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Chlorophyll Meter Assessments of Corn Response to Nitrogen Management Practices

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Environmentally sound nitrogen (N) management is necessary to simultaneously achieve high crop yields and protect surface and groundwater quality. We evaluated a hand-held chlorophyll meter as a diagnostic tool for improving N management for corn (*Zea mays* L.). Five N fertilizer rates (0, 67, 134, 201 and 280 kg N ha^{-1}) were evaluated in one study, and in a second study, the meter was used to evaluate the N status of corn plants grown under varying tillage (chisel plow vs no-till), crop rotation (continuous corn vs corn-soybean [*Glycine max* (L.) Merr.]), and N management treatments. Meter readings were taken at several plant growth stages in both studies and correlated with plant N concentrations and grain yield. The chlorophyll meter readings detected differences in corn plants receiving low and high fertilizer N rates, as well as those grown with different tillage, N fertilizer management, and crop rotation practices. We recommend taking measurements between plant growth stages V9 and V12 and conclude that chlorophyll meters can be effective tools for improving N fertilizer management.

INDEX DESCRIPTORS: nitrogen, plant nutrition, fertilizer management, tillage, crop rotation, manure effects, soil quality, sustainability

The application of N fertilizer is essential for corn production at current levels, but to prevent water quality problems it is also important to minimize the amount of residual soil nitrate (Magdoff 1992). Some residual nitrate can be recovered by subsequent crops, but when rainfall exceeds evapotranspiration, the unrecovered nitrate can be leached from the crop root zone and become a health risk if concentrations in drinking water exceed 10 mg L^{-1} nitrate-N (Bundy and Malone 1988). Because of the high amount of N that is applied to farmland throughout Iowa and other Midwestern states, minimizing the amount of residual soil nitrate at the end of each growing season is economically and environmentally very important.

By using better methods to predict fertilizer N requirements, farmers and land managers can use N fertilizer more efficiently, thus saving them money and reducing the potential for surface and groundwater contamination. Several plant and soil measurements have been evaluated to help optimize fertilizer applications, but many of the procedures are costly and substantial time is required to process the samples. New approaches that utilize leaf and canopy characteristics to quantify the N status of a crop could enhance fertilizer N management (Marquard and Tipton 1987, Sinclair and Horie 1989, Dwyer et al. 1991, Wolfe et al. 1988) and also improve crop yield predictions (Blackmer et al. 1994, 1996a, 1996b).

Recent studies indicate that commercially available chlorophyll meters can be used as a diagnostic tool to predict the fertilizer N requirement for corn (Piekielek and Fox 1992, Schepers et al. 1992, Wood et al. 1992, Berghoefer and Killorn 1994, Blackmer and Schepers 1995). These meters are hand-held instruments with a digital readout. The measurements are based on light transmittance characteristics of chlorophyll, and their use does not require any complicated calibration. Chlorophyll meters can be used to assess plant N status because N is an integral part of chlorophyll and other major photosynthetic enzymes (Yadava 1986, Wolfe et al. 1988). Because the green color of plant canopies is determined primarily by chlorophyll content, its intensity affects spectral characteristics of the leaf (Al-Abbas et al. 1974, Thomas and Gausman 1977, Maas and Dunlap 1989, Dwyer et al. 1994).

Based on the experiences summarized above and because the Minolta[a] (SPAD) chlorophyll meters are relatively simple to use, we hypothesized that this tool could be very useful for monitoring crop N conditions in the senior author's home country (Kenya), where analytical services are often too costly to be practical. Our objectives were (1) to determine if chlorophyll meters could efficiently detect differences caused by N fertilizer rates and other soil and crop management practices, and (2) to determine the best plant growth stage and number of measurements needed to accurately detect differences in N content within corn plants growing at two Iowa locations.

METHODS

Study 1

Field layout and experimental design

A field experiment was carried out in 1996 on the Donald Larson Farm near Story City, Iowa. Predominant soil map units within the field were Kossuth silty clay loam (fine-loamy, mixed, mesic Typic Haplaquolls), Ottosen clay loam (fine-loamy, mixed, mesic Aquic Hapludolls), and Harps loam (fine-loamy, mesic, Typic Calciaquolls). These soils are generally poorly drained with moderately slow water permeability in the upper portion of the profile. As result, the field has been pattern-drained by installing plastic drainage tubes every 30 to 40 meters across the field. This management practice has created a series of tile-drained strips approximately 520 m long and

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[a] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or Iowa State University, and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

Table 1. Soil and crop management systems being evaluated for corn production at the Nashua site.

