Orchard Water Stress Detection Using High-Resolution Imagery

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Abstract

This communication presents the Photochemical Reflectance Index as a pre-visual water stress indicator for olive and peach trees. Experiments were conducted on orchards located in southern Spain, where different deficit irrigation treatments were applied. The first field campaign was carried out in 2005 acquiring 2 m spatial-resolution imagery with the hyperspectral sensor AHS operated by the Spanish Aerospace Institute (INTA). The other campaigns happened in the summers of 2007 and 2008 when a thermal camera (Thermovision A40M; FLIR, USA) and a 6-band multispectral camera (MCA-6, Tetracam, Inc., California, USA) with a spatial resolution of 0.40 and 0.15 m respectively were used. Results show high correlation between PRI derived from high-resolution imagery and conventional water stress indicators measured in the field (i.e. stomatal conductance and stem water potential). For instance, a coefficient of determination of 0.8 was found for the relationship between crown PRI and temperature for peach trees, and for that between crown PRI and stem water potential in olive trees. We conclude that high-resolution multispectral imagery can be used for the remote detection of water stress via a physiological index, PRI, and that this technique is a viable option for irrigation scheduling of orchard crops.

INTRODUCTION

Recent advances in remote sensing include the development of platforms to acquire high-resolution thermal and multispectral imagery with rapid revisit time. In the scope of precision agriculture, the high spatial resolution is critical to map vegetation status at the stand level. Remote sensing of water stress has been traditionally attempted by using thermal information related to canopy temperatures and indices related to vegetation structure or, indirectly, to leaf water status. Until now, assessment of pre-visual water stress via remote sensing has been limited by the fact that many of the indices are indicative of stress only once the effects are visible. However, other indices related to internal physiological processes and photosynthetic capacity can be used to assess pre-visual water stress. This is the case of the Photochemical Reflectance Index (PRI), developed for the study of the epoxidation state of xanthophyll pigments. Xanthophyll pigment composition changes under stress conditions to avoid excessive energy accumulation in photosystems when photosynthetic rate is limited by water stress. Before these studies were conducted, PRI had been demonstrated to be related to photosynthetic capacity and stress conditions at leaf scale (Thenot et al., 2002; Winkel et al., 2002) or using laboratory experiments (Evain et al., 2004; Dobrowsky et al., 2005; Peguero-Pina et al., 2008; Sun et al., 2008). This manuscript presents the first studies carried out on water stress detection using PRI derived from multispectral imagery on commercial fields. The methodology presented here could be applied for water stress detection in orchards where the trees have identical structural characteristics. In case of heterogeneity in leaf area index or chlorophyll content, a more complex methodology should be applied for water stress detection as presented in Suárez et al. (2009).

MATERIALS AND METHODS

This manuscript presents results from two study sites located in Andalusia (Spain). The first site is an irrigated 4 ha-orchard established in 1997 with olive trees (*Olea europaea* L. cv. “Arbequino”) in a 3.5x7 m grid. Drip irrigation permitted the use of different water treatment amounts within the same field. The experiment was designed in an area of six rows with three different water treatments: 2 deficit-irrigation treatments and one block of full-irrigated trees used as control (see Suárez et al. (2008) for a full description). The second study site was within a commercial peach orchard (*Prunus persica* cv. “BabyGold8”) planted in 1990 in a 5x3.3 m grid. A subset of 6 lines x 30 peach trees each were irrigated differently than the rest of the orchard. The non-stressed trees were drip irrigated starting in mid May with an application rate equivalent to 80% of calculated crop ET. Three different deficit irrigation treatments were applied starting irrigation at Stage III of fruit development (rapid growth stage), a full description can be found in Suárez et al. (2010).

In the field, stomatal conductance (G) and stem water potential (Ψ) were measured with a leaf steady-state porometer (model SC-1, Decagon Devices, Washington, DC, USA) and a Scholander pressure bomb (PWSC Model 3000, Soil Moisture Equipment Corp., California) respectively. Leaf reflectance measurements were also taken in the field at the time of the flights overpass with an ASD Field Spectrometer (FieldSpec Handheld Pro, ASD Inc., CO, USA) with a leaf clip probe.

Two airborne campaigns were conducted in collaboration with the Spanish Aerospace Institute (INTA) using the Airborne Hyperspectral Scanner (AHS) developed by Sensytech Inc. (Argon St. Inc., USA) over the first experimental field to acquire six images corresponding to three flight times (7:30, 9:30 and 12:30 GMT) on two consecutive years (25^{th} July 2004 and 16^{th} July 2005). The flight height was set to 1000 m above ground level, acquiring imagery with a 90º field of view (FOV) and 2.5 mrad instantaneous FOV, produced a spatial resolution of 2 m. In the 2004 campaign, imagery was collected at 38 bands over the 0.430-1.550 mm and 8.20-12.70 mm spectral regions. In the 2005 campaign, 80 bands were available in the 0.430-2.49 mm and 8.20-12.70 mm ranges. Atmospheric correction and radiometric calibrations were applied as can be found in Sobrino et al. (2006).

