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Field Chlorophyll Measurements to Assess the Nitrogen Status of Potato Varieties

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Abstract. **We report three N rate experiments conducted on a gravelly loam soil to assess the N status of potato (*Solanum tuberosum* L.) using a Minolta SPAD-502 chlorophyll meter. Highly significant linear and quadratic trends were obtained for the regression of N rate on marketable tuber yields and SPAD readings. SPAD readings were taken at four times during the growing season and decreased as plants aged. Based on regression analysis, the early season SPAD readings, associated with N rates giving maximum marketable tuber yields, ranged from 49 to 56 units depending on year, variety, and location. Potato variety significantly affected SPAD values in eight of the 12 situations where readings were obtained. Precision in interpretation was improved when the highest N rates were considered "reference strips" to standardize the SPAD readings across varieties and growing seasons. Our results suggest that field SPAD readings can readily identify severe N deficiency in potatoes, have the potential to identify situations where supplementary sidedressed N would not be necessary, but would be of limited value for identifying situations of marginal N deficiency unless reference strips are used.**

Potato plants require relatively large amounts of N for optimum growth and tuber production. Ideally, the fertilizer requirement should meet the difference between plant need (total N uptake at high yield) and the N contribution from the soil (soil organic matter, incorporated legume crops, manures, etc.). However, accurate prediction of soil N contribution is difficult because it varies considerably with soil type and environmental conditions (temperature, soil aeration, rainfall) beyond the control of growers. To ensure against such uncertainties, growers traditionally apply large amounts of N at the time of planting.

A more environmentally sound and cost-effective strategy to improve N-use efficiency would be to apply moderate amounts of N at planting and the remainder as sidedressings, as needed, before the last cultivation at hilling. Growers would be more likely to adopt such a strategy if they had a reliable, rapid method to assess N status at the field site. Traditional tissue testing and laboratory analysis for N are often too slow for timely response by growers.

A small, lightweight, portable, hand-held meter (SPAD-502 chlorophyll meter; Minolta Corp., Ramsey, N.J.) is available that provides instant, nondestructive chlorophyll readings of plant leaves (Yadava, 1986). This meter has been used in Japan (Takebe and Yoneyama, 1989; Takebe et al., 1990) and the United States (Turner and Jund, 1989) to predict N requirements of rice (*Oryza sativa* L.). According to Alabama researchers (Wood et al., 1992), it also has potential for estimating seasonal N requirements of maize (*Zea mays* L.). Working over an N application range of 0 to 336 kg·ha^{-1} for 2 years, they showed SPAD chlorophyll measurements of maize at the 10-leaf stage and at midsilk to be highly correlated with tissue N concentrations, and both SPAD readings and N concentrations showed excellent grain yield prediction capabilities. Piekielek and Fox (1992) tested the meter with maize over 3 years for 67 situations in Pennsylvania and concluded that the SPAD readings of the fifth leaf could accurately predict whether maize would respond to sidedressed N fertilizer. They emphasized, however, that the SPAD chlorophyll readings were not well enough correlated with soil N supplying capability to determine precisely what rate of N to apply to a responsive site. Schepers et al. (1992) compared SPAD readings and maize leaf disk N concentrations in N rate studies at several locations in Nebraska. They included several hybrids in their experiments to address the problem of the unique "greenness" characteristics associated with the diverse varieties. Although SPAD readings correlated well with leaf N concentrations for a given hybrid and location, they concluded that the use of SPAD meters to assess N status may not be practical without some kind of normalization procedure to account for hybrid and location effects on the SPAD values.

The objectives of the present study were to determine the feasibility of using field chlorophyll measurements for evaluating potato N status and the extent to which potato variety might influence these measurements.

Materials and Methods

Two N rate experiments were conducted in 1990 and one in 1991 at the Homer C. Thompson Vegetable Research Farm in Freeville, N.Y., on a Howard gravelly loam soil (loamy-skeletal, mixed mesic Glossoboric Hapludalf). The first experiment in 1990 consisted of four N rates: N at 0, 84, 168, and 252 kg·ha^{-1} and two varieties, 'Allegheny' and 'Castile'. The second 1990 experiment consisted of five N rates: N at 0, 112, 168, 224, and 280 kg·ha^{-1} and two varieties, 'Katahdin' and 'Superior'. The 1991 experiment also used 'Katahdin' and 'Superior' and had four N rates: N at 0, 84, 168, and 252 kg·ha^{-1}. In all three experiments, all of the N was applied in the band as NH_4NO_3.

