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REMOTE-SENSING MEASURES OF COTTON MATURITY – CUTOUT AND BOLL OPENING

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Abstract

Imagery data were used in 2001 to classify a cotton field into two zones based on COTMAN spray termination rules. NDVI (Normalized Difference Vegetation Index) was used to classify portions of the field to spray (NAWF = 5 + <350 HU) or no spray (NAWF = 5 + > 350 HU) where NAWF = Node Above first position White Flower. Replicated experiments with planting date and cotton variety treatments were conducted in 2002 and 2003 to determine if radiometry data and/or multi-spectral imagery data could be used to estimate time of cutout (NAWF = 5) in a cotton crop. This report focuses on radiometry data acquired with a GER 1500® spectroradiometer. Reflectance data were used to calculate percent reflectance from which various indices were calculated and analyzed for correlation to NAWF and percent open bolls. The widely used NDVI was not closely correlated to NAWF or percent open bolls. Two other indices, VARI (Visible Atmospherically Resistant Index) and GVI (Green Vegetation Index), were closely correlated to the maturity parameters, especially for 2002 data.

Introduction

The COTMAN rule of NAWF=5 + 350 HU as the time to terminate control of boll-feeding insects has been reliable in Mississippi cotton producing areas of the Midsouth (Harris et al. 1997). Defoliation based on the COTMAN rule of NAWF=5 + 850 HU also appears to be an effective decision-aid for Mississippi cotton producers. The conventional method of measuring a cotton crop's progression toward cutout for use in the COTMAN program is to routinely count nodes above a first position white flower (NAWF). When a field (or management unit, i.e. field portion or multiple fields) averages NAWF=5, it is determined to have reached cutout (the time when the last cohort of blooms will produce harvestable bolls and significantly affect yield). Cutout becomes the benchmark for other end-of-season decisions such as the termination of insecticidal control of boll-feeding insects and the timing of harvest-aid chemical applications. Research has been conducted for four years at Stoneville, Mississippi, to study the potential for using remote-sensing data as the basis for precision application of insecticides and other components in the cotton production system. One particular area of interest has been cotton-crop maturation. There were early indications that multi-spectral imagery could be used to classify a cotton field on the basis of crop maturity. Imagery data were used in a 2001 on-farm experiment in August to classify a cotton field into two zones based on COTMAN spray termination rules. NDVI was used to classify portions of the field to spray (NAWF=5 + <350 HU) or no spray (NAWF=5 + >350 HU). The field was then treated on a prescription basis with 62% sprayed with insecticide and 38% not sprayed. Consequently, experiments were conducted in 2002 and 2003 with the objective of determining if radiometry data and/or multi-spectral imagery data could be used to estimate the time of cutout (NAWF=5) in a cotton crop.

Methods

A field experiment was planted in a factorial arrangement of treatments replicated four times in both 2002 and 2003. Factor A was planting date with three levels: (1) early (2 May 2002 and 30 Apr 2003), (2) mid (14 May 2002 and 13 May 2003), and (3) late (28 May 2002 and 28 May 2003). Factor B was cotton variety with two levels: (1) Sure Grow 747, and (2) Deltapine 5415. Each plot consisted of 20 rows (40-in row width) that were 67 ft long to create a 67-ft square plot.

Radiometry data were acquired with a GER 1500® spectroradiometer in both 2002 and 2003. Radiometry readings were made 15 times in 2002 between 26 Jun and 23 Sep with intervals ranging from 2 to 12 days. Radiometry readings were made 17 times in 2003 between 9 Jun and 17 Sep with intervals ranging from 2 to 11 days.

The GER 1500 spectroradiometer acquired 512 bands of reflectance data. Two readings per plot were made in 2002 and four readings per plot in 2003. Each reading consisted of a reflectance measurement of a standard white reference and two readings above the center of the furrow. Percent reflectance was calculated by T/S * 100, where T = reflectance of the target plant (row center reading) and S = reflectance of the standard. Data were averaged to obtain a single mean percent reflectance per plot. Average percent reflectance of the bands shown in Table 1 was used to calculate the vegetation reflectance indices (NDVI, GRNDVI, VARI, GVI – Tables 2-5) used in this study. Seven bands were averaged in each of the blue, green, and red visible color regions and fourteen bands were averaged in the near infrared region.

