A Hand-Held Radiometer for Assessment of Nitrogen and Potassium Status in Cotton

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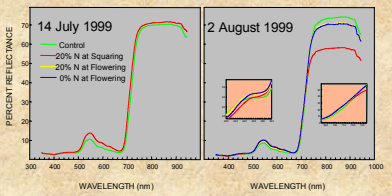
Abstract

This study evaluated the Spectrum Technologies CM1000 chlorophyll meter as compared to the GER 1500 spectroradiometer for remote estimation of chlorophyll (Chl), and thereby nitrogen (N) concentration in cotton (*Gossypium hirsutum* L.). Strong linear relationships were obtained between Chl and the ratio of single-leaf reflectance at 840 and 700 nm (R_{840}/R_{700}) across various N-stress treatments. Reflectance measures agreed well between the CM1000 and GER 1500; however, SPAD-502 readings were often a more sensitive indicator of Chl than R_{840}/R_{700}. In providing a rapid and reliable assessment of plant N status, the CM1000 should be useful for nutrient management in cotton, as well as for calibration of airborne multispectral reflectance images.

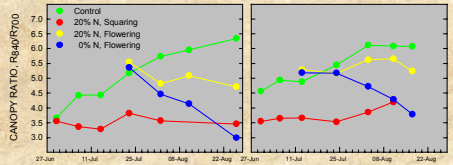
Introduction

When Chl pigments begin to decline, the amount of reflected radiance from within the leaf interior increases, providing an optical indicator of stress. In full canopies of cotton, changes in reflectance at the red-edge (690-730 nm) and at the near-infrared (720-900 nm) regions appear to be a consistent response to N stress. Depending on the severity of stress, this reflectance response may be more sensitive than the unaided eye. We've also detected a change in reflectance in the blue region (near 400 nm), but this response may only occur in chlorotic leaves.



The CM1000 records ambient and reflected light at 700 and 840 nm (± 3 nm). Laser beams define the target area when the trigger is pressed. Reflectance data and R_{840}/R_{700} ratio are recorded by releasing the trigger. At a distance of 38 cm, the field of view is about 1.5 cm in diameter.

In 1999, changes in leaf N status were closely associated with single waveband reflectance ratios, R_{360}/R_{710}, R_{415}/R_{710}, R_{415}/R_{695}, R_{415}/R_{585}, and R_{840}/R_{700} (Read et al., 2000). When data were combined across 1999 and 2000, R_{840}/R_{700} decreased significantly under N stress. The difference in R_{840}/R_{700} between N treatments was most apparent between control (C1) and canopies supplied 20% of control N at first floral bud (square) stage onward (N1S). Values for R_{360}/R_{710} and R_{415}/R_{710} did not differ significantly between N treatments.



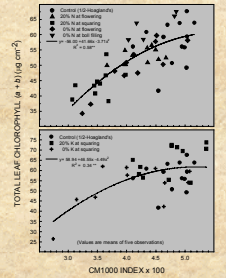
ANOVA		C1, N1S		C1, N1F, N2F
Effect	df	Pr > F	df	Pr > F
Year	1	0.02	1	0.14
N Level	1	< 0.001	2	< 0.001
Harvest	5	< 0.001	5	0.30
N x Harvest	5	< 0.01	10	< 0.01

Materials and Methods

- Plants (NuCOTN 33B) were grown outdoors in large pots. Water and nutrient were supplied via a drip-irrigation system. Each treatment comprised three rows spaced 1-m apart with 20 plants per row.
- Treatments were 1/2-strength Hoagland's (control), 20% of control N or K at first floral bud (squaring) onward, 0% and 20% N at first flower onward, and 0% N at fruit (boll) filling onward.
- On each day, leaf optical properties were measured on uppermost, fully expanded leaves from five randomly selected plants during the mid-day period (1100-1300 h), and in the absence of cloud cover.
- Samples were taken from the central lobe of the leaf.
  - Hyperspectral reflectance from 350 to 950 nm (1.5 nm resolution) was measured using a GER-1500[1] with 4° field of view foreoptic from a height of 30 cm, giving a 9.5 cm^2 area.
  - Multispectral reflectance was measured using the CM1000 meter from a height of 38 cm.
  - SPAD-502[2] values are the average of five readings.
- Total Chl (*a* + *b*) concentration was determined from six discs (equivalent to 1.0 cm^2 one-sided leaf area) after extraction in 4 ml DMSO for 24 h.

Results and Discussion

Leaf Chl content decreased the most in plants supplied either 20% of control N or 0% of control K at first square stage onward. Quadratic functions best described the relationship between Chl and CM1000 values for R_{840}/R_{700} across all treatments and sampling dates. Values for Chl remained relatively high in plants supplied 20% N at boll filling or 20% K at squaring, supporting evidence that fixed minerals can be readily mobilized to support continued growth in cotton.



On most sampling dates, significant linear correlation (r) was obtained between total Chl and leaf optical properties across N treatments. Analysis involved five plants in each treatment. The SPAD meter was often a more sensitive indicator of Chl concentration than either the CM1000 or GER 1500 meter. In both radiometers, values for R_{840}/R_{700} were particularly sensitive to Chl in August, when stress-induced changes in Chl were significantly related to leaf N. Five leaves were bulked for tissue N analysis.

