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Assessment of N status of cotton and forage plant using remote sensing

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Abstract

Accurate detection of plant N status can help growers make appropriate N management decisions. Leaf or plant tissue N concentration is an important indicator of plant N status, but laboratory methods of quantifying N content are costly and time consuming. Non-destructive measurements of leaf or canopy spectral reflectance using remote sensing techniques may provide an alternative means of N assessment. Two field experiments were conducted using cotton and bermudagrass pastures. The first experiment included four N-rate treatments (0, 56, 112, and 168 kg N ha^{-1}) to determine leaf critical N level associated with cotton yield loss at different growth stages and to select appropriate reflectance ratios for estimating leaf N content. Three bermudagrass pastures were used in the second experiment to determine the relationship between forage N concentration and canopy reflectance. Leaf (cotton) or canopy (forage) reflectance and N concentration were measured throughout the growing seasons. Cotton leaf N decreased linearly as plants aged and the leaf critical N levels at first square (FS), first flower (FF), 2 wks after FF, and 4 wks after FF stages were 48.9, 40.8, 39.7, and 37.2 g kg^{-1} DW, respectively. Both cotton leaf N and forage N concentrations linearly correlated with the reflectance ratio of R_{915}/R_{515} or R_{915}/R_{705}. The reflectance ratios may be used for real-time and nondestructive monitoring of plant N status and N fertilizer recommendation in cotton and for estimating forage N or crude protein content and adjusting stocking rate in bermudagrass pastures.

Introduction

Changes in cotton leaf N concentration depend on not only soil N availability and other environmental conditions, but also on developmental stages (Oosterhuis et al., 1983). Leaf N concentration has been used to monitor cotton plant N status. Forage N content is associated with nutritive quality and livestock gain. Traditional methods of determining tissue N contents in a laboratory are time consuming and costly. Current advances in remote sensing have allowed collection of timely data for assessing crop growth, physiology, and yield as affected by environmental stresses. Such information can be used for in-season crop management.

In order to determine dynamics of N concentration in cotton leaves or forage throughout the growing seasons as affected by N rates and to select spectral wavebands for estimating tissue N content, we conducted two experiments in 2001-2003. The objectives of our studies were to (1) determine leaf critical N levels associated with a 10% of yield loss at different stages and (2) develop functional relationships between leaf- or canopy-reflectance ratios and N content in leaves or biomass for nondestructive assessment of plant N status in cotton and bermudagrass pastures.

Materials and Methods

Exp 1 was conducted at the Mississippi A & F Exp. Station, Mississippi State Univ., USA. Cotton cv. NuCOTN 33B was seeded on 14 May 2001 and 24 May 2002. First square (FS) and first flower (FF) stages were on June 23 and July 17, respectively, in 2001 and June 28 and July 19 in 2002. Four N treatments were 0, 56, 112, and 168 kg N ha^{-1} (control). Exp 2 was conducted at the USDA-ARS Grazinglands Research Laboratory, El Reno, OK, USA in 2002-2003 using three bermudagrass pastures.

In Exp 1, reflectance and N content of cotton top fully expanded leaves were measured biweekly throughout the growing seasons. Five leaves in each plot were randomly collected starting from FS through 3 wks after the first boll opening to measure reflectance and area of the leaves. Reflectance data were averaged across the five leaves and described in a 10-nm waveband interval. Leaf samples were immediately dried, weighed, and ground to determine N content. Lint yield was recorded and relative yield was obtained by dividing lint yield of each plot by highest yield within a year. The relative yield was used for developing algorithms of yield and leaf N. In Exp 2, pasture canopy reflectance and forage N content were determined over the growing seasons. Details of all measurements have been described by Starks et al. (2004) and Zhao et al. (2005).

Results and Discussion

Cotton leaf N concentration and relative lint yield

Leaf N was the highest around FS and rapidly declined as plant aged. Nitrogen rates affected leaf N significantly (Zhao et al., 2005). Leaf N ranged from 15.2 to 52.6 g kg^{-1} DW across years, treatments and sampling dates. Yield did not differ among treatments in 2001 due to high soil N level and great yield variation among plots within a treatment. In 2002, lint yields of the 0 and 56 N treatments were lower than that of the control (Table 1). Regardless of N treatments, relative yield ranged from 73 to 100% in 2001 and 48 to 100% in 2002 across all plots with a CV of 10-21%.

Table 1. Relative lint yield (%) ± SE of the four N treatments

Treatment	2001	2002
0 N	81.8 ± 1.5 a[†]	57.7 ± 1.2 c
56 N	84.3 ± 1.4 a	79.4 ± 0.9 b
112 N	87.5 ± 1.6 a	91.3 ± 0.7 a
168 N (Control)	86.7 ± 1.5 a	95.2 ± 0.5 a

[†]Means followed the same letter within a year are not significant at $P = 0.05$ level.

