Advanced Irrigation Management for Young and Mature Almonds

Project No.: 18.HORT38.Kisekka

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Grantee(s) of the Almond Board are REQUIRED to address sections A through G. These should be **sumitted in PDF**, using Arial font size 12 for the main text, and be five to seven pages in length.

A. Summary *(In laymen's terms – emphasize key findings and recommendations)*

The almond community in California has agreed to reduce the amount of water used to grow a pound of almonds by 20% by the year 2025. Novel irrigation management strategies are needed to achieve this goal. We set up two experiments to evaluate the effects of tree age and variety on irrigation management of almond orchards.

In Arbuckle, CA, we investigated the effects of irrigating by variety-specific growth stages on yield, nut quality, and water use. The impact of irrigating by variety on yield, quality and water productivity was not significant in the first year but needs to be evaluated for more years. We found that irrigating the Butte variety according to its hull-split period instead of according to the Nonpareil hull-split period significantly reduced the percent of sealed shells. We recommend continuing the experiment for one more year to better test the effects of irrigation management by variety.

In Corning, CA, we measured evapotranspiration in young almond orchards from 1st through 4th leaf. In 2018, we found a significant increase in crop coefficients between 1st and 2nd leaf almond trees. We recommend that farmers consider age as a factor in irrigation management because the water consumption rapidly increases when the trees are young.

B. Objectives *(300 words max.)*

1. Specify the goal(s) and specific objectives of the proposal – if a collaborative effort, identify who is the lead for each objective
2. Identify annual outputs or milestones for each of the objectives

Table 1. Main Goal(s), key objectives, timelines and milestones

Main Goal: Evaluate the effects of site-specific factors, such as tree age and variety, on irrigation management of almond orchards.		
Objective(s)	**Date to be accomplished**	**Milestones and deliverables associated to the objective**
1. Establish an automatic precision irrigation system capable of remotely irrigating almond trees by variety within a 4-acre almond orchard at Nickels Soil Lab near Arbuckle, CA.	June 03, 2018	**Milestone:** An automated precision irrigation system installed in a 4-acre almond orchard and used in implementation of Objective 2. **Deliverables:** • Description of a precision irrigation system capable of remotely irrigating almonds trees by variety within the same orchard. • Estimation of example retrofit costs on per acre basis.
2. Evaluate regulated deficit irrigation implemented by almond tree variety (Nonpareil, Butte, Aldrich) during hull split to harvest and post-harvest periods and quantify effects on total yield, nut quality, water applied, water productivity, fruit set and % Navel Orange Worm (NOW) infestation.	July 31st, 2021	**Milestone:** Quantify effect of irrigating almond orchards by tree variety on yield and nut quality, applied water, water productivity and % NOW infestation. Provide the information needed to determine if this is a profitable and sustainable management practice. **Deliverables:** • Annual reports to ABC • Presentation of findings at ABC conference • Publications
3. Quantify crop water use (ET) of young almond orchards and determine corresponding crop coefficients (K_c) for 1st, 2nd, 3rd, and 4th leaf) almond trees.	July 31st, 2021	**Milestone:** Install ET flux towers in three 80 acre young almond orchards and quantify crop water use (ET) and crop coefficients (K_c) of young almond orchards. **Deliverables:** • Annual report to ABC containing K_c of young almond orchards • Presentation at ABC conference • Publications

C. Annual Results and Discussion *(This is the core function of this report)*

1. Describe activities and outputs for each objective

Objective 1: Irrigation Management by Variety: Establish an automatic precision irrigation system capable of remotely irrigating almond trees by variety

We established an automated precision irrigation system to remotely irrigate each variety at a 4-acre almond orchard in Arbuckle, CA. The orchard consisted of 15 rows and we divided each row into 4 units for a total of 60 experimental units that we could independently irrigate in the orchard. In each row, we installed a valve actuator circuit board capable of opening and closing 4 latching solenoid valves, as shown in Figure 1. The valve actuators were connected to a wireless communication system of motes that allowed us to control the valves through a cloud-based website hosted by Node-RED (IBM Emerging Technology) and customized by Metronome Systems. We developed a Python program for calculating runtimes for each treatment based on the representative area of the experimental unit, irrigation system specifications, and ET_c calculated from reference ET from the nearest CIMIS station and crop coefficients for mature almonds. These runtimes are the input to the website that determine how long to keep each valve open.

