Corn Hybrid Growth Stage Influence on Crop Reflectance Sensing

Alexander H. Sheridan, Newell R. Kitchen,* Kenneth A. Sudduth, and Scott T. Drummond

ABSTRACT

Active-light crop canopy sensing for corn (*Zea mays* L.) N fertilizer rate decisions typically include measurements of N-sufficient plants as a reference. When producers use multiple hybrids in one field, the question is raised of whether an N-sufficient reference is needed for each hybrid. The objective of this research was to assess the impact of sufficiently N-fertilized, similar-maturing corn hybrids on crop-reflectance measurements. Eleven similar-maturing hybrids were selected from three sites in 2008 and eight hybrids from two sites in 2009. When the corn was about 10 cm tall and on 3 to 5 d intervals canopy reflectance, leaf chlorophyll, and plant height measurements were obtained. Results were classed into two growth periods based on crop height: 20 to 70 cm and 71 to 120 cm. In three of the four growing periods assessed corn hybrid had no significant effect on reflectance. In 2008, reflectance for corn 71 to 120 cm tall was affected by hybrid; however the effect was minor leading to an average N rate recommendation difference of 10 kg ha^{-1}. More pronounced differences occurred among hybrids for leaf chlorophyll measurements, resulting in differences in N fertilizer recommendations of 55 kg ha^{-1}. Reflectance differences among similar maturing hybrids would have minimal impact on N fertilizer recommendations. Models were also developed to represent typical upper and lower values for various vegetative indices as a function of corn height. These models can help guard against using questionable data when assessing N-sufficient corn.

A number of recent studies have assessed the use of active-light crop canopy sensors to help guide corn N fertilizer management decisions (Raun et al., 2005b; Teal et al., 2006; Dellinger et al., 2008; Solari et al., 2008; Schmidt et al., 2009; Samborski et al., 2009; Sawyer and Barker, 2010; Kitchen et al., 2010). These crop reflectance sensors make use of light emitting diodes (LEDs) to project light at prescribed wavelengths onto plants and then use photodiodes to sense the energy of the reflected light (Stone et al., 1996). Active sensors are designed to be insensitive to ambient light, detecting only the reflected energy of the light emitted by the sensor. In many of these studies reflectance measurements have been effectively related to metrics of N management, such as crop biomass, plant color, yield potential, and economic optimal N rate. Common to most of these studies has been the employment of an N sufficient reference where measurements from corn known to be nonlimited in N are compared with measurements from plants suspected of being N deficient. This comparison, either as a sufficiency index or response index, has been described as essential in making effective N management decisions using these crop sensors (Shanahan et al., 2008).

The value of using an N-sufficient reference for monitoring and responding to crop N needs is in helping to normalize confounding management and environmental factors (Blackmer and Schepers, 1995; Blackmer et al., 1996; Shanahan et al., 2003; Samborski et al., 2009). Guidelines for using active-light crop canopy sensing recommend producers establish an N-sufficient area or field-long N-sufficient strip for each field where sensing will be used to conduct in-season N fertilizer applications (Missouri USDA-NRCS, 2009; Shanahan, 2010). Whenever growing conditions vary within fields as a result of factors such as variable planting date, multiple hybrids, or changing soil type, a separate N-sufficient reference for each unique condition has been encouraged. The basis for hybrid-specific guidelines comes from earlier work where an N sufficient reference was found important for each hybrid when using a leaf chlorophyll sensor or other passive reflectance crop sensing (Bausch and Duke, 1996; Blackmer et al., 1996; Scharf et al., 2006). Comparable studies evaluating the effect of corn hybrids on active-light crop sensing is lacking.

Current guidelines for active-light crop sensors also lack information on the normal ranges of canopy reflectance readings for N-sufficient reference (Missouri USDA-NRCS, 2009; Shanahan, 2010), to guard against situations when the crop has been negatively affected (e.g., poor crop germination, disproportionate weed growth compared to the rest of the field). Since a reflectance value for N-sufficient corn is a key component in determining N fertilizer recommendations, having values that represent a normal range of N-sufficient

A.H. Sheridan, Dep. of Biological Engineering, Univ. of Missouri, Columbia, MO 65211; N.R. Kitchen, K.A. Sudduth, and S.T. Drummond, USDA-ARS, Cropping Systems and Water Quality Research Unit, Columbia, MO 65211. Received 5 July 2011. *Corresponding author (KitchenN@missouri.edu).

