Variable Rate Irrigation Practices on Almond

Project No.: HORT32.Bali

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

A. Summary

Almond growers in California are under continuous pressure to grow orchards with limited water supplies. In recent decades, pressurized micro-irrigation systems have greatly improved distribution uniformity and water use efficiency of applied water. However, different portions of a field may have varying water and fertilizer requirements due to soil spatial variability, water quality, climate and other factors influencing tree growth across the block.

Most irrigation systems have little capacity to differentially irrigate different sections of the field to account for various factors that affect crop water needs. Water applications to the entire field are based on the needs of the ‘weakest’ areas, which may lead to over applications and reduced system efficiency and yield potential. Variable rate irrigation (VRI) systems may improve water use efficiency by tailoring irrigation zones and sets to meet changing tree water requirements. We are testing here VRI system on a 70-acre block to document the impact of using such technology on crop yield, water use efficiency, economic feasibility, and potential improvements in energy and fertilizer use efficiency.

B. Objectives *(300 words max.)*

1. Demonstrate variable rate irrigation capacity to improve water and nutrient use efficiency, tree growth, and yield in commercial almond orchards.

2. Determine variable irrigation requirements based on site climatic conditions, soil texture and salinity, and tree growth stage among other site-specific factors to improve water use efficiency.
3. Develop a system to assist growers in defining "zones" of similar characteristics, then develop variable irrigation scheduling programs for each zone to meet crop needs.
4. Retrofit existing irrigation systems to control water applications in small zones (1 acre)
5. Develop irrigation schedules that meet an orchard's crop water requirements, maintain favorable plant water status in orchard trees, decrease water and nitrogen losses and reduce energy use.

Identify annual outputs or milestones for each of the objectives
1- Ongoing work, 2019 season represented the first year of implementation of VRI. Baseline data were obtained during the 2018 growing season.
2- We developed an index to identify zones of similar characteristics and used a combination of canopy coverage and NDVI as criteria to identify 6 different irrigation management zones (A through F).
3. Ongoing, we developed a system based on several indices including tree volume, canopy coverage, NDVI and other site-specific information such as tree height and circumference. The index that we used was discussed earlier (NDVI and canopy coverage) but we are assessing using a combination of other variable based on the correlation between the various variables and yield.
4. Retrofitting was accomplished in late summer of 2018 and the system was ready for implementation during the 2019 season. However, we encountered unexpected issues such as programing and other logistics issues since this is still a prototype system.
5. We developed irrigation recommendation on a weekly basis that was implemented during the growing season until harvest. Standard uniform irrigation was implemented after harvest.

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

1. Describe activities and outputs for each objective
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

Implementation of irrigation scheduling on VRI zones was initiated in April 2019 with the first irrigation of the season. Using the data collected from the virtual orchard work and NDVI, we determined the average canopy coverage and NDVI in each zone and used it as an index to define irrigation management zones as discussed in the materials and methods section.

Irrigation Management zones
Figure 3 shows the irrigation management zone based in 2018 and 2019. The baseline management zones shown in 2018 are based on the index that consists of a combination of NDVI and canopy index. Zone A represents the most stress zone and Zone F the least stressed zones. As shown, most zones

showed improvements in late June 2019 as compared to the baseline data from 2018.

Tree circumference (Figure 4) measured during the January and February of 2019 (before the implementation of VRI) were measured for very other tree in the VRI and the averages are shown in this figure. Tree circumference is typically smaller in the stressed zones. We are in the process of conducting the statistical analysis in this area to determine if the tree circumference could be used a simple criterion to establish irrigation management zones for VRI.

Actual Evapotranspiration:
Two Tule stations (figures 5-6) were installed in the field in 2018, one in management zone D of the VRI and one in the control. Data from the Tule station during the 2019 season shows higher Kc for both the VRI and control section in 2019 as compared to 2018. This higher Kc is also translated to higher yields in both sections in 2019 as compared to 2018. In addition to the Tule stations, we installed in 2019 a surface renewal (SR) and eddie covariance (EC) weather stations in the control section to verify the accuracy of data collected by the Tulle stations. Figure 7 shows a strong correlation between actual ET measured by Tule as compared to well established scientific methods (SR and EC) to estimate actual evapotranspiration.

Infiltration rate
Based on data collected to this date, we believe that the variability in tree size and production is mostly related to a combination and the uniform application of water to the entire of water to the entire field. We measured the infiltration rate in the field and conducted extensive data collection and determined the average infiltration rate as well as cumulative infiltration during a typical summer irrigation events of 7 hrs. It appears that the lower infiltration rates were mostly related to small tree and located in stressed zones (Figure 8). The data shown in this figure have some correlation to the baseline zones that were established earlier.

Yield
Baseline yield data for the VRI site in 2018 (non-pareil) and 2019 data are shown in Figure 10. Using 2018 as a baseline, it appears that the yields were higher in 2019 in most zones. Figure 10b. summarizes the number of zones based on yield. The number of stressed zones (zones A and B) were lower in 2019 as compared to 2018. Data for the control are shown in Figures 11 and 12and 2019 yield data in the control were higher than those in 2018 as well.

Stem water potential
Stem water potential data are shown in Figures 13-15 for various dates in 2018 and 2019. In general, for any given date in June, July, or August, the trees in the VRI zones in 2019 were less stressed than 2018. Stem water potential in the VRI trial averaged -4.7 bars below the baseline for a well-watered tree, compared to an average -1.7 bars below baseline for the grower control from June to September 2019. A higher level of stress in the VRI trees likely resulted from a 20% deficit applied during hull split from mid-June to mid-July in the VRI treatment, which was not implemented in the grower control. The observed VRI SWP is consistent with the level of stress predicted

when applying a moderate deficit during this stage in nut development to reduce hull rot. We also ended up with under irrigation in the VRI plots due to technical issues related to VRI system that were later resolved.

Water use efficiency

Water use efficiency for the 2018 baseline year and the first year of VRI implementation in 2019 are shown in tables 1 and 2. In general, water use efficiency was higher in 2019 as compared to 2018. The average water use efficiency in 2019 was significantly higher in 2019. The water use included both the applied irrigation water as well as the effective rainfall during the winter of each year.

D. Outreach Activities

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

- Presentation by Bali.; Irrigation & Nutrient Management Workshop. Irrigation Scheduling Considerations to help identity yield thresholds and management allowable depletions using calculations of daily crop use. East Stanislaus RCD. Modesto, CA. May 29. 2019. Audience; approximately 50 people attended the event, mostly growers.

