IS A NITROGEN-RICH REFERENCE NEEDED FOR CANOPY SENSOR-BASED CORN NITROGEN APPLICATIONS?

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ABSTRACT

The nitrogen (N) supplying capacity of the soil available to support corn (*Zea mays* L.) production can be highly variable both among and within fields. In recent years, canopy reflectance sensing has been investigated for in-season assessment of crop N health and fertilization. Typically, the procedure followed compares the crop in an area known to be non-limiting in N (the N-rich area) to the crop in a target area, which may be inadequately fertilized. Measurements from the two areas are used to calculate a relative reflectance to represent the potential need for additional N fertilizer. Establishing N rich areas or strips is often inconvenient for farmers, since this coincides with other demanding spring operations. Thus the question has been asked, is an N-rich reference needed? The objective of this study was to answer that question. A total of 16 field-scale experiments were conducted over four growing seasons (2004-2007) in three major soil areas of Missouri, USA: river alluvium, deep loess, and claypan. Multiple blocks of randomized N rate response plots traversed the length of each field. Each block consisted of 8 N treatments from 0 to 235 kg N ha^{-1} on 34 kg N ha^{-1} increments, top-dressed between vegetative growth stages V7 and V11. Adjacent to the response blocks, N-rich (235 kg N ha^{-1}) reference strips were applied at or just after planting. Crop canopy reflectance sensor measurements in the format of inverse simple ratio values (Vis/NIR) were obtained from the N response blocks and adjacent treatment strips at the time of top-dress N application. Viewed in frequency distribution diagrams, canopy sensor ISR values for target corn were almost always higher than those for N-rich corn, had a greater range of values, and were more positively skewed. Using multiple linear regression, we developed a model that used only the average sensor readings of unfertilized corn, growth stage, and planting N amount. This model successfully predicted 75% of the variation in average N-rich reference sensor measurements. If this N-rich reference strategy proves consistent and reliable for making in-season N fertilization recommendations, the resulting simplifications may result in more farmers adopting this technology.

Keywords: canopy sensing, corn, variable-rate nitrogen, N-rich reference

INTRODUCTION

In recent years, a flurry of investigations have explored active crop-canopy reflectance sensing for assessing the N status of crops and deciding how much in-season N fertilizer to apply (Raun et al., 2002; Mullen et al., 2003; Raun et al., 2005; Freeman et al., 2007; Teal et al., 2006; Dellinger et al., 2008; Shanahan et al., 2008; Solari et al., 2008; Sripada et al., 2008; Kitchen et al., 2010). A major justification of this technology is that when used along with variable-rate N fertilization equipment, it helps to account for the spatially variable nature of mineralization and N loss potential over non-uniform agricultural landscapes. Previous field studies have indicated both economic and environmental benefit for spatially-variable N applications across a variety of agricultural landscapes (Malzer et al., 1996; Mamo et al., 2003; Koch et al., 2004; Scharf et al., 2005; Shahandeh et al., 2005; Lambert et al., 2006; Hong et al., 2007; Roberts et al., 2010). Without tools to address spatially-variable crop N need, farmers tend to apply N at a uniform rate to meet crop needs in the more N-demanding areas of the field, resulting in greater risk of N loss from field areas needing less N (Hong et al., 2007; Roberts et al., 2010).

Algorithms that use crop-canopy reflectance measurements for N fertilizer recommendations are under development or are currently in use for wheat, corn, cotton, rice, and other crops. Typically the algorithms used to determine how much N to apply are derived by comparing sensor measurements of the crop in an area known to be non-limiting in N (also called N-rich or N-rich reference) to sensor measurements of the crop where N fertilization is likely needed (sometimes called the target area) (Teal et al., 2006; Solari et al., 2008; Sripada et al., 2008; Kitchen et al., 2010). Measurements from the two areas are used to calculate a relative reflectance to represent the potential need for additional N fertilizer. In principle, the greater the difference in sensor measurements between sufficient-N reference crop and un-fertilized or deficiently-fertilized crop, the more N fertilizer is needed. In addition to active crop-canopy reflectance sensing, this approach of relative reflectance of well-fertilized crop to un-fertilized crop has also been shown to be successful with other spectral-based measurements (Chappelle et al., 1992; Blackmer et al., 1996; Shanahan et al., 2003; Flowers et. al., 2001; Scharf and Lory, 2002). The approach somewhat normalizes the confounding effects numerous management (e.g., hybrid) and environmental (e.g., soil and precipitation) factors will have on understanding N need for the specific location in question.