SYSTEM	TILLAGE PRACTICES	N PROGRAM
1	No-tillage after soybean	28 kg N ha^{-1} preplant + 167 kg N ha^{-1} sidedressed at V6
2	No-tillage after soybean	110 kg N ha^{-1} preplant
3	Field cultivate soybean residue	28 kg N ha^{-1} preplant + 141 kg N ha^{-1} sidedressed at V6
4	Field cultivate soybean residue	110 kg N ha^{-1} preplant
5	Chisel plow soybean residue after manure application	83 kg N ha^{-1} applied through fall application of swine manure†
6	Chisel plow corn residue after manure application	102 kg N ha^{-1} applied through fall application of swine manure‡
7	Chisel plow corn residue	134 kg N ha^{-1} preplant

†61 kg N ha^{-1} was estimated as carry-over from 1994 manure application
‡69 kg N ha^{-1} was estimated as carry-over from 1993, 1994, and 1995 manure applications

ranging from 30 to 40 m in width. In 1995, nine of the drainage lines were intercepted and a series of sump pumps and water samplers were installed so that the volume of flow and N concentrations in the tile drainage water could be quantified. Three N fertilizer treatments (67 kg, 134 kg, and 201 kg per hectare) were applied to the soil above these nine tile lines using a randomized complete block design with three replicates. Narrow (10 m wide) check strips with no N fertilizer or 280 kg N per hectare were established over adjacent, nonintercepted tile lines to provide additional treatments for testing the chlorophyll meter response. Each of the N fertilizer strips were subdivided into eight 60-m segments from which experimental data were collected (72 plots for the three primary N fertilizer treatments plus 16 plots for the 0 kg N ha^{-1} and 24 plots for the 280 kg N ha^{-1} treatment). Data from the eight "plot" areas within each N strip were considered repeated measures for each of the fertilizer treatments. All data were analyzed for treatment and replicate effects using the general linear model (GLM) analysis of variance (ANOVA) procedure (SAS Institute 1985). Means for treatments which were significantly different at $P=0.05$ based on the F test were separated by computing least significant difference (LSD) values for that probability level.

Management practices

The field was chisel plowed during the fall of 1995 and received secondary tillage with a field cultivator in April 1996 to incorporate herbicide and prepare the seedbed. Nitrogen fertilizer treatments were imposed by our cooperator using an anhydrous ammonia applicator on April 17, 1996. A high-oil hybrid corn ('Brown 6840') was planted on May 25, 1996. Seasonal weather patterns were generally quite favorable for corn production with a total of 1330 (°C) growing degree units between planting and harvest and 658 mm (25.9 inches) of rainfall. One early-season rainfall event, during which 170 mm of rainfall was measured at the site, resulted in some short-term flooding across much of the field. All treatments had areas that were affected by this flooding, but ponding was not uniform across all of the "plot" areas from which chlorophyll meter and plant data were collected.

A Minolta SPAD 502 chlorophyll meter (Spectrum Technologies, Inc., Plainfield, IL) was used to assess leaf N status. This meter measures light at the 430 nm wavelength where chlorophyll *a* and *b* have the highest absorption and at 750 nm where the least absorption occurs and most of the light is reflected or transmitted. A unitless measurement (SPAD Reading) is computed by the chlorophyll meter, based on differences in light attenuation at the two wavelengths. The SPAD readings range from 0 to 80, with a higher number representing a greener leaf.

