Assessment of Almond Water Status Using Inexpensive Thermographic Imagery

Project No.: **17-HORT31-Bailey**

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Objectives:

The primary aim of this study is to develop a method that utilizes inexpensive thermal imagery to quickly evaluate tree water status and help guide irrigation decisions. The measurements will not require any expensive/cumbersome sensors or sensor networks to be installed, but rather a smartphone-based thermal camera that can be purchased for ~$200. The tool will provide a quick and inexpensive means for growers to estimate almond water needs in order to guide more efficient irrigation practices.

The specific objectives of this project are:

- Develop a model for evapotranspiration inversion from thermographic imagery
- Collect validation data for model calibration, validation and testing
- Develop a smartphone application for distribution

Interpretive Summary:

In order for almond growers to meet the increasing demands for reduced water consumption, the efficiency of irrigation practices must be improved. The overarching aim of this study is to develop a quick and inexpensive tool that can be used to evaluate almond tree water needs in order to help guide efficient irrigation practices. The tool is based on the use of inexpensive smartphone-based thermal cameras to measure leaf temperatures, which are used to infer leaf water status. Water lost by the leaf (transpiration) creates a cooling effect and can reduce the leaf temperature to several degrees below the ambient air temperature in the case of a well-watered tree. As trees run out of water, transpiration begins to decline and the discrepancy between leaf and air temperature is reduced. However, transpiration is only one of several factors that affects the temperature of a leaf. A primary challenge in applying this type of approach is the separation of the effects of weather from transpiration within the leaf

temperature measurement, since ambient weather conditions also play an important role in determining the temperature of a leaf. This project will explore several potential methods for “calibrating” the measured leaf temperature for current weather conditions to allow for a determination of the influence of water availability on leaf surface temperature.

For this first year of this project, we chose to (1) characterize the accuracy and sensitivity of the low-cost thermal camera, (2) define the best reference surfaces used to calibrate leaf temperature measurements for local weather conditions, (3) develop a method/model to calibrate leaf temperature measurements that minimizes effort by the grower, and (4) collect validation data on *Prunus dulcis* Mill. cv. ‘Nonpareil’, other similar species for method calibration, validation and testing. In collaboration with Dr. Astrid Volder, an orchard of four-year-old almond trees with variable irrigation treatments was chosen as the primary site for initial tool development, with some other *Prunus* species being used for preliminary proof-of-concept tests before moving to full-scale orchard experiments. For each tree and each species, three leaves were chosen at two positions (sunny and shaded) in the tree crowns. For all leaves, temperature was measured using thermal imagery, then the water potential was measured for the leaf after taking the thermal picture.

Key words: Thermal imaging, water stress, irrigation, smartphone app

Materials and Methods:

<u>Plant material</u>

Full-scale field testing for this study will be performed in summer 2018 in twelve four-year-old almond trees (*Prunus dolcis* Mill. cv. ‘Nonpareil’) in an experimental orchard at the University of California in Davis (**Figure 1**). Three treatments of irrigation (100%, 85% and 70% of water needs of the tree) were carried out (4 trees/treatment). Several campaigns of measurement will be conducted to obtain a range of water status levels: at the beginning of August, September and October. Six fully developed leaves with the same orientation and size (three in the shaded zone and three in the sunny zone of the canopy), will be selected on each tree.

Figure 1: Experimental almond orchard used in this study (in collaboration with Dr. Astrid Volder, U.C. Davis). The orchard has three different irrigation treatments: 100%, 85%, and 70% of ‘well-watered’ conditions.

Experimental procedure based on single-leaf temperatures

Our initial approach was to develop a thermography-based technique that is well-corelated with leaf water potential measurements obtained from a pressure chamber/bomb. The overall goal is to determine a method that utilizes measured leaf surface temperature along with a minimal number of supporting measurements in order to predict leaf water potential.

