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# Measurements of Specularly Reflected Radiation from Individual Leaves

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Measurements of Specularly Reflected Radiation from Individual Leaves.

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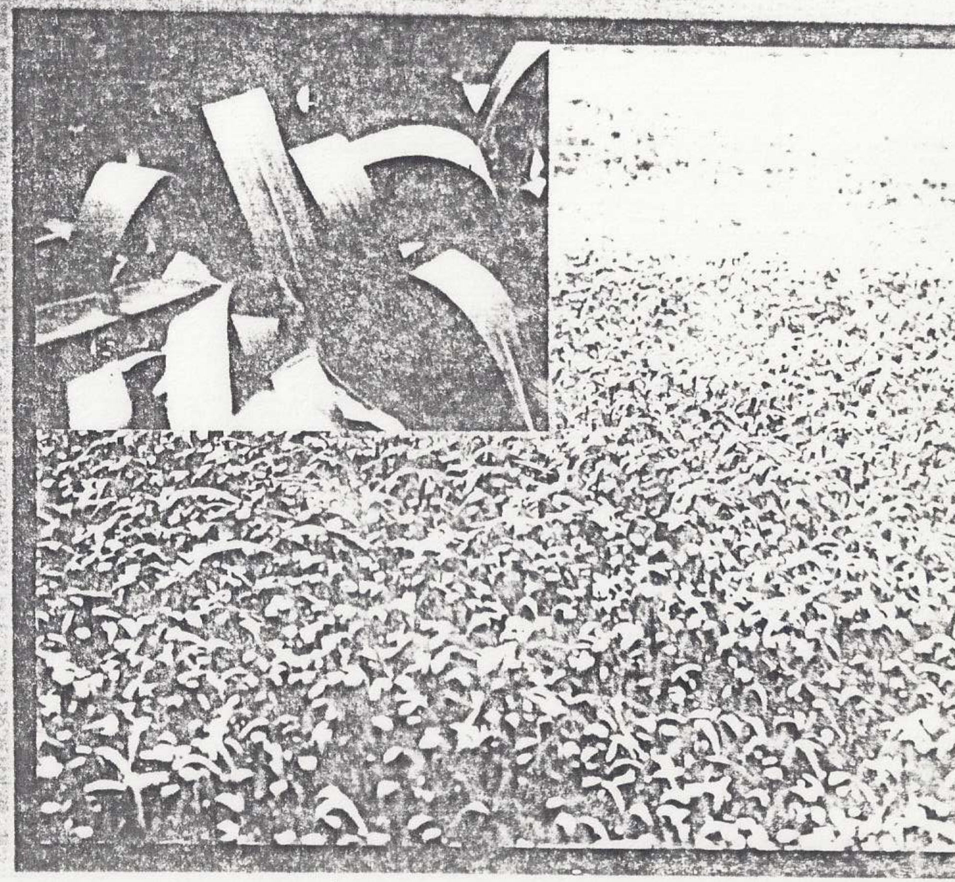
Total reflectance of leaves is comprised of two components: the specular, a first surface phenomenon dependent on characteristics of the leaf cuticle; and the diffuse, a subsurface phenomenon dependent on absorption and anatomical relationships. Specular reflectance cannot be measured directly but may be derived from measurements of polarized, reflected radiation since all specular reflectance is polarized as described by Fresnel equations. The polarized reflectance at the Brewster angle in six bands in the visible and near infrared wavelength regions was measured using a leaf polarization photometer. The specular reflectance from individual leaves was determined *in situ* in a survey of cultivated and wild species. The results illustrate the variation in the specular response among and within species. The poster will discuss the usefulness of considering the specular reflectance and characteristics of the leaf surfaces when using reflectance measurements for species identification. The authors hypothesize that factors affecting characteristics at the leaf cuticular surface are reflected in the specular response.