For each N treatment, three corn rows were identified and marked within each 60 m plot. Chlorophyll measurements were made at each site by selecting 30 plants within each of the three, 6-m lengths of row. Therefore, 90 measurements per site or 720 readings per N management strip were taken on the top, fully-expanded leaf at growth stages V6, V9, and V15 (Ritchie et al. 1996). At each sampling site, three representative plants from within the three rows but outside the 6 m sample area were collected and taken to the laboratory for N analysis. Corn plants were dried at 65°C, weighed, ground in a hammer mill and sub-sampled, further ground in a Wiley mill (Thomas Scientific, Philadelphia, PA) and subsampled again, before grinding through a Cyclone sample mill (Udy Corporation, Fort Collins, CO) to pass a 0.5-mm stainless steel screen. A final subsample was then ball-milled for 5 minutes, and approximately 10 mg was used for total N measurements with a Carlo-Erba (Haake Buchler Instruments, Inc., Patterson, N.J.) dry combustion analyzer.

Study 2

A second experiment was conducted in 1996 at the Iowa State University Northeast Research Farm near Nashua, Iowa. Predominant soils at this site are Floyd loam (fine loamy, mixed, mesic Aquic Hapludolls), Kenyon loam (fine-loamy, mixed, mesic Typic Hapludolls), and Readlyn loam (fine-loamy, mixed, mesic Aquic Hapludolls). Seven soil and crop management systems which incorporated tillage, crop rotation, and N source, rate, and timing components were imposed on 0.4 ha plots that were replicated three times in a randomized complete block experimental design (Kanwar et al. 1997). Tillage and N management components included in each of the management systems are presented in Table 1. A commercial corn hybrid ('Golden Harvest 2343') was planted on May 21, 1996. Temperature was not a limiting growth factor, but the total seasonal amount (68.3 cm) and distribution of rainfall was poor causing severe drought stress during July when less than 4 cm of rainfall were received.

At six plant growth stages (V6, V9, V12, V15, VT, and R1), chlorophyll meter readings were taken at three locations along a diagonal transect through each plot. At each location three rows were selected and SPAD readings were taken for 30 plants. This provided a total of 270 SPAD readings per plot. Two representative plants were removed from each treatment near the sites where SPAD readings were taken. The six plants from each plot were dried, ground,

Table 2. Nitrogen rate effects on plant growth and N concentrations in 1996 at selected growth stages on the Larson Farm near Story City, IA.

N RATE kg ha^{-1}	V6		V9		V15	
	g plant^{-1}	% N	g plant^{-1}	% N	g plant^{-1}	% N
0	31 cd†	1.90 b	81 c	1.65 d	161 bc	1.42 b
67	24 d	1.81 b	60 d	1.84 c	170 abc	1.53 b
134	36 bc	2.04 b	103 b	2.20 b	147 c	1.46 b
202	40 b	2.53 a	117 ab	2.49 a	195 a	1.91 a
280	47 a	2.70 a	126 a	2.43 a	184 ab	1.81 a
LSD$_{(0.05)}$	7	0.38	16	0.15	26	0.16

†Means within a column followed by the same letter are not significantly different at P = 0.05

Table 3. Chlorophyll meter (SPAD) response to N fertilizer rates in 1996 at selected growth stages on the Larson Farm near Story City, IA.

N RATE kg ha^{-1}	GROWTH STAGE		
	V6	V9	V15
0	37.0 b†	34.7 c	39.5 c
67	30.5 c	33.7 c	44.5 b
134	39.2 ab	43.3 b	48.4 a
202	40.3 a	45.0 ab	48.7 a
280	42.2 a	46.1 a	48.2 a
LSD$_{(0.05)}$	3.1	2.0	1.4

†Means within a column followed by the same letter are not significantly different at P = 0.05

and prepared for N analysis as described fot Study 1. Finally, since the existing study would not accommodate the creation of a "high N" reference area, SPAD readings were also taken from nearby plots where the same hybrid was being grown with a fertilizer rate of 240 kg N ha^{-1}.

RESULTS AND DISCUSSION

Study 1—Larson Farm

Tissue N concentrations

The short-term flooding that occurred after the intensive rainfall in mid-June submerged several plants for a few days. Most of the plants recovered, but in general, the lower leaves in the 0 and 67 kg N ha^{-1} strips were more yellow and gradually turned brown along the margins (called firing) in an apparent response to inadequate amounts of plant available N. Furthermore, plants in the strips which received the higher rates of N (134, 202, or 280 kg N ha^{-1}) developed brace roots more quickly and also had more rapid leaf appearance and expansion rates (growth) than those fertilized with 0 or 67 kg N ha^{-1}.

