Updating information on evapotranspiration (ET) and crop coefficients (Kc) of micro-irrigated almond production orchards grown in California for use in water resource management and irrigation scheduling decisions

Project No.: ie: HORT52:Snyder

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A. Summary

During this period,we began collecting datasets from earlier almond orchard ET measurements and we started working on a quality control (QC) application program to standardize the analysis and make comparisons between results throughout the Central Valley. We developed this new QC and analysis program using data from near Lerdo in Kern County. A new, improved method to obtain better estimates of actual crop coefficients (Ka) by comparing predicted and observed evapotranspiration (ET) rather than curve fitting through Ka data was developed. We identified that the ET drops considerably below what was expected during the harvest period, and we will attempt to develop a correction for the Ka values during harvest as we analyze data from additional orchards. As we improve the Ka values, our plan is to incorporate the new ideas into existing irrigation scheduling programs.

B. Objectives *(300 words max.)*

With this project, we propose to conduct applied-science work for:

1. updating ET, Kc and possibly water productivity (WPR) information for well-watered mature almond orchards grown in California with micro-irrigation for commercial production, through retrieval, quality control, analysis, review and interpretation of field datasets collected from studies conducted in California since 2008;

2. compiling the updated *ET*, K_a (and possibly WPR) information in peer-reviewed documents with the consensus of industry leaders and representatives from the almond production and regulatory communities;
3. determining the *ET* of applied water (ET_{aw}) for almond in the major production areas of California, under three different water supply scenarios (dry, average, and wet year) for use in climate-adaptive water resource planning, allocation, and management;
4. developing an easy-access web repository of updated water-related information and materials published for almond, and enable their use with existing tools (CropManage, Aquacrop, Cup Plus, CalSimETaw, etc.), thus enhancing the capability for modeling/forecasting water demand and irrigation scheduling;
5. supporting wide dissemination of the updated information on almond water use through training and workshops to encourage adoption by stakeholders within the agricultural production and regulatory communities of California.
6. Identify annual outputs or milestones for each of the objectives

C. Annual Results and Discussion

1. **Describe activities and outputs for each objective**:

During the first months of this project, we worked on obtaining the data from earlier studies on almond ET measurements since 2008. This was somewhat delayed by restrictions due to COVID-19. We now have access to most of the collected data. From November, work on standardizing the quality control (QC) and analysis of almond ET data was initiated. Initially, we worked with the almond ET datasets provided by Blake Sanden from his experiments on almond ET in an orchard near Lerdo in Kern County. The orchard ET was measured during the years 2015-2018. Data collection began on 1 May in 2015 and there were data until the end of the year. Except some some periods with missing data, ETa was computed all year in 2016-2017. Data were available during early 2018, but the data collection stopped at the end of July. As a result, there were two mostly complete datasets in 2016 and 2017 and partial datasets in 2015 and 2018.

In general, the collected data from the Lerdo site had good quality, but there were examples of missing and possibly incorrect data that helped us to develop a data QC program using Excel software. From this initial analysis we determined that our QC process should include the following:

a. the creation of a separate file from the original data to protect against data loss when data are modified to correct obvious errors;
b. standardize an "Input" worksheet to accept columns based on the latest analysis, but make it easily populated from data collected going back in time;
c. creating a self populated worksheet from the "Input" data to deal with missing data parameters;
d. create filters based upon expected and/or realistic values. For example, net radiation for almonds grown in the Central Valley should not fall below -80 W m^{-2}. We are experimenting with either forcing values that fall below this threshold to be forced to -80 W m^{-2} or be removed and then interpolate the results.Create standardized coefficients when parameters are missing. In the Lerdo experiments, the volumetric water content (θ) measurements were not included in the soil heat flux measurements. To account for this deficiency, a default value of θ=0.25,

which is about midway between field capacity and the permanent wilting point was used to calulate G for all half hour periods for all three ground packages in the Lerdo experiments. Using a default value rather than a measured value for θ has little impact on daily G measurements, which are commonly close to zero, so there is also little impact on daily ET_a calculations. For remote sensing estimates of orchard ET, it is important to measure θ because it improves accuracy of instantaneous G estimates, which are needed for accurate validation of remote sensing; and

e. check to ensure that there is a time stamp for all half hours during the season. Any missing data is linear interpolated or replaced from days where conditions were similar.

For the final calculations, it is common for researchers to determine predicted K_a (PK_a) curves using least squares multiple regression of the observed K_a values versus the day of the year. This, however, is sometimes problematic because K_a values tend to have bigger spikes during low ET periods like late fall through early spring in the Central Valley. Also, regression curves often work in one climate but are not necessarily transferrable to another climate. Because the instrument error is as big or bigger during lower ET periods, the same error in ET_a or ET_o will likely have bigger K_a=ET_a/ET_o errors during low ET periods. Using linear regression with big K_a errors can lead to inaccurate PK_a curves.