An aspect of this technology that has discouraged some farmers from considering adoption is the requirement to have an N-rich reference area. Guidelines for using these canopy sensors for corn in Missouri (USDA-NRCS, 2009) typically suggest farmers establish a sufficient-N reference area before or just after planting by adding an ample amount of N fertilizer to a selected area. The area can be a single location on the field as small as 20 by 20 m, or a strip or strips through the field so that varied conditions within the field are considered. Farmers have been encouraged to have an N reference in each field. Further, they are encouraged to avoid areas that historically have had other management problems (e.g., heavy weed infestation, head-lands with soil compaction) and to mark the corners of the reference area by GPS, flags, or stakes for easy identification later. Many farmers are unwilling to consider this approach once they realize the time commitment of these extra tasks coincides with other time-demanding spring operations. The challenge amplifies when, if on the day of canopy sensing and N application, the N-rich reference areas require revisiting because of spatial or diurnal effects on the measurements (Scharf et al., 2007).

Given these challenges, questions have been asked by farmers and researchers alike. Is it necessary to have actual N-rich reference areas in a field to do canopy sensor-based corn N applications? Could an N-rich reference value be predicted based upon crop growth stage, cumulative growing degree units, or even on sensor measurements taken from the crop that is yet to be fertilized? And if some procedure could be developed for predicting N-rich reference values, what additional potential error would be introduced into the N fertilizer recommendation? This concept of predicting an N-rich reference has been explored by others (Holland and Schepers, 2010).

If a proven procedure could be developed where an N-rich reference value could be predicted, as opposed to empirically measured, adoption of this technology for N management would be greatly accelerated. The objective of this research was to assess from a range of corn production fields whether N-rich reference values could be estimated from plants being sensed for fertilization.

MATERIALS AND METHODS

Fields and General Management

A total of 22 field-scale (400 to 800 m in length) experiments were conducted over four growing seasons (2004-07) in three major soil areas of Missouri: river alluvium, deep loess, and claypan. However, six experiments (three in 2005, one in 2006, and two in 2007) experienced severe drought, minimizing N rate as a factor for crop growth, and therefore were discarded for this analysis. A summary of the 16 remaining fields, soils, and N management practices are provided in Table 1. In general, these fields were representative of other cropped fields in their locale, with some within-field variability in landscape and soil. For many of these experimental fields, historical yield maps provided by producers confirmed within-field variability. Cooperating producers selected the planting date, hybrid, planting population, and prepared and planted each field with their own equipment. Most fields were rain fed only. Three exceptions are noted in Table 1. Temperatures and rainfall amounts and distribution in 2004 were highly favorable for corn production. The 2005 growing season was very droughty for much of the state and only two fields from that year are included. Rainfall amounts and distribution were generally favorable for corn production in 2006 and 2007.

Experimental Design and Operations

Multiple blocks of N rate response plots were arranged in a randomized complete block design traversing the length of the field. Each block consisted of 8 N treatments from 0 to 235 kg N ha^{-1} on 34 kg N ha^{-1} increments, top-dressed sometime between vegetative growth stages V7 and V11 (Table 1).

Table 1. Soil type and N management information for 16 research fields.

