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SPECTRAL REFLECTANCE ESTIMATES OF COTTON BIOMASS AND YIELD

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Abstract

Cotton was grown under three irrigation levels in 2002 and four irrigation levels in 2003 using subsurface drip irrigation. Multi-spectral reflectance measurements made periodically in both years were related to periodic biomass, leaf water potential measurements and final lint yield. Reflectance measurements were made with a hand-held CROPSCAN radiometer equipped with sensors that measured radiation in 16 wavelengths. The objective of this study was to determine the level of correlation of multi-spectral reflectance of cotton with leaf water potential, leaf area, and final yield. After an analysis that included the plotting of all bands for all measurement dates in both years high correlation was observed between several bands. Seven uncorrelated bands were selected to correlate with leaf water potential (LWP), leaf area index (LAI), and final lint yield. Among the individual bands wave lengths of 750 nm and 880 nm were highly correlated with LWP, LAI, and lint yield. The highest correlation with LWP and LAI was $R^2 = 0.80$. The highest R^2 values for final lint yield were between 0.7 and 0.8, which tended to increase as measurement date approached the time of crop maturity in 2003. Reflectance correlations in band 660 nm with final lint yield reached R^2 values between 0.55 and 0.75. The highest NDVI(880,660) values were 0.70 with LWP in 2003, LAI was 0.75 in 2003, and lint yield reached 0.60 and 0.75 in 2002 and 2003, respectively. While reflectance was significantly correlated with each of the canopy factors, higher precision would be needed to replace measurement of the canopy factors with spectrally-based estimates.

Introduction

Remote sensing is an information technology that gathers information without physically contacting or destructively sampling the subject of interest. In crop production remote sensing is usually applied to measure the emitted energy that is related to crop canopy temperature or the measurement of reflected radiation in multiple wavelengths that estimate crop size and vigor. Past research has established correspondence between selected wavelengths and leaf chlorophyll concentration and with the amount of leaf area in a stand of plants in the field (Gausman, 1977). Chlorophyll content in leaves is a general indicator of plant vigor and leaf area determines the amount of incident radiation intercepted.

In general the reliability of remote sensing for estimating crop yield decreases with the amount of time before crop maturity because there is more opportunity for drought, nutrient supply, insect infestation, and disease to affect its yield, Pinter, et al., 2003. Research studies concerned with monitoring crop development during the growing season utilize plant sampling of various kinds. Sampling and the process of obtaining various measurements that indicate crop growth and vigor are time consuming. In irrigation studies we frequently make periodic spectral reflectance measurements with hand-held multi-spectral radiometers and biomass harvests to track crop development for the purpose of comparing treatments. The use of remote sensing measurements to estimate crop development progress without crop sampling could greatly reduce the effort to obtain periodic estimates of leaf area index (LAI) and yield. The objective of this study was to determine the level of correlation of multi-spectral reflectance of cotton with leaf water potential (LWP), leaf area, and final lint yield.

Materials and Methods

Studies were conducted in a field at the Plant Stress and Water Conservation Laboratory at Lubbock, TX during 2002 and 2003. The cotton variety Paymaster 2326 BG/RR was planted on 13 May in both years in north-south rows having a spacing of 1 m. Irrigation studies were conducted in both years by establishing multiple water level treatments using the BIOTIC protocol (Upchurch, et al., 1996) to schedule irrigation. By selecting different time threshold (TT) values to control irrigation multiple crop water status conditions were created. Three irrigation treatments in 2002 were established with TT of 2.5 hr, 5.5 hr, and 7.5 hr. In 2003 irrigation treatments were established using TT of 5.5 hr, 6.5 hr, 7.5 hr, and 8.5 hr. Final plant populations averaged 51,000 and 48,000 plants/acre, respectively, in 2002 and 2003.

A subsurface drip irrigation system was installed in a field at the Plant Stress and Water Conservation Laboratory at Lubbock, TX during March 2002. The spacing of irrigation laterals was 1 m and located under each bed. Drip tubing diameter was 0.875 in. ID with 0.23 gph emitters spaced every 24 in. Each irrigation zone was 8 rows wide by 542 feet long and water application was individually metered.

Reflectance measurements that coincided with LWP and biomass sampling were made on 10 days between DOY 206 and DOY 256 in 2002 and on 12 days between DOY 136 and DOY 269 in 2003. A hand-held CROPSCAN radiometer was used to measure reflectance in 16 wavelengths in each plot. The radiometer contained sensors that measured radiation in wavelengths of 460, 485, and 500 nm in the blue region; 560, and 600 nm in the green region; 660 nm in the red region; 700 nm in the transition region between the red and NIR regions; and 750, 800, 830, 880, 940, 1100, 1260, 1480, and 1650 nm in the NIR. The radiometer was positioned directly above the row of plants. Measurements were made at four locations along the row in 2002 and three locations in 2003. Reflectance measurements began at 1100 h and were usually completed by 1300 h. On days with partial cloudiness spectral readings would be interrupted if clouds were close to obscuring the sun.

Biomass hand-harvests were made periodically during the season to document cotton vegetative growth and crop boll development. LWP was measured weekly in plots between 1400 and 1600 h using the pressure chamber method from late June through mid August. Lint yield was determined from hand-harvest of selected areas in all plots and from stripper harvesting entire rows.

The studies were arranged in a randomized complete block design with four replications in each year. In addition to monitoring canopy temperatures, air temperature, relative humidity, net radiation, and wind speed were measured at a 2 m height in 6 s intervals and recorded as 15-minute averages.

Results and Discussion

The measurement dates for reflectance, LWP, and biomass harvests are summarized in Table 1. The spectral measurement dates include only those made when LWP measurements and biomass harvests were taken.

Reflectance data for all wavelengths were first plotted for all measurement dates. These plots showed that some wavelengths displayed similar patterns over time and differed only slightly in the magnitude of reflectance values. Four wave lengths in the visible region (560, 600, 660, and 700 nm) are shown in Fig. 1 for 2002 and 2003. Bands 560 and 600 nm have similar reflectance values in both years. Reflectance curves for four bands in the near infrared region show that the 880 and 1100 nm wavelengths are identical, Fig. 2. Reflectance values in band 1260 nm wavelength were erroneous and unstable across dates in 2002 and were omitted from analysis in both years. The 1100 nm because of its high correspondence with the 880 nm band in both years and 1260 nm wavelength because of unstable readings in 2002 were eliminated from further analysis.

