

# Polarization Sensing of Environmental Stress in Plants

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***Polarization spectrometry*** provides strong signals and eliminates the specular interference associated with reflectance from vegetation, or the problems of weak signals associated with chlorophyll fluorescence, e.g., at low temperatures.

***Reflection of polarized light*** from leaves occurs in a specular component that remains polarized and a diffuse component that is depolarized.

***In this research***, we have applied spectroscopic polarimetry to separate the specular and diffuse components. This approach achieves high sensitivity to the diffuse reflectance, which best characterizes the leaf chemistry.



Photo by Aaron Woodbury

Operational prototype (c. August 2003) of polarizing spectrometer set up to measure diffuse reflectance spectra in plants of *Zea mays* L. cv. Golden Beauty.

## ***Theoretical considerations***

p-polarized light in the waveband ~ 400 to 800 nm is incident on the leaf. The polarimeter measures the p- and s-polarized components of reflected light. The degree of polarization of the reflected light is given by:

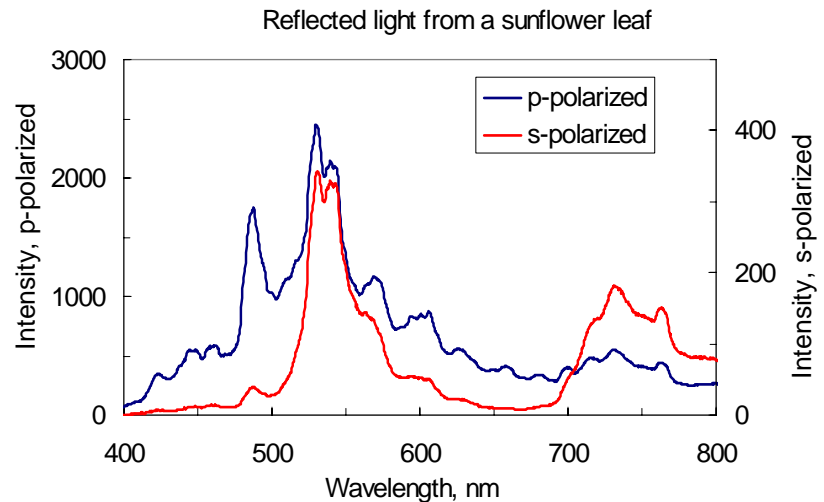
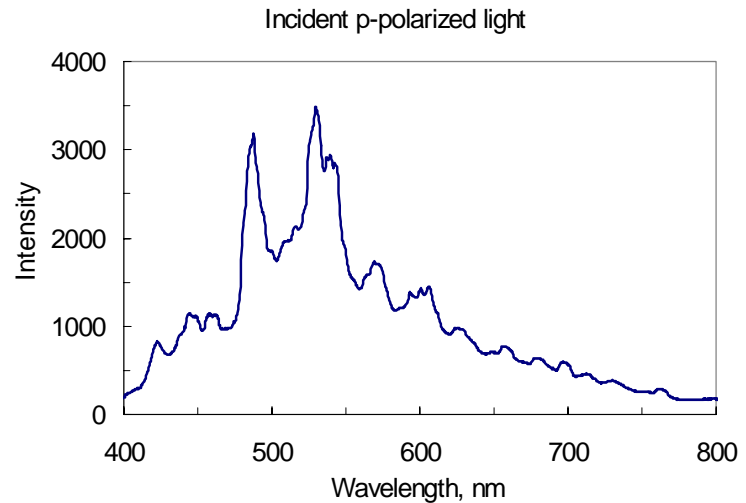
$$P = [(I(p) - I(s)) / (I(p) + I(s))]$$

The depolarized part is [1 - P ]

