2004 BELTWIDE COTTON CONFERENCES, SAN ANTONIO, TX – JANUARY 5-9

LEAF INDICES TO QUANTIFY NITROGEN IN COTTON

J. Ojala, W. DeTar, J. Chesson, V. Penner, and H. Funk
USDA-ARS
Western Integrated Cropping Systems Unit
Shafter, CA

Abstract

Acala cotton (*Gossypium hirsutum*, var. Maxxa) was planted into a split-plot factorial design field trial on the Shafter Research and Extension Center, Shafter, CA. The two main treatments were optimum irrigation (Io) and stressed irrigation (Is) containing five levels of soil nitrogen availability (-100, -50, optimum, +50, and +100 lbs N/ac). The objective of this field trial was to determine if nitrogen levels could be estimated from narrow-band spectra and vegetation indices derived from leaf reflectance measurements, and to determine if water stress caused by deficit irrigation influences prediction accuracy. Leaf reflectance in the visible bands increased slightly as nitrogen availability decreased. Leaf reflectance in the near-infrared region increased slightly as nitrogen availability increased. Water stress decreased the range in leaf reflectance among nitrogen levels compared to optimum irrigation. The vegetation indices GDVI and MCARI, and others utilizing the green band, regressed very well to nitrogen availability. Minolta Chlorophyll SPAD 502 meter readings had high correlation to nitrogen treatments in both optimum and stressed irrigation plots.

Introduction

Conventional methods for determining seasonal nitrogen fertilizer recommendations typically rely on petiole or leaf samples. Plant samples are collected along scouting transects and often a single transect is used to represent an entire field. A small amount of the dried plant material is analyzed for soluble or total nitrogen using one or more standard laboratory methods. A response curve based on crop growth stage determines sufficiency or deficiency of nitrogen in the sample, and is used to represent the entire field. If the sample is deficient, a uniform rate of nitrogen fertilizer is usually applied to the field. There are inherent limitations to diagnosis and recommendation of nitrogen fertilizer based on tissue tests. First, the diagnosis is based on a small, non-representative sample from the field. The time and labor required to properly scout and collect samples that accurately represent a typical, non-uniform field is cost prohibitive for commercial farming operations. Second, the diagnosis and recommendation is valid for the transect area, but is not valid for other areas in a field that are in different stages of crop development. The fertilizer response curve used to interpret the tissue analysis, and therefore yield response to fertilizer addition, is different for each region and soil type in a non-uniform field.

Remote sensing could provide several advantages for assessing nitrogen status of cotton crops. Aerial imagery offers spatial information that is difficult and impractical to obtain from ground transect surveys. Assessments can be made across an entire field instead of a transect area. Remote images offer a total view of the field that is not detected in a sampling transect. Diagnosis and fertilizer recommendations could be adjusted according to non-uniform conditions in the crop canopy. Remote sensing of individual leaves or plants could offer rapid in-field diagnosis. Remotely sensed data can be converted into prescription maps that are seamlessly incorporated into precision application systems.

Objective

The objective of this field trial was to determine if nitrogen levels could be estimated from select narrow-band spectra and vegetation indices derived from leaf reflectance measurements, and to determine if water stress influences prediction accuracy. This project is also currently processing canopy imagery to test these same objectives using aerial remote sensing. The long-term goal is to develop remote sensing techniques that can be used in precision crop management (PCM) systems for nitrogen fertilization of cotton.

