Canopy Reflectance of Seven Rangeland Plant Species with Variable Leaf Pubescence

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ABSTRACT: Spectroradiometric canopy light reflectance measurements of seven rangeland weed species with variable leaf pubescence characteristics were made at six wavelengths: 0.45, 0.55, 0.65, 0.85, 1.65, and 2.20 μm. The weeds consisted of three species with dense leaf pubescence, two species with sparse pubescence, and two nonpubescent species. Field (biological) measurements were related to spectral measurements of the plant species. Discriminant and factor analysis results showed that increased reflectance in the visible (0.45-, 0.55-, and 0.65-μm) wavelengths distinguished dense from sparse and nonpubescent species. Generally, water content and plant height were the most important field variable effects for distinguishing nonpubescent from sparsely and densely pubescent species. Correlation analysis showed that water content was related to reflectance at 0.65, 0.85, 1.65, and 2.20 μm. Canopy cover was related to reflectance at 0.45, 0.55, and 0.85μm. Although field measurements showed that densely and sparsely pubescent species had similar water content and plant heights, spectrally they were different. These results indicate the potential of using remote sensing to distinguish densely pubescent from sparsely and nonpubescent plant species.

INTRODUCTION

MANY RESEARCHERS have reported that leaf pubescence (hairiness) affects both visible (0.45- to 0.75-μm) and infrared light (0.75- to 2.45-μm) reflectance (Billings and Morris, 1951; Gates and Tantraporn, 1952; Pearman, 1966; Gausman and Cardenas, 1969; Gausman *et al.*, 1977; Szwarcbaum, 1982; Everitt *et al.*, 1984). It is generally agreed that pubescent leaves reflect more visible light than glabrous (nonhairy) leaves because hairs increase scattering of incident radiation, and leaves with white hairs have higher visible reflectance than leaves with purple hairs (Gausman and Cardenas, 1969; Gausman *et al.*, 1977). Conversely, near-infrared light (0.75 to 1.35 μm) may be trapped by hairs (Gausman and Cardenas, 1969). The majority of these studies have been conducted on single leaf spectra measured in the laboratory.

Gausman *et al.* (1977) and Everitt *et al.* (1984) made spectroradiometric plant canopy reflectance measurements on pubescent and glabrous plant species in the field. They reported that pubescent plant species had higher visible reflectance than glabrous species and could be distinguished on aerial photos, but this research involved only two pubescent plant species. Little other information is available on the canopy reflectance characteristics of pubescent plant species in the field.

Many pubescent plant species occur on rangelands, often in the same plant community. The lack of basic information on the canopy reflectance of pubescent plant species in the field prompted further research on this subject. The objective of this study was to use plant canopy reflectance to distinguish among seven rangeland weed species with various amounts of leaf pubescence (densely pubescent to glabrous) and relate these to field measurements of the species. This information would be useful to personnel involved in using remote sensing imagery for mapping plant communities and identifying plant species of rangeland environments.

METHODS AND MATERIALS

Seven weed species consisting of three with dense leaf pubescence, two with sparse pubescence, and two with glabrous leaves were selected for study. The densely pubescent species were Cory croton (*Croton coryi* Croizat), woolly stemodia [*Stemodia tomentosa* (Mill.) Greenm. & Thomps], and silverleaf sunflower (*Helianthus argophyllus* T. & G.). The sparsely pubescent species included copperleaf (*Acalyphya radians* Torr.) and bullnettle [*Cnidoscolus texanus* (Muell. Arg.) Small], while the nonpubescent species were prairie coneflower [*Ratibida columnaris* (Sims) D. Don] and cowpen daisy [*Verbesina enceloides* (Cav.) Gray]. The species typically occur together in sandy and sandy loam soil rangeland areas of southern Texas.