In order to develop the approach, the following group of measurements were simultaneously collected for a number of both shaded and sunlit almond leaves:

- Leaf surface temperature: Thermal images are obtained for leaves of interest with a FLIR smartphone camera (FLIROne® Pro for iOS) connected to an iPhone. This provides the spatial distribution of surface temperature across the leaf and forms the basis of the measurement technique.
- Minimum and maximum possible leaf surface temperatures: The minimum and maximum possible leaf temperatures that could exist given current weather conditions are determined by placing 'reference' leaves within the image of the leaf of interest. To measure the minimum possible leaf temperature, T_{wet}, a leaf will be sprayed on both sides with water approximately 1 min prior to measurement of its temperature. To measure the maximum possible leaf temperature, T_{dry}, another leaf will be covered in petroleum jelly on both sides of the leaf (Jones et al. 2002).
- Non-leaf reference surfaces: Various reference surfaces are also placed in the image of the leaf of interest to determine whether they could effectively predict the dry leaf temperature (T_{dry}) or the ambient air temperature. Reference surfaces considered are white, green, and black paper.
- Water potential (ψ): After the taking pictures, the stem water potential of the leaf is measured using a pressure chamber (Scholander, 1965).
- Maximum stomatal conductance and photosynthesis rate: Gas exchange measurements with saturating light (maximum stomatal conductance and photosynthesis rate) are carried out using an LI-6800 portable photosynthesis system for the leaf of interest.

Results and Discussion:

Before conducting the full-scale tests in the experimental almond orchard, initial testing was performed on isolated plants of *Prunus sp* near the lab. The measurement campaign for *Prunus dulcis* Mill. (Almond trees) is planned to start at the beginning of August 2018. It will continue until October 2018 to obtain a wide range of water status.

Objective 1 - Develop a model for evapotranspiration inversion from thermographic imagery

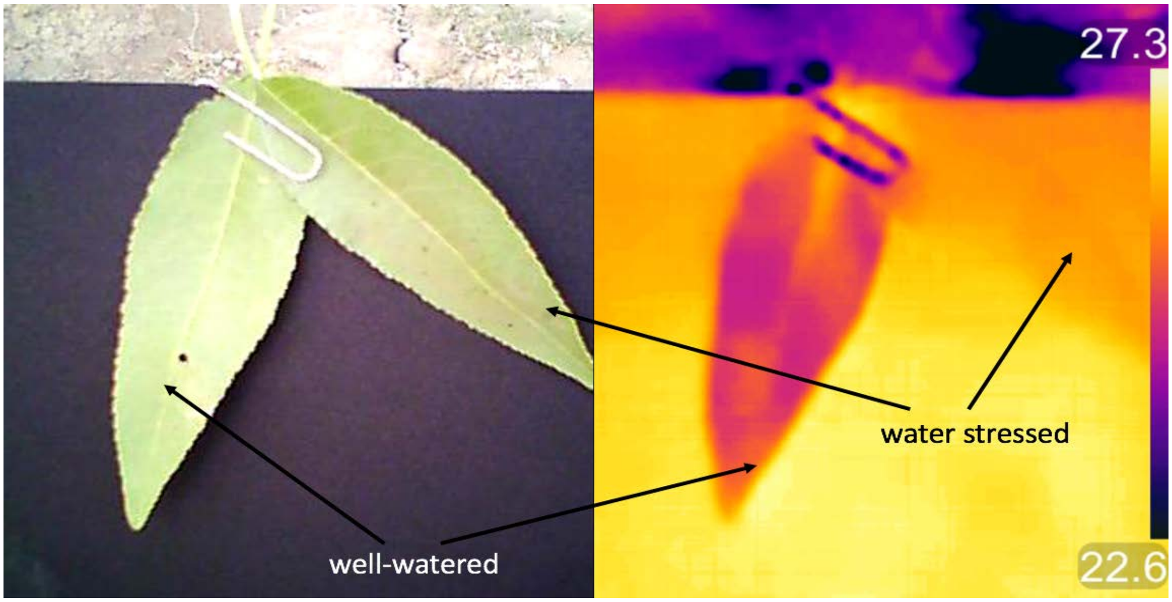

Figure 2. Visual color image (left) and thermal image (right) for two almond leaves from trees with different irrigation treatments. Temperature units are in Celsius. A difference in temperature of 1-2^{o}C between the two treatments was observed.

- Accuracy/sensitivity of instrument

(**Figure 2**) shows a visual and thermal image of two almond leaves from different irrigation treatments (70% and 100%), which was collected as an initial test to determine whether the thermal camera is able to detect a difference between the treatments. A temperature difference of 1-2^{o}C (roughly 2-4^{o}F) between leaves from the 70% and 100% irrigation treatments was consistently observed. Qualitatively, leaves that were water stressed were only slightly cooler than the matte black background, while well-watered leaves were several degrees cooler than the background.