Plant samples taken at V6, V9, and V15 showed statistically significant differences (P=0.01) in plant growth and N concentration due to the fertilizer rate which had been applied (Table 2). Nitrogen concentrations at V6 were highest in plants receiving 280 kg N ha^{-1}, with those values being significantly greater than in plants receiving 134 kg N ha^{-1} or less. Average N concentrations in plants growing in strips that received 202 kg N ha^{-1} were lower, but not significantly different from those receiving 280 kg N ha^{-1}.

Significant differences in plant growth and tissue N concentration were also observed at the V9 growth stage (Table 2). Plants receiving either 202 or 280 kg N ha^{-1} had N concentrations that were not significantly different from each other, but both were different from the lower N treatments. N concentrations in plants fertilized with 0, 67, or 134 kg N ha^{-1} were directly proportional to the amount of N applied. At V15, N concentrations in plants fertilized with either 202 or 280 kg N ha^{-1} were significantly greater than in plants receiving less N (Table 2). Among the lower rates of fertilization, N concentration differences were not significant.

Chlorophyll meter measurements

Chlorophyll meter readings at all three corn growth stages showed significant differences due to N fertilization rate (Table 3). At V6, SPAD readings for the 134, 202, and 280 kg N ha^{-1} rates were not significantly different from each other, but the 202 and 280 kg N ha^{-1} treatments were significantly different from the 0 and 67 kg N ha^{-1} strips. The same relationship between the two lower and two upper N fertilizer rates was evident at the V9 growth stage, but in addition, the 134 and 280 kg N ha^{-1} treatments were also significantly different.

Comparing the V6 and V9 sampling dates, it is interesting that the average chlorophyll meter reading for the two lower fertilizer rates was essentially the same, while readings for the higher N treatments increased by four or five units. This suggests that as the demand for N increased due to nearly a tripling in plant weight (Table 2), there simply was not enough available N where 0 or 67 kg ha^{-1} had been applied to increase the SPAD readings in the newest, fully-expanded leaves. Furthermore, firing or browning of leaf edges due to inadequate N was also observed during these early growth stages within the 0 and 67 kg N ha^{-1} strips. This indicates that there was a net translocation of N from older leaves to newly formed leaves, another indication that N was limiting growth in those strips.

Highly significant differences in chlorophyll meter readings were also observed at V15 (Table 3). Unlike the earlier growth stages, the 0 kg N ha^{-1} treatment had significantly lower SPAD readings than the 67 kg N ha^{-1} treatment. Readings from both treatments (0 and 67 kg N ha^{-1}) were significantly lower than for plants from the 134, 202 and 280 kg N ha^{-1} treatments. SPAD readings for the three high N treatments were not significantly different from each other at this growth stage.

Correlation and regression analyses

Simple Pearson correlation coefficients (r) between tissue N concentration and SPAD readings were highly significant for 67, 134, 202, and 280 kg N ha^{-1} N fertilization rates at the V6 growth stage with values of 0.52, 0.56, 0.76, and 0.62, respectively. When all SPAD readings and N concentration data were averaged across N rates for this site, correlation coefficients for the mean values were 0.83, 0.95, and 0.65 for the V6, V9, and V15 growth stages, respectively. Correlation coefficients between fertilizer rate and tissue N concentrations were 0.53, 0.76, and 0.67 for the V6, V9, and V15 growth stages, respectively, when all data were used, or 0.93, 0.94, and 0.82, respectively, when mean values were correlated. Similar correlations between mean SPAD readings and fertilizer rates and mean tissue N concentrations and fertilizer rates suggest that chlorophyll meter readings can be used to accurately assess plant N status. Furthermore, at growth stage V15 the chlorophyll meter was able to distinguish between plants fertilized with 67 kg N ha^{-1} and 0 kg N ha^{-1} at V15, but tissue N analysis could not (Tables 2 and 3).

Regression analyses for the SPAD meter readings versus fertilizer

Table 4. Chlorophyll meter SPAD readings for corn grown under eight different management systems in 1996 near Nashua, Iowa.