Yr	Field	Soil	Producer N Rate	Preplant N	N for 2nd Set of Plots	Growth Stage at Top-dress
			---------- kg N ha^{-1}	-------------		
2004	Ben[†]	claypan	179	32	na	9.5
2004	Cop	alluvium	157	0	na	7
2004	Die	alluvium	202	0	na	8
2004	Hay	claypan	168	30	na	10.5
2004	Pet	loess	202	0	na	9
2004	Sch	claypan	168	34	na	8
2004	Wil	claypan	134	45	na	8
2005	Geb	loess	202	0	na	11
2005	Lic	loess	202	0	na	11
2006	Ben[†]	claypan	179	39	34	11
2006	Cop	alluvium	157	28	34	9.5
2006	Geb2	loess	202	12	67	10
2006	Rie	claypan	157	30	34	9.5
2007	Geb	loess	202	12	67	10
2007	Hc[†]	alluvium	258	0	67	9
2007	San	alluvium	196	0	67	9

[†] Fields sprinkler rrrigated.

Because of plot dimensions differed over the four year period. Details of the design of each year are described in Kitchen et al. (2010).

For 2006 and 2007, a complete second set of field-length blocks was also established where either 34 or 67 kg N ha^{-1} was uniformly applied over the whole set of blocks shortly after corn emergence. The 34 kg N ha^{-1} rate was used when the producer had applied ~ 33 kg N ha^{-1} during pre-plant operations (Table 1). This second set of treatments was added in response to farmers expressing concern over an N management system where little or no N fertilizer was provided to the crop during emergence and early growth. Therefore this second set tested the sensitivity of the reflectance sensors for assessing N fertilizer need when the crop was generally not as N stressed.

The number of treatment sets varied from 3 to 28 per field, depending on the plot length, length of the field, and whether the study included the second set of blocks with early N fertilization. In all, a total of 223 sets of response plots were obtained from the 16 field experiments. Adjacent to and usually on both sides of the response blocks, N-rich (235 kg N ha^{-1}) reference strips were also established. These ran the full length of the field and were treated shortly after corn emergence or as soon thereafter as field conditions allowed. An AGCO Spra-Coupe (AGCO Corp., Duluth, GA) high-clearance applicator equipped with an AGCO FieldStar Controller was used to top-dress solution UAN (28 or 32% N) fertilizer shortly after emergence in order to establish the N-rich reference strips. Fertilizer was not incorporated.

Previous work reported on the relationships of canopy sensor readings and yield response to added N at the time of sensing (Kitchen et al., 2010). Using information from that investigation, we focus here on differences in canopy sensor measurements from N-rich corn and target corn that had only received 0 to 67 kg N ha^{-1} near planting time.

Crop canopy reflectance sensor (model ACS-210, Holland Scientific, Inc., Lincoln, NE) measurements were obtained within the same day from the corn canopy of N-rich reference strips and the corn where little or no N had been applied at planting (target area). Light emission bands from these sensors were at 590 (Vis) and 880 (NIR) nm. Two sensors were mounted on the front of the applicator at ~ 60 cm above rows 2 and 5 of the 6-row corn strip. As the Spra-Coupe drove through the field, reflectance data and GPS coordinates were recorded on the tablet PC in the Spra-Coupe cab.

Data Analysis

Canopy sensor data from the N-rich reference area and the target area were collected, and the inverse simple ratio (ISR) (Gong et al., 2003), which is the ratio of the visible to near-infrared (Vis/NIR) measurements was the canopy measurement selected for use in this study. This ratio is directly related to the commonly used NDVI index as follows: ISR = (1-NDVI)/(1+NDVI). With the ISR, greener healthier corn has a lower value than corn showing an N deficiency.

Frequency distribution figures were created for each site to visually observe the population of sensor readings associated with N-Rich and Target areas. Next, multiple linear regression was used to model the field-average ISR values of N-rich reference corn. Variables considered were field-average ISR values of target corn, standard deviation of target ISR values, crop growth stage, and N amount applied at or near planting. Variables were included in the model if the F-test was significant at 0.10 or less. Including the extra sets of response plots for 2006 and 2007, 23 observations were used for this regression.

