Spectral Reflectance Patterns of Flooded Rice

*R. D. Martin, Jr.,** and *J. L. Heilman*
Soil and Crop Sciences Department, Texas A&M University, College Station, TX 77843

ABSTRACT: Research was conducted to evaluate the spectral response of rice (*Oryza sativa* L.) grown in small, conventional research plots with flooded soils, and to assess the feasibility of estimating leaf area index (LAI) of small rice plots using field remote sensing techniques. Spectral reflectance of several rice varieties with different morphological characteristics was measured at Thematic Mapper wavebands using a portable radiometer. The visible and near infrared response of rice growing in flooded soils was similar to that of other crops growing in dryland conditions. At middle infrared wavelengths, however, reflectance either increased with leaf area index or remained relatively unaffected by leaf area index in contrast to what has been found for other crops. Three spectral vegetation indices (ratio vegetation index, normalized difference, and greenness vegetation index) were highly correlated with measured leaf area index (LAI). The indices were insensitive to morphological differences among the varieties. Results of the research suggest that LAI of conventional rice research plots may be monitored using field spectral measurements.

INTRODUCTION

VARIETAL IMPROVEMENT and production management research in rice frequently involves hundreds of small research plots representing different varieties and growing conditions. Ideally, assessment of crop development and condition should involve the quantitative monitoring of a set of agronomic parameters on a repetitive basis throughout the growing season. Unfortunately, frequent quantitative measurements by conventional methods are difficult to obtain because of the large number of plots and restrictions imposed on destructive sampling. Instead, many researchers rely on final yield measurements or qualitative evaluations of growth as indicators of varietal performance. These practices do not provide adequate information regarding a variety's response and resilience to environmental or nutritional stress.

A rapid, non-destructive method of estimating factors such as leaf area index (LAI) would allow crop growth to be quantitatively evaluated on a repetitive basis. LAI is an important growth parameter because it provides information on the interception of photosynthetically active radiation and is an important component of evapotranspiration, crop growth, and yield models (Asrar *et al.*, 1985; Wiegand *et al.*, 1979).

It has been demonstrated that LAI for a number of crops growing in dryland conditions can be estimated using spectral reflectance measurements (Aase and Siddoway, 1980; Gardner, 1983; Heilman *et al.*, 1977; Kanemasu, 1974; Tucker, 1979). Most rice, however, is grown on flooded soils. Thus, the water background may significantly affect the spectral response of rice and the sensitivity of spectral vegetation indices to LAI.

We conducted a study to evaluate the spectral response of several varieties of rice in Thematic Mapper wavebands and to assess the feasibility of estimating LAI of rice from spectral measurements of conventional research plots.

*Presently with the Evapotranspiration Laboratory, Department of Agronomy, Kansas State University, Manhattan, KS 66506.

MATERIALS AND METHODS

The study was conducted during the months of May through August of 1982 and 1983 at the Beaumont Research and Extension Center Western Operations Site near Eagle Lake, Texas (29.7° N, 96.5° W) in the coastal plains region of Texas. Seven varieties of rice (*Oryza sativa* L.) with different canopy morphologies were selected for the investigation. In 1982, the varieties chosen were Brazos, L-201, Labelle, Nato, Starbonnet, and Bellemont. In 1983, Bellemont was replaced with the variety Lemont. Table 1 summarizes morphological characteristics of the rice varieties.

A completely randomized planting design consisting of 24 plots was used for both years. The 24 plots represented six varieties and four nitrogen levels (0, 55, 108, and 163 kg/ha). Each plot consisted of six rows (0.9 m long, 0.15-m row spacing) with a northeast-southwest orientation. In 1982, the plots were planted on 17 March at a seeding rate of 112 kg/ha on a Clodine loam (thermic Vertic Albaqualf). In 1983, the plots were planted on 6 April at a rate of 134 kg/ha on an Edna fine sandy loam (thermic Typic Ochraqualf).

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 52, No. 12, December 1986, pp. 1885–1890.