The normalized difference vegetative index NDVI(880,660), composed of the 880 nm and 660 nm wave lengths, for 2002 and 2003 are shown for different dates for each water level treatment, Fig. 3. In both years NDVI (880,660) values for the highest water level treatments (smallest TT values) are relatively constant after DOY 200. The lower water level treatments show greater fluctuation with slightly declining values as the season progresses. In general NDVI (880,660) values decline as water level is lowered.

Based on the preliminary analysis above, 7 of the 15 wavelengths were selected to correlate with lint yield, biomass, and LWP measurements. These 7 wave lengths were 560 nm in the green region, 600 nm and 660 nm in the red region, 700 nm in the transition region between red and NIR, 750 nm and 880 nm in the NIR, and 1650 nm in the water absorption area of the NIR. The NDVI(880,660) was computed using reflectance from the 880 nm and 660 nm wave lengths as (R880 – R660)/(R880 + R660). Correlations of reflectance in different wavelengths with LWP, LAI, and lint yield were made using plot data from all replications of all irrigation treatments.

The LWP values in Table 2 for the 5.5 hr TT and 7.5 hr TT treatments had a comparable range of values within treatments across both years. The LWP values of the relatively well irrigated treatments, 2.5 hr TT and 5.5 hr TT, indicate all treatments were experiencing some degree of water stress. LWP values < –20 bars are likely to be less than well-watered, (Hake et. al, 1996).

The 5.5 hr TT and 7.5 hr TT treatments were used in both years. The 5.5 hr TT treatment reached a final height of 95 cm in 2002 and 90 cm in 2003, Fig. 4. The final plant height for the 7.5 hr TT treatment was about 85 cm in 2002 and slightly < 80 cm in 2003. A comparison of the plant height curves in Fig. 4 indicated that growth rate was slower in 2003 than in 2002. On DOY 200 plant heights were approximately 90 cm in 2002 and only 50 cm in 2003. By DOY 220 in both years plants in all irrigation treatments had attained maximum height. The LAI curves in Fig. 5 also indicated a slower rate of vegetative development during the early season of 2003. On DOY 190, LAI was around 2.2 in 2002 and 0.7 in 2003. LAI values among the water level treatments were different beginning on DOY 210 in 2002 and DOY 224 in 2003. Late cool fronts lowered air temperature and some damage from wind and hail during thunderstorm events in June 2003 were contributing factors to slower growth and high variability in accumulated vegetation development among seedlings. These combined factors resulted in high variability in vegetative growth for the 2003 plant population.

The final lint yields are shown for each replication and water level treatment for both years in Table 3. Comparisons between treatments which were included in both years indicated that yields were higher in 2002 than 2003. The range of lint yields across replications within a treatment also showed greater variability in 2003. Other than the slow early plant growth and the variability in vegetative damage in 2003 there is no obvious explanation for the high yield variability.

Spectral Relationships

Linear correlations were performed by using all replications for LWP, LAI, and final yield for individual spectral wavebands and NDVI(880, 660).

In both years the 750 and 880 nm wavelengths were most highly correlated with LWP, Fig. 6. The highest overall correlations occurred on DOY 227 in 2002 and DOY 233 in 2003 with R^2 values of 0.80 and 0.83, respectively. The effect of LWP differences on cotton growth should be cumulative with longer exposure causing greater differences among water level treatments. This is a possible explanation for correlations in all wave lengths being highest on the latest measurement dates. The correlation of NDVI(880,660) with LWP in 2002 increased as the season progressed with R^2 values between 0.4 and 0.65, Fig. 7. The NDVI(880,660) correlations in 2003 were near zero on DOY 192 and increased to 0.7 which also coincided with the maximum LAI values measured during the season. It is likely that the low correlation of LWP on DOY 192 was influenced by low LAI values, which allowed bare soil to be a significant component of the reflectance signal.

LAI was also highly correlated with spectral reflectance in the 750 and 880 nm bands, Fig. 8. The best 2002 correlations were obtained in these bands on DOY 213 (R^2 = 0.61) and DOY 227 (R^2 = 0.64). In 2003, correlations were consistently high for DOY 224 and DOY 266 in bands 750 and 880 nm with R^2 values averaging 0.80 on both dates. There was a decline in the correlation of NDVI(880,660) with LAI in 2002 as the season progressed, but in 2003 there was continuous linear increase between DOY 174 and DOY 266, Fig. 7. Spectral measurements began earlier in the 2003 season when LAI values were only about 0.1 compared with 2002 where the earliest measurements occurred when LAI values were near maximum values in all irrigation levels ranging from 2.2 to 4.2. The seasonal progression of R^2 values ranged from 0.55 to 0.40 in 2002 and from 0.2 to 0.75 in 2003.

Spectral band correlations with lint yield in 2002 were generally highest in bands 750 and 880 nm followed by band 660 nm, but there was no trend in correlation values as the season progressed, Fig. 9. The highest correlation in band 750 nm occurred on DOY 213 and DOY 220 having R^2 values near 0.75, and on DOY 220 for band 880 nm (R^2 = 0.70). The best correlations in band 660 nm were observed on DOY 247 and DOY 256 with R^2 values 0.65 and 0.55, respectively. The best spectral correlation with yield for band 1650 nm was 0.6 on DOY 256. In 2003, all bands had R^2 values of 0.75 or higher on DOY 254 with the exception of band 750 nm. In comparison with 2002 there was a stronger tendency for higher correlation with lint yield as the season progressed, except for the 750 nm band. The correlation of NDVI(880,660) with lint yield increased during the season until DOY 256 in 2002 and DOY 254 in 2003, with the exception of DOY 240 in both years, Fig. 7. The R^2 values on DOY 240 for NDVI(880,660) in both years was around 0.35 and the correlations of bands 660 nm and 880 nm were also low.

Summary

Reflectance measurements were made in 2002 and 2003 with a hand-held CROPSCAN radiometer equipped with sensors that measured radiation in 15 wavelengths. The plotting of reflectance for all bands for the measurement dates in 2002 and 2003 indicated that several bands were highly correlated. Seven uncorrelated bands were selected to correlate with, LWP, LAI, and final lint yield. In both years the 750 and 880 nm wavelengths displayed the highest correlation with LWP having maximum R^2 values of 0.80. The correlations with LAI were also best in these bands ranging from R^2 = 0.61 to 0.64. The highest correlations with final lint yield also occurred for bands 750 and 880 nm with R^2 values between 0.7 and 0.8 which tended to increase as measurement date approached the time of crop maturity in 2003. Reflectance in band 660 nm had R^2 values between 0.55 and 0.75 with final lint yield. The highest NDVI(880,660) values were 0.70 with LWP in 2003, LAI was 0.75 in 2003, and lint yield reached 0.60 and 0.75 in 2002 and 2003, respectively. Although the spectral correlations were statistically significant, they are not high enough to replace direct measurement of the plant characters studied.