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Abbreviations: CI, chlorophyll index; CV, coefficient of variation; G1 growth phase 1; G2, growth phase 2; ISR, inverse simple ration; NDVI, normalized difference vegetative index; NIR, near-infrared; RMSE, root mean square error; VIS, visible.

reflectance would provide an additional check and increase the robustness of N recommendation algorithms (Missouri USDA-NRCS, 2009). This would be especially important when the N-sufficiency reference determination is automated, such as for sensing field-long N-sufficient strips. Knowing the normal range of reflectance would also be essential if N-sufficient values are to be estimated from on-the-go readings of underfertilized corn, as proposed by Holland and Schepers (2010). One objective of this research was to assess the impact of sufficiently N-fertilized, similar-maturing corn hybrids on active crop-reflectance sensor measurements during mid-vegetative growth stages. A second objective was to characterize the normal range of reflectance readings for N-sufficient corn as a function of corn height.

MATERIALS AND METHODS

Three Missouri sites were chosen for the 2008 and 2009 growing seasons. Sites are identified by the name of the nearest city (Table 1). Because of persistent wet conditions during the spring and early summer of 2009, the Marshall site was not planted that year. Thus, 5 site-years were available for analysis. Each site was planted and maintained by the University of Missouri Agricultural Extension Service Variety Trial Testing Program. Each year more than 100 corn hybrids are grown at these locations for yield performance evaluation. For this study of the 100 possible corn hybrids, a subset of similar maturing hybrids (114 d relative maturity ±1 d) was selected. Eleven hybrids were used in 2008 and eight hybrids were used in 2009. Sites were planted in a randomized complete block design with three blocks of replications. Each plot was 7.6 m long and 3.0 m wide. Planting was done at a rate of 70,700 seeds ha^{-1} at a depth of about 5 cm. Other management details including fertilizer application and pest control as well as rainfall and growing degree day information can be obtained in the University of Missouri Crop Performance annual reports (Weibold et al., 2008, 2009). Land used for these sites are either at designated research locations owned by the University of Missouri or rented and has been in a corn and soybean rotation since the initiation of the crop performance trials.

Early in the growing season at about the three leaf collar stage, each selected hybrid plot was flagged for identification. Starting when the corn was about 10 cm tall and on 3 to 5 d intervals, each site was revisited and a set of growth and reflectance measurements obtained (Table 1). A handheld Crop Circle crop sensor (Model ACS-210, Holland Scientific, Inc., Lincoln, NE) was used to measure reflectance at two wavelengths, 590 and 880 nm. Readings were obtained by holding the sensor approximately 50 cm over the top of the plants and taking measurements from the nadir view directly over each row for the center two rows of each plot. A total of 6 m of crop row was sensed, giving 90 to 120 readings per plot. Mean and standard deviation of sensor measurements were determined by plot.

Reflectance was expressed as the inverse simple ratio (ISR), which is the ratio of the reflectance of the visible (VIS) wavelength to that of the near infared (NIR) wavelength:

$$\text{ISR} = \text{VIS}/\text{NIR} \quad [1]$$

Two other reflectance indices were examined as a part of objective 2 of this study: normalized difference vegetative index (NDVI) and the chlorophyll index (CI; Gitelson et al., 2003).

$$\text{NDVI} = (\text{NIR} - \text{VIS})/(\text{NIR} + \text{VIS}) \quad [2]$$

$$\text{CI} = (\text{NIR}/\text{VIS}) - 1 \quad [3]$$

Leaf chlorophyll content was assessed using the Minolta 502 SPAD chlorophyll meter (Konica Minolta, Hong Kong). This sensor measures 650 nm light transmittance through the leaf, a wavelength associated with chlorophyll activity and N deficiency (Blackmer et al., 1994). At each measurement date (Table 1), chlorophyll content was assessed for each hybrid at the same time (within minutes) of crop-reflectance sensor readings. The SPAD meter was clamped onto the most recently collared leaf, mid-way along the blade. Fifteen plants were randomly selected for SPAD readings and averaged. From a separate randomly-selected set of four plants, height measurements were obtained from the soil surface to the top of the corn plant whorl and averaged.

Reflectance measurements of bare soil areas were also obtained using the Crop Circle sensor. For this measurement stationary readings were taken in an alley between plots, at one location in 2008 and six locations in 2009, with little to no foot traffic. These values changed as a function of soil surface moisture. During 2009, one soil sample was taken at the location where soil sensor readings occurred. The soil sample was taken from a depth of <3 cm and gravimetrically analyzed for soil moisture. Soil moisture content affecting soil color was assessed as a potential factor affecting crop reflectance readings.

