# Advanced Irrigation Management for Young and Mature Almonds

**Project No.:** 18.HORT38.Kisekka

**Project Leader:**
Isaya Kisekka
Mailing Address: One Shields Avenue, PES 1110, Davis, CA
Phone: 530-379-9549
E-mail: ikisekka@ucdavis.edu

**Project Cooperators and Personnel:**
Kelley Drechsler, Graduate Student, UC Davis
Franz Niederholzer, Farm Advisor, UCANR
Allan Fulton, Irrigation and Water Resources Advisor, UCANR
Andre Daccache, Assistant Professor, UC Davis
Bruce Lampinen, Specialist in Cooperative Extension, UC Davis
Steve Gruenwald, Cooperator, Almond Grower
Stan Cutter, Cooperator, Nickels Soil Lab

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)*

*1. Variety specific regulated deficit irrigation management during hull-split in almonds*

Regulated deficit irrigation (RDI) during hull-split can reduce water use in almond orchards, but strategies for imposing RDI in almond orchards with multiple varieties with different hull-split schedules have not been extensively developed. Commonly, irrigation system design restricts all varieties in the same orchard to be on the same irrigation schedule. A 2-year study evaluated the impacts of two different regulated deficit irrigation schedules under two levels of crop evapotranspiration irrigation replacement rates in an almond orchard with Butte, Aldrich, and Nonpareil varieties in the Sacramento Valley of California, USA. The two irrigation schedules were (1) regulated deficit irrigation in Butte, Aldrich, and Nonpareil varieties during Nonpareil hull-split timing and (2) regulated deficit irrigation in each variety according to variety-specific hull-split timing. The two levels of irrigation were 50% and 75% of crop evapotranspiration (ETc) replacement during the hull-split period. Results show that the kernel thickness of Aldrich almonds increased under 75% ETc irrigation replacement during Aldrich hull-split period compared to 75% ETc and 50% ETc irrigation replacement during Nonpareil hull-split period. In the Butte almonds, 75% ETc and 50% ETc irrigation replacement during variety-specific hull-split reduced the fraction of sealed shells of the Butte variety compared to 75% ETc and 50% ETc irrigation replacement during Nonpareil hull-split period perhaps increasing vulnerability of the kernel to pests. This study demonstrated that almond physical quality can be altered in the Butte and Aldrich varieties when RDI is imposed according to variety-specific hull-split schedules, revealing previously unknown effects from irrigation system designs that permit independent irrigation scheduling of each variety. No marketable kernel yield improvements were achieved by implementing RDI according to variety-specific hull-split after two years, so the least labor-intensive strategy of RDI during Nonpareil hull-split in all three varieties is recommended.

*2. Crop coefficients and water use of young almond orchards*

An observational study was conducted in the northern Sacramento Valley to determine crop water use and crop coefficients of three adjacent young Nonpareil/Monterey almond orchards. Methods used to quantify evapotranspiration estimates of crop water use include (1) soil water balance and (2) land surface energy balance using eddy covariance. Three adjacent almond orchards that were planted in 2016, 2017, and 2018 were monitored from 2018 to 2020. Crop coefficients were determined using actual evapotranspiration estimates from each orchard and short grass reference evapotranspiration from the Gerber South California Irrigation Management Information System (CIMIS) station (ID #222) and refined to adjust for water stress using a dual crop coefficient approach. Results showed that crop water use and crop coefficients increased until the 4th leaf, indicating the need to closely consider tree development and orchard age as factors in irrigation scheduling of young almond trees. The results led to the conclusion that farmers should use development or age-specific crop coefficients in developing orchards for irrigation-scheduling until the 4th leaf when they can start using mature almond $K_c$ values. This study has generated baseline data on crop water requirements of young almond orchards that could prove useful for (1) developing irrigation scheduling tools for young almond orchards, and for (2) determining water budgets for areas with new almond orchards.

## B. Objectives *(300 words max.)*

**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)** | **Deadline** | **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.<br>**Deliverables:**<br>• Description of a precision irrigation system capable of remotely irrigating almonds trees by variety within the same orchard. |
| **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.<br>**Deliverables:**<br>• Annual reports to ABC<br>• Presentation of findings at ABC conference<br>• 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.<br>**Deliverables:**<br>• Annual report to ABC containing $K_c$ of young almond orchards<br>• Presentation at ABC conference<br>• Publications |

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

1. Describe activities and outputs for each objective

*Objective 1:*

The automatic precision irrigation system was discussed in last year's annual report. For purposes of brevity, we have not described it again in this report.