References

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Table 1. Summary of data collection dates for reflectance wavelengths, leaf water potential, biomass, and yield, 2002-2003.

		Measurement Dates, DOY				
					Yield	
Year	**Spectral Wave Lengths, nm**	**Reflectance**	**Leaf Water Potential**	**Biomass Harvests**	**Hand Harvest**	**Stripper Harvest**
2002	600, 660, 700 750, 880, 1100, 1650, NDVI(880,660)	206, 213, 220, 227, 240, 247, 256	205, 213, 217, 227	210, 226, 254	288	316
2003	600, 660 700, 750, 880, 1100, 1650, NDVI(880,660)	174, 191, 205, 219, 225, 233, 240, 254, 269	192, 199, 206, 213, 233	174, 190, 224, 266	308, 316	323

Table 2. Mid-day leaf water potentials, 2002-2003.

	Treatments					
Date,	**2.5 hr TT**	**5.5 hr TT**	**6.5 hr TT**	**7.5 hr TT**	**8.5 hr TT**	**Dryland**
DOY	**Leaf Water Potential, bars** [1]					
2002						
205	-20.6 a	-23.4 b		-28.1 c		
213	-22.0 a	-27.3 b		-29.4 c		
217	-24.1 a	-27.8 b		-30.0 c		-38.8 d
227	-26.4 a	-27.9 b		-33.1 c		
2003						
192		-20.3 a	-20.2 a	-19.9 a	-21.0 a	-24.8 a
203		-17.6 a	-17.6 a	-17.8 a	-19.1 b	-26.1 c
206		-17.0 a	-17.8 a	-19.6 b	-27.1 d	-25.5 c
213		-21.6 a	-22.6 a	-27.1 b	-31.7 c	-34.8 d
233		-28.6 a	-29.3 b	-33.6 b	-35.2 c	-37.9 d

[1] Values for the same date followed by a common letter are statistically similar at the 0.05 probability level according to Duncan's New Multiple Rang Test.

Table 3 Lint yields for water level treatments, 2002-2003.

Date, DOY	2.5 hr TT	5.5 hr TT	6.5 hr TT	7.5 hr TT	8.5 hr TT	Dryland
	Lint Yield, kg / ha [1]					
2002						
Rep 1	1486	1417		926		
Rep 2	1550	1604		934		
Rep 3	1573	1517		1127		
Rep 4	1745	1682		1085		
Mean	1588 a	1555 a		1018 b		307
2003						
Rep 1		1297	974	718	892	
Rep 2		1131	983	727	453	
Rep 3		657	1098	1161	1018	
Rep 4		984	636	711	687	
Mean		1017 a	923 a	829 a	762 a	275

[1] Values for the same date followed by a common letter are statistically similar at the 0.05 probability level according to Duncan's New Multiple Range Test.

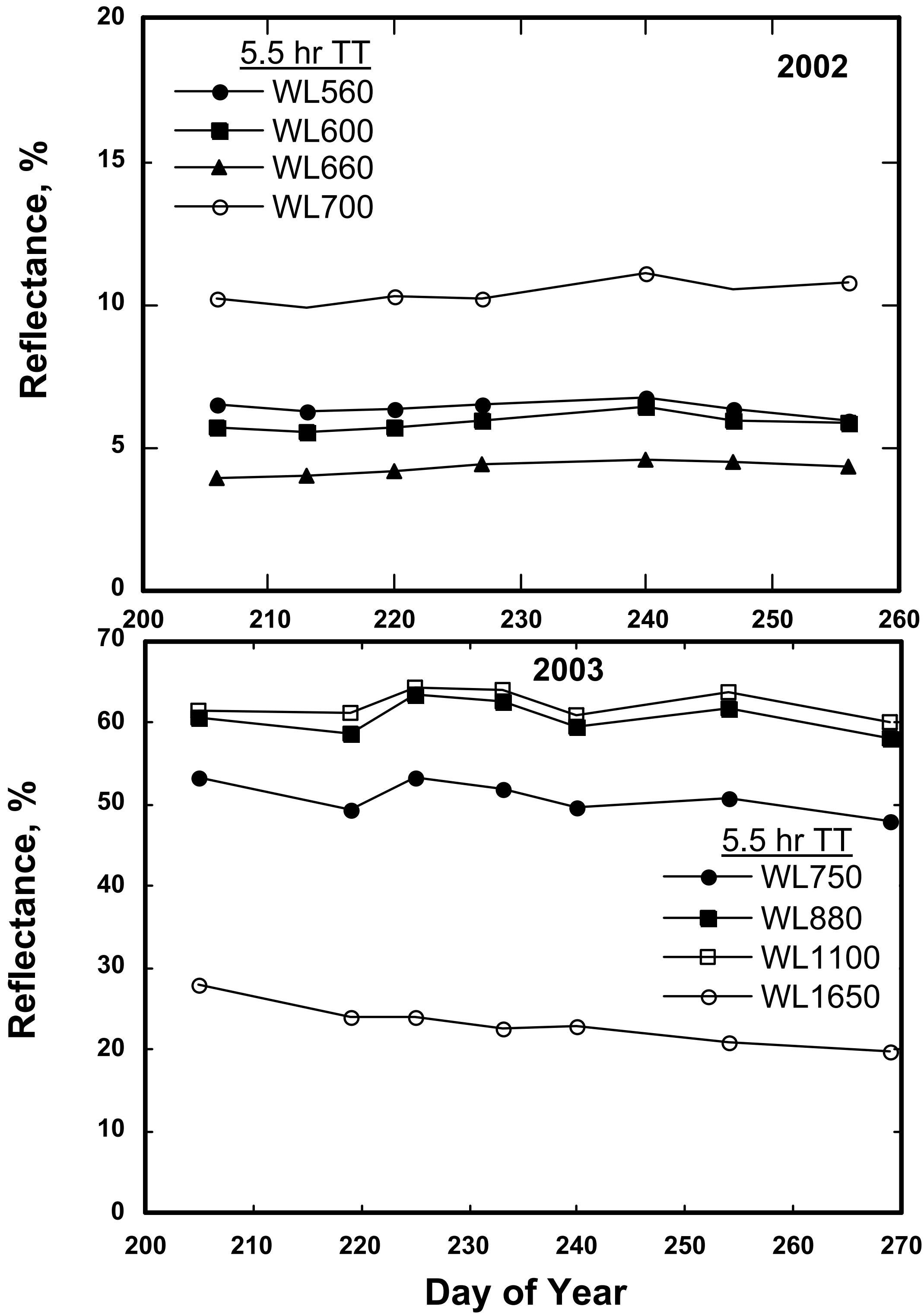

Figure 1. Reflectance of 5.5 hr TT treatment on multiple days during the growing season for the 560, 600, 660, and 700 nm wavelengths in 2002 and 2003.