This study was conducted in a rangeland area near Rachal, Texas, in June and July 1985. The study area was comprised of deep sandy soils of the Nueces series (loamy, mixed, hyperthermic Aquic Arenic Paleustalfs, 10 YR 6/2). Plant canopy reflectance measurements were made on six randomly selected canopies of each species with an Exotech Model 20 spectroradiometer at 0.05-μm increments over the 0.45- to 2.45-μm wavelength range (Leamer *et al.*, 1973). The sensor had a 15° field-of-view and was placed about 1.5 m above each of the plant canopies. All measurements were made under dry ground surface conditions. Measurements were made between 1100 and 1300 hours CDT under clear conditions. Reflectance data were studied at six wavelengths: 0.45, 0.55, 0.65, 0.85, 1.65, and 2.20 μm, representing, respectively, the blue light reflectance (0.40- to 0.50-μm) chlorophyll absorption band, 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 (0.75 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 light was converted into an analog signal in the range of 1 to 5 volts for both incoming and reflected light. Percent reflectance was then calculated by ratioing the reflected and incoming light multiplied by the percent transmission of a diffusing plate.

Reflectance measurements were also made on soil from the study area. Six soil samples were collected at random from the surface 10 cm, transported to the laboratory, air dried, and passed through a sieve screen (2 cm) to remove clods. Reflectance measurements were made on soil placed in a square (45-cm by 45-cm wide, by 2.5-cm deep) in the center of a black background (1 m by 2 m). The square was filled to overflowing with soil, and excess soil was removed by a straight edge. Measurements were made according to the procedures used for the plant canopies, and the same wavelengths were studied.

Water content and chlorophyll concentration of leaves were determined of each species at the time of reflectance measurements. Water content was determined by collecting a composite of two mature leaves from each of the randomly selected plants of each species. For chlorophyll, leaf sample composites (five leaves) were collected from each of the same plants from which leaves were sampled for water content. Leaves were enclosed immediately in air-tight plastic bags, stored on ice to minimize dehydration, and transferred to the laboratory within two hours for measurements. Water content was determined on an oven

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dry weight basis (68°C for 72 hours). Total chlorophyll was determined by a routine method (Horwitz, 1965).

Canopy cover and plant height were determined for each plant canopy to help interpret reflectance measurements. Canopy cover was determined by the line transect method (Canfield, 1941).

Discriminant and factor analysis techniques as well as simple correlation analysis were used to characterize water content, chlorophyll concentration, structure, and reflectance variables. Discriminant analysis was used to test separability among densely pubescent, sparsely pubescent, and nonpubescent plant species. Factor analysis was used to characterize the prinicipal 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, chlorophyll concentrations, structure, and reflectance variables (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

The seven plant species varied greatly in foliage coloration. Foliage color ranged from the whitish Cory croton and woolly stemodia plants to the darker green cowpen daisy and copperleaf plants. The contrasting differences in color among the plants were primarily attributed to differences in leaf pubescence. Figure 1 shows leaves of the seven species. Cory croton, woolly stemodia, and silverleaf sunflower (Figures 1A, 1B, and 1C, respectively) were densely pubescent. Cory croton leaves were covered with shaggily whitish-stellate (star-shaped)-tomentose (matted and woolly) pubescence, while those of woolly stemodia were covered with white, woolly-lanose (long entangled) pubescence (Correll and Johnston, 1970). Leaves of silverleaf sunflower were covered with densely white-tomentose hairs (Correll and Johnston, 1970; Gausman *et al.*, 1977). The leaves of copperleaf and bullnettle (Figures 1D and 1E, respectively) had a moderate to sparse cover of white hairs. Copperleaf had short stiff and long spreading hairs while those on bullnettle were short stiff and rigid (Correll and Johnston, 1970). The leaves of prairie coneflower and cowpen daisy (Figures 1F and 1G, respectively) were nonpubescent.