# BACKGROUND

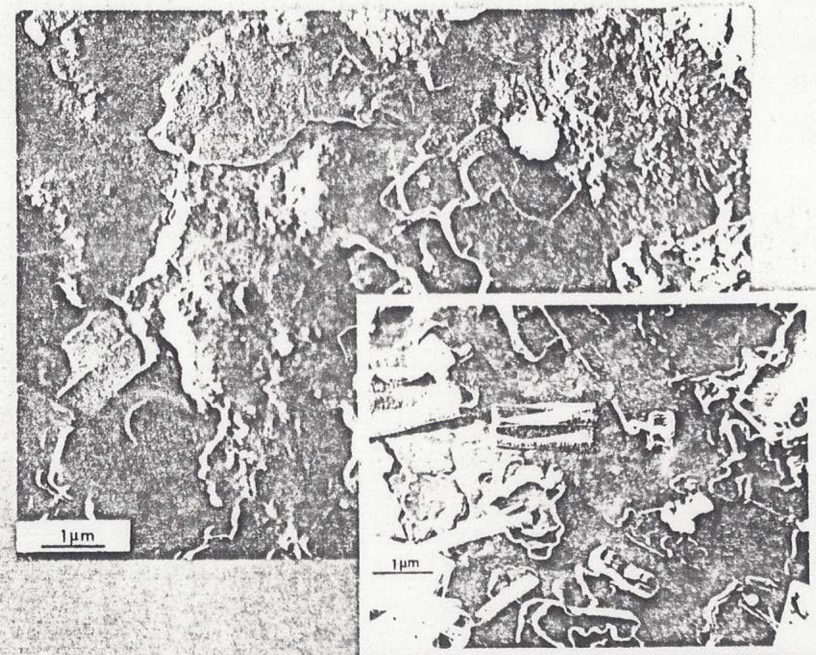
**Leaf Reflectance = Surface Reflectance**
**+**
**Bulk Reflectance**

Most investigations of leaf reflectance have measured total reflectance assuming total reflectance is comprised primarily of diffuse reflectance arising from the bulk of the leaf tissue and is dependent on absorption characteristics and geometric relationships of internal anatomical features. However, when a crop is viewed obliquely, the light reflected from the leaves often appears white. Some of the reflected radiation originates at the leaf surface and appears white because it has never entered the leaf to interact with cellular pigments and structures. This suggests that consideration of the reflectance from the leaf surface may contribute and enhance information about a crop gathered by remote sensing systems.



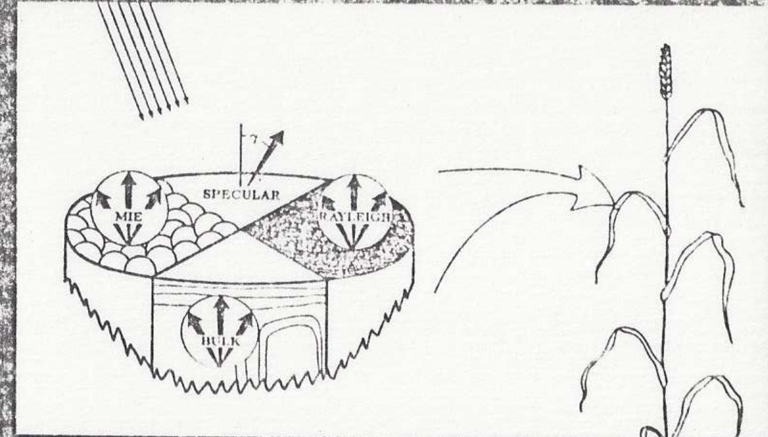
## Leaf Surface Reflection is from Cuticle, Leaf's "Skin"

The surface of leaves is covered by the cuticle, a multi-layered membrane of cutin, pectin, cellulose and wax which forms a continuous skin at the air-surface interface. Variations in the thickness of the cuticle creates a surface microtopography. The outermost surface of the cuticle may be covered with epicuticular waxes in the form of projecting platelets, rods or acicular forms. This microscale architecture and topography may be uniquely characteristic of a species and serve as an identifying 'fingerprint' in taxonomic studies.