The plots were located on the site of a previous meadow with a history of limited fertilization and only 3 years of prior vegetable production. According to Cornell soil testing procedures (Greweling and Peech, 1965), the site tested low to medium with respect to P and low with respect to K. Therefore, in addition to the indicated N rates, all plots in 1990 received P at 73 kg·ha^{-1} as ordinary superphosphate and K at 140 kg·ha^{-1} as muriate of potash applied in the same band. Rates of these same materials for 1991 were 122 and 232 kg·ha^{-1} for P and K, respectively, to ensure that N was the only growth-limiting nutrient, although there was no evidence that P and K were limiting in 1990. The fertilizer was banded 5 cm away on both sides of the seed piece and 2.5 cm below the seed. The pH of the 1990 sites was 5.3 and that of the 1991 site was 5.6. Commercial certified seed was stored at 5C before a 7-day warm-up at 16C, after which the seed was cut, suberized for 4 to 5 days, and then planted. Planting dates were 23 and 24 May 1990 and 15 May 1991.

The design was a randomized complete block with four replications. Plots consisted of four rows with 23-cm intrarow and 90-cm interrow spacings. Data were obtained from the center two rows. Plot length was 5.5 m, which included a 1.2-m section of red 'Chieftain' potatoes to mark the division between plots at harvest. Cultural practices (Cornell Cooperative Extension, 1990) and a combination of hilling, cultivation, pest and disease control, and irrigation were applied as required by the crop and the growing season. We observed no apparent growth-limiting factors other than the N treatments.

The Minolta SPAD-502 meter was used to obtain readings estimating chlorophyll concentration on the fourth or fifth leaf down from the top of the plant, the youngest fully expanded leaf, on 22 and 29 June and 6, 24, or 25 July for the 1990 experiments. Dates were 21 and 28 June, and 12 and 19 July for the 1991 experiment, which was planted 1 week earlier than the 1990 experiments. At 29 to 37 days after planting, when the first SPAD readings

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Table 1. Summary of the factorial analysis of variance for the three field experiments.

	1990 (Expt. 1)			1990 (Expt. 2)			1991		
Source	df	SS	F	df	SS	F	df	SS	F
				Tuber yield					
Replication	3	127.10	3.11*	3	9.22	0.31	3	67.60	0.99
N at plant (N)	3	1275.86	31.22***	4	1396.81	34.91***	3	1188.92	17.41***
Variety (V)	1	163.25	11.99**	1	81.33	8.13**	1	526.86	23.15***
N × V	3	13.51	0.33	4	41.07	1.03	3	41.29	0.60
		SPAD 30 dap[z]			*SPAD 29 dap*			*SPAD 37 dap*	
Replication	3	1.77	0.21	3	47.46	3.44*	3	5.22	0.78
N at plant (N)	3	611.25	72.61***	4	745.74	40.54**	3	301.07	44.95***
Variety (V)	1	26.83	9.56**	1	12.43	2.70	1	0.26	0.12
N × V	3	66.63	6.61**	4	16.90	0.92	3	7.03	1.05
		SPAD 27 dap			*SPAD 36 dap*			*SPAD 44 dap*	
Replication	3	4.96	1.05	3	12.06	0.89	3	21.01	3.18*
N at plant (N)	3	871.55	184.35***	4	850.34	47.14***	3	1258.10	190.14***
Variety (V)	1	0.78	0.50	1	14.88	3.30	1	52.28	23.70***
N × V	3	4.81	1.02	4	4.36	0.24	3	6.37	0.96
		SPAD 44 dap			*SPAD 43 dap*			*SPAD 58 dap*	
Replication	3	17.00	1.86	3	9.38	0.87	3	1.95	0.90
N at plant (N)	3	1062.36	116.51***	4	1274.54	88.76***	3	950.88	439.67***
Variety (V)	1	54.34	17.88***	1	54.75	15.25***	1	44.89	62.77***
N × V	3	19.12	2.10	4	26.36	1.84	3	12.62	5.83**
		SPAD 62 dap			*SPAD 62 dap*			*SPAD 65 dap*	
Replication	3	4.23	0.51	3	34.74	4.03*	3	2.10	0.64
N at plant (N)	3	321.59	39.08***	4	466.26	40.59***	3	897.64	272.67***
Variety (V)	1	159.76	58.25**	1	386.88	134.71***	1	6.94	6.32*
N × V	3	14.83	1.80	4	119.87	10.43***	3	8.85	2.69

[z]Readings are taken on days indicated; dap = days after planting.
*, **, ***Significant at $P \leq 0.05$, 0.01, or 0.001 by F test, respectively.

were taken, the potato plants had three to five fully expanded leaves. For consistency, measurements were always made on the leaflet adjacent to the terminal leaflet. Fifteen readings, one reading on each of 15 plants, were taken in each replication and averaged.

