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REMOTE DETECTION OF SUGAR BEET LEAF NITROGEN

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Introduction

Remote sensing data, such as Landsat, is commonly utilized to help farmers determine beet top nitrogen (N) credits, which is the product of leaf N content (%) and leaf biomass. It is unclear if satellite sensors such as Landsat can actually detect the leaf N content. Some researchers have remotely mapped sugar beet Leaf Area Index (LAI) and biomass (Bouman 1992, Clevers 1997). Others in the Red River Valley have found that the green band in aerial photographs can be helpful for identifying canopy vigor and for determining N fertilization rates (Sims et al. 2002). Vigor, however, is a subjective term, and quantitative evaluation of remote detection capabilities for sugar beet leaf N are lacking. Remote estimation of N in fresh leaves is very difficult because water is the main constituent of the sugar beet leaf. For example, natural vegetation studies report that the proportion of leaf N per gram of fresh weight is <2% (Jacquemoud et al. 1995). Our goal was to use a randomized block design to demonstrate whether leaf N could be detected remotely for Red River Valley sugar beet canopies. We address the following questions: 1) Can leaf N (%) be detected remotely using ground-based, full-range spectral instruments? 2) Can leaf N (%) be detected using aerial or satellite imagery where only specific (green, red, near-infrared, mid-infrared) spectral bands are available? 3) Are there differences in leaf N (%) among beet varieties? 4) Does leaf N (%) vary with leaf size in the same plant?

Methods

The research site is a sugar beet field owned by Pete Caron Farms, SW of St. Thomas, ND. Four sugarbeet varieties were seeded with two replicates in a randomized block design. Varieties were ACS 999, Beta 6600, Holly 811 and Vanderhoff 556. They were seeded at the same time in May and harvested in early October 2003. We collected leaf samples for physical, chemical and spectral analysis on Sept 15, 2003 by randomly selecting 2 point locations per field replicate (16 points). At each point, one beet plant was cut to ground level, and leaf material was separated into 3 leaf size groups: small (2-4” wide), medium (4-6” wide) and large (>6” wide). Spectra were measured for each plant leaf size (48 spectra) using a hand-held radiospectrometer (ASD Instruments Boulder, CO), which detects light in the 350-2500 nanometers (nm) wavelength range. Fresh biomass for one complete plant was determined for each variety to determine moisture (%). All samples were weighed, dried and leaves ground to a fine powder. These were sent to the USDA ARS Research Lab (Mandan, ND) for carbon (C) and N analyses. Leaf N and leaf C:N ratio was analyzed using SAS Proc GLM (SAS Institute, Cary, NC) to test for differences in variety and leaf size. We also summed leaf weights to determine biomass per plant, calculated total N per plant on a mass basis, and determined total number of plants harvested to determine average total leaf N (lbs/acre) per variety. In addition, we calculated the proportion of leaf N by mass that was found in fresh leaf biomass.

The spectral data measured on the ground were aggregated to multi-spectral Landsat bands. These data simulate satellite-based multi-spectral data and were analyzed to test for spectral differences among varieties and leaf sizes. The ground-based hyperspectral data were also analyzed to test for spectral differences among varieties and leaf sizes. We ran a correlation analysis between leaf N and spectra and used the spectral region most highly correlated with leaf N for further analyses. The hyperspectral green band (550-560 nm), as determined on the ground with the radiospectrometer, and the multi-spectral green band (520-610 nm), available through Landsat, were analyzed separately using SAS Proc GLM.

Results

A total of 15 plants were collected, as one Holly 811 sample was lost. Average leaf N (%), leaf C:N ratio and the mass of nitrogen per plant per variety are reported in Table 1a. Average leaf N just prior to harvest was ~3% per unit dry mass and <1% per unit fresh mass. The C:N ratio for the ACS 999 variety was significantly higher, compared to the other varieties. C:N ratio is commonly used as an indicator of leaf quality. Further, results indicate that leaf N was not significantly different among varieties. Leaf N was, however, did vary with leaf size. We found that small leaf N was significantly higher large leaf N content for all varieties (Table 1b).