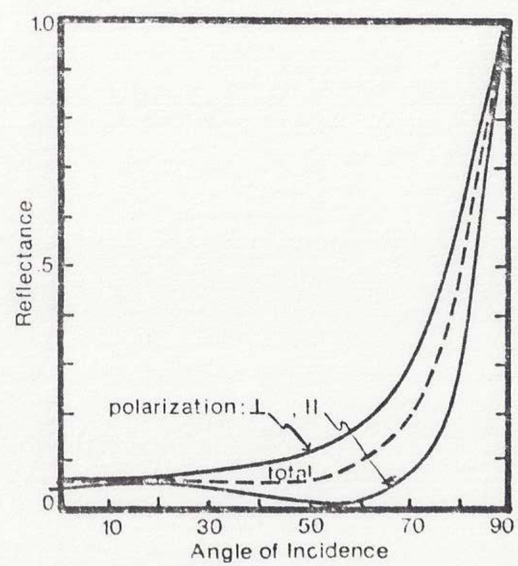
## Three Leaf Surface Reflections: Specular, Rayleigh, and Mie

Study of the surface microtopography shows that the surface of leaves is not optically smooth and suggests that three optical phenomena may be involved in the light scattering properties of leaf surfaces. Specular reflection may arise from optically smooth and similarly oriented facets of the surface. Rayleigh scattering may occur from particles on the surface smaller than the wavelengths of impinging radiation. Mie scattering may occur from small particles greater than wavelengths of impinging radiation. This study investigates the occurrence of specular reflectance.




## Specular Leaf Reflection can be Estimated

Specular reflectance cannot be measured directly. But specular reflectance is linearly polarized and with Fresnel's equations which describe the polarized state of the reflected flux, specular reflectance can be estimated. Specular reflectance increases with increasing angle of incidence and is maximally polarized at the Brewster angle.



# EXPERIMENT

# Objectives

This experiment determines the specular, diffuse and polarized light scattering properties of individual leaves at the Brewster angle.

## Specific Objectives

Document the phenomenon of specular reflectance from individual leaves.

Investigate the properties of the specular reflectance of single leaves of 10 representative plant species.

Verify that the specular reflection is from the surface -- not the bulk -- of the leaf.

# Approach

(Rmax – Rmin)/2

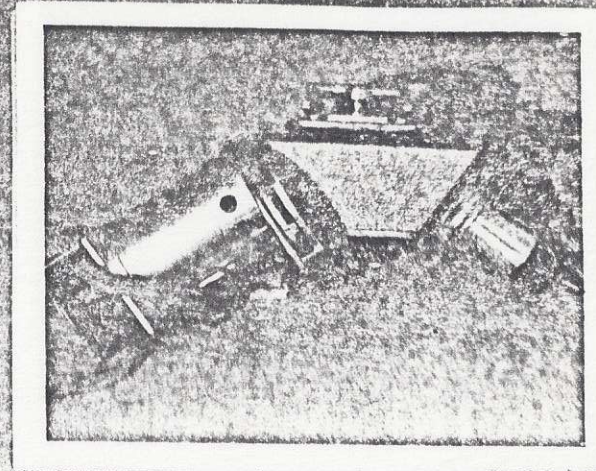
A portable, polarization photometer was designed and constructed and 10 plant species were measured. The species were especially selected to investigate the properties of specular reflection. A maximum polarization reading and a minimum polarization reading were taken for each observation.

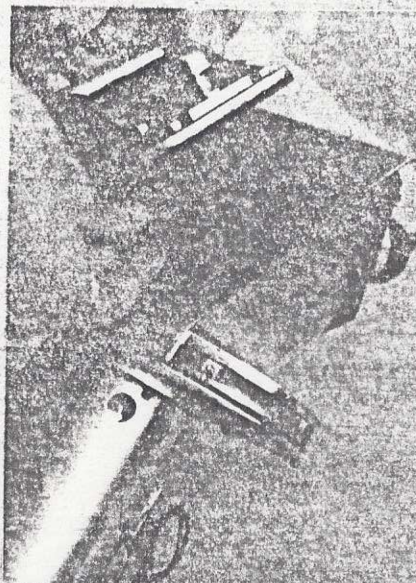
Specular reflectance was calculated as
(maximum reflectance factor - minimum reflectance factor)/2

