FINAL PROJECT REPORT

Project Title: Optimizing irrigation frequency and timing to improve fruit quality

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Total Project Request: **Year 1:** $118,792 **Year 2:** $~~84,137~~ 64,137 **Year 3:** $89,794

Other funding sources

Agency Name: Bonneville Environmental Foundation water stewardship
Amt. awarded: $30,000
Notes: Since this was awarded, we reduced our requested budget request by $20000 in 2019 to $64,137. The remaining $10,000 in supplies will allow us to install better instrumentation at grower sites

Agency Name: Province of Murcia (Spain)
Amount awarded: $72,836
Notes: This was awarded to Dr. Victor Blanco to join Dr. Lee Kalcsits' lab for two years and supported Victor's salary and benefits He was able to participate in the research objectives of this project and expand on the physiology research being conducted.

Budget 1
Organization Name: Washington State University **Contract Administrator: Shelli Tompkins**
Telephone: 509-663-8181 **Email address: shelli.tompkins@wsu.edu**

Item	2018	2019	2020
Salaries[1]	45,503	47,723	49,216
Benefits[2]	18,119	18,844	19,598
Wages	0	0	0
Benefits	0	0	0
Equipment	0	0	0
Supplies[3]	~~47,170~~[4]27,140	9,970	12,970
Travel[5]	8,000	8,000	8,000
Miscellaneous	0	0	0
Plot Fees	0	0	0
Total	118,792	~~84,137~~64,137	89,784

Footnotes:
[1] Salaries to support a technician at $3500/month at 75% FTE in the Kalcsits lab and a technician at $3500/month at 33.34% FTE in Tianna DuPont's program. The budget includes a 4% salary increase per year.
[2] Benefits for both technicians calculated at 39.8 %

[3] Supplies include irrigation supplies for objective 1, lab and field consumables, extension materials, analysis costs for nutrient analysis and fruit storage costs.
[4] $30,000 of supplies in year 1 is requested for irrigation supplies to retrofit commercial blocks for testing. Funding for this is also included in the grant application to Bonneville Environmental Foundation.
[5] Travel includes mileage for Kalcsits, DuPont, and Peters for regular trips to commercial orchards and the Sunrise Research Orchard and for hotel and meal per diems for overnight trips to the Wenatchee region for Dr. Peters and his M.S. student to make measurements.

OBJECTIVES

1. Test whether increasing the frequency of irrigation or changing irrigation volume applied during specific times during the season affects fruit productivity and quality.
2. The extension portion of the project will establish demonstration which showcase irrigation optimization strategies to show versus tell growers how changes to irrigation are critical to impact yield and pack out.
3. Conduct a cost-benefit analysis comparing potential increased revenue from changes to irrigation strategies with the costs of making the change.

From the completion of these objectives, we have a) showed what impact irrigation decisions have on fruit size, cork spot, and other fruit quality metrics b) documented the return on investment of different case studies; c) document the changes in the water efficiency of each of these strategies. We have combined research and Extension-based approaches to collect and deliver industry-relevant information on pear irrigation practices in Washington State.

SIGNIFICANT FINDINGS

Cork spot was the highest in the research orchard when trees were watered fully or when water was withheld later in the season. When water was withheld early in the season or a stem water potential based decision process was used, cork spot % was lower.

Late season water deficits also had lower fruit firmness suggesting that it affects fruit maturity going into storage.

Irrigation strategy had no major impact on fruit nutrient composition.

For a commercial orchard (Caudle-Dryden Case Study) located on a large hill, irrigation distribution was improved using microsprinklers versus impact sprinklers. Fruit weight in the upper part of the orchard was equal to the bottom section when microsprinklers were used but there were large differences between the upper and lower sections in the section with the old irrigation system. These improvements were enough to pay for the irrigation system in just one year of larger fruit.

Five different irrigation case studies were used to demonstrate problem solving and value to the industry for changing irrigation practices in pear orchards. These pear orchards were located in the Wenatchee Valley in 2018-2020. Two of the case studies had challenges with distribution on sloped terrain either from poor pressure or from excessive runoff and uneven distribution within the orchard. Two other orchards had the desire to use soil moisture monitoring to make more precise irrigation decisions to control vigor and cork spot. The last orchard had issues with dynamic pressure from intake filter plugging in the canal and was fixed with a simple change to the filter that saved man hours and ensured consistent delivery and water pressure to their orchards.

Stem water potential based irrigation appeared to be a better approach to managing irrigation decisions but it still remains labor-intensive. We will be pursuing plant-based irrigation sensors as part of a two-year technology proposal beginning in 2021 on both apple and pear.

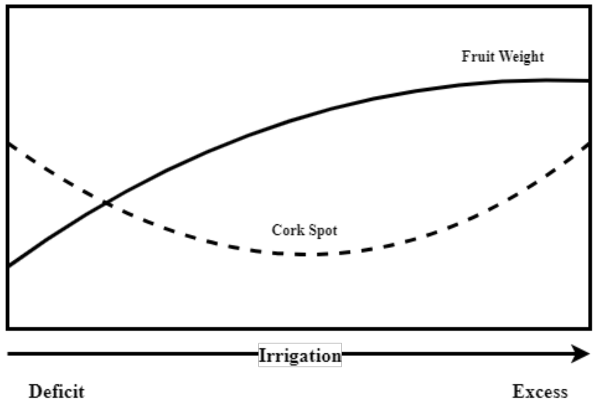

Figure 1. Conceptual figure showing the relationship between irrigation strategy and fruit weight and cork spot incidence in pear