We installed the automated precision irrigation system before the start of the 2019 experiment. Since the precision irrigation system we established was for an experiment, we divided the orchard into smaller units than necessary to irrigate by variety in a commercial orchard where the farmer would probably want to independently control whole rows rather than subdivisions of rows like we did.

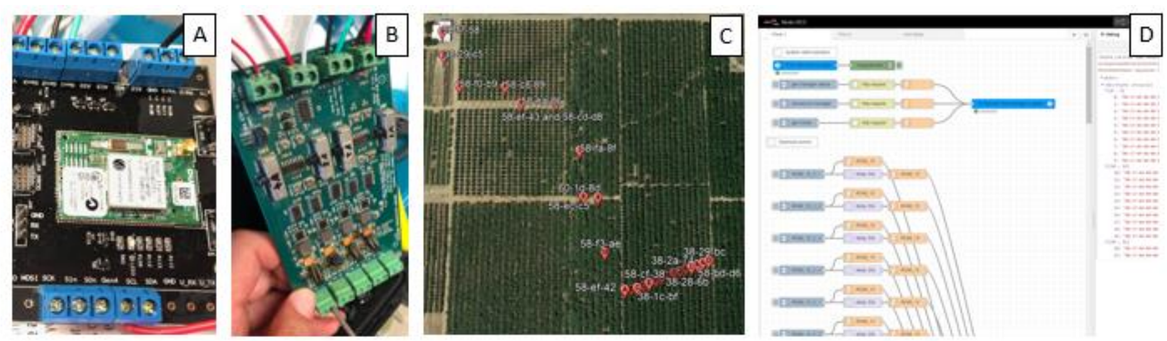


Figure 1: Left: Valve actuator boards (A) and motes for wireless communication (B). A map of the wireless network of motes and valve actuators (C). The website for remotely controlling the valves (D).

Objective 2: Irrigation Management by Variety

We used the precision irrigation system developed in Objective 1 to implement two regulated deficit irrigation treatments, 50% ET_c and 75% ET_c from hull split initiation until harvest in Butte, Aldrich, and Nonpareil trees according to two different schedules, (1) irrigating all varieties according to Nonpareil hull split initiation (mimicking common practice), and (2) irrigating according to variety-specific hull split initiation and harvest dates to simulate an orchard with the ability to irrigate by variety.

We evaluated the effects of irrigation by variety on kernel yield, nut quality, water applied, water productivity, and % Navel Orangeworm infestation. No significant differences in kernel yield or kernel count per ounce were found between irrigating according to variety-specific hull-split and irrigating according to Nonpareil-specific hull-split in either 50% ET_c or 75% ET_c treatments after one year of treatments. Delaying RDI until Butte hull-split initiation was associated with a statistically significant reduction in percent sealed shells compared to implementing RDI according to Nonpareil hull-split timing in Butte. No other quality parameters were found to be significantly different between irrigating according to variety-specific hull-split timing and irrigating according to Nonpareil hull-split timing. Stem water potential measurements indicated clear differences in water stress levels across varieties by irrigating according to variety-specific hull-split timing, as shown in Figure 2.

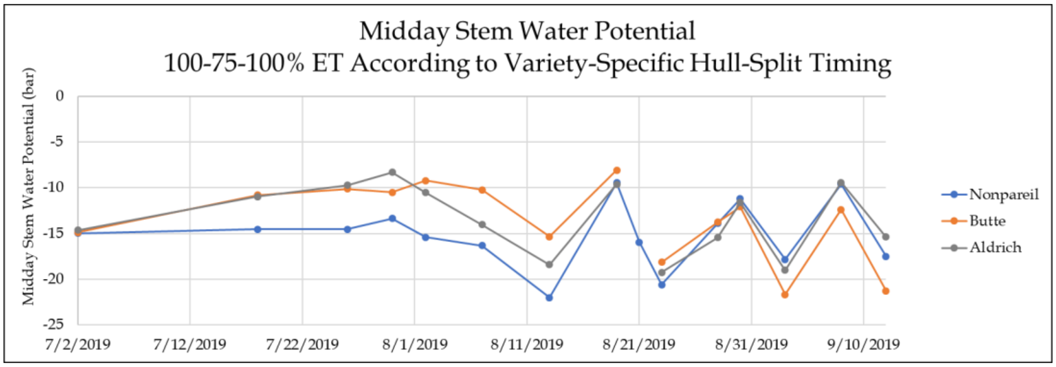


Figure 2: Stem water potential in the 75% ET_c hull-split to harvest treatment according to variety-specific timing in Butte, Aldrich, and Nonpariel.