	CROP GROWTH STAGE					
SYSTEM	V6	V9	V12	V15	VT	R1
1	46.3 d†	54.4 b	55.5 bcd	57.6 b	54.9 cd	56.2 bc
2	42.9 e	55.7 ab	56.5 bc	58.3 ab	56.1 bcd	57.4 abc
3	49.0 c	56.5 ab	56.5 bc	58.6 ab	57.6 abc	59.0 ab
4	51.5 b	56.5 ab	57.2 b	59.6 a	58.5 ab	59.0 ab
5	49.1 c	54.0 b	54.6 cd	56.7 b	54.1 d	54.7 c
6	48.4 cd	54.1 b	54.5 d	56.7 b	54.5 cd	55.3 c
7	49.9 bc	54.6 b	54.6 cd	57.0 b	54.9 cd	55.6 c
8‡	57.7 a	58.1 a	61.5 a	57.3 b	60.1 a	60.0 a
$LSD_{(0.05)}$	2.4	2.7	1.9	2.0	3.4	3.2

†Means within a column followed by the same letter are not significantly different at P = 0.05
‡High-N reference plot fertilized with 240 kg N ha^{-1}

rate and the rate squared showed that at the V6 growth stage, the relationship was linear ($r^2 = 0.28$). However, at V9 and V15 the addition of a significant (P = 0.01) negative quadratic component resulted in slightly higher correlation values ($r^2 = 0.60$ and 0.66, respectively) than the simple linear relationships ($r^2 = 0.58$ and 0.45, respectively). Presumably this reflects the plateau effect in chlorophyll meter readings (Dwyer et al. 1994), which was also confirmed by the lack of significant differences for both SPAD readings and N concentrations in plants fertilized with either 201 or 280 kg N ha^{-1} (Tables 2 and 3) . The regression analyses also suggest that by allowing plants to reach the V9 growth stage before taking readings, it will be more likely that maximum values will be seen than if readings are taken at the earlier growth stages.

The presence of a plateau in SPAD readings has been criticized (Dwyer et al. 1994), because it often prevents the user from distinguishing between higher rates of N (i.e., 202 versus 280 kg N ha^{-1}). However, it can be argued that this distinction may not be necessary, provided the meter can simply detect that a sufficient amount of N is available. Based on that philosophy, SPAD readings appear to be of greatest value when used to identify deficiencies and to indicate when more fertilizer N may be beneficial. The plateau type response also provides a practical technique for using chlorophyll meters to assess plant N status when the crop is exposed to different weather patterns or when different hybrids are being used (Berghoefer and Killorn 1994). Rather than attempting to establish a "critical SPAD level" a small but well-fertilized (≥200 kg N ha^{-1}) calibration area can be established within each field as a reference that would give SPAD readings above which there would be no advantage to having more available N. Farmers could then measure SPAD values in other portions of their field and if the readings were similar to the well-fertilized plot, they could be comfortable that plant N requirements were being met through their experience or their use of other N management tools including the late-spring (LSNT) or pre-sidedress (PSNT) soil nitrate test (Blackmer et al. 1993). In summary, this study confirmed that SPAD chlorophyll meters could be used as a diagnostic tool to reduce the risk of applying excess N when deficiencies might be perceived because of weather and/or general plant growth patterns.

Study 2—Nashua Experiment Station

Chlorophyll meter measurements

Chlorophyll meter readings for a "high-N" reference area plus the seven management systems being evaluated at Nashua (Table 1) were taken at the V6, V9, V12, V15, VT, and R1 growth stages, and are presented in Table 4. Based on an ANOVA "F" test, SPAD readings for conventionally tilled corn with 110 kg N ha^{-1} applied prior to planting (System 4) were significantly lower than the high-N reference area at only two of the six growth stages. System 2 , which had the same N rate and timing as system 4, but was planted without surface tillage had the lowest SPAD reading at V6, but showed no significant difference from system 4 at the V9, V12, V15, VT, or R1 growth stages. This suggests that chisel plowing increased the amount of available N early in the season, presumably by hastening decomposition of soybean residue from the previous crop. Furthermore, the V6 chlorophyll meter readings (Table 4) appear to have successfully detected this difference.

