

Abstract

Nitrogen stress in crops has been measured for many years using inexpensive spectrometers with ranges up to 1000 nm. Detectors for spectral measurements above 1000 nm are expensive, but they can be used to analyze water stress in plants by measuring reflectance of the major water bands at 1450 nm and 1900 nm. Although there is a water band at 970 nm, it is generally considered to be too small and inconsistent to use as an indicator of water stress. This experiment aims to determine the correlation between reflectance at 970 nm and 1450 nm. This was done by taking single-leaf spectral measurements of excised soybean leaves over a two hour period. This data was then analyzed using three water stress indices and compared to the values at 1450 nm. Reflectance values at 970 nm were highly correlated with values at 1450 nm. The data indicate that water stress can be determined using the 970 water band.

Introduction

Water stress in crops is usually detected only after it becomes visually apparent. This is often too late to avoid a reduction in crop yield. Expensive spectrometers with ranges beyond 1000 nm have been used to determine water stress

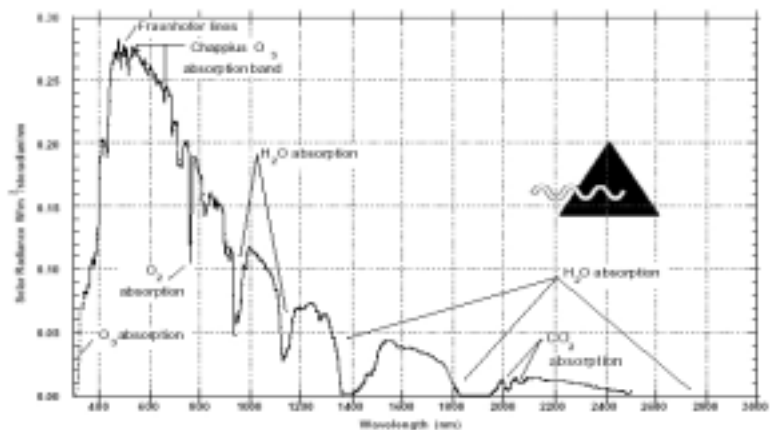


Figure 1: The most common water bands between 400-3000 nm (adapted from ASD, 1999).

in plants by analyzing reflectance measurements at several key wavelengths called water bands.

The most prominent water bands are at 1400 and 1900 nm (Figure 1) and reflectance at these wavelengths has been shown to correspond to water content in plant tissue (Peñuelas *et al.*, 1997). However, spectroradiometers with wavelength ranges high enough to measure these water bands are expensive. It is also difficult to measure water stress at these wavelengths from satellites due to high levels of water absorption in the earth's atmosphere (Figure 1). Although the 970 nm band has historically been considered too small to accurately measure water stress, Peñuelas *et al.* (1993) found that it can be a useful water status indicator for complete canopies where Leaf Area Index does not vary greatly. There are now several less-expensive silicon-diode spectrometers available that can accurately measure wavelengths up to 1000 nm. The objective of this study was to determine if these silicon-diode spectrometers can be used to measure water stress in soybean leaves by measuring reflectance at the 970 nm water band.

The following three indices were compared:

1. Reflectance Water Index (WI);
2. Band depth analysis; and
3. First-order derivative green vegetation index (1DGVI).

The **Water Index (WI)** is the ratio between the reflectance at a water band wavelength to a nearby reference wavelength where there is no absorption due to water content variability (Peñuelas *et al.*, 1993; Peñuelas *et al.*, 1997).

Band depth analysis uses a process called continuum removal (Kokaly and Clark, 1999) in which a linear continuum line is approximated across an area of absorption, connecting two unaffected points of the spectrum. The band depth is then calculated by dividing the reflectance values by the values of the continuum line and integrating across the length of the continuum line (Kokaly and Clark, 1999; Curran *et al.*, 2001).

First derivative green vegetation index (1DGVI) can also be used to estimate water content in plant tissue (Elvidge and Chen, 1995). This index, while based on a complex calculus formula involving integrated derivatives, reduces down to a simple difference between a wavelength within the water band, which is subtracted from a reference point wavelength. This difference is the 1DGVI.

Materials and Methods

This test was conducted using multiple leaves from a mature soybean plant grown in soil-less media under greenhouse conditions. Reflectance measurements were taken of intact leaves, which were then excised from the plant. Spectral measurements were then taken every 20-30 minutes for two hours as the water content decreased. The spectral values for the leaves were averaged and normalized to a wavelength not affected by water content (1080 nm, Figure 2). Three indices (WI, band depth, and 1DGVI) were used to compare water band