- Poster Presentation at the IX International Symposium on Irrigation of Horticultural Crops. June 17-20, Matera, Italy. Culumber, C.M., Bali, K., Rinkenberger,T., Rossini, D., Nadav, I., Pourreza, A., Lampinen, B., Zaccaria, D., Fulton, A, Cooper, S. and J. Nichols. 2019. "Evaluation of Variable Rate Irrigation Systems in California Almond Orchards" IX International Symposium on Irrigation of Horticultural Crops. June 17-20, Matera, Italy. Audience; 300, mostly researchers and industry.
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- Presentation by Culumber. University of California Cooperative Extension, Almond Short Course, November 6, 2019. Visalia, CA. “Soil Amendments”. Audience; Approximately 200 people attended the event. Audience; 155, mostly growers

- Presentation by Bali. University of California Cooperative Extension, Almond Short Course field tour, November 8, 2019. Parlier, CA. “Irrigation Systems and Maintenance”. Audience; Approximately 90 people attended the event, mostly growers

- Presentation by Culumber .South Valley Nut Conference, West Coast Nut, November 20, 2019. Tulare, CA “How to Get the Most Out of Your Irrigation Management Tools”. Audience; 120, mostly growers
- Presentation by Bali.; Irrigation & Nutrient Management Workshop. Irrigation Scheduling Considerations to help identity yield thresholds and management allowable depletions using calculations of daily crop use. East Stanislaus RCD. Modesto, CA. December 5. 2019. Approximately 30 people attended the event, mostly growers.

- Poster Presentation at the 2019. Almond Board of California Annual Conference. December 2019. Sacramento, CA. Bali, K., Culumber, C.M., Zaccaria D., Pourreza A., Munk D., Lampinen B., Sanden B., Fulton, A., Correia, A., Rinkenberger, T., Rossini D., and Nadav, I. 2019. "Variable Rate Irrigation Practices on Almond "Almond Board of California Conference. December 11, 2019. Sacramento, CA. Audience; 700, mostly growers, researchers and industry.

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

1. Outline materials used and methods to conduct experiment(s)
2. Note any challenges or unforeseen developments that were encountered resulting in change of methodology, timeline, or scope of project

In October 2017, a 70 acre, 4-year old commercial almond orchard was selected in near Hanford in Tulare County, CA to establish the trial in 2018 (Figure 1). Thirty six 1-acre variable irrigation zones were implemented on approximately 50% of the field and the other 50% were used as control. Netafim installed the variable rate irrigation system during the spring of 2018, however, was not functional until the summer of 2018. The VRI system was used during the 2019 growing season from the first irrigation in the season through late summer just before the August harvest. We utilized the VRI technology and compared it to the grower standard irrigation practices on the other 50% during the 2019 growing season. Each zone is approximately one acre in size with approximately 105 trees per plot (total 3,781 trees on 34.378 acres). Two Tule evapotranspiration weather stations (Figure 2) were installed in each of the VRI and control sections of the field. A minimum of two locations per management zone (A, B, C, D, E, and F) for soil moisture measurements were established to estimate soil moisture in the root zone. In zones A and F, we installed additional soil moisture sensors. The additional stations were installed in zones representing low and high density vegetation soil moisture sensors and one station in the control (Figure 2).

Irrigation scheduling:

The 2018 growing season was used as a baseline for standard irrigation practices on the entire field. During the 2018 season, the grower irrigated using their standard irrigation practices. Average application rates and irrigation duration were determined to establish baseline figures for the farm. Soil moisture data and Tule actual evapotranspiration were recorded. During the 2019 growing season, irrigation scheduling for each the 6 VRI management zones was determined using a method developed for this project utilizing almond crop coefficient, actual evapotranspiration in the field as measured by Tule station and forecasted ETo. The method is discussed in detail in Attachment A. The management zones as well as sample of weekly irrigation recommendations are presented in Attachment B.

Plant Water Status

Baseline soil and tree water status, and canopy parameters were collected at Clark Ranch (36.240445, -119.4670198) in Tulare, CA. Data observations were initiated in early April and continued through July 2019. The 2013 planted orchard block of Nonpareil are arranged in a 18ft x 22ft, and the second variety Wood Colony, in a 15ft x 22 ft pattern. Both varieties are on Nemaguard rootstock. Baseline data was collected during the 2018 season to identify any spatial variation in tree canopy size and plant water status prior to implementing the variable rate irrigation trial. There are 36 zones from which data was collected. Stem water potential (SWP) readings were collected from the two centermost trees within each 1-acre plot at least twice a month. Reference baseline values were determined according to the temperature and relative humidity (RH%) as outlined in Fulton and Buchner (2014). Canopy light interception as midday canopy photosynthetically active radiation (PAR) (Lampinen et al. 2012) was measured and data analysis is still ongoing. Dendrometers were installed in 2019 in subset of zones to compare continuous plant water status measurements with SWP.

Virtual Orchard

Drone flights were conducted in June 2018 and also in June 2019 to determine the area, canopy coverage, average height, maximum height, and volume index in each zone. The parameters were determined for each of the tree in the orchard and we are in the process of determining the average parameter in each zone as well as the control zones.

Yield

A weigh cart with load cells, GPS, and auto-sub sampler will be used to measure continuous almond yields within each irrigation zone in both the VRI and conventional systems. The almond sub-samples will be evaluated for kernel weight and quality. Canopy light bar measurements at harvest and almond yield will be correlated to records of total water, to identify changes in productivity in response to the VRI system.

F. Publications that emerged from this work

1. List peer review publications in preparation, accepted or published

Jingyuan Xue, Khaled Bali, Sarah Light, Tim Hessels, Isaya Kisekka. 2020. Evaluation of remote sensing based evapotranspiration models against surface renewal in almonds, tomatoes and maize. 2020. Submitted for publication. Agricultural water Management 1/10/2020.

2. Other publications (e.g. outreach materials)

3. Please provide copies of publications

Please see the attached abstract of paper.

References Cited:

Fulton, A. and R. Buchner. (2014). Using the pressure chamber for irrigation management in walnut, almond, and prune. UCANR pub 8503.

Lampinen, B., V. Udompetaikul, G. Browne, S. Metcalf, W. Stewart, L. Contador, C. Negron, and S. Upadhyaya (2012). A Mobile Platform for Measuring Canopy Photosynthetically Active Radiation Interception in Orchard Systems. HortTechnology vol. 22:2, p. 237-244