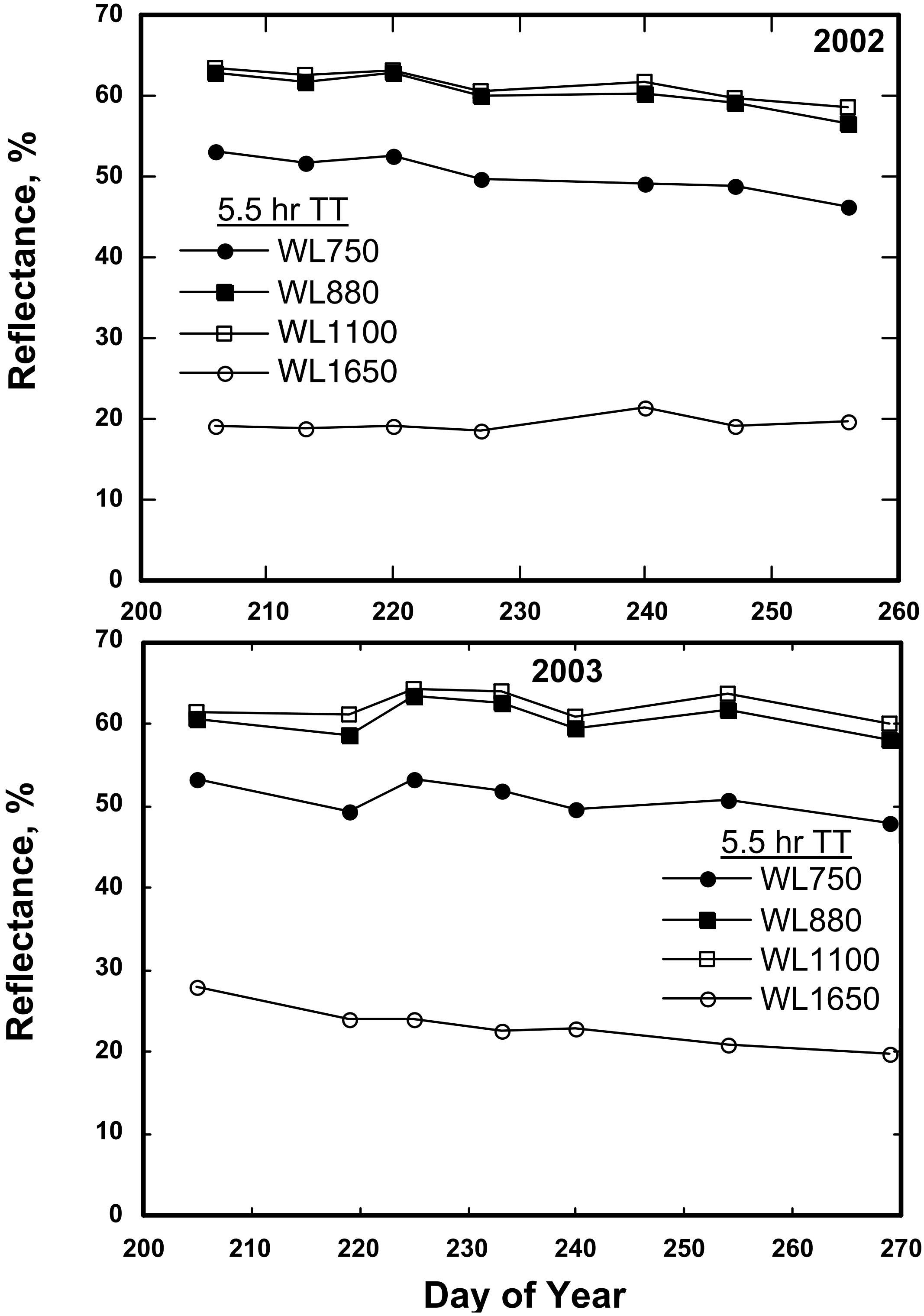

Figure 2. Reflectance of 5.5 hr TT treatment on multiple days during the growing season in four infrared region wavelengths, 2002 and 2003.

