Canopy Reflectance of Two Drought-Stressed Shrubs

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ABSTRACT: Spectroradiometric canopy reflectances of two drought-stressed shrubs [Texas persimmon (*Diospyros texana*) and lime pricklyash (*Zanthoxylum fagara*)] were compared with those of nonstressed shrubs at five wavelengths: 0.55-, 0.65-, 0.85-, 1.65-, and 2.20-μm. Stressed plants had higher reflectance than nonstressed plants at the visible (0.55- and 0.65-μm) wavelengths, while nonstressed plants had higher reflectance than stressed plants in the near-infrared (0.85-μm). At the two mid-infrared water absorption peaks (1.65- and 2.20-μm), stressed plants had higher reflectance than nonstressed plants. Reflectance differences between stressed and nonstressed plants in the visible, near-infrared, and mid-infrared water absorption regions was partially attributed to differences in leaf chlorophyll, canopy density, and leaf water content, respectively. The greater amount of exposed soil background of the stressed plants also contributed significantly to reflectance differences between stressed and nonstressed plants in all three spectral regions. Results indicate the potential for using remote sensing to distinguish drought from nonstressed shrubs.

INTRODUCTION

STUDIES ON THE USE OF reflectance measurements and remote sensors for detecting stress conditions (drought, soil salinity, nutrient, etc.) have been conducted on crop plants such as cotton (*Gossypium hirsutum* L.), grain sorghum (*Sorghum bicolor* (L.) Moench), and corn (*Zea mays* L.) (Wiegand *et al.*, 1972; Gausman *et al.*, 1978; Wiegand *et al.*, 1983; Myers *et al.*, 1983; Gardner, 1983; Jackson and Ezra, 1985). Little information is available concerning the reflectance characteristics of stressed rangeland plants. This information would be useful to personnel working with remote sensing imagery of rangelands.

This study was conducted to determine if plant canopy reflectance measurements could be used to detect drought stress in two shrub species on Texas rangelands.

MATERIALS AND METHODS

This study was conducted in two rangeland areas of southern Texas in late June 1984. One site was located near La Joya, Texas, while the second was near Linn, Texas. The two sites are approximately 70 km apart, but have similar native vegetation and sandy loam soils. On the Munsell soil color chart, soil from the La Joya site was classified as a grayish brown (10 YR 5/2) while that at the Linn site was brown (10 YR 5/3). It was assumed that the soils had similar spectral response. The La Joya site had received below normal rainfall during the late spring period and many of the plant species were drought-stressed, whereas the Linn site had received average rainfall and the vegetation was actively growing. Two shrubs common on both sites were selected to compare their reflectance characteristics under stressed and nonstressed conditions. The species were Texas persimmon (*Diospyros texana* Scheele) and lime pricklyash (*Zanthoxylum fagara* (L.) Sarg.). Both are important shrubs on Texas rangelands and provide food for wildlife (Arnold and Drawe, 1979).

Plant canopy reflectance measurements were made at each study site using an Exotech Model 20 spectroradiometer (Leamer *et al.*, 1973). Canopy measurements were made on ten randomly selected plant canopies of stressed and nonstressed Texas persimmon and lime pricklyash plants. Measurements of the stressed plants were made on 25-26 June 1984, while measurements of the nonstressed plants were made on 28 June 1984. Reflected solar radiation was measured over the 0.45- to 2.45-μm range with a 15-degree field-of-view sensor. Measurements were made at 2.5 to 3.0 metres above each plant canopy under clear conditions between 1100 and 1400 hours CDT. Reflectance data were studied at five wavelengths: 0.55-, 0.65-, 0.85-, 1.65-, and 2.2-μm, representing, respectively, the green reflectance peak, 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 spectral interval. To obtain percent reflectance from field spectral data, radiant light 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 × percent transmission of a diffusing plate.

