Fertigation: Interaction of Water Management and Nutrient Management in Almond

Project No.: **10-HORT11-Shackel/Sanden**

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Objectives:

1) Monitor the effects of irrigation management on tree stem water potential (SWP) at all sites of the fertilizer management project, and relate tree performance and nut quality to tree water status
2) Test the technology of using remotely sensed information to guide irrigation management

Interpretive Summary:

The four sites of this study exhibited clear differences in stem water potential (SWP) over the 2010 season, with all sites showing occasional mild to moderate levels of stress at mid-season and harvest time. Consistent with previous studies, there was a small but measurable decrease in kernel weight associated with declines in SWP, indicating that almond trees are physiologically responding to these levels of mild to moderate stress. A major effort this year was to evaluate the 2009 year data from one

site (Belridge) at which instrumentation for the measurement of canopy evapotranspiration (ET) was installed. Canopy transpiration had a very clear and consistent relation to reference evapotranspiration (ETo), but also appeared to be relatively insensitive to periods of mild to moderate stress that were caused by extended irrigation intervals or irrigation cutbacks around harvest. Similar results were found for both low (RSET) and high (SEBAL) spatial resolution, satellite-based approaches to the measurement of ET, with the satellite-based approaches also showing somewhat more variability over time compared to measured ET. The apparent lack of an ET sensitivity stress, despite the presence of a physiological sensitivity, indicates the possibility that improved irrigation management may result in an increase in orchard water use efficiency.

Figure 1. Experimental site at Belridge and the instrumentation used to measure orchard ET.

Materials and Methods:

The basic experimental approach for this project was established by P. Brown and cooperators in a proposal entitled "Development of a Nutrient Budget Approach to Fertilizer Management in Almond". Briefly, there are 4 orchard locations distributed across the almond growing regions of the state (from north to south: Arbuckle, Salida, Madera, and Belridge) in which plant nutrient status and yield of individual trees are being monitored. This project adds the monitoring of irrigation practices, stem water potential (SWP), yield and other parameters to the larger project. At the Belridge site, a metereological tower (**Figure 1**) is also using an eddy co-variance approach to measure orchard evapo-transpiration (ET) directly, and in 2010 a major effort was applied to comparing the 2009 ET data with satellite-based methods for estimating ET (**Figure 2**). Both of the satellite-based methods use infrared measurement of canopy temperature to estimate orchard ET, with the assumption that canopy temperature is determined by a combination of weather factors (ambient temperature, humidity, windspeed, and sunlight), as well as evaporative cooling effects (canopy ET). Water evaporates from almond canopies via the stomatal pores in the leaves, and research has shown a reduction of about 50% in stomatal pore opening (stomatal conductance) at the leaf

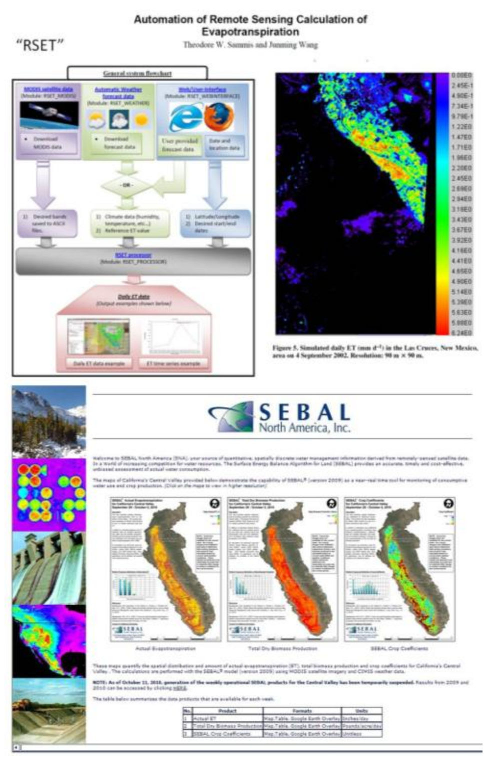

Figure 2. Examples of "RSET" and "SEBAL" website materials describing the basis for calculating ET from satellite imagery.

level with a 10 bar reduction in SWP in almonds (**Figure 3**). In addition, a similar reduction in ET at the canopy level has been reported for the same change in SWP in peaches (**Figure 4**), and hence we hypothesized that measureable reductions in canopy ET should occur any time there are meaningful reductions in SWP in almonds, for instance, during an extended irrigation interval or during irrigation cutback for harvest. The most sensitive index of a reduction in orchard ET below that expected for fully irrigated conditions is a decrease in the ratio of orchard ET to reference ET (ETo). This ratio was calculated as an apparent crop coefficient (Kc) where Kc = ET/ETo.