The spectral signatures for small and the large leaf sizes are shown in Figure 1. Leaf heterogeneity is apparent especially in the near-infrared (NIR) and mid-infrared (MIR) regions. Only in the green region is the signal similar among varieties, where large leaf reflectance is greater than small leaf reflectance. The correlation data corroborate this observation for the green region (Figure 2). This spectral region is sensitive to leaf chlorophyll differences (Gitelson and Merzlyak, 1997). The analysis of variance for the hyperspectral green band collected on the ground showed significantly lower reflectance for small leaves, which were also higher in N. We did not find a significant spectral difference for leaf size when the data were aggregated to simulate the Landsat Green band. Despite the fact that small leaves are higher in N, the multi-spectral, aggregated data (analogous to Landsat) does not indicate leaf spectral differences among leaf sizes.

Nitrogen credit calculation requires consideration of total plant N by mass per unit area. When nitrogen mass in leaves was summed by plant, we found that the average total plant N for the Beta variety was 2.55 g, compared to Holly, which was 1.1 g. The number of plants harvested was multiplied by total plant N, and we found that the amount of beet top N for Beta was 240 lb/acre for Beta and 102 lbs/acre for Holly. Biomass determination was not within the scope of this study; however, the impact of beet top mass on N credit is readily apparent (Table 1a).

Summary

Results indicate that fresh leaf N represents <1% of the plant wet weight. Nonetheless, the green region of the spectrum (550-560 nm), when measured on the ground with radiospectrometer, appears to be sensitive to relative differences in N leaf. Multi-spectral data, however, were not useful for detecting leaf N differences. Only narrow, hyperspectral data offer potential for N detection, and whether or not a hyperspectral satellite platform would be capable of N detection is unknown. Leaf N content was similar for all varieties tested; however, the amount of N in beet tops was strongly influenced by plant mass, suggesting leaf biomass may be a more significant determinant of the N credit calculation than leaf N (%). We recommend further study of beet top biomass to better quantify the potential for remote sensors to estimate N credits.

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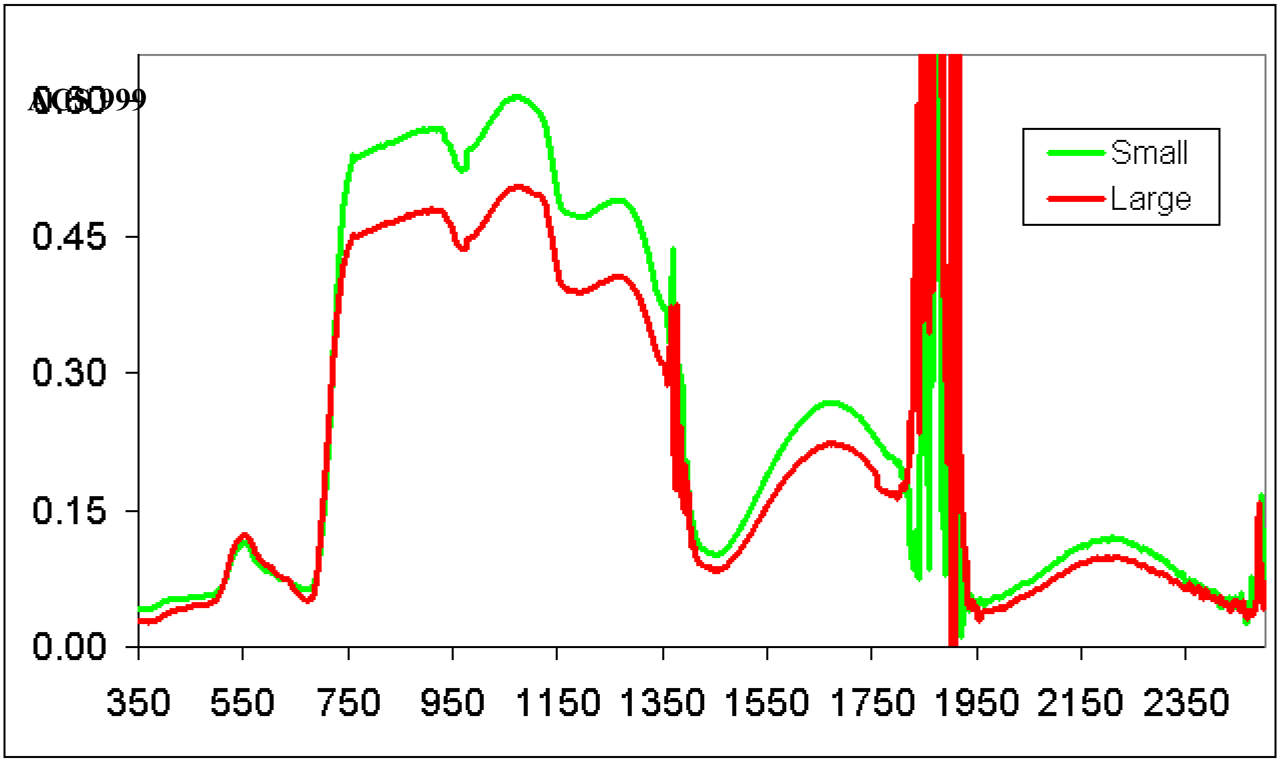
Table 1a. Sugar Beet Leaf Variables Measured and Beet Top N Credit for each Variety, St. Thomas, ND. Statistically significant differences ($p<0.05$) are denoted by letters in superscript.