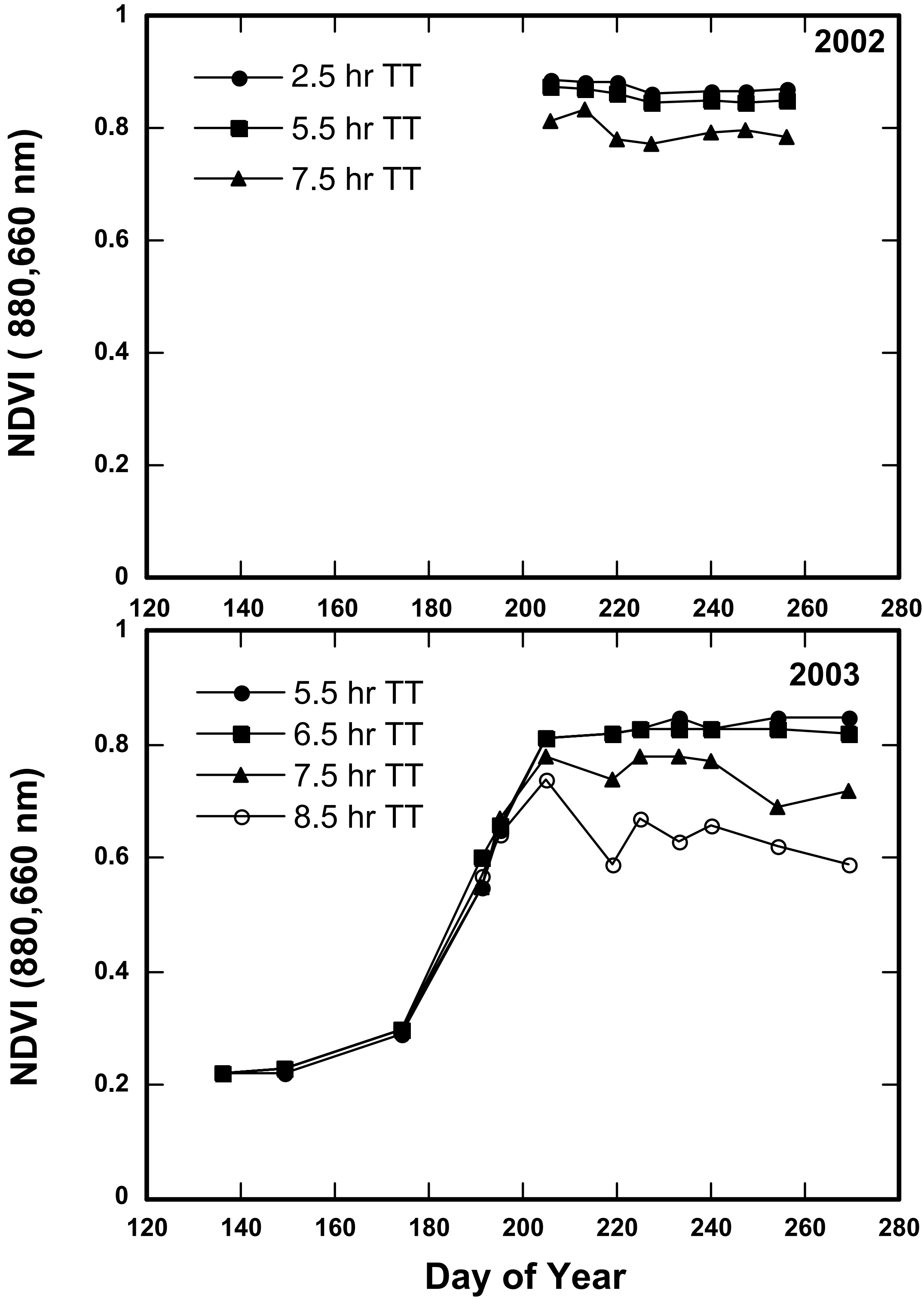

Figure 3. Normalized difference vegetative index values for water level treatments in 2002 and 2003.

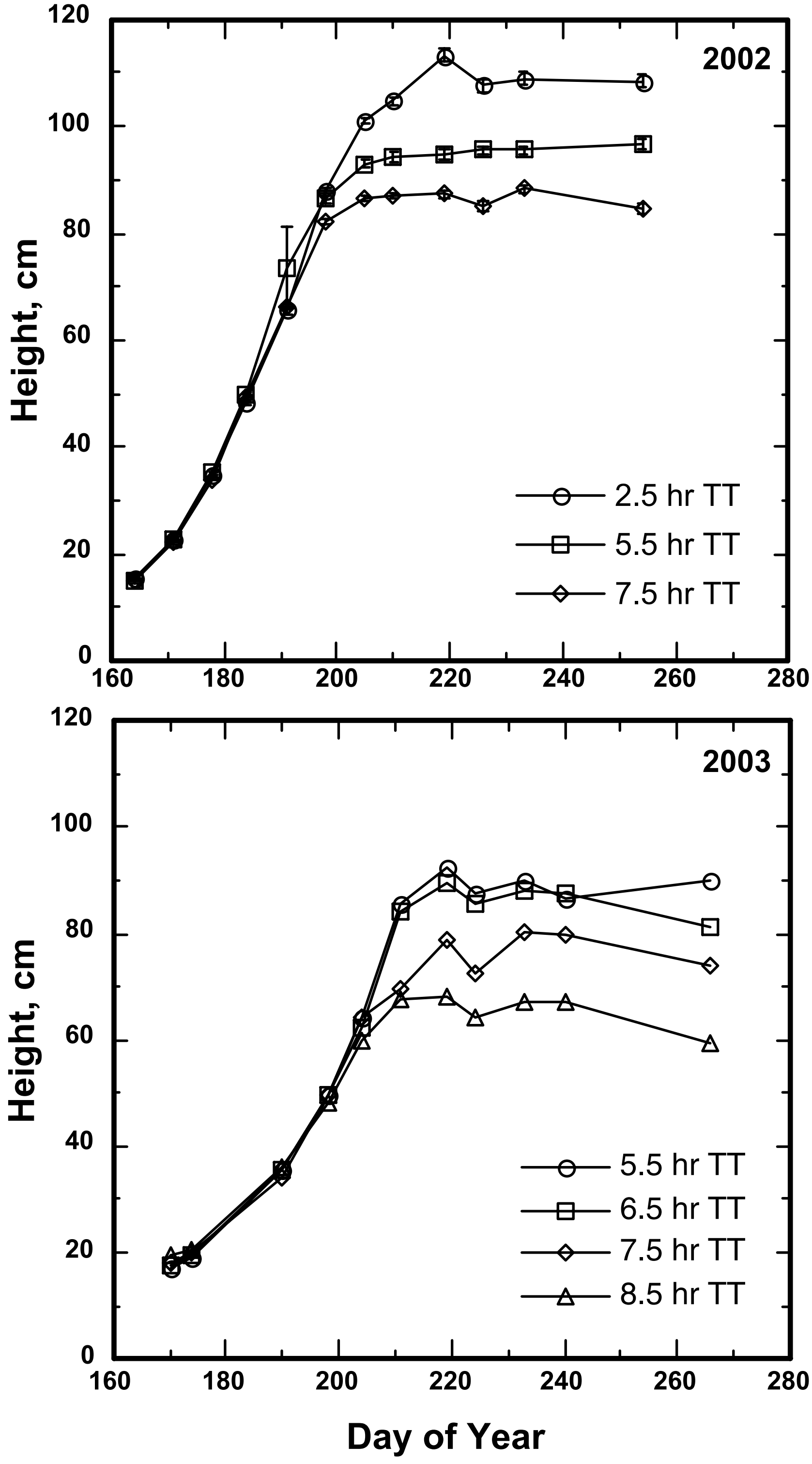

Figure 4. Comparison of plant heights for irrigation treatments in 2002 and 2003.

