Canopy Reflectance Characteristics of Succulent and Nonsucculent Rangeland Plant Species

J. H. Everitt, A. J. Richardson, and *P. R. Nixon*
USDA Agricultural Research Service, Remote Sensing Research Unit, Weslaco, TX 78596

ABSTRACT: Spectroradiometric canopy light reflectance measurements of four succulent and eight nonsucculent rangeland plant species differing in canopy architecture were made in the visible (0.55- and 0.65-μm), near-infrared (0.85-μm), and mid-infrared (1.65- and 2.20-μm) spectral regions to determine if succulents could be distinguished from nonsucculents. Reflectance measurements were made in both June and September, 1984. Discriminant analysis using reflectance measurements in all wavelengths showed that succulent and nonsucculent rangeland plant species could be spectrally differentiated on both dates. Factor analysis of the September reflectance data showed that the three principal components of the total variation were partitioned among the visible (49 percent), the mid-infrared (29 percent), and the near-infrared (21 percent) wavelengths. Simple correlation analysis for both June and September showed that the visible, mid-infrared, and near-infrared wavelength regions were independent. Also, reflectance measurements in the mid-infrared wavelengths were found to be significantly correlated to plant water content. The 1.65 μm wavelength was better correlated to plant water content than was the 2.2 μm wavelength. These findings indicate that the visible, near-infrared, and mid-infrared spectral regions are independently important for differentiating between succulent and nonsucculent range plants.

INTRODUCTION

PAST RESEARCH has shown that water in plant leaves is a strong absorber of infrared radiation over the 1.35- to 2.5-μm mid-infrared water absorption region (Gates *et al.*, 1965; Knipling, 1970; Allen *et al.*, 1970; Thomas *et al.*, 1971; Woolley, 1971). Succulent plants have water-storage tissue developed in their leaf mesophyll (Fahn, 1967). Consequently, they have higher water content and absorb more radiation in the mid-infrared region than nonsucculent plants (Allen *et al.*, 1970; Gausman *et al.*, 1977; Gausman *et al.*, 1978).

Gausman *et al.* (1978) conducted a study on ten plant species (six succulent, four nonsucculent) and reported that the succulent species could be distinguished from the nonsucculent species based on spectral response in the 1.35- to 2.5-μm interval. Their results were based primarily on laboratory leaf spectra; however, field spectroradiometric plant canopy reflectance measurements were conducted on three of the species (one succulent, two nonsucculent) and these results substantiated the laboratory findings. Little other information is available on the spectral characteristics of succulent versus nonsucculent plant species.

Many succulent plant species occur in rangeland areas, particularly the arid and semi-arid rangelands of the southwestern United States where numerous species of cacti and other succulent halophytes (plants of salty or alkaline soils) are found (Correll and Johnston, 1970; Weniger, 1970). The lack of basic information on the canopy reflectance characteristics of succulent plant species and for rangeland species in general prompted further research in this area. Our objective was to characterize the canopy reflectance characteristics of 12 rangeland plant species (four succulent, eight nonsucculent) found on southwestern rangelands and to determine whether the succulent species could be distinguished from the nonsucculent species. This information would be beneficial to resource personnel using remote sensing imagery for mapping plant communities and identifying plant species of arid environments.

MATERIALS AND METHODS

We selected 12 plant species comprised of four succulents and eight nonsucculents commonly found in south and west Texas. The succulent species were tasajillo (*Opuntia leptocaulis*), strawberry cactus (*Echinocereus enneacanthus*), Texas varilla (*Varilla texana*), and guapilla (*Hechtia glomerata*). The four succulent species had gelatinous water-storage tissue in their leaves and/or stems (Fahn, 1967). Nonsucculent species included wax euphorbia (*Euphorbia antisyphilitica*), creosote bush (*Larrea tridentata*), coyotillo (*Karwinskia humboldtiana*), coma (*Bumelia celastrina*), Berlandier acacia (*Acacia berlandieri*), cenizo (*Leucophyllum frutescens*), allthorn (*Koeberlinia spinosa*), and threadleaf snakeweed (*Gutierrezia microcephala*). Tasajillo and strawberry cactus are abundant

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 52, No. 12, December 1986, pp. 1891–1897.

