Remote Sensing of Thermal Water Stress Indicators in Peach

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Keywords: crop water stress index, vapor pressure deficit, unmanned aerial vehicle

Abstract

Canopy temperature is a well known indicator of water stress, as any reduction in canopy conductance due to stomatal closure results in a further increase of canopy temperature. However, canopy temperature is affected by different ambient factors, such as air temperature, vapor pressure deficit, and net radiation, among others. Standardization is required in order to obtain reliable indicators of plant water status from canopy temperature. Different approaches have been developed during the past decades, such as the Crop Water Stress Index (CWSI) developed in the 80s by Idso and Jackson’s group (Idso et al., 1981), providing a normalized 0-1 index to quantify water stress independently of air temperature and humidity. Nevertheless, extensive use of thermal based indicators to map water stress has been limited by the lack of spatial and temporal resolution of satellite sensors. Airborne thermal scanners could provide an alternative, but the high operational costs and complexity have limited their use to real applications. Nowadays the use of commercial off-the-shelf thermal sensors onboard of Unmanned Aerial Vehicles (UAVs) offers a new important monitoring option for water management of high value crops such as fruit trees.

INTRODUCTION

Water stress in fruit crops causes reduction in yield (Hsiao et al., 1976). In addition, water is becoming a very limited resource in many agricultural regions thus requiring special control. Traditionally water stress monitoring has been assessed using pressure chambers to measure water potential and steady state porometers to monitor stomatal conductance. However, both measurements are very time consuming and are not free of errors (Hsiao, 1990; Shakel et al., 1997). Their use being mainly limited to research. Recently some automation is being installed in commercial farms using soil moisture sensors, trunk diameter or even temperature sensors. However, all these methodologies only provide point measurements that lack the information about the spatial variability all over the farm, caused by differences in soil, orchard development or nutrition status. Therefore information extracted from these point measurements are extrapolated to the rest of the farm which could lead to erroneous management.

Remote sensing brings us the opportunity to map the entire farm and provides information about the spatial distribution of biophysical parameters such as water status. Water stress leads to a reduction in the transpiration rate which can be detected by thermal sensors. Research work in olive trees and peach orchards (Sepulcre-Cantó et al., 2006, 2007) has shown that high resolution thermal imagery can be used to track water stress in woody crops. However, the spatial resolution of current satellite sensors together with the high operational complexity and costs of airborne sensors have prevented the extensive use of remote sensing applications in agriculture. Unmanned Aerial Vehicles (UAVs) equipped with commercial thermal cameras could fill this gap and provide a new important monitoring option for water management of high value crops such as fruit trees.

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Proc. 7th Intl. Peach Symposium
Eds.: J. Girona and J. Marsal
Acta Hort. 962, ISHS 2012
MATERIALS AND METHODS

Study Site
The study site consisted of a commercial peach orchard (*Prunus persica* ‘BabyGold8’) where a subset of 6 lines x 30 peach trees were subjected to regulated deficit irrigation (RDI). This treatment received no irrigation until Stage III of fruit development (July 5th), over irrigating afterwards until tree water status was fully recovered. Water status was checked using a Scholander pressure chamber (PWSC Model 3000, Soilmoisture Equipment, USA). For the rest of the orchard (control) a rate equivalent to 80% ETc was applied.

Data Acquisition
Four thermal infrared (IRT) sensors (Model IRR-P, Apogee, USA) were installed over two trees of each treatment during the summer of 2008. A weather station (Model VXT-500, Vaisala, Finland) with pyranometer (Model IRR-P, Apogee, USA) was also installed above the trees (Fig. 1). Data were retrieved every 10 s, then averaged and stored every 5 minutes using a datalogger (CR1000, Campbell, USA).

Thermal imagery was acquired over the study site with 3.2-m wingspan UAV (Fig. 2) completing 20 flights in 14 days from June 6th and September 2nd. The UAV was equipped with a thermal camera (Thermovision A40M, FLIR, USA). The flights were conducted at 150 m above ground altitude, delivering 40 cm spatial resolution imagery. See Berni et al. (2009) for further description of the system and image processing.

Methodology
Diurnal course of crown temperature for both treatments showed temperature differences higher than 2K, reaching the maximum differences at noon. This suggests that both treatments can clearly be identified using crown temperature.

