

EFFECTS OF LEAF WATER CONTENT ON REFLECTANCE

Chun Qi Joy NG¹, Yun Ying TOH¹, Chee Yong Leslie LAM¹,
Chew Wai CHANG², Soo Chin LIEW²

¹NUS High School of Mathematics and Science
20 Clementi Avenue 1, Singapore 129957

²Centre for Remote Imaging, Sensing and Processing, National University of Singapore
Blk SOC1 Level 2, Lower Kent Ridge Road, Singapore 119260
Email: scliew@nus.edu.sg

KEY WORDS: Reflectance, Leaf Water Content, Reflectance Ratio

ABSTRACT The aim of this project was to study how the reflectance spectra of leaves were affected by water content. Reflectance spectra of leaves were measured using a portable field spectrometer (ASD FieldSpecPro). The leaf water content was measured in the laboratory by measuring the fresh weight and the dry weight after heating in an oven. The leaf reflectance at several stages of drying was measured to determine the change in reflectance due to decreasing water content. The reflectance spectra were analyzed to determine specific spectra features that correlate well with the equivalent water thickness (EWT). The wavelengths that have high correlation with EWT are near the green peak at 550 nm, near the red edge at 730 nm and the water absorption band at 1440 nm. Correlation with EWT can be improved when ratios of reflectance at wavelengths where there is high correlation with EWT are taken. The results are useful in developing non-destructive methods of determining the water content of leaves.

INTRODUCTION

Green vegetation has a unique reflectance signature when compared to other types of land cover. Reflectance of green vegetation depends on the absorption and scattering properties of leaves. In the short-wave infrared (SWIR) region, the reflectance depends on the plant's water content. Plant water status may be revealed by measuring the spectral absorption features by water in the near infrared (NIR) to short-wave infrared (SWIR) region. Water exhibits strong absorption bands located at 1450, 1940 and 2500nm. There are also weak absorption bands at the NIR region near 970 and 1200nm. On top of that, the reflectance of dry vegetation shows an absorption feature that is centered at 1780 nm due to other chemicals in the plant such as sugar, starch and cellulose.

In the SWIR region, water is the dominant factor for the reflectance. It has been observed that leaf reflectance in this region is related to changes in the equivalent water thickness (EWT) but not to the gravimetric water content. EWT is defined as the mass of water per unit leaf area. It is an absolute measure of water content that is independent of the dry matter content of leaves. A significant correlation was found to exist between EWT and reflectance throughout most regions of the NIR wavelengths at 1120 – 1870 nm and 1980-2440 nm wavelengths (Datt 1999). NIR reflectance was also shown to have potential usefulness in monitoring the water status of woody plants (Baldini et. al. 1997). Ceccato et. al. (2001) showed that it was possible to retrieve EWT at the leaf level from leaf reflectance measurements. A combination of SWIR and NIR was necessary to provide a better estimation of EWT. The simple ratio of reflectance at 1600nm and 820nm was used as a first approximation to retrieve EWT. Yu et.al. (2000) proposed universal formulae for estimating leaf water status of herbaceous and woody plants based on

spectral reflectance properties. In their experiment, reflectance in visible and near infrared regions increased with the progression of air-drying soybean leaves.

In this study, the correlation of the equivalent water thickness (EWT) and the reflectance of the leaf from 350 nm to 2500 nm was studied, specifically at wavelengths 970 nm, 1200 nm, 1400 nm and 1940 nm. Experiments were carried out to measure reflectance spectra of the leaves of a leafy green vegetable, *B. chinensis* var. *parachinensis*, which is also commonly known as *Choy Sum*.

METHODOLOGY

Leaves of *B. chinensis* var. *parachinensis* were dehydrated by heating in an oven. At regular interval during the drying process, the mass of the leaf was measured and the leaf reflectance was measured with a spectroradiometer (FieldSpec-Pro) using the integrating sphere method. Leaves of *Choy Sum* used in the experiments were purchased from local grocery stores. In order to have a wide range of *Choy Sum* leaf water content, *Choy Sum* originated from different countries were used.

Thirty leaves of *Choy Sum* were randomly chosen. Prior to heating, the mass of each leaf was measured and the leaf outline was traced out on a piece of A4 size paper to find the leaf surface area. The leaf reflectance spectrum was measured before heating. At 15 minutes intervals during the process of heating in the convection oven (at 60°C), each leaf was removed from the oven and transferred to a sealed ziploc bag to prevent water loss before its mass was measured. The leaf was then removed from the bag and placed in the integrating sphere for reflectance measurement. The procedure was repeated until the leaves are too crispy to be placed in the integrating sphere. Heating stopped when the leaf reached its dry mass. This happened when the mass of the leaf measured did not change for at least two consecutive measurements.