During late vegetative growth stages (>V12, Ritchie et al., 1997) for the Columbia site in 2009, visual indication of N deficiency was observed. This was not unexpected because of the persistent and heavy rainfall during the months of June and July. Data for this site when corn was >120 cm tall was therefore removed.

Since the timing and frequency of sampling days were not the same for each site and year (Table 1), measurements were pooled to test the question of whether hybrids affected reflectance. Since sensor readings when corn was <20 cm were dominated by soil, these measurements were excluded from

Table 1. Site information and dates of crop reflectance sensing relative to days after planting (DAP).

Year	Location in Missouri	Georeference	Soil type	Planting date	DAP					
2008	Columbia	38°53' N, 92°12'W	Mexico Silt Loam mesic Vertic Epiaqualfs	22 June	19	23	25	29	37	47
	Henrietta	39°12' N, 93°54' W	Haynie Silt Loam mesic Mollic Udifluvents	30 April	36	42	47	50		
	Marshall	39°13' N, 93°18' W	Joy Silt Loam mesic Aquic Hapludolls	30 May	19	24	28	31	39	41
2009	Columbia	38°53' N, 92°12' W	Mexico Silt Loam mesic Vertic Epiaqualfs	24 June	20	26	32	36	41	46
	Henrietta	39°12' N, 93°54' W	Haynie Silt Loam mesic Mollic Udifluvents	3 May	15	21	29	33	37	42

this hybrid-effect analysis. When the scene for the sensor was a mix of soil and corn (20–70 cm corn height; V5–V9, Ritchie et al., 1997), readings were pooled together and called growth period 1 (G1). A second growth period (G2) when corn was 71 to 120 (V9–V13, Ritchie et al., 1997) cm was also pooled for this analysis. This period was referred to as "mostly corn" since the sensor view was dominated by corn. At corn heights >120 it was difficult to obtain sensor measurements, causing little data to be obtained. Therefore these measurements were excluded for the statistical test on hybrid. Data were then analyzed by these two growth periods using the GLM procedure of SAS (SAS, SAS Institute, Cary, NC) for a randomized complete block treatment design, with three blocks per site. Block effect was included in the model and all block interactions remained with the error term. Main and interaction effects of hybrid and site were examined (e.g., hybrid, site, and hybrid × site). Analysis was not combined across years because most hybrids were unique to 1 yr. Response variables included ISR from crop reflectance sensors, SPAD chlorophyll, and plant height. Mean separations using Fisher's protected LSD test were determined when F tests were significant at P values ≤ 0.05.

For characterizing the normal range of crop reflectance readings to represent N-reference corn, ISR values from the 2 yr were combined. For each 10-cm increment in plant height, ISR values were binned and the upper and lower 10% of data from each bin identified. These upper and lower data over all bins were then combined and the best fitting regression models were fit to create functions characterizing the upper and lower boundary of ISR as a function of plant height (Webb, 1972). Best fitting models using Table Curve 2D (Systat Software Inc., San Jose, CA) were selected based on the model with the lowest root mean square error (RMSE) out of the simple linear equations category. Both RMSE and coefficient of determination (r^2) are reported along with the model results. The procedure followed was similar to the boundary line analysis done by Kitchen et al. (1999). Because little data was obtained both when the crop was young and during late vegetative growth stages, we limited the regression fitting to corn in the 20 to 120 cm height range. Following a similar procedure, we also obtained upper and lower boundary regressions representing N-sufficient corn for NDVI and CI.

RESULTS AND DISCUSSION

Variation of Crop Reflectance with Crop Growth

During early vegetative growth stages when corn plants were ≤20 cm, reflectance measured as ISR was mainly affected by soil color, since plants represented a very small portion of the sensor view (labeled as "mostly soil" in Fig. 1). Corn growth stages for these early season measurements were V4 or less (Ritchie et al., 1997). For these soil-dominated observations, ISR values were >0.38 and the coefficient of variation (CV) within each plot <12%. In our work, reflectance measurements on bare soil have resulted in varying ISR values in the range of 0.40 to 0.52 (unpublished data, 2010), with lighter color soils giving higher ISR values. Others using this same sensor have reported bare soil measurements (expressed as ISR values) in the range of 0.48 to 0.55 (Roberts et al., 2010).