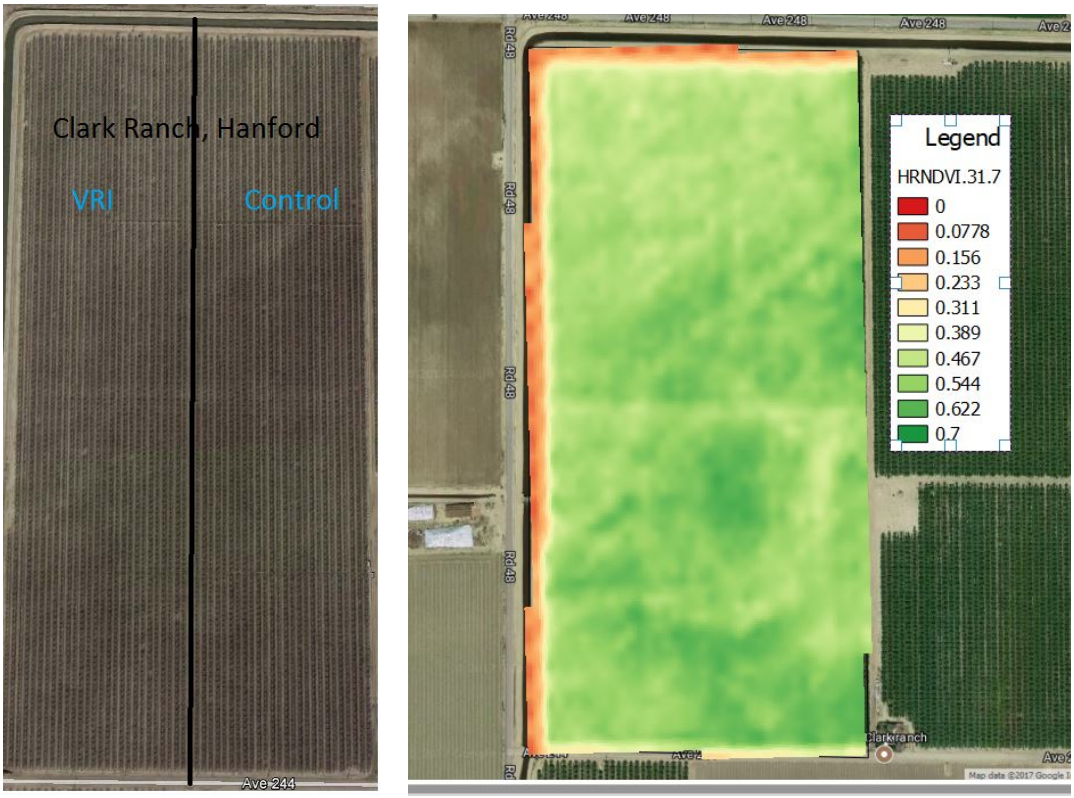

Figure 1. Clark Ranch, Hanford, CA.

Figure 2. Variable rate zones and Tue locations.

2018 CC_NDVI Index	Increment	0.0358944		Zone management by 2018 CC_NDVI Index		
Region	Min	Max				
A	0.5502222	0.5861166		Zone 1 A	Zone 7 B	Zone 13 C
B	0.5861166	0.6220109		Zone 2 A	Zone 8 A	Zone 14 B
C	0.6220109	0.6579053		Zone 3 C	Zone 9 C	Zone 15 D
D	0.6579053	0.6937996		Zone 4 D	Zone 10 D	Zone 16 D
E	0.6937996	0.729694		Zone 5 C	Zone 11 D	Zone 17 F
F	0.729694	0.7655883		Zone 6 B	Zone 12 E	Zone 18 F
				Zone 19 A	Zone 25 C	Zone 31 E
				Zone 20 C	Zone 26 D	Zone 32 E
				Zone 21 C	Zone 27 D	Zone 33 D
				Zone 22 D	Zone 28 D	Zone 34 E
				Zone 23 C	Zone 29 D	Zone 35 E
				Zone 24 B	Zone 30 A	Zone 36 B

CC_ArcGIS NDVI Index	Increment	0.0440018	6/26/2019	Zone management by CC_ArcGIS NDVI		
Region	Min	Max				
A	0.6120829	0.6560847		Zone 1 A	Zone 7 B	Zone 13 B
B	0.6560847	0.7000865		Zone 2 B	Zone 8 D	Zone 14 C
C	0.7000865	0.7440883		Zone 3 C	Zone 9 D	Zone 15 D
D	0.7440883	0.7880901		Zone 4 D	Zone 10 E	Zone 16 E
E	0.7880901	0.8320919		Zone 5 D	Zone 11 F	Zone 17 F
F	0.8320919	0.8760938		Zone 6 D	Zone 12 F	Zone 18 F
				Zone 19 C	Zone 25 E	Zone 31 F
				Zone 20 D	Zone 26 E	Zone 32 F
				Zone 21 E	Zone 27 F	Zone 33 F
				Zone 22 F	Zone 28 F	Zone 34 F
				Zone 23 D	Zone 29 C	Zone 35 F
				Zone 24 D	Zone 30 D	Zone 36 E

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Figure 3. 2018 and 2019 Management zones based on NDVI and canopy coverage.

Trunk Circumference (cm)	Increment	1.128358417		Zone Management by Trunk Circumference		
Region	Min	Max				
A	52.25869565	53.38705407		Zone 1 A	Zone 7 A	Zone 13 A
B	53.38705407	54.51541249		Zone 2 A	Zone 8 B	Zone 14 B
C	54.51541249	55.6437709		Zone 3 C	Zone 9 B	Zone 15 B
D	55.6437709	56.77212932		Zone 4 C	Zone 10 B	Zone 16 D
E	56.77212932	57.90048774		Zone 5 C	Zone 11 C	Zone 17 F
F	57.90048774	59.02884615		Zone 6 C	Zone 12 D	Zone 18 F
				Zone 19 C	Zone 25 C	Zone 31 E
				Zone 20 D	Zone 26 D	Zone 32 F
				Zone 21 E	Zone 27 F	Zone 33 F
				Zone 22 E	Zone 28 F	Zone 34 F
				Zone 23 D	Zone 29 E	Zone 35 F
				Zone 24 C	Zone 30 C	Zone 36 D

Figure 4. 2019 average tree circumference and average tree height in the VRI zones