System 5, which was also managed in a corn-soybean rotation but received swine manure as its N source, had significantly lower SPAD readings than system 4 at five of the six sampling stages. Also, even though 144 kg N ha^{-1} were anticipated to be available to the crop (83 kg N ha^{-1} applied plus 61 kg N ha^{-1} carryover), SPAD values for system 5 were among the lowest values measured at the V15, VT, and R1 growth stages. Presumably, carry-over from prior swine manure applications was much less than anticipated (Table 1). Unfortunately, this was not confirmed with spring soil nitrate tests, but it certainly is a nutrient management issue that warrants further investigation.

Another N management strategy for evaluation at the Nashua site (Table 1), was the use of a split N fertilizer application program, with the majority of N applied based on the pre-sidedress soil nitrate test (PSNT) recommendations (Blackmer et al. 1993). Chlorophyll meter readings for system 1, which used the PSNT in a no-till environment, were significantly lower at the V6 growth stage than for system 3, which was also fertilized based on the PSNT, but had received surface tillage with a field cultivator prior to planting. By the late vegetative (V15 and VT) and early reproductive growth stages (R1), however, the average SPAD readings for systems 1 and 3 were not significantly different (Table 4). Once again, this suggests that preplant tillage hastened decomposition of soybean residue and soil organic matter, thus providing more available N during the early plant growth stages. Finally, as shown in Study 1 and expected for 240 kg N ha^{-1}, the high N reference area had SPAD readings which simply reached a plateau (~60) when N was not considered a limiting factor for corn growth.

Plant dry matter and N concentrations

Siambi (1997) showed that tissue N concentrations were highest at V4, but declined because of dilution as the plants increased in

Table 5. Management system effects on plant dry matter at selected growth stages and grain yi8ld in 1996 near Nashua, Iowa.

SYSTEM	V4	V6	V9	V12	VT	YIELD
	g plant^{-1}					Mg ha^{-1}
1	1.7 bc†	12 a	42 a	108 bc	170 a	9.33 a
2	1.6 c	11 a	45 a	106 bc	156 a	8.47 b
3	2.0 a	14 a	54 a	115 ab	167 a	9.36 a
4	1.9 ab	13 a	53 a	107 bc	179 a	8.99 ab
5	2.1 a	15 a	58 a	122 a	158 a	8.88 ab
6	2.0 a	13 a	50 a	99 c	161 a	8.37 b
7	2.1 a	13 a	46 a	112 ab	154 a	7.19 c
LSD$_{(0.05)}$	0.3	NS	NS	12	NS	0.66

†Means within a column followed by the same letter are not significantly different at $P = 0.05$

size. He also reported significant differences among management systems for plant dry weight at growth stages V4 and V15 and for total N content at the V6 and V15 stages. These fluctuations were not considered unusual since tillage, and N rate, timing, and source were all incorporated as variable component within the various management systems (Table 1).

Comparisons of plant dry weight at the V4 growth stage (Table 5) indicated that the no-till treatments (systems 1 and 2) had slower vegetative growth than tilled treatments with the same N management (systems 3 and 4). This slower growth was presumably related to N availability since chlorophyll meter readings at V6 were also lower with no-till than other treatments (Table 4).

Use of the PSNT resulted in the application of higher N fertilizer rates to the no-till plots than were expected (Table 1). However, growth responses and increases in SPAD readings in response to the sidedress N applications were not observed until after the V6 growth stage. Preplant fertilizer application plus surface tillage hastened early-season growth by corn plants under system 4, but later in the season, plants from these plots were smaller than plants from some of the other treatments.

Rainfall in July was very low (3.3 cm compared to a 30-yr average of 11.8 cm). This created severe plant water stress during the early reproductive growth stages. Visual observations of leaf roll indicated that plant stress was most severe for plants which grew vigorously during the early vegetative stages. This suggested that those plants exhausted plant available soil water supplies more quickly than plants grown using no-till practices (systems 1 and 2). As a result, plants which grew vigorously during the vegetative growth stages and should have had a higher yield potential (Karlen et al. 1987) could not sustain their early-season growth advantage through the grainfill period. Water stress during reproductive growth stages (Ritchie et al. 1996) thus resulted in lower grain yield (Table 5), even though the plants maintained SPAD readings that were among the highest until the end of the season (Table 4). This confirms that factors other than N (in this case water) were more limiting to plant growth, but also verifies that the chlorophyll meter was still giving an accurate assessment with regard to N status.