*Objective 2:*

Two years of the regulated deficit irrigation have been implemented in 2019 and 2020. The Nonpareil, Butte, and Aldrich rows had treatments S1 (75% ETc during Nonpareil hull-split) and S3 (50% ETc during Nonpareil hull-split). In addition, the Aldrich and Butte rows had treatments S2 (75% ETc during variety-specific hull-split) and S4 (50% ETc during variety-specific hull-split). In Nonpareil, S1 and S2 would be identical and S3 and S4 would be identical. The Nonpareil row in each block also had a control treatment S5 (100% ETc during Nonpareil hull-split). The following summary describes the effects of these treatments on almond physical quality, yield, and water use efficiency.

1. *Effect of RDI by variety on almond physical quality:*

In the Aldrich variety, the thickness per 10 kernels was significantly higher in S2 than S3 in 2019 and significantly higher in S2 than both S1 and S3 in 2020 at the 95% confidence level. This means that 75% ETc during variety-specific hull-split period (S2) in Aldrich resulted significantly thicker kernels than 75% ETc and 50% ETc during Nonpareil hull-split period (S1 and S3). In the Aldrich variety, S3 resulted in significantly higher occurrence of severe shrivel in S3 than in S1 and S4 in 2020. Although not significant, both Nonpareil-based hull-split RDI treatments resulted in higher occurrence of severe shrivel than both variety-specific hull-split RDI treatments in 2019. No significant differences were found across irrigation treatments in the Aldrich variety in the length and width per 10 kernels, sealed shells per 50 shells, grams per 50 kernels, double, twin, blank, gum, or insect damage at the 95% confidence level. S1 resulted in significantly fewer sealed shells out of 50 shells than S3 in 2019 at the 90% confidence level.

In the Butte variety, in 2019, both variety-specific hull-split RDI treatments (S2 and S4) resulted in significantly fewer sealed shells out of 50 shells than both Nonpareil-based hull-split RDI treatments (S1 and S3). In 2020, although only S2 had significantly fewer sealed shells out of 50 shells than S3, both variety-specific hull-split RDI treatments (S2 and S4) resulted in fewer sealed shells out of 50 shells than both Nonpareil-based hull-split RDI treatments (S1 and S3). No significant differences were found across irrigation treatments in the Butte variety in the thickness, length, width per 10 kernels, grams per 50 kernels, shrivel, double, twin, blank, gum, or insect damage at the 95% confidence level. However, the occurrence of severe shrivel was significantly higher in S2 than S1 in 2019 at 90% confidence level. S2 and S4 (according to variety specific hull-split) tended to have more shrivel than S1 and S3 (according to Nonpareil hull-split), although not significant.

In the Nonpareil variety, no significant differences were found across irrigation treatments in the thickness, length, width per 10 kernels, sealed shells per 50 shells, grams per 50 kernels, shrivel, double, twin, blank, gum, or insect damage at the 95% confidence level. However, S5 resulted in significantly higher thickness per 10 kernels than S3 in 2020 at the 90% confidence level. Also, S1 resulted in significantly higher occurrence of severe shrivel than S5 in 2020 at the 90% confidence level.

2. *Effect of RDI by variety on yield*

No significant differences in marketable kernel yield were found across any of the irrigation treatments in the Aldrich, Butte, and Nonpareil varieties in 2019 and 2020 at the 90% or 95%

confidence levels. Although not statistically significant, the marketable kernel yield of the Aldrich variety under both variety-specific hull-split RDI regimes (S2 at 4048 kg/hectare and S4 at 4180 kg/hectare) was higher than the marketable kernel yield of the Aldrich variety under the Nonpareil-based hull-split RDI regimes (S1 at 3993 kg/hectare and S3 at 3825 kg/hectare). The marketable kernel yield in 2020 was considerably higher than in 2019 in the Aldrich and Nonpareil varieties (between 123% and 147% increase in Aldrich and between 37% and 45% increase in Nonpareil), which was likely due to no rainfall during peak bloom in 2020 and was corroborated by record-breaking almond yields across California. The Butte variety showed minimal increase in marketable kernel yield between 2019 and 2020, possibly related to its later maturity. In 2019 and 2020, the marketable kernel yield of the Nonpareil variety was the highest in S5 (100% $ET_c$ during Nonpareil hull-split period), followed by S1 (75% $ET_c$ during Nonpareil hull-split period), and then by S3 (50% $ET_c$ during Nonpareil hull-split period), meaning that marketable kernel yield increased with increased water applied, although the differences were not statistically significant.