0099-1112/86/5212-1885$02.25/0

TABLE 1. QUALITATIVE DESCRIPTIONS OF THE MORPHOLOGICAL CHARACTERISTICS OF THE RICE VARIETIES USED IN THE INVESTIGATION.

Variety	Height	Leaf Inclination Angle	Flag Leaf Position	Leaf Area	Flag Leaf Inclination Angle
Bellemont	short	erect	tip above panicle	low	erect
Brazos	average	erect	tip above panicle	moderate	erect
L-201	short	erect	tip above panicle	moderate	erect
Labelle	average	erect	tip below panicle	moderate	horizontal
Lemont	short	erect	tip above panicle	moderate	erect
Nato	tall	horizontal	tip below panicle	high	horizontal
Starbonnet	average	erect	tip above panicle	high	erect

TABLE 2. SPECTRAL WAVEBANDS OF THE BARNES MODULAR MULTIBAND RADIOMETER (MMR).

Channel	Wavelength (μm)
MMR1	0.45 - 0.52
MMR2	0.52 - 0.60
MMR3	0.63 - 0.69
MMR4	0.76 - 0.90
MMR5	1.15 - 1.30
MMR6	1.55 - 1.75
MMR7	2.08 - 2.35
MMR8	10.40 - 12.50

Spectral radiances were measured in eight wavelength intervals (Table 2) with a 15° field-of-view Barnes modular multiband radiometer (MMR) positioned over the middle two rows of each plot at a height of 1.4 m above the crop. The thermal infrared band of the MMR was not used in the study. The MMR was attached to a boom mounted on the backhoe of a four-wheel drive tractor equipped with wedge-shaped metal wheels designed for use in flooded rice fields. The backhoe apparatus allowed the operator to hydraulically control the position of the radiometer.

Clear skies are a rare occurrence during the rice growing season in the coastal plains of Texas. Most radiometric measurements were made during partly cloudy conditions of 30 percent or less cloud cover. Cloud cover dictated the time and illumination angles at which the measurements were made. Most measurements occurred between 0930 and 1430 CST at solar zenith angles of 20 to 45°.

The spectral measurements were used to calculate a bidirectional reflectance factor, defined as

$$\mathrm{BRF}(\lambda) = [L_c(\lambda) - D(\lambda)]/[L_p(\lambda) - D(\lambda)]\ \rho_p(\lambda)$$

where BRF(λ) is the bidirectional reflectance factor at wavelength interval, λ, $L_c(\lambda)$ is sensor response voltage corresponding to the radiance of the crop, $L_p(\lambda)$ is the response voltage corresponding to the radiance of a barium sulfate reference panel, $D(\lambda)$ is the dark level voltage at (λ), and $\rho_p(\lambda)$ is the laboratory determined reflectance of the panel. Panel reflectances were corrected for solar zenith angle variations.

After each spectral measurement, the center of the field-of-view was marked with a flag. Following completion of all spectral measurements in a given day, plants within 0.3 by 0.3-m areas centered on the flags were removed at water level, stored on ice, and taken to the laboratory for leaf area measurements. Leaf areas were measured with an optically scanning leaf area meter.

The BRFs were used to calculate the vegetation indices listed in Table 3. Coefficients for the greenness vegetation index (GVI) were calculated from our data using the *n*-space procedure of Jackson (1983).

TABLE 3. SPECTRAL VEGETATION INDICES CALCULATED FROM BIDIRECTIONAL REFLECTANCE FACTOR (BRF) MEASUREMENTS OF RICE. THE COEFFICIENTS OF GVI WERE DEVELOPED FROM THE RICE SPECTRAL MEASUREMENTS USING THE *n*-SPACE PROCEDURE OF JACKSON (1983). THE NUMBERS FOLLOWING BRFS REFER TO THE MMR CHANNEL NUMBERS LISTED IN TABLE 1.