Table 1: Yield Data for the Irrigation Management by Variety Experiment in 2019

Irrigation Treatment Hull-Split to Harvest		Average Kernel Yield (lb/acre)			Kernel Count per Ounce		
		Aldrich	Butte	Nonpareil	Aldrich	Butte	Nonpareil
S1	75% ET_c From Nonpareil Hull-Split Initiation to Harvest Dates	1774 c	2911 ab	3045 ab	28.1 bcd	24.9 e	35.5 a
S2	75% ET_c From Variety-Specific Hull-Split Initiation to Harvest Dates	1679 c	2796 b		28.7 b	26.5 bcde	
S3	50% ET_c From Nonpareil Hull-Split Initiation to Harvest Dates	1594 c	2707 b	2745 b	28.1 bcd	25.8 de	33.9 a
S4	50% ET_c From Variety-Specific Hull-Split Initiation to Harvest Dates	1676 c	2626 b		28.5 bc	26.2 cde	
S5	100% ET_c From Nonpareil Hull-Split Initiation to Harvest Dates	n/a	n/a	3493 a	n/a	n/a	34.1 a
S6	100% ET_c From Nonpareil Hull-Split Initiation to Harvest Dates	n/a	n/a	3001 ab	n/a	n/a	34.2 a

Note: Same letters indicate that the treatments are not significantly different.

Objective 3: Crop Water Use and Crop Coefficients in Young Almond Orchards

We gathered the data needed to calculate ET using eddy covariance and surface renewal methods in 1st and 2nd leaf almonds trees in 2018 and in 2nd, 3rd, and 4th leaf almond trees in 2019. Figures 3 and 4 show our results for actual evapotranspiration and crop coefficients in the 1st and 2nd leaf orchards, respectively, in 2018 using eddy covariance techniques to measure the sensible heat fluxes and estimating ETa as the residual of the energy balance.

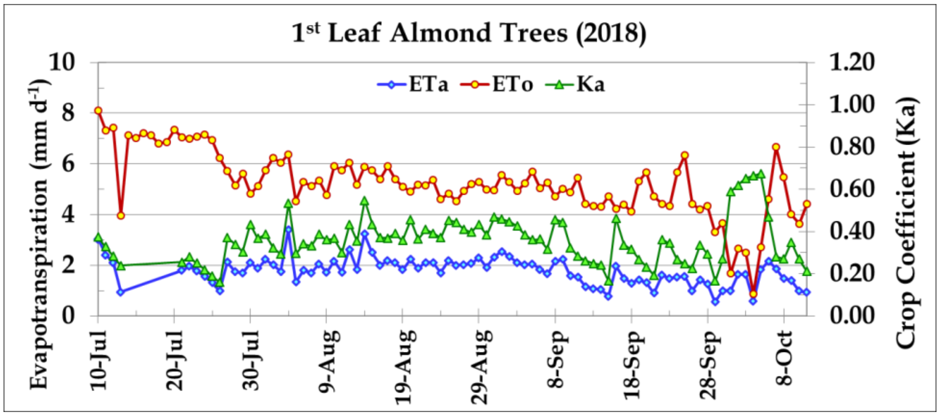


Figure 3: Daily actual evapotranspiration and crop coefficients in 1st leaf almond trees in Corning, CA.