As plants increased in height, the scene observed by the sensors included a greater portion of reflectance from plant. This feature of more evenly-mixed soil and corn plant reflectance primarily occurred when corn height ranged from 20 to 70 cm, and corresponded to recorded growth stages V5 to V9 (Ritchie et al., 1997). During this phase ISR values decreased rapidly and CV values increased, indicative of sensor readings being a mixture of more equal proportions of plant and soil; greatest CV averaged 19%. Theoretically, the highest CV occurs when the soil–plant mixture is about 50%, as described by Raun et al. (2005b). Thereafter, average CV declined as canopy closure progressed (Fig. 1). At the same time, the rate of ISR decrease became less once corn reached 50 cm in height. According to Raun et al. (2005a) canopy closure proceeds rapidly after growth stage V6 causing dramatic changes in sensor readings as the effect of soil color diminishes. Based on our field observations and other previous work (Raun et al., 2005b; Kitchen et al., 2010), when the corn crop was approximately 70 cm in height (about V9, Ritchie et al., 1997) canopy closure was about 80% (i.e., only ~20% of the sensor scene was soil). For the purposes of this study, we identified corn 20 to 70 cm tall as a growth phase labeled "mix of soil and corn" in Fig. 1.

For corn >70 cm, both ISR and CV measurements decreased modestly up to height of 120 cm. We identified this phase as "mostly corn" (Fig. 1). For plants >120 cm CV increased again, but we have no good explanation for this. While others have reported a secondary increase in reflectance CV in response to tasseling (Raun et al., 2005b; Martin et al., 2007), this did not explain the increase we observed since all measurements were obtained in pre-reproductive stages.

Effects of Hybrid on Crop Reflectance

During G1 of either cropping year, ISR values were not found to be different by hybrid (Table 2). This was true within research sites as well as averaged across research sites. Only during G2 for 2008 when averaged across sites were significant ISR differences found between hybrids (Tables 2 and 3). The lack of a strong hybrid effect is illustrated by the overlapping of hybrid observations in Fig. 2. At the same time, hybrid differences were found during both G1 and G2 of both years with chlorophyll meter sensing. But mean separations of 2008 G2 ISR values were not the same as those found with chlorophyll meter (Tables 2 and 3). Comparison of the ranked means of ISR and chlorophyll values demonstrates this. While significant correlation between chlorophyll meter and crop reflectance measurements have previously been shown in N rate studies (Shanahan et al., 2008; Solari et al., 2008), subtle differences in crop spectral characteristics like those due to hybrid appear to be more difficult to delineate with the crop sensors than with chlorophyll measurements. Other work contrasting crop sensing measurements with chlorophyll measurements supports this conclusion (Kitchen et al., 2010). Difference in sensing technology as well as sampling procedures of these two types of measurements are noteworthy. For the chlorophyll meter, transmittance of chlorophyll-absorbing light through the leaf is determined with the sensor device clamped directly onto the leaf. Only a small leaf area (<1 cm^2) is sensed per reading (Minolta, 1990). For the crop reflectance sensing, plant biomass and color are integrated with soil for a relative soil–plant