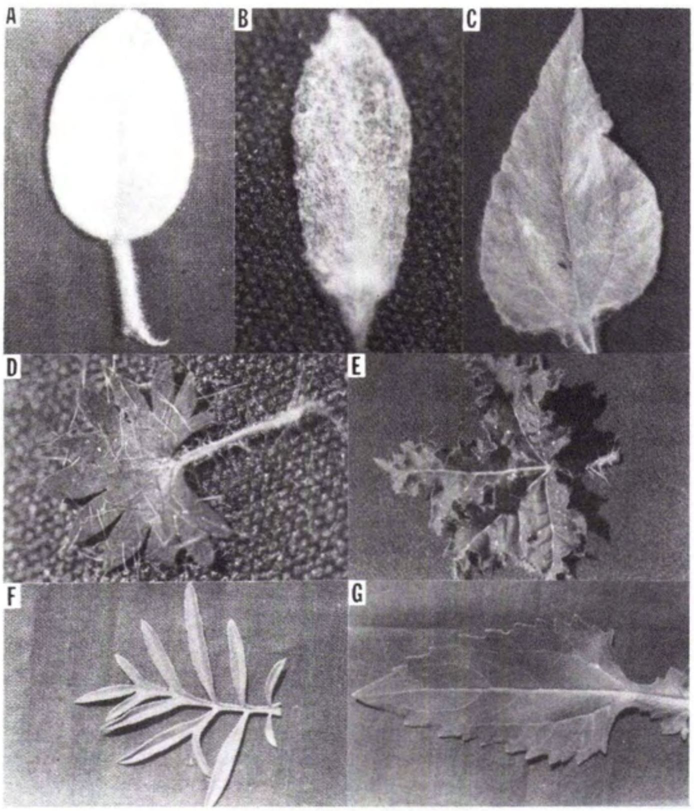

FIG. 1. Photographs of leaves of Cory croton (A), woolly stemodia (B), silverleaf sunflower (C), copperleaf (D), bullnettle (E), prairie coneflower (F), and cowpen daisy (G).

TABLE 1. MEAN AND STANDARD DEVIATIONS FOR CHLOROPHYLL CONCENTRATION, WATER CONTENT, AND STRUCTURE VARIABLES FOR SEVEN RANGELAND PLANT SPECIES WITH VARIABLE LEAF PUBESCENCE.

Plant Species	Leaf Chlorophyll (mg/g)	Leaf Water Content (%)	Structure: Canopy Cover (%)	Structure: Height (cm)
Densely Pubescent				
Cory Croton	2.1 ± 0.2	68 ± 1.8	81 ± 2.4	61 ± 12.4
Silver Sunflower	2.1 ± 0.2	78 ± 1.0	90 ± 4.4	101 ± 19.2
Woolly Stemodia	1.3 ± 0.2	65 ± 1.2	87 ± 3.3	14 ± 2.3
Sparsely Pubescent				
Bullnettle	2.4 ± 0.3	78 ± 1.5	84 ± 3.5	50 ± 14.6
Copperleaf	1.9 ± 0.4	62 ± 1.8	76 ± 4.4	17 ± 4.0
Nonpubescent				
Cowpen Daisy	1.8 ± 0.2	77 ± 1.3	80 ± 3.3	92 ± 12.0
Prairie Coneflower	1.7 ± 0.1	76 ± 1.8	75 ± 4.2	62 ± 10.5

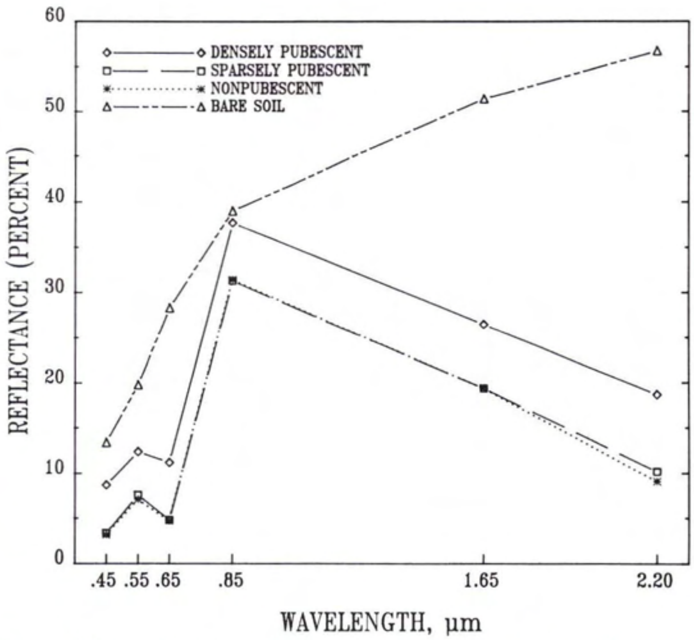

FIG. 2. Mean reflectance values for nonpubescent, sparsely pubescent, and densely pubescent plant species, and for sandy soil, at six wavelengths (0.45, 0.55, 0.65, 0.85, 1.65, and 2.20 μm).