0099-1112/86/5212-1891$02.25/0

cactus species found on rangelands, whereas Texas varilla and guapilla are common succulent halophytes. Creosote bush, coyotillo, coma, berlandier acacia, cenizo, and allthorn are common shrub species found on rangelands. Wax euphorbia and threadleaf snakeweed are abundant subshrubs (partially woody).

Plant canopy reflectance measurements were made on the 12 species in early June and late September of 1984. Reflectance measurements of cresote bush and threadleaf snakeweed were made near Laredo, Texas. Measurements of coyotillo, strawberry cactus, Texas varilla, guapilla, and wax euphorbia were made near Roma, Texas, while measurements of coma, allthorn, and Berlandier acacia were made near Sullivan City, Texas. Cenizo and tasajillo measurements were made near Edinburg, Texas. The study areas had mostly sandy soil surfaces that varied in color from light brown to grayish brown. Reflected radiation of seven randomly selected plant canopies of each species were measured with an Exotech* Model 20 (Leamer *et al.*, 1973) spectroradiometer from 0.45- to 2.45-μm wavelength range. The sensor had a 15 degree field-of-view and was placed about 2 m above each of the plant canopies (0.2 m^2 view of canopy top). All measurements were made under dry ground surface conditions. Measurements taken in June were made between 1100 and 1300 and 1400 and 1500 hours. Measurements were not made between 1300 and 1400 hours because the sensor platform shadow was cast over the plant canopies. September measurements, however, were taken between 1100 and 1400 hours because there were no shadow problems. Reflectance data were studied at five wavelengths: 0.55, 0.65, 0.85, 1.65, and 2.20 μm, representing, respectively, the green light reflectance (0.50 to 0.60 μm) peak, red light reflectance (0.60 to 0.70 μm) chlorophyll absorption band, a point on the near-infrared plateau (0.70 to 1.35 μm), the 1.65-μm peak of the 1.55- to 1.75-μm mid-infrared water absorption region, and the 2.20-μm peak of the 2.10- to 2.35-μm mid-infrared water absorption region. To obtain percent reflectance from field spectral data, radiant energy is converted into an analog signal in the range of 1 to 5 volts for both incoming and reflected light. Percent reflectance is then calculated by ratioing the incoming and reflected light multiplied by percent transmission of a diffusing plate. Overhead photographs were taken of the various species to help interpret canopy reflectance data.

Water content was determined at the time of reflectance measurements by sampling one mature leaf or stem from each of ten randomly selected plants of each species. Stems were sampled from strawberry cactus, tasajillo, wax euphorbia, and allthorn because these species produce rudimentary leaves that are present for only a short period of time in spring and following rainfall or do not produce leaves at all. Leaves or stems were wrapped immediately in plastic wrap, stored on ice to minimize dehydration, and transferred to the laboratory for measurements. Water content was determined on an oven dry weight basis (68°C for 72 hours) and cooling in a desiccator before final weighing.

Canopy cover, plant height, and leaf or stem angle measurements were made on the 12 species in June 1985 at the same locations and on the same plant populations where canopy reflectance measurements were made in June and September 1984. Plant species were at approximately the same phenological stages in June 1985 as in June 1984. Percent canopy cover and plant height were taken on 15 randomly selected plants of each species. Canopy cover was determined by the line transect method (Canfield, 1941). Leaf or stem angle measurements were made on one leaf or stem from each of 20 randomly selected plants of each species. Leaves or stems were measured from the plane parallel to the horizon with a gravity protractor. Leaves of several species drooped downward or curved upward at approximately the middle of the leaf. Consequently, angle measurements were made separately from the petiole to mid-leaf and from mid-leaf to the leaf tip, and the two measurements were averaged to give a mean leaf angle for each leaf.