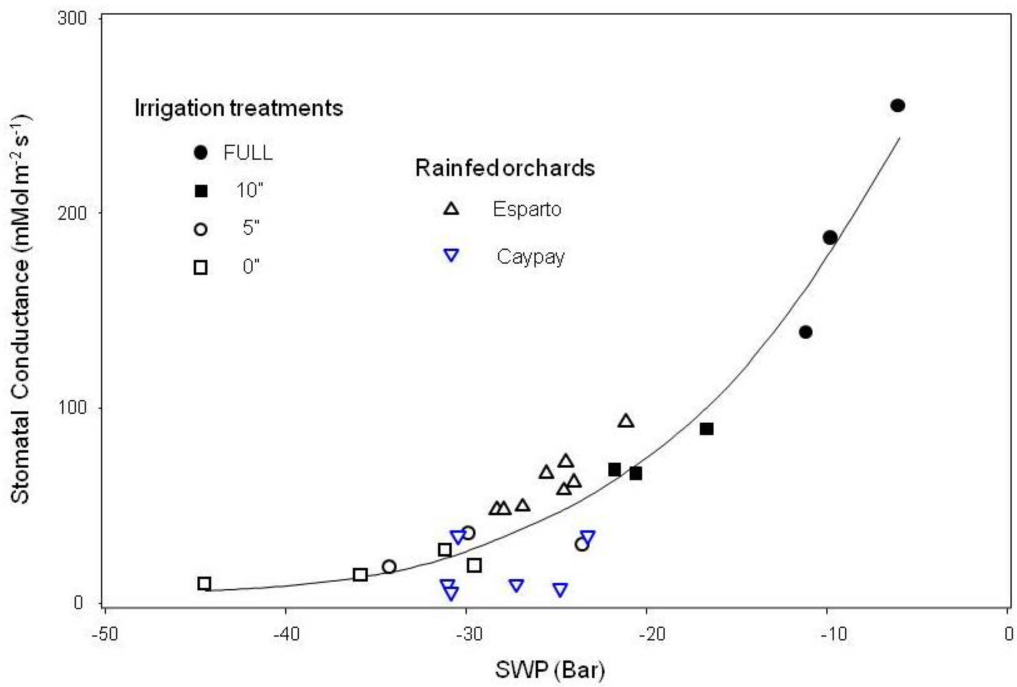

Figure 3. Stomatal conductance response to SWP observed in almond under rainfed conditions and a drought experiment conducted in 2009.

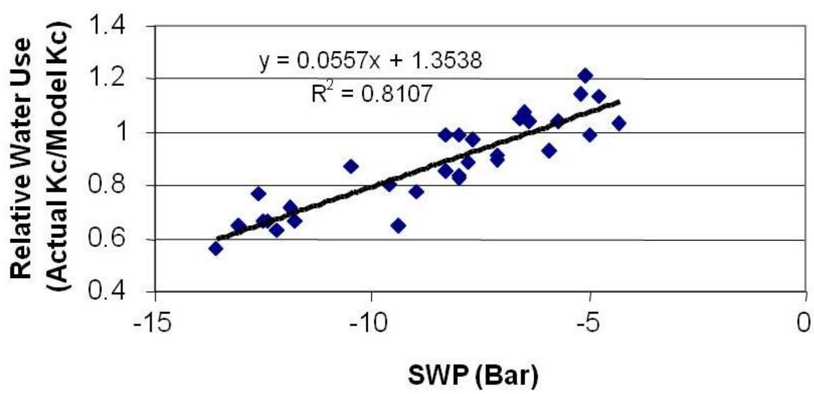

Figure 4. Linear decline in lysimeter-measured canopy water use with decreases in SWP in field grown peaches (adapted from Johnson et al, 2005).