The chlorophyll meter consistently identified management systems 5, 6, and 7 as being different from the high-N reference area (Table 4). The SPAD readings also showed that systems 5 and 6 (rotated versus continuous corn with N from swine manure) were not significantly different from each other. High tissue N concentrations at V6 in plants from system 6 (Siambi 1997) indicated that early-season N stress was not the limiting factor associated with continuous corn production. Low tissue N at the V6 growth stage in plants grown using no-till practices (system 1) presumably occurred because readings were taken before the plants could respond to the sidedress N application. However, by the latter part of the growing season, plants responded to the N fertilizer, indicating use of the PSNT accurately predicted the need for additional N to meet crop demand.

Grain yield

Highly significant differences in grain yield were observed between the seven management systems (Table 5). Systems 1 and 3, which, based on the PSNT, had the highest N fertilization rate (Table 1) had the highest yields, but they were not significantly different from systems 4 and 5. Systems 2 and 6 had similar yields, which were not significantly different from those achieved with systems 4 and 5. System 7 (continuous corn with 134 kg N ha^{-1}) had a significantly lower yield than the other treatments.

Correlation analyses

The Nashua study enabled us to evaluate the chlorophyll meter as a diagnostic tool for N management under two tillage systems with various N management scenarios. Correlations between SPAD readings and plant N concentrations at the V9 and V15 growth stages were good ($r = 0.53$ and 0.52), but correlations between grain yield and tissue N at all growth stages were poor (Siambi 1997). The correlation between whole plant total N at physiological maturity and fertilizer rate ($r = 0.81$) was also positive and significant.

There was also a good correlation ($r = 0.56$) between SPAD readings at V12 and grain yield. Blackmer et al. (1994) stated that the number of leaves sampled can affect the statistical relationship between chlorophyll meter readings and yield because of high variability in the data. However in our study, the number of leaves sampled (270 per plot) was sufficient to develop a good relationship between SPAD readings and grain yield.

Water stress due to low July rainfall was a problem that undoubtedly affected all relationships between the leaf characteristics and grain yield at the Nashua site, but the magnitude of stress was never quantitatively established. Therefore, we can only hypothesize that the positive relationship between SPAD readings at V12 and grain yield would have continued through the later growth stages if summer rainfall would have been normal. The water stress is also hypothesized to have been a major factor contributing to the lack of correlation between SPAD readings and N fertilizer rates associated with the various management systems at this site. It was encouraging, however, that early in the growing season, management practices that presumably affected N uptake were detected by differences in the chlorophyll meter readings.

CONCLUSIONS

These studies demonstrated that chlorophyll meters can be used to assist with fertilizer N management under different tillage and management practices. To effectively use this tool, we recommend taking SPAD measurements between plant growth stages V9 and V12, and using two reference strips (N limiting and N non-limiting) to calibrate the meters for the hybrid, soil, management history, and other factors which could affect corn growth and N uptake within each field.

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LITERATURE CITED

AL-ABBAS, A.H., R. BARR, J.D. HALL, F.L. CRANE, and M.F. BAUMGARDNER. 1974. Spectra of normal and nutrient-deficient maize leaves. Agronomy Journal 66:16–20.

BERGHOEFER, C. and R. KILLORN. 1994. Chlorophyll meter, promising as tool for nitrogen management. Fluid Journal 2:9–11.

BLACKMER, A.M., T.F. MORRIS, B.G. MEESE, and A.P. MALLARINO. 1993. Soil testing to optimize nitrogen management for corn. Pm-1521, Iowa State University Cooperative Extension Service, Ames, IA. 4 pp.

BLACKMER, T.M., J.S. SCHEPERS, and G.E. VARVEL. 1994. Light reflectance compared with other nitrogen stress measurements in corn leaves. Agronomy Journal 86:934–938.

BLACKMER, T.M. and J.S. SCHEPERS. 1995. Use of a chlorophyll meter to monitor nitrogen status and schedule fertigation for corn. Journal of Production Agriculture 8:56–60.