Materials and Methods

The first year of this trial was initiated in 2003. Acala cotton (*Gossypium hirsutum*, var. Maxxa) was planted on May 12 into a split-plot factorial design field trial on Field 21 at the Shafter Research and Extension Center, Shafter, CA (Figure 1). The main plots were surface irrigated to provide an optimum irrigation (Io) and a stressed (deficit) irrigation (Is) on the July 24 and August 20 aerial flight dates. The main plots were randomly replicated within each of four blocks. Preplant soil samples were used to assess residual nitrogen availability and for determining preplant fertilizer nitrogen application. The subplots were five levels of soil nitrogen availability (-100, -50, Optimum, +50, and +100 lbs N/ac) randomly assigned within each plot. The Optimum level was the recommended amount of nitrogen fertilizer required for optimizing cotton yield based on spring soil tests (University of California Pub. No. 33522). Each subplot was four rows wide and 100 feet in length. There were 40 subplots in the trial. The plots received six irrigations beginning on June 3 and ending on August 8. Data collected from each subplot included plant water stress, soil moisture level, canopy temperature, plant tissue for nitrogen analysis, canopy biomass sub-samples, leaf spectra, airborne hyperspectral, multispectral, and thermal remote sensing, and at harvest lint yield and quality.

Leaf Data

Fifteen leaf and petiole samples were collected from each subplot within 1 day of the aerial flights. Each leaf sample was placed in an external integrating sphere and scanned for adaxial reflectance near the leaf apex using an ASD FieldSpec Pro spectroradiometer. Each leaf was also scanned in five locations with a Minolta Chlorophyll SPAD 502 meter. The reflectance spectra were used to calculate vegetation indices (Table 1). The leaf spectra and indices were correlated to nitrogen availability using linear regression. Leaf and petiole plant tissues have been dried and ground for total nitrogen and nitrate-nitrogen analysis.

Canopy Data

Airborne multispectral and hyperspectral flights were conducted over the plots on July 10, July 24, August 21 and September 10. The Airborne Visible-Near Infrared (AVNIR) hyperspectral camera system collected 60 bins of imagery in the 400 to 1000 nm wavelength range. The Shafter Airborne Multispectral Remote Sensing System (SAMRSS) collected images in the green (550 nm), red (675 nm), near-infrared (850 nm), and thermal (8 – 12 µm) regions of the electromagnetic spectrum. The remote images were calibrated to reflectance, georectified, trimmed, and georeferenced. In progress, ENVI GIS software is being used to draw regions of interest (ROI) around each subplot and query the spectral data on each of the 60 hyperspectral and 4 multispectral images for each flight date. Vegetation indices will be calculated from the spectra in the ROI's and correlated to nitrogen availability and plant tissue nitrogen content.

Results and Discussion

Leaf Spectra

Leaf reflectance spectra of optimum irrigated treatments showed similar patterns for July 24 (Figures 2 & 3) and August 21 (data not shown) sampling dates. In general, reflectance in the visible bands increased slightly as nitrogen availability decreased. The opposite trend occurred in the near-infrared region where reflectance increased as nitrogen availability increased. Reflectance values among nitrogen treatments changed only slightly, less than 1% in the visible bands, between nitrogen levels in stressed irrigation plots (Figure 4), but slightly larger range in reflectance occurred in the optimum irrigation plots (Figure 5).

Correlation of Leaf Indices to Nitrogen Availability

Vegetation indices (Table 1) were calculated from the spectroradiometer leaf scans and were correlated to nitrogen availability treatment levels for each sampling date (Table 2). The vegetation indices RVI, NDVI, OSAVI, NR, NNIR had poor correlations to nitrogen treatments on both sampling dates. This is not unexpected for NDVI and OSAVI, since they were developed for mixed soil-vegetation spectra. The vegetation indices GDVI, GNDVI, MCARI, SR and NG had the best correlations to nitrogen treatments. The indices GDVI and MCARI (Figures 6 & 7) related best to the nitrogen treatment levels, even when the cotton experienced water stress (Is) from deficit irrigation. The green peak (550 nm) by itself had at best moderate correlation to nitrogen levels, and the NIR (at either 750 nm or 800 nm) and red (676 nm) wavebands each were poorly correlated to nitrogen treatments.

These results suggest that at least two indices, GDVI and MCARI, corresponded well to nitrogen treatment levels, even if the cotton has moderate water stress. In general, the indices in this study that utilized a green waveband were better predictors of nitrogen treatment levels than indices using other wavebands. However, the green band by itself (Table 2) did not consistently regress well to nitrogen levels.

