FINAL PROJECT REPORT

Project Title: Control of fruit size and bitter pit in Honeycrisp using irrigation

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Total Project Request: **Year 1:** $53,442 **Year 2:** $74,199 **Year 3:** $84,972

Other funding sources

Agency Name: Lawrence Berkeley National Lab, Berkeley, CA
Amt. awarded: ~$32,000
Notes: This is work in collaboration with scientists at the University of California, University of Kentucky, and Lawrence Berkeley National Lab to look at how irrigation regimes change fruit structure, porosity and how it relates to quality. The funding supports beamline access to make measurements in the spring and fall.

Agency Name: Canadian Light Source Synchrotron, Saskatoon, SK
Amt. awarded: ~$30,000
Notes: This is work in collaboration with scientists at the Canadian Light Source to look at how irrigation regimes change fruit vasculature in developing fruit. The funding supports beamline access to make measurements in the summer 2019.

Agency Name: Pacific Northwest National Lab, Richland, WA
Amt. awarded: ~$20,000
Notes: This is work in collaboration with scientists at the PNNL to look at how irrigation regimes change fruit vasculature in developing fruit. The funding supported instrumentation access to make measurements in the fall of 2017 from these experiments.

Budget 1

Organization Name: WSU Contract Administrator: Katy Roberts/Shelli Tompkins
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Item	2017	2018	2019
Salaries[1]	18,000	46,026	47,867
Benefits	7,942	10,809	11,306
Wages[2]	0	5,223	12,192
Benefits	0	141	1,607
Equipment[3]	8,000	0	0
Supplies[4]	17,000	9,500	9,500
Travel	2,000	2,000	2,000
Miscellaneous	0	0	0
Plot Fees	500	500	500
Total	53,442	74,199	84,972

Footnotes:

[1] Salaries are budgeted to support a research technician at 50% for three years and the salary for a M.S. student for two years.

[2] Wages provide summer salary for a M.S. student and a summer student for year 3

[3] Equipment in year 1 will be for the purchase of a pressure bomb to measure stem water potential

[4] Supplies are for irrigation set-up supplies in year 1 combined with lab consumables, leaf and fruit nutrient testing and fruit quality analysis for years 1-3.

OBJECTIVES

1. Test how early, middle and late-season deficit irrigation affects fruit size, quality and return bloom in Honeycrisp.

2. Identify whether bitter pit occurrence can be reduced by reducing fruit size in a bitter pit susceptible orchard.

3. Develop horticultural indicators (e.g., visual indicators, stem water potential and/or soil moisture) for monitoring plant water status to guide the deployment of deficit irrigation for the control of fruit size.

SIGNIFICANT FINDINGS

- When water limitations were applied, fruit size was reduced in all treatments but timing affected the degree of size reductions and periods with low evaporative stress will be harder to achieve a response (cooler, cloudy, or smoky periods).
- Bitter pit was lower when water was limited during the middle and later part of the summer (45-105 DAFB).
- Red color was the greatest when water was limited later in the season (75-105 DAFB)
- Irrigation cannot correct for nutrient imbalances. For commercial sites, bitter pit was low when nutrient balance was achieved. However, bitter pit was still high for sites with nutrient imbalances.
- Stomatal conductance was strongly affected by irrigation regime.
- Photosynthesis decreased during periods of water limitation indicating a change in stomatal conductance and plant water-status.
- Midday leaf water potential increased during drought treatments and then recovered once irrigation was brought back to normal. When using stem water potential as an indicator for watering Honeycrisp, -1.2 to -1.5 MPa can be used as a watering trigger depending on crop load and forecasted fruit size.
- Vigor was reduced by more than 25% by any of the deficit irrigation treatments

METHODS

Experimental site and tree management

An experiment was set up at the WSU Sunrise research orchard using 240 Honeycrisp trees on M9-T337 that were planted in 2015 at a spacing of 3’ x 12’ (1,210 trees/acre). The soil is an alluvial shallow sandy loam soil. The trees filled their canopy space in 2015 and 2016. The first year crop was in 2017. Using a randomized complete block design, irrigation regimes were used that will withhold irrigation either early, middle or late in the season and compare it to a fully watered control. In 2018, trees were sprayed with calcium starting in June at standard commercial rates.

Experimental design and irrigation treatments

The irrigation system at Sunrise was controlled with a variable speed pump drive and electrovalves. Using exclusion valves and by-pass lines, the entire block was appropriately randomized. Irrigation was applied using emitters at 1 foot spacing at 0.42 gal/hour and supplemented with microsprinkler irrigation to maintain the grass between rows. The well irrigated control was irrigated four times per day for 30 minutes. This was significantly above evapotranspiration demand.

The early irrigation deficit where irrigation was reduced by approximately 80-90% from 15-45 days after full bloom (DAFB), middle irrigation deficit with irrigation was reduced by approximately 80-90% from 45-75 DAFB and late irrigation deficit where irrigation was reduced by approximately 80-90% from 75-105 DAFB. Full bloom occurred on May 3rd, 2017 and on April 27th, 2018. All treatments were returned to the well-watered irrigation schedule after the predetermined deficit irrigation period.