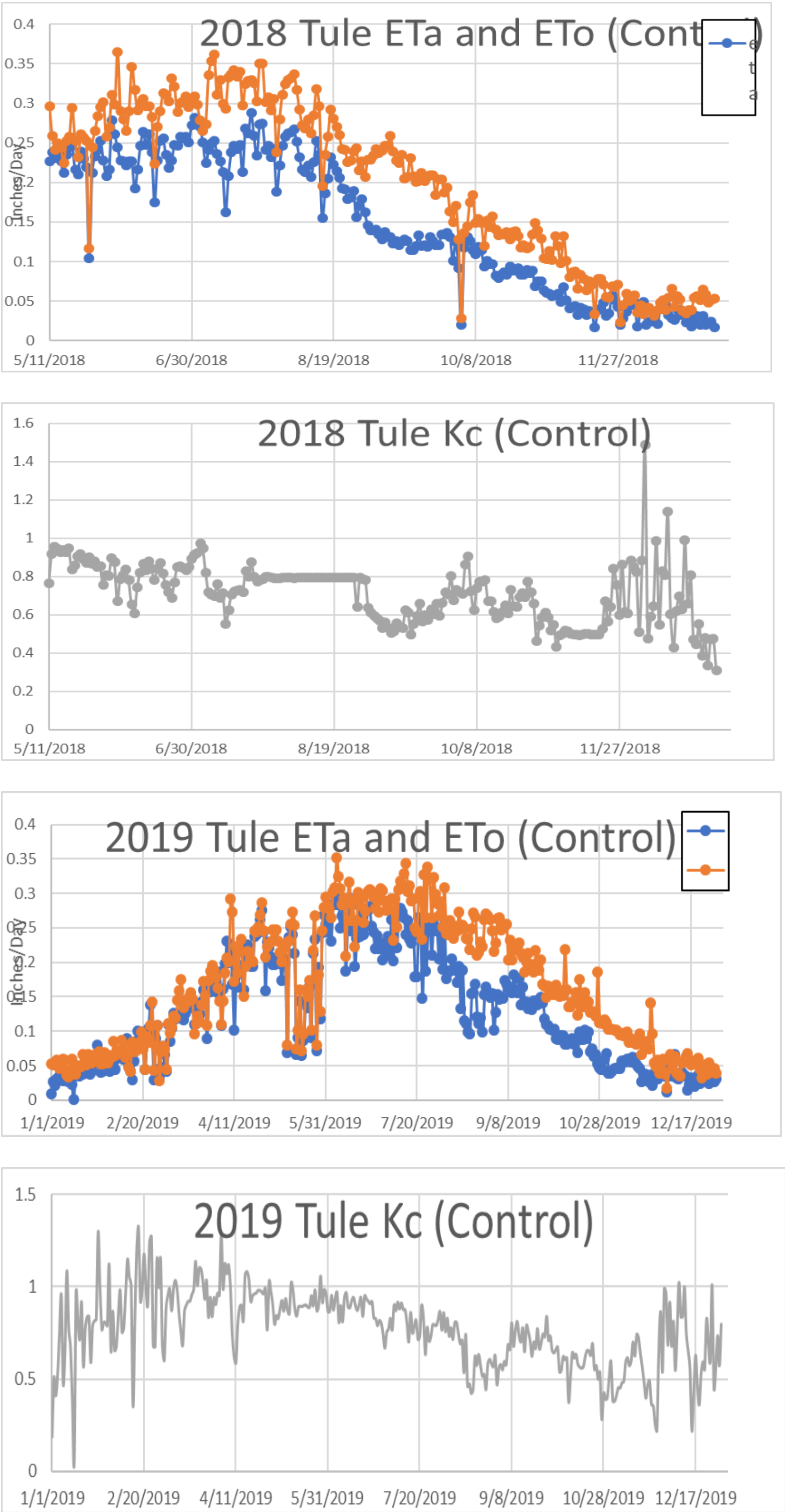

Figure 5. Daily reference evapotranspiration, actual Tule ETa, and crop coefficient (Kc) for the control section of the field (2018 and 2019). ETa Blue line, ETo Orange line.

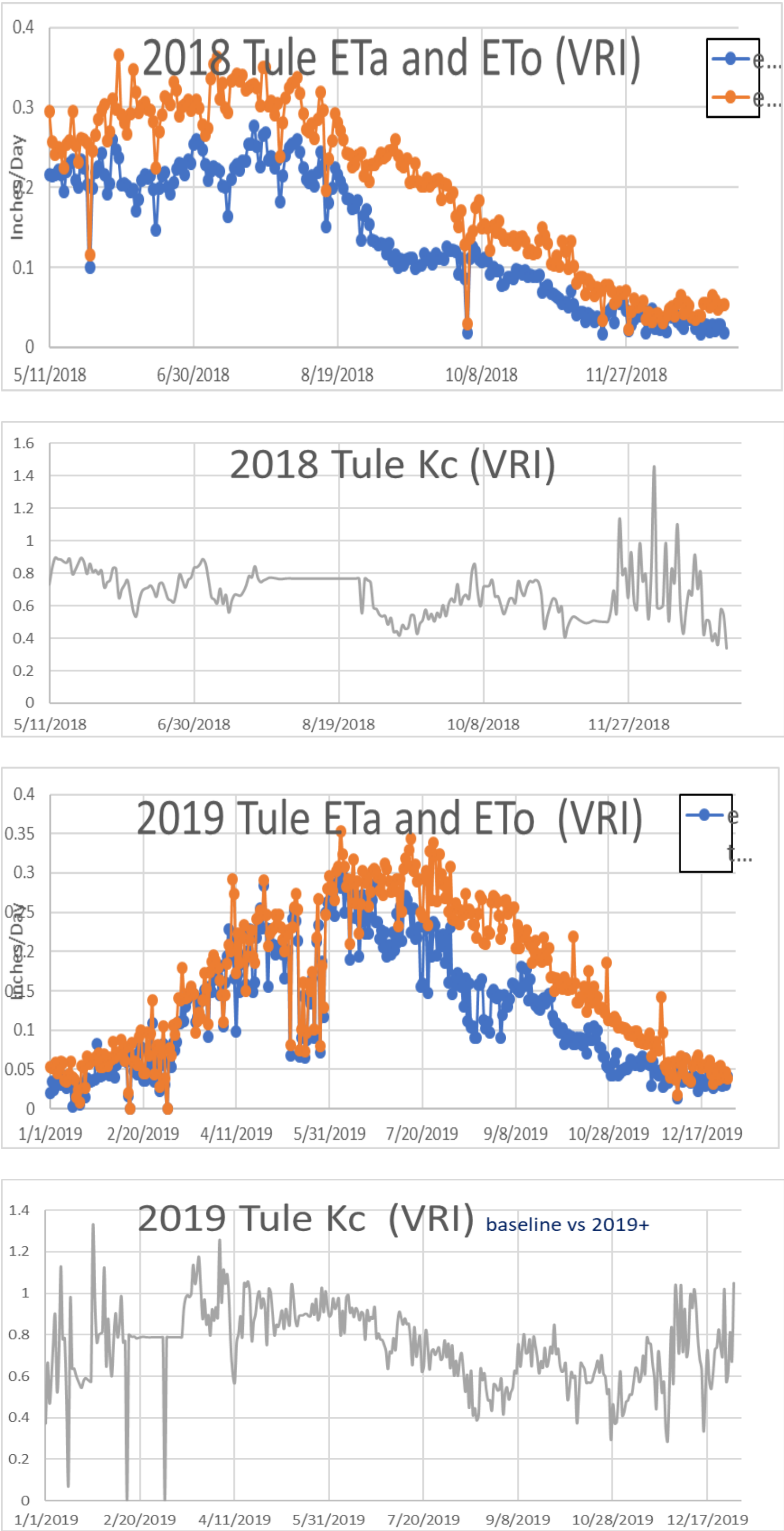

Figure 6. Daily reference evapotranspiration, actual Tule ETa, and crop coefficient (Kc) for the VRI section of the field (2018 and 2019). ETa Blue line, ETo Orange line