Results and Discussion

Research Study

For this objective, research was conducted at the Sunrise Research Orchard in Rock Island, WA in a semi-mature block of Anjou and Bartlett pears that was planted in 2007 at a spacing of 6' between trees and 14' between rows. The orchard was irrigated using microsprinklers hooked up to a variable speed drive system that allows for flexibility in water schedules. The soil in this site is a sandy loam soil with a high percentage of sand. The poor water holding capacity of the soil makes this an excellent location to manipulate soil water content and ensure that we are getting enough variation to achieve the desired effects on the trees. There were four treatments applied. The first was where soil moisture levels were maintained near field capacity for the entire irrigation season. The second was limiting irrigation to 60% field capacity from 15-60 DAFB. The third treatment was limiting soil moisture to 60% of field capacity from 60-105 DAFB. The last treatment was modified from the original proposal. We opted to implement a stem water potential based irrigation scheme where irrigation was triggered when the mean stem water potential for sampled trees was more negative than -1.0 mPa. This strategy reduced overall water use by more than 40%.

Fruit was harvested on August 30, 2018, September 2, 2019, and August 28, 2020 from sample trees. Fruit was stored in regular atmosphere at 33 °F for 12 weeks. After storage, fruit was placed on racks to ripen for 7 days at 68 °F. Fruit quality was assessed including fruit size, weight, firmness, and soluble solids content. Cork spot incidence was also assessed in these same fruit samples. Subsamples were then taken for nutrient analysis for K, Ca, and Mg to look for changes in the ratios among these competing nutrients that may correspond to differences in cork spot or fruit size.

During the season, we measured plant indicators of water stress during the growing season to relate to horticultural responses such as vegetative and fruit growth. Physiological measurements were made including mid-day stem water potential and stomatal conductance. Plant water status, measured as Ψ_{md} was assessed using a 3005 Series Plant Water Status Console (Soilmoisture Equipment Corp, Goleta, CA, USA). Leaves used for measurement of Ψ_{md} were bagged for at least one hour in silver reflective bags to equalize the leaf and xylem water potential before readings are taken. Ψ_{md} will be measured around solar noon. Stomatal conductance (mmol m^{-2} s^{-1}) was measured on mature, sun-exposed leaves on the upper half of the canopy using a LiCor-6400XT Gas Exchange System.

Soil moisture was monitored using Decagon 5TM soil moisture and temperature sensors in each plot over the entire season to capture seasonal changes in soil moisture profiles in addition to the treatment level variations in soil moisture. In the early and late withholding treatments, volumetric soil water content was used to guide irrigation events where volumetric water content below 13% vol/vol triggered a small irrigation set to bring soil moisture levels above that threshold.

Soil moisture was substantially lower during the early season period in late June and early July and for late July and August for the late summer deficit period (Figure 2). Where trees were watered based on stem water potential, soil moisture followed similar patterns as the control. During hot periods, water was turned on so that delivery was equal to the control during this period because stem water potential was below the threshold for much of this time (Figure 3). Stem water potential appeared to be a good approach to ensuring that over irrigation did not occur. By sampling twice per week, we were able to gauge tree stress in each block and associate it with plant demand at that time. Later in the season, regardless of irrigation frequency, stem water potential at this site was above the -1.0 MPa threshold because of hot, dry conditions and sandy soil. A richer soil with a greater water holding capacity may not have produced the same results.

Cork spot was the highest for the excessively irrigated control and when deficit irrigation was applied during late summer before harvest. Cork spot was lowest for when stem water potential was used all season and when early season water deficits were applied (Figure 4; P=0.09). Fruit quality was relatively unaffected by irrigation treatments (Table 1) although physiological metrics indicate that the tree was affected (data not presented here and will be presenting in publications or Extension material). Fruit weight, height: width ratios, and soluble solids content were unaffected by treatments in both 2019 and 2020. Fruit firmness had a tendency to be lower for fruit from the treatment where late summer deficits were applied indicating that there may be an effect on fruit maturity. Abiotic stress in fruit has been shown to accelerate ripening in apple and other tree fruit and may also be related to elevated cork spot incidence observed in this treatment.

