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Distinguishing Succulent Plants from Crop and Woody Plants†

Sensor bands encompassing either the 1.6- or 2.2-μm wavelengths may be useful for distinguishing succulent from nonsucculent plant species.

Abstract: *We compared laboratory spectrophotometrically measured leaf reflectances of six succulents (peperomia, possum-grape, prickly pear, spiderwort, Texas tuberose, wolfberry) with those of four nonsucculents (cenizo, honey mesquite, cotton, sugarcane) for plant species discrimination. Succulents (average leaf water content of 92.2 percent) could be distinguished from nonsucculents (average leaf water content of 71.2 percent) within the near-infrared water absorption waveband (1.35 to 2.5 μm). This was substantiated by field spectrophotometric reflectances of plant canopies. Sensor bands encompassing either the 1.6- or 2.2-μm wavelengths may be useful to distinguish succulent from nonsucculent plant species.*

Introduction

Previous research has indicated that a waveband encompassing the 2.2-μm wavelength might be useful for plant species discrimination by remote sensing (Gausman *et al.*, 1972; Richardson *et al.*, 1969; Wiegand *et al.*, 1972). This is supported by the absence of reflectance at the 2.2-μm wavelength for leaves of a succulent plant (*Peperomia obtusifolia* A. Dietr.) (Gausman *et al.*, 1977). We speculated that a waveband encompassing the 2.2-μm wavelength should be considered in the future design of multispectral scanners to enhance plant species discrimination, particularly for distinguishing succulent from nonsucculent plant species.

Succulent plants have water-storage tissue developed in their leaf mesophyll (Fahn, 1967). Therefore, they have a higher water content and absorb more radiation in the near-infrared water absorption region (1.35 to 2.5 μm) than nonsucculent plants (Allen *et al.*, 1970).

Our objective was to test this hypothesis by comparing the reflectances of six succulent plant species among themselves and with: (1) nonsucculent cotton and sugarcane crops with distinctly different but typical reflectances caused by lacunose (dorsiventral) and compact (centric) leaf mesophyll arrangements, respectively (Gausman *et al.*, 1973) and (2) nonsucculent honey mesquite and cenizo plants—two important woody rangeland species that were easily distinguishable spectrophotometrically and photographically because cenizo's visible (0.4 to 0.75 μm) and near-infrared (0.75 to 1.35 μm) reflectances were much greater

† Contribution from the Soil and Water Conservation Research, Southern Region, Agricultural Research Service, USDA.

TABLE 1. MEAN LEAF WATER CONTENTS AND LEAF THICKNESSES, ARRANGED IN DESCENDING ORDERS OF MAGNITUDE FOR SIX SUCCULENT (S) AND FOUR NONSUCCULENT (NS) PLANT SPECIES.

Plant species	Water content	Plant species	Thickness
	%		mm
Spiderwort (S)	96.8 a[1]	Prickly pear (S)	10.66 a[1]
Prickly pear (S)	93.6 b	Possum-grape (S)	1.28 b
Peperomia (S)	93.3 b	Texas tuberose (S)	1.09 bc
Possum-grape (S)	92.4 b	Wolfberry (S)	0.75 bc
Wolfberry (S)	89.0 c	Spiderwort (S)	0.69 bc
Texas tuberose (S)	88.1 c	Peperomia (S)	0.55 bc
Cotton (NS)	78.2 d	Cenizo (NS)	0.40 bc
Cenizo (NS)	77.9 d	Sugarcane (NS)	0.24 c
Sugarcane (NS)	69.7 e	Cotton (NS)	0.21 c
Honey mesquite (NS)	58.8 f	Honey mesquite (NS)	0.19 c

[1] Column values not followed by the same letter differ significantly at the 1 percent level, according to Duncan's multiple range test.

than those of honey mesquite (Gausman *et al.*, 1976).

