DEVELOPMENT OF A VARIABLE-RATE NITROGEN APPLICATOR BASED ON SPECTRAL REFLECTANCE CHARACTERISTICS OF COTTON PLANTS

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Abstract

A field-based spectrometer was used to characterize the spectral reflectance from the cotton canopy at various growth stages (pinhead square to early bloom). A spectral index model was developed based on extracting reflected light energy data in four wavelength bands ranging from 460 to 770 nm. A good correlation (R^2=0.91) existed between soil applied nitrogen and cotton yield. Correlations between petiole nitrate and soil applied nitrogen ranged from 0.85 to 0.90 depending of the stage of plant growth. The average correlations between spectral index and petiole nitrate (R^2= 0.74) were very promising as a possibility for remotely sensing nitrogen deficiency in cotton at a growth stage where supplemental nitrogen could be applied site-specifically. The implementation of artificial neural networks also showed promise as a possibility to further increase the measurement accuracy by identifying patterns in the spectral data.

Introduction

It is well-known that nitrogen (N) fertilizer is one of the most essential nutrient elements required by crops. A proper N application must be provided in order to maximize cotton yields. Both under-fertilization and over-fertilization of N could negatively affect plant growth thereby reducing yields. Additionally, the over-application of N has potential negative environmental effects as well as increased production costs. Although soil and plant tissue testing can be used to predict N requirements for plants, these soil and plant N analyses often require considerable time and expense (Tracy et. al., 1992). Extensive research has been conducted to devise a quick and reliable method to diagnose the N status of plants non-intrusively. Leaf color is considered one of the most sensitive indicator of sub-optimal nutrient levels (Blinn, 1988). The main pigment responsible for leaf color is chlorophyll. Because N is a major component of the chlorophyll molecule (Tracy et. al., 1992), chlorophyll and leaf N are usually correlated.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:439-442 (1998)
National Cotton Council, Memphis TN

To date, an application unit is not available for applying supplemental nitrogen to cotton plants based on spatially variable nitrogen deficiencies. Researchers have established nutrient level requirements for healthy plants. Gerik et al. (1994) reported that deficiency symptoms do not usually appear until petiole NO_3 levels fall below 2000 µg g^{-1}. Whereas leaves are usually considered N deficient if they contain less that 25 g kg^{-1}. Positive research results have shown promise in predicting cotton plant nitrogen level based on spectral reflectance characteristics of plant leaves. The green leaf pigments (chlorophyll) are influenced by nitrogen nutrition (Thomas and Oerther, 1972). High substratum nitrogen produces leaves that are greener than those low in nitrogen.

The objective of this project was to develop a real-time variable-rate nitrogen application system based on chlorophyll levels in the cotton canopy. Specifically, this project involves the sensing of nitrogen-deficiencies within a cotton plant and applying supplemental nitrogen at a variable-rate based on the plant's current need for nitrogen. The first, and most critical phase of this research was to develop a sensing technique for identifying nitrogen-deficient plants under natural illumination conditions.

Procedures

Spectral Data Acquisition

Reflectance spectra were obtained using an SD-1000 Fiber Optic Spectrometer manufactured by Ocean Optics, Inc. It is a low cost, miniature spectrometer which interfaces to a laptop PC through a PCMCIA interface. This unit accepts reflected light from the plant canopy and disperses it across a linear array of 1024 CCD detectors. Cotton plant canopy reflectance spectra were measured by positioning a fiber optic cable connected to the spectrometer vertically above the cotton plants (Figure 1). The distance between the leaf surface and the sensor was approximately 6 inches. Reflectance spectrum wavelengths ranged from 250 nm to 800 nm. The spectrum was normalized using its total intensity (summation of intensity counts at each wavelength) as a reference. Through experimentation over the past two years, four wavelength bands were extracted from the total wavelength band. They are referenced as the blue band from 460 to 490 nm, green band from 540 to 565 nm, amber (red-yellow) band from 600-610 nm, an near infrared band from 740 to 770 nm.