Results and Discussion:

SWP and kernel weight effects across sites. In 2010, the SWP at most sites was near the baseline value through June, but in July and August many sites showed mild to moderate stress, with the Madera site reaching values of about -25 bars and experiencing extensive defoliation at this time (**Figure 5**). In order to evaluate whether these differences in SWP may be related to tree performance, a subsample of the yields of the trees monitored for SWP in 2010 was analyzed. The yields showed a decline in kernel weight with reductions in July SWP; similar in overall trend as that found in the drought study of 2009 (**Figure 6**). Both of these studies indicate a 15 – 20% reduction in kernel weight with a 10 bar reduction in July SWP, which is a significant effect on current year production for the typical range in SWP observed in these orchards (**Figure 6**).

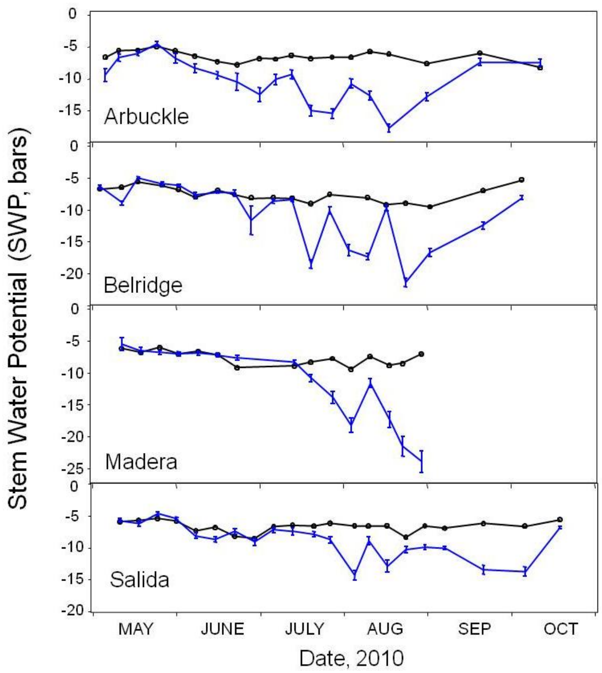

Figure 5. Variation in stem water potential (SWP) between sites monitored in 2010. Upper black line indicates baseline SWP (fully wet soil conditions) and blue line (+/-2SE) indicates measured orchard values. Values below the baseline indicate some degree of stress, with -20 corresponding to moderate stress.

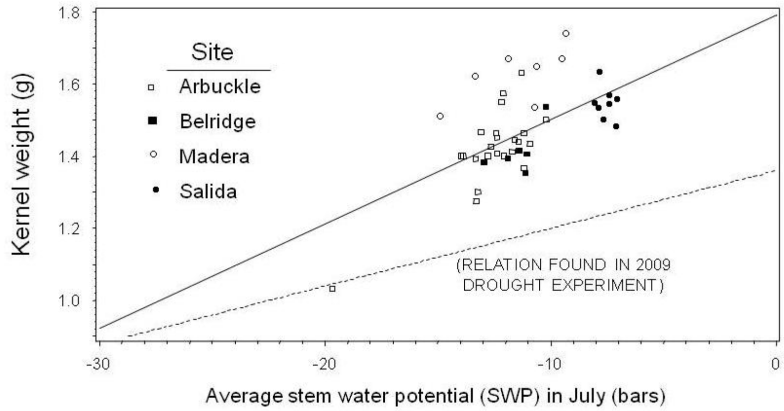

Figure 6. Relation of the average kernel weight in individual trees, to July tree average SWP for the sites shown in **Figure 1**. Solid line is the regression for all sites (highly significant). Also shown for reference is the relation found in the drought experiment of 2009.

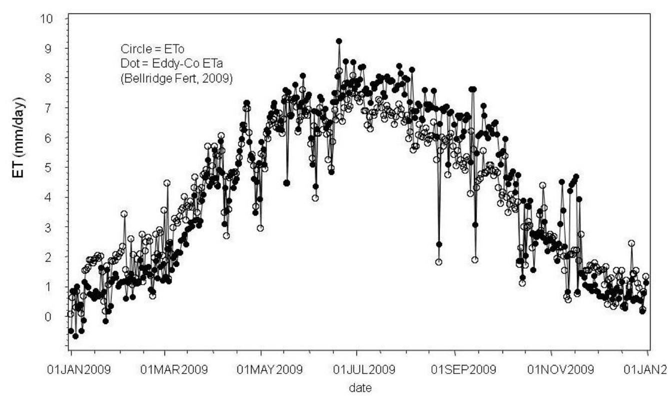

Figure 7. Daily ETo (CIMIS, open circles) and ET as measured by the eddy covariance tower (dots) at the Belridge site in 2009.