Plant species height and canopy cover are given in Table 1. Woolly stemodia and copperleaf are low growing herbs with a prostrate growth form, while the other species have upright growth forms. All the species had essentially planophile (horizontal leaf) canopy structures and ranged in cover from 75 percent for prairie coneflower to 90 percent for silverleaf sunflower. Leaf water content and chlorophyll concentrations are also given for the seven species (Table 1).

Figure 2 shows the mean reflectances at the six wavelengths for the nonpubescent, sparsely pubescent, and densely pubescent plant species, and for sandy soil from the study area. These results indicate that the soil was highly reflective at all wavelengths. It has been shown that exposed soil background can contribute to plant canopy reflectance measurements (Satterwhite and Henley, 1982; Miller *et al.*, 1984; Huete *et al.*, 1985).

TABLE 2. MEANS AND STANDARD DEVIATIONS OF MEASURED REFLECTANCE VALUES AT SIX WAVELENGTHS FOR SEVEN RANGELAND PLANT SPECIES WITH VARIABLE LEAF PUBESCENCE.

Plant Species	Reflectance (%) at given wavelength (μm) 0.45	0.55	0.65	0.85	1.65	2.20
Densely Pubescent						
Cory Croton	9.5 ± 0.9	14.0 ± 1.1	14.3 ± 0.6	34.5 ± 2.6	32.3 ± 1.8	26.9 ± 2.6
Silverleaf Sunflower	7.7 ± 0.7	11.0 ± 0.5	7.5 ± 0.6	45.4 ± 1.7	20.6 ± 0.9	9.9 ± 0.6
Woolly Stemodia	9.0 ± 0.6	12.3 ± 1.0	11.7 ± 1.3	33.2 ± 3.1	26.5 ± 2.9	19.3 ± 2.9
Sparsely Pubescent						
Bullnettle	3.6 ± 0.2	8.7 ± 0.3	4.7 ± 0.2	34.5 ± 2.6	18.1 ± 1.4	8.6 ± 1.0
Copperleaf	3.0 ± 0.4	6.5 ± 0.5	4.9 ± 0.6	28.1 ± 2.7	20.7 ± 2.2	11.7 ± 1.8
Nonpubescent						
Cowpen Daisy	3.0 ± 0.6	6.9 ± 0.5	4.5 ± 0.6	30.8 ± 2.4	18.4 ± 4.8	7.8 ± 1.6
Prairie Coneflower	3.2 ± 0.4	7.3 ± 0.9	4.8 ± 0.8	31.9 ± 2.3	20.3 ± 2.5	10.4 ± 2.2

TABLE 3. DISCRIMINANT ANALYSIS OF SEVEN RANGELAND PLANT SPECIES WITH DENSE, SPARSE, AND NONPUBESCENT LEAVES. WATER CONTENT, LEAF CHLOROPHYLL, CANOPY COVER, AND PLANT HEIGHT FIELD MEASUREMENTS WERE OBTAINED ALONG WITH SPECTRAL REFLECTANCE MEASUREMENTS AT 0.45-, 0.55-, 0.65-, 0.85-, 1.65-, AND 2.20-μM WAVELENGTHS. CORRECTLY IDENTIFIED OBSERVATIONS ARE ON DIAGONALS WITHIN EACH FIELD, SPECTRAL, AND FIELD AND SPECTRAL ANALYSIS. OMISSION AND COMMISSION ERRORS ARE ON THE ROWS AND COLUMNS, RESPECTIVELY, FOR EACH ANALYSIS.