In order to normalize canopy temperature and avoid the influence of ambient factors such as radiation and pressure vapor deficit, Crop Water Stress Index (CWSI) was used following the methodology developed by Idso et al. (1981). The non-water stressed baseline (NWSB) was calculated using the data from the IRT sensors of the control trees and weather data at noon for clear days, using averaged hourly data (Fig. 3). For the determination of the NWSB, vapor pressure deficit vs. canopy minus air temperatures was plotted. The relationship for the whole dataset showed a very large dispersion and poor correlation coefficient suggesting that some degree of water stress was present on the time series. Data from day of the year (DOY), for 165 to 209, were removed, yielding the relationship shown on Figure 4.

CWSI was calculated using the following equation:

$$CWSI = \frac{(T_c - T_a) - (T_c - T_a)_{ul}}{(T_c - T_a)_{ul} - (T_c - T_a)_{ll}}$$

where $T_c$ is the crown temperature, $T_a$ is the air temperature, and the subscripts $ll$ and $ul$ represent the lower limit (calculated using the NWSB) and the upper limit, respectively. The upper limit was fixed to 5°C according to some authors (Irmak, 2000).

RESULTS AND DISCUSSION
The two treatments initially differed in Tc by 2°C and this difference was reduced to 1°C after DOY 178 (Fig. 5). The gap between DOY 168 and 177 was caused by a spider that nested inside one of the IRT sensors. After the beginning of the recovery (DOY 191), there was a reduction in the $T_c$ difference with even negative values at the end of the experiment. The main limitation of this indicator is that well irrigated trees are needed as a reference to obtain the temperature difference, which is not always possible. In this case, the reduction in the $T_c$ difference suggests that the control trees also suffered water stress given that they were only supplied with 80% of ETc.
The seasonal changes of CWSI (Fig. 6) show an increase for the control treatment after DOY 180. CWSI for both treatments started to decrease after the recovery, reaching values close to 0 for both treatments. This confirms that control trees were under water stress, showing a behavior similar to the RDI treatment. Compared with the previous indicator, Trdi-Tc masks water stress if control trees are also under stress, meanwhile CWSI does not require control trees as reference and successfully tracked water stress also on the control treatment.

Two high resolution thermal images from the UAV were selected. The first image, acquired on DOY 188 at 13:00 GMT, was taken before the beginning of the recovery which could be considered as the maximum water stress. The second image was acquired at 13:00 GMT on DOY 202, when the recovery was reached as it was confirmed by the xylem water potential (-0.84 MPa for both treatments). Two CWSI maps were generated from thermal imagery atmospherically and geometrically corrected. CWSI equation was applied to the thermal image, resulting in images ranging from 0 to 1 (Fig. 7).

Figure 7a shows the higher values in the RDI plot but also shows a large spatial variability of water status around the entire plot. Figure 7b shows lower values of CWSI as compared with Figure 7a and it shows how RDI trees had very low values of CWSI after recovering.

CONCLUSIONS

Canopy temperature is a good indicator for monitoring water status differences between well watered and deficit irrigated trees without any additional weather data. However, canopy temperature alone is unable to detect water stress unless well irrigated trees are available in the image and can be successfully identified.

CWSI is a better indicator of water stress and could successfully track water stress even on the control treatment.

Thermal imagery of very high resolution can be used to generate CWSI maps which allow mapping the spatial variability of water stress and detecting potential problems in the irrigation system or could provide useful information for irrigation scheduling.

Unmanned aerial vehicles (UAV) equipped with thermal imagers could provide high spatial and temporal resolution imagery with short turnaround time which is critical for real-time applications required in agriculture.

Literature Cited


Hsiao, T.C. 1990. Measurements of plant water status. American Society of Agronomy, Madison (EUA); Crop Science Society of America, Madison (EUA); Soil Science Society of America, Madison (EUA).


Figures

Fig. 1. Installation of the IRT sensors and weather station over the peach trees in the study site.

Fig. 2. Unmanned aerial vehicle (UAV) for thermal imagery collection
Fig. 3. Diurnal course of canopy temperature for two selected days in 2008.

Fig. 4. NWSB for CWSI calculation.
Fig. 5. Seasonal changes of the temperature difference between both treatments, showing a reduction in the difference after the beginning of recovery (DOY 191).

Fig. 6. Seasonal changes of CWSI for both treatments. Note that CWSI tracks water stress for the control treatment which was not detected with temperature differences.
Fig. 7. CWSI maps generated from the UAV thermal imagery: a) CWSI map before recovery (DOY182) and b) CWSI after recovery (DOY233).