Vegetation Index	Equation
Ratio	RVI = BRF4/BRF3
Normalized Difference	ND = (BRF4-BRF3)/(BRF4+BRF3)
Greenness	GVI = − 0.3762×BRF1 − 0.4213×BRF2 − 0.6414×BRF3 + 0.3870×BRF4 + 0.3387×BRF6 + 0.0723×BRF7

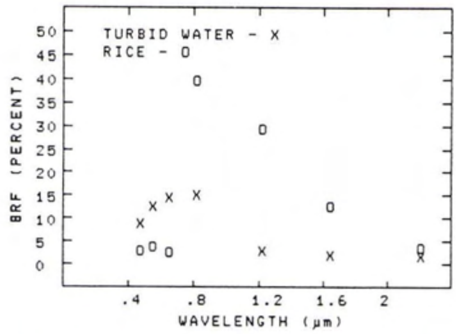

FIG. 1. Comparison of spectral reflectance of the rice variety Nato with that of the turbid water background.

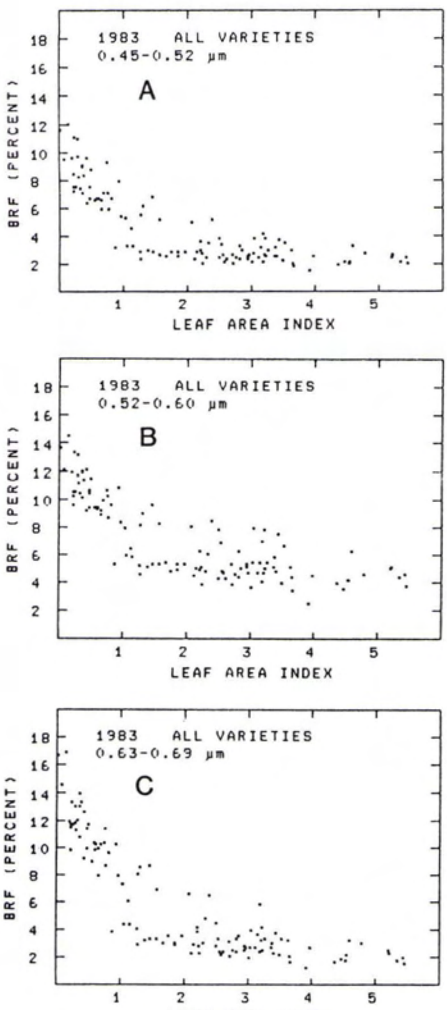

FIG. 2. Relationship between the bidirectional reflectance factor (BRF) and leaf area index at visible wavelengths 0.45 to 0.52 μm (A), 0.52 to 0.60 μm (B), and 0.63 to 0.69 μm (C) from the 1983 experiment.

The vegetation indices were statistically compared with observed values of LAI to develop LAI prediction equations.

RESULTS AND DISCUSSION

Unlike other grain crops, most rice grows in flooded soils. As a result, the background reflectance is determined by the reflectance characteristics of water, suspended sediments, and, if the water is shallow, the soil beneath the water. In our study, the tractor created a great deal of turbidity. Thus, the soil was seldom visible beneath the water even though the water was shallow (0.08 to 0.15 m).

Figure 1 compares the reflectance of the turbid water background with that of the rice variety Nato at full cover. Water reflectance increased with wavelength in MMR bands 1 to 4. Reflectances were low in bands 5 to 7. A minor water absorption band exists at 1.1 μm and strong absorption bands exist at 1.4, 1.9, and 2.7 μm. Hoffer (1978) reported that these bands influenced the spectral response in wavelengths between the absorption bands. The reflectance of the turbid water was higher than that of the rice in the visible wavebands and lower in the near and middle infrared. The peak reflectance of the water background was higher than that reported for turbid river water by Bartolucci *et al.* (1977), and it extended further into the infrared.

The seasonal reflectance patterns for rice were similar to those reported for other crops in the visible and near infrared regions of the spectrum (Kanemasu, 1974; Tucker, 1979). As shown in Figure 2, visible reflectances in MMR1 (0.45 to 0.52 μm), MMR2 (0.52 to 0.60 μm), and MMR3 (0.63 to 0.69 μm) decreased as leaf area index (LAI) increased and the rice covered the water.