12 observations from both the adaxial and abaxial leaf surfaces were made for each of the 10 species:

| Botanical Name | Common Name |
|---|---|
| Zea mays | Corn |
| Sorghum bicolor | Sorghum |
| Glycine max | Soybean |
| Helianthus annuus | Sunflower |
| Abutilon theophrasti | Velvet leaf |
| Chenopodium album | Lambsquarters |
| Solarium nigrum | Black nightshade |
| Asclepias syriaca | Milkweed |
| Coleus blumei | Coleus |
| Gynura aurantiaca | Purple passion |

# Instrument





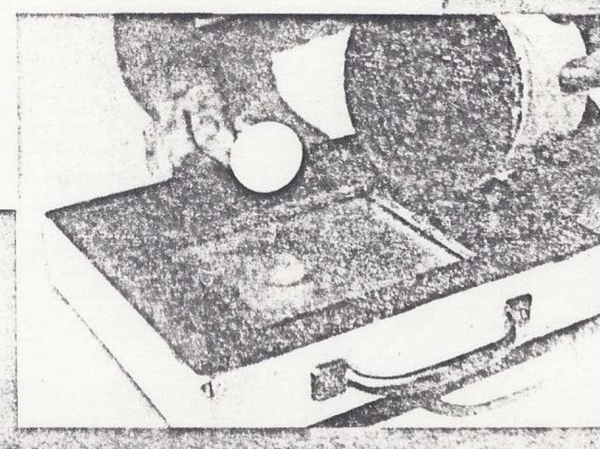
The polarization photometer has 4 parts

- a lamp housing containing a quartz halogen lamp
- a filter housing containing interference filters with bandpass centered at 0.45, 0.5, 0.55, 0.65, 0.73$\mu$m with half power band widths of 0.07$\mu$m
- a frame which positions the leaf to be illuminated at 55°, an approximation of the Brewster angle
- a stage assembly including a polarization analyzer and a silicon photodetector

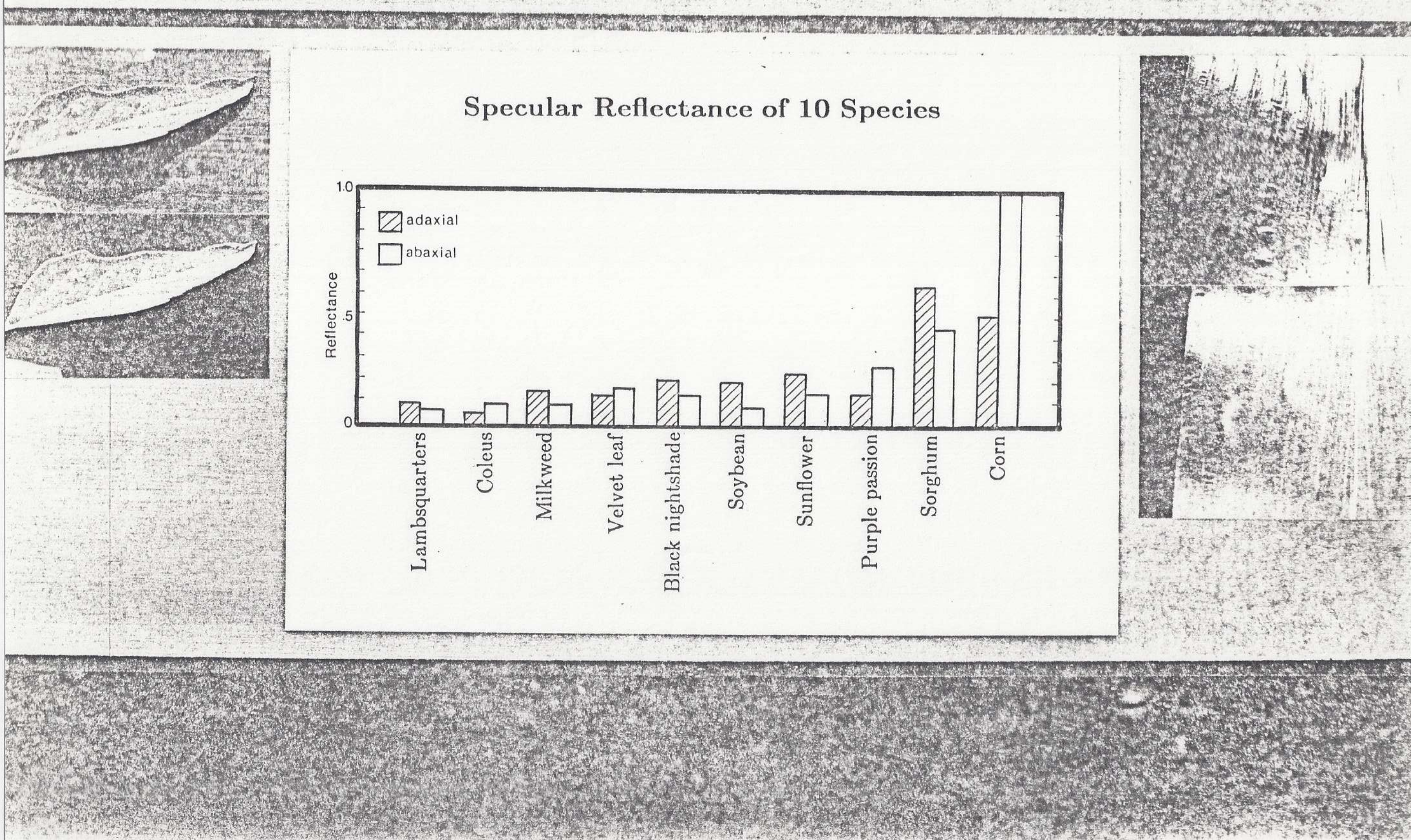
Energy for the lamp is provided by a portable, regulated 12V power supply

