

LEAF RELATIVE WATER CONTENT ESTIMATED FROM LEAF REFLECTANCE AND TRANSMITTANCE

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ABSTRACT

Remotely sensing the water status of plants and the water content of canopies remain long term goals of remote sensing research [1]. In the research we report here, we used optical polarization techniques to monitor the light reflected from the leaf interior, R , as well as the leaf transmittance, T , as the relative water content (RWC) of corn (*Zea mays*) leaves decreased. Our results show that R and T both change nonlinearly. The result show that the nonlinearities cancel in the ratio R/T , which appears linearly related to RWC for $RWC < 90\%$. The results suggest that potentially leaf water status and perhaps even canopy water status could be monitored starting from leaf and canopy optical measurements.

Index Terms— leaf relative water content, RWC, leaf reflectance, leaf transmittance

1. INTRODUCTION

Remotely sensing the water status of plants and the water content of canopies remain long term goals of remote sensing research [1]. Estimates of canopy water content

commonly involve measurements in the 900nm – 2000nm portion of the optical spectrum [1]. We have used optical polarization techniques, Fig. 1, to remove leaf surface reflection and to demonstrate that the visible light reflected by the interior of green healthy corn leaves measured *in situ* inversely depends upon the leaf relative water content (RWC) [2].

In the research reported here, we again used optical polarization techniques in order to remove the leaf surface reflection from our measurements. This allowed us to monitor the interiors of detached corn leaf samples during leaf dry down — measuring for each sample the RWC, bidirectional spectral reflectance and bidirectional spectral transmittance over the wavelength range 450nm to 2,500nm. Our new results — like our earlier results [2] — show light scattered by the leaf interior measured in the visible wavelength region generally increased as leaf RWC decreased. However, the spectral character and the much improved signal-to-noise ratio of our new results shows the RWC-linked visible light scattering changes are due to structural changes occurring inside the leaf. Our new results show that scattering changes that occur with changing leaf RWC are not attributable to molecular configuration changes in cellular pigments.

2. METHODS

We harvested fully expanded upper leaves of corn (*Zea mays*) plants in a large field in the vegetative development stage just prior to flowering, immediately placed the leaves in an ice chest partially filled with ice covered with cloth and transported the chest to the lab. We rehydrated the leaves overnight by placing the cut end of each leaf in water and enclosing the remainder of the leaf in a clear plastic bag.

The next morning in the lab, when a leaf sample was needed for purposes of measuring the leaf bidirectional reflectance and bidirectional transmittance, we first completed as quickly as possible the following sequence: remove the now fully hydrated leaf from the plastic bag, blot the leaf dry, trim the leaf in order to select a 4.5 cm x

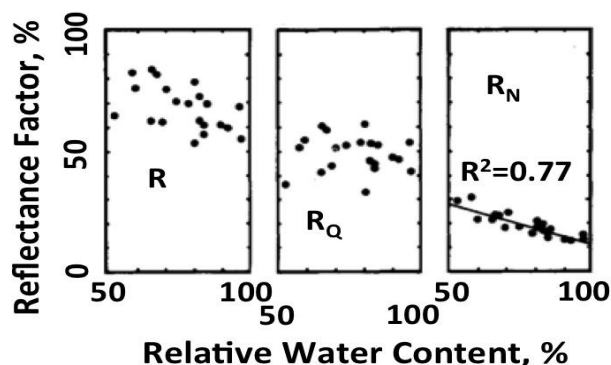


Fig. 1. Leaf relative water content could be estimated from R_N , the non-polarized portion of the leaf reflectance, R , but not R_Q , the polarized portion of leaf reflectance [2].

