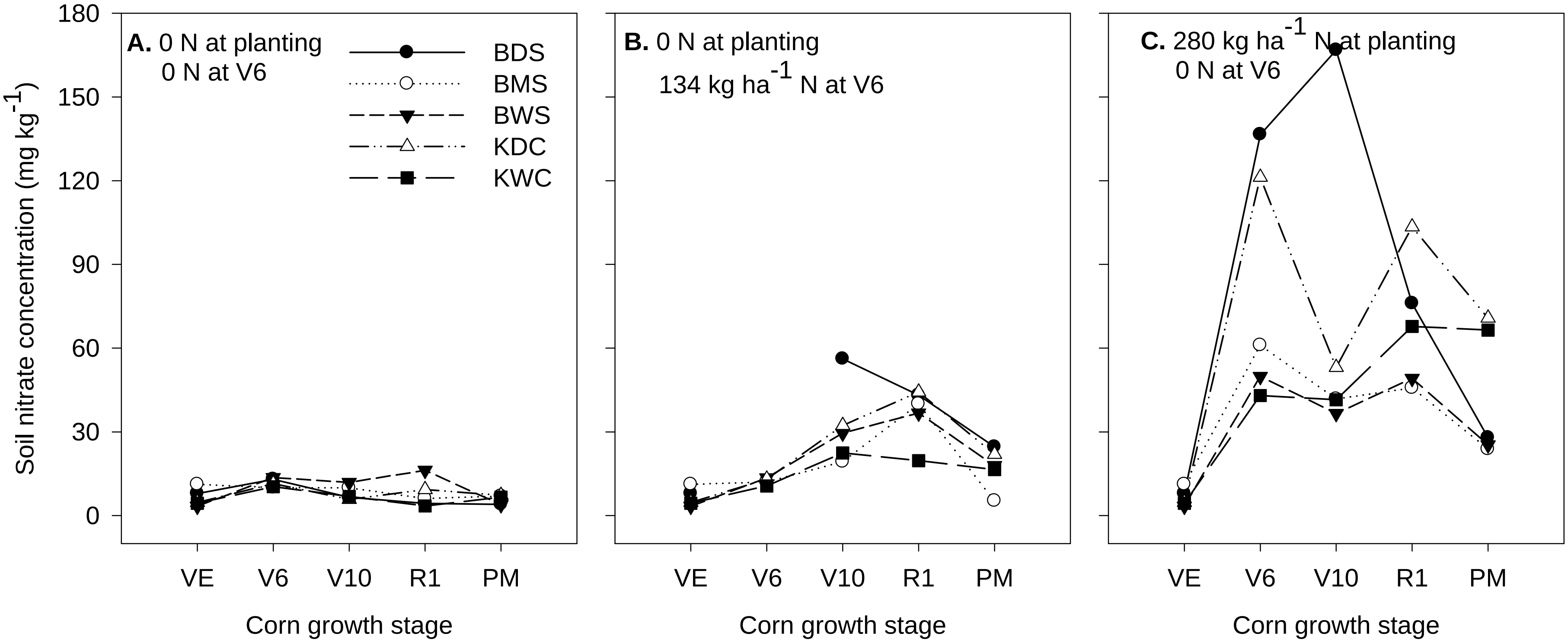

Fig 3. Soil NO_3–N concentration (mg kg^{-1}; 0- to 30-cm depth) at planting/emergence (VE), six leaf growth stage (V6), ten leaf growth stage (V10), tasseling (R1), and physiological maturity (PM) observed at each site during 2007 for three N treatments: (A) 0 kg ha^{-1} N applied at planting and V6; (B) 0 kg ha^{-1} N applied at planting and 134 kg ha^{-1} N applied at V6; and (C) 280 kg ha^{-1}N applied at planting and 0 kg ha^{-1} N applied at V6. At BDS, the soil sample at V6 was compromised during field activity and was not used for analysis.

