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 (hairs) 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 (Ste media tomentosa (Mill.) Greem. & Thomps), and silverleaf sunflower (Helianthus argophyllus T. & G.). The sparsely pubescent species included copperleaf (Acalypha radicans Torr.) and bull nettle (Cnidoscolus texanus (Muell. Arg.) Small), while the nonpubescent species were prairie coneflower (Ratibida columnaris (Sims) D. Don) and cowpen daisy (Verbesina encelioides (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, hyper thermic 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 (Learner 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. Percent reflectance was obtained 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.
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)

**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).**

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.

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, at six wavelengths (0.45, 0.55, 0.65, 0.85, 1.65, and 2.20 μm).

![](image)

**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).**

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

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

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 principal components of variability in terms of the first two dominant original data variable eigenvector weighting factors (Steel and Torrie, 1980). Simple correlation matrices were developed to study the interaction among water content, chlorophyll concentrations, structure, and reflectance variables (Steel and Torrie, 1980).

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

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Reflectance (%) at given wavelength (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.45</td>
</tr>
<tr>
<td>Densely Pubescent</td>
<td></td>
</tr>
<tr>
<td>Cory Croton</td>
<td>9.5 ± 0.9</td>
</tr>
<tr>
<td>Silverleaf Sunflower</td>
<td>7.7 ± 0.7</td>
</tr>
<tr>
<td>Woolly Stemodia</td>
<td>9.0 ± 0.6</td>
</tr>
<tr>
<td>Sparsely Pubescent</td>
<td></td>
</tr>
<tr>
<td>Bullneltine</td>
<td>3.6 ± 0.2</td>
</tr>
<tr>
<td>Copperleaf</td>
<td>3.0 ± 0.4</td>
</tr>
<tr>
<td>Cowpen Daisy</td>
<td>3.0 ± 0.6</td>
</tr>
<tr>
<td>Prairie Coneflower</td>
<td>3.2 ± 0.4</td>
</tr>
</tbody>
</table>

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.
2.20-μm visible wavelengths was the most important in separating the densely from the sparsely and non-pubescent species. The importance of the visible wavelengths in separating the densely pubescent plant species from sparsely and densely pubescent species (Table 1). Plant cover was the next most important variable where non-pubescent 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 omission errors occurred between plants with densely and sparsely pubescent leaves. There were two omission errors of dense and sparse pubescent plants due to non-pubescent 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 non-pubescent compared to sparsely and densely pubescent species (Table 1). Plant cover was the next most important variable where non-pubescent 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 omission errors occurred between plants with sparsely and non-pubescent leaves. Thus, spectrally, plants with dense pubescence were different from plants with sparse and no pubescence. Factor analysis results (Table 4) indicated that the 0.45- 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 non-pubescent 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 non-pubescent species. The importance of the visible wavelengths in separating the densely from the sparsely and non-pubescent 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 non-pubescent 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 chlorophyll 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 consistent 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-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 non-pubescent plant species. Water content and plant height were the most important field variable effects for distinguishing non-pubescent 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 non-pubescent 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 stemsodia can be separated from other plant species in aerial photography (Gausman et al., 1977; Villarreal et al., 1987) and satellite imagery (Richardson et al., 1983) of rangelands.

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**REFERENCES**


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Restoring the Earth • 1988 Conference
Berkeley, California
13–16 January 1988

The first national gathering to consider the restoration of all natural resource types and the redesign of urban areas will be held on January 13–16 at the University of California, Berkeley. The conference is organized by the Restoring the Earth project of The Tides Foundation, San Francisco, and cosponsored both by the College of Natural Resources and the Center for Environmental Design Research of the University of California, Berkeley. It will bring experts in natural resource restoration and management together with a broad selection of academic, government, industry, foundation, labor, public health, and environmental representatives. Participants will help create new solutions to the nation’s environmental problems, through restoration of damaged resources. Topics to be covered include restoration of coastal ecosystems and estuaries; rivers and lakes; streams and fisheries; rangelands, prairies, mined lands, forests and wildlife; atmosphere and climate; dry lands and agricultural lands; urban environmental planning; and control of toxic wastes. Formal refereed papers will be presented at scientific and technical sessions. Nontechnical sessions will include accounts of restoration successes and discussions of policy issues, legislation, litigation, trends, and resource conflict resolution. The program also includes keynote panels, plenary sessions, workshops, films, and exhibits.

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