Tree Selection

Sample trees were selected for uniformity. Bloom clusters were counted to continue checking uniformity. Three trees were selected from each replicate with uniformity in fruit load, trunk cross-sectional area (TCSA), and height.

Physiological Measurements

At the beginning, middle, and end of each deficit irrigation period, physiological measurements were made including mid-day leaf water potential and photosynthesis. 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 were taken. Ψ_{md} was measured around solar noon. Leaf gas exchange was measured using a LI-6400XT infrared gas analyzer (Li-COR, Lincoln, NE, USA). Reference carbon dioxide concentration was set at 400 ppm, leaf temperature at 25 °C (77 °F), and photosynthetic photon flux density (PPFD) to 1500 µmol CO_2 m^{-2} s^{-1}.

Harvest and Fruit Quality

All of the fruit was harvested from sample trees on September 6th in 2017, August 30th in 2018, and September 7th in 2019. The total amount of fruit from each tree was weighed in the field, categorized by diameter, and counted. Then, 20 fruits were randomly subsampled from each tree, 10 for at-harvest fruit quality and then 10 fruit for quality evaluation after storage. The storage samples were stored in regular atmosphere (RA) for 3 months at 33°F. Quality analysis was performed two days after harvest testing for standard quality metrics including color, firmness, soluble solids content, titratable acidity, starch and mineral analysis.

Commercial Orchard Sampling

In each of 2018 and 2019, five commercial orchard blocks were used for testing out deficit irrigation on bitter pit in Honeycrisp. Growers implemented irrigation practices using sensor-based information in a way that worked best for their operations. Then, just prior to commercial harvest, two boxes of fruit were taken from each orchard. One box was analyzed for fruit quality at harvest using quality metrics described above. Fruit samples were also analyzed for mineral nutrient composition. The other box was stored for three months in regular atmosphere at 33°F and then bitter pit incidence and fruit quality were analyzed again.

RESULTS AND DISCUSSION

Despite early thinning in the 3rd leaf in 2017, there was still a biennial bearing pattern in the experimental orchard block we are using for this experiment. 2018 had significantly less bloom than 2017 or 2019. There were no significant differences in return bloom between deficit treatments and the normally watered control (Figure 1). Crop load was standardized as much as possible using bloom thinners, post-bloom thinners and hand thinning to target fruit and crop load differences between years were much lower than bloom differences. There were no treatment effects on crop load with the exception where trees that had early season deficit irrigation applied in the first year were over thinned by approximately 4 fruit per tree.

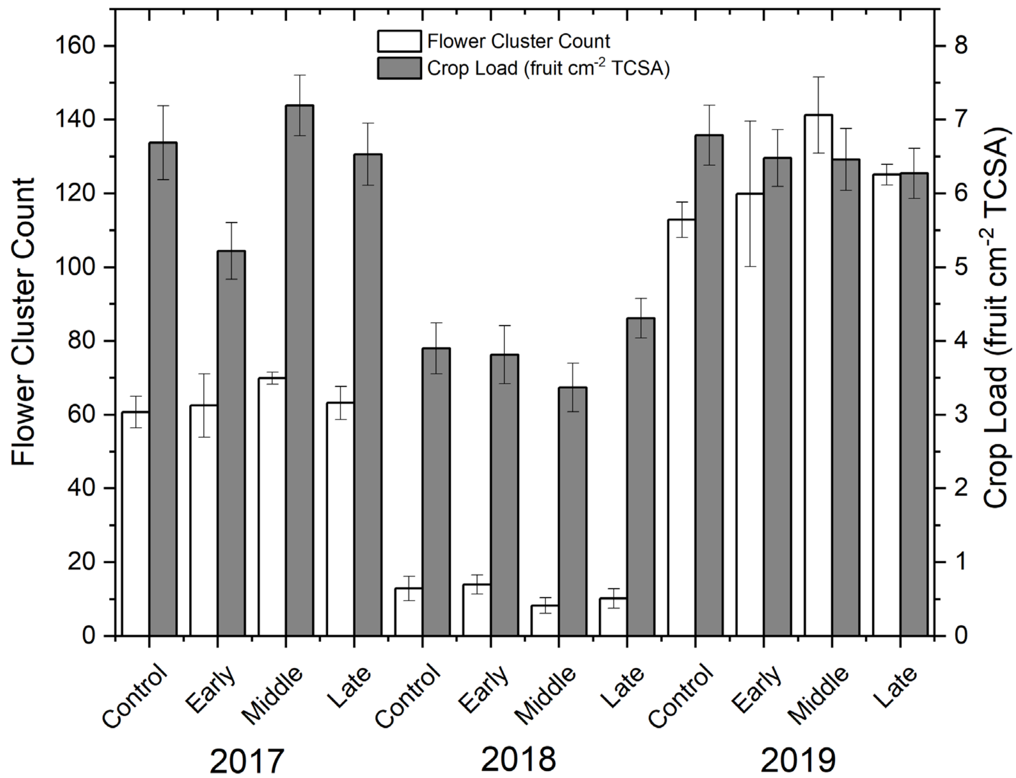
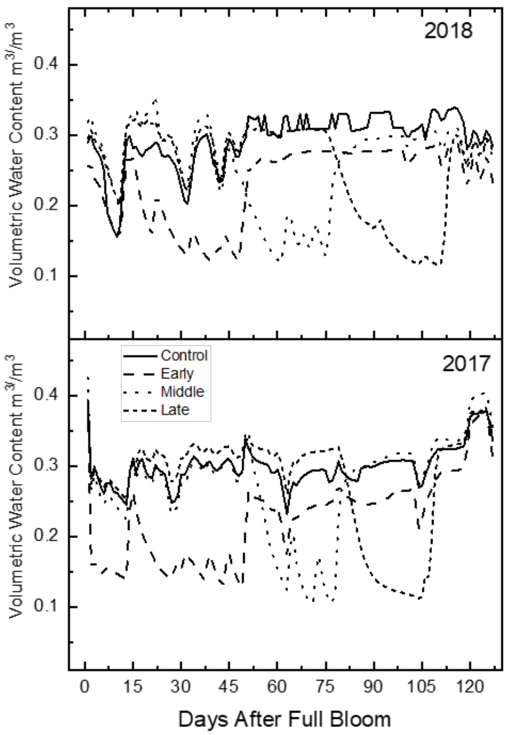