Near infrared reflectance in MMR4 (0.76 to 0.90 μm) increased with LAI (Figure 3a) since the reflectance of rice at full cover was higher than that of the water. In MMR5 (1.15 to 1.30 μm), reflectance also increased with LAI (Figure 3b), unlike what Blad *et al.* (1983) found for corn growing on dry soil. In their case, the reflectance of corn and soil were similar. As a result, they found little change in the reflectance in MMR5 throughout the season. Under our conditions, the background reflectance was much lower than the reflectance of the vegetation. Thus, MMR5 was quite sensitive to LAI.

In MMR6 (1.55 to 1.75 μm), rice reflectance was higher than the water background reflectance, and reflectance increased as LAI increased (Figure 4a). MMR7 (2.08 to 2.35 μm) was insensitive to LAI (Figure 4b) due to similarities of rice and water reflectance in that waveband. For most dryland conditions, reflectance in the middle infrared decreases with canopy cover because vegetation usually has a lower reflectance than soil in the middle infrared (Gardner, 1983).

The spectral measurements shown in Figures 2 through 4 are from the 1983 growing season. The behavior of the 1982 measurements was similar, but

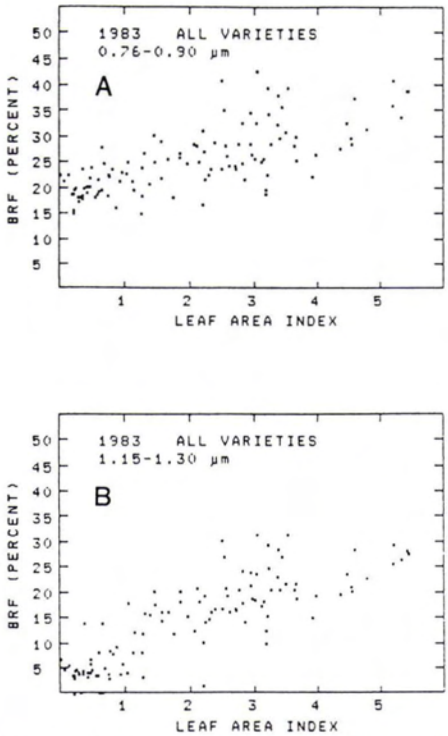

FIG. 3. Relationship between the bidirectional reflectance factor (BRF) and leaf area index at near-infrared wavelengths 0.76 to 0.90 μm (A), and 1.15 to 1.30 μm (B) from the 1983 experiment.

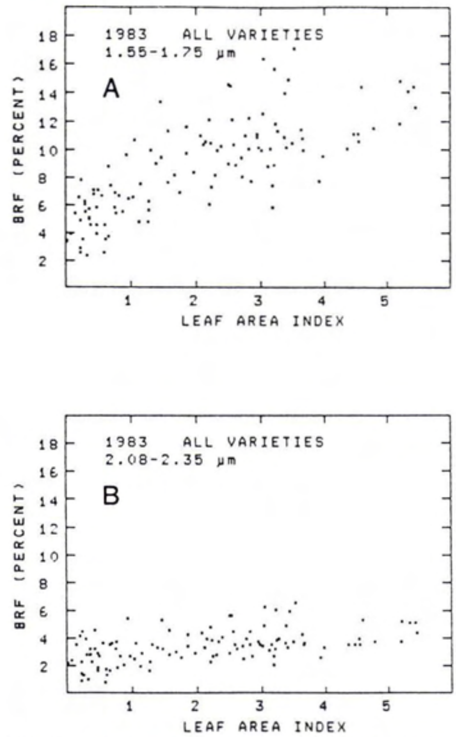

FIG. 4. Relationship between the bidirectional reflectance factor (BRF) and leaf area index at middle-infrared wavelengths 1.55 to 1.75 μm (A), and 2.05 to 2.35 μm (B) from the 1983 experiment.

TABLE 4. LEAF AREA INDEX (LAI) PREDICTION EQUATIONS, DEVELOPED FROM THE RATIO VEGETATION INDEX (RVI), AS A FUNCTION OF RICE VARIETY AND YEAR (1982 AND 1983). *Sy.x* IS THE STANDARD DEVIATION FROM REGRESSION.