MATERIALS AND METHODS

We selected ten plant species comprised of six succulents [Texas tuberose (*Polianthes variegata* (Jacobi) Shinners), peperomia (*Peperomia obtusifolia* A. Dietr.), possum-grape (*Cissus incisa* (Nutt.) Des Moul.), prickly pear (*Opuntia lindheimeri* Engelm.), spiderwort (*Tradescantia micrantha* Torr.), wolfberry (*Lycium berlandieri* Dun.)], two woody shrubs [cenizo (*Leucophyllum frutescens* (Berl.) I. M. Johnst.), and honey mesquite (*Prosopis glandulosa* Torr.)], and two agricultural crops [cotton (*Gossypium hirsutum* L.), and sugarcane (*Saccharum officinarum* L.] for reflectance measurements. Prickly pear, wolfberry, cenizo, and mesquite are abundant and important rangeland plant species that provide food for livestock and wildlife. Peperomia is a common ornamental plant, whereas Texas tuberose, possum-grape, and spiderwort are typical succulent rangeland herbaceous species.

One mature leaf* was collected from each of ten plants of each species. Leaves were wrapped immediately in Glad** (plastic wrap), stored on ice to minimize dehydration, and transferred to the laboratory for measurements. (Leaf collection and measurements for each plant species were conducted on different dates.) In the laboratory, leaf reflectance, thickness, area, and green weight measurements and tissue cross section samplings were completed for all leaves of each species within 6 h.

Total diffuse reflectance of upper (adaxial) surface of single leaves over the 0.5- to 2.5-μm and 0.35- to 0.7-μm wavebands was measured with a Beckman Model DK-2A spectrophotometer, equipped with a reflectance attachment. Data were corrected for decay of the barium sulfate standard to give absolute radiometric data (Allen and Richardson, 1971). Leaf thickness was measured using a linear displacement transducer

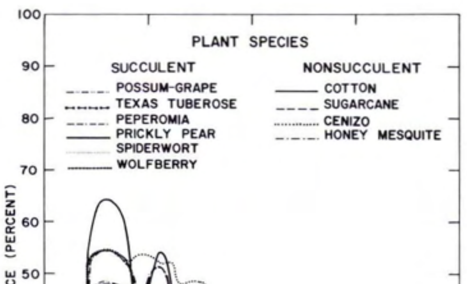

FIG. 1. Laboratory spectrophotometric reflectances measured over the 0.5- to 2.5-μm waveband for leaves of six succulent and four nonsucculent plant species.

* Botanically, prickly pears' above ground appendages are flattened stems called platy cladis, but they will be referred to as leaves for simplicity.

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

and digital voltmeter (Heilman *et al.*, 1968). Leaf areas were measured with a planimeter. Water content was determined on an oven dry weight basis (68 C for 72 h) and cooling in a desiccator before final weighing.

Plant canopy reflectances of prickly pear, honey mesquite, and sugarcane over the 0.5- to 2.5-μm waveband were measured 3.5 m above the canopies in the field with an Exotech Model 20 spectroradiometer (Leamer *et al.*, 1973) whose sensor had a 15-degree field-of-view (0.5 m^2). Percent covers for prickly pear, honey mesquite, and sugarcane within the instrument's field-of-view were 65, 75, and 90 percent, respectively. Some plant canopies on the rangelands were inaccessible to the available equipment. Field spectroradiometric measurements were made to support laboratory results.

Laboratory reflectance data for each of the 41 wavelengths measured over the 0.5- to 2.5-μm waveband and for the 0.45-μm wavelength (chlorophyll absorption band) from the 0.35- to 0.7-μm waveband were analyzed for variance (Duncan's multiple range test was used to test mean differences, p = 0.01) (Steel and Torrie, 1960).