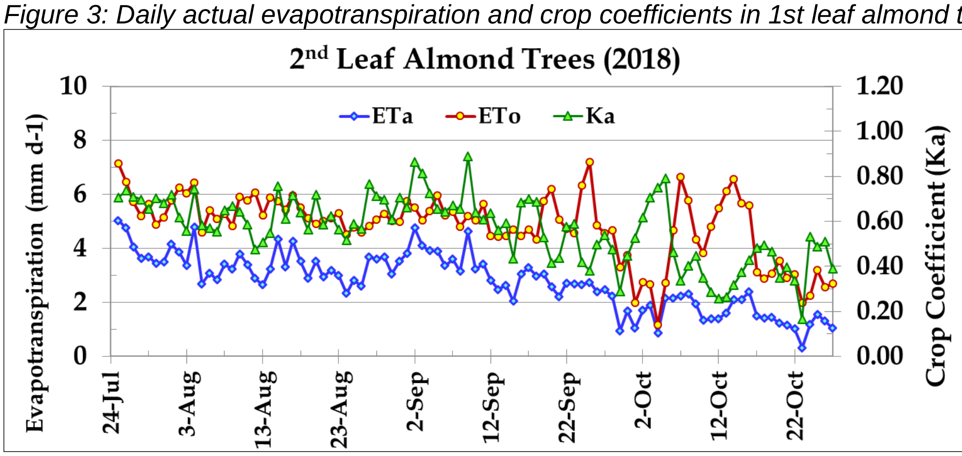


Figure 4: Daily actual evapotranspiration and crop coefficients in 2nd leaf almond trees in Corning, CA.

Table 2: Average monthly crop coefficients in 1st and 2nd leaf almond trees

	June	July	August	September	October
1st Leaf	0.30	0.29	0.39	0.32	0.41
2nd Leaf		0.70	0.62	0.59	0.44

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

Objectives 1-2: Irrigation Management by Variety

We successfully established the automated precision irrigation system and completed the first year of the irrigation treatments to evaluate the effects of irrigation management by variety. After one year of the experiment, we found that RDI according to variety-specific hull-split initiation in Butte was associated with a statistically signficant decrease in the percent sealed almonds at harvest. We wonder if this finding might have implications on machine-based shelling requirements or vulnerability to disease due to increased exposure of the kernel to its surroundings. One year of treatments testing the differences between irrigating according to variety-specific hull-split and irrigating according to Nonpareil hull-split was not long enough to make concerete conclusions on the effect of this type of management on kernel yield, so the treatments will be continued in 2020.

We did not implement any post-harvest irrigation treatments because we wanted to isolate the effects of the in-season treatments from 2019 on the yield and quality in 2020. We chose not measure fruit set due to the large quantity of bloom count measurements required to achieve a representive sample size for the experiment. Instead, we chose to focus on yield and nut quality as measures of production in each treatment.

Objective 3: Crop Water Use and Crop Coefficients in Young Almond Orchards

We successfully maintained three ET flux towers in 2^{nd}, 3^{rd}, and 4^{th} leaf trees in 2019, which we originally installed in 2018. So far, we have generated baseline data to quantify water consumption of 1^{st} through 4^{th} leaf almond orchards that could prove useful for (1) developing irrigation scheduling tools for young almond orchards, and for (2) water resources planning i.e., determining water budgets for areas with new almond plantings. We found that evapotranspiration was higher in 2^{nd} leaf almond trees than 1^{st} leaf almond trees. Average monthly crop coefficients differed between 1^{st} leaf to 2^{nd} leaf ages by 141% in July, 59% in August, 84% in September, and 7% in October, indicating the need to closely consider age as a factor in irrigation scheduling of young almond trees.

D. Outreach Activities

1. Please describe outreach activities including the event description (date, location, topic of the presentation, aprox number of participants and type of audience)

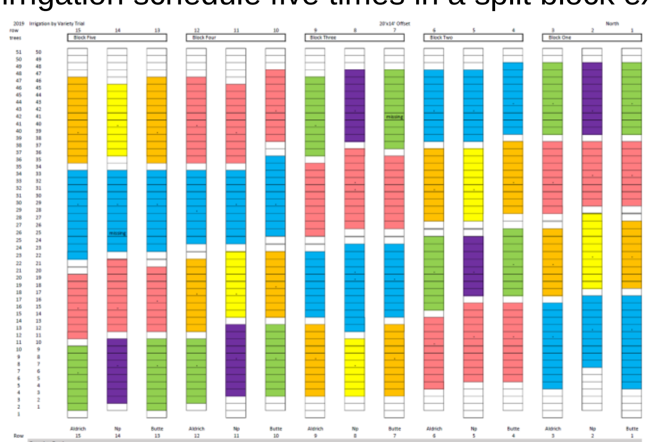
We presented our work on the irrigation by variety experiment to a group of approximately 30 UC almond and walnut farm advisors at their annual professional development tour on May 22, 2019 at Nickels Soil Lab. We also gave a presentation about the irrigation by variety experiment to approximately 80 almond farmers and industry members at Nickels Field Day on May 7, 2019 at Nickels Soil Lab.