Radiometry data were analyzed by the PROC REG procedure, SAS 8.2, SAS Institute Inc., Cary, NC. Since radiometry and biological data were often not recorded on the same date, interpolated values were used when observation dates did not match. Simple linear regression of NAWF and percent open bolls on Julian date was done in Microsoft Excel 2002.

Results

Selected indices and the biological parameters used in regression analyses for all treatments in the 2002 and 2003 experiments are shown in Tables 2-5. Several other indices that are not shown were studied, but correlations were as low or lower than those for NDVI and GRNDVI. The indices shown in Tables 2-5 footnotes are discussed by Gitelson et al. (2002) and Spencer and Spry (2003), including the commonly used NDVI that was proposed by Rouse et al. (1974), and except GRNDVI. Green Normalized Difference Vegetation Index, GRNDVI, is obtained with a calculation similar to NDVI, but where GRNDVI = (NIR – green)/(NIR + green).

Statistics relative to the linear regression and analyses for various spectral reflectance indices on NAWF and percent open bolls are shown in Tables 2-5. Many of the regressions show very poor fit of the index to NAWF or percent open bolls. The best fit for NAWF data was to VARI. VARI uses percent reflectance in green and red bands of the spectrum with data from the blue band used to adjust for differences in atmospheric influences, where VARI = (Green – Red) / (Green + Red – Blue). Because there is only a short distance between a hand-held radiometer and a target plant, the atmosphere has little to no influence on reflectance. Therefore, the GVI (green vegetation index) = (Green – Red) / (Green + Red) provides regression relationships very similar to VARI.

Regressions of NDVI, VARI, and GVI on NAWF and percent open bolls are shown in Figure 1 (A-F) for 2002 and in Figure 2 (A-F) for 2003. The widely used NDVI was poorly correlated to NAWF and percent open bolls in both years (Figure 1A, 1B, 2A, 2B). VARI and GVI showed a fairly good correlation for 2002 data for the relationships being studied (Figure 1C-F). Correlations were poor for all models with 2003 data (Figure 2A-F).

Highly correlated linear relationships (negative) of NAWF to date (DOY = Day of Year) as the cotton crop progressed to maturity are shown in Figure 3 for Sure Grow 727 and Deltapine 5415 planted early (late April – early May) in both 2002 and 2003. Similar highly correlated linear relationships (positive) of percent-open-bolls to date (DOY) as the bolls mature, open, and progress toward readiness for harvest are shown in Figure 4. Although these linear relationships show a fairly high correlation, the raw data plotted in Figures 3-4 suggest that a curvilinear relationship may be even more highly correlated and this will be investigated in future work.

Conclusions

These studies show that there are potentially useful correlations of spectral-reflectance indices to crop maturity factors (cutout and boll opening). Preliminary attempts to validate the simple linear relationships on other fields to estimate time of cutout and time to apply harvest-aid chemicals have not given satisfactory results. Development of useful predictive estimates of crop maturity is the ultimate goal of this research. This will require investigation of other indices and algorithms. The results reported here are based on radiometry data. Spectral reflectance data acquired from aerial imagery (currently available and to be acquired) will be important for development of a practical application of this research. Changes in aerial imagery, spectral bands, and acquisition scheduling (flight frequency) may be needed.

References

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Table 1. GER 1500 spectral bands.

	Bands (nm)						
Blue	445	446	448	450	451	453	455
Green	545	547	548	550	552	554	555
Red	645	647	648	650	652	653	655
NIR	840	842	843	844	846	848	849
	850	852	854	855	857	858	860

Table 2. NAWF x indices regression analyses, 2002.