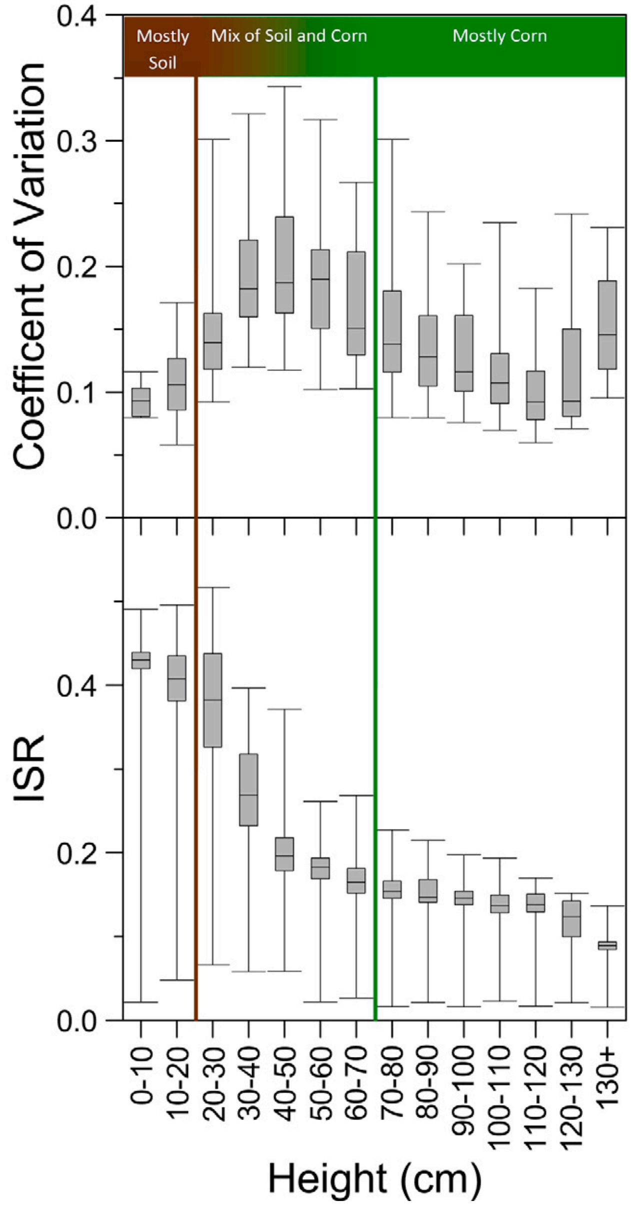

Fig. 1. Box and whisker plot displays of the trend of inverse simple ratio (ISR) and CV with the advancement of growth stage over both years of data. The whiskers contain the full range of data, the box is the upper and lower quartile and the box line is the median.

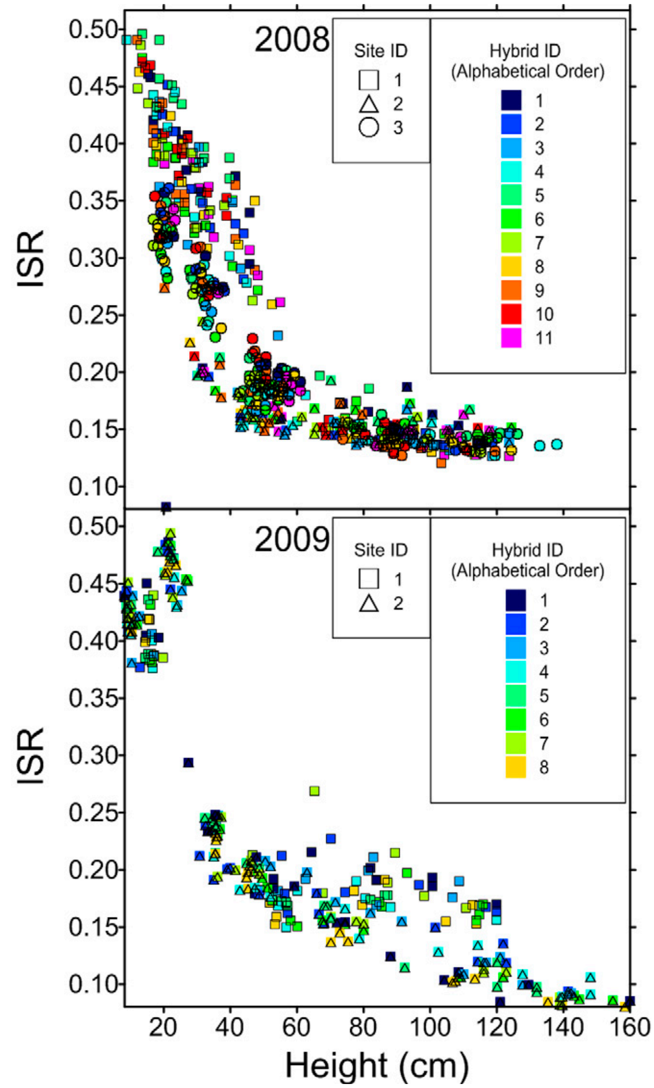

Fig. 2. Crop sensor inverse simple ratio (ISR) as a function of crop height for field sites in (top) 2008 and (bottom) 2009.

reflectance reading. This usually is from above the crop in a nadir view. For the sensor make/model used in this study the sensed footprint is approximately 300 to 400 cm^2 at the prescribed operating heights (Holland Scientific, 2004). Such technology and scale differences undoubtedly will produce unique outcomes when comparing these two technologies.

What impact would the hybrid differences shown for ISR and chlorophyll measurements in this investigation have on N fertilizer recommendations? Using the hybrids with the highest (0.158) and the lowest (0.141) ISR values to represent an N-sufficient reference (2008 G2 only), N fertilizer recommendations were calculated using an algorithm currently advocated in Missouri (Missouri USDA-NRCS, 2009). Since the recommendations are dependent on the ISR value of the corn yet to be fertilized, a wide range of potential ISR values for unfertilized corn was tested (0.16–0.22). The difference

Table 2. Analysis of variance results for crop reflectance inverse simple ratio (ISR), chlorophyll meter readings (SPAD), and corn height. Measurements were determined for two growth phases: growth phase 1 (G1) for corn 20 to 70 cm in height; and growth phase 2 (G2) for corn 71 to 120 cm in height.