Remote sensing of ET and tree stress (analysis of 2009 data). Over the entire 2009 year, there was a close relation between measured ET and the independently determined ETo from a nearby CIMIS weather station (**Figure 7**), indicating that the eddy co-variance method was reliable. The seasonal pattern of Kc was also very consistent throughout the 2009 season, particularly from Late March through October (**Figure 8**). The high variation observed in Kc during the winter months (December to March) is primarily due to the fact that both ET and ETo are very low at this time, and hence their ratio can show high variation, but with very little practical consequence. While the consistency of Kc from late March to October is a desirable outcome from the perspective of calculating ET, it was a surprising outcome from the perspective of using Kc as a measure of stress. In 2009 there were clear periods of mild to moderate stress measured by SWP, particularly in July when the irrigation interval was extended, in September for harvest, and in October/November when irrigation was reduced/discontinued (**Figure 8**). A more detailed view of the patterns in SWP and Kc

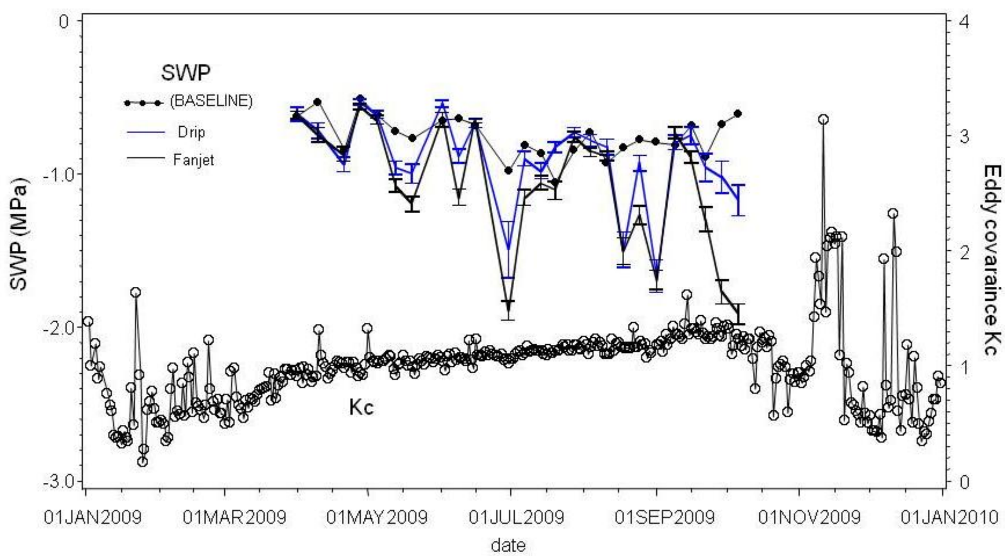

Figure 8. Seasonal pattern of SWP (left axis) and daily Kc (= ET/ETo, right axis) as determined using the eddy co-variance tower in 2009.

is shown in **Figure 9**, and it is clear that even though the SWP was about 5 bars less than the baseline value, there was no indication of any clear reduction in Kc. These data are consistent with the hypothesis that SWP is a more sensitive measure of stress than ET-based measures, but also raise the question of whether canopy-level water loss is less sensitive to SWP in almonds than peach (**Figure 4**), or whether the stomatal responses observed in other almond orchards (**Figure 3**) did not occur in the Belridge orchard. This latter question is currently under study.

One advantage of satellite-based ET measurements is that they are widely available for any orchard location in the state, and not dependent on site-specific equipment. Currently there are two options for ET measurements: 1) daily values at a relatively low and variable spatial resolution (RSET, spatial resolution of ¼ to 1 mile), and monthly values at a very high spatial resolution (30 feet). The variability in spatial resolution of RSET data is caused by slight variations in satellite orientation, and in some cases there will be many measurements on and around the field of interest, whereas in others none of the measurements will correspond to the field of interest (**Figure 10**). However an analysis of the 2009 data did not indicate any relation between the ET estimates and distance to the target area (not shown), and hence all estimates were used. The seasonal pattern in RSET estimates of Kc (**Figure 11**) were slightly lower and more variable than the measured Kc (**Figure 8**), but, as with the measured Kc, RSET data did not indicate any reduction in Kc associated with periods of low SWP (**Figure 11**). One common measure of reliability for satellite-based ET estimates is to compare them to locally measured values, and across the season for this location there was reasonable agreement between ET from the satellite and ET from the eddy co-variance system (**Figure 12**), but much of this agreement came from the wide range of seasonal ET values (**Figure 7**). In order to use ET estimates as a measure of stress they must be expressed as a Kc, and based on this value, there was very poor agreement between satellite and eddy co-variance estimates (**Figure 13**).