RESULTS AND DISCUSSION

The power of this investigation is that it included a large number of side-by-side canopy sensor measurements for both N-rich and target corn over many fields and years. The number of sensor observations collected for each site varied, but ranged from about 2,000 to 13,000/site for N-rich corn and 4,000 to 39,000/site for target corn.

Fig. 1 provides relative frequency distribution of ISR canopy sensor readings from 16 site-years. The legend of each site-year shows the amount of N applied near planting. Sites from 2006 and 2007 include two target areas, as described in the methods. A quick glance at these frequency figures shows great variance from site to site when comparing sensor values from the N-rich reference to the target corn.

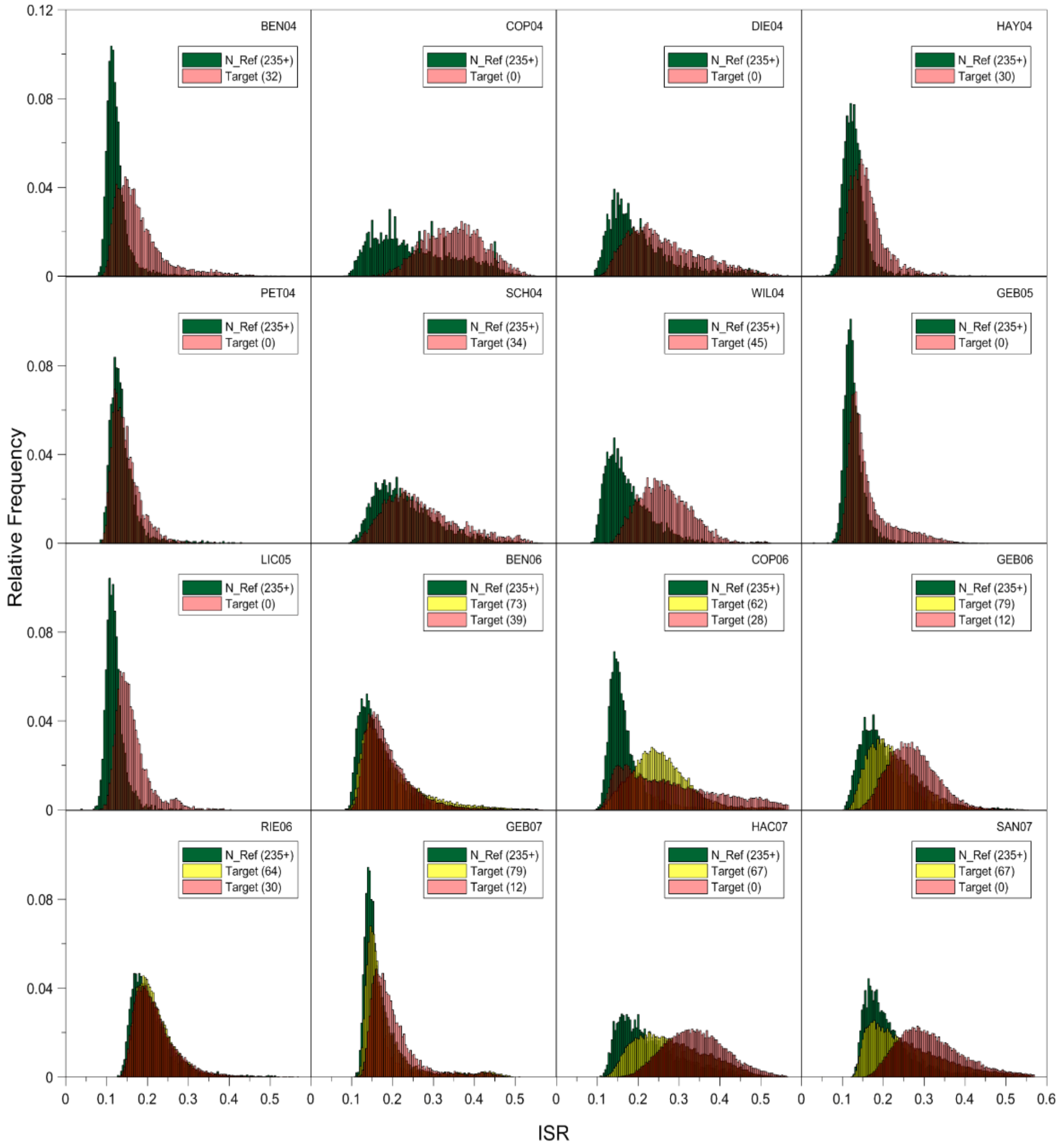

Figure 1. Relative frequency of inverse simple ratio (ISR) canopy sensor readings for 16 fields over 4 growing seasons.

Target Corn

As a population, canopy sensor ISR values for target corn were almost always higher than for N-rich corn, had a greater range in values, and were more positively skewed (Fig. 1). Higher values of ISR represent corn under greater N stress, because of less biomass and/or less leaf chlorophyll. Relative differences between the target corn and the N-rich corn can be partially explained by three factors. First, the more mature the crop at the time of sensing, the closer to canopy closure, such that less soil is in view of the sensor with it in the nadir position. As this happens, both the target corn and the N-rich corn tend to converge to values in the 0.10 to 0.25 range. (See Table 1 to compare growth stage between the site-years.)

Second, the amount of N fertilizer applied either before planting or shortly after emergence helps explain differences in sensor values for some sites. From this study we have target corn receiving a range of N from 0 to 67 kg N ha^{-1}. Greatest differences between N-rich corn and target corn generally occurred when the target corn had no early N (compare frequency distributions of COP04, HAC07, and SAN07 sites).