SPAD Meter

Minolta Chlorophyll SPAD 502 meter readings of cotton leaves under optimum irrigation had high correlation ($r^2 = 0.942$ and 0.998) to nitrogen treatments on both sampling dates (Figs. 8 & 9). The meter readings were on average 3.4 units higher on August 20 and 1.8 units higher on September 11 sampling dates in the water stressed plots compared to optimum irrigation (data not shown). This suggests that calibration curves developed for well-irrigated cotton may not be suitable for areas within a field that are experiencing water stress.

Conclusions

These are preliminary results from the first year of a three-year strip-plot field trial with Maxxa cotton. Several vegetation indices appear to correlate well to nitrogen availability, even when cotton is exposed to water stress. Reflectance in narrow green, red or infrared bands did not individually correlate well to nitrogen availability. However, vegetation indices, particularly MCARI and GDVI, that used the green band in their algorithm correlated well to nitrogen availability. It appears that vegetation indices are a more useful tool than simple narrow visible band reflectance for detecting relative levels of nitrogen. Minolta Chlorophyll SPAD 502 meter readings also regressed very well to nitrogen treatments. Leaf tissues that were collected during the sampling dates will be analyzed for total and soluble nitrogen to determine if relationships between leaf or petiole nitrogen content also follow these same trends.

Acknowledgments

The authors wish to express their appreciation to Cotton Incorporated and the National Aeronautics and Space Administration (NASA) for funding to support this research.

Table 1. Algorithms of selected vegetation indices.

Index	Algorithm
Chlorophyll Index	MCARI = [(ρ700 - ρ670) – 0.2(ρ700 - ρ550)](ρ700 / ρ670)
Difference Vegetation Index	DVI = ρ800 - ρ675
Green Difference Vegetation Index	GDVI = ρ550 - ρ675
Green Normalized Difference Vegetation Index	GNDVI = (ρ800 - ρ550) / (ρ800 + ρ550)
Normalized Difference Vegetation Index	NDVI = (ρ800 - ρ675) / (ρ800 + ρ675)
Normalized Green	NG = ρ550 / (ρ800 + ρ675 + ρ550)
Normalized Near Infrared	NNIR = ρ800 / (ρ800 + ρ675 + ρ550)
Normalized Red	NR = ρ675 / (ρ800 + ρ675 + ρ550)
Optimized Soil-Adjusted Vegetation Index	OSAVI = (ρ801 - ρ670) / (ρ801 + ρ670 + 0.16)
Ratio Vegetation Index	RVI = ρ800 / ρ675
Simple Reflectance	SR = ρ750 / ρ550

Table 2. Linear regression of vegetation indices and narrow bands to nitrogen availability on three sampling dates.

	Coefficient of Determination, r^2					
	07/11/03		07/24/03		08/21/03	
Index	**Io***	**Is****	**Io**	**Is**	**Io**	**Is**
DVI	.42	.54	.77	<.01	.46	<.01
GDVI	.79	.94	.89	.97	.90	.81
GNDVI	.54	.83	.83	.61	.84	.33
MCARI	.83	.84	.80	.96	.85	.81
NDVI	.16	.01	.06	.17	.20	.19
NG	.63	.88	.86	.74	.88	.44
NR	.30	.03	<.01	.32	.05	.40
NNIR	.18	.58	.65	.16	.66	.05
OSAVI	.20	<.01	.15	.18	.30	.12
RVI	.15	.01	.08	.15	.16	.20
SR	.54	.80	.86	.64	.83	.29
Narrow Bands						
green (550 nm)	.50	.74	.76	.41	.76	.20
NIR (750 nm)	.10	.39	.01	.06	.01	.04
NIR (800 nm)	<.01	.19	.17	.09	.09	.11
red (675 nm)	.13	.03	.02	.16	.17	.19