*3. Effect of RDI by variety on water use efficiency*

In 2019 and 2020, the water use efficiency of the Butte variety was higher in both Nonpareil-based hull-split RDI treatments, S1 and S3, than the two variety-specific hull-split RDI treatments, S2 and S4, meaning that more marketable kernel yield was produced per volume of water applied when irrigating the Butte trees according to Nonpareil hull-split schedule. Earlier RDI application in both Nonpareil-based hull-split RDI treatments (S1 and S3) resulted in less total water applied during the growing season than RDI application according to variety-specific hull-split (S2 and S4) due to variety differences in the duration between hull-split initiation and harvest. In 2019, the water use efficiency in Butte of S1 was significantly higher than in S4 at the 95% confidence level. In 2020, the water use efficiency in Butte of S3 was significantly higher than in S2 and S4 at the 95% confidence level. No significant differences in water use efficiency were found across irrigation treatments in the Aldrich and Nonpareil varieties in 2019 and 2020.

*Objective 3: Crop water use and crop coefficients in young almond orchards*

Figure 1 (top) shows the daily $ET_a$ [mm/day] of 1$^{st}$ and 2$^{nd}$ leaf almond orchards in 2018 measured using eddy covariance residual of the energy balance method. The 2$^{nd}$ leaf trees had higher daily $ET_a$ than the 1$^{st}$ leaf trees in June through September. Figure 1 (bottom) shows the daily $ET_a$ [mm/day] of 3$^{rd}$, 4$^{th}$, and 5$^{th}$ leaf almond orchards in 2020 measured using eddy covariance energy balance method. Both the 4$^{th}$ and 5$^{th}$ leaf orchards had similar daily $ET_a$, with the 4$^{th}$ leaf orchard typically slightly above the 5$^{th}$ leaf orchard. The 3$^{rd}$ leaf orchard had the lowest daily $ET_a$. Daily $ET_a$ increased beginning in January and peaked in all three orchards in July before decreasing as the atmospheric evaporative demand lowered in August through October and leaves began to fall due to harvest activities and senescence. All three orchards were harvested with a mechanical shaker in August for the Nonpareil trees and September for the Monterey trees. The farmer reduced irrigation during August and September to prepare for the harvest activities, resulting in a reduction in $ET_a$. Also, smoke from the LNU Lightning Complex Fires between August 17$^{th}$ and the end of September reduced net radiation, which also contributed to a decline in $ET_a$.

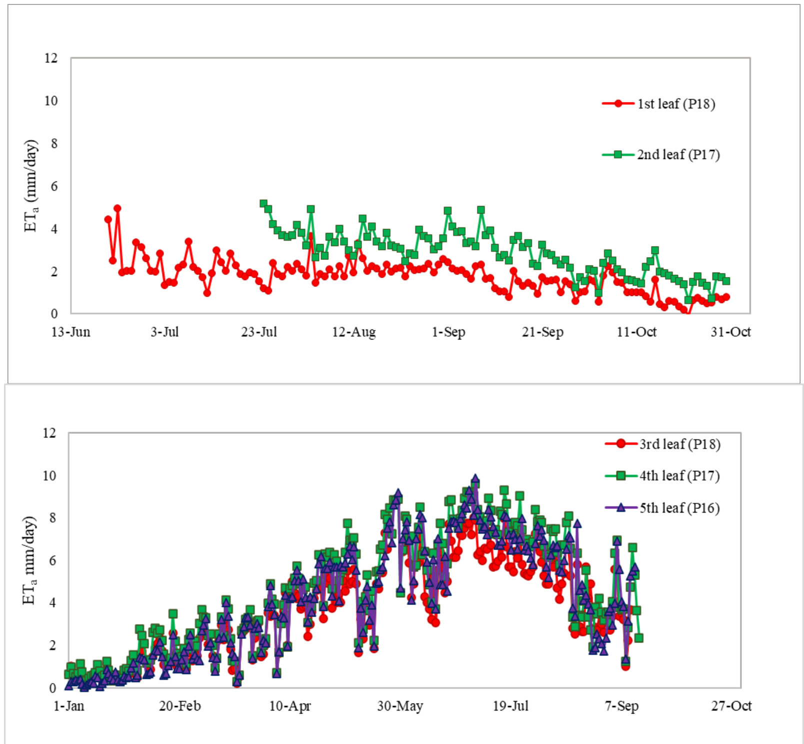


Figure 1. Top: Daily crop water use ($ET_a$) of 1st and 2nd leaf almond orchards in 2018 near Corning, CA measured using an eddy covariance energy balance. Bottom: Daily crop water use ($ET_a$) of 3rd, 4th, and 5th leaf almond orchards in 2018 near Corning, CA measured using an eddy covariance energy balance.

