Whole Tree ET Responses to Mind and Moderate Water Stress

Project No.: HORT22.Shackel

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A. Summary This research project is based on determining almond tree water use (ET_c) using a weighing lysimeter, which is the only direct ('gold standard') method for this measurement. In order to interpret water use values independent of local weather conditions, ET_c is expressed as a crop coefficient (K_c) for each crop. The measured midseason K_c in this project has increased each year after planting, as expected based on the annual increase in tree size, but this increase in K_c has been much more rapid than reported in the literature,. Effective tree size is measured by canopy shaded area, and the currently accepted midsummer K_c for a "mature" almond orchard (at least 60% shaded area) is about 1.2, which was reached in year 3 of this project (2017), even though the canopy shaded area was only about 40% at that time. Hence, one important result found in this project is either that young orchards may exhibit 'mature' water use much sooner than is normally assumed, or that fully mature almond orchards may use substantially more water than previously thought. Since 2017, shaded area has only increased to about 50%, with no measureable change in K_c, while Nonpareil yield has increased from 770 to 2070 kernel pounds/acre (2017-2019), indicating a substantial increase in 'crop per drop' from year 3 to 5. In 2019, deficit irrigation during hull split and harvest resulted in a substantial reduction in K_c, and a net savings of 4.3" in tree consumptive water use. A reduction in K_c of 0.7 was found to be linearly associated to a 10 bar decline in stem water potential (SWP), remarkably consistent with the same value that was reported by S. Johnson for peach, also using a weighing lysimeter. If these values are reproducible over years, then they will represent a documented savings of water that can be attributed to hull split and harvest deficit irrigation management in almonds. The lysimeter is also being used to 'ground truth' the more widely used, but indirect, micrometeorological (eddy co-variance) method for measuring K_c. 2019 was the first full year for this comparison, and the results indicated that the micrometeorological method may substantially (20%) underestimate K_c from July-August. The reasons for this discrepancy are not clear and are currently under study. If this is confirmed by further study, it will significantly impact our confidence (and that of water regulators) on the accuracy of the current K_c values for almonds, and potentially other tree crops. The lysimeter tree and an adjacent tree were also used to test a recently developed sensor (microtensiometer) which allows continuous and automated SWP measurement. The sensors clearly showed that midday SWP could change from a value associated with fully irrigated conditions, to a value associated with a substantial level of stress, over a very short period (1-2 days). This was particularly evident when trees were deficit irrigated during hull split and harvest. Rapid development of water stress is consistent with the sandy soil prevalent at this site, but these results also underscore the practical benefits of using automated sensors, or daily pressure chamber SWP

measurements, to fine tune the irrigation schedule, particularly under deficit irrigation conditions. Commercial dendrometers (Phytech) were also used as a guide for reducing irrigation enough to stop the daily growth of trunks prior to shaking, and hence to reduce the susceptibility of the tree to shaker injury. Trees with supplemental irrigation prior to shaking exhibited higher (wetter) SWP, more growth, and substantially more shaker injury, than did trees without supplemental irrigation. Further tests of this approach will allow us to propose SWP and/or trunk growth rate guidelines for irrigation management to reduce susceptibility to shaker injury.

B. Objectives *(300 words max.)*

1. The overall objective of this study is to accurately measure almond evapotranspiration (ET_c) using a weighing lysimeter (the ET_c "gold standard"), and to determine how ET_c is influenced by water stress. In order to account for weather conditions, measured ET_c is always expressed as a 'crop coefficient' (K_c). The main sub-objectives of this study are to: 1) establish the relation between K_c and canopy shaded area from planting to maturity; 2) estimate the reductions in K_c (and water savings) that are associated with the practice of regulated deficit irrigation (RDI) for hull split and/or harvest; 3) utilize the lysimeter tree and other trees in the experimental plot to test alternative methods of measuring water stress, alternative methods for applying irrigation, and approaches for irrigation management that are designed to reduce shaker injury during harvest; and 4) in cooperation with other scientists, use the lysimeter data as the 'ground truth' for other indirect measures of K_c (e.g., remote sensing and micro-meteorological methods).
2. The outputs/milestones are: 1) publishing the relation of K_c to shaded area spanning all years until a "mature" canopy is achieved (80% light interception, based on Lampinen's work); 2) determining a reproducible (over multiple years) relation of SWP or other measures of stress to K_c; 3a) developing/supporting the development of a reliable method for automated measurement of SWP; 3b) establishing objective criteria (SWP or dendrometer-based) for water management practices that reduce shaker injury at harvest; and 4) determining to what extent remote sensing or micrometeorological measures of K_c are accurate.