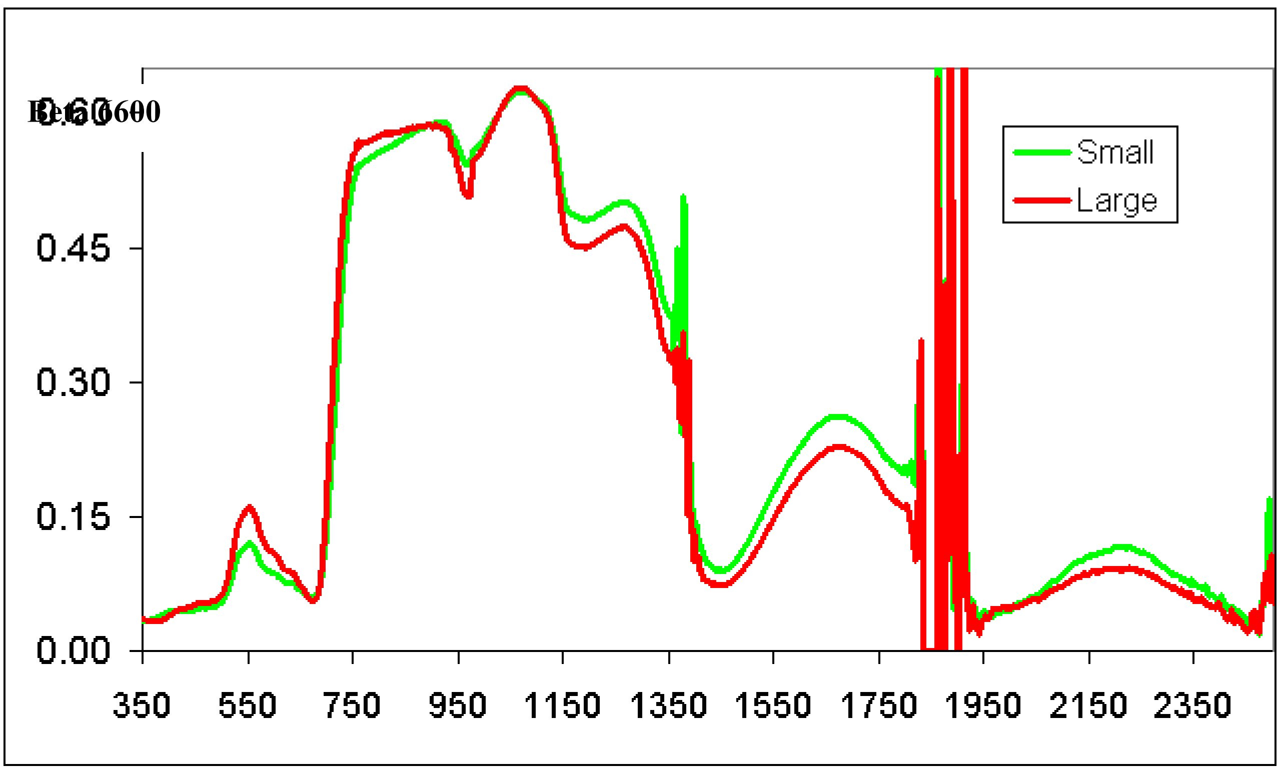
Variety	%N in Dry Matter	%N in Fresh Matter	C:N ratio	Leaf N (g/plant)	Plants Harvested (per acre)	Beet top N (lb/acre)
ACS 999	3.01	0.80	14.38[a]	1.51	40448	134
Beta 6600	3.81	0.58	11.05[b]	2.55	42673	240
Holly 811	3.72	0.46	11.23[b]	1.10	42183	102
Vanderhoff 556	3.58	0.54	11.79[b]	1.99	42250	185

Table 1b. Sugar Beet Leaf N content for each Leaf Size Category.