			ISR		SPAD		Height	
Year	Effect	df	G1	G2	G1	G2	G1	G2
2008	Site	2	***	***	ns†	***	***	*
	Hybrid	10	ns	***	***	***	ns	ns
	Hybrid × site	20	ns	ns	ns	ns	ns	ns
2009	Site	1	***	***	ns	ns	***	ns
	Hybrid	7	ns	ns	**	***	ns	ns
	Hybrid × site	7	ns	ns	ns	*	ns	ns

* Significant at 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† ns, not significant.

in the N rate recommendation from these two hybrids varied from 34 to 47 kg N ha^{-1} depending on the ISR value used for unfertilized corn (0.16–0.22). The range of differences is shown as the ISR box plot in Fig. 3. This range represents the greatest effect hybrid would have on reflectance-based N fertilizer recommendations. Using ISR values of all 11 hybrids as if these values were the N-sufficient reference corn and the same wide range of potential ISR values for unfertilized corn, the average difference in N fertilizer recommendation between hybrids would only be 10 kg N ha^{-1}. Hybrid differences affecting recommended N were much more pronounced with SPAD chlorophyll values than ISR. Again, the hybrids with highest and lowest SPAD values for each growth period and each year were used to represent the N-sufficient reference. Fertilizer N recommendations in this case were calculated using a regional algorithm developed by Scharf et al. (2006). Again a wide range of potential SPAD values for unfertilized corn were tested (40–52). The difference in the N rate recommendation between the hybrids with the highest and lowest SPAD values are also shown for each of the growth periods as box plots in Fig. 3. Over growth periods and years, the average effect of hybrid on N rate recommendation was nearly 100 kg N ha^{-1}. Therefore, relative to N recommendations, the impact of corn hybrid on N fertilization based on SPAD readings was about 2.5 times greater than the hybrid effect with crop reflectance sensing. Because of this lower sensitivity with crop sensor data, and the fact that significant hybrid differences were found with crop sensor measurements in only one of four growth periods tested, we conclude reflectance differences among similar maturing hybrids will have minimal impact on N fertilizer recommendations.

Table 3. Hybrid mean values and statistical differences of crop reflectance inverse simple ratio (ISR) and chlorophyll meter readings (SPAD). Measurements were determined for two growth phases: growth phase 1 (G1) for corn 20 to 75 cm in height; and growth phase 2 (G2) for corn 76 to 160 cm in height. Corn height not shown because analysis of variance detected no significant differences among hybrids.

Year	Hybrid ID	Hybrid	ISR		SPAD	
			G1	G2	G1	G2
2008	1	AgriGold A6632VT3	ns†	0.152ab‡	48.7c	54.5c
	2	Burrus 750	ns	0.143a	44.7ab	54.0bc
	3	Dekalb DKC64–24 (VT3)	ns	0.142a	44.7ab	49.5a
	4	Dekalb DKC65–24 (VT3)	ns	0.145ab	48.0bc	51.9abc
	5	Hubner H5828VT3	ns	0.158b	43.7a	50.8abc
	6	Lewis 815VT3	ns	0.153ab	44.2a	51.4abc
	7	Lewis 915 CB	ns	0.144ab	46.7abc	50.0ab
	8	Merschman M-314A-10	ns	0.141a	48.6c	54.7c
	9	Mycogen 2T783	ns	0.144ab	48.7c	53.6abc
	10	Mycogen 2T826	ns	0.143a	48.5c	54.8c
	11	Pioneer 33K44 (HX1,LL,RR2)	ns	0.141a	45.5abc	53.2abc
2009	1	AgriGold A6632VT3	ns	ns	52.1b	60.0a
	2	Crow's 5292VT3	ns	ns	51.0b	52.5b
	3	Dekalb DKC65–63 (VT3)	ns	ns	46.0a	52.3b
	4	Hubner H5828VT3	ns	ns	50.6b	57.2a
	5	Lewis 914VT3	ns	ns	45.8a	52.2b
	6	Power Plus 7D51	ns	ns	48.5ab	57.5a
	7	Stone 8T597VT3	ns	ns	51.4b	57.8a
	8	Taylor 2260	ns	ns	50.2b	60.8a

† ns, not significant.

‡ Means within the same column and year followed by the same letter are not significantly different at the 0.05 probability level.