C. Annual Results and Discussion

<u>Objectives 1 and 2:</u> 2019 was the first year in which we observed a substantial and repeated reduction in K_c as a result of deficit irrigation for hull split and harvest. Prototype microtensiometers were installed in the lysimeter tree in late June, and the analysis (see poster for this project presented at the annual almond conference for details) showed a strong relation between 24h average SWP and K_c. Interestingly, the substantial reduction that we found (about an 0.7 reduction in K_c for 10 bars reduction in SWP) was essentially identical to the reduction reported by Scott Johnson for peach, also using lysimeter data. This result, combined with the microtensiometer data, which showed a fairly rapid and substantial decline in SWP over the irrigation cycle in August, may indicate that thus far, our K_c values, even though they were largely consistent with previous K_c estimates in almond, may be underestimates. The potential impact of these findings is great – in the first 2 years we found that the measured K_c for young trees was about double the K_c predicted based on the literature. Since then, K_c has been similar to the literature values,

but has also exhibited a wide range of variability during the season (as presented in the annual almond conference poster for this project). As commonly done in other studies, we attributed this variability to random effects, but if the variability was caused, even in part, by periods of mild/moderate water stress, then our values for 'fully irrigated' almond K_c would be substantial underestimates. In order to address this issue in 2020, we will need to make more frequent (in some cases daily) SWP measurements starting earlier in the season (May/June), unless we are otherwise able to prevent the trees from exhibiting the feast/famine behavior that we observed over irrigation cycles in 2019. Deficit irrigation will still be practiced during hull split and harvest. Based on the 2019 data, this deficit irrigation strategy represented a reduction in consumptive water use of 4.3", but if our current K_c estimates are below the correct values for fully irrigated conditions, then this estimate for a reduction associated with deficit irrigation will likely increase.

Objective 3: In 2019, prototype commercial (FloraPulse) microtensiometer sensors were installed in the lysimeter and an adjacent tree, and commercial (Phytech) dendrometers were installed in a number of additional trees in the lysimeter block. As mentioned above, the microtensiometer sensors provided valuable insight into the wide swings in SWP that occurred within a few days of irrigation in August. This information has already indicated the need for more frequent and targeted SWP monitoring in 2020, probably substantially earlier than August, based on the observed variability in early season K_c as noted above. The commercial Phytech dendrometer sensors use a proprietary algorithm to determine a relative level of daily water stress, which is divided into 4 broad categories (no, low, mild, and severe water stress), and there was general agreement for the trends over time in SWP and in the Phytech stress categories. In addition to stress categories however, the phytech dendrometers measure daily growth, which may be a useful relative indicator of cambial activity and hence in the tendency of the bark to slip and become damaged by shakers. As reported in the annual almond conference poster for this project, in the week prior to shaking, 8 of 9 trees that received additional irrigation and that exhibited positive growth throughout the week prior to shaking, were damaged by shaking (3 showing severe damage). Only 3 of 9 trees that were irrigated normally (i.e., with the rest of the block) and showed no or negative growth (shrinkage) in 5 of the 7 days prior to shaking, were damaged (only 1 severely). One day prior to harvest, the additional irrigation trees averaged -9.7 bars SWP whereas the normally irrigated trees averaged -14.5 bars. This is the first controlled field experiment to show a clear difference in shaker injury that could be attributed to irrigation management. This experiment should be repeated with more frequent SWP measurements in 2020, in order to develop at least preliminary SWP guidelines for irrigation management prior to shaking in order to reduce tree susceptibility to shaker damage. However, an additional key factor is wound healing and whether or not shaker damage will result in infection by Ceratocystis. In 2019, a number of the damaged trees were wrapped with Saran soon after damage, with or without additional zip tie support, in order to test if this practice resulted in rapid would healing and delayed or prevented disease development. These trees were inspected on 2/3/20, and most showed a surprisingly intact bark and a strong bark/wood connection, but disease symptoms, to be evaluated by cooperator Florent Trouillas, will not be evaluated until later in the spring. A novel commercial approach to sub-surface irrigation ("Deep Root Irrigation" or DRI) was tested on 5 paired Nonpareil trees in the plot. Four of the 7 surface emitters on one tree of each pair were connected to subsurface DRI devices, which applied water in a zone of from about 4 inches to 10 inches below the soil surface. Otherwise, all trees received the same amount and schedule of irrigation as the rest of the trees in the lysimeter orchard. It was anticipated that applying water to the subsurface might increase water availability to the tree, in part due to the reduction in surface evaporation, but the SWP measurements over the season were essentially identical between surface and sub-surface irrigated trees. There may be some important practical advantages of using this sub-surface irrigation approach in almonds, for instance the ability to continue some irrigation even when nuts are on the ground. It should be noted that this approach should not suffer from the well-known gopher-damage problems that are typical of a completely buried sub-surface system. Hence, this lack of difference in tree stress, given the same amount of applied water, indicates that there are no negative effects of this approach.