* Io = optimum irrigation

** Is = stressed (deficit) irrigation

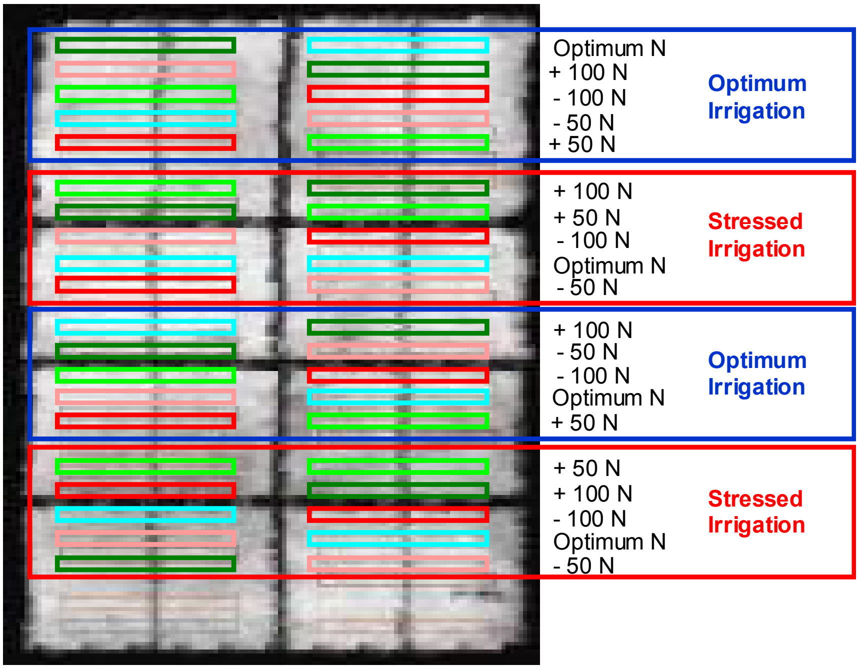

Figure 1. Split-plot trial design with randomized irrigation and nitrogen treatments.

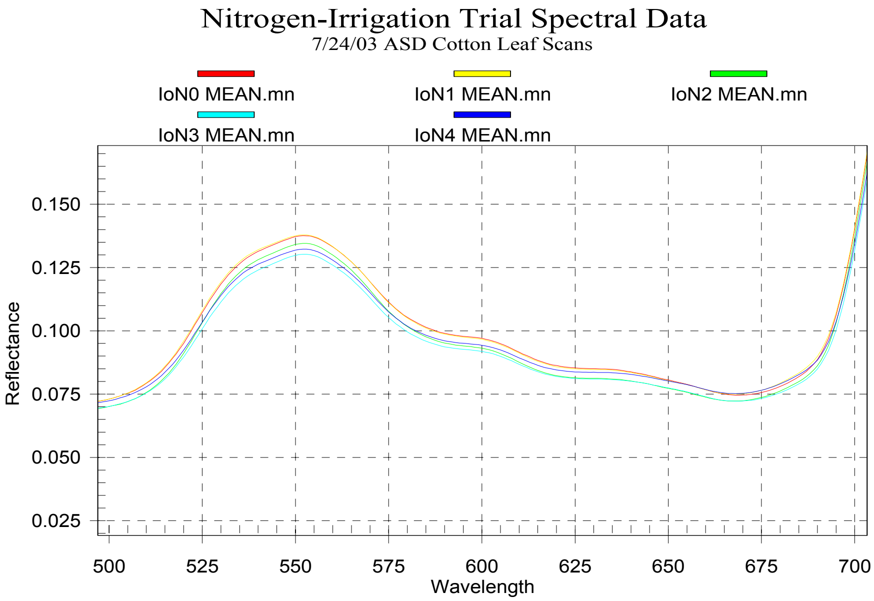

Figure 2. Visible leaf spectra on July 24 for cotton grown in deficient, optimum and excess available soil nitrogen (N0=-100, N1=-50, N2=optimum, N3=+50, N4=+100 lbs N/ac) under optimum irrigation