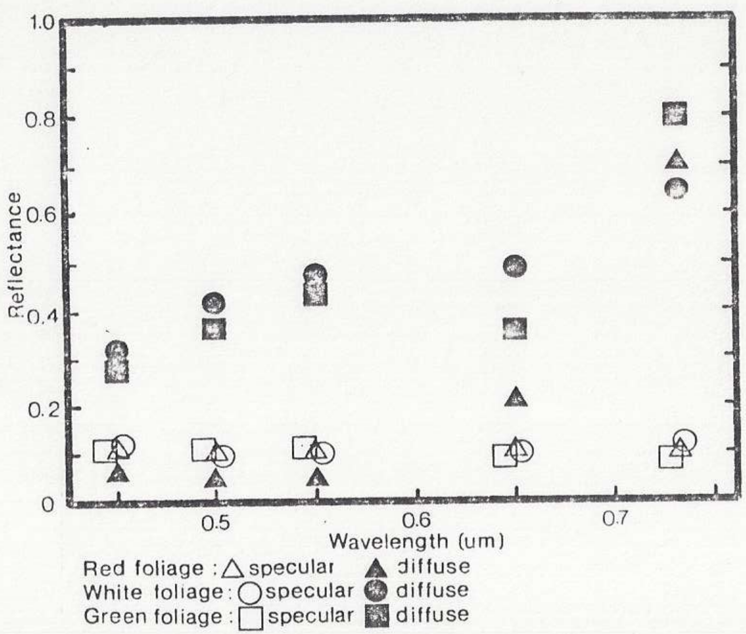
The signal from the photodetector is amplified and digitally stored in solid state memory