Variety	LAI Prediction Equation	r^2	*Sy.x*
	1982		
Bellemont	LAI = 0.24*RVI − 0.12	0.87	0.43
Brazos	LAI = 0.31*RVI − 0.06	0.75	1.17
L-201	LAI = 0.28*RVI − 0.22	0.83	0.38
Labelle	LAI = 0.31*RVI − 0.28	0.78	0.58
Nato	LAI = 0.37*RVI − 0.32	0.69	1.07
Starbonnet	LAI = 0.21*RVI + 0.34	0.71	0.85
All varieties	LAI = 0.29*RVI − 0.10	0.73	0.88
	1983		
Lemont	LAI = 0.31*RVI − 0.12	0.77	0.69
Brazos	LAI = 0.32*RVI − 0.08	0.89	0.57
L-201	LAI = 0.30*RVI + 0.09	0.89	0.95
Labelle	LAI = 0.25*RVI + 0.38	0.73	0.63
Nato	LAI = 0.27*RVI + 0.26	0.93	0.51
Starbonnet	LAI = 0.31*RVI − 0.12	0.77	0.65
All varieties	LAI = 0.28*RVI + 0.16	0.85	0.58

the variability in the data was greater. Much of the variability was due to errors in locating the center of the field-of-view of the radiometer for collecting the plant samples. Because the sampling area and the sample size were small, errors in locating the center of the radiometer footprint were significant, especially in plots with high variability in LAI. The precision of the sampling improved with our experience.

The LAI prediction equations developed from the three vegetation indices are listed in Tables 4 through 6. LAI was linearly related to the RVI, and exponentially to the other indices. In the 1982 data, the RVI and ND produced the highest correlation with LAI

TABLE 5. LEAF AREA INFEX (LAI) PREDICTION EQUATIONS, DEVELOPED FROM THE NORMALIZED DIFFERENCE (ND), AS A FUNCTION OF RICE VARIETY AND YEAR (1982 AND 1983). *Sy.x* IS THE STANDARD DEVIATION FROM REGRESSION.

Variety	LAI Prediction Equation	r^2	*Sy.x*
	1982		
Bellemont	LAI = 0.03*exp(5.36*ND)	0.86	0.44
Brazos	LAI = 0.05*exp(5.15*ND)	0.75	1.44
L-201	LAI = 0.05*exp(4.64*ND)	0.79	0.42
Labelle	LAI = 0.04*exp(5.13*ND)	0.85	0.56
Nato	LAI = 0.09*exp(7.18*ND)	0.66	1.13
Starbonnet	LAI = 0.04*exp(5.19*ND)	0.69	0.78
All varieties	LAI = 0.03*exp(5.39*ND)	0.77	1.05
	1983		
Lemont	LAI = 0.18*exp(3.55*ND)	0.91	0.60
Brazos	LAI = 0.15*exp(3.75*ND)	0.94	0.65
L-201	LAI = 0.15*exp(3.70*ND)	0.96	0.41
Labelle	LAI = 0.19*exp(3.40*ND)	0.88	0.61
Nato	LAI = 0.13*exp(3.97*ND)	0.89	0.60
Starbonnet	LAI = 0.09*exp(4.25*ND)	0.85	0.63
All varieties	LAI = 0.14*exp(3.78*ND)	0.89	0.61

TABLE 6. LEAF AREA INDEX (LAI) PREDICTION EQUATIONS, DEVELOPED FROM THE GREENNESS VEGETATION INDEX (GVI), AS A FUNCTION OF RICE VARIETY AND YEAR. *Sy.x* IS THE STANDARD DEVIATION FROM REGRESSION. THE COEFFICIENTS OF GVI WERE DERIVED FROM THE RICE SPECTRAL MEASUREMENTS.