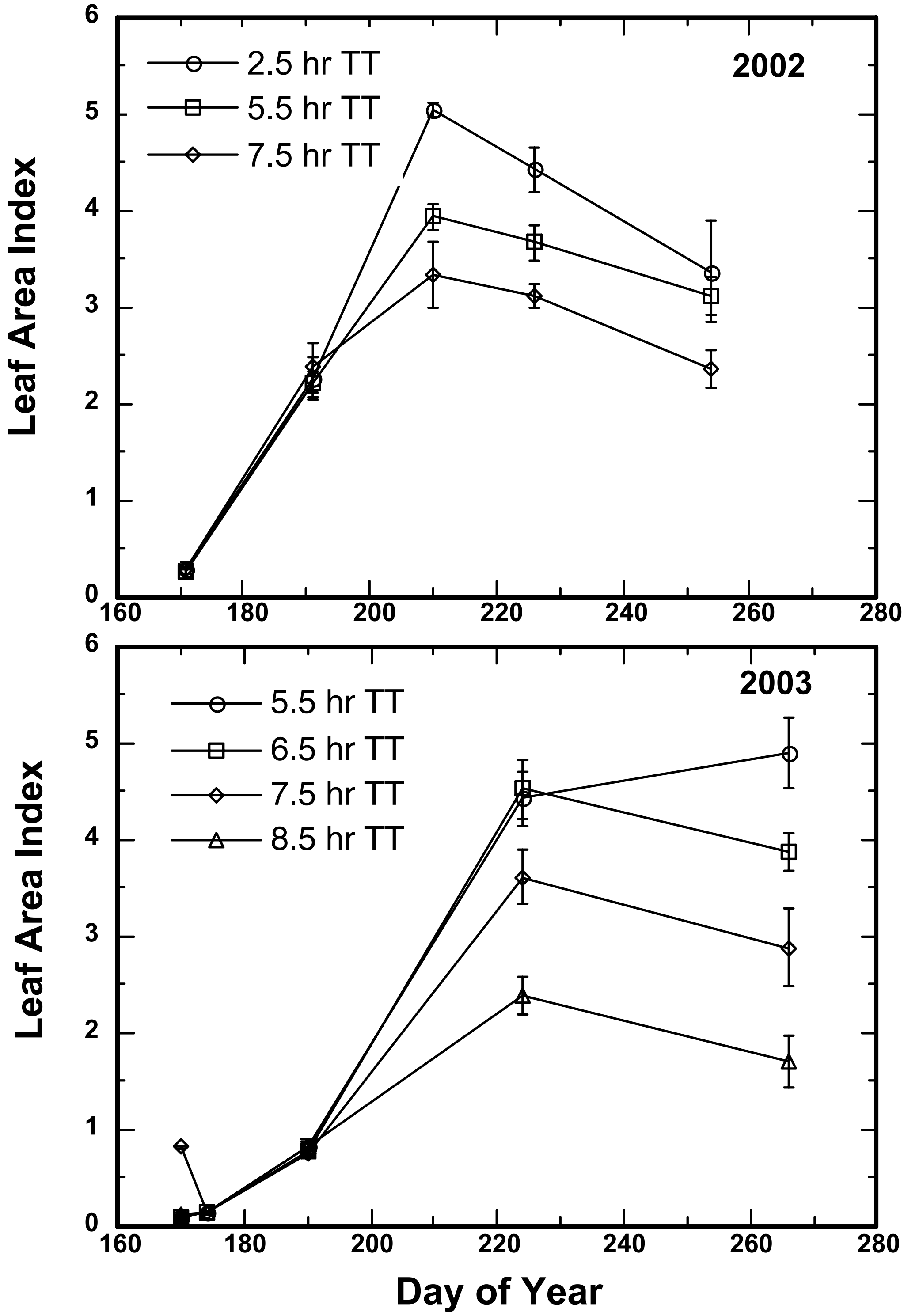

Figure 5. Comparison of leaf area index values during the growing season in 2002 and 2003.

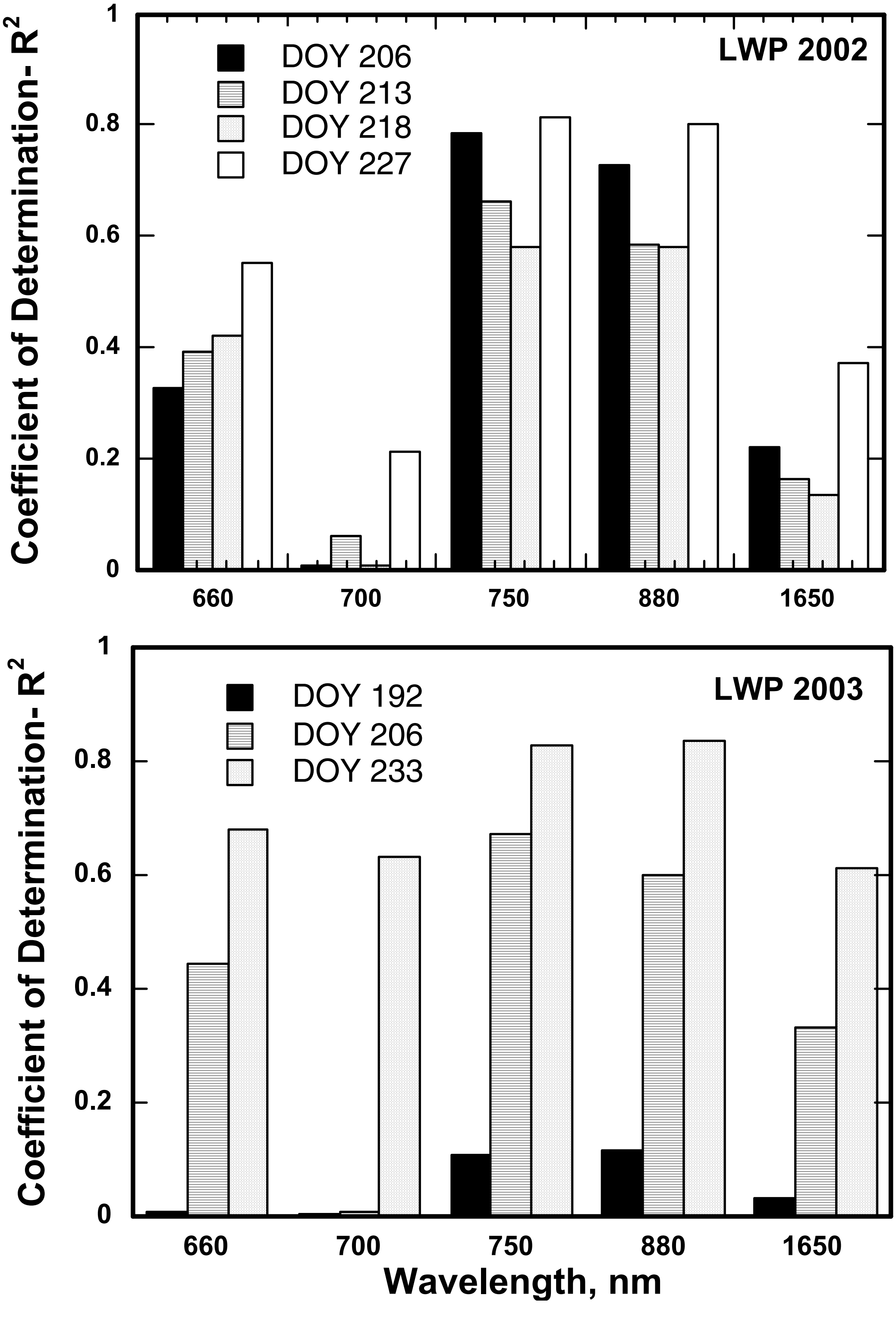

Figure 6. Correlation of spectral reflectance in multiple wavelengths with leaf water potential on selected dates during the growing season, 2002 and 2003.