Simple correlation analysis as well as discriminant and factor analysis techniques were used to characterize water content, structure, and reflectance variables. Discriminant analysis was used to test separability between succulent and nonsucculent plant species. Factor analysis was used to characterize the principal components of variability in terms of the first two dominant original data variable eigenvector weighting factors (Dixon and Brown, 1979). Simple correlation matrices were developed to study the interaction among water content, structure, and reflectance measurements (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

Table 1 presents the means and standard deviations for plant water content and structure variables. Table 2 presents the reflectance data (means and standard deviations) for the four succulent and eight nonsucculent plant species. Tables 3 and 4 present the discriminant, factor, and correlation analysis results based on the data in Tables 1 and 2.

Discriminant analysis showed wax euphorbia was misclassified as a succulent plant based on plant water content (Table 3). The relatively high water content of wax euphorbia probably contributed greatly to its misclassification (Table 1). Otherwise, classification results based on water content were good. The June and September water content mea-

* Mention of company name or trademark is included for the reader's benefit and does not constitute endorsement of a particular product by the U. S. Department of Agriculture over others that may be commercially available.

TABLE 1. MEAN AND STANDARD DEVIATIONS FOR PLANT STRUCTURE VARIABLES AND WATER CONTENT.

Plant Species[a]	Structure[b]: Canopy Cover (%)	Height (cm)	Leaf or stem angle (degrees)	Water Content (%): June 1984	Sept. 1984
Strawberry cactus (S)	62 ± 12	18 ± 4	66 ± 12	87.7 ± 1.7	86.1 ± 1.6
Texas varilla (S)	78 ± 6	18 ± 5	64 ± 7	87.1 ± 1.1	85.7 ± 1.1
Guapilla (S)	89 ± 5	31 ± 8	8 ± 7	87.0 ± 1.3	84.3 ± 1.7
Tasajillo (S)	68 ± 7	105 ± 32	55 ± 23	85.6 ± 1.6	84.9 ± 0.4
Wax euphorbia (NS)	47 ± 10	47 ± 6	86 ± 3	72.2 ± 2.5	72.1 ± 1.7
Cenizo (NS)	75 ± 7	92 ± 20	36 ± 19	62.8 ± 2.9	65.8 ± 2.2
Coyotillo (NS)	84 ± 6	65 ± 14	10 ± 9	52.3 ± 0.8	64.6 ± 2.0
Threadleaf snakeweed (NS)	64 ± 7	50 ± 8	74 ± 5	51.7 ± 2.7	57.2 ± 4.3
Coma (NS)	59 ± 9	103 ± 24	44 ± 23	50.1 ± 1.5	52.4 ± 1.7
Creosote bush (NS)	58 ± 11	106 ± 27	37 ± 10	48.8 ± 2.9	48.3 ± 2.9
Berlandier acacia (NS)	86 ± 6	117 ± 22	6 ± 9	47.4 ± 2.7	51.4 ± 1.5
Allthorn (NS)	54 ± 10	105 ± 21	26 ± 29	42.0 ± 2.2	41.5 ± 2.9

[a] S = Succulent; NS = Nonsucculent.
[b] Plant structure data collected in June 1985.

surement transformation coefficients used to compute the two principal components of variation were equal. The first principal component explained 97 percent of the variation based on plant water content, indicating that water content in June and in September was highly correlated. As shown in Table 1, the measured water content changed very little.

A knowledge of vegetation geometry is needed to understand canopy reflectance among plants. Overhead views of the 12 species in both June and September 1984 showed that guapilla, Berlandier acacia, and coyotillo had fewer gaps in their canopies than did the other species. All three species had greater plant cover and lower leaf angles than did the other species. Conversely, wax euphorbia had more gaps in its canopy than did the other species. Wax euphorbia's more open canopy was attributed to its lower vegetative cover and higher stem elevation angle. Wax euphorbia and threadleaf snakeweed had primarily erectophile (high leaf or stem elevation angle) canopies and the other species had either planophile (horizontal leaves and/or stems) or intermediate (mixed) canopy structures (Allen *et al.*, 1975). Mean canopy cover, plant height, and leaf or stem angle measurements in June 1985 generally support the physical observations made on the plant species in 1984 (Table 1). However, discrimination analysis indicate that plant structure variables (Table 3) alone cannot be used to discriminate between succulent and nonsucculent plants.