Variety	LAI Prediction Equation	r^2	*Sy.x*
	1982		
Bellemont	LAI = 0.06*exp(0.14*GVI)	0.70	0.54
Brazos	LAI = 0.17*exp(0.11*GVI)	0.64	1.31
L-201	LAI = 0.06*exp(0.15*GVI)	0.70	0.58
Labelle	LAI = 0.08*exp(0.13*GVI)	0.69	0.75
Nato	LAI = 0.23*exp(0.10*GVI)	0.34	1.62
Starbonnet	LAI = 0.05*exp(0.15*GVI)	0.70	0.74
All varieties	LAI = 0.09*exp(0.13*GVI)	0.64	1.07
	1983		
Lemont	LAI = 0.19*exp(0.12*GVI)	0.94	0.64
Brazos	LAI = 0.17*exp(0.13*GVI)	0.94	0.57
L-201	LAI = 0.18*exp(0.12*GVI)	0.94	0.62
Labelle	LAI = 0.24*exp(0.11*GVI)	0.82	0.75
Nato	LAI = 0.18*exp(0.12*GVI)	0.89	0.80
Starbonnet	LAI = 0.11*exp(0.14*GVI)	0.87	0.70
All varieties	LAI = 0.18*exp(0.12*GVI)	0.86	0.71

while, in 1983, the highest correlations were produced by ND and GVI. Correlations between the indices and LAI were higher for the 1983 data.

The indices were not sensitive to specific morphological characteristics of the varieties. Results in Tables 4 through 6 suggest that, for each index, a single equation may provide acceptable estimates of LAI for all varieties. The apparent lack of sensitivity to morphological differences among varieties is not surprising considering the wide range of illumination angles at which the measurements were made.

Based on these results, operational use of spectral measurements with the normalized difference has begun in Texas to monitor and evaluate the response of selected varieties to environmental factors and management practices. Hand-held radiometers containing the first four MMR wavelengths listed in Table 2 are being used.

ACKNOWLEDGMENTS

Research reported in this paper was funded by the Texas Rice Research Foundation. This paper was approved as technical article TA 21013 by the Texas Agricultural Experiment Station, College Station, Texas.

REFERENCES

Aase, J. K., and F. H. Siddoway, 1980. Determining winter wheat stand densities using spectral reflectance measurements. *Agronomy Journal*. 72:149–152.

Asrar, G., E. T. Kanemasu, and M. Yoshida, 1985. Estimates of leaf area index from spectral reflectance of wheat under different cultural practices and solar angle. *Remote Sensing of Environment*. 17:1–11.

Bartolucci, L. A., B. F. Robinson, and L. F. Siva, 1977. Field measurements of the spectral response of natural waters. *Photogrammetric Engineering and Remote Sensing*. 43:595–598.

Blad, B. L., J. M. Norman, and B. R. Gardner, 1983. *Field measurements, simulation modeling and development of analysis techniques for moisture stressed corn and soybeans*. CAMAC Progress Report 83-5, Center for Agricultural Meteorology and Climatology, University of Nebraska, Lincoln, NE. 187 p.

Gardner, B. R., 1983. *Techniques for remotely monitoring canopy development and estimating grain yield of moisture stressed corn*. CAMAC Progress Report 83-9, Center for Agricultural Meterology and Climatology, University of Nebraska, Lincoln, NE. 187 p.

Heilman, J. L., E. T. Kanemasu, J. O. Bagely, and W. L. Powers, 1977. Evaluating soil moisture and yield of winter wheat in the great plains using Landsat data. *Remote Sensing of Environment*. 6:315–326.

Hoffer, R. M., 1978. Biological and physical considerations in applying computer-aided analysis techniques to remote sensor data. In P. H. Swain and S. M. Davis (eds.) *Remote Sensing, the Quantitative Approach*. McGraw-Hill, Inc., New York. pp. 228–289.

Jackson, R. D., 1983. Spectral indices in n-space. *Remote Sensing of Environment*. 13:401–429.

Kanemasu, E. T., 1974. Seasonal canopy reflectance patterns of wheat, sorghum, and soybean. *Remote Sensing of Environment*. 3:43–47.

Tucker, C. J., 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*. 8:127–150.

Wiegand, C. L., A. J. Richardson, and E. T. Kanemasu, 1979. Leaf area index estimates for wheat from Landsat and their implications for evapotranspiration and crop modeling. *Agronomy Journal*. 7:336–342.

(Received 19 October 1985; revised and accepted 24 April 1986)