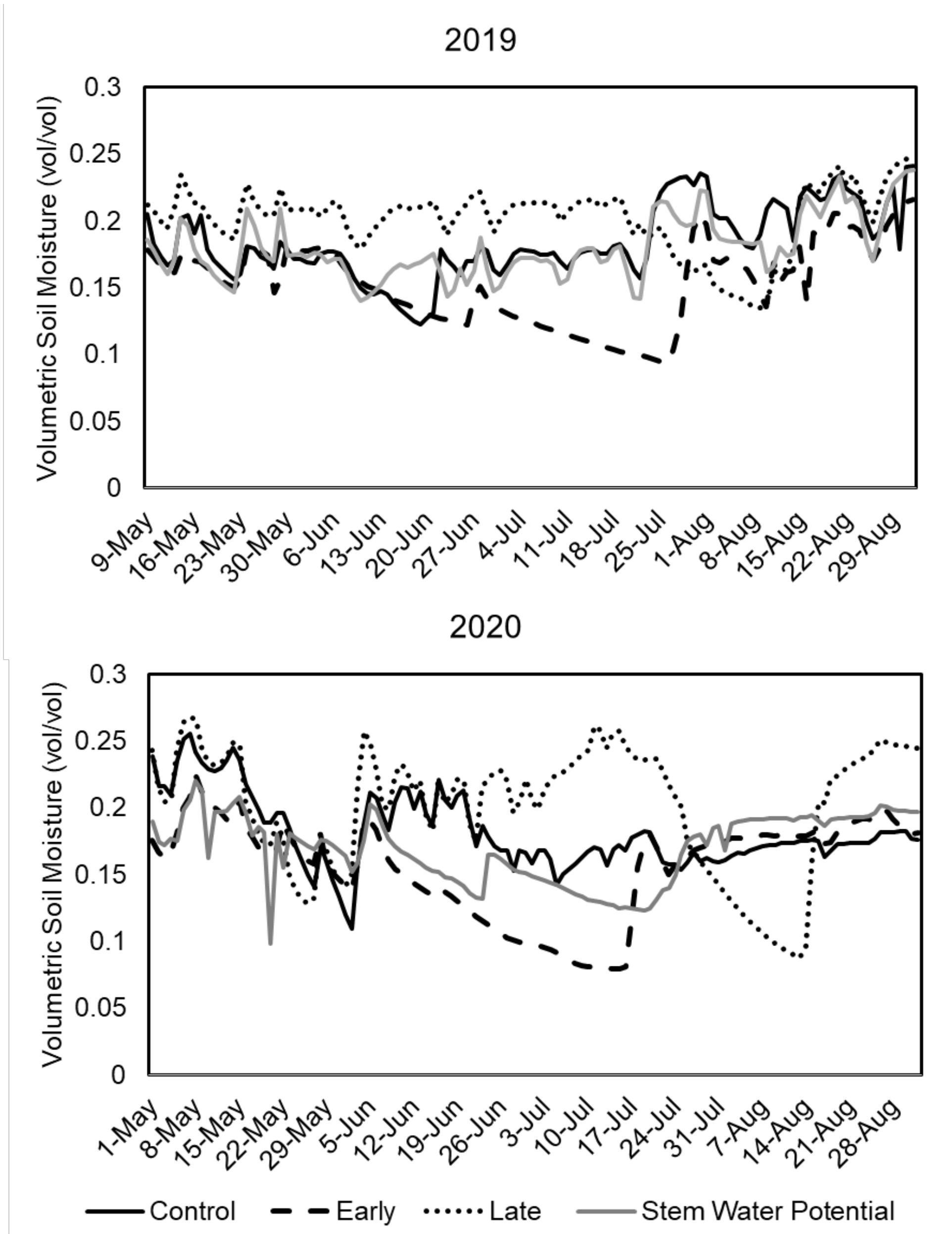

Figure 2. Soil moisture at 12" depth From May 1 to September 1 for 2019 and 2020 for each of early summer deficit (Early), late summer deficit (Late), stem water potential based irrigation (Stem Water Potential) treatments compared to an fully irrigated control (N=3) measured with a Meter Group EC-5 volumetric soil moisture sensor

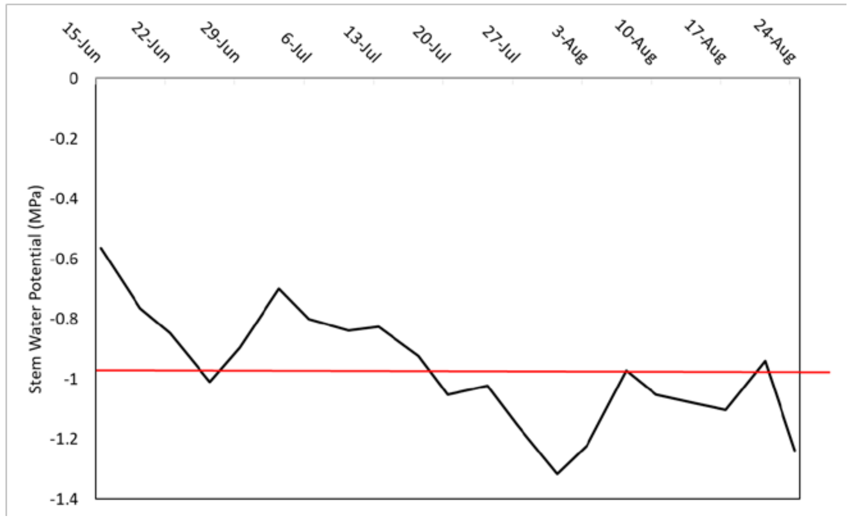

Figure 3. Stem water potential measured every Monday and Friday from June 15 to August 24, 2020. Red line represents the threshold for irrigation to occur.