In the summers of 2007 and 2008, a 6-band multispectral camera (MCA-6, Tetracam, Inc., California, USA) onboard an Unmanned Aerial Vehicle (UAV) flying at 150 m above ground level (Berni et al, 2009) was used to acquire imagery from all the study sites. The characteristics of the camera and images acquired as long as the calibration procedures applied can be found in Berni et al. (2009) and Suárez et al. (2009). The camera camera bandset comprised bands centered at 530, 550, 570, 670, 700 and 800 nm used to calculate the PRI (Gamon et al., 1992). The thermal camera installed on board the airborne platform was the Thermovision A40M (FLIR, USA). The camera, imagery characteristics, and calibration methods can be found in Berni et al. (2009). To correct for the temperature changes along the day when analysing diurnal data, crown temperature minus air temperature was used (Tc-Ta).

RESULTS AND DISCUSSION

High determination coefficients between PRI and crown temperature, stem water potential and stomatal conductance were obtained before structural effects of water stress appeared, demonstrating PRI is a pre-visual water stress indicator. Trees under high levels of water stress presented PRI values higher than trees under moderate or low level of stress. A detailed study was conducted to assess the relationship between crown-level PRI calculated from the AHS and multispectral imagery and field-measured physiological indicators of water stress, such as crown temperature directly related with leaf transpiration (Figures 1a, 2a and 2b), stomatal conductance (G) (Figure 1c), stem water potential (ψ) (Figure 1b and 2c), and steady-state chlorophyll fluorescence (Ft) (data not shown).

For the AHS campaigns conducted over the olive orchard, the relationships found between Tc-Ta and the airborne vegetation indices for individual trees in the 2005 campaign show that PRI tracks diurnal Tc-Ta changes as function of transpiration rate (r^2=0.64, Figure 1a). The PRI derived from the imagery acquired with the multispectral camera yielded coefficients of determination up to 0.8 with temperature in peach trees (Figure 2a) and with stem water potential in olive trees (Figure 2c). This methodology permits the water status determination of a whole orchard by representing the PRI value of every individual crown as can be seen in Figure 3.

CONCLUSIONS

The airborne campaigns conducted for four years over the experimental crop field demonstrate that the airborne-level PRI index is sensitive to the different water stress levels. The high-spatial resolution imagery (2 and 0.15 m.) gave the possibility of extracting pure crown spectral information minimizing background effects. Further works present a methodology to determine stress levels in orchards where structural and biophysical heterogeneity exist.

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Figures

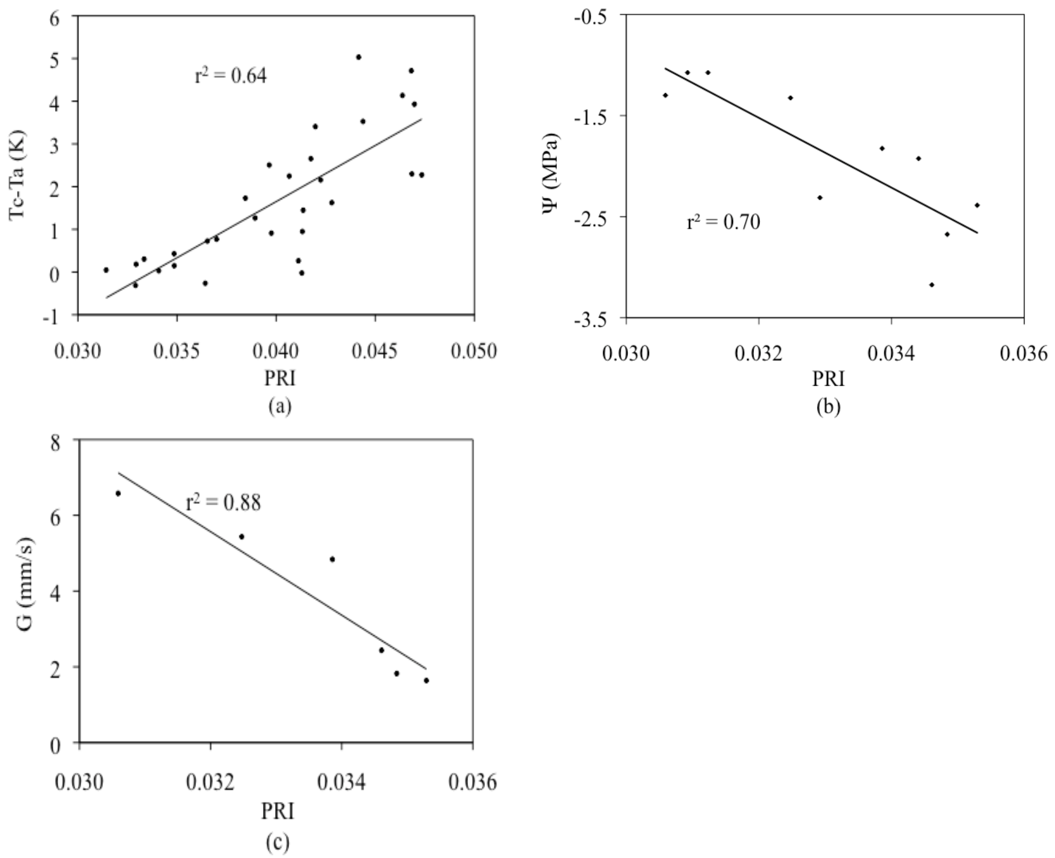

Fig. 1. Relationship between diurnal crown temperature minus air temperature (Tc-Ta) (a), stem water potential (Ψ) (b) and stomatal conductance (G) (c) and PRI obtained from AHS imagery acquired over the olive orchard in 2005 (data from Suárez et al., 2008).