Experimental Plot Layout

The experiment was conducted on a Loring Silt Loam soil located on the Milan Experiment Station. Test plots were in continuous nitrogen rate experiments for three consecutive years. Nitrogen fertilizer was applied at rates of 0, 30, 60, 90 and 120 lbs/ac to generate a range of cotton plants with varying levels of plant nitrogen and yields. Each application rate was replicated five times. All experimental plots were planted with the same cotton variety, DPL20.

Field Test Protocol

Reflectance spectra of cotton leaves were respectively measured at the growth stages mid-pinhead square, late pinhead square and early bloom. Ten spectral scans were made at various locations within each plot at the three stages of growth noted above. Petioles were collected from 10 plants within each plot concurrently with the reflectance measurements. Petiole samples were analyzed as a composite for each plot. A total of 750 spectral reflectance scans and 75 petiole samples were analyzed.

Petiole Analysis

Petioles were analyzed using a laboratory procedure documented by the soil testing laboratory at the University of Arkansas (1991). The petiole samples were dried for 48 hours at 83 degrees (C). An extracting solution composed of aluminum sulfate and deionized water was used. Dry petiole samples were added to the solution and the nitrogen content was measured using a nitrate selective electrode.

Spectral Index Model

A spectral index function was developed based on selected features extracted from a normalized spectral reflectance curve in the visible and NIR region of the wavelength band. The spectral index function used relative reflectance values from the cotton canopy in the blue, green, amber, and NIR wavelength bands to predict plant nitrogen levels. The model evaluated with the highest correlations with petiole nitrogen, yield, and nitrogen application rate was based on ratios of reflected light energy according to the following model.

Spectral Index = (NIR + Blue) / (Green + Amber)

Results

Spectral index data, petiole nitrogen, yield, and nitrogen application rates were all statistically analyzed for correlations between measured variables. Results of a correlation analysis are summarized in Tables 1, 2, and 3 for three different growth stages. Figure 2 illustrates the relationship between the nitrogen application rate and yield. Each point on the graph represents the average yield by application rate for all five replications. This finding is fairly well documented and is consistent with previous years results.

Figures 3, 4, and 5 illustrate the non-linear relationship between petiole nitrogen content and nitrogen application rate. Recognition of this relationship is fundamental to the operation of the nitrogen sensing unit. Note the highest correlation was at mid-pinhead square with an R^2=0.907 using a second-order polynomial.

Figures 6, 7, and 8 illustrate the linear relationship between the spectral index and petiole nitrogen at the same three stages of growth with R^2 values of 0.59, 0.74, and 0.70 respectively. Figures 9, 10, and 11 show a correlation between the spectral index and the nitrogen application rate.

Figure 12 illustrates the excellent linear relationship between the spectral index and yield (R^2=0.96 at mid-pinhead square). In fact, spectral index was a better predictor of yield than petiole nitrogen levels. The average correlation coefficient (r) for predicting yield and petiole nitrogen as a function of spectral index was 0.89 and 0.82 respectively.

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Application of Artificial Neural Networks

A pattern recognition algorithm was investigated as a means to more accurately group cotton plants into classes of "nitrogen deficiency" rather than the traditional continuous modeling approach. The data set was analyzed using an artificial neural network algorithm. Architecture of the neural network consisted of one hidden layer with three neurons, five inputs, and two outputs. The five inputs were the normalized spectral data in the four wavelength bands plus the stage of plant growth. Outputs were defined an "deficient in nitrogen" and "non-deficient". Deficient was defined as plants with nitrogen application rates of 30 lbs/ac or less. One-half of the data set was used to train the neural network and the second-half was used to test the model. Test results showed that the generalization error was less than 9 percent. While this analytical approach has not been fully refined, preliminary results suggest that pattern analysis of the spectral reflectance characteristics of cotton plants may prove to be a more reliable method for sensing and classifying cotton plants according to their level of nitrogen deficiency.