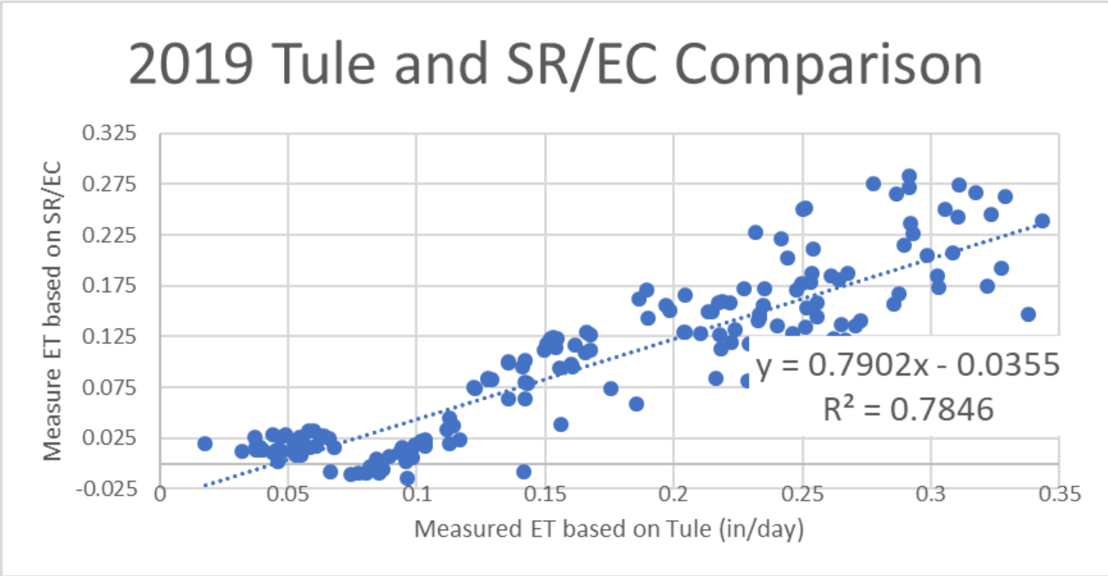

Figure 7. Relationship between Tule actual ETa and actual evapotranspiration as measured by eddy covariance (EC) and surface renewal (SR) methods.

Average Infiltration Rate (in/hr)

0.8958	0.3438	0.6525	
1.2273	0.9609	0.5078	
0.8194	0.4766	0.9916	
0.4792	1.8438	0.4609	
0.3654	3.3365	.	
3.2644	2.125	1.8942	2.201923077
0.9856	1.7404	0.7981	
0.9087	0.5481	1.7981	
0.8403	0.25	1.1634	
0.2361	0.1806	0.399	
1.0069	0.3056	0.9712	
0.7847	0.2847	0.6875	

Total Infiltration (in)

5.69	2.00	3.78	
6.75	5.44	2.88	
4.94	2.19	5.43	
2.63	10.63	2.63	
2.38	21.69	.	
21.22	13.81	12.31	14.31
6.41	11.31	5.19	
5.91	3.56	11.69	
5.06	1.38	7.56	
1.50	1.06	2.59	
6.56	1.81	6.31	
5.00	1.81	4.47	

Figure 8. Average infiltration rate in inches per hr and total volume infiltrated (7hrs).

Trunk Circumference (cm)	Increment	1.128358417
Region	Min	Max
A	52.25869565	53.38705407
B	53.38705407	54.51541249
C	54.51541249	55.6437709
D	55.6437709	56.77212932
E	56.77212932	57.90048774
F	57.90048774	59.02884615

Zone Management by Trunk Circumference		
Zone 1 A	Zone 7 A	Zone 13 A
Zone 2 A	Zone 8 B	Zone 14 B
Zone 3 C	Zone 9 B	Zone 15 B
Zone 4 C	Zone 10 B	Zone 16 D
Zone 5 C	Zone 11 C	Zone 17 F
Zone 6 C	Zone 12 D	Zone 18 F
Zone 19 C	Zone 25 C	Zone 31 E
Zone 20 D	Zone 26 D	Zone 32 F
Zone 21 E	Zone 27 F	Zone 33 F
Zone 22 E	Zone 28 F	Zone 34 F
Zone 23 D	Zone 29 E	Zone 35 F
Zone 24 C	Zone 30 C	Zone 36 D

Figure 9. Zone management by tree circumference

Comparison of 2018 and 2019 Yield

2018

Zone 1 A1	Zone 7 B1	Zone 13 C2
Zone 2 A2	Zone 8 A2	Zone 14 A2
Zone 3 A2	Zone 9 B1	Zone 15 B2
Zone 4 C1	Zone 10 B2	Zone 16 A1
Zone 5 B2	Zone 11 C1	Zone 17 B2
Zone 6 B1	Zone 12 B1	Zone 18 B1
Zone 19 B2	Zone 25 A2	Zone 31 B1
Zone 20 A1	Zone 26 C1	Zone 32 B1
Zone 21 B1	Zone 27 D1	Zone 33 A2
Zone 22 D1	Zone 28 D2	Zone 34 C1
Zone 23 B2	Zone 29 C1	Zone 35 D1
Zone 24 A1	Zone 30 B2	Zone 36 B1

2019

Zone 1 D2	Zone 7 C2	Zone 13 D1
Zone 2 C1	Zone 8 A2	Zone 14 B2
Zone 3 C2	Zone 9 B1	Zone 15 B1
Zone 4 D1	Zone 10 B1	Zone 16 D1
Zone 5 C1	Zone 11 B2	Zone 17 E2
Zone 6 D2	Zone 12 D1	Zone 18 F2
Zone 19 F1	Zone 25 B2	Zone 31 F1
Zone 20 C1	Zone 26 C2	Zone 32 D2
Zone 21 B2	Zone 27 B1	Zone 33 D2
Zone 22 D2	Zone 28 C2	Zone 34 F1
Zone 23 B1	Zone 29 B2	Zone 35 D2
Zone 24 A2	Zone 30 A2	Zone 36 B2

Figure 10a. Almond yield in 2018 and 2019.