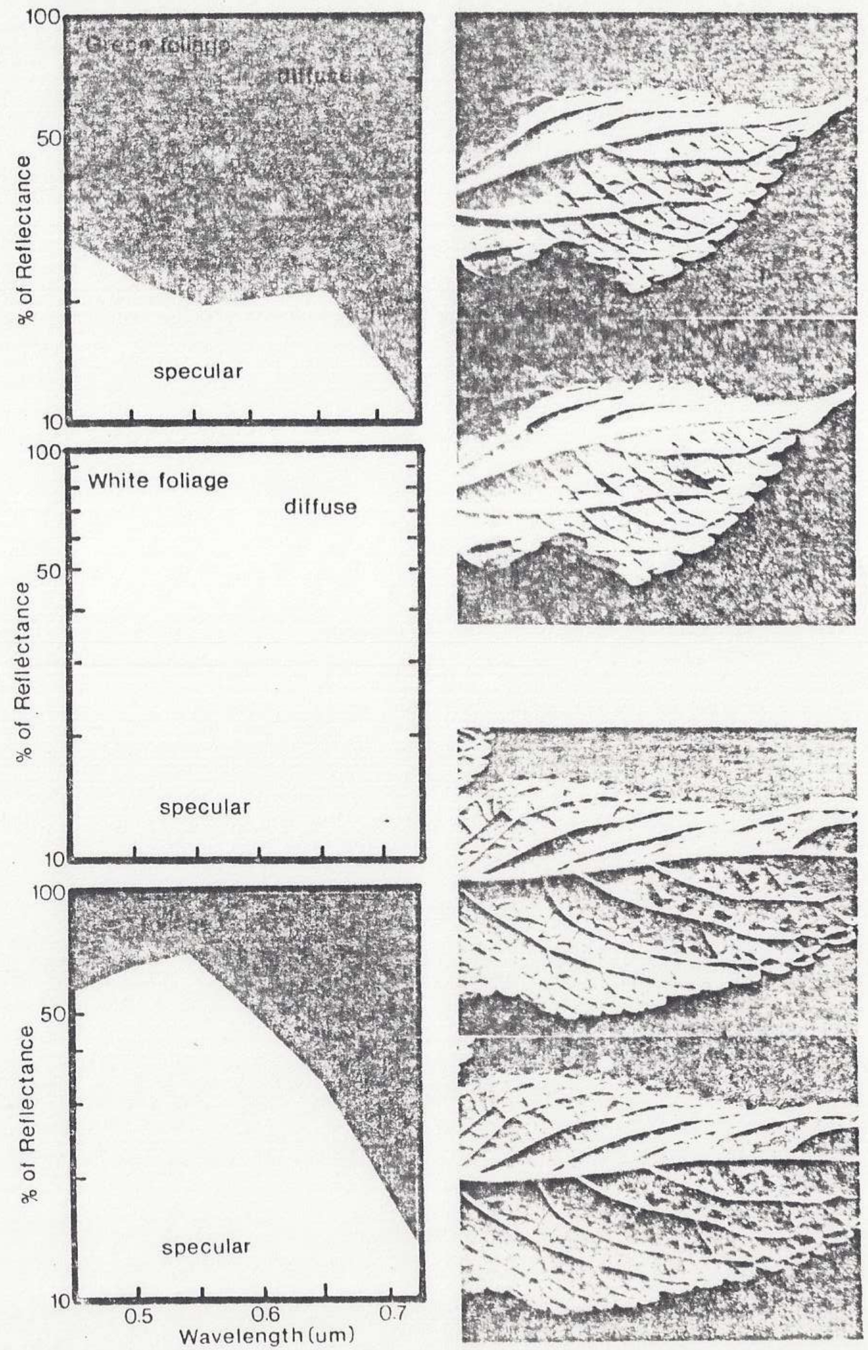
Readings are calibrated with
$BaSO_4$, a diffuse reflecting standard
glass, a specular reflecting standard
dark standard



# RESULTS


Specular Reflectance of 10 Species
1.0
.5
0
Reflectance
adaxial
abaxial
Lambsquarters
Coleus
Milkweed
Velvet leaf
Black nightshade
Soybean
Sunflower
Purple passion
Sorghum
Corn




# Specular Reflectance of Coleus

Coleus provides a unique opportunity to investigate the specular reflecting properties of leaves of a single species but with diverse pigmentations. The specular reflecting properties were measured of (1) the green and white pigmented areas of single variegated leaves of one variety and (2) red pigmented leaves of another variety.

# Conclusions

Specular reflection essentially does not change with either leaf pigmentation or wavelength.

Diffuse reflection does change with leaf pigmentation and wavelength.

Specular reflection can be the predominant factor in leaf reflectance, particularly in portions of the spectrum where pigment absorption occurs.

Specular reflection changes with species.

Specular reflectance of the adaxial and abaxial surfaces is strikingly different for some of the measured species.

These results provide additional evidence that the specular reflectance is a surface phenomena dependent on the micro scale topography and architecture at the air-cuticle interface.