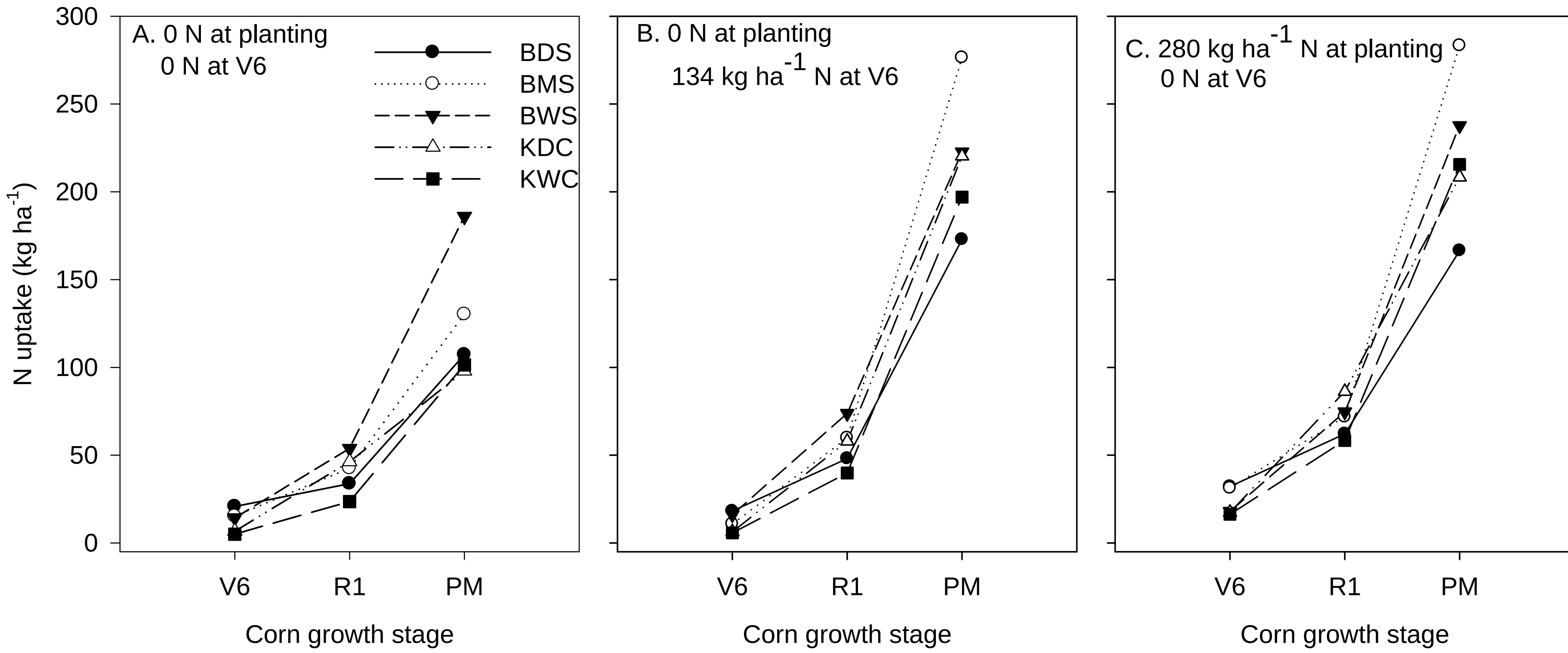

Fig 4. Crop N uptake (kg ha^{-1}) at six leaf growth stage (V6), tasseling (R1), and physiological maturity (PM) observed at each site during 2007 for three N treatments: (A) 0 kg ha^{-1} N applied at planting and V6; (B) 0 kg ha^{-1} N applied at planting and 134 kg ha^{-1} N applied at V6; and (C) 280 kg ha^{-1}N applied at planting and 0 kg ha^{-1} N applied at V6.

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