Water content and chlorophyll concentration of leaves were determined at the time of reflectance measurements. Water content was determined by

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collecting one mature leaf from each of ten randomly selected stressed and nonstressed plants of each species. For chlorophyll, leaf sample composites (five leaves) were collected from each of the same ten plants from which leaves were sampled for water content. Leaves were wrapped immediately in plastic wrap, stored on ice to minimize dehydration, and transferred to the laboratory within two hours for measurements. Water content was determined on an oven dry weight basis (68°C for 72 hours) and cooling in a desiccator before weighing. Total chlorophyll was determined by a routine method (Horwitz, 1965).

Mature leaves were collected for tissue analyses. Tissue pieces from near the center of leaves were fixed in formalin-acetic acid-alcohol, dehydrated with tertiary butanol, embedded in paraffin, stained with safranin-fast green, and transversally microtomed at 12-μm thickness (Jensen, 1962). Photomicrographs were obtained with a Zeiss Standard Universal Photomicroscope. This was done to relate internal leaf structure to drought stress.

The t-test was used to test the differences between canopy reflectances at the five wavelengths selected for study and between leaf water content and chlorophyll concentrations for stressed and nonstressed plants of both Texas persimmon and lime pricklyash (Steel and Torrie, 1960). All statistical comparisons were made at the 0.05 percent probability level.

RESULTS AND DISCUSSION

Stressed Texas persimmon and lime pricklyash plants could be visually distinguished from nonstressed plants. Leaves of stressed plants of both species were a lighter green than those of the nonstressed plants, and the leaves of stressed lime pricklyash plants were curled. Overhead views of stressed and nonstressed plants showed that stressed plants had more breaks in their canopies, had less leaf density but more stem coverage, and exhibited more soil background through their canopies than did nonstressed plants.

Internal leaf structures for the nonstressed and stressed Texas persimmon and nonstressed and stressed lime pricklyash leaves are shown in Figure 1. Leaf structure of the stressed leaves of both species were distorted, showing the effect of dehydration. However, the internal structure of the stressed Texas persimmon leaf showed a more pronounced effect of drought than that of the stressed lime pricklyash. The palisade and spongy parenchyma cells of the stressed Texas persimmon leaf had undergone plasmolysis and, as a result, it had more inter-cellular air spaces than that of the nonstressed leaf. Leaf water contents of the stressed plants were significantly lower ($p \leq 0.05$) than those of the nonstressed plants (Table 1).

Table 2 contains the canopy reflectance data for the stressed and nonstressed Texas persimmon and lime pricklyash plants at five wavelengths. Percent reflectance values of stressed plants were significantly different ($p \leq 0.05$) from those of nonstressed plants at all five wavelengths. Mean reflectances at the 0.55- and 0.65-μm in the visible region (0.50- to 0.75-μm) were higher for stressed plants than for nonstressed plants, whereas nonstressed plants had higher reflectance than stressed plants at the 0.85-μm in the near-infrared region. The higher visible reflectance of the stressed plants was attributed to the lower chlorophyll concentrations in their leaves (Table 1) and to the greater amount of soil background exposed through their more open canopies. The higher near-infrared reflectance of the nonstressed plants was attributed to their greater leaf density (Wiegand *et al.*, 1974) and, consequently, to less soil background exposed through their canopies. The lighter green canopies (lower leaf chlorophyll concentrations) of the stressed plants absorbed less energy, giving higher visible reflectance, whereas the darker green canopies (higher leaf chlorophyll concentrations) of the nonstressed plants absorbed more energy, giving lower visible reflectance (Myers *et al.*, 1983). The influence of the sandy loam soil background on the visible and near-infrared reflectance of the shrubs is in agreement with the findings of Satterwhite and Henley (1982) who reported that, for vegetation-sand targets, percent vegetation cover varied inversely with reflectance in the visible region and directly in the near-infrared region.