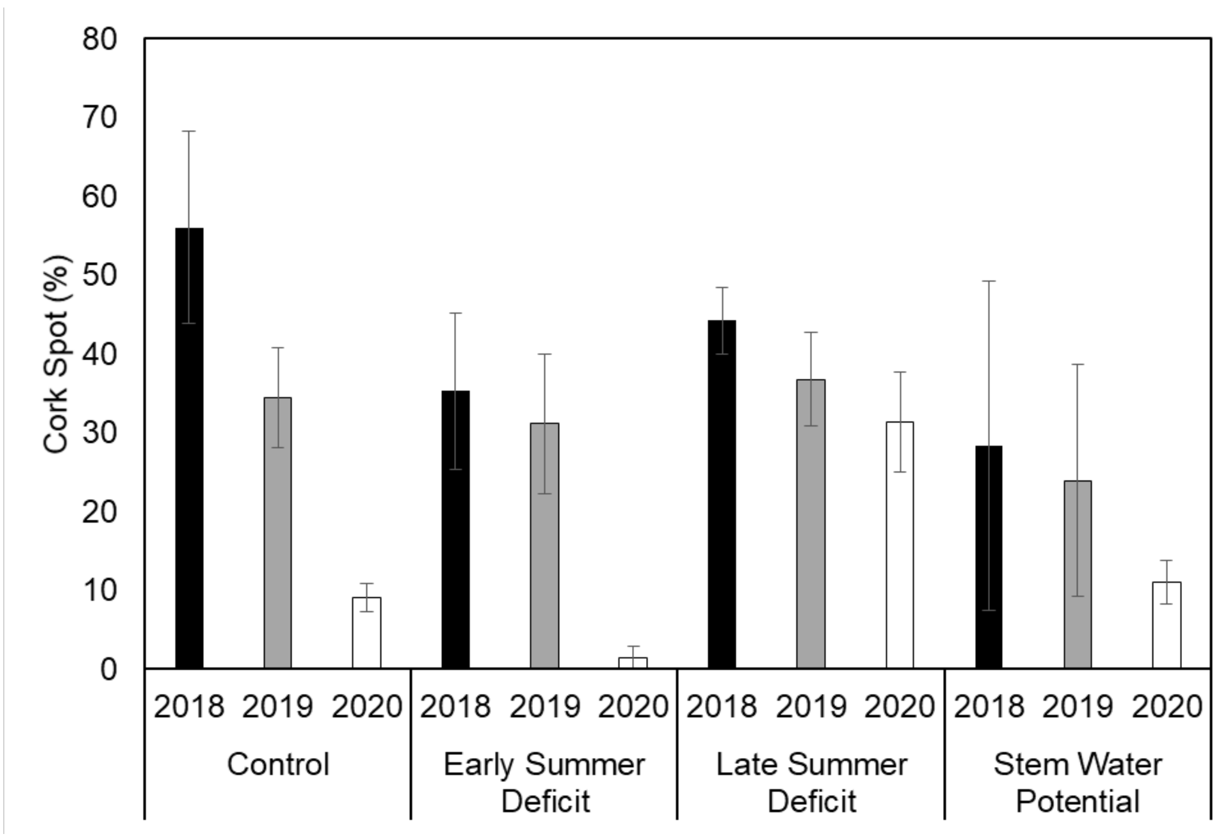

Figure 4. Cork spot incidence (%) for Anjou pear for each of early summer deficit (Early), late summer deficit (Late), stem water potential based irrigation (Stem Water Potential) treatments compared to an fully irrigated control (N=3).

Table 1. Mean fruit weight, shape, soluble solids content (°Brix), and fruit firmness (lb) of D'Anjou pears harvested in 2019 and 2020 after two months of storage at 33°F and then ripened for 7 days at 68°F

	Weight (oz)	Height: Diameter	Soluble Solids Content (°Brix)	Fruit Firmness (lb)
2019				
Control	6.96 a	1.15 a	14.55 a	9.86 a
SWP	7.04 a	1.17 a	14.35 a	9.94 a
Early	6.78 a	1.18 a	14.63 a	9.80 a
Late	7.21 a	1.17 a	14.35 a	9.71 a
2020				
Control	6.99 a	1.13 a	14.58 a	7.8 b
SWP	6.95 a	1.18 a	14.5 a	6.5 ab
Early	6.35 a	1.17 a	15.18 a	7.1 ab
Late	7.48 a	1.15 a	15.05 a	5.7 a

Dryden Case Study

Challenge: Excessive runoff and small fruit size, particularly at the top of the hill.

Solution: This change was completed by the grower in 2017-2018. The cost for this conversion, not including labor, was $1,489 per acre. The changes resulted in an additional ~$2,400 per acre for three years with improvements to fruit quality. The site consists of two side by side 10-acre blocks: 'hill' and 'clover.' The existing irrigation system consisted of Rainbird impact sprinklers on a 36' x 36' spacing (34 heads/ A). The application rate was approximately 0.3 inch/ hr or 0.14 inch/ hr at 50% efficiency. The new system consists of R10 micro-sprinklers with a lower output per sprinkler (0.43 gph) installed at a 18' x 18' spacing (134 heads/ A). At 50% efficiency the standard system delivers 0.15 in/hr, at 70% efficiency the upgrade delivers 0.09 in/hr and smaller droplet size and less output per sprinkler should result in a larger percentage of water infiltrating vs running off the soil. Block 'hill' was designated as the 'Standard' treatment and not changed, block 'clover' was designated the 'new' treatment with R10s installed in June 2018.

Summary: After the first year the grower collaborator's impression of the new system was that there was *"Zero run off in the new system. Leaf color was more uniform."* He was happy that *"Before the quickest we could water was 9 days. Now if we want to, we can water the whole block in 2 days (20 lines at a time)"* This gives them more flexibility. Measurements were taken in 'Standard' versus 'New' blocks to compare tree water stress, soil moisture and fruit quality. Please note as un-replicated blocks information comparative not statistical.

Tree water stress measurements were taken in July 2018 and August 2019 measuring leaf water potential using a pressure bomb. Measurements were taken from one tree in every other row at the top of the hill. In the 'New' system trees displayed less stress with all values falling under the -1.2 MPa threshold considered to be water limited. In comparison in the 'Standard' block leaf water potential had more variation and more trees above a -1.2 MPa threshold (Figure 3).