EWT was measured by taking the difference between the fresh mass and dry mass, divided by leaf area. An image of the leaf outline was captured using a digital camera and imported to an image processing software (ENVI). The surface area of the leaf was found by calculating the number of pixels occupied by the leaf. The area of an A4 paper was used as a normalizing factor to calculate the leaf area. The correlation of EWT with the leaf reflectance spectra were computed using a spreadsheet software (Microsoft Excel) with statistical analysis functions.

RESULTS AND DISCUSSIONS

Fig. 2 shows the typical reflectance spectra at different stages of dryness. The greatest reflectance change occurs in the major water absorption band near 1440 nm. The reflectance increases as the leaf desiccates. At the green region ($\approx 550\text{nm}$), the height of the peak decreases with decreasing water content. However, the peak remains at roughly the same wavelength because the pigment and chlorophyll are still absorbing at the same wavelength, unaffected by the change in water content. Furthermore, the position of the red edge (near 720 nm) shifts towards the NIR region.

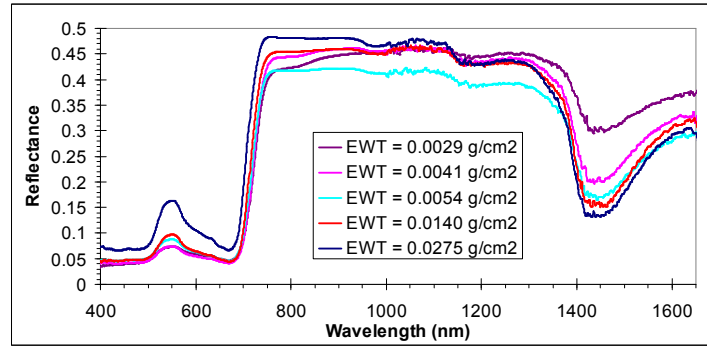


Fig. 2: Typical leaf reflectance at different stages of heating

Fig. 3 shows a linear correlogram for the 30 leaves which have undergone heating in the oven. A positive correlation coefficient means that the reflectance increases with increasing EWT while a negative correlation coefficient means that the reflectance decreases with increasing EWT. The wavelength ranges with relatively high correlation of the reflectance with EWT are:

- near 550 nm (correlation coefficient ≈ 0.23),
- near 730 nm (correlation coefficient ≈ 0.36),
- near 1440 nm (correlation coefficient ≈ -0.64).

At the absorption band of water near 1440 nm, reflectance has the highest correlation with the water content. This is also evident from the reflectance spectra shown in Fig. 2 that the reflectance increases as the leaf water content decreases. The reflectance peak at 550 nm and the wavelength just beyond the red edge (at 730 nm) have positive correlation with EWT. It is interesting to note that the reflectance at the minor absorption bands near 970 nm and 1220 nm do not have much correlation with EWT.

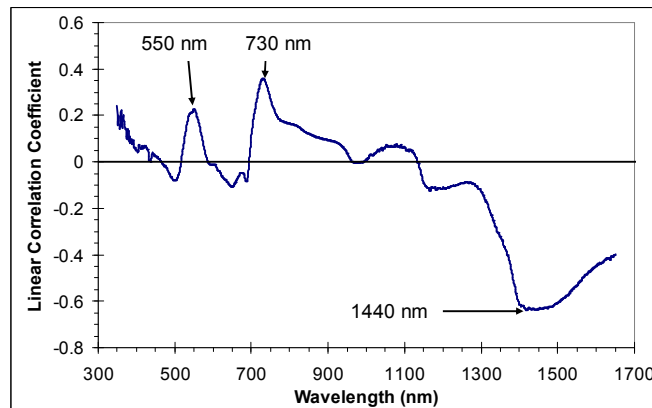


Fig. 3: Correlogram of reflectance with water content for all wavelengths from 350 nm to 1650 nm

Further analysis is carried out at 5 different wavelengths: 560nm, 680nm, 800nm, 1440nm and 1600nm. These wavelengths were chosen due to their correspondence to peaks and absorption bands in the reflectance spectra. From Fig. 3, it is seen that the reflectance at 1440nm and 1600nm has high correlation with EWT whereas the other three wavelengths are practically uncorrelated with EWT. The scatter plots of the reflectance versus EWT are plotted for each wavelength in Fig. 4 to Fig. 8. Indeed for 1400nm (Fig. 7), a clear relationship can be seen ($R^2 = 0.50$) that as water content increases, reflectance decreases. The correlation is weaker for 1600 nm ($R^2 = 0.28$). For the other 3 wavelengths, generally, there is no clear relation between the reflectance and EWT ($R^2 < 0.05$), indicating that these wavelengths do not correlate with water content.