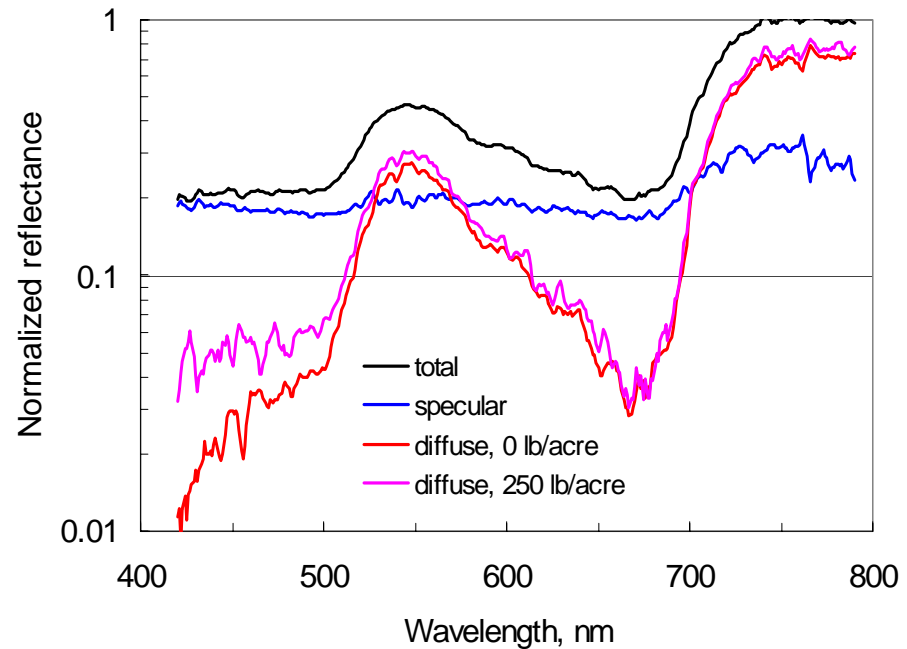
Reflectance (in arbitrary units) is determined by comparing the total reflected intensity with the incident light intensity. The polarized and depolarized reflectivities are then calculated.

**The specular reflectivity** equals the polarized reflectivity. It depends only on the properties of the leaf surface. It varies little with wavelength and may dominate the total intensity of reflected light.

**The diffuse reflectivity** is calculated from the depolarized reflectivity. It depends on the absorption and scattering processes for light that enters the leaf. The diffuse reflectivity is sensitive to leaf chemistry, varies strongly with wavelength, and is accurately measured even if diffusely reflected light is a small fraction of the total reflected intensity.



## Field Evaluations: Crop plant (maize)

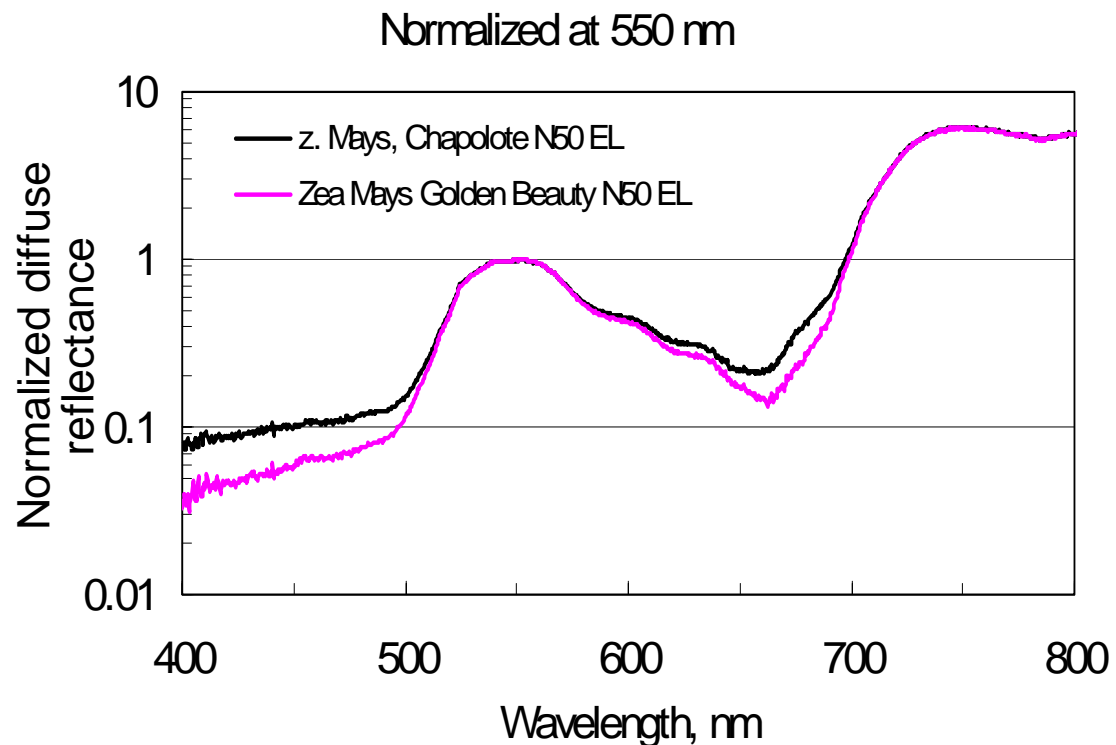


Normalized reflectance from maize (*Zea mays* L.) grown in soil with 0 or 250 lb/acre of N fertilizer. No significant difference is observed in the specular and total reflectances for the two levels of fertilization. The diffuse reflectance depends on the fertilizer level in a part of the spectrum where total reflectance is dominated by the specular component, at 400-500 nm.