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

1. Outline materials used and methods to conduct experiment(s)

Objectives 1-2: Irrigation Management by Variety

Figure 5 shows the experimental design we used to evaluate the effects of irrigating by variety specific growth stages on production. We replicated each combination of RDI and irrigation schedule five times in a split block experimental design.



2019	Overall Treatment
S1	100-75-100% ET based on nonpareil growth stages (in all varieties)
S2	100-75-100% ET based on variety-specific growth stages (in all varieties)
S3	100-50-100% ET based on nonpareil growth stages (in all varieties)
S4	100-50-100% ET based on variety-specific growth stages (in all varieties)
S5	100-100-100% ET based on nonpareil growth stages (in nonpareil only) with single dripline during harvest season
S6	100-100-100% ET based on nonpareil growth stages (in nonpareil only) with double dripline during harvest season

Figure 5: The experimental layout for the irrigation by variety experiment. Note: The first number is the pre-hull-split treatment, the second number is the hull-split to harvest treatment, and the third number is the post-harvest treatment.

In determining when to begin regulated deficit irrigation treatments, we carefully observed all rows of each variety leading up to when we expected hull-split to begin. Although the trees at the ends of the rows began hull-split first, we waited until the majority of the trees in the inner parts of the orchard showed approximately 1% hull-split initiation, typically starting at the top of the trees and we marked the date as the 1% hull-split initation. These dates are shown in Table 3 along with the harvest and pickup dates.

Table 3: 2019 Hull-Split and Harvest Dates

2019 Dates	Nonpareil	Aldrich	Butte
1% hull-split initiation	7/9	7/27	8/7
Harvest date	8/22	9/11	9/11
Pickup date	9/4	9/25	9/25

We calculated ET_c using the single crop coefficient method using the reference evapotranspiration from the Williams CIMIS station and crop coefficients for mature almonds. We calculated the cumulative ET_c since the previous irrigation in terms of water depth, which we then converted into a runtime using the representative area of the experimental unit (approximately 8-10 trees), the irrigation system specifications, and either 50% or 75% ET_c adjustment depending on the treatment. We had one treatment of sustained 100% ET_c in Nonpareil as a control.

We collected stem water potential measurements twice a week to monitor how often to irrigate. We expected the 50% ET_c treatments to be water stressed, but tried to irrigate frequently enough to keep the stem water potential above -20 bars, although this became challenging later in the season as the deficit irrigation accumulated. Typically, we irrigated all treatments once every 3-4 days. We also collected soil water content measurements using a neutron probe twice a week in each of the 60 experimental units to gather feedback on the irrigation treatments.

At harvest of each variety, we collected yield data and almond samples for quality analysis. We quantified (1) fractions of sealed shells, (2) weights of hulls, inshell kernels, and kernels, (3) counts of double, twin, navel orangeworm, blank, gum, shrivel, total defects, and (4) measurements of kernel length, width, and thickness. We used a Generalized Linear Mixed model at 95% confidence level to analyze differences in yield and quality parameters using the Proc Glimmix procedure in SAS.

Objective 3: Crop Water Use and Crop Coefficients in Young Almond Orchards

We measured sensible heat flux (through eddy covariance techniques), ground heat flux, and net radiation, and calculated the latent heat flux from as the residual of the energy balance, which we converted into half-hourly and daily ET. We calculated daily crop coefficients for each age as the ratio of the daily actual ET that we measured and the daily reference ET from the Gerber CIMIS station (based on Penman-Monteith equation).