Dependent Variable[1/]	Independent Variable[2/]	F-value	Prob > F	R^2
NAWF	NDVI	19.7	<0.0001	0.10
LOG NAWF	NDVI	32.5	<0.0001	0.16*
NAWF	LOG NDVI	19.9	<0.0001	0.10
LOG NAWF	LOG NDVI	33.0	<0.0001	0.16
NAWF	GRNDVI	12.9	<0.0004	0.07
LOG NAWF	GRNDVI	8.1	<0.0048	0.04
NAWF	LOG GRNDVI	13.4	<0.0003	0.07
LOG NAWF	LOG GRNDVI	8.6	<0.0038	0.05
NAWF	VARI	200.1	<0.0001	0.53
LOG NAWF	VARI	280.4	<0.0001	0.62*
NAWF	LOG VARI	178.3	<0.0001	0.51
LOG NAWF	LOG VARI	258.6	<0.0001	0.60
NAWF	GVI	171.8	<0.0001	0.50
LOG NAWF	GVI	228.3	<0.0001	0.57*
NAWF	LOG GVI	159.2	<0.0001	0.48
LOG NAWF	LOG GVI	221.4	<0.0001	0.56

[1/]NAWF = nodes above white flower
[2/]NDVI = normalized difference vegetation index = (NIR–Red)/(NIR+Red)
GRNDVI = green NDVI = (NIR – green) / (NIR + green)
VARI=visible atmospherically resistant index=(green–red)/(green+red–blue)
GVI = green vegetation index = (green – red) / (green + red)
LOG = Log 10
*Regression equations and graphs shown in figures.

Table 3. Percent open bolls x indices regression analyses, 2002.

Dependent Variable[1/]	Independent Variable[2/]	F-value	Prob > F	R^2
PCTOPEN	NDVI	74.7	<0.0001	0.39*
LOG PCTOPEN	NDVI	41.3	<0.0001	0.26
PCTOPEN	LOG NDVI	59.0	<0.0001	0.33
LOG PCTOPEN	LOG NDVI	31.1	<0.0001	0.21
PCTOPEN	GRNDVI	39.0	<0.0001	0.25
LOG PCTOPEN	GRNDVI	22.6	<0.0001	0.16
PCTOPEN	LOG GRNDVI	35.3	<0.0001	0.23
LOG PCTOPEN	LOG GRNDVI	19.2	<0.0001	0.14
PCTOPEN	VARI	191.1	<0.0001	0.62*
LOG PCTOPEN	VARI	123.6	<0.0001	0.52
PCTOPEN	LOG VARI	93.5	<0.0001	0.44
LOG PCTOPEN	LOG VARI	47.3	<0.0001	0.29
PCTOPEN	GVI	176.8	<0.0001	0.60*
LOG PCTOPEN	GVI	117.4	<0.0001	0.50
PCTOPEN	LOG GVI	104.2	<0.0001	0.47
LOG PCTOPEN	LOG GVI	54.1	<0.0001	0.32

[1/]PCTOPEN = percent open bolls
[2/]NDVI = normalized difference vegetation index = (NIR – Red) / (NIR + Red)
GRNDVI = green NDVI = (NIR – green) / (NIR + green)
VARI = visible atmospherically resistant index=(green–red)/(green+red–blue)
GVI = green vegetation index = (green – red) / (green + red)
LOG = Log 10
*Regression equations and graphs shown in figures.

Table 4. NAWF x indices regression analyses, 2003.

Dependent Variable[1/]	Independent Variable[2/]	F-value	Prob > F	R^2
NAWF	NDVI	6.9	0.0093	0.04
LOG NAWF	NDVI	9.5	0.0025	0.06*
NAWF	LOG NDVI	6.9	0.0095	0.04
LOG NAWF	LOG NDVI	9.5	0.0025	0.06
NAWF	GRNDVI	0.4	0.5403	0.003
LOG NAWF	GRNDVI	1.2	0.2826	0.008
NAWF	LOG GRNDVI	0.4	0.5156	0.003
LOG NAWF	LOG GRNDVI	1.3	0.2642	0.008
NAWF	VARI	13.0	0.0004	0.08
LOG NAWF	VARI	12.3	0.0006	0.07*
NAWF	LOG VARI	13.1	0.0004	0.08
LOG NAWF	LOG VARI	12.3	0.0006	0.07
NAWF	GVI	4.8	0.0293	0.03
LOG NAWF	GVI	4.2	0.0415	0.03*
NAWF	LOG GVI	5.3	0.0232	0.03
LOG NAWF	LOG GVI	4.5	0.0366	0.03