Inverse simple ratio measurements were found to vary by site during G1 for 2008 and G2 for both years of the study (Tables 2 and 4). These differences were especially notable during the 2008 G1 growth phase and could be attributed to soil color differences between the sites. Site differences are obvious as displayed in Fig. 2. Sensor measurements of bare soil for Columbia, Henrietta and Marshall, obtained when corn height was <27 cm (about V4–V5, Ritchie et al., 1997) were 0.423, 0.473, and 0.404, respectively. These ISR values are averages for all measurements combined. Soil moisture at the same time of reflectance sensing ranged from 4% to 38%. These surface soil moisture values span the range that could be expected within a field with variable soil conditions. The ability of the Crop Circle sensor to discern soil differences has been previously used to delineate variations in soil organic matter and other properties within fields to help create management zones (Roberts et al., 2010).

Table 4. Site mean values and statistical differences of crop reflectance inverse simple ratio (ISR), chlorophyll meter readings (SPAD), and corn height. Measurements were determined for two growth phases: growth phase 1 (G1) for corn 20 to 75 cm in height; and growth phase 2 (G2) for corn 76 to 160 cm in height.

Year	Site	ISR		SPAD		Height	
		G1	G2	G1	G2	G1	G2
2008	Columbia	0.344a†	0.143a	ns‡	56.2a	34.3a	92.4ab
	Henrietta	0.174b	0.153b	ns	48.3b	46.1b	90.2a
	Marshall	0.233c	0.142a	ns	53.2c	40.2b	96.8b
2009	Columbia	0.179a	0.180a	ns	ns	46.0a	ns
	Henrietta	0.283b	0.134b	ns	ns	38.0b	ns

† Means within the same column and year followed by the same letter are not significantly different at the 0.05 probability level.

‡ ns, not significant.

Corn height was not affected by hybrid, but was affected by site for both years, with this effect mainly observed in the initial phase of growth (G1) (Tables 2 and 4). These results might indicate that local environmental conditions have a greater impact on hybrid expression during the earlier vegetative growth stages.

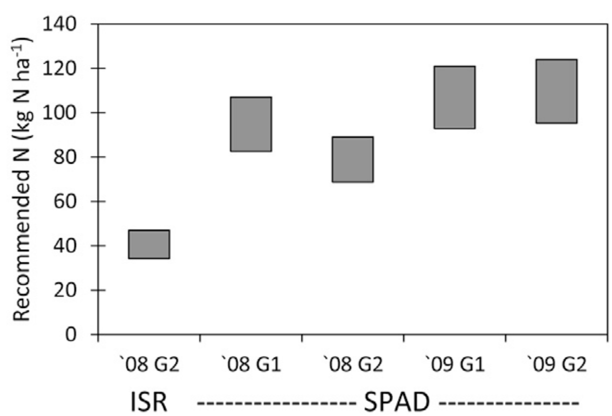

Fig. 3. The difference in N rate recommendations from the hybrids with the highest and lowest inverse simple ratio (ISR) or chlorophyll SPAD values. Each box represents the range of potential recommendation differences between the two hybrids based on a wide range of potential values for unfertilized corn. Fertilizer recommendations for ISR from Missouri USDA-NRCS (2009) and from SPAD used Scharf et al. (2006). Shown are only those site-years that were statistically significant.

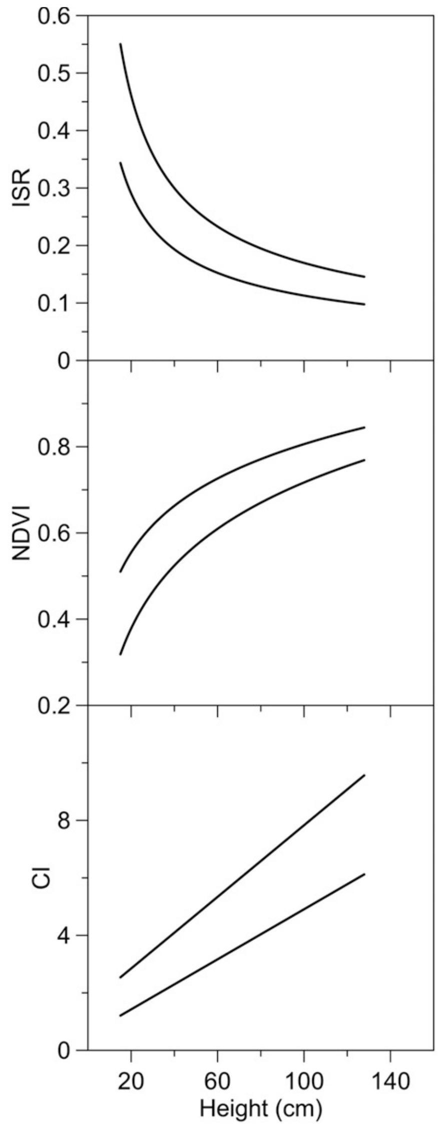

Fig. 4. Upper and lower 10% boundary line model results for inverse simple ratio (ISR), normalized difference vegetative index (NDVI), and chlorophyll index (CI) reflectance indices for normal N-sufficient corn as a function of corn height.