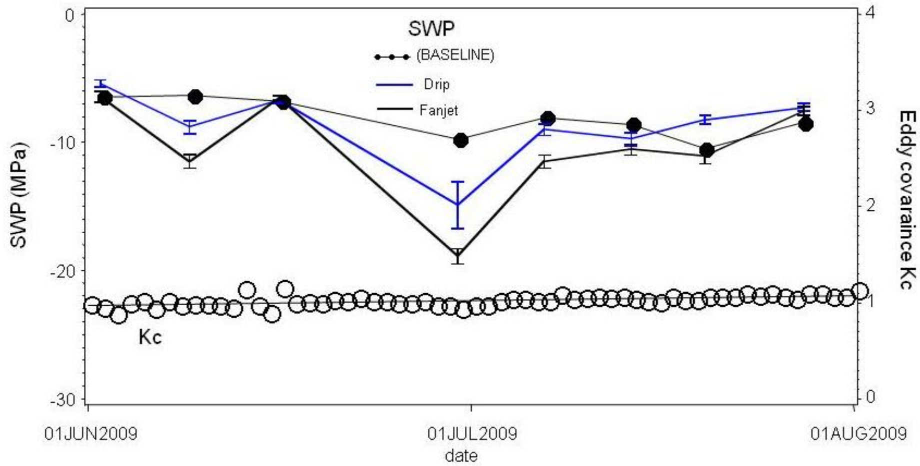

Figure 9. Detail of the June-July period shown in **Figure 8**, showing no meaningful decrease in Kc during a period of water stress.

Even though the SEBAL ET values have higher spatial resolution such that within-orchard points can be separated from between-orchard points (**Figure 14**), there was no indication of any stress periods in 2009 (**Figure 15**). Also, notably absent from the SEBAL data is any indication of a decline in Kc at the end of the season, when the eddy co-variance system did indicate a drop that was consistent with a large decline in SWP (**Figure 8**). Taken together, these data indicate that neither remotely sensed nor locally measured ET are sensitive indicators of stress, but also reiterate the question of whether canopy-level water loss is in fact responsive to declines on SWP in almonds. The answer to this question may have important practical consequences for irrigation management in almonds. For instance, if physiological processes, such as photosynthesis and kernel growth, are sensitive to declines in SWP (**Figure 6**), but orchard ET is not (**Figures 8 and 9**), then it may be anticipated that orchard water use efficiency may be reduced with mild to moderate stress. Since mild-to-moderate stress appears to be common in almond orchards (**Figure 5**), efforts to improve irrigation management may result in an industry-wide improvement in water use efficiency.

Research Effort Recent Publications:
(None for this project)

References Cited:
Johnson RS. LE Williams, JE Ayars, T Trout. (2005) Weighing lysimeters aid study of water relations in tree and vine crops. California Agriculture 59:133-136.

Figure 10. Aerial view of the experimental site on two consecutive dates, showing the high degree of variability that occurs in the location of data points (cells) used by the RSET program.

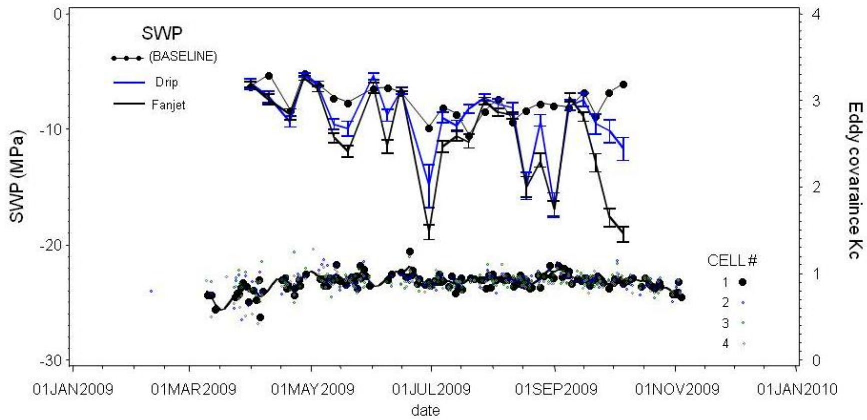

Figure 11. Seasonal pattern of baseline and orchard SWP (right hand axis), and the ET, expressed as an equivalent Kc, obtained from RSET (left hand axis) from the 4 cells closest to the target location.