Among plant structure variables, leaf angle and plant cover were the dominant eigenvector weighting factors in the first principal component that explained 58 percent of the total variation (Table 3). Height and cover were dominant for the second principal component that explained an additional 37 percent of the variation. Only two out of three possible principal components were needed to explain 95 percent of all variation based on plant structure measurements. Even though leaf or stem angle and plant cover were the most important plant structure measurements, it appears that all three measurements are important to plant structure characterization.

Plant reflectance in both June and September distinguished between succulent and nonsucculent plants with no classification errors (Table 3). However, the classification probabilities were less than 0.9 for both tasajillo and wax euphorbia. Their lower classification probabilities may be due to differences in soil background at the measurement locations.

In September, the visible wavelengths (0.55 and 0.65 μm) were the dominant eigenvector weighting factors of the first principal component that accounted for 49 percent of the total variation. The mid-infrared wavelengths (1.65 and 2.20 μm) were the dominant eigenvector weighting factors of the second principal component and accounted for 29 percent more of the total variation. Last, the near-infrared wavelength (0.85 μm) was the dominant eigenvector weighting factor of the third principal component, accounting for an additional 21 percent of the total variation. These three principal components (accounting for 99 percent of the total variance) can be attributed to the visible, mid-infrared, and near-infrared spectral regions.

The ordering of the eigenvector weighting factors was not as systematic in the June factor analysis as those in September, perhaps due to changes in phenology among the species between the two dates. For example, color varied from whitish (cenizo) and light green (guapilla and cresote bush) to darker green (coyotillo, berlandier acacia, allthorn, and wax euphorbia), and some species changed slightly in color between the two sampling dates. Several species exhibited new growth following rainfall and cooler temperature in September, while other species were in fruit. These phenological changes may have decreased the amount of exposed soil back-

TABLE 2. MEANS AND STANDARD DEVIATIONS OF MEASURED REFLECTANCE VALUES FOR TWELVE RANGELAND PLANT SPECIES.

	Reflectance (%) at given wavelength (μm)									
	June 1984					September 1984				
Plant Species[a]	0.55	0.65	0.85	1.65	2.20	0.55	0.65	0.85	1.65	2.20
Strawberry cactus (S)	6.5±0.4	7.2±0.4	19.5±0.9	11.2±1.2	7.8±1.2	6.0±0.7	6.3±0.8	18.1±1.9	10.9±1.4	8.8±1.1
Texas varilla (S)	7.1±0.3	5.4±0.3	27.4±1.7	11.2±0.4	7.1±0.7	8.0±0.5	5.7±0.5	31.4±1.3	10.6±0.8	5.9±0.8
Guapilla (S)	9.1±1.2	8.0±0.9	31.5±2.3	9.4±0.7	6.5±0.6	12.3±1.0	9.7±1.0	40.9±3.9	10.7±1.3	6.0±0.9
Tasajillo (S)	5.5±1.0	4.0±0.8	24.1±4.7	9.3±2.0	6.7±2.0	5.7±0.8	4.9±0.7	26.2±3.5	10.4±1.4	8.0±0.9
Wax euphorbia (NS)	2.7±0.4	2.2±0.2	17.9±2.1	6.9±0.9	5.5±1.0	2.9±0.6	2.9±0.5	11.5±2.2	8.7±2.0	8.6±2.4
Cenizo (NS)	8.8±0.4	7.1±0.4	29.1±1.2	18.3±1.0	12.1±1.6	9.5±1.4	8.9±1.8	25.4±3.8	22.1±2.6	17.3±3.6
Coyotillo (NS)	4.5±0.7	2.9±0.8	30.7±2.1	19.1±1.6	10.9±1.4	5.3±0.7	3.1±0.7	35.7±2.8	21.7±1.2	12.2±0.8
Threadleaf snakeweed (NS)	6.9±0.5	7.1±1.0	22.5±1.4	19.8±1.9	13.8±2.1	8.3±0.8	6.9±1.0	28.1±1.9	21.5±1.9	13.8±2.3
Coma (NS)	6.8±0.8	6.3±1.1	21.6±2.0	17.6±2.5	12.7±1.3	5.1±0.4	3.8±0.4	26.6±3.8	19.0±2.2	11.8±2.2
Creosote bush (NS)	8.1±0.9	8.7±1.1	22.2±0.6	22.2±1.2	17.5±1.7	8.9±0.8	10.1±1.1	24.9±1.0	24.9±4.2	23.2±1.8
Berlandier acacia (NS)	5.3±0.7	3.3±1.0	29.9±1.1	17.7±2.2	9.6±2.1	4.8±1.1	2.0±0.3	41.5±3.6	21.7±3.8	10.8±2.5
Allthorn (NS)	5.3±0.6	4.3±0.6	21.1±2.2	13.2±1.4	8.7±1.6	4.7±0.5	3.4±0.5	23.3±2.4	13.7±2.3	8.7±2.4