The reflectances from the stressed Texas persimmon and lime pricklyash plants were higher than those for the nonstressed plants at both the 1.65- and 2.20-μm (Table 2). The higher reflectance values of the stressed plants were attributed to their lower leaf water contents which absorbed less solar radiation (Table 1) and to more exposed soil background. Conversely, the lower reflectance values of the nonstressed plants were attributed to their higher water contents, which absorbed more radiation, and to less exposed soil background (Thomas *et al.*, 1971; Miller *et al.*, 1984).

CONCLUSIONS

Results presented in this study showed that plant canopy reflectance measurements in either the visible, near-infrared, or mid-infrared water absorption regions can be used to detect drought stress in two shrub species found on Texas rangelands. No single spectral region appeared best for differentiating between stressed and nonstressed shrubs. Spectral differences between stressed and nonstressed shrubs were attributed to specific absorbance-reflectance effects, to variable canopy density, and to the greater amount of exposed soil background of the stressed plants. These findings indicate that remote sensing may have some potential for distinguishing drought-stressed shrubs from shrubs growing under adequate moisture conditions.

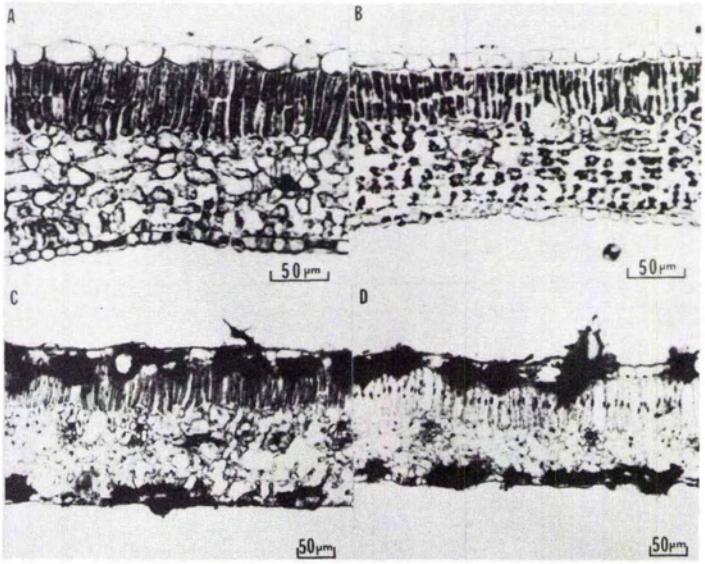

FIG. 1. Transections of nonstressed (A) and stressed (B) Texas persimmon and nonstressed (C) and stressed (D) lime pricklyash leaves.

TABLE 1. MEAN LEAF WATER AND CHLOROPHYLL CONTENTS OF STRESSED AND NONSTRESSED TEXAS PERSIMMON AND LIME PRICKLYASH PLANTS.

Leaf Water and Chlorophyll	Texas Persimmon		Lime Pricklyash	
	Stressed	Nonstressed	Stressed	Nonstressed
Water (%)	30.7*	46.2	37.3*	56.5
Chlorophyll (mg/g)	1.9*	2.4	1.2*	1.8

*Significantly different from nonstressed at the 0.05 percent probability level.

TABLE 2. MEAN CANOPY PERCENT REFLECTANCE OF STRESSED AND NONSTRESSED TEXAS PERSIMMON AND LIME PRICKLYASH PLANTS FOR FIVE WAVELENGTHS.

Wavelength (µm)	Texas Persimmon		Lime Pricklyash	
	Stressed	Nonstressed	Stressed	Nonstressed
0.55	6.5*	4.8	6.0*	4.0
0.65	4.6*	2.9	4.6*	1.9
0.85	24.1*	31.2	19.8*	31.3
1.65	21.6*	18.8	17.6*	14.7
2.20	14.4*	9.7	11.9*	6.6

*Significantly different from nonstressed at the 0.05 percent probability level.

The shrubs studied in this investigation were deemed to be either stressed or nonstressed. Future studies need to be conducted under controlled environmental conditions to determine if reflectance measurements can be used to detect a gradient in stress conditions of shrubs.

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