Conclusions

- The dimensionless ratio of reflected light at four wavelength bands from the cotton canopy (as early as pinhead square) is a good predictor of plant nitrogen content and expected yield.

- Based on the correlations obtained between spectral index and plant nitrogen, we are optimistic that a four wavelength band sensor can be implemented for field-based application of supplemental nitrogen in cotton.

- The application of artificial neural networks shows great promise for the cotton nitrogen sensing unit. Based on the spectral data from cotton leaves in one field, the trained neural network was able to diagnose the nitrogen status of cotton plants with more than 90% accuracy.

Acknowledgements

This research was funded in part by Cotton Incorporated through the Tennesssee State Support Committee. Their support is very greatly appreciated.

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Table 1. Correlations (r) between the parameters at the growth stage of ***Mid-Pinhead Square*** with 7-10 nodes.

Parameter	N Rate	Petiole Nitrate	Spectral Index	Yield
N Rate	1.00	0.85	0.81	0.96
Petiole Nitrate	0.85	1.00	0.77	0.92
Spectral Index	0.81	0.77	1.00	0.88
Yield	0.96	0.92	0.88	1.00

Table 2. Correlations (r) between the parameters at the growth stage of ***Late Pinhead Square*** with 8-11 nodes.

Parameter	N Rate	Petiole Nitrate	Spectral Index	Yield
N Rate	1.00	0.90	0.86	0.96
Petiole Nitrate	0.90	1.00	0.86	0.89
Spectral Index	0.86	0.86	1.00	0.92
Yield	0.96	0.89	0.92	1.00

Table 3. Correlations (r) between the parameters at the growth stage of ***Early Bloom***.

Parameter	N Rate	Petiole Nitrate	Spectral Index	Yield
N Rate	1.00	0.89	0.85	0.96
Petiole Nitrate	0.89	1.00	0.83	0.87
Spectral Index	0.85	0.83	1.00	0.88
Yield	0.96	0.87	0.88	1.00

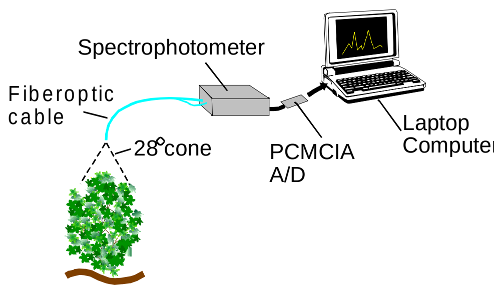

Figure 1. Illustration of the field-based spectral reflectance instrumentation.

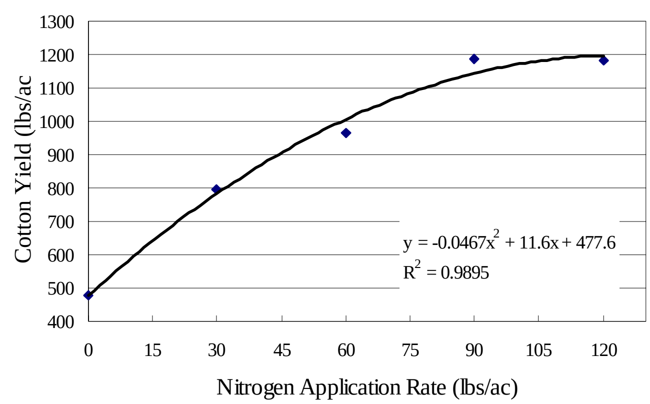

Figure 2. Cotton yield vs soil applied nitrogen application rate.