The accuracy of the FLIR One Pro camera was assessed by comparing the temperature measured by the camera against that of a thermocouple pressed against the leaf surface. The manufacturer quotes ±3^{o}C (approx. ±6^{o}F) accuracy, but our tests indicated errors up to ±5^{o}C (approx. ±10^{o}F).

The above results have important implications moving forward. The unit appears sensitive enough to detect temperature differences resulting from differing water treatments, and that when compared with other temperatures *in the same image*, values are relatively precise. However, absolute accuracy of the instrument is low. This means that any calibration procedure will need to be performed based on reference surfaces in the same image and not based on independent temperature measurements such as that coming from a weather station or smartphone air temperature/humidity sensor.

- Choice of the image background to facilitate the extraction of leaf pixels from a thermal image

(Figure 3) shows visual and thermal images of different image background and reference surfaces, for both shaded (top row) and sunny (bottom row) conditions for *Prunus sp*. leaves. In the shade, the temperature of the black paper background is about 19.5°C and that of the actual leaf is about 16 °C (**Figure 3b**). In direct sunlight, we can observe the presence of several shadow zones around the leaves (**Figure 3c**), which could lead to difficulty of separating leaves from the background surface. The thermal temperature of the black paper background can reach up to nearly 40°C, which could have an influence on the temperature of the actual leaf (**Figure 3d**). In the shade, the uncrumpled aluminum foil doesn't allow for differentiation between the leaves and the background (**Figure 3f**). Under the sun, the apparent thermal temperature of uncrumpled aluminum foil is close to 0°C (because of its low emissivity) and that of the leaf is about 34°C (**Figure 2h**). This gap between leaf temperature and the temperature of the background will facilitate the separation of leaf pixels from background pixels in the thermal image in sunny conditions. Therefore, we have chosen to use a black paper as a background in the shade and the aluminum foil as a background in sunny conditions.

- Model the temperature of the dry and wet reference surface in sunny and shady conditions

In order to determine whether other reference surfaces can be used to estimate T_{wet} and T_{dry} so as to avoid having to use petroleum jelly or a spray bottle, a comparison is made in (**Figures 4 and 5**) between various reference surfaces and actual measured values of T_{wet} and T_{dry}. Sunny conditions created high variability in measured temperatures, which resulted in poor correlations between the reference surface temperatures and T_{wet} and T_{dry} (**Figure 4**). Results were much more consistent in shaded conditions (**Figure 5**), with clear trends emerging for both T_{wet} and T_{dry}. However, the correlations for estimating T_{wet} from the reference surfaces is likely to be unreliable under large changes in ambient humidity.