To avoid this problem, we developed a new statistical approach to optimize the predicted PET_a=$ET_o \times K_a$ by minimizing the root mean square error (RMSE) of the measured ET_a versus PET_a during the midseason when the K_a is flat. A smaller RMSE indicates that the predicted values are accurately predicting the measured values. The PK_a values are linear from 1 Mar to 10 Jun, from 10 Jun to 31 Jul, and from 31 Jul to 15 Dec, which fits with irrigation planning and scheduling models like BIS, SIMETAW, and CalSimetaw. In Figure 1, the rapid growth line (1 Mar to 10 June) was fixed at PK_a=0.96 on 10 Jun and the PK_a on 1 Mar was varied until the minimum RMSE for PK_a versus K_a between 1 Mar and 9 Jun was found. The senescence line (31 Jul to 15 Dec) was fixed at PK_a=0.96 on 31 Jul and the PK_a value on 15 Dec was varied until the minimum RMSE between ET_a and PET_a was found for the data pairs from 25 Aug to 15 Dec. The observed ET_a fell well below PET_a during the period 31 Jul to 25 Aug (during harvest), so data pairs between those dates were not included in the RMSE calculation. The dip in K_a during harvest is often not included in water resourses or irrigation scheduling models (black dashed line in Figure 1), so we will investigate how we can modify existing models to improve estimation of water needs.

A plot of the seasonal ET_a and PET_a values is shown in Figure 2 along with the RMSE values for the various comparison intervals and overall. In Figure 2, the PET_a matched the ET_a well except for a period just before midseason and during the harvest period just after midseason. A RMSE=0.39 indicates an error during midseason of less than 10%, which is excellent. Most likely the lower ETa values before midseason are due to mild to moderate water stress and the lower ETa values after midseason are due to dry down for harvest. We will investigate these hypotheses in the future.

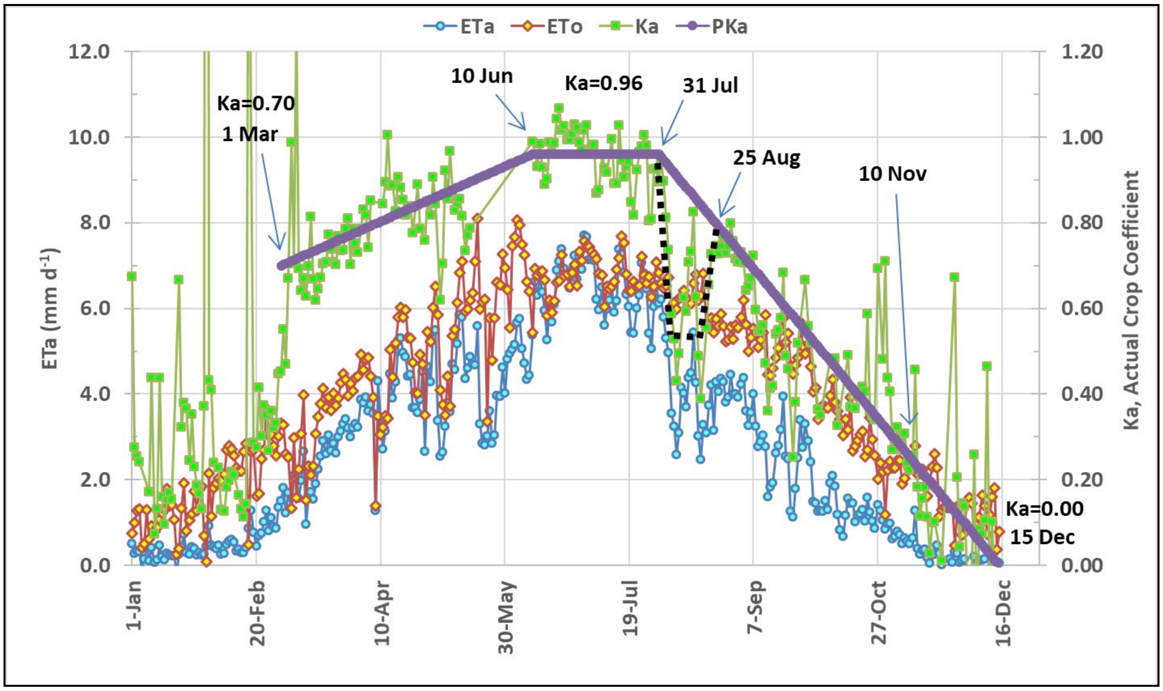

Figure 1. A comparison of ET_o, observed ET_a, observed K_a, and predicted K_a from the Lerdo orchard during 2016.