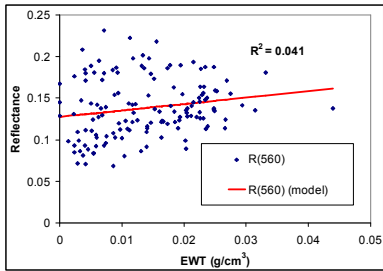


Fig. 4: Reflectance vs EWT at 560nm

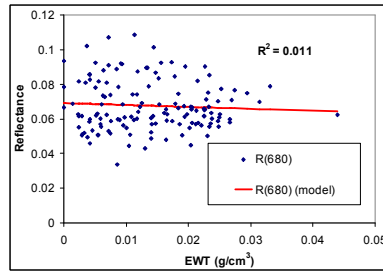


Fig. 5: Reflectance vs EWT at 680nm

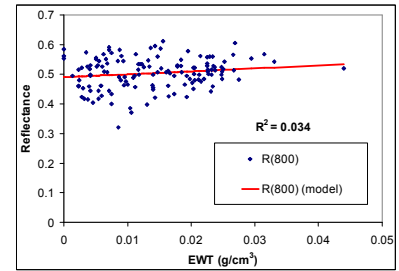


Fig. 6: Reflectance vs EWT at 800nm

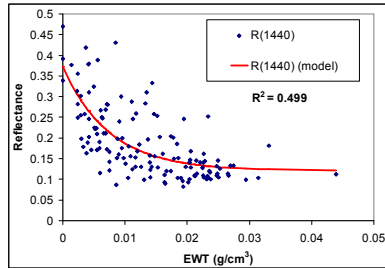


Fig. 7: Reflectance vs EWT at 1400nm

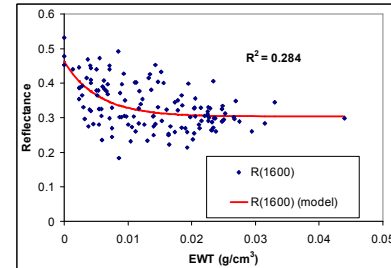


Fig. 8: Reflectance vs EWT at 1600nm

It is seen that the reflectance at 1440 nm and 1600 nm potentially can be used for characterizing the leaf water content. By normalizing the reflectance at these to wavelengths by the reflectance at another suitably chosen wavelength, the correlation can be improved. We next compute the reflectance ratios: $R(1440)/R(560)$, $R(1440)/R(680)$, $R(1440)/R(800)$, $R(1600)/R(560)$, $R(1600)/R(680)$, and $R(1600)/R(800)$. Scatter plots of these reflectance ratios are plotted in Fig. 9 to Fig. 14.

