Assessing Orchard and Vineyard Irrigation Needs with Thermal Aerial Imagery

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Executive Summary

Every method currently used to schedule irrigations in orchards and vineyards has major shortcomings. The most widely used technique is atmospheric monitoring of weather data to calculate evapotranspiration (ETc). While this is very cost effective since California Irrigation Management Information System (CIMIS) data is widely available free of charge, there is some question as to the accuracy and applicability of the modified Penman equation used to calculate reference crop water use (ETo) and the site and irrigation system specificity (surface systems versus micro systems) of crop coefficients (Kc). Soil-based monitoring all suffer from two primary shortcomings: they monitor only a single point in the field and soil water content or potential are only indirectly related to tree water status. The tree is the best indicator of its environment and it's the tree that should be monitored in irrigation scheduling. The current state of the art in plant-based monitoring is the pressure chamber. However, using the pressure chamber is a manual operation that measures one leaf at a time and there is a relatively short period (generally 12:00 to 2:00 pm) recommended for monitoring. With the pressure chamber, it's simply not possible to monitor more than an infinitesimally small part of the orchard.

<u>Infrared Thermometers</u> In the late 1970s and early 1980s, there was a flurry of work on using canopy temperature (Tc) measurements taken with hand-held infrared thermometers (IRTs) for irrigation scheduling, primarily in field and row crops. The theory was that as a plant becomes stressed due to inadequate soil moisture, the stomata will begin to close, reducing transpiration and thus, also evaporative cooling from the leaf surfaces. This would cause the transpiring surfaces to heat up. An easily obtained remote (non-contact) measurement of this increasing canopy Tc could be used in developing a Tc-based indicator of stress. The descriptive parameter that evolved was the difference between canopy and air temperatures (Tc-Ta). This parameter would be a negative number (canopy cooler than the air) under non limiting soil water due to evaporative cooling of the leaves. To normalize the Tc-Ta measurement to take into account evaporative demand, the crop water stress index (CWSI) concept emerged. This approach requires the development of upper and lower "baselines" representing behavior of Tc-Ta for the crop in question to vapor pressure deficit (VPD); the best index of evaporative

demand. The CWSI ranges from 0 to 1; the former indicating no stress and the latter indicating a near dead plant.

Another approach to using thermal measurements as an indicator of stress was assessing the variability of Tc over an entire field. The theory is that as soil water is consumed between irrigations, there will be some plants that go into stress earlier, either due to shallower soil, smaller root zones, less applied irrigation, poor health, etc. A variability index should reflect this and indicate the need for irrigation.

For full canopy conditions (mature plants covering 100% of the soil surface), the CWSI approach using hand-held IRTs provided a fairly accurate stress index and had the advantage of being simple to take. However, a single measurement would cover only a small part of the field since it was manually taken. It was also difficult to accurately measure Tc in the early stages of crop development. The field of view of the IRT would include other than transpiring surfaces; mostly soil. Dry soil is much hotter than transpiring leaves. There were additional problems: the Tc measurement with the IRT was very sensitive to the solar zenith angle. For all these reasons and more, the use of the IRT and associated CWSI parameter for practical irrigation management is limited. In fact, the research activity in this area slowed tremendously after the mid 1980s.

<u>Thermal Imagery</u> Advances in remote sensing were spurred by the use of aerial imagery in the defense industry. The advent of the global positioning system (GPS) in the 1980s enhanced development of weapons systems. The Landsat series of satellites provided the first spaced-based images of the earth available to the public. However, the Landsat satellites orbited at 440 miles and the resolution of the infrared (IR) images was relatively poor. Pixel size was more than 100 ft making it impractical for use in orchards/vineyards. There have been numerous government and private image-taking satellites since Landsat but none have the resolution necessary to get Tc of individual tree canopies. Moreover, Landsat and most other satellites pass over the same point once every 16 days and same time. If one is attempting to monitor midday Tc, this is a problem.

In 2006, we conducted an intensive study in cooperation with scientists from IAS-CSIC, Cordoba, Spain to look, in detail, at pistachio tree response to water stress. We subjected trees to a progressive stress and monitored canopy temperature with infrared radiometers mounted about 4 ft above the canopies and pointed vertically downward. The field of view of these sensors was about 15 x 15 inches and was virtually all sunlit leaves at midday. Diurnal measurements of Tc showed relatively large differences between stressed and well watered trees and when converted to CWSI value, tracked changes in tree water status (pressure chamber readings) quite well. Even under mild stress, the CWSI differences were significant. We are encouraged that Tc, measured overhead and with as small a zenith angle as possible, appears to be a very sensitive indicator of water stress. Recent work in Israel with grapevines also shows a promising relationship between vine water status and CWSI. We must point out that the use of ground-based individual tree sensors as a practical tool to characterize the irrigation needs of an orchard/vineyard is impractical; it is simply impossible to afford the number of sensors required, let alone the logistics of data collection.

What we need are thermal images of entire orchards with a small enough scale that temperatures of individual tree/vines can be made. Clearly, satellites are not currently the answer; thermal images from lower altitudes are required.

Questions that must be answered with thermal imagery

1) What's the influence of pixel size on assessing canopy temperature and thus, CWSI? The smaller the pixels, the greater will be the number of sunlit leaf pixels per tree. As the pixel size increases, this number will decline. Eventually, there will be only a single pixel per tree and it will include all the surfaces. How much precision is lost when the number of pixels used to determine Tc of an individual tree canopy decreases due to different elevations of the cameras.

2) How sensitive a stress indicator can be obtained by quantifying CWSI spatial variability over a large orchard compared with the standard approach that uses a fixed point measurement of CWSI.

3) How do different crop canopies influence the answers for Questions 1 and 2. Additionally, are there differences in the relationships between CWSI and tree water status for different tree/vine crops.

Objectives

1) Establish the relationships between CWSI and tree/vine water status for almonds, pistachios, and grapevines in the San Joaquin Valley using thermal imagery,

2) Assess the relative utility of spatial variability in CWSI versus fixed point CWSI as a stress indicator, and

3) Determine the pixel size required to adequately characterize the canopy temperature of individual trees/vines.

Anticipated Results

As competition for the state's water supply intensifies, managing stress will become more important in terms of both maximizing water productivity (lb crop per unit of applied water) and grower profit. We believe that the use of thermal images taken from aerial platforms offers the best approach for much more precise water management than is currently available. The challenge is to first prove that stress indicators derived from thermal images indeed is well related to plant water status and second, to develop practical approaches that can be used to obtain the thermal images in the most effective, cost efficient manner. These include the optimal height and speed of the aerial platform. We believe that this proposed work will provide valuable information toward addressing these challenges.

With the rapid advance of imaging technology, we expect that thermal imagery will eventually be available to the public, much as CIMIS information, which did not exist 20 years ago, is today. We anticipate that eventually, low altitude platforms will be replaced by high altitude fixed wing aircraft and possibly satellites.

We are firmly convinced that the effort described in this proposal is the future of orchard irrigation management. Our ultimate goal is for growers to be able to view the water status of all their trees, not just a faction of a percent as is currently done, on a near real time basis to allow for the most precise irrigation possible. An added benefit is that thermal images can identify other than irrigation-related stress; for example, insects.