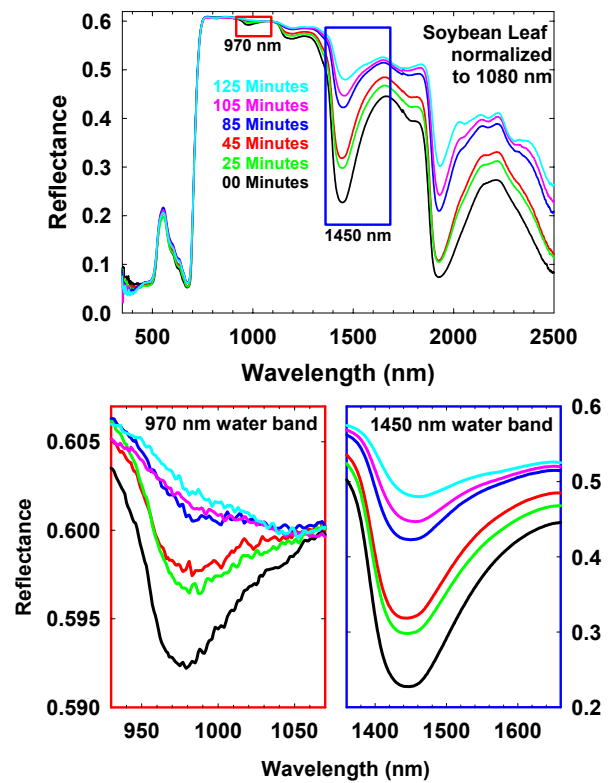


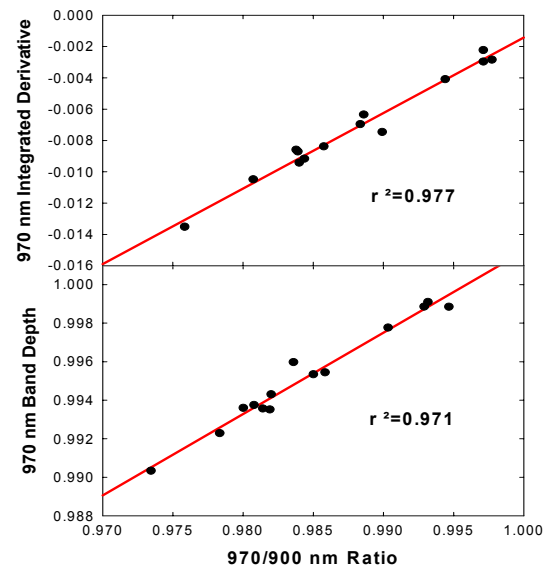
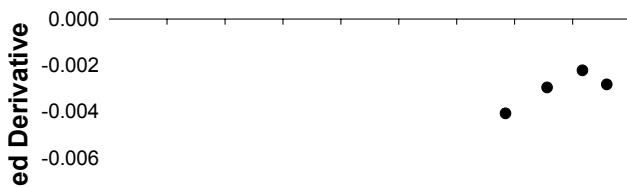
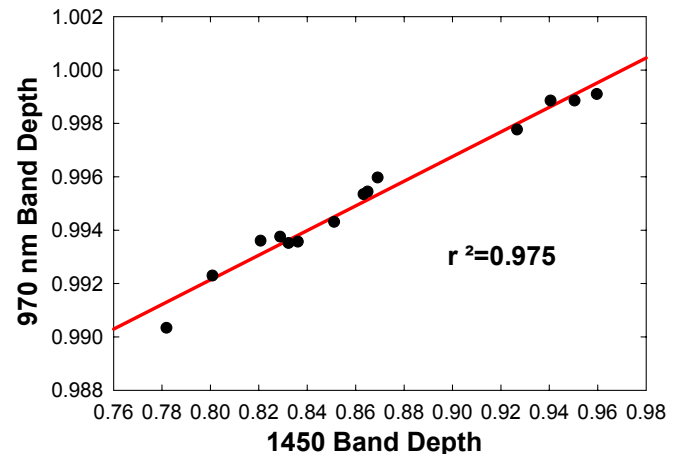
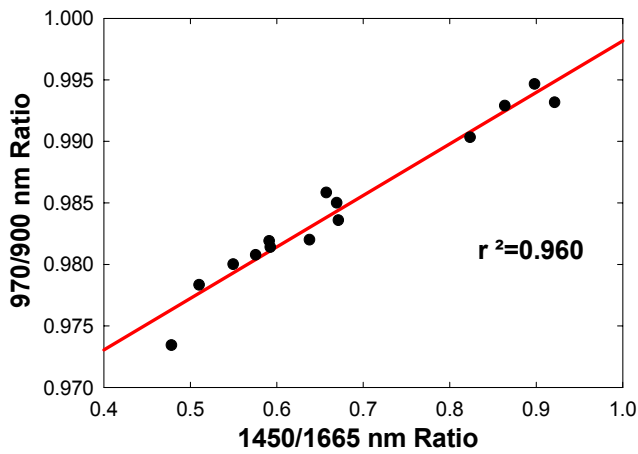
Figure 2: 970 and 1450 nm water bands show similar trends as water content decreases.

reflectance values at 970 nm and 1450 nm. Linear regression analysis was used on the results from all three indices to determine how well water stress indicated by the smaller band at 970 nm correlated to the differences found at the larger 1450 nm band. Regression was also used to compare how well the three indices correlated with one another. Both the $R_{970/R900}$ and $R_{1450/1665}$ values were used to perform these regressions.

Results

All three indices demonstrated that the 970 nm water band indicates water stress (Figures 3 to 6). The correlation between the test results for 970 nm and 1450 nm was surprisingly high. The r^2 for the Water Index was 0.960 (Figure 3), the r^2 for the band depth was 0.975 (Figure 4), and the r^2 for the 1DGVI was 0.944 (Figure 5).

All three tests correlated well with each other. The R970/R900 values are shown, but the R1450/1665 values were equally correlated. The band depth vs. WI ratio had an r^2 of 0.971 and the 1DGVI vs. WI ratio test had an r^2 of 0.977 (Figure 6).



Conclusion

Although the water absorption band at 970 nm is small, accurate estimates of water stress in plant tissue might be possible through the use of any, or all, of the three indices used in this study. The quantitative relationship between leaf water content and the water absorption band depth, measured with any of the three indices, remains to be determined. Based on the results found in this study, and using reflectance at 1450 nm as reference, all three of the indices appear to provide accurate estimates of water stress at the 970 nm water band.

The results of this study were based entirely on single leaf measurements on leaves that experienced rapid and severe water content depletion caused by removing the leaves from the plant. Similar reflectance measurements on intact plants need to be conducted to confirm the results found in this preliminary report. Further studies could also include comparison of leaf reflectance with actual soil and plant water content to develop a method to quantify water stress based on reflectance values. This would help track plant watering more accurately, which in turn could reduce over-watering and increase crop yield.

Literature Cited

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