[1/]NAWF = nodes above white flower
[2/]NDVI = normalized difference vegetation index = (NIR – Red) / (NIR + Red)
GRNDVI = green NDVI = (NIR – green) / (NIR + green)
VARI=visible atmospherically resistant index=(green–red)/(green+red–blue)
GVI = green vegetation index = (green – red) / (green + red)
LOG = Log 10
*Regression equations and graphs shown in figures.

Table 5. Percent open bolls x indices regression analyses, 2003.

Dependent Variable[1/]	Independent Variable[2/]	F-value	Prob > F	R^2
PCTOPEN	NDVI	65.9	<0.0001	0.36*
LOG PCTOPEN	NDVI	67.6	<0.0001	0.36
PCTOPEN	LOG NDVI	66.3	<0.0001	0.36
LOG PCTOPEN	LOG NDVI	67.42	<0.0001	0.36
PCTOPEN	GRNDVI	4.7	0.0326	0.04
LOG PCTOPEN	GRNDVI	1.6	0.2075	0.01
PCTOPEN	LOG GRNDVI	5.1	0.0252	0.04
LOG PCTOPEN	LOG GRNDVI	1.8	0.1799	0.02
PCTOPEN	VARI	49.8	<0.0001	0.23*
LOG PCTOPEN	VARI	75.0	<0.0001	0.38
PCTOPEN	LOG VARI	46.8	<0.0001	0.28
LOG PCTOPEN	LOG VARI	63.7	<0.0001	0.35
PCTOPEN	GVI	36.3	<0.0001	0.24*
LOG PCTOPEN	GVI	56.8	<0.0001	0.33
PCTOPEN	LOG GVI	35.4	<0.0001	0.23
LOG PCTOPEN	LOG GVI	50.5	<0.0001	0.30

[1/]PCTOPEN = percent open bolls
[2/]NDVI = normalized difference vegetation index = (NIR–Red)/(NIR+Red)
GRNDVI = green NDVI = (NIR–green)/(NIR+green)
VARI = visible atmospherically resistant index=(green–red)/(green+red–blue)
GVI = green vegetation index = (green – red)/(green + red)
LOG = Log 10
*Regression equations and graphs shown in figures.