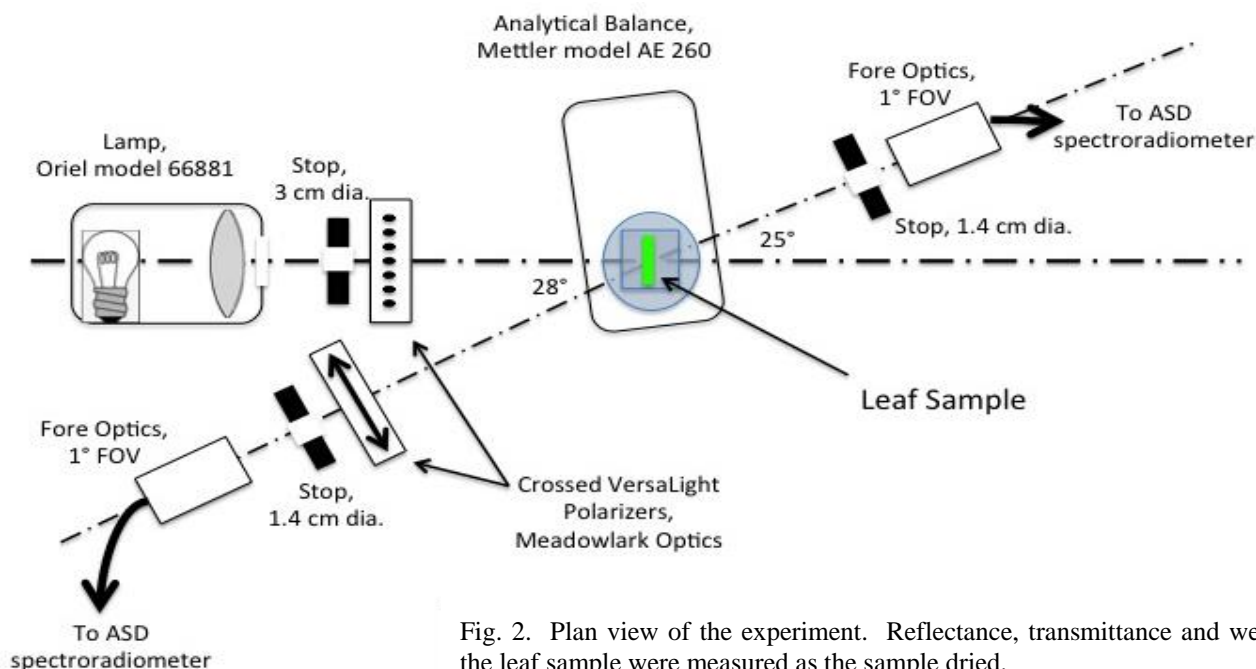


Fig. 2. Plan view of the experiment. Reflectance, transmittance and weight of the leaf sample were measured as the sample dried.

4.5 cm leaf sample, mount the leaf sample in the sample holder and, Fig. 2, place it on the pan of the analytical balance, Mettler model AE 260.

We illuminated the leaf sample, Fig. 2, with a collimated beam of white light provided by a current controlled lamp, Oriol model 6681, and immediately began collecting spectral data and sample weights with the aid of the analytical balance and two Analytical Spectral Devices spectroradiometers. The leaf sample, initially fully hydrated at 100% RWC, rapidly began losing water when exposed to the light beam.

Data collection continued for typically 1.5 to 2 hours until we estimated the leaf sample RWC was less than 65% (approximately the permanent wilting point for corn).

We later dried the leaf samples in a 65 °C oven for 2 days, cooled the leaf samples and estimated RWC for a specific leaf weight as

$$RWC = \frac{(\text{fully hydrated leaf weight}) - (\text{leaf weight})}{(\text{fully hydrated leaf weight}) - (\text{dry leaf weight})}$$

We calibrated the spectra using a multi step procedure involving observation of Spectralon™ by both reflectance and transmittance spectrometers and observation of opal glass by the transmittance spectrometer. The crossed polarizers eliminated the light reflected by the leaf surface, allowing the reflectance spectrometer to observe only the

light reflected by the leaf interior. We collected spectral data as the leaf dried and later calculated the leaf interior reflectance, R , and the leaf transmittance, T .

3. RESULTS AND DISCUSSION

Our results, Figs. 3 and 4, show that the ratio R/T increases as RWC decreases for $RWC < 90\%$. (For the cells of these corn leaves, $RWC = 90\%$ is approximately zero turgor, the point at which the internal hydrostatic pressure in the leaf cells is zero.) We found that R increased and T decreased as RWC decreased from 90%. In the wavelength region between 550nm and 650nm, Fig. 3, the R/T ratio changed slowly with wavelength as RWC decreased, revealing no fine spectral structure. This suggests these RWC-linked visible light scattering changes are due to leaf structural changes rather than wavelength dependent pigment changes; that is, as RWC decreases, the cells of the leaf change structurally from what are initially fully hydrated 'plump grapes,' becoming more like 'wrinkled raisins' as the RWC approaches the permanent wilting point of the leaf.



Our model for the leaf dehydration process assumes that within a cell the cell wall and cell membrane surface areas do not change as the cell loses water and its volume