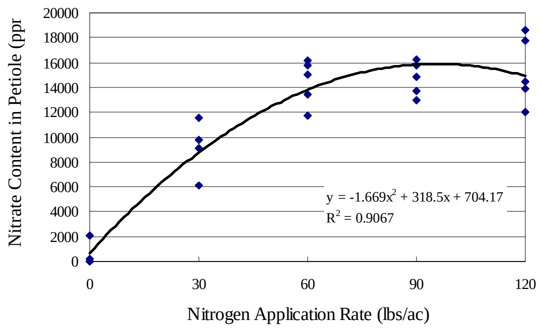

Figure 3. Petiole nitrate content as a function of applied nitrogen at mid-pinhead square.

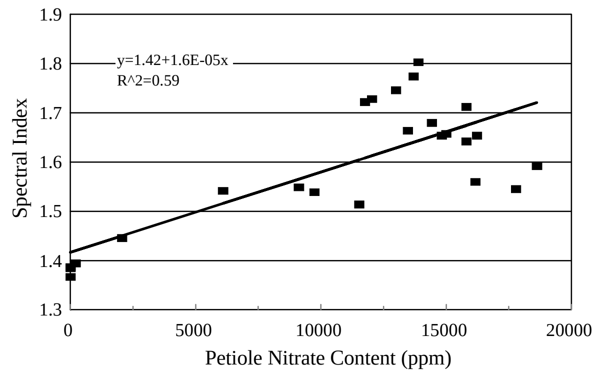

Figure 6. Spectral Index as a function of petiole nitrate content at mid-pinhead square.

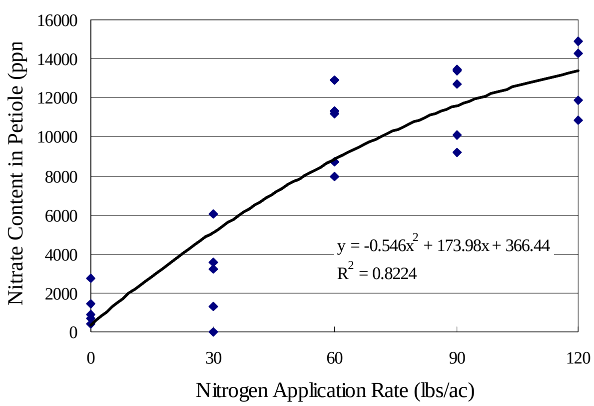

Figure 4. Petiole nitrate content as a function of applied nitrogen at late pinhead square.

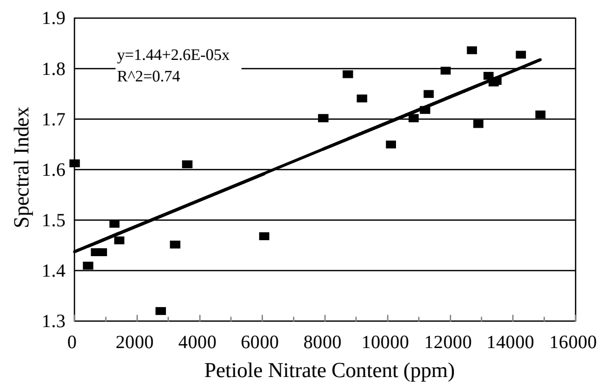

Figure 7. Spectral reflectance index as a function of petiole nitrate at late pinhead square.

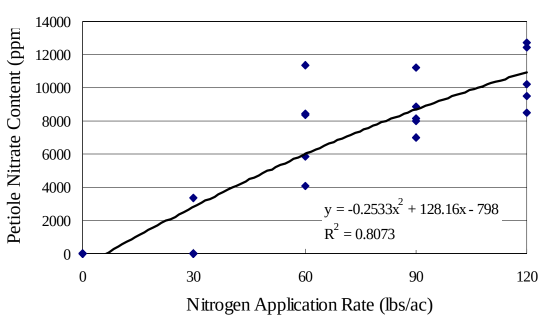

Figure 5. Petiole nitrate content as a function of applied nitrogen at early bloom.