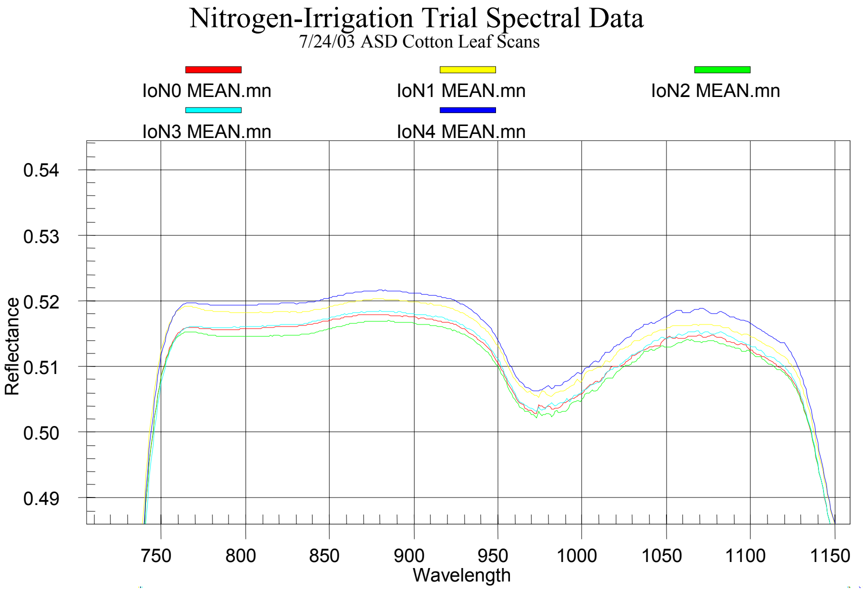

Figure 3. Near-infrared leaf spectra on July 24 for cotton grown in deficient, optimum and excess available soil nitrogen (N0=-100, N1=-50, N2=optimum, N3=+50, N4=+100 lbs N/ac) under optimum irrigation

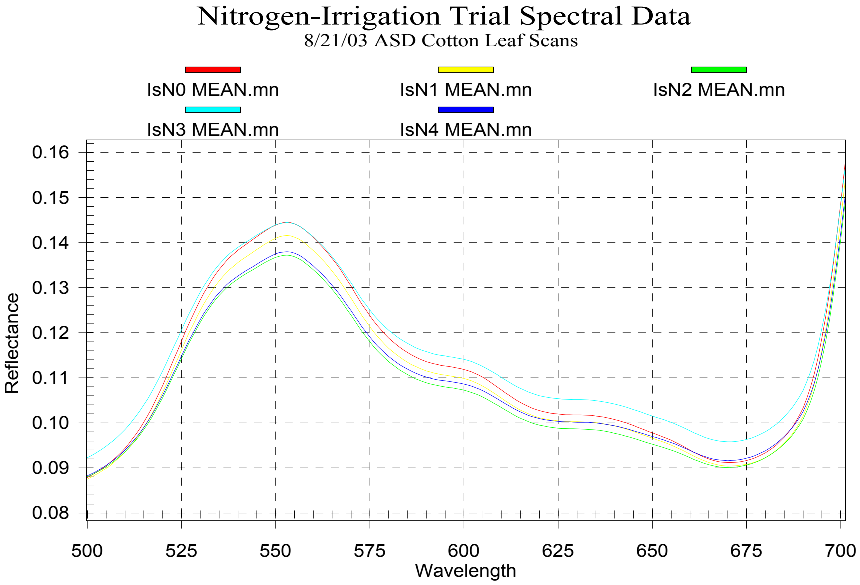

Figure 4. Visible bands leaf spectral on August 21 for cotton under stressed irrigation (Is) at five levels of available soil nitrogen (N0=-100, N1=-50, N2=optimum, N3=+50, N4=+100 lbs N/ac).