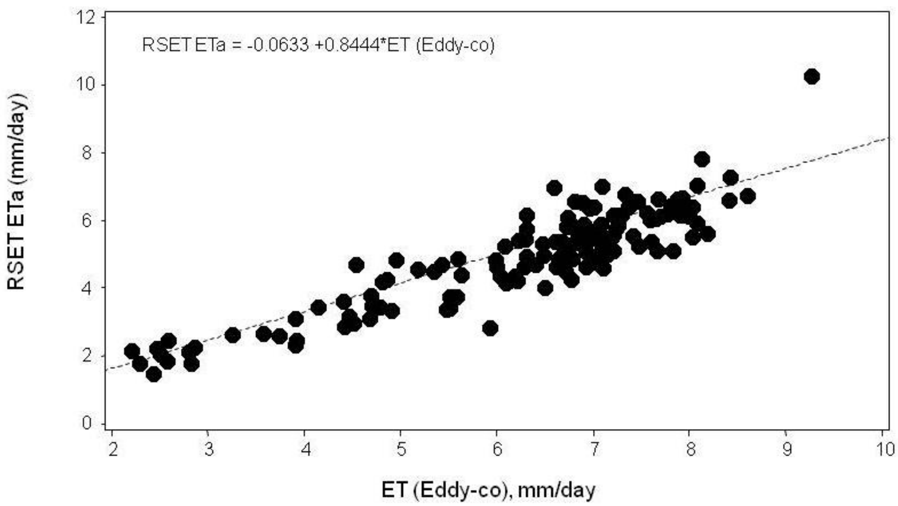

Figure 12. Relation between ET measured by the eddy co-variance system (x-axis), and ET measured by RSET (y-axis). Dashed line is the linear regression (r-square = 0.82).

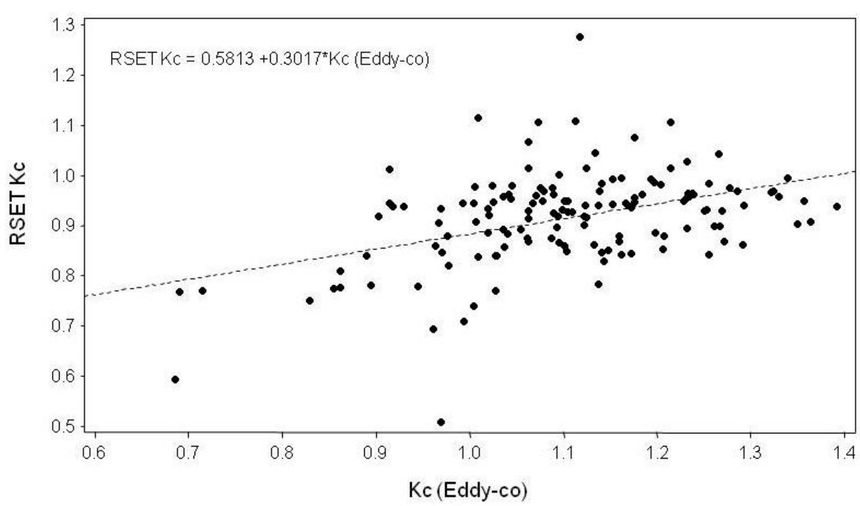

Figure 13. Poor correlation between Kc measured by the eddy co-variance system (x-axis), and Kc measured by RSET (y-axis). Dashed line is the linear regression (r-square = 0.18).