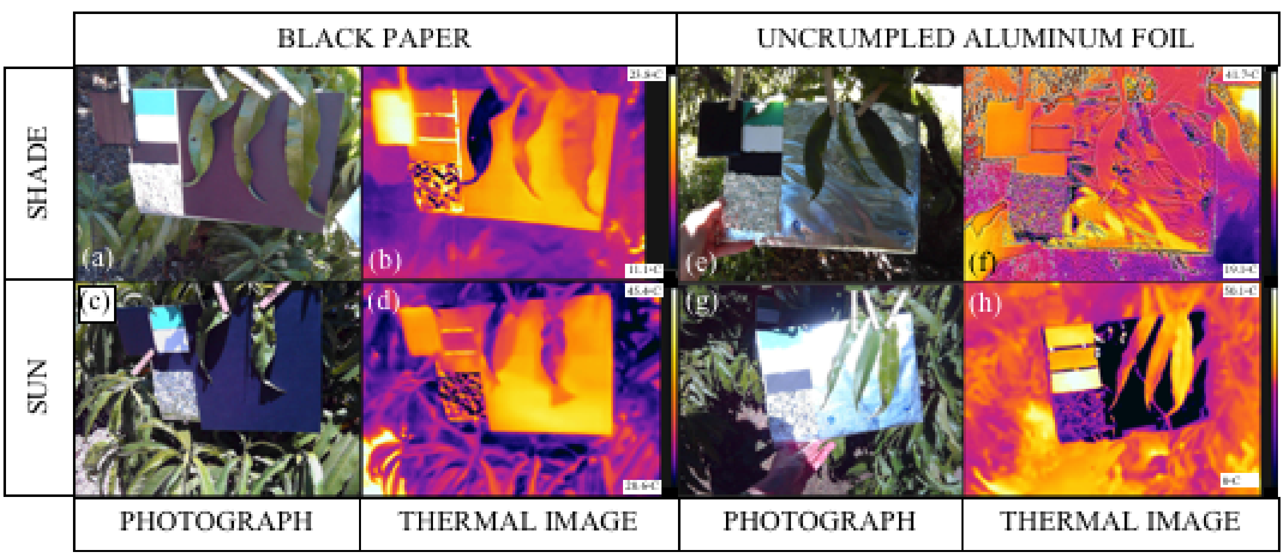

Figure 3: Result of thermal image for sunny and shady conditions in *Prunus sp.* leaves (b, h: left: leaf for T_{wet}; middle: leaf for T_L; right: leaf for T_{dry}).

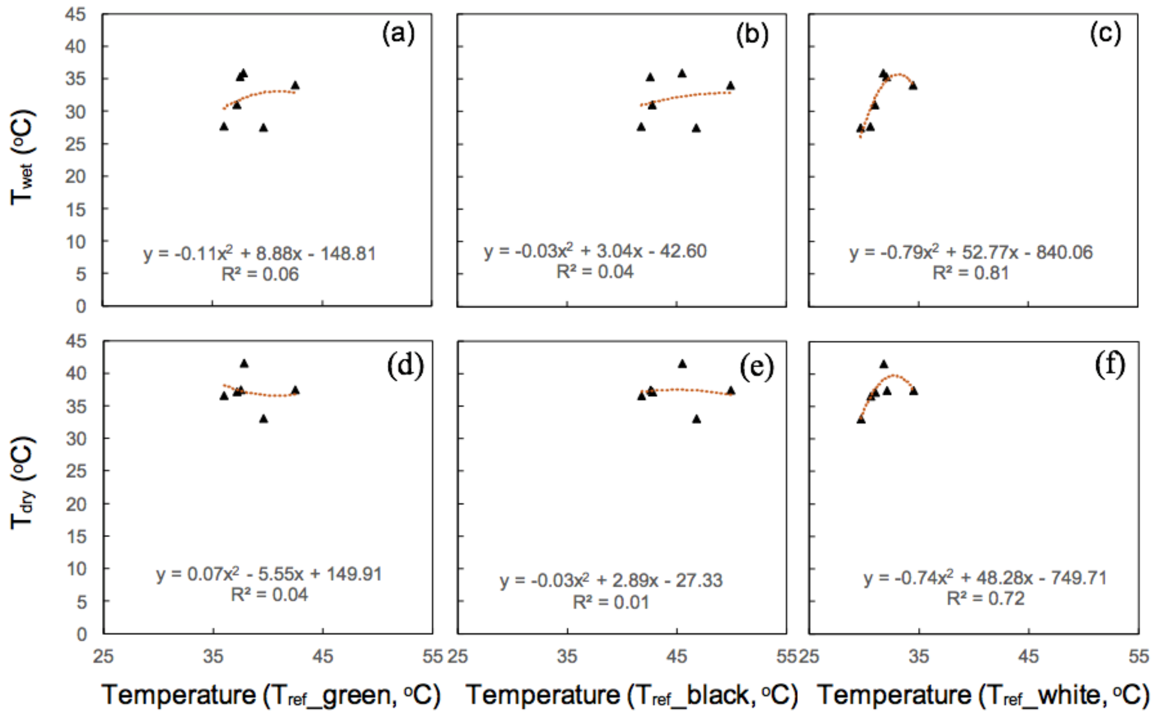

Figure 4: Relationship between the temperature of the paper reference (T_{ref}) [green (a, d), black (b, e) or white (c, f)] and T_{wet} or T_{dry} in *Prunus sp*. under sunny conditions. Individual values, the equation of the trendline and its R^2 were indicated.