Figure 2 shows the seasonal average $K_c$ in each age orchard from 1st leaf to 5th leaf. The correlation between orchards of different age and canopy size and $K_c$ is excellent ($R^2$=0.94) and the curve flattened when the age reached 4th and 5th leaf.

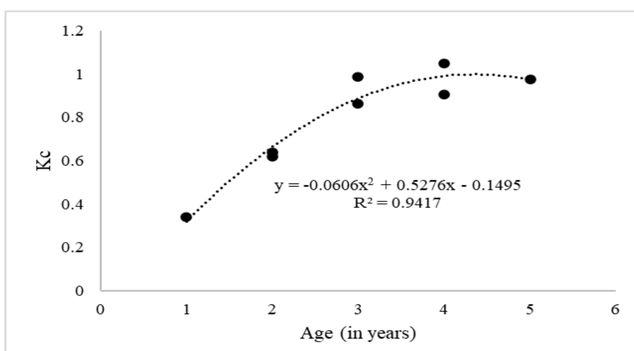


**Figure 2. Seasonal average $K_c$ in young almond orchards of age 1 to 5 years.**

Table 2 shows the seasonal average crop coefficients in 1st through 5th leaf almond orchards estimated in 2018 to 2020. Generally, the crop coefficient increased as each orchard increased in age.

Table 2. Seasonal average $K_c$ in 1st through 5th leaf almond orchards in 2018 to 2020 near Corning CA.

| Age (Years) | 2018 | 2019 | 2020 |
|---|---|---|---|
| **1** | 0.34 | | |
| **2** | 0.64 | 0.62 | |

| | | |
|---|---|---|
| **3** | 0.99 | 0.86 |
| **4** | 0.90 | 1.05 |
| **5** | | 0.97 |

Table 3 shows the crop coefficient as a function of percent PAR intercepted by the canopy in relation to the percentage of $ET_c$ of a mature almond orchard using $K_c$ estimates from the average of Sanden (2007) June and July estimates.

Table 3. Crop coefficient as a function of percent PAR intercepted by the canopy in relation to %$ET_c$ of a mature almond orchard

| Percent PAR Intercepted by the Canopy | $ET_a/ET_o$ | Mature $K_c$ (June/July Average from Sanden, 2007) | % $ET_c$ of a Mature Almond Orchard |
|---|---|---|---|
| **10** | 0.53 | 1.05 | 51 |
| **20** | 0.72 | 1.05 | 69 |
| **30** | 0.86 | 1.05 | 82 |
| **40** | 0.95 | 1.05 | 90 |
| **50** | 0.98 | 1.05 | 94 |

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:*

We successfully established the automated precision irrigation system and completed two years of the irrigation treatments to evaluate the effects of irrigation management by variety. After two years of the experiment, we conclude that RDI according to Butte hull-split period in Butte decreased the percent sealed almonds at harvest compared to RDI according to Nonpareil hull-split in Butte at both 75% $ET_c$ and 50% $ET_c$ irrigation replacement rates. 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. Also, we conclude that the kernel thickness of Aldrich almonds increased under 75% $ET_c$ irrigation replacement during Aldrich hull-split period compared to 75% $ET_c$ and 50% $ET_c$ irrigation replacement during Nonpareil hull-split period.

*Objective 3:*

We obtained baseline data to quantify water consumption of 1$^{st}$ through 5$^{th}$ 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. The results led to the conclusion that farmers should use development or age-specific crop coefficients in developing orchards for irrigation-scheduling until the 4th leaf when they can start using mature almond Kc values.

## 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)

Kelley Drechsler presented a poster on objectives 1 and 2 at the Irrigation Association Show in 2019 in Las Vegas, NV and received 1st place in the graduate student competition in December 2019. Dr. Kisekka presented an invited presentation on Almond Irrigation Management at the Irrigation Association Show in Las Vegas, NV in December 2019. Kelley Drechsler presented a poster on objectives 1-3 at the California Irrigation Institute Conference in February 2020 in Sacramento, CA. Dr. Kisekka gave an invited seminar at the Foster Our Future 2020 in Washington DC on February 05, 2020. Dr. Kisekka presented an invited seminar at the Climate Risk Interactions in Agriculture and Food Systems at UC Davis in Octomber 2020. Dr. Kisekka gave an invited seminar at the University of Minesota on November 05, 2020.