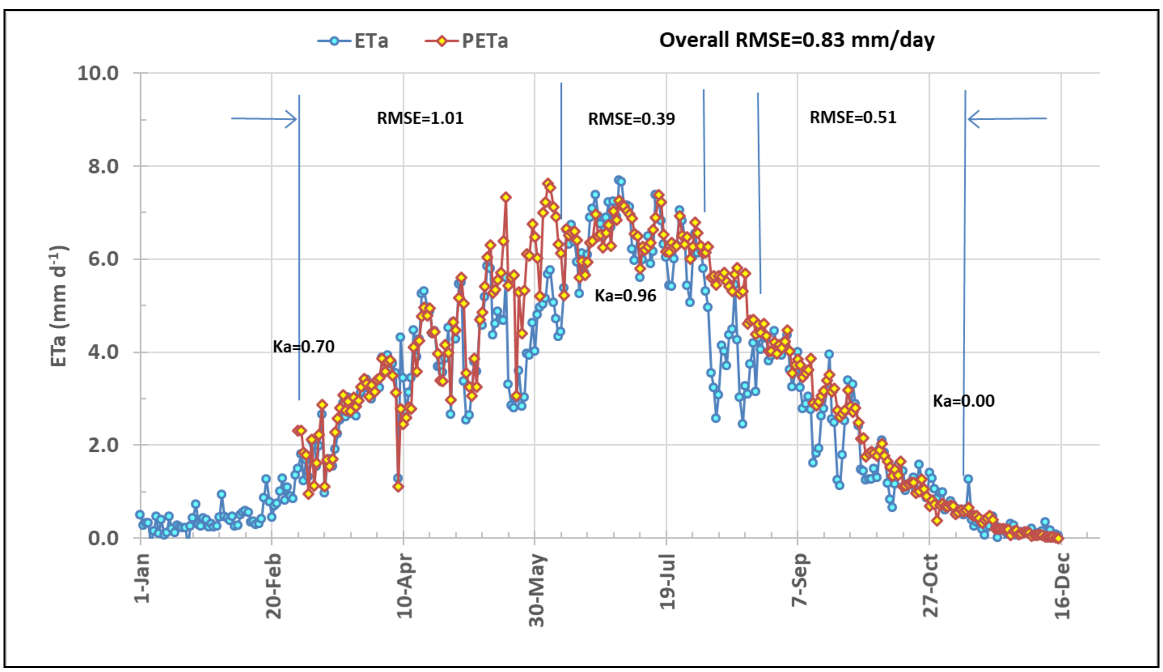

Figure 2. A comparison of predicted (PET_a) and observed ET_a from the Lerdo orchard during 2016. The RMSE values for were computed using data pairs from 1 Mar–9 Jun, 10 Jun-31 Jul, and 25 Aug–15 Dec.

Cumulative ET_a and PET_a curves are plotted in Figure 3. The seasonal total PET_a and ET_a were about 1000 mm in both 2016 and 2017. The PET_a was slightly higher than ET_a presumably due to reduce ET_a during the harvest period and possibly slightly lower ET_a prior to midseason. These seasonal total ET_a was a bit lower than we anticipated, but we need to complete analysis of the other orchards to make comparisons. The data sets for 2015 and 2018 Lerdo orchards did not cover the season, so a total season ET_a was unavailable. The years 2015, 2016, and 2017 had midseason PK_a values of 1.00, 0.96, and 0.99, respectively. For some reason, the midseason PK_a was 0.83 in 2018. We are still investigating the reason.