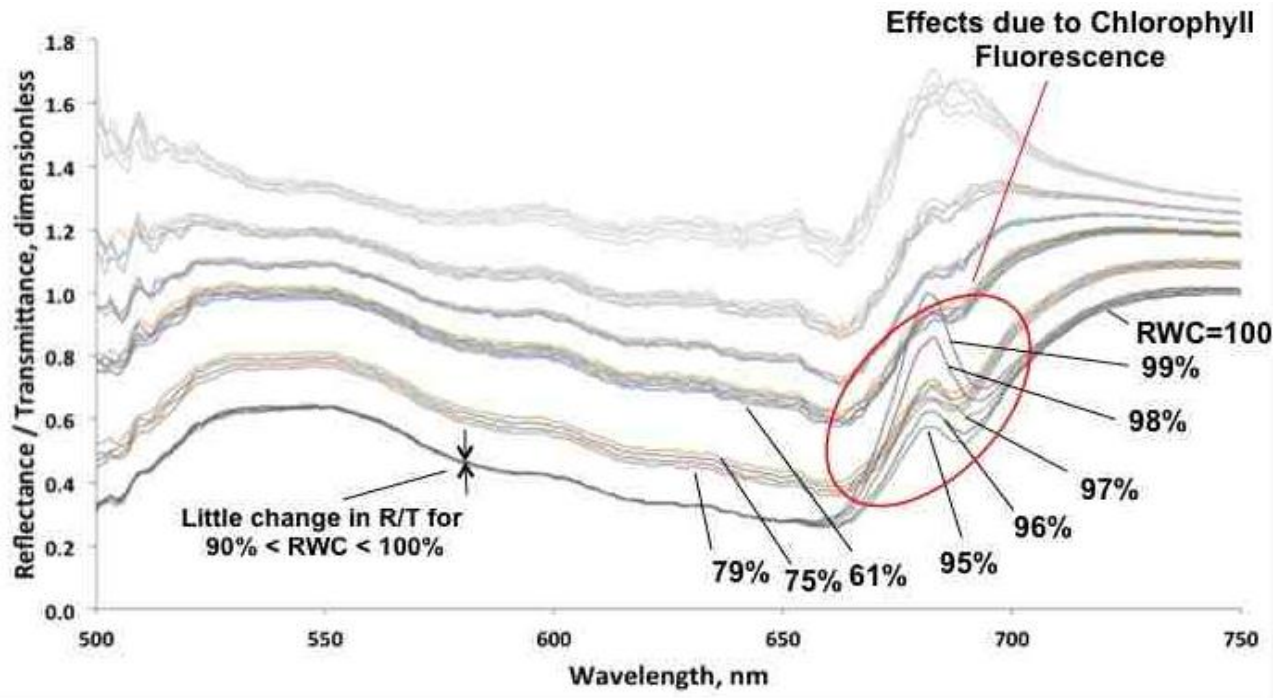


Fig. 3. The ratio of the leaf reflectance/leaf transmittance increases as the relative water content of the leaf decreases.

decreases. This means that as RWC decreases from zero turgor to the permanent wilting point, the cell surface area per unit volume increases. And from optics this means the amount of light scattered by each cell increases.

The percent increase in scattering from a cell, as RWC decreases, is assumed approximately the same for similar cells throughout the leaf. As a consequence, the intensity of the light scattered out of an incident, penetrating light beam

is greatest where the intensity of the light beam is greatest – which is where the incident beam enters the leaf. Thus, the leaf internal reflectance, R , which is determined as the portion of the light beam first scattered out of the beam and then out of the leaf, increases as RWC decreases below 90%. Finally, as R increases, the amount of light passing through the leaf – its transmittance, T – decreases. Both R and T change nonlinearly as RWC decreases.

As Fig. 4 shows, the ratio R/T linearizes the changes in R and T as RWC decreases below zero turgor. The results, Fig. 4, reveal the R/T curves for various wavelengths are offset vertically, one compared to another, suggesting that measurements of R and T at one visible wavelength might allow estimation of the RWC of water stressed corn canopies for which $RWC < 90\%$.

The results, Fig. 3, suggest that chlorophyll fluorescence strongly affects the magnitude of the R/T ratio in the red chlorophyll absorption region around 680 nm.

It must be noted that while the transmittance, T , is easily measured using a commercially available spectroradiometer, our measurement of the leaf interior reflectance, R , required use of polarization filters; these filters effectively allowed us to remove from the calculations that portion of the total leaf reflectance that originates at the leaf surface.

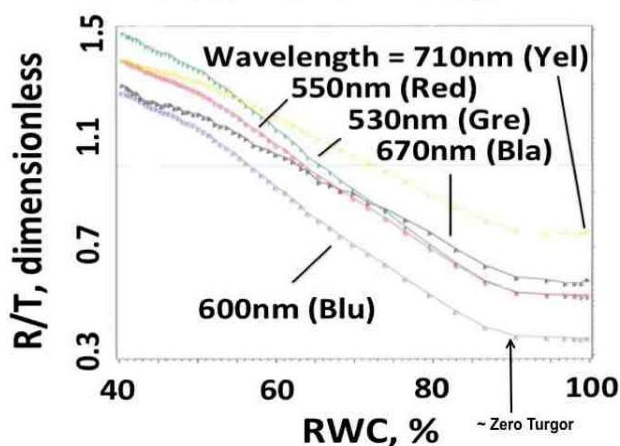


Fig. 4. The ratio leaf interior reflectance/leaf transmittance increases linearly as relative water content (RWC) decreases below zero turgor, approximately 90%.

4. CONCLUSIONS

Our results show that for our corn leaves the ratio of leaf interior reflectance divided by leaf transmittance appears linearly related to RWC for $RWC < 90\%$. The results suggest that potentially leaf water status and perhaps even canopy water status could be monitored starting from leaf and canopy optical measurements. The remote sensing approach would depend upon applying optical polarization techniques [3] to plant canopy spectra in order to remove from the measurements the light reflected by the surfaces of the leaves of the canopy.

5. REFERENCES

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