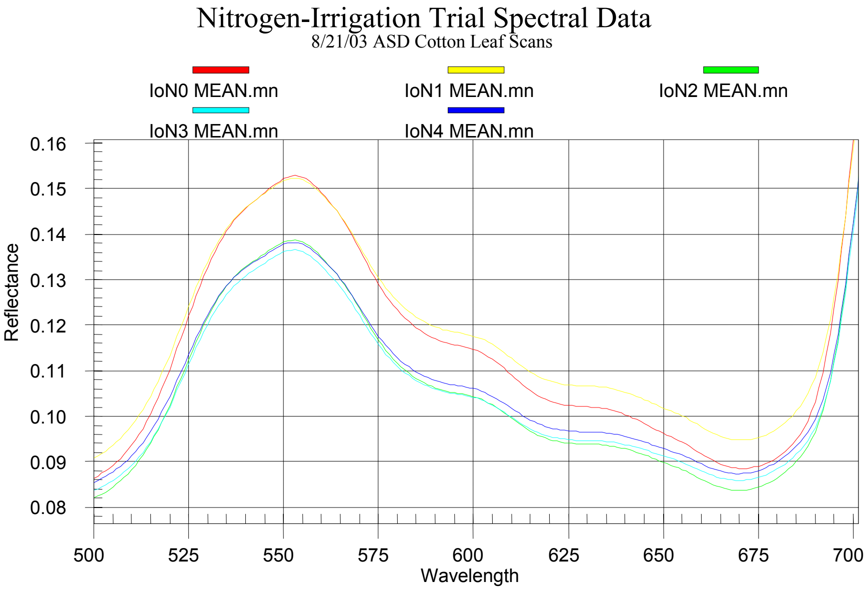

Figure 5. Visible leaf spectra on August 21 for cotton grown in optimum (Io) irrigation plots at five levels of available soil nitrogen (N0=-100, N1=-50, N2=optimum, N3=+50, N4=+100 lbs N/ac).

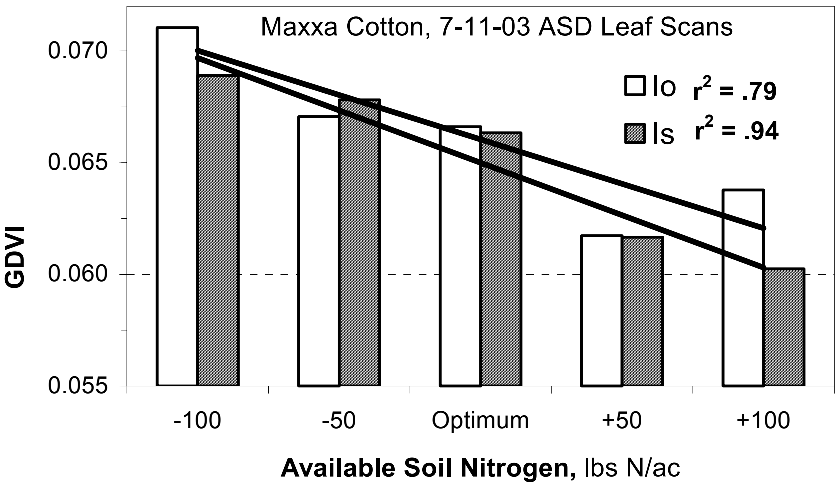

Figure 6. Linear regression of Green Difference Vegetation Index (GDVI) measured on July 11 to nitrogen treatments in optimum (Io) and stressed (Is) irrigation plots.