Vine killing was initiated for all experiments in mid-September, and tubers were harvested in early October. Tubers were harvested from the two middle rows of each plot, graded for size, and weighed; only the yields of marketable tubers (tubers ≥4.8 cm in length and free from disease and defects) are presented.

Regression analyses for N rate on tuber yield and SPAD values were conducted to identify significant linear and quadratic trends and to estimate maximum yields with corresponding N rates and SPAD values. Factorial analyses were used to identify significant variety effects and any N rate × variety interactions. Analyses were performed using software version 2.0.5 of JMP (SAS Institute, 1989).

Results

Nitrogen rate. Nitrogen limited tuber yield in all experiments, and a curvilinear yield response was obtained to N rate (Table 1, Fig. 1). Similarly, a curvilinear response to N rate also was obtained for the SPAD readings taken during the season in all experiments (Figs. 2–4). Accordingly, the SPAD readings across N rates were well correlated with tuber yields under the N-limiting conditions of these experiments. Correlation coefficients averaged 0.80 and ranged from 0.61 to 0.87, depending on variety, experiment, and sampling time (data not shown).

The data in Figs. 2–4, which plot the average SPAD reading (based on 15 readings, each on a different plant) for each replication, show considerable scatter among replications. The average standard deviation for a replication mean, considering all the experiments, was 1.2 SPAD units, but ranged from 0.2 to 2.0 units, suggesting the need for numerous readings to adequately characterize even a small area.

Using the highly significant quadratic trends from the regression analysis of N rate on yield, we were able to estimate the N rates in each experiment that resulted in maximum yield: 195 kg N/ha for Expt. 1 in 1990; 205 or 225 kg N/ha for Expt. 2 in 1990, depending on variety; and 180 or 200 kg N/ha for the 1991 experiment, depending on variety (note arrows in Fig. 1). By similar regression technique, the SPAD readings associated with these N rates were estimated and varied between 39 and 56 units over all three experiments and sampling times (Figs. 2–4). The SPAD readings decreased as plants aged, and Fig. 5 plots the decrease in mean SPAD readings against days after transplanting (dap) for the N rate giving maximum yield, as determined by regression. The mean "maximum yield" SPAD readings were generally >50 units for the earliest two samplings, a time just before or at tuber initiation when it is not too late to sidedress additional N. The exception was the first sample of the first experiment where 'Castile' at 49 SPAD units had a lower reading than 'Allegany' and lower than it was at sampling 1 week later.

Variety. Variety significantly affected SPAD readings in eight of the 12 sample dates where readings were obtained across the three experiments (Table 1, Figs. 2–4). A significant N rate × variety interaction occurred on three dates (30 dap, Fig. 2; 62 dap, Fig. 3; and 58 dap, Fig. 4) and resulted from the fact that the varieties differed at the higher N rates but were similar or switched ranking at the zero N rate. The interaction was nearly significant ($P \cong 0.07$) for 65 dap, Fig. 4.

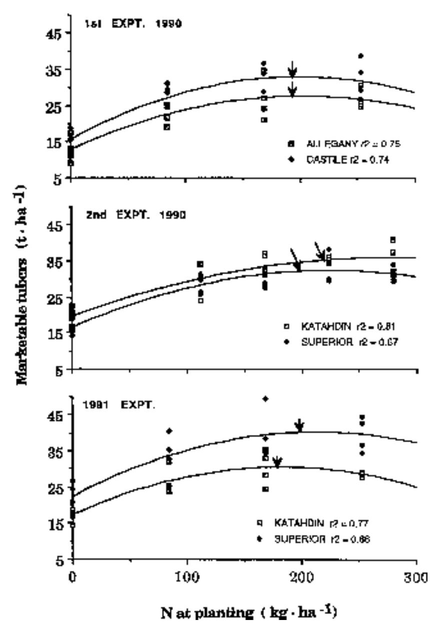

Fig. 1. Effect of N applied in the band at planting on marketable potato tuber yields (tubers ≥4.8 cm) for the three field experiments. Arrows indicate the N rates giving maximum tuber yield as estimated from the highly significant quadratic regressions ($P < 0.001$). Each point represents the yield of the individual replications; varieties differed significantly as determined by the factorial analysis of variance (Table 1).