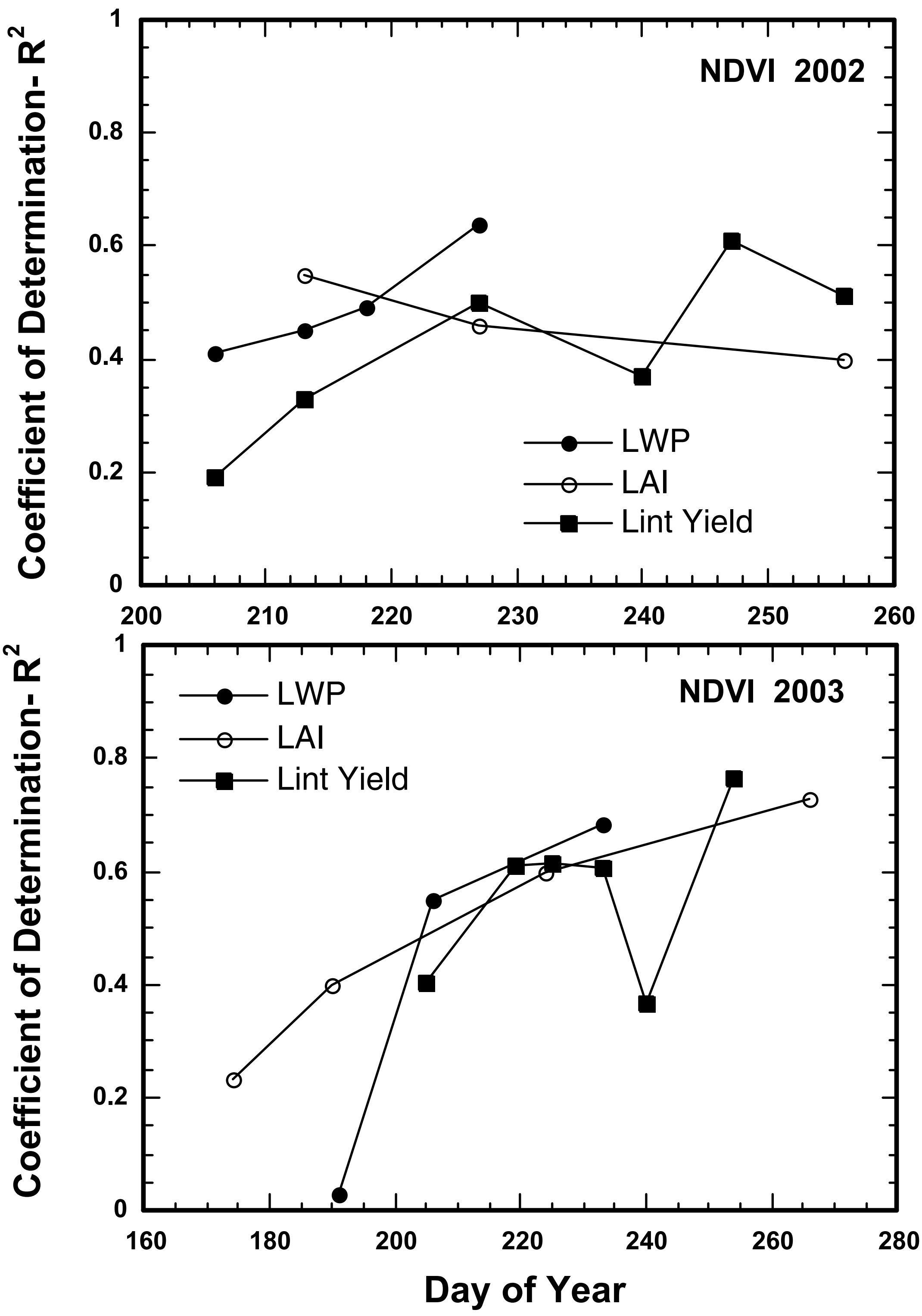

Figure 7. Correlation of NDVI (880,660) with leaf water potential (LWP), leaf area index (LAI), and lint yield, 2002 and 2003.