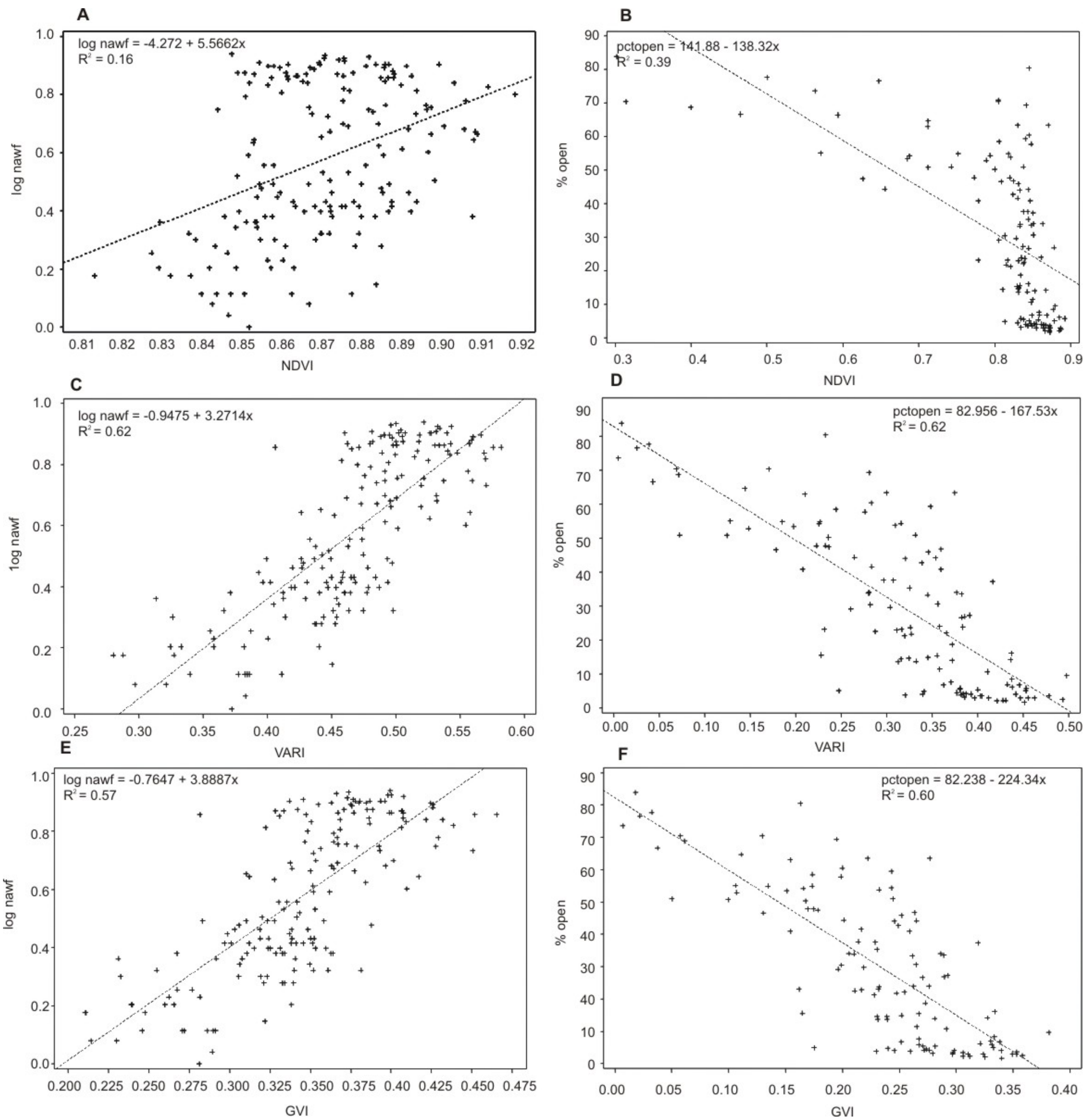

Figure 1. Regressions of NDVI, VARI, and GVI on NAWF and percent open bolls, 2002.