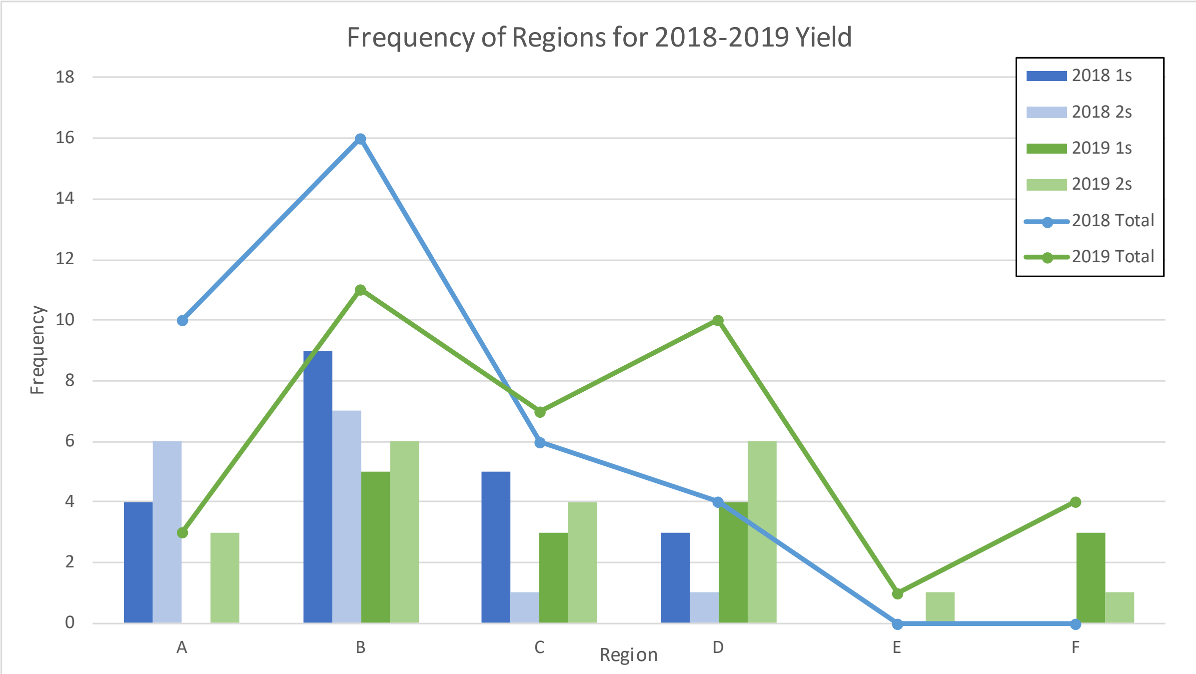

Figure 10b. Almond yield in 2018 and 2019.

2018 Yield (Kernel lbs/acre)

<table>
<tr><td>2101</td><td>2379</td><td>2778</td><td rowspan="12">2448</td></tr>
<tr><td>2206</td><td>2174</td><td>2160</td></tr>
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<tr><td>2954</td><td>3112</td><td>2642</td></tr>
<tr><td>2572</td><td>2663</td><td>2899</td></tr>
<tr><td>1989</td><td>2502</td><td>2319</td></tr>
</table>

Figure 11. 2018 yield baseline data for control and VRI.

2019 Yield (kernel lbs/acre)

<table>
<tr><td>3131</td><td>2765</td><td>2984</td><td rowspan="12">3144</td></tr>
<tr><td>2726</td><td>2180</td><td>2515</td></tr>
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<tr><td>3106</td><td>2800</td><td>3522</td></tr>
<tr><td>2350</td><td>2435</td><td>3098</td></tr>
<tr><td>2219</td><td>2211</td><td>2572</td></tr>
</table>

Figure 12. 2019 yield data for control and VRI.

June 2018 Stem Water Potential Average

-16.00	-16.69	-15.01
-18.00	-14.79	-15.02
-17.19	-14.03	-12.55
-16.25	-14.82	-13.98
-18.67	-15.28	-14.08
-19.19	-14.64	-12.63
-18.50	-15.68	-17.82
-16.13	-15.76	-14.65
-14.50	-15.85	-13.70
-15.56	-15.87	-13.31
-16.69	-14.95	-14.85
-17.56	-19.65	-15.86

June 2019 Stem Water Potential Average

-11.38	-11.75	-9.50
-9.50	-9.00	-10.00
-12.00	-9.00	-9.00
-11.00	-8.25	-9.50
-11.00	-9.75	-9.00
-9.25	-10.00	-10.75
-13.00	-14.50	-9.25
-11.25	-13.00	-11.50
-7.75	-8.00	-11.25
-9.75	-10.75	-11.00
-8.63	-10.00	-11.00
-10.88	-13.50	-10.50

Figure 13. Stem water potential June 2018 and June 2019

July 2018 Stem Water Potential Average

<table>
<tr><td>-19.60</td><td>-22.50</td><td>-19.75</td><td rowspan="12"></td></tr>
<tr><td>-20.63</td><td>-19.30</td><td>-19.38</td></tr>
<tr><td>-19.63</td><td>-19.90</td><td>-18.40</td></tr>
<tr><td>-17.25</td><td>-20.20</td><td>-18.83</td></tr>
<tr><td>-20.13</td><td>-19.70</td><td>-18.93</td></tr>
<tr><td>-21.50</td><td>-20.30</td><td>-18.08</td></tr>
<tr><td>-24.75</td><td>-19.40</td><td>-19.53</td></tr>
<tr><td>-22.88</td><td>-20.80</td><td>-20.40</td></tr>
<tr><td>-18.25</td><td>-20.20</td><td>-20.63</td></tr>
<tr><td>-20.13</td><td>-19.45</td><td>-18.75</td></tr>
<tr><td>-21.50</td><td>-19.20</td><td>-18.50</td></tr>
<tr><td>-26.13</td><td>-23.10</td><td>-20.45</td></tr>
</table>

July 2019 Stem Water Potential Average

<table>
<tr><td>-13.74</td><td>-12.75</td><td>-14.75</td><td rowspan="12">-11.34</td></tr>
<tr><td>-13.83</td><td>-11.50</td><td>-13.25</td></tr>
<tr><td>-15.80</td><td>-12.50</td><td>-11.88</td></tr>
<tr><td>-13.93</td><td>-12.38</td><td>-13.00</td></tr>
<tr><td>-15.68</td><td>-11.38</td><td>-11.63</td></tr>
<tr><td>-14.20</td><td>-12.38</td><td>-13.94</td></tr>
<tr><td>-15.75</td><td>-14.13</td><td>-14.31</td></tr>
<tr><td>-17.60</td><td>-14.25</td><td>-15.00</td></tr>
<tr><td>-11.10</td><td>-11.88</td><td>-16.50</td></tr>
<tr><td>-14.73</td><td>-13.25</td><td>-13.50</td></tr>
<tr><td>-12.58</td><td>-13.00</td><td>-14.38</td></tr>
<tr><td>-15.34</td><td>-13.50</td><td>-14.25</td></tr>
</table>

Figure 14. Stem water potential July 2018 and July 2019

August 2018 Stem Water Potential Average				Sep
-19.38	-23.80	-23.30		
-20.75	-22.50	-21.20		
-20.25	-20.50	-19.93		
-20.00	-22.20	-19.50		
-21.25	-22.60	-20.28		
-21.00	-23.05	-19.00		
-20.75	-20.60	-20.95		
-21.00	-22.10	-23.30		
-21.25	-22.10	-21.63		
-18.75	-21.60	-19.95		
-19.50	-22.20	-20.58		
-20.63	-24.50	-21.25		

August 2019 Stem Water Potential Average			
-13.75	-11.50	-14.50	
-15.50	-12.25	-15.50	
-14.50	-12.25	-15.50	
-16.50	-14.25	-15.00	
-14.50	-13.75	-14.00	
-13.00	-13.50	-15.00	-10.94
-16.50	-13.00	-15.50	
-17.00	-14.50	-17.50	
-14.00	-13.25	-15.88	
-16.50	-14.75	-14.50	
-13.50	-14.75	-16.00	
-13.75	-14.00	-14.25	

Figure 15. Stem water potential August 2018 and August 2019.