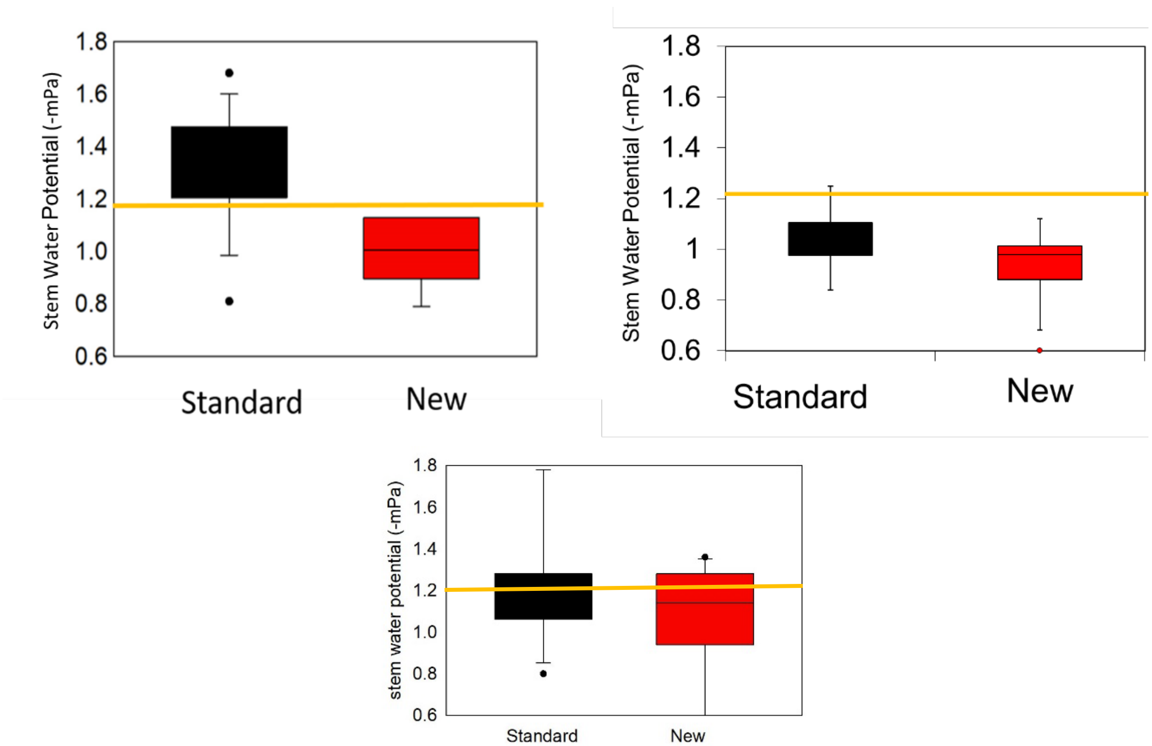

Figure 5. Box plot distribution of stem water potential for trees irrigated using the standard system compared to the modified (new) irrigation system.

For fruit quality, 20 Fruit were harvested from 8 trees in 2018 and 6 trees in 2019 on a grid pattern across the top and bottom of 'Standard' and 'New' plots. Fruit were stored for 12 weeks and then evaluated for size and quality. Fruit size was more uniform for both years in the 'New' plot compared to the 'Standard' plot (Figure 4).

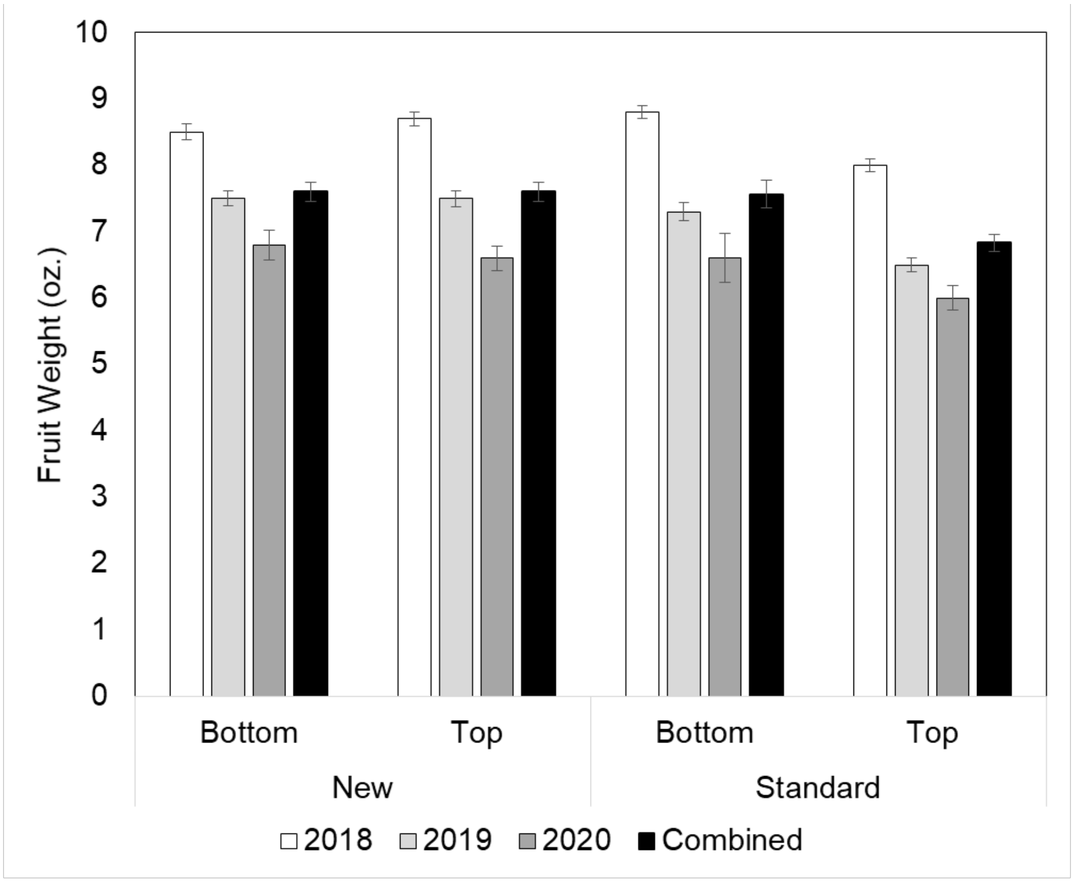

Figure 6. Fruit weight for D'Anjou pears with either the new system or old system in 2018 (solid bars) or 2019 (patterned bars).