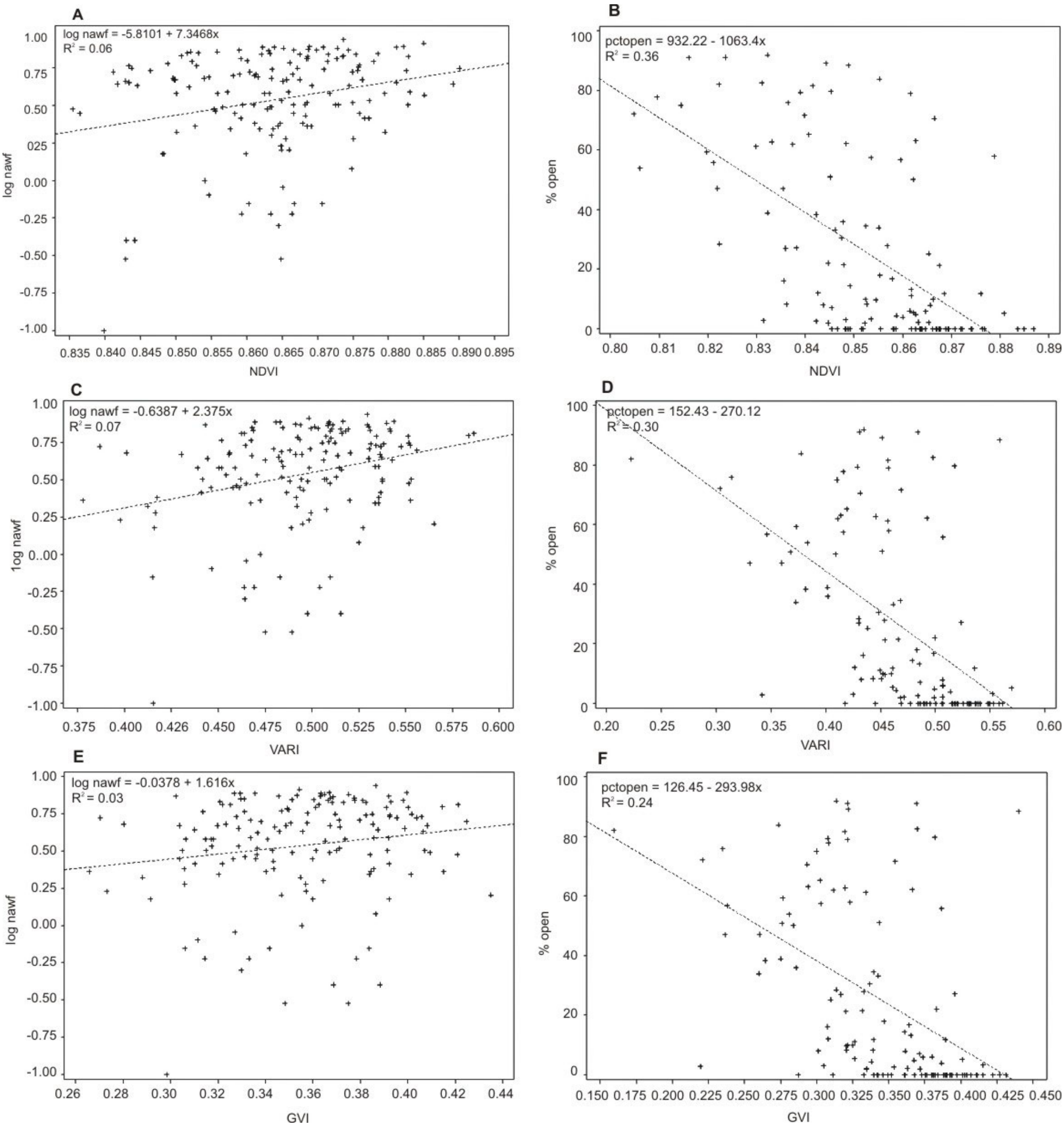

Figure 2. Regressions of NDVI, VARI, and GVI on NAWF and percent open bolls, 2003.