[a] S = Succulent; NS = Nonsucculent.

ground (Satterwhite and Henley, 1982; Miller *et al.*, 1984), and the decreasing solar elevation angle (Richardson *et al.*, 1975) may have increased the amount of plant shading between June and September.

Table 4 presents the correlation matrix of respective pair-wise relations among water content, cover, height, leaf or stem angle, and reflectance at 0.55, 0.65, 0.85, 1.65, and 2.20 μm for June and for September, 1984. Between date correlations were not done. Plant water content was found to be inversely correlated to the mid-infrared spectral reflectance wavelengths (1.65 and 2.20 μm) (Thomas *et al.*, 1971; Woolley, 1971). Water content was better correlated with reflectance at the 1.65-μm wavelength than at 2.20 μm in both June and September. Ripple *et al.* (1986) found that the water content of desert shrubs was better correlated with reflectance at the 2.20-μm wavelength than at 1.65 μm. Both studies show that the mid-infrared wavelengths are better correlated to water content of plants than either the visible or near-infrared wavelengths. Height was inversely correlated to plant water content; succulent plants tended to be shorter than nonsucculent plants. Reflectance in the visible wavelengths (0.55 and 0.65 μm) was not related to either plant water content or structure because spectral reflectance responds mainly to plant pigment in the visible spectral region (Myers *et al.*, 1983). Near-infrared reflectance (0.85 μm) was directly correlated to plant cover and inversely correlated to leaf or stem elevation angle (Wiegand *et al.*, 1974). These results indicate that near-infrared reflectance is higher for leaves or stems with low elevation angles (planophile) and lower for leaves or stems with high elevation angles (erectophile). These findings are in agreement with those of Everitt *et al.* (1984). Plant cover was found to be inversely correlated to leaf or stem elevation angle, indicating that cover tends to be higher for range plants with low elevation leaf angles (planophile) and lower for plants with high elevation leaf angles (erectophile). The two visible wavelengths (0.55 and 0.65 μm) and two mid-infrared wavelengths (1.65 and 2.20 μm) were directly related. Correlations among the visible, near-infrared, and mid-infrared spectral regions were not significant, indicating that information in each of these regions is different and independent of the other regions.

CONCLUSIONS

Discriminant analysis using field spectroradiometric canopy reflectance measurements at five wavelengths (0.55, 0.65, 0.85, 1.65, and 2.2 μm) showed that succulent and nonsucculent rangeland plant species could be spectrally differentiated. These results are in agreement with the leaf and canopy reflectance data reported for succulent and nonsucculent plant species by Gausman *et al.* (1978). Reflectance data for the two mid-infrared water ab-

TABLE 3. DISCRIMINANT AND FACTOR ANALYSIS OF FOUR SUCCULENT AND EIGHT NONSUCCULENT RANGELAND SPECIES BY PLANT WATER, WATER CONTENT, STRUCTURE, AND REFLECTANCE MEASUREMENTS.