## Greenhouse Evaluations: Maize lineages

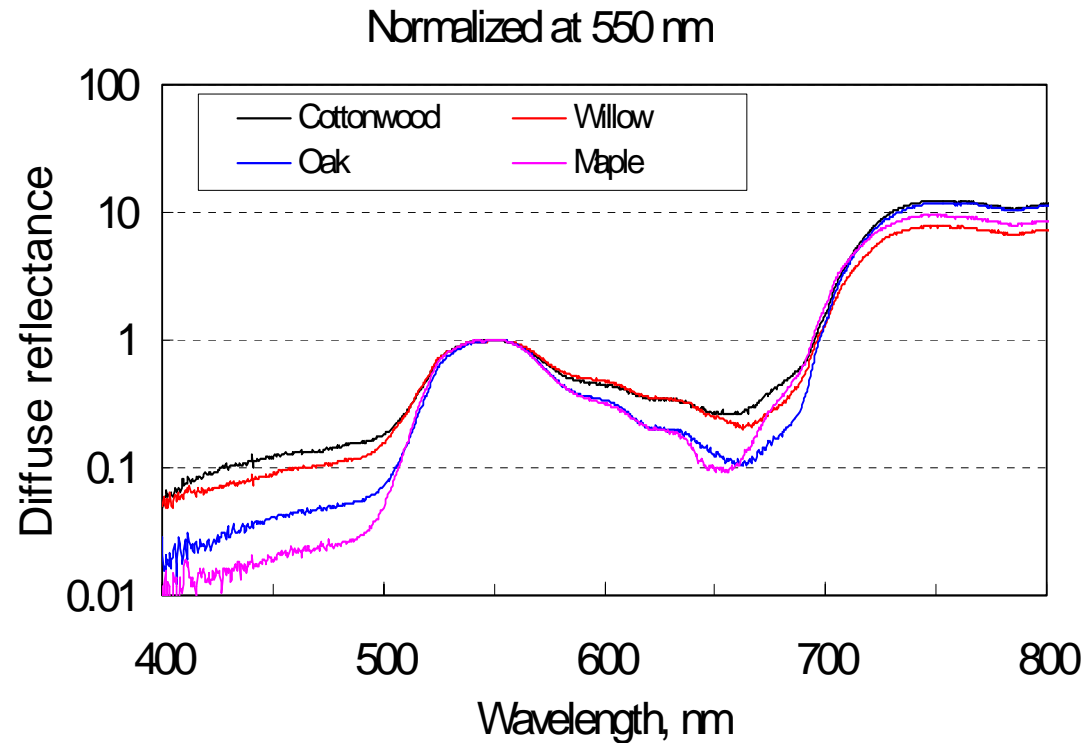


Photo by Aaron Woodbury



Normalized reflectances from a wild maize (Chapalote Pinole Maiz) and a cultivar (*Zea mays* L. cv. Golden Beauty). Preliminary data indicate discrimination between maize origins, and between fertilization applications.

## Ex- situ Evaluations: Trees and Annual plants



Normalized reflectances from leaves collected from common street trees. These spectra indicate differences in tree species identities based on shifts in the normalized diffuse reflectance at 600- 700 nm and 400- 500 nm. Measurements on invasive species indicate similar discrimination.

## ***Observations***

The field measurements were obtained with a remote sensing instrument that was delivered to NASA in 2000 as HYPOP (patent held by CRI). The greenhouse and ex-situ measurements are from preliminary testing of a much smaller and inexpensive instrument. Improvements in the noise characteristics of the new instrument have resolved the diffuse reflectance spectra at wavelengths where reflectance is particularly small. High sensitivity to species and growth conditions occurs where the diffuse reflectance is small.

## ***Prospectus for Ecological Research***

Our preliminary findings indicate that polarization sensing will be useful in both field and greenhouse evaluations of plant stress, such as N enrichment. Further, the strong differences in polarization spectral profiles among tree species, two maize cultivars, and other species (including conifers) strongly supports the use of this analytical tool as a discriminator in invasive species biology, agriculture, forestry, and ecology.



## ***Acknowledgments***

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