Third, differences in N-rich and target corn sensor readings were associated with within- and between-field variability of soil N-supplying capacity. With a few sites, the readings from N-rich and target areas were nearly identical. Usually, there was a reasonable explanation. For example, the Pet04 field had been a well-fertilized pasture for over 30 years prior to being put into soybean production in 2003 and then corn in 2004. Given this history, we concluded significantly more soil N was mineralized for the crop at this site. In another analysis, we found the average N fertilizer required to reach optimal yield for this field was at least 90 kg N ha^{-1} less than the average of all the other 2004 fields in this study (Kitchen et al., 2010). In another example, the GEB07 field was on a soil that showed great potential for mineralizing N, and therefore only subtle differences are seen when comparing target and N-rich corn.

The greatest within-field soil variation occurs with alluvial soils from along riverways. As such, alluvial fields in this investigation tended to give a wider range in sensor values (see COP04, DIE04, COP06, HAC07, and SAN07). Within-field variability is also the best explanation for unique sensor readings from one field. For COP06 the population distribution from the two target areas did not resemble that found on other fields. On closer examination of the soils at this field we found the target areas were on very different soils. For the target that received 28 kg N ha^{-1} the soil was moderately well drained and was classified as a Nodaway silt loam. For the target area that received 62 kg N ha^{-1} at planting the soil was closer to the Missouri river (slightly lower elevation), poorly drained, and was classified predominantly as Leta silty clay. The effect of these soil differences on target corn areas for this site is explained in more detail in Roberts et al. (2010).

N-Rich Corn

With most sites the distribution of readings for N-rich reference corn values is lower (meaning greater biomass and/or greener plants) and is less positively skewed when compared to the population of readings from the target corn. This result showing different populations of readings is consistent evidence of the sensor’s ability to detect differences in N status of the crop. The distribution shift can generally be seen as a two-step shift to lower values for 2006 and 2007 sites, where two target N areas were included. For the N-rich corn in this study, the lowest ISR values obtained were typically in the 0.10 to 0.15 range. These compare well with readings taken from a different study where well-fertilized corn hybrids of similar maturity were compared using this same canopy sensor (Sheridan et al., 2010).