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

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

*Objectives 1-2: Irrigation Management by Variety*

This work took place at a 1.6-hectare almond [Prunus dulcis] orchard of mature cv. 'Nonpareil,' 'Aldrich,' and 'Butte' trees planted near Arbuckle, CA at Nickels Soil Lab. The almond orchard was arranged in rows that alternate between three varieties, where each row contains all the same variety. The orchard was divided into five main blocks or replications, each block divided vertically into three rows (one Nonpareil row, one Butte row, and one Aldrich row). Each block was split horizontally into four sections in a strip plot experimental design, resulting in 12 subplots in each block. The Nonpareil, Butte, and Aldrich rows of each block had treatments S1 (75% $ET_c$ during Nonpareil hull-split) and S3 (50% $ET_c$ during Nonpareil hull-split). In addition, the Aldrich and Butte rows of each block had treatments S2 (75% $ET_c$ during variety-specific hull-split) and S4 (50% $ET_c$ during variety-specific hull-split). In Nonpareil, S1 and S2 would be identical and S3 and S4 would be identical. The Nonpareil row in each block also had a control treatment S5 (100% $ET_c$ during Nonpareil hull-split), which took two subplots in each block to double the number of replicates of this control treatment. Details of the experimental design, method of irrigation scheduling, and data collection were discussed in last year's report. The RDI treatments were scheduled following the dates in Table 4. Data were collected on marketable yield, total water applied, water use efficiency, nut physical quality, light interception, soil water content, and midday stem water potential in all treatments. Details can also be found in the publication (Drechsler and Kisekka, 2021).

Table 4. Number of days between 1% hull-split and harvest in Nonpareil, Butte, and Aldrich varieties

| **2019** | **Nonpareil** | **Aldrich** | **Butte** |
|---|---|---|---|
| **1% hull-split initiation** | July 9th | July 27th | August 7th |
| **Harvest** | August 22nd | September 11th | September 11th |
| **Pickup** | September 4th | September 25th | September 25th |
| **2020** | Nonpareil | Aldrich | Butte |
| **1% hull-split initiation** | July 7th | July 23rd | August 3rd |
| **Harvest** | August 13th | September 4th | September 4th |
| **Pickup** | August 26th | September 15th | September 15th |

Figure 2 shows the cumulative water applied in the Butte variety as an example of how the irrigation treatments were applied.

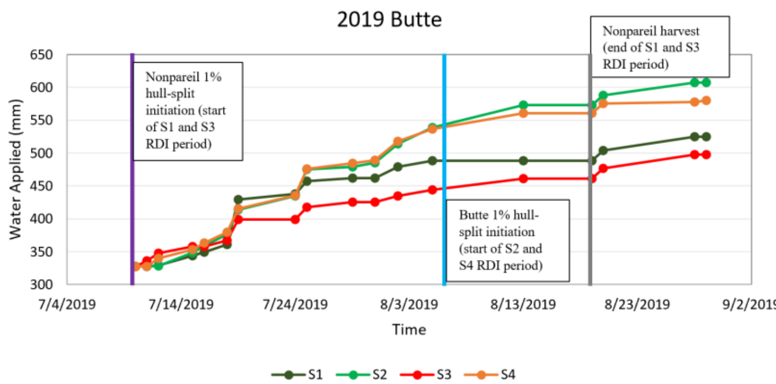


Figure 2. Cumulative water applied in the Butte variety under various irrigation regimes in 2019.

*Objective 3: Crop water use and crop coefficients in young almond orchards*

The study was conducted at a commercial almond orchard [Prunus dulcis, cultivars 75% Nonpareil and 25% Monterey], located in Corning, California (39.95° N, 122.13° W) with rows North-South oriented. The study area consisted of three adjacent orchards that were planted in 2016, 2017, and 2018. Each orchard had an ET flux station to measure sensible heat flux (using eddy covariance and surface renewal techniques), ground heat flux, and net radiation. The latent heat flux was calculated as the residual of the energy balance of the soil-vegetation surface and was 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). 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 to compare against the ET estimates from the flux stations. Details on sensors and data collection were given in last year's report.

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

We ecountered problems with the remote wireless irrigation control system, sometimes the nodes did not respond to commands to open or close a valve and required someone to physcicall drive to the site to implement the comand. We plan to update the system in the coming season.

## 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

A manuscript covering Objective 3, was submitted to *Agricultural Water Management* in December 2020 and we are waiting to hear if it has been accepted. We are nearly finished writing a manuscript covering Objectives 1 and 2, and we will submit it for publication by March 2021.