DISCRIMINANT ANALYSIS

Plant Species[a]	Actual Class	Water Content Class	Water Content Prob	Structure[b] Class	Structure[b] Prob	Reflectance June Class	Reflectance June Prob	Reflectance September Class	Reflectance September Prob
Strawberry Cactus	S	S	0.99	S	0.80	S	0.99	S	1.00
Texas varilla	S	S	0.99	S	0.95	S	0.95	S	0.99
Guapilla	S	S	0.99	S	0.86	S	1.00	S	1.00
Tasajillo	S	S	0.99	NS	0.76	S	0.69	S	0.99
Wax euphorbia	NS	S	0.79	NS	0.60	NS	0.91	NS	1.00
Cenizo	NS	NS	0.99	NS	0.66	NS	0.91	NS	1.00
Coyotillo	NS	NS	1.00	S	0.57	NS	1.00	NS	1.00
Threadleaf snakeweed	NS	NS	1.00	S	0.69	NS	1.00	NS	1.00
Coma	NS	NS	1.00	NS	0.91	NS	1.00	NS	1.00
Creosote	NS	NS	1.00	NS	0.94	NS	1.00	NS	1.00
Berlandier acacia	NS	NS	1.00	NS	0.79	NS	1.00	NS	1.00
Allthorn	NS	NS	1.00	NS	0.97	NS	0.97	NS	.99

FACTOR ANALYSIS

Vectors[c]	%	TC	%	TC 1	TC 2	%	TC 1	TC 2	%	TC 1	TC 2
1	97	equal	58	Ang,	Cov	55	220,	65	49	65,	55
2	100	equal	95	Hgt,	Cov	79	85,	65	78	220,	165
3			100	Ang.	Cov	99	85,	65	99	85,	65
4						99	65,	55	99	165,	220
5						100	220,	165	100	65,	55

[a] S = Succulent; NS = Nonsucculent.

[b] See text for plant structure variables.

[c] For the columns in factor analysis section: % = percent of total variation associated with each eigen value - eigenvector pain; TC = (transformation coefficient) designates variable with largest element (weight) in given eigenvector; Ang = angle; Cov = cover; Hgt = height. For each factor analysis, the variables given are those in the columns under Discriminant Analysis. Wavelengths are given in micrometers.

TABLE 4. CORRELATION MATRIX OF PLANT AND SPECTRAL VARIABLES OBTAINED FROM TABLES 1 AND 2. THE TABLE IS SPLIT INTO UPPER AND LOWER SECTIONS ALONG THE DIAGONAL FOR THE JUNE AND SEPTEMBER RESULTS, RESPECTIVELY.

	Water Content	Cover	Height	Angle	0.55μm	0.65μm	0.85μm	1.65μm	2.20μm
							JUNE		
Water Content	----	0.20	−0.60*	0.36	0.15	0.11	0.06	−0.75**	−0.67*
Cover	0.30	----	−0.13	−0.66*	0.36	0.04	0.96**	0.12	−0.13
Height	−0.70*	−0.13	----	−0.42	−0.08	−0.16	0.02	0.47	0.44
Angle	0.32	−0.66**	−0.42	----	−0.25	−0.01	−0.73**	−0.34	−0.15
0.55	0.25	0.49	−0.27	−0.25	----	0.90**	0.38	0.31	0.40
0.65	0.21	0.13	−0.22	−0.01	0.86**	----	0.01	0.33	0.51
0.85	0.03	0.90**	0.10	−0.77**	0.35	0.06	----	0.21	−0.03
1.65	−0.69**	0.16	0.54	−0.40	0.27	0.25	0.27	----	0.94**
2.20	−0.56**	−0.19	0.47	−0.10	0.32	0.43	−0.06	0.88**	----
		SEPTEMBER							

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.

sorption wavelengths (1.65 and 2.20 μm) were significantly correlated to plant water content with correlation at 1.65 μm better than at 2.20 μm. Our findings are in general agreement with those of Tucker (1980), who reported that the 1.55- to 1.75-μm region was the best-suited wavelength for monitoring plant canopy water status.