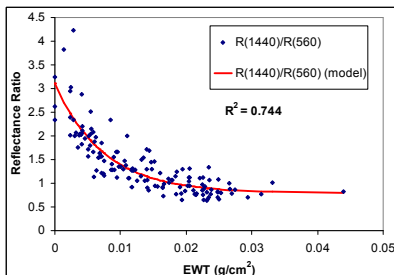


Fig. 9: Reflectance ratio $R(1440)/R(560)$ vs EWT

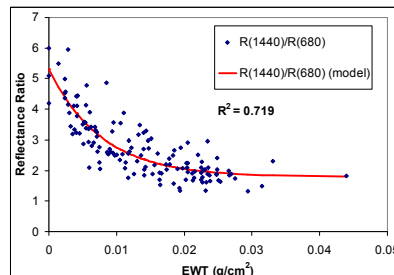


Fig. 10: Reflectance ratio $R(1440)/R(680)$ vs EWT

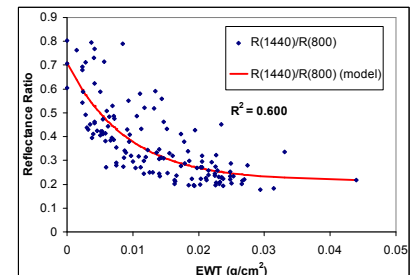


Fig. 11: Reflectance ratio $R(1440)/R(800)$ vs EWT

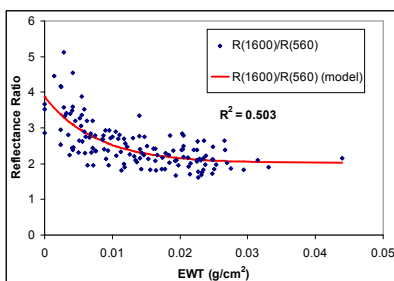


Fig. 12: Reflectance ratio $R(1600)/R(560)$ vs EWT

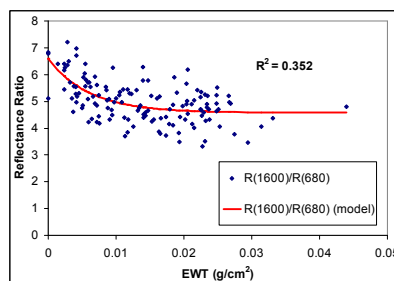


Fig. 13: Reflectance ratio $R(1600)/R(680)$ vs EWT

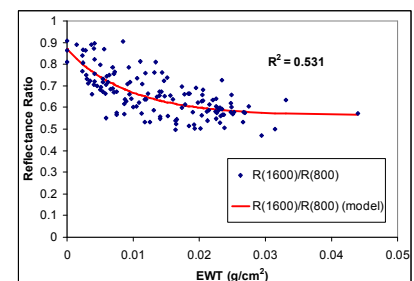


Fig. 14: Reflectance ratio $R(1600)/R(800)$ vs EWT

In these scatter plots, the reflectance ratios are fitted to a model equation of the form,

$$r = a \exp(-w/c) + b$$

where r is the corresponding reflectance ratio, w is the EWT and a , b , c are fitting parameters. The value of the coefficient of determination (R^2) is computed for each reflectance ratio and is tabulated in Table 1. Note that b in this equation is the value of the reflectance ratio at high water content while $a + b$ is the value of the ratio for a dry leaf with zero EWT.

Table 1: Coefficient of determination and fitting parameters for the relation between the various reflectance ratios and EWT

Reflectance Ratio	Coefficient of Determination (R^2)	a	b	c
R(1440)/R(560)	0.744	2.313	0.793	0.0074
R(1440)/R(680)	0.719	3.521	1.789	0.0077
R(1440)/R(800)	0.600	0.495	0.214	0.0091
R(1600)/R(560)	0.503	1.838	2.016	0.0078
R(1600)/R(680)	0.352	2.009	4.578	0.0061
R(1600)/R(800)	0.531	0.306	0.5618	0.0095

Indeed, the correlation improves for the relations between the reflectance ratios and EWT. For example, the relation between the reflectance ratio R(1440)/R(560) and EWT has the highest R^2 value of 0.744, which means that 74.4% of the variation of this reflectance ratio can be attributed to the difference in EWT. For the reflectance ratio involving the reflectance at 1600 nm, the ratio R(1600)/R(800) has the highest R^2 value of 0.531.

CONCLUSION

Highest negative correlation of reflectance with EWT occurs at 1440nm and hence this wavelength can be useful for non-destructive determination of leaf water content. However, since the absorption band of atmospheric water vapour is also near this wavelength, this wavelength is probably not useful for remote sensing of leaf water content using a space-borne sensor in the tropical regions. The high water vapour content in the atmosphere would result in a low signal to noise ratio in this wavelength region. For space-borne sensors, the reflectance peak near 1600 nm can be used instead, though the correlation with EWT is not as high. The correlation can be improved if reflectance ratios are used. The ratios R(1440)/R(560) and R(1600)/R(800) seem to be optimal for the reflectance at 1440 nm and 1600 nm respectively.

REFERENCES

1. Baldini, J, Facini, O, Nerozzi, F, Rossi, F, Rotondi, A, 1997, "Leaf characteristics and optical properties of different woody species", *Trees* 12: 73-81.
2. Carter, G. A. 1993, "Responses of leaf spectral reflectance to plant stress". *American Journal of Botany* 80: 239–243
3. Ceccato, P., Flasse, S., Tarantola, S, Jacquemoud, S. and Grégoire, J. 2001, "Detecting vegetation leaf water content using reflectance in the optical domain", *Remote sensing of Environment* 77: 22-23.
4. Curran, P. J., 1989, "Remote sending of foliar chemistry". *Remote Sensing of Environment*, 30: 271–278.
5. Datt, B., 1999, "Remote Sensing of Water Content in *Eucalyptus* Leaves", *Australian Journal of Botany*, 47: 909-923.

6. Peñuelas, J. and Inoue, Y., 1999, "Reflectance indices indicative of changes in water and pigment contents of peanut and wheat leaves", *Photosynthetica* 36 (3):355-360.
7. Yu G.Y., Miwa T., Nakayama K., Matsuoka N., Kon H., 2000, "A proposal for universal formulas for estimating leaf water status of herbaceous and woody plants based on spectral reflectance properties", *Plant and Soil* 227: 47-58.

ACKNOWLEDGMENT

The first three authors (CQJ Ng, YY Toh, CYL Lam) are students of the NUS High School of Mathematics and Science. This project was conducted under the mentorship of SC Liew and CW Chang of the Centre for Remote Imaging, Sensing and Processing (CRISP). Ng, Toh and Lam wish to express their thanks to their teacher mentor, Mr. Jeremy Ang, for his guidance and encouragement, and to the NUS High School for sponsoring their attendance at this Conference. Liew and Chang acknowledge funding support from the Agency for Science, Technology and Research (A*STAR), Singapore.