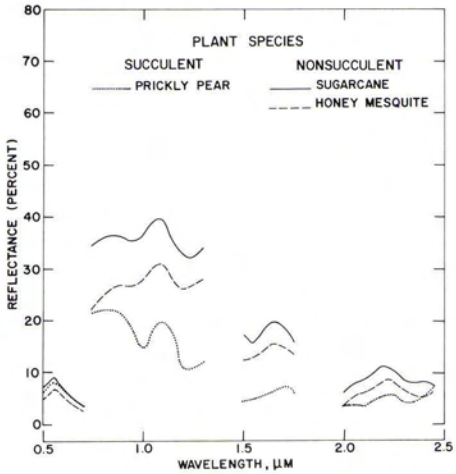

FIG. 2. Field spectroradiometric reflectances measured over the 0.5- to 2.5-μm waveband for succulent prickly pear and nonsucculent sugarcane and honey mesquite plant canopies.

Results and Discussion

Table 1 shows that the thick succulent leaves had an average water content of 92.2 percent as compared with 71.2 percent for the generally thinner nonsucculent leaves. There was no correlation between leaf water content and thickness.

Reflectance spectra

Reflectance measurements made over the

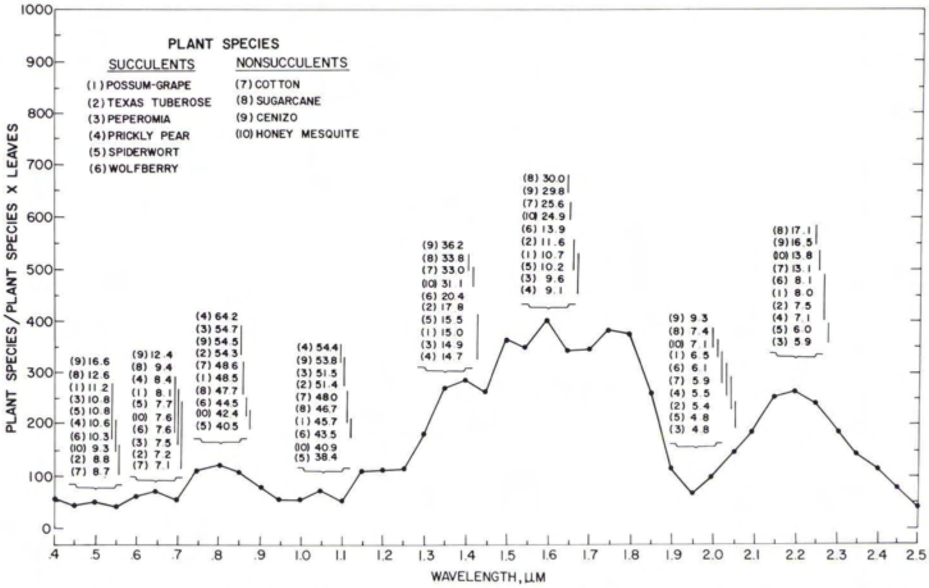

FIG. 3. Chart of plotted "F" values from the analysis of variance ratio (plant species/plant species × leaves) for reflectances of 10 leaves of each of 10 plant species at 0.05-μm increments over the 0.4- to 2.5-μm waveband. Results of Duncan's multiple range test are shown (vertical line) for the 0.5-, 0.65-, 0.8-, 1.05-, 1.35-, 1.6-, 1.95-, and 2.2-μm wavelengths; numbers (1) . . . (10) represent the plant species, and numerals following parenthesis are percent reflectance for that species. (Values along the same vertical line are not different statistically.)

0.35- to 0.70-μm waveband showed statistically significant differences among plant species, but succulents could not be separated from nonsucculents at this waveband (Figure 3).

Figure 1 shows laboratory spectrophotometric mean reflectances measured over the 0.5- to 2.5-μm waveband for ten leaves of each of the six succulent and the four nonsucculent plant species. Cenizo had higher visible (0.5 to 0.75 μm) and spiderwort generally had lower near-infrared (0.75 to 1.35 μm) reflectance than the other plant species. All succulents had lower reflectance values than the nonsucculents in the near-infrared water absorption region (1.35 to 2.5 μm).

Field spectroradiometric reflectances of canopies for succulent and nonsucculent plant species substantiated the laboratory results (Figure 2). The reflectance of prickly pear over the 0.75- to 2.5-μm waveband was lower than that of sugarcane and honey mesquite.