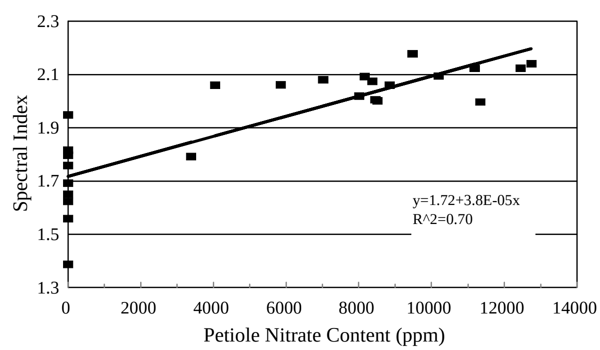

Figure 8. Spectral reflectance index as a function of petiole nitrate at early bloom.

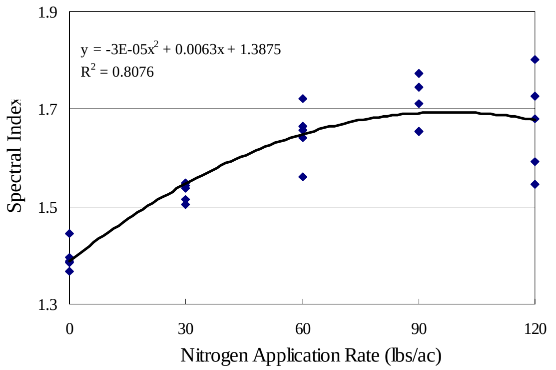

Figure 9. Spectral index measured at mid-pinhead square as a function of soil applied nitrogen.

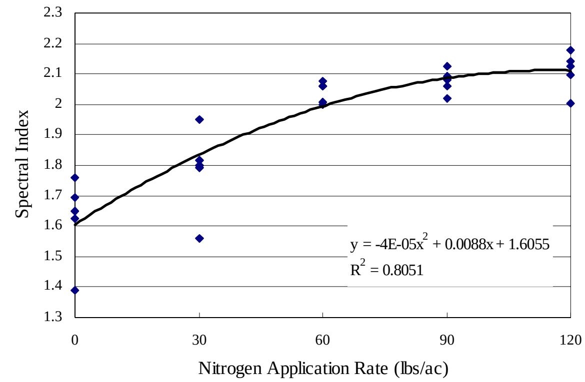

Figure 11. Spectral index measured at early bloom as a function of soil applied nitrogen.

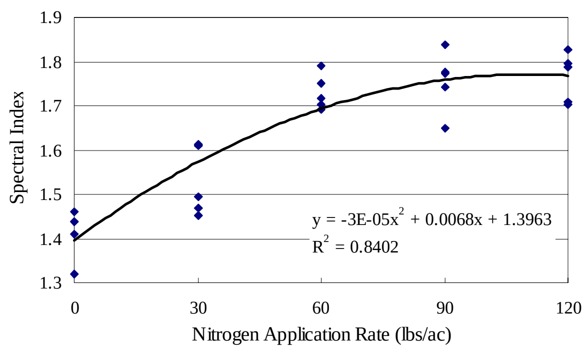

Figure 10. Spectral index measured at late pinhead square as a function of soil applied nitrogen.

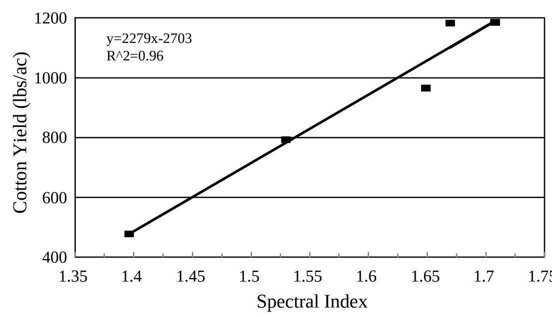

Figure 12. Cotton yield as related to spectral index. Each data point on the graph is the average of 5 replicated plots measured at mid-pinhead square.