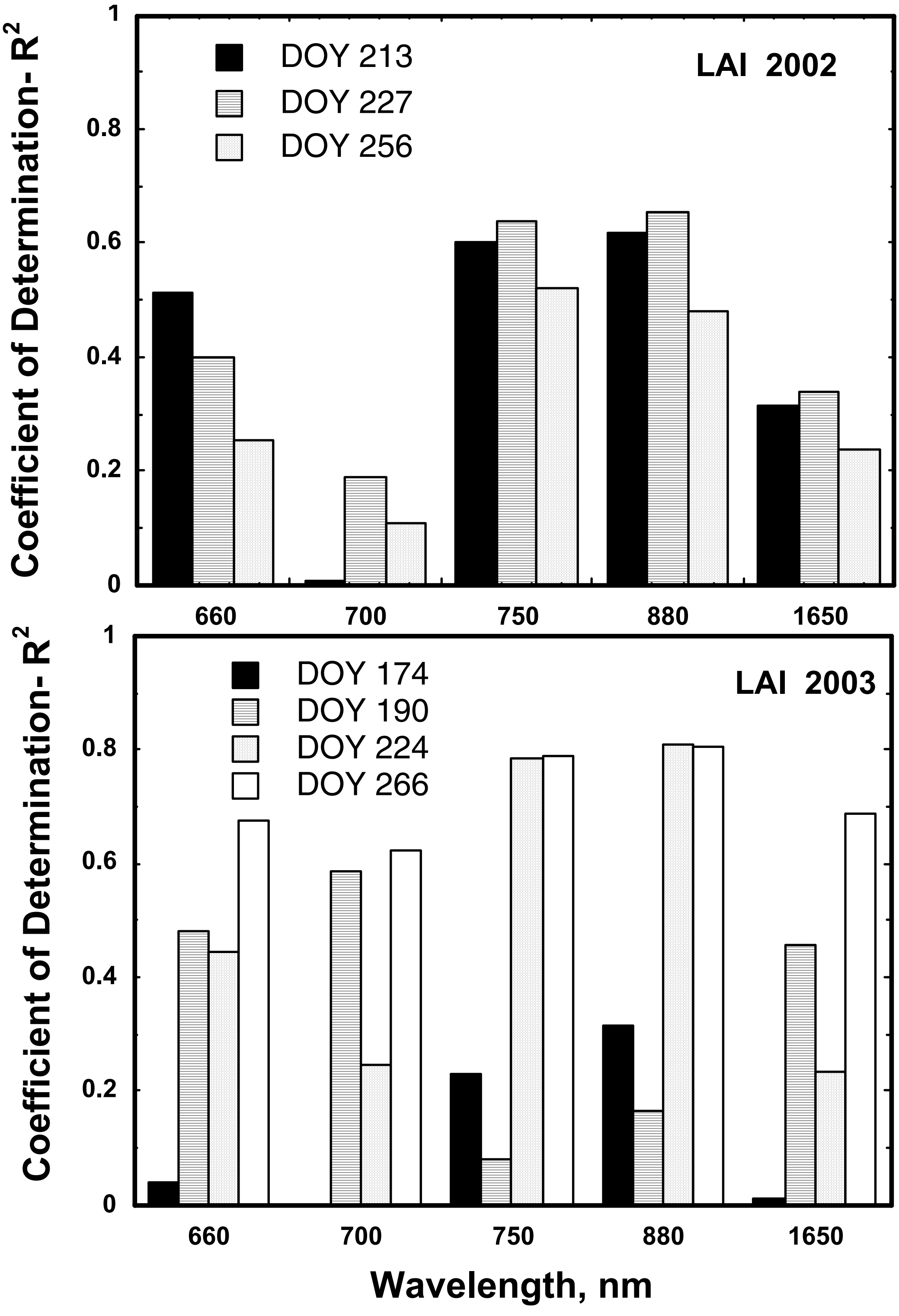

Figure 8. Correlation of spectral reflectance in multiple wavelengths with leaf area index (LAI) on selected dates during the growing season, 2002 and 2003.

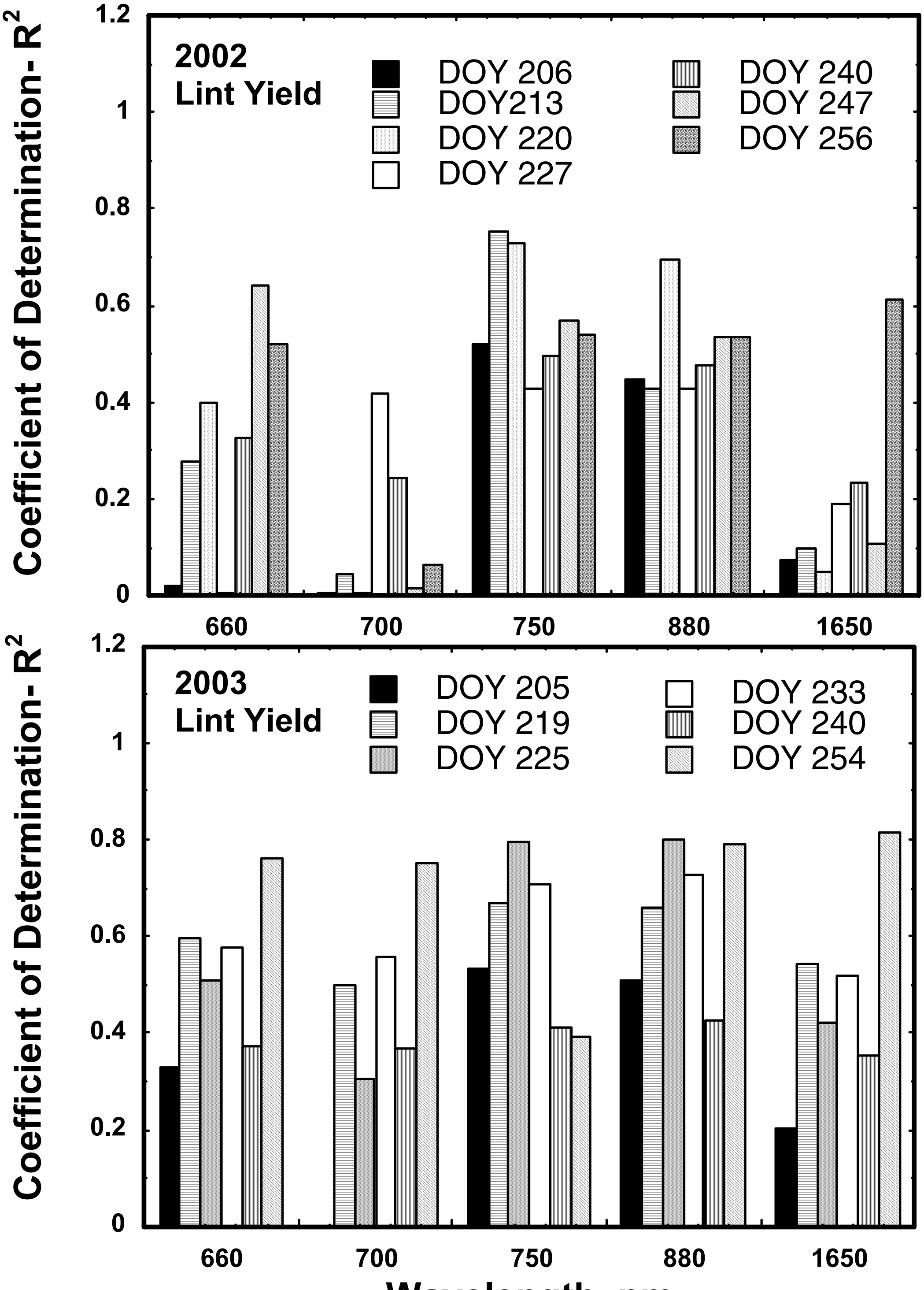

Figure 9. Correlation of spectral reflectance in multiple wavelengths with lint yield for selected dates during the growing season, 2002 and 2003.