Variety	Small leaf %N	Medium leaf %N	Large leaf %N
ACS 999	3.45[a]	3.26[ab]	2.31[b]
Beta 6600	4.61[a]	4.11[ab]	2.71[b]
Holly 811	3.94[a]	3.96[ab]	3.00[b]
Vanderhoff 556	4.12[a]	3.61[ab]	2.99[b]

Figure 1. Spectral signatures for small and large leaf sizes, plotted by variety


AGS1999
0.60
0.45
0.30
0.15
0.00
350
550
750
950
1150
1350
1550
1750
1950
2150
2350
Small
Large


Beta7600
0.60
0.45
0.30
0.15
0.00
350
550
750
950
1150
1350
1550
1750
1950
2150
2350
Small
Large

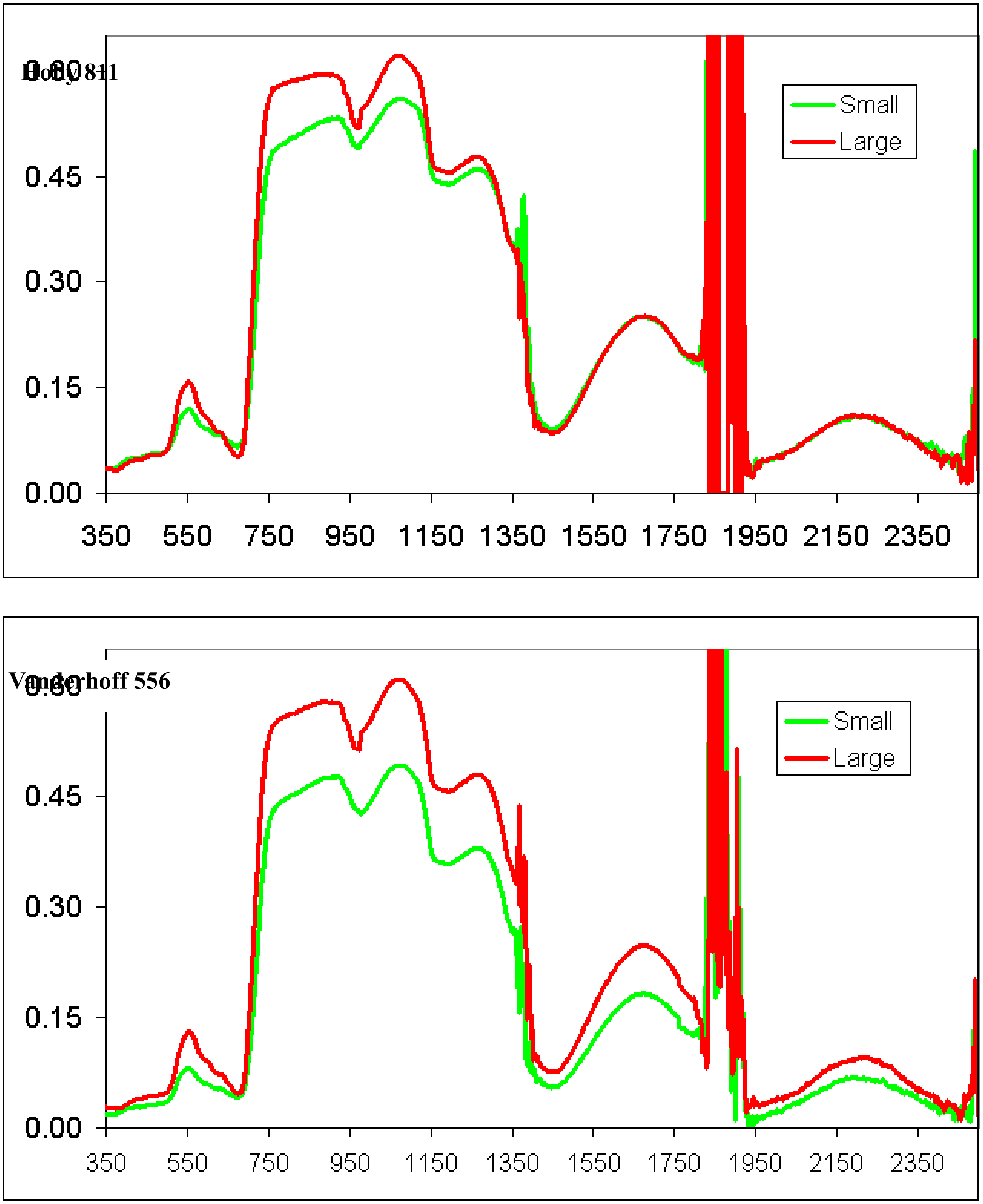
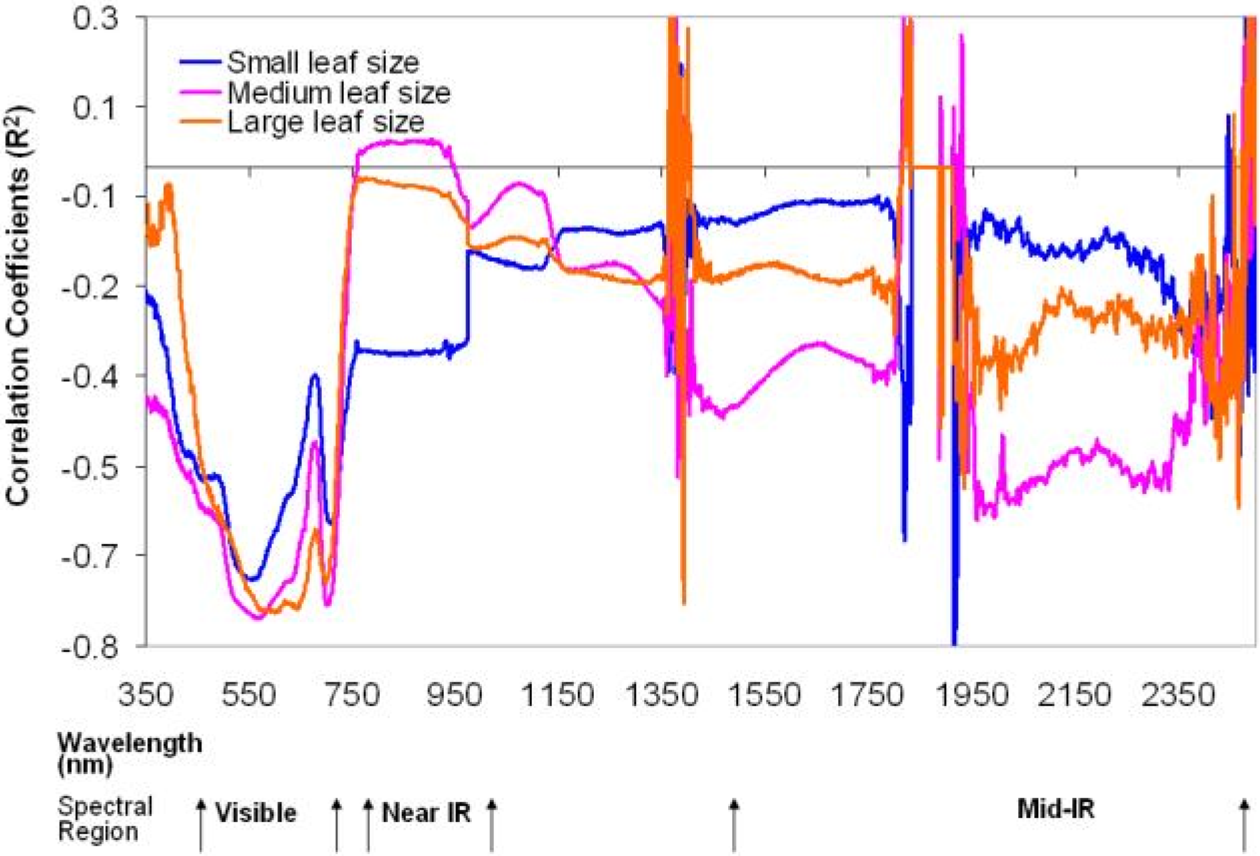


Figure 2. Correlation coefficients between leaf spectra and N (%)


Small leaf size
Medium leaf size
Large leaf size
Correlation Coefficients (R^2)
0.3
0.1
-0.1
-0.2
-0.4
-0.5
-0.7
-0.8
350
550
750
950
1150
1350
1550
1750
1950
2150
2350
Wavelength (nm)
Spectral Region
Visible
Near IR
Mid-IR