Dependence of the Algorithm on N-Rich Reference

The usual basis for using sensors for determining N fertilizer amounts for cereal crops is to compare the sensor readings from N-rich reference plants with plants likely in need of fertilization. Either a "response" or "sufficiency" index is derived and included in the algorithm that calculates the N fertilizer rate to apply. From this N management strategy, two points are worth highlighting. First, if no N reference is available or if the N reference plants don't provide meaningful values representing the conditions of the field being fertilized, then the ability to use sensors for N recommendations is compromised. If either of these two conditions exist (and a proven contingency method for generating an N-rich reference is not available), then there is little basis for making variable-rate N rate recommendations using sensors.

Second, the derivation of an algorithm starts with how sensor readings are obtained and processed for N reference corn. This point is obvious as one surveys the frequency distributions for the 16 site-years in Fig 1. How should one calculate a value for the N reference given these varied distributions? One could use the mean, the mode, or the median. One might also consider using the best N reference corn, that is some calculated value out of the distributed population (i.e., corn left of the peaks of Fig 1). However, each of these calculation methods would generate unique N reference values, and therefore would generate different N fertilizer rate recommendations when using the same algorithm. Thus, algorithm development needs to start with a consistent procedure for collecting data and determining the N reference value.

Is N-Rich Corn Needed?

As indicated earlier, the primary rationale for this analysis was that many farmers see the process of creating and managing for N-rich reference areas as time-consuming, and therefore a barrier to adoption. If N reference values could be reliably estimated somehow from corn that is being sensed for fertilization, then many more farmers might be willing to embrace this technology. So, is fertilizing an N-rich reference necessary? Our analysis here would suggest "perhaps not". Two regression models were developed for predicting the field-average N-rich reference obtained from this 16-field dataset (Table 2). The first model shows that the average ISR value of the target corn alone could be used to

Table 2. Regression models for predicting N-rich reference corn.

#	model	R^2	SE
1	$ISR_{ref} = 0.0959 + 0.38870^* ISR_{tar}$	0.65	0.0160
2	$ISR_{ref} = 0.1593 + 0.34004^*ISR_{tar} - 0.00618^*V_{stage} + 0.00023^*N_{pre}$	0.75	0.0142

Where ISR_{ref} = Predicted inverse simple ratio of N-rich reference corn
ISR_{tar} = Measured inverse simple ratio of unfertilized corn (called target)
V_{stage} = corn growth stage
N_{pre} = N rate at or near planting in kg N ha^{-1}

model 65% of the variation in ISR of N-rich reference corn. This regression model is illustrated in Fig. 2 with model predicted values for N-rich ISR shown relative to the measured ISR of N-rich corn (Fig. 2, left). Also included on this graph are the actual ISR values of the target corn. In a second regression model, additional variables were added (growth stage and planting N), and explained an additional 10% of N-rich reference variation (Table 2). This model is also illustrated (Fig. 2, right).

How much different would the N rate be using a predicted N-rich reference? Let's compute an example. Using a corn algorithm currently provided for growers in Missouri (USDA-NRCS, 2009), along with the average N-rich ISR value from all 16 sites (0.194), we will also assume a target ISR value of 0.200. If our estimate of the N-rich ISR value is off by $\pm$ 1 standard error (Table 2), the prescribed rates would range from +27.5 to -23.7 kg N ha^{-1} above or below the rate prescribed by using the actual N-rich ISR value. If the distribution were normal, we would expect the error to be within this band over 60% of the time.

This analysis provides promising evidence that an N-rich reference could be predicted directly from corn that is being sensed for fertilization. Operationally, when starting on a new field, the applicator vehicle equipped with sensors could quickly obtain enough values to calculate a value to represent the N-rich reference. Then as the vehicle continued through the field, that N-rich value could be adjusted to include the additional measurements being collected. Concepts of this approach are similarly advocated in another study reported in these proceedings (Holland and Schepers, 2010).