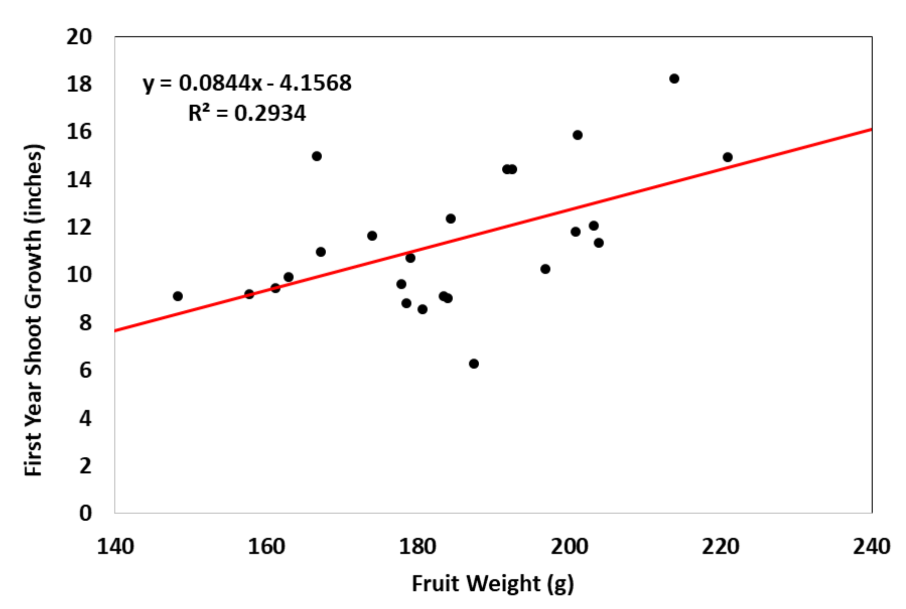

Figure 7. Fruit weight plotted against first-year shoot growth for commercially grown Anjou in Dryden.

Fifty-six bins were tagged separately, and pack-out data compared for each plot. In 2018, the percent packout was higher in the ‘New’ plot at 95.6% compared to 92.7% in the ‘Standard’ block with 22.95 packs per bin in ‘New’ and 22.27 in ‘Standard.’ **This resulted in 820 packs of US #1 per acre in the new system compared to 788 in the standard system.** The size distribution of US #1s included slightly more large fruit in the ‘New’ with 736 vs 734 packs of 90+ size fruit. These were primarily in the 60 and 70 class fruit with 73 vs 53 60 class and 210 vs 201 70 class. Using average FOB prices from the January , 2018 (Washington Tree Fruit Association Weekly Grower’s Bulletin) dollar values were assigned to each size class for US #1 fruit. In 2019 the upgrade packed 470 boxes of large fruit (90+) US#1 compared to 441 in the standard, a total of 521 vs 519. In 2019 assuming prices per box of 60s to 90s:$29.7; 100: $27.2; 110:$25.5; 120+:$23 revenue per acre was $23,482 in the upgraded block compared to $21,248 in the standard.In 2020, the packout for the upgraded block was 91.9% compared to the standard of 91.07%. 8% of the culls in the standard block were due to small fruit and 4% to cork whereas the upgraded block had 0% small fruit and 0% cork resulting in culls. The majority of culls in 2020 were due to stem punctures 50-54%. In 2020 assuming prices per box of 90s+:$26.13; 100:$23.23; 110:$21.63; 120-:$24.38 revenue per acre was $21,542 in the upgraded block compared to $21,833 in the standard but with reductions in culls from small fruit and cork in the upgraded block.

Figure 8. Estimated returns per acre in 2018-2020 for the Dryden upgraded orchard section compared to the standard irrigated control. Significant improvements were observed in 2019, largely due to increased yields and more consistent fruit size reported above. In 2020, there were no culls from small fruit and cork (compared to 8 and 4% of culls from small fruit and cork for the standard block, respectively) in the upgraded block. The packout for the upgraded block was 91.9% compared to the standard of 91.1% and was mostly due to higher stem punctures in the upgraded block.

Cashmere A Soil Water Content Monitoring Case Study

Challenge: **S**evere cork. The block was not picked in 2017 due to 80% cork. In general, there was poor control over water delivery and a concern of over-irrigation

Solution: Soil moisture sensors were installed in 2019 to inform watering decisions with the goal to meet an irrigation window. The costs for this monitoring was $304/acre annually for approximately 10 acres.

Summary: Water monitoring was installed in 2019 to help the grower make decisions on when to water and provided an irrigation target window to try to keep soil moisture within. The part of the block with irrigation decisions made using the window had substantially lower cork culls than the block that was irrigated using the normal, traditional schedule. In 2020, the block lease was not renewed but the single year data indicated substantially improved packouts and reduced culls from not excessively watering in the block with soil moisture monitoring in place.