Objective 4: In 2019, a number of drone flights as well as individual tree harvests in the lysimeter plot were conducted by the lab of Alireza Pourreza, in order to test whether these flights could reliably replace the need for under-canopy measured shaded area (Lampinen's light bar) and/or could be used to predict almond yield. The author assisted in this effort by processing nut samples to determine kernel yield from field sample weight, but the results are being reported by Pourreza. Four of the trees used in the shaker injury study (2 wet, 2 dry, under objective 3) were also instrumented with a system recently developed by Reza Ehsani (Ag Engineer, UC Merced) for measuring the transmission of shaking forces through the tree. A preliminary report from Ehsani indicates that somewhat more shaking force was transmitted to the dry tree trunks and primary scaffolds than to the wet tree trunks and primary scaffolds, but that secondary scaffolds and later branches experienced about the same shaking force. More tests will be required to determine if these patterns are repeatable. 2019 was the first year for which we have complete seasonal ET_c data from an eddy co-variance (micrometeorology) tower operated by Andrew McElrone (USDA/UC Davis). This cooperative effort is particularly significant, because in almonds as well as many other tree crops worldwide, this micrometeorology approach is essentially the only available method for determining ET_c, and is often used as the 'ground truth' for remotely estimated ET_c (e.g., satellite methods). It was expected that ET_c determined by the micrometeorology approach would closely match ET_c directly measured by the lysimeter. However, as presented in the poster for this project, there was a consistent and relatively large systematic difference between the two methods, with the micrometeorology approach substantially overestimating ET_c (more than double) through early April, and underestimating ET_c (by about 20%) July-September. The most likely explanation for the early spring discrepancy is the fact that per tree soil evaporation (the E of ET) from the lysimeter is only from the area of the lysimeter (8 m^2), whereas the equivalent evaporation detected by the micrometeorology approach is the planted area (26 m^2), and this hypothesis is currently being studied. For the bulk of the season however, the soil area wetted by the drip irrigation system is similar to the soil area of the lysimeter, and any substantial contribution from E should continue to lead to a higher, rather than lower ET_c estimate for the micrometeorology approach compared to the lysimeter estimate. It is difficult to overstate the importance of these discrepancies, especially because essentially all recent estimates of water use in almonds and other tree cops are based on the micrometeorology approach, and many governmental agencies are basing policy decisions on these estimates. A group of ET experts from UC Davis (R. Snyder, KT Paw-U, A. McElrone, N. Bambach) are currently discussing possible reasons for the discrepancy, but given the importance to the industry, lysimeter measurements should be continued.

D. Outreach Activities

In addition to presentations at the annual almond industry meetings, I participated in the 2019 almond short course (I am not sure about the attendance), and I am regularly asked to present to grower meetings by farm advisors, although in 2019 most of these were for walnuts.

E. Materials and Methods *(500 word max.)*:

All measurements were performed in a 3.5 acre, 13' x 21' offset planted Nonpareil (50%), Wood colony (25%), Monterey (25%) orchard, planted on February 3, 2015 at the Kearney agricultural experimental station in Parlier, CA. Trees were headed at planting but not pruned further except to remove lower branches that would interfere with harvest. The 13' (actually, 4m) tree spacing was determined by the dimensions of the lysimeter (4m long, 2m wide, 2m deep), because the within row distance measured by the lysimeter must match the within row distance occupied by the tree. Irrigation was provided by a single line drip system with one 2 gph (8 lph) dripper per tree starting in year 1, and was gradually increased as the trees grew to a double line drip system with 7 drippers per tree for the Nonpareils and 5 drippers per tree for the pollinizers, in order to favor the development of the Nonpareil. The lysimeter is irrigated by the same system as the rest of the orchard, in order to maintain as much uniformity as possible between the lysimeter tree and the rest of the Nonpareil trees in the orchard. Irrigation was manually managed by the PI, based on periodic SWP measurements, tree growth, the progress of K_c, and the weight of the lysimeter itself (as a relative measure of soil water content). Irrigation for the Nonpareil rows (every other row) and the pollinizer rows was controlled independently, although for most of the season the entire orchard was irrigated on the same schedule. Cultural practices (other than pruning and irrigation) were conducted by the experiment station staff, with pest and weed control as needed and fertigation applied in 4 equal portions over the growing season as needed based on tree growth, starting in year 3. The weighing lysimeter itself has been maintained by the PI and calibrated at least annually, with no detectible change in calibration since the start of the experiment. A rain gage also measures any drainage (leaching) from the lysimeter, but significant drainage has only occurred twice (2016/17 due to rains and 2019/20 due to winter irrigations) since the start of the experiment. Lysimeter, irrigation (water meter), and other system data is recorded each 10 minutes by a data logger in the lysimeter underground enclosure, and the data accessed over the internet through a dedicated cell phone modem. Percent shaded area was measured photographically for years 1-2, and by Bruce Lampinen's light bar starting in year 3. A CIMIS station located on the field station is used for all reference (ET_O) values as well as for other weather information. The micrometeorological tower for the measurement of ET_c is managed by a USDA colleague (Andrew McElrone) and the data analysis is being conducted by a UCD trained atmospheric science postdoc. Drone flights are being performed and analyzed by Alireza Pourreza.

F. Publications that emerged from this work

None.