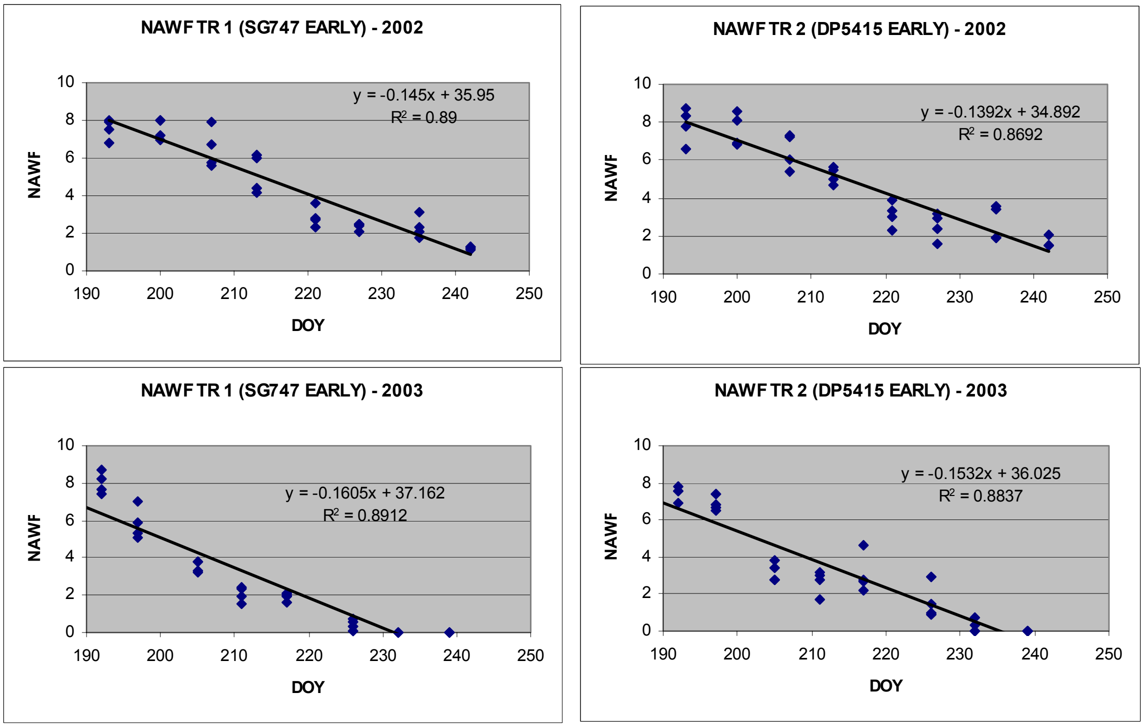

Figure 3. Regression of NAWF on date for two varieties planted on a normal early planting date in 2002 and 2003.

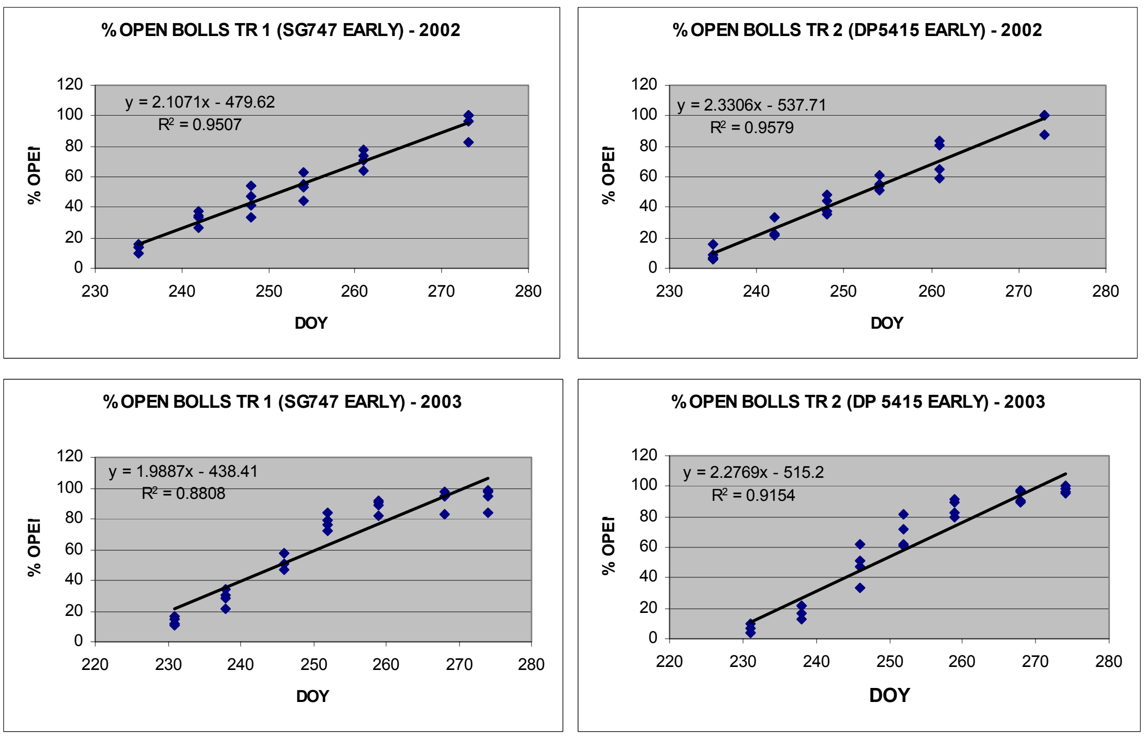

Figure 4. Regression of percent open bolls on a date for two varieties planted on a normal early planting date in 2002 and 2003.