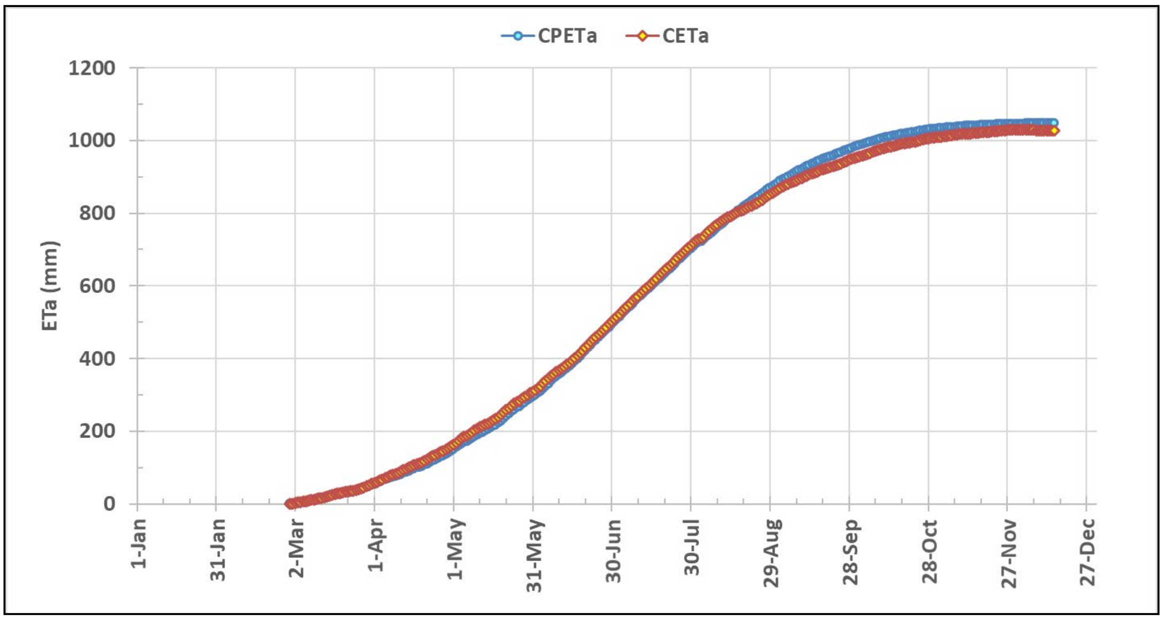

Figure 3. Cumulative predicted and observed ETa curves for the Lerdo orchard from 1 March to 15 December 2016

2. **Dicuss significance of these in terms of progress toward goals, change in approach, next steps or other conclusions based on this year's results**

We have developed a new statistical method using the RMSE of PET_a versus ET_a to improve the determination of PK_a curves. We identified that a correction is needed for PK_a curve to account for reduced ET_a during the harvest period. As we analyze additional orchards, we will try to develop a correction for regulated water stress and reductions during Discuss significance of these in terms of progress toward goals, change in approach, next steps or other conclusions based on this year's results

D. Outreach Activities

It is too early in the project schedule to outreach information. We are still working on standardization of the data quality control and analysis.

E. Materials and Methods:

1. **Outline**
   a. Almond evapotranspiration (*ET*) is measured with the residual of the energy balance (REB) method, which calculates the latent heat flux (*LE*) from net radiation (R_n), ground heat flux (*G*), and sensible heat flux (*H*) using Eq. 1. Note that *LE* is the vertical flux of water vapor in energy units.

$$LE = R_n - G - H \quad (1)$$

   b. The energy flux variables are measured each half hour in MJ $m^{-2}hh^{-1}$ and the resulting 48 half-hourly (hh) sums of the *LE* provide the daily *LE* (MJ $m^{-2}d^{-1}$). Within the humidity range in California, the value for *L* is approximately 2.45 mm per MJ $m^{-2}d^{-1}$, so the daily *ET* (mm) is calculated using Eq. 2.

$$ET = \frac{LE}{L} \quad (2)$$

   c. The data for calculating actual crop *ET* (ET_a) were collected in an almond orchard near Lerdo during four years (2015-2018). A net radiometer was used to measure R_n. Three soil heat flux packages consisting of a ground heat flux plate and soil temperature averaging were used to estimate conduction of heat vertically into and from the ground surface using a continuity equation. Soil sensor packages were installed at three locations. i.e. in the tree row and at 1/3 and 2/3 distance from the station tree row to an adjacent row. A three-dimensional sonic anemometer was used to measure *H* with the EC method, and a 76.2 μm-diameter chromel-constantan thermocouple was used to estimate sensible heat flux density with the SR method. The Cambell Scientific data logger was used to collect data and make calculations of *H* from the EC and SR methods, which are described in Shapland et al. (2012). The sensors were connected to a Campbell Scientific CR1000 micro-logger to collect the data. The sonic anemometer and the fine-wire thermocouples were sampled at a rate of 10 times per second (10 hz). The other sensors were sampled every 30 seconds. Half-hourly means and totals of all of the data were calculated from the high and low frequency data, and daily data were calculated in an Excel analysis program.

   d. The daily ET_a data were compared with reference *ET* (ET_o) from CIMIS to determine actual crop coefficient (K_a) data. Note that ET_a represents the actual crop evapotranspiration, whereas ET_c represents the well-watered *ET*. Similarly, the K_a and K_c are coefficients to estimate ET_a and ET_c, respectively, from ET_o. In this project, the goal is to compare past almond ET_a measurements in several locations within the Central Valley to standardize the analysis and determine if crop coefficient measurements are uniform throughout the Valley. This involves standardizing the measurements, quality control applications, and analysis. If the standardized crop coefficient measurements are not uniform, the goal is to determine why they differ and if the accuracy can be improved using local microclimate data.

2. **Note any challenges or unforeseen developments**
   a. COVID-19 slowed down the collection of data from previous experiments
   b. Recently, availability of data has improved and we are nearly on schedule.

F. Publications that emerged from this work

It is too early in the project to have publications.