BLACKMER, T.M., J S. SCHEPERS, G.E. VARVEL, and E.A. WALTER-SHEA. 1996a. Nitrogen deficiency detection using reflected shortwave radiation for irrigated corn canopies. Agronomy Journal 88:1–5.

BLACKMER, T.M., J.S. SCHEPERS, G.E. VARVEL, and G.E. MAYER. 1996b. Analysis of aerial photography for nitrogen stress within corn fields. Agronomy Journal 88:729–733.

BUNDY, L.G., and E.S. MALONE. 1988. Effect of residual profile nitrate on corn response to applied nitrogen. Soil Science Society of America Journal 52:1377–1383.

DWYER, L.M., M. TOLLENAAR, and L. HOUWING. 1991. A nondestructive method to monitor leaf greenness in corn. Canadian Journal of Plant Science 71:505–509.

DWYER, L.M., A.M. ANDERSON, B .L. MA, D.W. STEWART, M. TOLLENAAR, and E. GREGORICH. 1994. Quantifying the non-linearity in chlorophyll meter response to corn leaf nitrogen concentration. Canadian Journal of Plant Science 75:179–182.

KANWAR, R.S., D.L. KARLEN, C.A. CAMBARDELLA, T.B. MOORMAN, T.R. STEINHEIMER, and T.S. COLVIN. 1997. Impacts of swine manure application and alternative N-management practices on productivity, sustainability, and water quality. Final Report for Leopold Grant No. 97–60. Leopold Center for Sustainable Agriculture. Ames, IA.

KARLEN, D.L., R. L. FLANNERY, and E.J. SADLER. 1987. Nutrient and dry matter accumulation rates for high yielding maize. Journal of Plant Nutrition 10:1409–1417.

MAGDOFF, F.R.. 1992. Minimizing nitrate leaching in agricultural production: How good can we get? Communications in Soil Science and Plant Analysis 23:2103–2109.

MARQUARD, R.D., and J.L. TIPTON. 1987. Relationship between extractable chlorophyll and an in situ method to estimate leaf greenness. HortScience 22: 1327.

MAAS, S.J., and J.R. DUNLAP. 1989. Reflectance, transmittance, and absorptance of light by normal, etiolated, and albino corn leaves. Agronomy Journal 81:105–110.

PIEKIELEK, W.P., and R.H. FOX. 1992. Use of a chlorophyll meter to predict sidedress nitrogen requirements for maize. Agronomy Journal 84: 59–65.

RITCHIE, S.W., J.J. HANWAY, and G.O. BENSON. 1996. How a corn plant develops. Spec. Rept. No. 48. ISU Coop. Ext. Serv., Ames, IA.

SAS INSTITUTE INC. 1985. SAS User's Guide: Statistics, Ver. 5 Edition, Cary, NC, 956 pp.

SCHEPERS, J.S., D.D. FRANCIS, M.F. VIGIL, and F.E. BELOW. 1992. Comparison of corn leaf nitrogen concentration and chlorophyll meter readings. Communications in Soil Science and Plant Analysis 23:2173–2187.

SIAMBI, M. M. 1997. An assessment of diagnosric tools for improved soil and crop management. Ph.D. dissertation. Iowa State University, Ames (Dissertation Abstract Number 97–25460).

SINCLAIR, T.R., and T. HORIE. 1989. Leaf nitrogen, photosynthesis and crop radiation use efficiency: A review. Crop Science 29:90–98.

THOMAS, J.R., and H.W. GAUSMAN. 1977. Leaf reflectance vs. Leaf chlorophyll and carotenoid concentration for eight crops. Agronomy Journal 69:799–802.

WOLFE, D.W., D.W. HENDERSON, T.C. HSIAO, and A. ALVINO. 1988. Interactive water and nitrogen effects on senescence of maize. II. Photosynthetic decline and longevity of individual leaves. Agronomy Journal 80:865–870.

WOOD, C.W., D.W. REEVES, R.R. DUFFIELD, and K.L. EDMISTEN. 1992. Field chlorophyll measurements for evaluation of corn nitrogen status. Journal of Plant Nutrition 15:487–500.

YADAVA, U.L. 1986. A rapid non-destructive method to determine chlorophyll in intact leaves. HortScience 21:1449–1450.