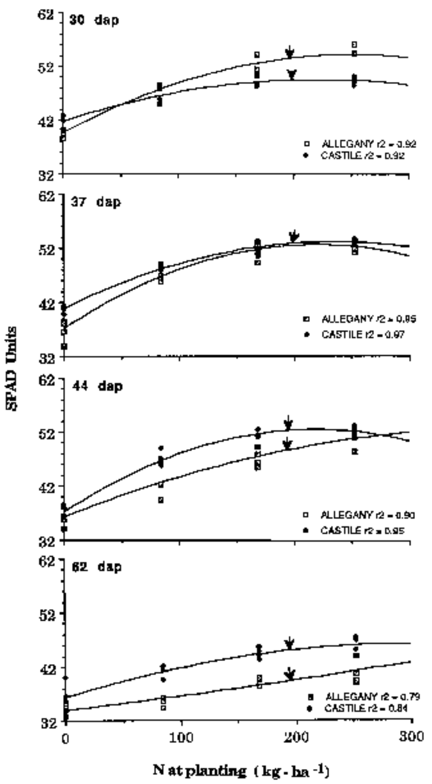

Fig. 2. Effect of N applied in the band at planting on SPAD readings over the growing season for 'Castile' and 'Allegany' potatoes, 1990. Arrows indicate the N rates giving maximum tuber yields as estimated from the highly significant quadratic regressions (from Fig. 1). Each point represents one replication that is the average of 15 readings, each from a different plant; dap = days after planting. Varieties differed significantly for 30, 44, and 62 dap (Table 1).

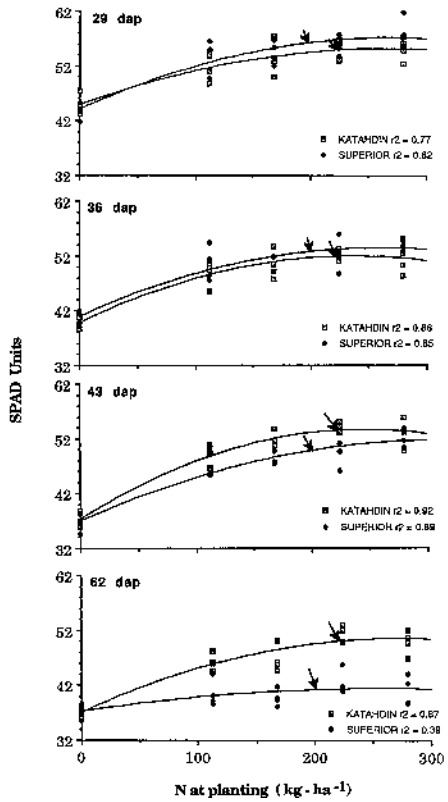

Fig. 3. Effect of N applied in the band at planting on SPAD readings over the growing season for 'Katahdin' and 'Superior' potatoes, 1990. Arrows indicate the N rates associated with maximum tuber yields according to the highly significant quadratic regression (from Fig. 1). Each point represents one replication that is the average of 15 readings, each from a different plant; dap = days after planting. Varieties differed significantly for 43 and 62 dap (Table 1).

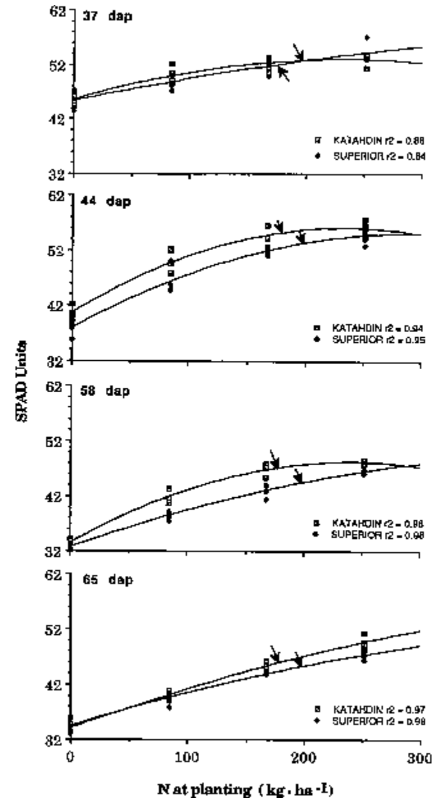

Fig. 4. Effect of N applied in the band at planting on SPAD readings over the growing season for 'Katahdin' and 'Superior' potatoes, 1991. Arrows indicate the N rates giving maximum yield as determined by the highly significant quadratic regressions (from Fig. 1). Each point represents one replication that is the average of 15 readings, each from a different plant; dap = days after planting. Varieties differed significantly for 44, 58, and 65 dap (Table 1).