ACKNOWLEDGMENTS

The authors thank Mario Alaniz and David Escobar for their assistance in the field. Thanks are also extended to Dan Butler, Richard Butler, Raul Tijerina, and Felix Vera for allowing us to conduct this research on their ranches.

REFERENCES

Allen, L. H., Jr., H. W. Gausman, and W. A. Allen, 1975. Solar ultraviolet radiation in terrestrial plant communities. *J. Envir. Qual.* 4:285–294.

Allen, W. A., H. W. Gausman, A. J. Richardson, and C. L. Wiegand, 1970. Mean effective optical constants of thirteen kinds of plant leaves. *Appl. Opt.* 9:2573–2577.

Canfield, R. H., 1941. Application of the line interception method in range vegetation. *J. Forest.* 39:388–394.

Correll, D. S., and M. C Johnston, 1970. *Manual of the vascular plants of Texas.* Tex. Res. Found., Renner, Texas. 1881 p.

Dixon, W. J., and M. B. Brown (Eds), 1979. *BMDP Biomedical computer programs, P-series.* University of California Press, Berkeley, CA. 880 p.

Everitt, J. H., S. J. Ingle, H. W. Gausman, and H. S. Mayeux, Jr., 1984. Detection of false broomweed (*Ericameria austrotexana*) by aerial photography. *Weed Sci.* 32:621–624.

Fahn, A., 1967. *Plant anatomy.* Pergamon Press, New York, NY. 534 p.

Gausman, H. W., D. E. Escobar, and E. B. Knipling, 1977. Anomalous leaf reflectance and leaf anatomy of *Peperomia obtusifolia. Photogrammetric Engineering and Remote Sensing* 43:1183–1185.

Gausman, H. W., D. E. Escobar, J. H. Everitt, A. J. Richardson, and R. R. Rodriguez, 1978. Distinguishing succulent plants from crop and woody plants. *Photogrammetric Engineering and Remote Sensing* 4:487–491.

Gates, D. M., H. J. Keegan, J. C. Schleter, and V. P. Weidner, 1965. Spectral properties of plants. *Appl. Opt.* 4:11–20.

Knipling, E. B., 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. *Remote Sens. Envir.* 1:155–159.

Leamer, R. W., V. I. Myers, and L. F. Silva, 1973. A spectroradiometer for field use. *Rev. Sci. Instru.* 44:611–614.

Miller, G. P., M. Fuchs, M. J. Hall, G. Asrar, E. T. Kanemasu, and D. E. Johnson, 1984. Analysis of seasonal multispectral reflectances of small grains. *Remote Sensing of Environment* 14:153–167.

Myers, V. I., M. E. Bauer, H. W. Gausman, W. G. Hart, J. L. Heilman, R. B. McDonald, A. B. Park, R. A. Ryerson, T. J. Schmugge, and F. C. Westin, 1983. Remote sensing applications in agriculture. *Manual of Remote Sensing,* American Society Photogrammetry, Falls Church, Va. pp. 2111–2228.

Pinter, P. J., R. D. Jackson, C. E. Ezra, and H. W. Gausman, 1985. Sun angle and canopy architecture effects on the spectral reflectance of six wheat cultivars. *Int. J. Remote Sens.* 6:1813–1825.

Richardson, A. J., C. L. Wiegand, H. W. Gausman, and J. A. Cuellar, 1975. Plant, soil, and shadow reflectance components of row crops. *Photogrammetric Engineering and Remote Sensing* 41:1401–1407.

Ripple, W. J., B. J. Schrumpf, and D. L. Isaacson, 1986. The influence of observational interdependence on spectral reflectance relationships with plant and soil variables. *Int. J. Remote Sensing* 70:291–294.

Satterwhite, M. B., and P. Henley, 1982. Effects of ground cover and leaf area on the spectral reflectance of vegetation-soil targets. *Technical papers, American Society Photogrammetry Fall Meeting,* Hollywood, Fla., 19–23 September 1982. pp. 352–361.