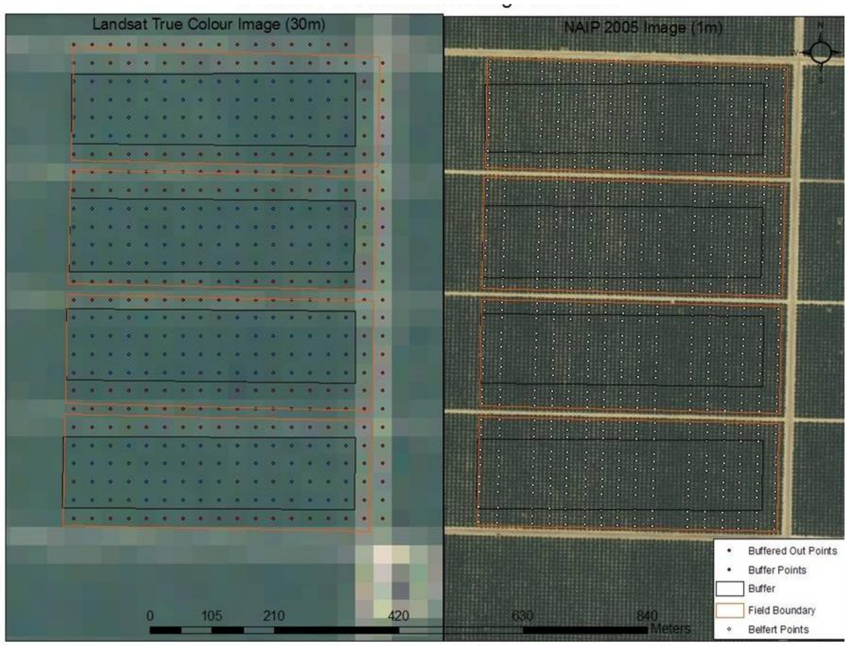

Figure 14. Aerial view of the experimental orchard (right) and the digitized SEBAL image (left) showing the high spatial resolution of the data points (dots) used to calculate ET. Dots corresponding to the roads between orchard sections are discarded.

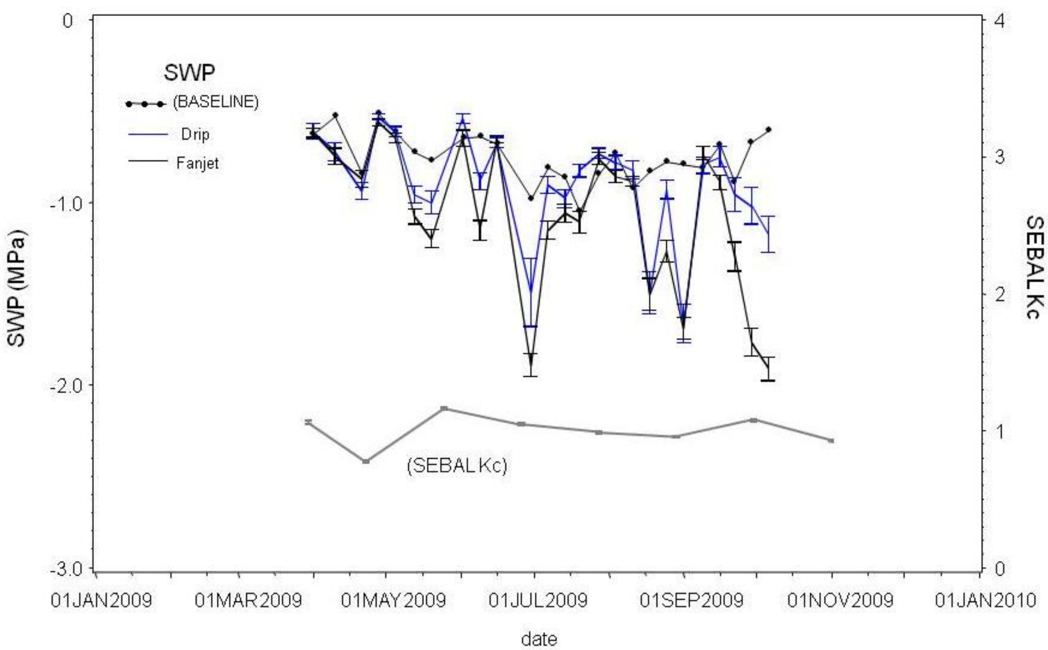

Figure 15. Seasonal pattern of baseline and orchard SWP (right hand axis), and the ET, expressed as an equivalent Kc, obtained from SEBAL (left hand axis), as in **Figure 11**. SEBAL data is presented as the mean value for all measurement points within the orchard on each date (+/- 2 standard errors).