Commission errors down columns		FIELD DATA ONLY DENSE	SPARSE	NONE	%	SPECTRAL DATA ONLY DENSE	SPARSE	NONE	%	FIELD AND SPECTRAL DENSE	SPARSE	NONE	%
DENSE	18	14	3	1	78	18	0	0	100	18	0	0	100
SPARSE	12	1	10	1	83	0	11	1	92	0	12	0	100
NONE	12	0	0	12	100	0	3	9	75	0	0	12	100
OVERALL					86				90				100

DENSELY PUBESCENT	*n*	SPARSELY PUBESCENT	*n*	NONPUBESCENT	*n*
Cory Croton	6	Bullnettle	6	Prairie Coneflower	6
Woolly Stemodia	6	Copperleaf	6	Cowpen Daisy	6
Silverleaf Sunflower	6				
TOTAL	18	TOTAL	12	TOTAL	12

TABLE 4. FACTOR ANALYSIS OF SEVEN RANGELAND PLANT SPECIES WITH DENSE, SPARSE, AND NONPUBESCENT LEAVES. WATER CONTENT, LEAF CHLOROPHYLL, CANOPY COVER, AND PLANT HEIGHT FIELD MEASUREMENTS WERE OBTAINED ALONG WITH SPECTRAL REFLECTANCE MEASUREMENTS AT 0.45-, 0.55-, 0.65-, 0.85-, 1.65-, AND 2.20-μM WAVELENGTHS. THE CUMULATIVE PERCENTAGE OF EIGENVALUES AND THE FIRST TWO MOST IMPORTANT VARIABLES TO EACH EIGENVECTOR ARE LISTED.

Field Data only Eigen-vector	Eigen-value	Variable	Spectral Data Only Eigen-vector	Eigen-value	Variable	Field and Spectral Eigen-vector	Eigen-value	Variable
	%			%			%	
1	51	WATER HEIGHT	1	77	0.65 μm 0.55 μm	1	49	0.65 μm 0.45 μm
2	74	COVER CHLOROPHYLL	2	96	0.85 μm 2.20 μm	2	76	0.85 μm HEIGHT
3	93	CHLOROPHYLL HEIGHT	3	98	1.65 μm 0.85 μm	3	85	CHLOROPHYLL COVER
			4	99	2.20 μm 0.45 μm	4	92	HEIGHT CHLOROPHYLL
						5	96	0.85 μm COVER

DENSELY PUBESCENT	*n*	SPARSELY PUBESCENT	*n*	NONPUBESCENT	*n*
Cory Croton	6	Bullnettle	6	Prairie Coneflower	6
Woolly Stemodia	6	Copperleaf	6	Cowpen Daisy	6
Silverleaf Sunflower	6				
TOTAL	18	TOTAL	12	TOTAL	12

Huete *et al.* (1985) reported that a soil spectral effect was found to influence greenness measures at canopy covers approaching 75 percent. Because canopy covers of the plants studied in this experiment were equal to or greater than 75 percent (Table 1) and all plant leaves were planophile, soil background probably had minimal influence on canopy reflectance data for this study (Table 2). Thus, pubescence appeared to be the main effect on canopy reflectance.

Tables 3, 4, and 5 present the discriminant, factor, and correlation analysis, respectively, for the plant structure, water content, and chlorophyll data in Table 1 and spectral data in Table 2 for the seven plant species.

TABLE 5. CORRELATION MATRIX OF PLANT WATER CONTENT, CHLOROPHYLL, COVER, HEIGHT, AND REFLECTANCE MEASUREMENTS AT THE 0.45-, 0.55-, 0.65-, 0.85-, 1.65-, AND 2.20-μM WAVELENGTHS. MEASUREMENTS WERE FROM PLANTS THAT HAD DENSE, SPARSE, AND NO PUBESCENCE ON THEIR LEAVES. THE DF WAS 40 FOR THE ANALYSIS.