Table 1. Baseline water use efficiency 2018

Zone	Treatment	Total Water Use (in)	Zone Yield (lb/acre)	WUE (lb/ac-ft)
1	A	43.32	2101	582
2	A	43.32	2206	611
3	C	43.32	2141	593
4	D	43.32	2665	738
5	C	43.32	2439	676
6	B	43.32	2307	639
7	B	43.32	2379	659
8	A	43.32	2174	602
9	C	43.32	2315	641
10	D	43.32	2557	708
11	D	43.32	2680	742
12	E	43.32	2408	667
13	C	43.32	2778	769
14	B	43.32	2160	598
15	D	43.32	2465	683
16	D	43.32	2126	589
17	F	43.32	2497	692
18	F	43.32	2332	646
19	A	43.32	2567	711
20	C	43.32	2072	574
21	C	43.32	2316	642
22	D	43.32	2954	818
23	C	43.32	2572	713
24	B	43.32	1989	551
25	C	43.32	2222	615
26	D	43.32	2632	729
27	D	43.32	2895	802
28	D	43.32	3112	862
29	D	43.32	2663	738
30	A	43.32	2502	693
31	E	43.32	2391	662
32	E	43.32	2346	650
33	D	43.32	2207	611
34	E	43.32	2642	732
35	E	43.32	2899	803
36	B	43.32	2319	642
Average		43.32	2439	677

Table 2. Baseline water use efficiency 2019

Zone	Treatment	Total Water Use (in)	Zone Yield (lb/acre)	WUE (lb/ac-ft)
1	A	41.36	3131	908
2	A	41.36	2726	791
3	C	38.82	2740	847
4	D	37.26	2916	939
5	C	38.82	2719	841
6	B	40.23	3173	946
7	B	40.23	2765	825
8	A	41.36	2180	632
9	C	38.82	2398	741
10	D	37.26	2385	768
11	D	37.26	2455	791
12	E	37.55	2964	947
13	C	38.82	2984	922
14	B	40.23	2515	750
15	D	37.26	2396	772
16	D	37.26	2906	936
17	F	37.30	3414	1098
18	F	37.30	3766	1211
19	A	41.36	3497	1014
20	C	38.82	2617	809
21	C	38.82	2451	758
22	D	37.26	3106	1000
23	C	38.82	2350	726
24	B	40.23	2219	662
25	C	38.82	2470	763
26	D	37.26	2762	890
27	D	37.26	2300	741
28	D	37.26	2800	902
29	D	37.26	2435	784
30	A	41.36	2211	641
31	E	37.55	3562	1138
32	E	37.55	3172	1014
33	D	37.26	3152	1015
34	E	37.55	3522	1126
35	E	37.55	3098	990
36	B	40.23	2572	767
Average		38.63	2801	872

Attachment A:
Irrigation Scheduling Algorithm for Variable Rate Irrigation (Example Clark Ranch)

Irrigation management zones are based on canopy coverage data from the 2018 growing season, as well as NDVI data obtained by ANR-IGIS unit. Current management zones based on canopy coverage are shown in Table 1. Six management zones will receive intensive soil moisture and stem water data collection, which will be used to adjust irrigation schedules as described below:

Zone 1-A (same zone under both CC and NDVI based on 2018 data)
Zone 10-D (same zone under both CC and NDVI based on 2018 data)
Zone 18- F (same zone under both CC and NDVI based on 2018 data)
Zone 23- C (same zone under both CC and NDVI based on 2018 data)
Zone 24- B (same zone under both CC and NDVI based on 2018 data)
Zone 31- E (same zone under both CC and NDVI based on 2018 data)

Soil moisture sensors are placed in approximately the middle of each of the above zone in rows 6, 16, and 26

Stem water potential (SWP) in these zones will be measured one-day prior to setting the weekly irrigation schedule on three of each Non-pareil (NP) and Wood Colony (WC) trees located near the center of each zone. SWP measurements will also be collected for one NP and one WC in all 36 zones, once every two weeks, to evaluate block wide responses to irrigation schedules.

Please note that row numbering that we utilize is based on x-y coordinates (tree 1,1) is the first tree in the southwest corner of the field.

Tule VRI is located on row 26, tree 52 (x=26,y=52) x,y coordinates (Zone 32)

Irrigation System design and evaluation:

Design irrigation application rates are based on data provided by Netafim. Netafim drippers 20mm, 0.53 gph @ 21.6” spacing, design application rate: 0.04276 inch/hr

Overall system DU for various zones was determined by North West Kern RCD. The VRI system had an overall DU of approximately 97-99%. CE measured the DU of various zones and the actual DU ranged from approximately 95-99%.

We will use an overall DU of 95% in our irrigation calculations.

Irrigation scheduling:

CE irrigation management decision for each zone:

Weekly crop water requirements are determined from CIMIS ETo, and Kc (based on actual Kc from Tule from the 2018 season then updated based on previous week’s Kc)

Weekly average ETc=ETo*Kc/DU

Weekly Average ETc will be the starting point to determine the first irrigation in the season.

Adjustments for management in each zone (up or down from average ETc) will be based on the soil moisture and stem water potential data collection zones mentioned above (starting the week of 4/10 or 4/17/2019). The target will be to maintain tree SWP within -2 to -3 bars below the baseline for a well-watered tree from April to June 15. We will impose a mild to moderate level of water stress with controlled regulated deficit irrigation for both varieties during pre-harvest period. SWP measurements will increase to a weekly frequency at

NP hull split initiation (around June 15). At this time, irrigation will be scheduled to target a mild to moderate level of tree stress -14 to -18 bars for NP trees, while WC trees will target the -2 to -3 bars until hull split initiation (around July 15th). Irrigation will return to normal (-2 to -3 bars below baseline) once visual estimations confirm trees have reached 90% hull split.
Adjustment for each zone will be based on a factor not to exceed 120% of Tule ETc or not below 80% of Tule ETc.
Once estimate ETc is determined for each zone for the week, irrigation set time is determined to split irrigation event on a 6 days/week with estimated daily application rates.
Most of the variability in the field is related to soil texture. We recommend daily application rates should be split into several irrigations.
Weekly irrigation scheduling events are communicated to Clark ranch on Thursday with cc to Spencer, Netafim, and other team members interested in receiving the updated irrigation scheduling.
All other additional technologies such as ANR-IGIS NDVI, thermal images, dendrometers, NDVI, CERES images will be utilized and tested to determine irrigation events, but the primary methods are based on actual ET and soil moisture and SWP.