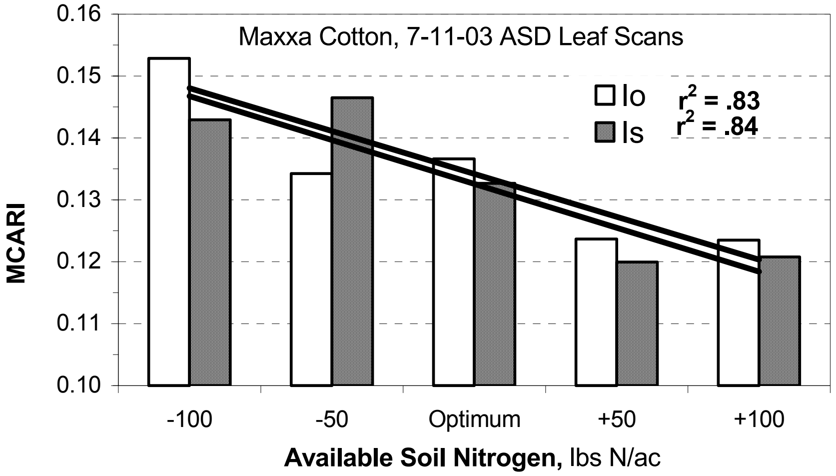

Figure 7. Linear regression of chlorophyll vegetation index (MCARI) measured on July 11 to nitrogen treatments in optimum (Io) and stressed (Is) irrigation plots.

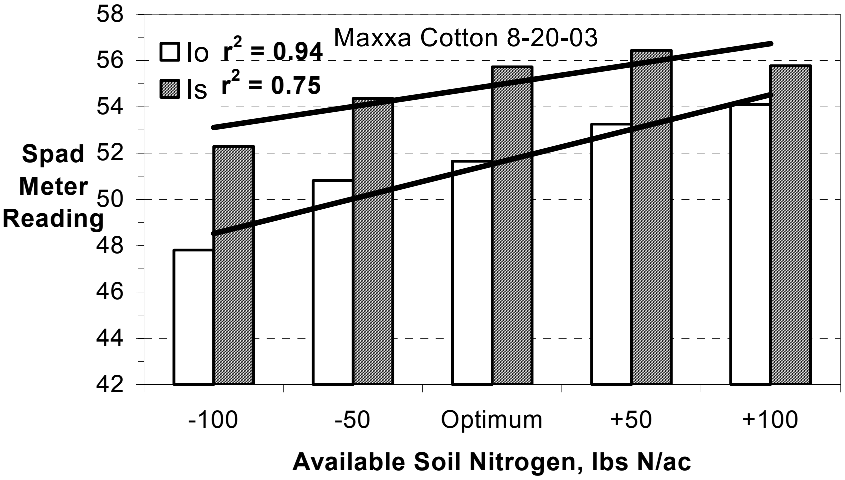

Figure 8. Linear regression of Minolta SPAD 502 meter readings on August 20 to nitrogen treatments in optimum (Io) and stressed (Is) irrigation plots.

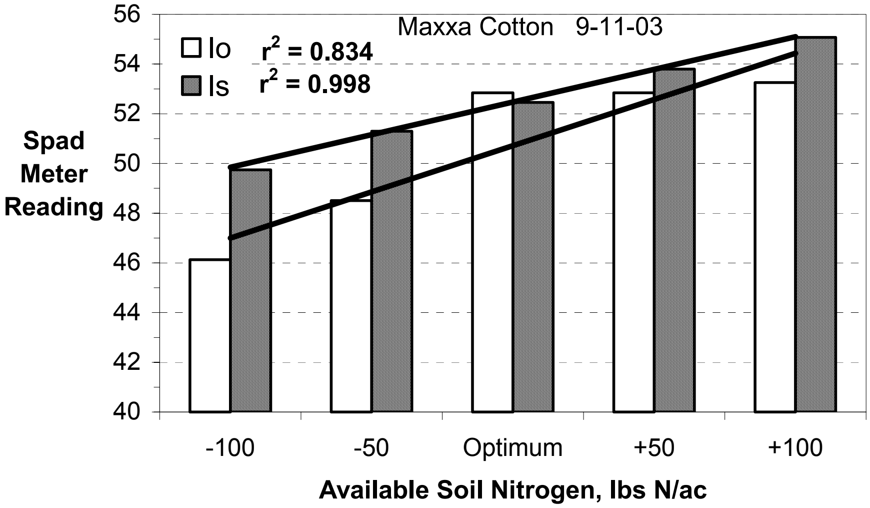

Figure 9. Linear regression of Minolta SPAD 502 meter readings on September 11 to nitrogen treatments in optimum (Io) and stressed (Is) irrigation plots.