Steel, R. G. D., and J. H. Torrie, 1960. *Principles and Procedures of Statistics.* McGraw-Hill Book Co., Inc., New York. 481 p.

Thomas, J. R., L. N. Namken, G. F. Oerther, and R. G. Brown, 1971. Estimating leaf water content by reflectance measurements. *Agron. J.* 63:845–847.

Tucker, C. J., 1980. Remote sensing of leaf water content in the near infrared. *Remote Sens. Envir.* 10:23–32.

Weniger, D., 1970. *Cacti of the Southwest*. Univ. of Texas Press, Austin, Texas. 249 p.

Wiegand, C. L., H. W. Gausman, J. A. Cuellar, A. H. Gerbermann, and A. J. Richardson, 1974. Vegetation density deduced from ERTS-1 MSS response. *Proc. 3rd Earth Resources Technolgical Satellite-1 Symp.*, Vol. 1, Section A, NASA SP-351.

Woolley, J. T., 1971. Reflectance and transmittance of light by leaves. *Plant Physiol.* 47:656–662.

(Received 4 November 1985; revised and accepted 30 May 1986)

Forthcoming Articles

William G. Cibula and *Maurice O. Nyquist*, Use of Topographic and Climatological Models in a Geographical Data Base to Improve Landsat MSS Classification for Olympic National Park.

P.J. Curran and *H. D. Williamson*, GLAI Estimation Using Measurementes of Red, Near Infrared, and Middle Infrared Radiance.

Philip A. Davis, Graydon L. Berlin, and *Pat S. Chavez, Jr.*, Discrimination of Altered Basaltic Rocks in the Southwestern United States by Analysis of Landsat Thematic Mapper Data.

Stephen D; DeGloria and *Andrew S. Benson*, Interpretability of Advanced SPOT Film Procucts for Forest and Agricultural Survey.

Steven E. Franklin, Terrain Analysis from Digital Patterns in Geomorphometry and Landsat MSS Spectral Response.

D.M. Gerten and *M. V. Wiese*, Microcomputer-Assisted Video Image Analysis of Lodging in Winter Wheat.

Kurt Kubik, Dean Merchant, and *Toni Schenk*, Robust Estimation in Photogrammetry.

Yukio Mukai, Toshiro Sugimura, Hiroshi Watanabe, and *Kuniyasu Wakamori*, Extraction of Areas Infested by Pine Bark Beetle Using Landsat MSS Data.

Anders Ostman, Accuracy Estimation of Digital Elevation Data Banks.

Steven A. Sader, Forest Biomass, Canopy Structure, and Species Composition Relationships with Multipolarization L-Band Synthetic Aperture Radar Data.

Horst H. Schöler, An FMC-Equipped Aerial Mapping Camera.

Charles T. Scott, Hans T. Schreuder, and *Douglas M. Griffith*, A Comparison of Optical Bar, High-Altitude, and Black-and-White Photography in Land Classification.

S. A. Veress and *Huang Youcai*, Application of Robust Estimation in Close-Range Photogrammetry.

Manfred Weisensee and *Bernhard Wrobel*, The Identification of Homologous Image Points by Multiple Stereoscopic Comparison.

V. L. Williams, W. R. Philipson, and *W. D. Philpot*, Identifying Vegetable Crops with Landsat Thematic Mapper Data.

Errata

In the Errata on page 832 of the June 1986 issue of *PE&RS*, which were meant to correct errors in the September 1985 issue, a further error was found. On page 1413 of the article by Malaret *et al.* (Sept. 1985 issue) Equation 6 should read

$$W_{\overline{SR}} = \Sigma_i \left[\left(\int_{\lambda_L + i\Delta\lambda}^{\lambda_L + (i+1)\Delta\lambda} 2hc^2\lambda^{-5} \; (e^{hc/\lambda kT} - 1)^{-1} d\lambda \right)_{\overline{SR}_i} \right]$$

The miniature "cover photo" on the table of contents page of the September 1986 issue of *PE&RS* was inadvertently "mirrored" right to left.