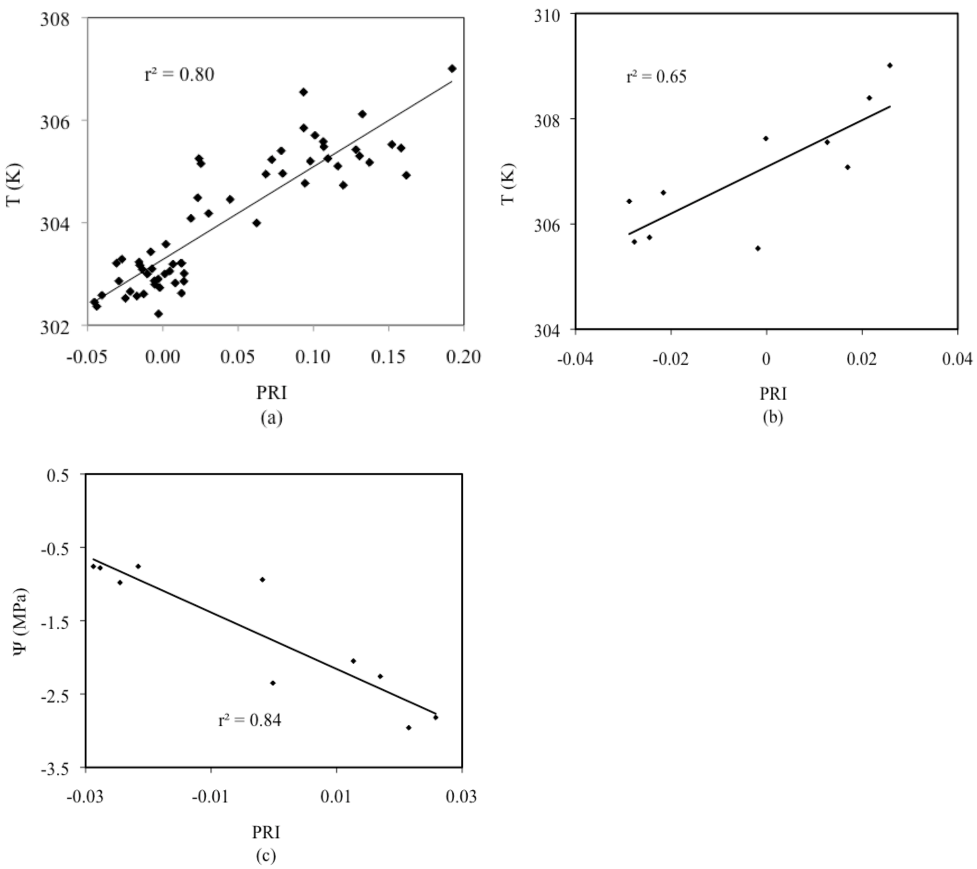

Fig. 2. Relationship between PRI derived from multispectral imagery acquired in 2007 and crown temperature for peach (a) and olive orchards (b); and PRI with stem water potential (Ψ) in the olive orchard (c) (data from Suárez et al., 2009).

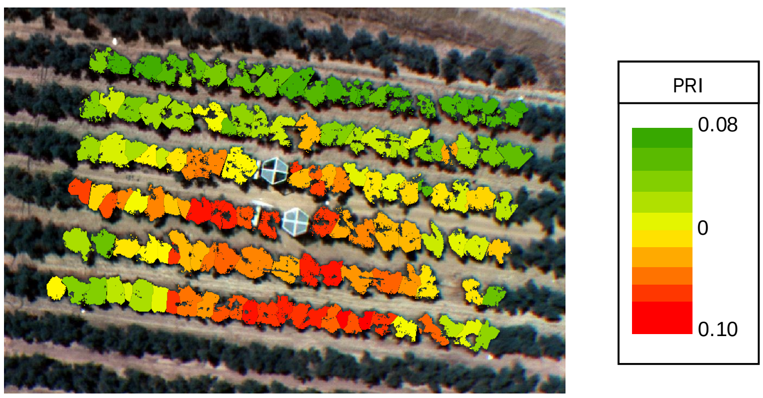

Fig. 3. PRI representation at tree scale for an olive orchard showing the water status level driven by different irrigation treatments (data extracted from Suárez et al., 2009).