DATE, 2000	TRTS	LEAF N	SPAD	CM1000	GER1500
11 July	1,2	na	0.78 **	0.80 **	0.67 *
13 July	1,2,3,4	0.70	0.86 **	0.67 **	0.62 **
17 July	1,2,3,4	0.67	0.35	0.49 *	0.58 **
20 July	1,2,3,4	0.48	0.79 **	0.55 *	0.59 *
24 July	1,2,3,4	0.94	0.75 **	0.50 *	0.22
27 July	1,2,3,4	0.37	0.97 **	0.66 **	0.76*
31 July	1,3,4	0.98	0.44	0.64 **	0.46
7 August	1,3,4	0.88	0.93 **	0.82 **	0.61 *
11 August	1,2,3,4	0.97 *	0.46 *	0.55 *	0.15
14 August	1,2,3,4	0.83	0.94 **	0.77 **	0.86 **
17 August	1,3,4	0.99 *	0.68 **	0.84 **	0.93 **

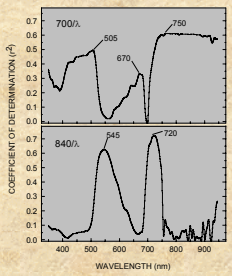
Treatments were ½-Hoagland's N at emergence (1), 20% N at floral bud stage onward (2), 20% N at first flower onward (3), and 0% N at first flower onward (4).

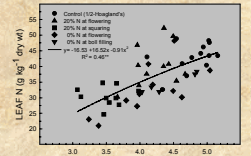
Based on r values across different N treatment, precision of CM1000 readings to estimate total Chl and other leaf traits was not consistently enhanced by multiple observations (n=5) from individual leaves.

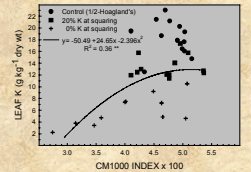
DATE, 2000	TRTS	TOTAL CHL	LEAF N	SPAD	GER1500
17 July	1,2,3,4	0.44	0.76	0.77**	0.50 **
3 August	1,3,4	0.82 **	0.92	0.77 **	0.80 **
7 August	1,2,3,4	0.71 *	0.99 **	0.61 *	0.62 **
14 August	1,2,3,4	0.93 **	0.73	0.91 **	0.84 **

The SPAD meter determines Chl from a 6 mm^2 leaf section using light transmitted at 650 nm in ratio to light transmitted at 940 nm, which serves as a reference. A similar optical property is featured in R_{840}/R_{700}, as changes in R_{700} are due to strong Chl *a* absorption at 660-680 nm; whereas R_{840} is not affected by Chl and would only change if leaf anatomy or water content changed in response to stress (Carter, 2001; Whaley, 2001). Moreover, single-waveband reflectance ratios may correct for variations during a measurement such as irradiance, leaf orientation, irradiance angles and shading (Tarpley, 2000).

Waveband centers used in the CM1000 appear to be properly tuned for estimation of total Chl in cotton leaves. Graphs at right show r^2 values for the linear relationship between leaf reflectance and Chl when R_{700} is divided by reflectance at the wavelength (λ) indicated by x-axis, and when R_{840} is divided by reflectance at each λ. Correlation analysis involved all plot means of total Chl and hyperspectral reflectance data from the GER 1500 (n=55).







Leaf N and K concentrations decreased as soil nutrient supply decreased. Cotton leaves are usually considered deficient if they contain < 25 g N kg^{-1} dry weight and < 20-15 g K kg^{-1} dry weight.

Only 46% of the variation in leaf N was explained by CM1000 index, R_{840}/R_{700}. This is because leaf N and Chl concentration were weakly associated in the present study (r^2=0.45, not shown).

Loss of Chl took longer to manifest under restricted K than under restricted N, supporting evidence that cotton can store excess K (Bednarz and Oosterhuis, 1995). In this K-stress study, the CM1000 index was largely influenced by changes in K status of plants supplied 0% K at squaring onward.

Conclusions

- The CM1000 has potential in comparative studies of leaf optical responses to stress that are indicative of general plant health in cotton.
- The leaf reflectance ratio, R_{840}/R_{700}, from either the CM1000 or GER 1500 radiometer was positively associated (r= 0.49 -0.93) with N-induced changes in chlorophyll concentration.
- While the two radiometers compared favorably, SPAD-502 readings were often most sensitive to loss of chlorophyll. Subsampling to minimize within-leaf variability in CM1000 index did not enhance instrument sensitivity to chlorophyll
- Although R_{840}/R_{700} may not accurately estimate leaf N and K in cotton, monitoring plant nutrient status should be less costly than periodic estimates based on tissue analysis. With further testing and refinements, the CM1000 should be a practical tool for nutrient management.
- Accurate estimates of chlorophyll may require a fully absorptive (black) background behind the measured leaf. This is because R_{840} can be artificially enhanced due to additive reflectance of near-infrared light from healthy green leaves in the vicinity of the field of view, which may reflect about 80% of the incident near-infrared energy at 900 nm.
- Because airborne multispectral cameras often acquire imagery at wavebands near 700 and 840 nm, the CM1000 may be used to measure reflectance of known surface features near the time of an over-flight in order to calibrate the resulting image data to percent reflectance.

This evaluation of the Spectrum Technologies Field Scout CM1000 chlorophyll meter is not an endorsement by the USDA Agricultural Research Service.
[1]Geophysical and Environmental Research Corp., Millbrook, NY.
[2]Minolta SPAD-502, Spectrum Technologies, Inc., Plainfield, IL.

References

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