	WATER	CHL	COVER	HEIGHT	0.45 μm	0.55 μm	0.65 μm	0.85 μm	1.65 μm	2.2 μm
Water	–	0.36*	0.20	0.74**	−0.29	−0.20	−0.44**	0.42**	0.47**	−0.55**
CHL		–	0.11	0.32*	−0.11	0.01	−0.15	0.35*	−0.11	−0.14
COVER			–	0.19	0.49**	0.45**	0.29	0.55**	0.07	0.05
HEIGHT				–	−0.04	−0.03	−0.18	0.47**	−0.26	−0.32*
0.45μm					–	0.96**	0.93**	0.51**	0.77**	0.76**
0.55μm						–	0.93**	0.51**	0.77**	0.78**
0.65μm							–	0.24	0.90**	0.94**
0.85μm								–	0.13	0.01
1.65μm									–	0.95**
2.20μm										–

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

Discriminate analysis for field data only (Table 3) showed that four commission and ommission errors occurred between plants with densely and sparsely pubescent leaves. There were two ommission errors of dense and sparse pubescent plants due to nonpubescent plants. Generally, field data for plants with dense pubescence were more similar to that of plants with sparse pubescence than to that of plants with no pubescence. Factor analysis results (Table 4) indicated that plant water content and height were the predominant variables of the first principal component of variation that accounted for 51 percent of the total variation. Mean water content and plant height were slightly higher for nonpubescent compared to sparsely and densely pubescent species (Table 1). Plant cover was the next most important variable where nonpubescent plants had generally less cover than sparsely and densely pubescent plants (Table 1).

Discriminant analysis for spectral data only (Table 3) showed that all of the commission and ommission errors occurred between plants with sparsely and nonpubescent leaves. Thus, spectrally, plants with dense pubescence were different from plants with sparse and no pubescence. Factor analysis results (Table 4) indicated that the 0.55- and 0.65-μm wavelengths were the predominant variables of the first principal component of variation that accounted for 77 percent of the total variation. The 0.45-μm wavelength was ranked third. Thus, Table 2 and Figure 2 show that the reflectance means at the 0.45-, 0.55-, and 0.65-μm wavelengths were much lower for the nonpubescent and sparsely pubescent compared to the densely pubescent species. The reflectance at the 0.85-, 1.65-, and 2.20-μm wavelengths were also important because they accounted for 21 percent of the total variation. The 0.45- and 0.65-μm wavelengths were the predominant variables of the first principal component of variation that accounted for 49 percent of the total variation when using both field and spectral variables. Thus, it appears that the visible wavelengths are the most important variables for distinguishing densely pubescent plant species from sparsely or nonpubescent species. The importance of the visible wavelengths in separating the densely from the sparsely and nonpubescent species was probably due to the characteristic white hairs on the leaves of the densely pubescent species. The near-infrared (0.85-μm) and mid-infrared (1.65- and 2.20-μm) wavelengths were not as important in separating the densely from the sparsely and nonpubescent species because these portions of the spectrum are more sensitive to plant structure (Myers and Allen, 1968; Gausman, 1974) and water content (Thomas *et al.*, 1971; Gausman *et al.*, 1977), respectively.

The matrix of all possible correlations among field and spectral variables are presented in Table 5. We found that water content was significantly correlated to both chlorlophyll and height and that chlorophyll and height were significantly correlated. Canopy cover was not correlated with any of the field variables. Water content was correlated with reflectance at the 0.65-, 0.85-, 1.65-, and 2.20-μm wavelengths, a result consistant with previous findings (Thomas *et al.*, 1971; Tucker, 1979; Everitt *et al.*, 1986). Chlorophyll was found to be correlated only to reflectance at 0.85 μm (Tucker, 1979). Canopy cover was correlated to the 0.45-, and 0.55-, and 0.85-μm wavelengths. Plant height was correlated with reflectance at the 0.85- and 2.20-μm wavelengths. We found that all spectral wavelengths were correlated except that the 0.85-μm wavelength was not correlated to the 0.65-, 1.65-, and 2.20-μm wavelengths. Thus, the visible and mid-infrared wavelengths were correlated over all wavelengths and the visible and near-infrared are correlated at the 0.45- and 0.55-μm wavelengths. The near and mid-infrared bands were not correlated.