Table 3. Zone management based on canopy coverage data from June 2018

C. C. divided into 6 "Regions"	Increment	0.048449835		Zone Management by C.C. region		
Region	Min	Max				
A	0.505818188	0.554268023		Zone 1 A	Zone 7 A	Zone 13 A
B	0.554268023	0.602717858		Zone 2 A	Zone 8 A	Zone 14 B
C	0.602717858	0.651167694		Zone 3 C	Zone 9 D	Zone 15 D
D	0.651167694	0.699617529		Zone 4 D	Zone 10 D	Zone 16 D
E	0.699617529	0.748067364		Zone 5 D	Zone 11 D	Zone 17 F
F	0.748067364	0.796517199		Zone 6 B	Zone 12 E	Zone 18 F
				Zone 19 A	Zone 25 C	Zone 31 E
				Zone 20 D	Zone 26 C	Zone 32 E
				Zone 21 C	Zone 27 D	Zone 33 D
				Zone 22 D	Zone 28 E	Zone 34 E
				Zone 23 C	Zone 29 D	Zone 35 E
				Zone 24 B	Zone 30 A	Zone 36 A

Table 4. Zone management based on a weighing index of canopy coverage and NDVI.

Zone management by CC_NDVI Index		
Zone 1 A	Zone 7 B	Zone 13 C
Zone 2 A	Zone 8 A	Zone 14 B
Zone 3 C	Zone 9 C	Zone 15 D
Zone 4 D	Zone 10 D	Zone 16 D
Zone 5 C	Zone 11 D	Zone 17 F
Zone 6 B	Zone 12 E	Zone 18 F
Zone 19 A	Zone 25 C	Zone 31 E
Zone 20 C	Zone 26 D	Zone 32 E
Zone 21 C	Zone 27 D	Zone 33 D
Zone 22 D	Zone 28 D	Zone 34 E
Zone 23 C	Zone 29 D	Zone 35 E
Zone 24 B	Zone 30 A	Zone 36 B

Control side:

Tule control and soil moisture row 50 tree 71 (x=50,y=71)

Irrigation is determined by Clark Rach and actual application rates determined from irrigation times and flow meter.

Attachment B. Example of weekly irrigation Schedule

Clark Ranch Irrigation Recommendations

Week of 4/21/2019

Zone No	Zone Type	Rec. App. in/wk	Total Runtime hrs/wk
1	A	1.281	30.0
2	A	1.281	30.0
3	C	1.281	30.0
4	D	1.22	28.5
5	C	1.281	30.0
6	B	1.281	30.0
7	B	1.281	30.0
8	A	1.281	30.0
9	C	1.281	30.0
10	D	1.22	28.5
11	D	1.22	28.5
12	E	1.22	28.5
13	C	1.281	30.0
14	B	1.281	30.0
15	D	1.22	28.5
16	D	1.22	28.5
17	F	1.22	28.5
18	F	1.22	28.5
19	A	1.281	30.0
20	C	1.281	30.0
21	C	1.281	30.0
22	D	1.22	28.5
23	C	1.281	30.0
24	B	1.281	30.0
25	C	1.281	30.0
26	D	1.22	28.5
27	D	1.22	28.5
28	D	1.22	28.5
29	D	1.22	28.5
30	A	1.281	30.0
31	E	1.22	28.5
32	E	1.22	28.5
33	D	1.22	28.5
34	E	1.22	28.5
35	E	1.22	28.5
36	B	1.281	30.0

Zone	Eta basline (in/wk)
A	1.28
B	1.28
C	1.28
D	1.22
E	1.22
F	1.22

Zone 1-A (same zone under both CC and NDVI based on 2018 data)

Zone 10-D (same zone under both CC and NDVI based on 2018 data)

Zone 18- F (same zone under both CC and NDVI based on 2018 data)

Zone 23- C (same zone under both CC and NDVI based on 2018 data)

Zone 24- B (same zone under both CC and NDVI based on 2018 data)

Zone 31- E (same zone under both CC and NDVI based on 2018 data)

Table 2. Zone management based on a weighing index of canopy coverage and NDVI

Zone management by CC_NDVI Index

Zone 1 A	Zone 7 B	Zone 13 C
Zone 2 A	Zone 8 A	Zone 14 B
Zone 3 C	Zone 9 C	Zone 15 D
Zone 4 D	Zone 10 D	Zone 16 D
Zone 5 C	Zone 11 D	Zone 17 F
Zone 6 B	Zone 12 E	Zone 18 F
Zone 19 A	Zone 25 C	Zone 31 E
Zone 20 C	Zone 26 D	Zone 32 E
Zone 21 C	Zone 27 D	Zone 33 D
Zone 22 D	Zone 28 D	Zone 34 E
Zone 23 C	Zone 29 D	Zone 35 E
Zone 24 B	Zone 30 A	Zone 36 B

Application Rate in/hr	0.04276
ET baseline in/wk	1.22

Attachment C:
Publications

Submitted for publication on January 10, 2020. Agricultural Water Management Journal

Evaluation of remote sensing based evapotranspiration models against surface renewal in almonds, tomatoes and maize

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Abstract:

Evapotranspiration (ET) is a major hydrologic flux used in water resources planning and irrigation management. While recent advances in remote sensing (RS) have enabled availability of high spatial and temporal resolution ET data, a lack of information related to error in the estimations has made it challenging to use this data for on-farm irrigation management decision making. In this project, three commonly used single-source RS ET models (pySEBAL- a new version of Surface Energy Balance Algorithm for Land; SEBS-Surface Energy Balance System algorithm; and METRIC - Mapping Evapotranspiration at High Resolution with Internalized Calibration) were used to estimate daily ET for almond, processing tomato, and maize in the Central Valley of California. Model evaluation was conducted by comparing the predicted ET from RS with in-situ measured ET using surface renewal. Results indicated that the RS-based ET estimations for all three models were within acceptable levels of uncertainty and agreed well with surface renewal estimates except for the underestimation by pySEBAL and METRIC during early season growth stages of processing tomatoes. This underestimation was attributed to the lack of single source models to ET lower vegetation cover (when ET is dominated by soil evaporation). Better performance of pySEBAL and METRIC were detected at full cover, which explains the applicability of these two models to irrigation management during peak crop water demand. SEBS performed the best among the three RS-based models for daily ET estimation for all crops. This suggests that SEBS-based ET estimates can be adopted in operational irrigation management programs for farms that have not installed in field ET sensors such as Tule Sensors (Tule Technologies Inc.). In addition, RS based ET is spatially distributed which can help to identity spatial variability between different irrigation zones.

Keywords: Remote sensing, daily evapotranspiration, California, pySEBAL, METRIC, SEBS, Surface renewal.