'Castile' outyielded 'Allegany' in 1990 (Fig. 1), but the SPAD values for 'Castile' were higher only for the first sampling, after which the SPAD values for 'Allegany' were higher (Fig. 2). 'Katahdin' outyielded 'Superior' in 1990 (Fig. 1) and similarly had higher SPAD values for the later two samples (Fig. 3). 'Katahdin' also had higher SPAD values than 'Superior' for all but the first sampling dates in 1991 (Fig. 4), but in this year 'Superior' was the higher yielder (Fig. 1). 'Superior' emerges earlier than 'Katahdin' and grows faster earlier in the season but also matures earlier. Therefore, the earlier planting date in 1991 could be part of the reason 'Superior' yielded more in 1991 than 1990; but we cannot account for the lower yield of 'Katahdin' in 1991 than in 1990.

Discussion

As indicated by tuber yields (Fig. 1), the experiments allowed us to compare SPAD readings over a range of N status from insufficiency to excess. The marked effect of N rate on SPAD readings (Figs. 2–4) and the resulting high correlation between these readings and tuber yield suggest a potential usefulness for SPAD readings, in making judgments about the need for further N in a growing potato crop. In this regard, SPAD readings taken early are of greater interest because there is still time to sidedress the potatoes before a final cultivation. Based on the regression analysis for N rate on yield and SPAD readings, we estimated threshold SPAD values (values associated with the lowest N rate giving maximum yield). These values ranged from ≈49 to 56 units for the late-June readings (29 to 37 dap) where growing season and variety were variables (Fig. 5). This range might be considered a tentative benchmark above which no further N would be necessary, but the variability and range (the earliest sample of 'Castile' at optimum N gave 49 SPAD units) would make it difficult to identify a slight or even a moderate deficiency, as opposed to the severe deficiency represented by the treatments where zero N was applied.

Piekielek and Fox (1992) suggested a critical SPAD value for field corn of ≈43 units to separate responsive and nonresponse sites with respect to sidedressing. They concluded, however, that the SPAD readings were too weakly correlated with soil N supplying power, as estimated by soil nitrate-N ($r = 0.59$), to specify N rates on needy sites. Nevertheless, avoiding N applications to sites where there is already enough N should, in itself, be sufficient justification for further experimentation with the SPAD meter. It might prove particularly useful in situations where low to moderate amounts of N were applied at planting because of expected N contributions from soil organic matter, incorporated legumes, or manure breakdown. The meter could provide a good indication of whether these expected contributions from the soil are developing fast enough to meet plant needs.

In the conduct of potato variety trials over the years, we have noticed that varieties often differ in greenness and light reflectance, as well as general canopy development. Thus, we were not surprised to note that the SPAD readings were significantly affected by variety in eight of the 12 dates that readings were taken over the three experiments. Some potato varieties could vary more than the ones used in this study, although 'Superior' matures early and 'Katahdin' matures relatively late; this was reflected in the higher SPAD readings for 'Katahdin' later in the season. The maize experiments of Schepers et al. (1992) deal directly with the variety effect, and they concluded that the unique greenness characteristics of the various maize hybrids were significant enough to limit the practicality of SPAD technology unless a normalization procedure using a well-fertilized reference strip was adopted.

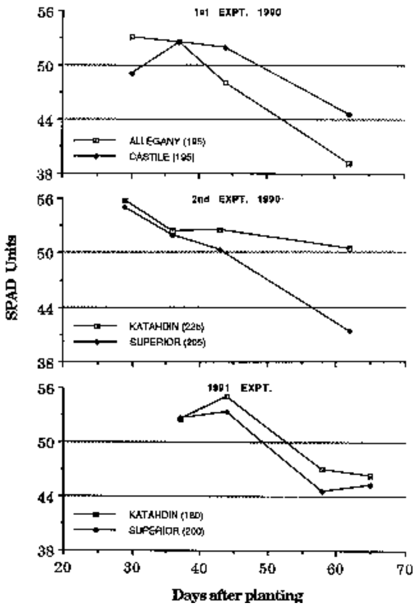

Fig. 5. Effect of sampling date on SPAD readings at maximum tuber yield. The values plotted are means of the four replications and represent the SPAD reading at the N rates (kg•ha^{-1}, shown in parenthesis) associated with maximum yields, all determined from the regression curves (Figs. 1–4).