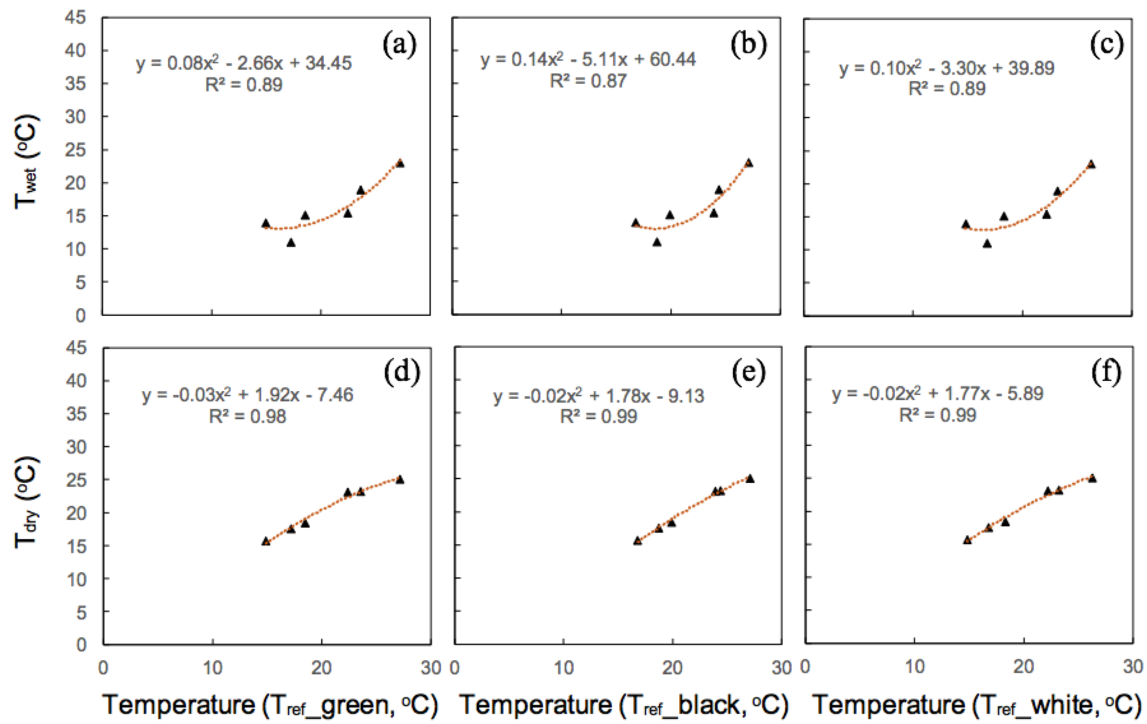

Figure 5: Relationship between the temperature of the paper reference (T_{ref}) [green (a, d), black (b, e) or white (c, f)] and T_{wet} or T_{dry} in *Prunus sp*. under shady conditions. Individual values, the equation of the trendline and its R^2 were indicated.

Objective 2. Collect validation data for model calibration, validation and testing

Data collected to date has been primarily small-scale and for initial testing purposes. Full-scale collection of data in the experimental Almond orchard will start at the beginning of August 2018. This data will be used to further test the best means of 'calibrating' measured leaf surface temperatures against current weather conditions.

Objective 3. Develop a smartphone application for distribution

We have begun experimenting with the FLIR One API, which allows users to directly interact with thermal camera data within custom apps. The API appears to work as expected, and implementation of the methodology developed in Objectives 1 and 2 within the app will be performed in year 3 of the project. We will also work with Dr. Bruce Lampinen and will incorporate his light interception app within our app.

Conclusion

The FLIR One Pro smartphone thermal camera appears sensitive and precise enough to detect topical differences in leaf surface temperature created by varying irrigation treatments. However, it does not appear accurate enough to consistently compare the thermal temperatures with other independent measures of temperature such as through a nearby weather station or other handheld temperature sensor. Thus, thermal temperatures must be calibrated against other measured temperatures within a given image. Our initial approach moving forward for measurement of individual leaves will be to primarily consider shaded leaves placed on a sheet of black paper. Shaded leaves appear preferable because thermal temperatures are much more consistent, yet the effect of water treatment is still discernable. The black background allows for easy separation between the background and leaf surfaces in the thermal images. Strong correlations were observed between the temperature of green paper and the "dry" leaf temperature (T_{dry}), which should allow us to use the temperature of shaded green paper in the image to calibrate actual transpiring leaf temperature against that of a dry, nontranspiring leaf.

Research Effort Recent Publications:

N/A

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