Each ET flux tower consists of a three-dimensional, sonic anemometer (Model 81000 VRE, R.M. Young Company, Traverse City, MI, USA) oriented in the prevailing wind direction, a net radiometer (NR-LITE, Campbell Scientific, Logan, UT, USA), and soil heat flux plates (HFT3.1, REBS, Bellevue, WA, USA). Auxiliary data include air temperature and relative humidity, soil water content at 5 cm, soil thermocouples, and a tipping rain gauge. There is enough fetch in each of the approximately 40-acre young almond orchards for us to accurately estimate ET using each flux tower. The towers allow us to estimate ET using either eddy covariance or surface renewal methods. Figure 6 shows a map of the three ET flux towers and a picture of the ET flux tower in the 2nd leaf orchard in 2019. In addition, we collected soil water content measurements to estimate ET using a soil water balance method through transects of neutron probe access tubes in each age, which we will compare to the seasonal ET estimates from the flux towers.

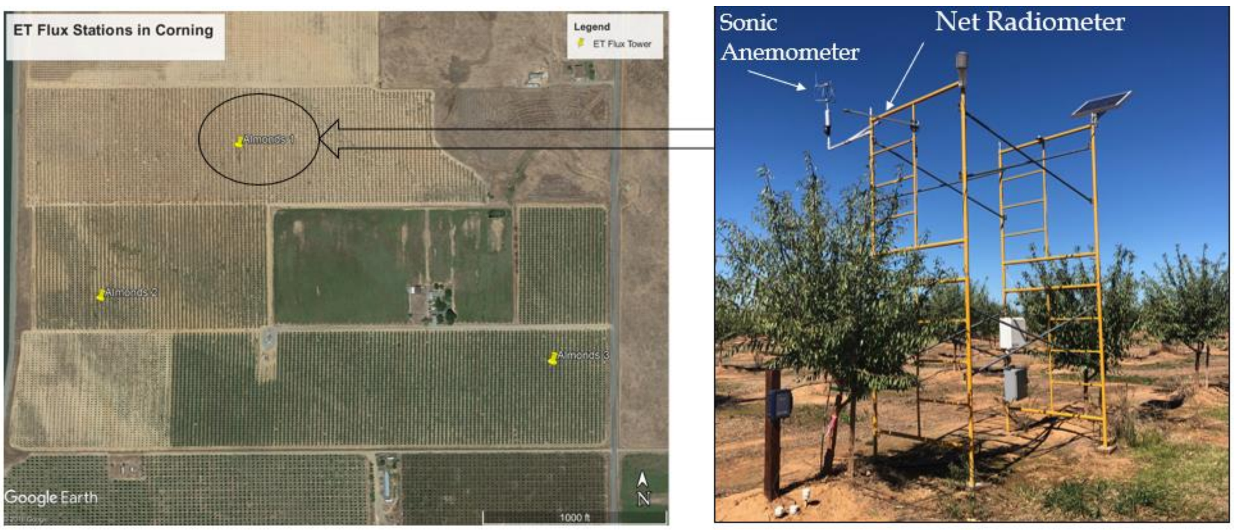


Figure 6: Left: Three evapotranspiration (ET) flux towers were initially installed in 1st, 2nd, and 3rd leaf orchards in Corning, CA in 2018. Right: The ET flux tower in the 2nd leaf orchard in 2019.

2. Note any challenges or unforeseen developments that were encountered resulting in change of methodogy, timeline, or scope of project

We did not encounter any major challenges or unforeseen developments that resulted in a change of methodology, timeline, or scope of the project.

F. Publications that emerged from this work

1. List peer review publications in preparation, accepted or published
2. Other publications (e.g. outreach materials)
3. Please provide copies of publications

We have not yet submitted any papers for peer-review, but plan to begin preparing papers after the end of the 2020 growing season. However, we did produce a outreach flyer as a part of Nickels Field Day in 2019. Kelley Drechsler wrote an article on the irrigation by variety experiment in West Coast Nut magazine in the July 2019 issue. Kelley Drechsler presented a poster on the irrigation by variety experiment at the Irrigation Association Show in 2019 and received 1st place in the graduate student competition. Isaya Kisekka presented an invited presentation on Almond Irrigation Management at the Irrigation Association Conference 2019.