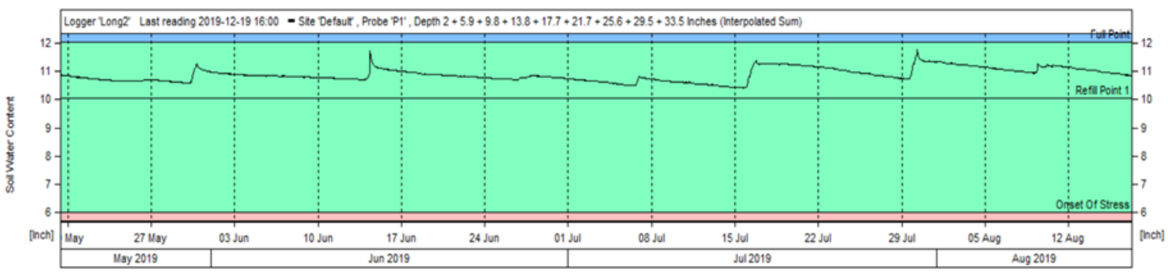

Figure 9. Output from soil water content monitoring indicating full point, refill point, and onset of stress with the goal of maintaining soil moisture between the refill and full point.

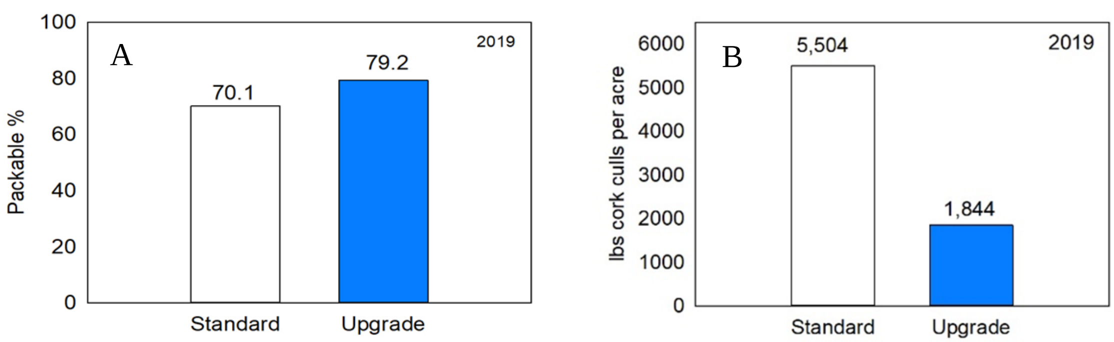

Figure 10. A. A comparison of packout percentage for the normally irrigated standard compared to the soil water content informed scheduling section. B. A comparison of the total weight of cork culls per acre in the normally irrigated standard compared to the soil water content informed scheduling section.

Cashmere B Water Distribution Improvement Case Study

Challenge: Poor water pressure at the top of the orchard and non-uniform irrigation sprinkler heads.

Solution: A pressure elevating pump at the canal at the top of the orchard was installed to improve distribution new sprinkler heads installed for uniform distribution throughout the orchard. The cost of making these changes was approximately $475/acre for 4.2 acres. These changes were made in early season of 2020. Stem water potential measurements were made during a hot period at the end of August and then fruit was sampled from six trees per plot in upper and lower sections that were either changed or were equal to the old system.

Summary: In 2020, there were no differences in returns per acre. This may be a result of this change being applied too late in the season to have a major effect. We will continue monitoring this site in 2021 if the grower is receptive to this to gather more information on this change. We did, however, observe more stable and higher stem water potential in the upgraded orchard section indicating more uniform water distribution among the trees.

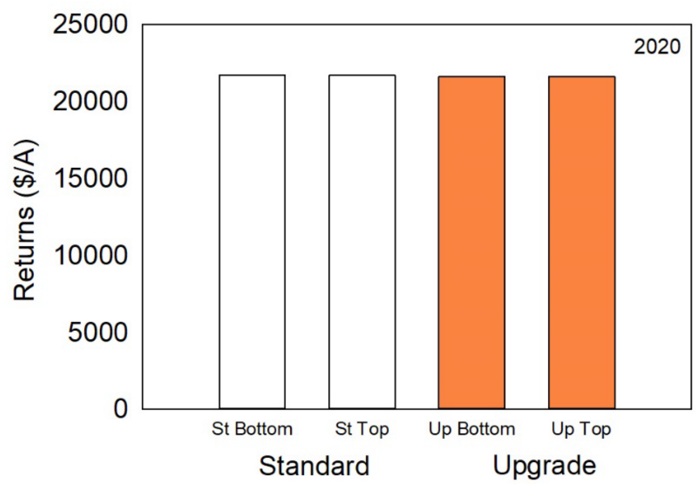

Figure 11. Return estimates per acre for the old system (Standard) compared to the upgraded system (Upgrade) for the bottom and top of the orchard. There were no differences between the sections in total returns after three months of the change in place.

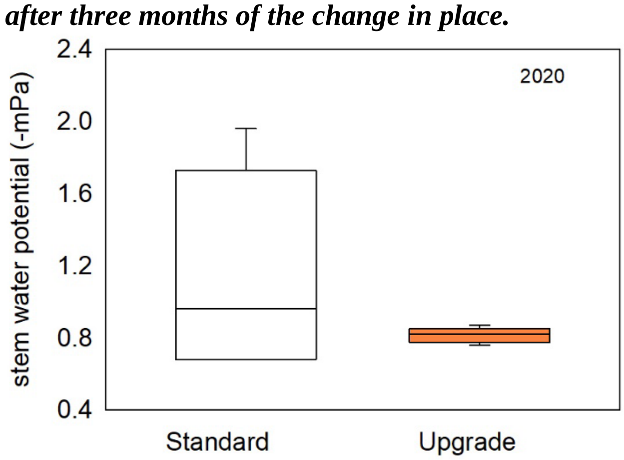

Figure 12. Stem water potential for the standard block compared to the upgraded block at a sloped site where water distribution is a problem.