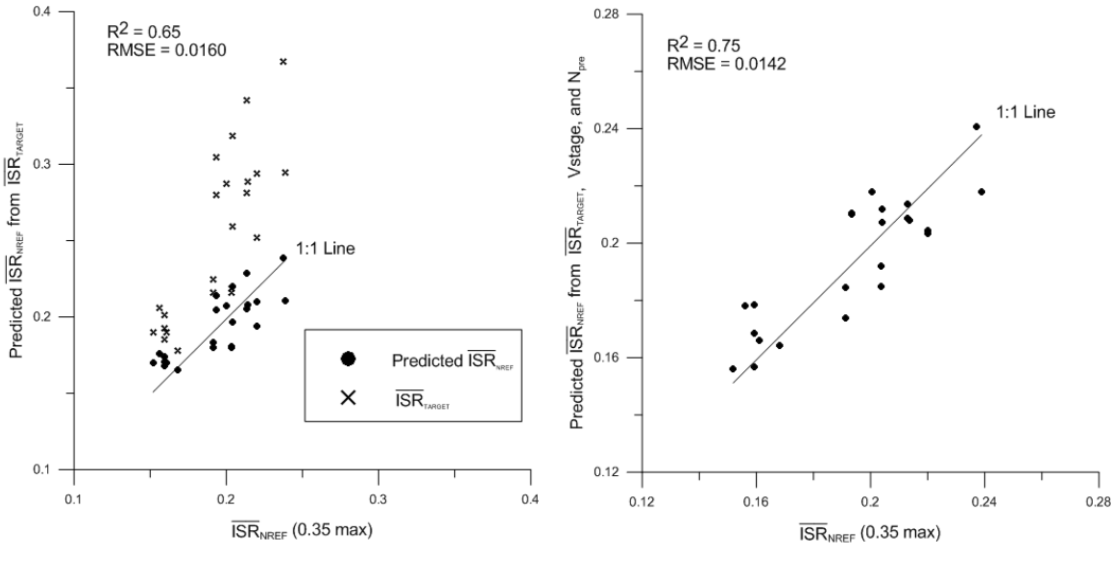

Figure 2. Two models developed (see Table 2) to predict N-rich reference ISR values.

Advantages

A real advantage of this procedure is that the N-rich reference is being derived from readings over all areas of the field being sensed, not just a small reference area (often near the field entrance) that may not be representative of the field as a whole. Thus, the procedure automatically captures the effects that within-field soil and landscape variations have on the sensor values. Similarly, any daily temporal factors that might affect sensor readings [e.g., leaf wetness, sun angle, sensor drift, clouds (Scharf et al., 2008)] could be easily accounted for by including a time filter which uses only recently collected sensor measurements when estimating the N-rich reference value. The value of accounting for both spatial and temporal effects in an N-rich reference might more than compensate for the potential error associated with this method of predicting an N-rich reference for N fertilizer applications.

One other potential advantage of this strategy would be the ability to determine the N-rich reference based on prescribed management zone maps, loaded into the applicator onboard computer prior to sensing and N fertilization. For example, zone maps based on apparent profile soil electrical conductivity (EC_a) could be especially warranted for alluvial soils near rivers, where extreme soil texture variability can be mapped using soil EC_a (Kitchen et al., 1996). For the fields of this study that are near the Missouri River, it is not uncommon to go from a sandy loam to clay within a very short distance. Visually, we often see corn growth differences across such soil changes. While we have not evaluated this concern specifically, averaging sensor values across these types of boundaries probably adds error to the N fertilizer rate determination. By using management zone maps, onboard real-time GPS and processing hardware/software, canopy sensing and N-rich reference estimates could be done by zones, and better account for fields that have such extreme soil variability.

CONCLUSIONS

This analysis of active crop-canopy reflectance sensing was conducted on field-average values of N-rich reference and target area corn. While our results look promising, further evaluation is needed before advocating such a strategy to farmers. For example, this analysis was obtained from the whole-field populations of sensor readings and should be compared to a similar analysis done only from portions of the field. Further, verification of N-rich reference prediction models using independent datasets obtained from other fields is needed.

If this N-rich reference strategy proves consistent and reliable for making in-season N fertilization recommendations, more farmers will likely be interested in adopting this technology.

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