Relationships between cotton leaf N and relative yield

Relationships between relative lint yield and leaf N concentration at different growth stages could be expressed with linear models (Table 2). Based on equations in Table 2 and a 90% relative yield, leaf critical N associated with yield loss at different stages were also calculated (Table 2).

Table 2. Relationships between relative lint yield (Y, %) and leaf N (X, g kg^{-1}) at different growth stages as well as leaf critical N concentration (g kg^{-1}) associated with cotton yield loss.

Stage†	Equation	r^2	Critical N
FF- 2 wks	Y = 1.36X+23.35	0.20*‡	49.0
FF	Y = 1.85X+14.44	0.44***	40.8
FF+2 wks	Y = 1.54X+28.98	0.40***	39.6
FF+3 wks	Y = 1.62X+29.07	0.41***	37.6
FF+4 wks	Y = 1.28X+42.61	0.36**	37.0
FF+7 wks	Y = 1.34X+48.01	0.18*	31.3

† FF = first flower stage; ‡ *, **, and *** are significant at $P < 0.05$, 0.01, and 0.001 levels, respectively

Relationships between cotton leaf N and reflectance ratios

Leaf reflectances in two wavebands centered 555 and 705 ±5 nm increased with decrease in N fertilizer rates (data not shown). Leaf N was most closely related to reflectances at 515 and 705 nm (r^2 =0.57-0.69), but the relationships were not linear. Two reflectance ratios with the greatest r^2 with leaf N were R_{915}/R_{515} and R_{915}/R_{705}. Both leaf DW- and leaf area-based N linearly correlated (r^2 = 0.65-0.78) with the two reflectance ratios ($P < 0.0001$, Fig. 1).

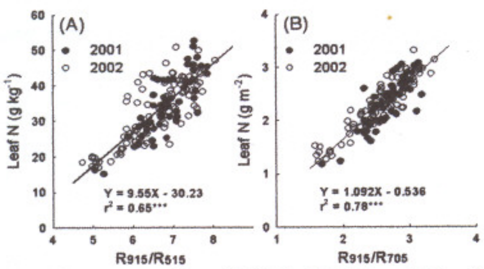

Fig. 1. Linear regression of (A) leaf DW-based N with leaf reflectance ratio of R_{915}/R_{515} and (B) leaf area-based N with R_{915}/R_{705} (n = 150).

It is noted that leaf N linearly correlated with numerous reflectance ratios in the present study, but the two reflectance ratios reported here had greatest r^2 with N concentration among all the combinations of wavebands when we used 10-nm waveband reflectances. The equations in Fig. 1 could be used to estimate cotton leaf N content on either dry weight or leaf area basis during the growing season. In order to reduce the risk of yield loss due to N deficiency and to improve NUE, cotton leaf N concentration at early square, FF, and 3 wks after FF should be higher than 49.0, 40.8, and 37.6 g kg^{-1} DW, respectively (Table 2). Based on the critical N levels and the equations in Fig. 1, we can further calculate critical leaf reflectance ratios at different growth stages.

Forage N concentration and canopy reflectance

The R_{915}/R_{515} and R_{915}/R_{705} were calculated using pasture canopy reflectance data and regressed with N concentration in aboveground biomass (Fig. 2). Although the r^2 of linear regressions of the pastures was smaller than that of cotton in Fig. 1, significant linear relationships between the canopy reflectance ratios and N concentration were detected. We are reanalyzing forage data to select other reflectance ratios for better estimation of forage quality.

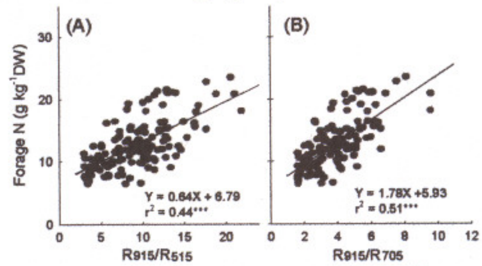

Fig. 2. Linear regression of forage N content with (A) canopy reflectance ratio of R_{915}/R_{515} and (B) R_{915}/R_{705} (n = 144).

Conclusions

Cotton leaf critical N associated with yield loss was 49 g kg^{-1} at early square stage, 41 g kg^{-1} at FF, and 38 g kg^{-1} around 3 wks after FF. Leaf N content highly and linearly correlated with R_{915}/R_{515} and R_{915}/R_{705}. The reflectance ratios may be used for quick estimating cotton leaf N concentration during growth. Forage N concentration was also related to the canopy reflectance ratios. Therefore, nondestructive measurements of leaf reflectance can be used for real-time monitoring cotton plant N status and reducing the risk of yield loss due to N deficiency. Even though relationships between forage N content and the two reflectance ratios developed from cotton were significant, the ratios might not be the best for estimation of forage N concentration. More studies are undergoing for real-time assessment of forage N and quality using remote sensing.

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