PLANT SPECIES DISCRIMINATION

The "F" values from the analysis of variance ratio (plant species/plant species × leaves) are plotted in Figure 3. Large as compared with smaller ratio values indicated wavelengths with the most reflectance variability among plant species. Generally, larger values occurred in the near-infrared water absorption region (1.35 to 2.5 μm) rather than in the visible (0.4 to 0.75 μm) or near-infrared (0.75 to 1.35 μm) wavebands. Wavelengths were selected for Duncan's multiple range tests, $p = 0.01$, throughout the entire 0.4- to 2.5-μm waveband, where values "peaked" (i.e., at 0.5-, 0.65-, 0.8-, 1.05-, 1.35-, 1.6-, 1.95-, and 2.2-μm), except for the water absorption band valley at 1.95 μm. Succulents had consistently lower reflectance than nonsucculents (Figure 1) at the 1.35-, 1.6-, and 2.2-μm wavelengths, but not at the 0.5-, 0.65-, 0.8-, 1.0-, and 1.95-μm wavelengths. The 1.6- and 2.2-μm wavelengths are probably best for distinguishing between succulent and nonsucculent plant species because they lie near the peak of atmospheric windows and would be accessible to remote sensors above the atmosphere. Mean differences in percent reflectances between succulents and nonsucculents for these two wavelengths were about 17 and 8 percent, respectively; however, reflectances among the six succulents were quite similar, and within the nonsucculents the crop plants could not be distinguished from the woody plants.

Sensor bands encompassing either the 1.6- or 2.2-μm wavelengths should be useful to distinguish succulent from nonsucculent plant species. These results agreed with previous results (Gausman *et al.*, 1972) that intervals centered around either the 1.6- or 2.2-μm wavelengths should be useful for optimum discrimination of vegetation, although the energy level at the 2.2-μm wavelength is lower than that at the 1.6-μm wavelength. Also, a sensor near the 2.2-μm wavelength would need additional cooling.

ACKNOWLEDGMENT

We thank Maria Guadalupe Rodriguez for her art work and Juan Noriega for his help in obtaining field spectroradiometric measurements. This study was supported in part by the National Aeronautics and Space Administration under Contract No. S-53876-AG.

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BOOK REVIEW

The World Remote Sensing Bibliographic Index. Compiled by Paul F. Krumpe. Tensor Industries, Inc. 14.8 × 20.5 cm, 619 pages, paperback, December 1976, $16.95 (within USA); $18.00 (outside USA), order from Tensor Industries, Inc., 8415 Arlington Boulevard, Fairfax, Virginia 22030.

This is an extremely useful reference book covering remote sensing works published during 1970-1976. More than 4000 works from over 850 sources are cited and categorized. The principal section of the book contains a geographically indexed bibliography citing books, articles, reports, etc., categorized according to geographic area and application discipline. The United States section is subdivided into 53 areas. The Foreign Countries and Continental Areas section is subdivided into 107 areas. Within each geographic area listing, works cited are arranged according to discipline category using the following basic categories: General, Multidisciplinary, Forestry/Range, Environment/Land Use, Agriculture/Soils, Geology/Minerals, Hydrology/Water Management, Oceanography/Marine, and Cartography/Mapping.

In addition to the geographically indexed bibliography, this book contains a listing of selected Remote Sensing Bibliographies, as well as extensive information on the sources of the cited documents, giving specific addresses to which the reader should write in order to obtain copies of the cited works. Also, there are extensive listings of institutions, corporations, universities, and colleges which originated the works cited. This volume also contains an extensive list of books, journals, periodicals, and conference proceedings which contain remote sensing information.

This book is highly recommended as a reference source. Persons wishing to obtain bibliographic information on remote sensing related to specific geographic areas will find this book a great time saver. Also, the listing of remote sensing books, journals, periodicals, and conference proceedings is an extremely worthwhile inclusion.

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