CONCLUSIONS

These results showed that the increase in reflectance at the 0.45-, 0.55-, and 0.65-μm visible wavelengths was the most important effect for distinguishing densely from sparsely and nonpubescent plant species. Water content and plant height were the most important field variable effects for discriminating nonpubescent from sparsely and densely pubescent species. These findings indicate that the higher reflectance of densely pubescent plant species in the visible wavelengths should provide a spectral signature that enables them to be distinguished from sparsely and nonpubescent plant species in remote sensing imagery of rangelands, provided that they occur in relatively dense stands. Research has shown that both silverleaf sunflower and woolly stemodia can be separated from other plant species in aerial photography (Gausman *et al.*, 1977; Villarreal *et al.*, 1987) and satellite imagery (Richardson *et al.*, 1981) of rangelands.

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REFERENCES

Billings, W. D., and R. J. Morris, 1951. Reflection of visible and infrared radiation from leaves of different ecological groups. *Amer. J. Bot.* 38:327–331.

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*. Texas Research Foundation, Renner, Texas. 1881 p.

Dixon, W. J., and M. B. Brown (Eds.), 1979. *BMDP Biomedical Computer Programs, P-Series*. University of California Press, Berkeley, California. 880 p.

Everitt, J. H., H. W. Gausman, and S. J. Ingle, 1984. Pubescence of Texas lantana affects leaf spectra and imagery. *Proc. 9th Biennial Workshop on Color Aerial Photography in Plant Sciences*. Amer. Soc. Photogrammetry, Falls Church, Virginia. pp. 89–97, 202.

Everitt, J. H., A. J. Richardson, and P. R. Nixon, 1986. Canopy reflectance characteristics of succulent and nonsucculent rangeland plant species. *Photogrammetric Engineering and Remote Sensing* 52:1891–1897.

Gates, D. M., and W. Tantraporn, 1952. The reflectivity of deciduous trees and herbaceous plants in the infrared to 25 microns. *Science* 115:613–616.

Gausman, H. W., 1974. Leaf reflectance of near-infrared. *Photogrammetric Engineering* 40:183–191.

Gausman, H. W., and R. Cardenas, 1969. Effect of leaf pubescence of *Gynura aurantiaca* on light reflectance. *Bot. Gaz.* 130:454–459.

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., R. M. Menges, D. E. Escobar, J. H. Everitt, and R. L. Bowen, 1977. Pubescence affects spectra and imagery of silverleaf sunflower (*Helianthus argophyllus*). *Weed Sci.* 25:437–440.

Horwitz, W., 1965. *Official Methods of Analysis*, Ed. 10. Assoc. Offic. Agric. Chemists. Washington, D.C. 957 p.

Huete, A. R., R. D. Jackson, and D. F. Post, 1985. Spectral response of a plant canopy with different soil backgrounds. *Remote Sensing of Environment* 17:37–53.

Leamer, R. W., V. I. Myers, and L. F. Silva, 1973. A spectroradiometer for field use. *Rev. Sci. Instrum.* 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., and W. A. Allen, 1968. Electroptical remote sensing methods as nondestructive testing and measuring techniques in agriculture. *Applied Optics* 7:1818–1838.

Pearman, G. I., 1966. The reflection of visible radiation from leaves of some western Australian species. *Aust. J. Biol. Sci.* 19:97–103.

Richardson, A. J., D. E. Escobar, H. W. Gausman, and J. H. Everitt, 1981. Use of LANDSAT-2 data technique to estimate silverleaf sunflower infestation. *Proc. Symp. Machine Processing Remotely Sensed Data.* LARS, West Lafayette, Indiana. pp. 676–683.

Satterwhite, M. D., 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, Florida, 19–23 September 1982. pp. 352–361.

Steel, R. G. D., and J. H. Torrie, 1980. *Principles and Procedures of Statistics.* McGraw-Hill Book Co. New York. 481 p.

Szwarcbaum, I., 1982. Influence of leaf morphology and optical properties on leaf temperature and survival in three Mediterranean shrubs. *Plant Sci. Letters.* 26:47–57.

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

Villarreal, R., J. H. Everitt, M. A. Alaniz, and R. D. Pettit, 1987. Computer analysis of aerial photographs for quantification of brush and weeds on rangelands. *Proc. 11th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences.* Amer. Soc. Photogrammetry, Falls Church, Virginia. (In press).

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