Development of Models to Represent Normal Ranges

In a typical growing season there can be many and varied environmental factors with negative effects on the health of crop plants, both temporally over the season and spatially within a field. Examples include excess or deficient water, extreme temperatures, inadequate fertility, soil compaction, insect and disease stress, and weed competition. If any one or combination of these factors is at play within the area set as the high-N reference area, determination of appropriate N fertilizer rates using crop reflectance sensing will likely be compromised. Having contingency procedures for determining an N-sufficient reference is needed in these situations.

Since hybrid had little impact on crop reflectance, we first investigated using this data to develop a universal equation for estimating an N-sufficient reference as a function of plant height. For this analysis we explored taking the effect of soil color and moisture on ISR readings into account by using bare soil reflectance, taken the same day as crop reflectance sensing.

Table 5. Equations for the upper and lower boundaries for three different crop sensor indices of N-sufficient corn as a function of corn plant height.

Index	Boundary	Equation†	r^2	RMSE
ISR	upper	$Y = 0.1144 + 6.986/X$	0.87	0.0441
	lower	$Y = 0.06949 + 4.688/X$	0.91	0.0224
NDVI‡	upper	$Y = 0.1561 \times \ln(X) + 0.08702$	0.88	0.0362
	lower	$Y = 0.2103 \times \ln(X)- 0.25145$	0.89	0.0458
CI	upper	$Y = 0.0622 \times X + 1.602$	0.88	0.739
	lower	$Y = 0.0435 \times X + 0.5545$	0.86	0.583

By averaging out soil color based on the height of sensing, we hypothesized readings would be more similar for a given height when combined across sites. Even after doing so, there was large variation in ISR values for a given plant height. We concluded using this data to generate a universal equation would have a high risk of producing erroneous N rate recommendations.

Because this study included multiple hybrids, soils, and years, we concluded the results could at the least be used to characterize the normal range of reflectance readings for N-sufficient corn as a function of corn height. Such values are needed with N rate application algorithms to help guard against including anomalous readings. To characterize normal N-sufficient corn we developed models to represent reflectance values as a function of corn height. These models provide both the minimum and maximum values expected, and are shown for ISR, NDVI, and CI (Fig. 4; Table 5). For both ISR and NDVI, minimum and maximum 10% boundary lines generally parallel each other as a function of plant height, with the range of values slightly decreasing with increasing corn height. In comparison, boundary lines for CI widened with plant height. This was likely caused by changes in visible wavelength reflectance values with corn growth affecting this index more than the other two indices.

We propose that when using sensors for corn N fertilizer rate recommendations, these boundary models should be included as a check to the N-sufficient reference sensing values. Plant readings that fall within the minimum and maximum boundary lines are assumed to be of normal growth. Readings above the maximum or below the minimum represent unusual conditions and should be removed before calculating an N fertilizer rate. In situations where the majority of readings are outside the minimum and maximum values, using crop reflectance sensors for determining N rates should be questioned. For automated collection of strips of N-sufficient corn or for virtual N-reference strategies (Holland and Schepers, 2010), height sensing may be needed to check on-the-go for suspect readings using these boundary line models.

CONCLUSIONS

When sufficiently fertilized with N, similar-maturing corn hybrids had little effect on active crop reflectance sensor measurements. More pronounced differences were observed with leaf chlorophyll sensor measurements. The findings indicate hybrid-specific N-sufficient reference areas may not be necessary for fields planted at the same time with multiple but similar maturing hybrids. It is not uncommon for farmers to split their planter boxes with two hybrids to assess yield performance in side-by-side strips. These results would suggest using crop reflectance sensing of an N-sufficient reference area of just one hybrid acceptable for in-season N fertilization of such fields.

From 2004 to 2008, our group worked closely with producers on more than 50 different production-scale fields to direct in-season N applications using crop reflectance sensors (Scharf et al., 2011). On several occasions portions of the N-sufficient reference areas were compromised (e.g., weeds, wheel traffic, etc.) and extra care was needed on the day of sensing and N application to ensure reliable N-sufficient sensor values. With this study we generated models to represent typical upper and lower values for several different vegetative indices as a function of corn height. Employing these models can help guard against using questionable data when calculating N fertilizer rate.

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