Major advantages for adopting SPAD technology are speed of measurement, simplicity, and convenience. Several nondestructive measurements can be taken from several plants and averaged in <1 h. A decision about N sufficiency could be reached before leaving the field. However, the relatively high cost (≈$1200) might discourage small growers who would otherwise be interested, although the cost becomes less significant when viewed over many years because maintenance involves only battery replacement.

The most important limitation is that factors other than available N (variety, growing season, location) can affect plant growth and chlorophyll development and thus the SPAD values obtained. This makes it difficult to establish interpretive guidelines that are widely adaptable. To address this problem, Schepers et al. (1992) suggested a normalization procedure that would compare SPAD readings from well-fertilized (not necessarily efficient but insurance-type fertilization) reference strips to the SPAD readings obtained from the test field where a decision about the need for additional N is to be made. Although this approach gives up much of the convenience, in that a reference area has to be established, it does standardize the tissue readings across varieties, growing seasons, and locations and across all the variables the latter two factors encompass.

We applied this approach to the first two samplings using the highest N rate applied as the reference strip (Table 2). In general, we conclude, without concern about variety and growing-season effects, that a treatment was fertilized sufficiently when the SPAD values were within 1 to 2 units of the reference. This approach is preferable, from an interpretation standpoint, to dealing with a range of 49 to 56 SPAD units when trying to relate values to a standard of absolute values.

Table 2. Comparison of SPAD readings at N rate giving maximum yield with SPAD readings at the highest N rate applied (reference strip) for the first two sampling times.

	Sampling times					
	21–22 June			28–29 June		
Experimental	Optimum N rate SPAD	Reference SPAD	Differential	Optimum N rate SPAD	Reference SPAD	Differential
	SPAD units					
	1990					
Expt. 1						
Allegany	53.1	54.0	0.9	52.5	53.7	1.2
Castile	49.1	49.2	0.2	52.5	53.2	0.7
Expt. 2						
Katahdin	55.8	56.4	0.6	52.3	52.6	0.3
Superior	55.0	57.7	2.7	51.9	53.7	1.8
	1991					
Katahdin	52.5	53.4	0.9	55.1	56.3	1.2
Superior	52.7	54.0	1.3	53.5	54.8	1.3

Literature Cited

Cornell Cooperative Extension. 1990. Annual pest management recommendations for commercial vegetable and potato production, p. 60–32. Cornell Coop. Ext., Cornell Univ., Ithaca, N.Y.

Greweling, T. and M. Peech. 1965. Chemical soil tests. Cornell Agr. Expt. Sta. Bul. 960. p. 12.

Piekielek, W.P. and R.H. Fox. 1992. Use of a chlorophyll meter to predict sidedress nitrogen requirements for maize. Agron. J. 84:59–65.

SAS Institute. 1989. JMP® user's guide, version 2.0.5. SAS Inst., Cary, N.C.

Schepers, J.S., D.D. Francis, M. Vigil, and F.E. Below. 1992. Comparison of corn leaf nitrogen concentration and chlorophyll meter readings. Commun. Soil Sci. Plant Anal. 23:2173–2187.

Takebe, M. and T. Yoneyama. 1989. Measurement of leaf color scores and its implication to nitrogen nutrition of rice plants. Jpn. Agr. Res. Quarterly 23:86–93.

Takebe, M.T., T. Yoneyama, K. Inada, and T. Murakami. 1990. Spectral reflectance ratio of rice canopy for estimating crop nitrogen status. Plant & Soil 122:259–297.

Turner, F.T. and M.F. Jund. 1989. A chlorophyll meter's potential to predict topdress N requirement of semidwarf rice, p. 254. In: Agronomy abstracts. Agron. Soc. Amer., Madison, Wis.

Wood, C.W., D.W. Reeves, R.R. Duffield, and K.L. Edmister. 1992. Field chlorophyll measurements for evaluation of corn nitrogen status. J. Plant Nutr. 15:487–500.

Yadava, U.L. 1986. A rapid and nondestructive method to determine chlorophyll in intact leaves. HortScience 21:1449–1450.