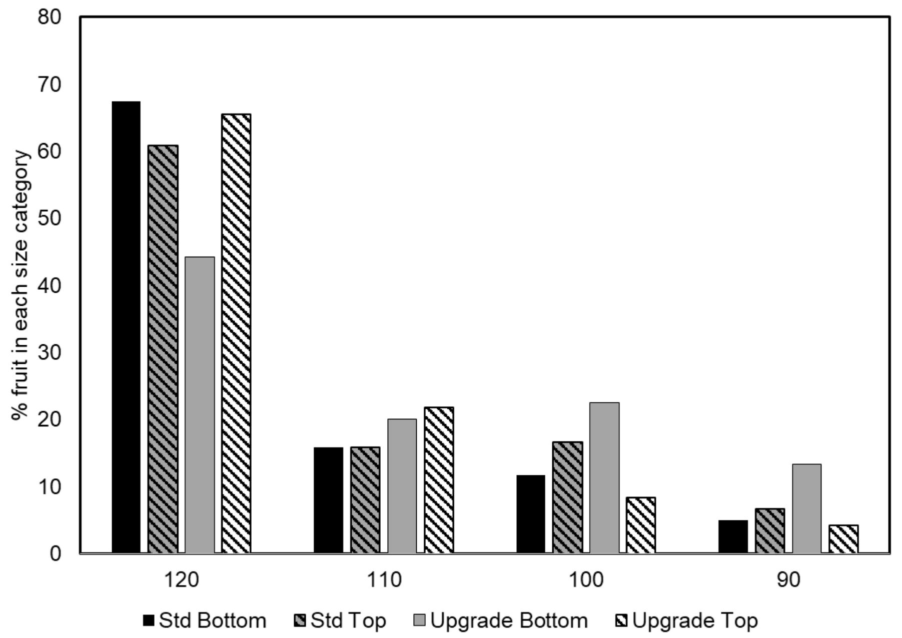

Figure 13. The % of fruit belonging to each size category (90 box size and higher, 100 box size, 110 box size, and 120 box size and smaller) for fruit harvested from six random trees within each section in 2020.

For additional details on case studies visit **http://treefruit.wsu.edu/orchard-management/irrigation-management/improving-irrigation-efficiency/**

Extension Outputs

May 27, 2020. Pear Irrigation Virtual Field Day. – 60 participants

January 28, 2020. Irrigating for Fruit Quality. Pear Day. Wenatchee, WA. Kalcsits, L., DuPont, S.T.

Improving Irrigation Efficiencies in Pears Case Studies. DuPont, S.T., Kalcsits, L. 2020. http://treefruit.wsu.edu/orchard-management/irrigation-management/improving-irrigation-efficiency/

Using Irrigation Sensors Video with Troy Peters. Improving Irrigation Efficiency in Pears Virtual Field Day. *DuPont, S.T., Peters, T., Kalcsits, L. May 2020.* http://treefruit.wsu.edu/videos/using-irrigation-sensors-troy-peters/

Irrigation Sensors with Jac LeRoux. Improving Irrigation Efficiency in Pears Virtual Field Day. *DuPont, S.T., Peters, T., Kalcsits, L. May 2020.* http://treefruit.wsu.edu/videos/irrigation-sensors-with-jac-leroux-improving-irrigation-efficiency-in-pears-virtual-field-day/

Long Case Study. Improving Irrigation Efficiency in Pears Virtual Field Day. *DuPont, S.T., Peters, T., Kalcsits, L. May 2020.* http://treefruit.wsu.edu/videos/long-case-study-improving-irrigation-efficiency-in-pears/

Caudle Case Study. Improving Irrigation Efficiency in Pears Virtual Field Day. *DuPont, S.T., Peters, T., Kalcsits, L. May 2020.* http://treefruit.wsu.edu/videos/improving-irrigation-efficiency-in-pears-caudle-case-study-summary/

EXECUTIVE SUMMARY

Project title: Optimizing irrigation frequency and timing to improve fruit quality

Key words: Volumetric soil moisture content, stem water potential, Anjou, cork spot,

Abstract: Irrigation is essential for the production of high quality pears in the Pacific Northwest (PNW). PNW pear orchards are distributed among varying soil types, topographies, and environments and older, low density pear orchards have root systems that extend deep into the soil profile combined with older irrigation systems with uneven distribution can create problems of over watering or under watering occurring within, or between blocks. With this project, we sought to identify water management factors contributing to poor sizing or losses due to cork spot in PNW orchards. We conducted a three year research experiment looking at the timing and frequency of irrigation in an Anjou orchard. We found that irrigation within a given soil moisture window did not substantially alter fruit quality metrics in a uniform orchard block. However, late summer water deficits promoted higher cork spot and a trend towards reduced firmness after two months of storage and 7 days of ripening at room temperature. This project also conducted five case studies to improve water delivery and solve common problems experienced in pear orchards in the PNW. These included two orchards with poor distribution on a hilly site, two orchards with the heavy soils and issues with over watering and one orchard with a filter that clogged causing losses in pressure between cleaning. In two of the most documented cases studies, we observed significant improvements in packouts and returns per acre that were economically feasible for the adoption in other orchards experiencing these problems. The other case studies demonstrated the value of soil moisture monitoring, even water distributions, and filter cleaning. Incremental changes to irrigation systems to ensure that neither excess nor deficits are being experienced in an orchard as both of these scenarios can cause increased losses from cork spot in the packing house and can affect overall fruit sizing. In this project we show the value in meeting irrigation needs through enhanced monitoring, more uniform distribution, or less variable supply in pear orchards.