Figure 1. Mean flower cluster count and crop load in 2017, 2018, and 2019 for treess exposed to early, middle, or late summer water limitations compared to a well-watered control.

At WSU Sunrise which has a shallow sandy loam soil, the maximum volumetric soil water content was approximately 33% vol/vol. Water was turned off at the beginning of these three periods in the associated treatments. Volumetric soil water content was allowed to decrease until it reached approximately 12% vol/vol. At this point, water was turned on for 1-2 hours every 3-4 days to deliver small amounts of water but still keeping soil volumetric water content well below the well-watered control (Figure 2). We used soil moisture to determine when to water, not based on evapotranspirative demand or when visual symptoms were present. These periodic water limitations translated into real responses in the tree. At the end of the early, middle, and late water-limitation periods, leaf photosynthetic rates were lower than the well-watered controls. After resuming irrigation, the trees quickly recovered and photosynthetic rates increased back to levels that were not signficantly different than the controls. Midday leaf water potential followed a similar pattern where the highest leaf water potential was observed during periods when there were water limitations and water potential quickly increased again once irrigation patterns returned to normal (Figure 3).

Environmental conditions appear to directly influence the response to stress. During the middle and late deficit periods in 2018, drought responses were lower than 2017. We think this might be because cooler temperatures were present during the middle deficit period that limited stem water potential decreases. Heavy smoke then influenced the responses seen during the end of the late period. Environmental conditions need to be considered when deciding on watering patterns, whether your operation is deficit irrigating or not.



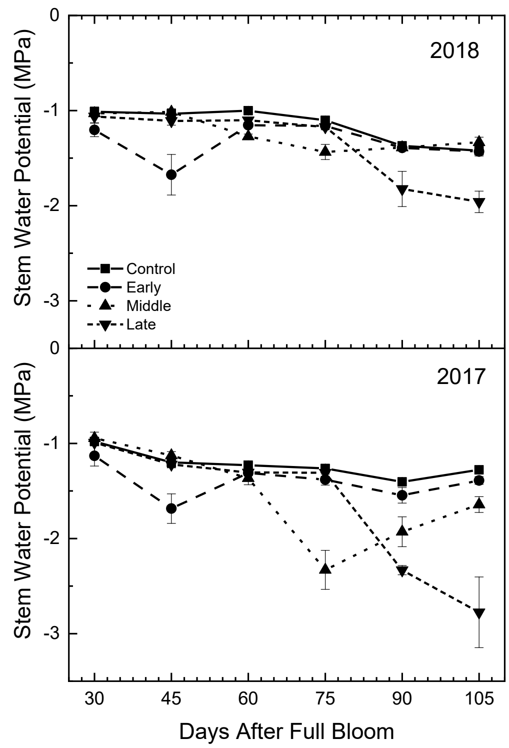


Figure 2 (left). *Volumetric water content (m^3/m^3) during the 2017 growing season (N=3) for trees within a well-watered control (solid grey line), early water limitation (dashed line; 15-45 DAFB), middle water limitation (solid black line; 45-75 DAFB), and later water limitation (dotted black line; 75-105 DAFB). Light grey, medium grey, and dark grey squares represents the early, middle and late periods of water limitation, respectively.*

Figure 3 (right). *Mean midday leaf water potential (ψ_{md}) during the 2017(below) and 2018 (above) growing season (N=3) for trees within a well-watered control (solid grey line), early water limitation (dashed line; 15-45 DAFB), middle water limitation (solid black line; 45-75 DAFB), and later water limitation (dotted black line; 75-105 DAFB). Higher values indicate greater water stress. Light grey, medium grey, and dark grey squares represents the early, middle and late periods of water limitation, respectively.*

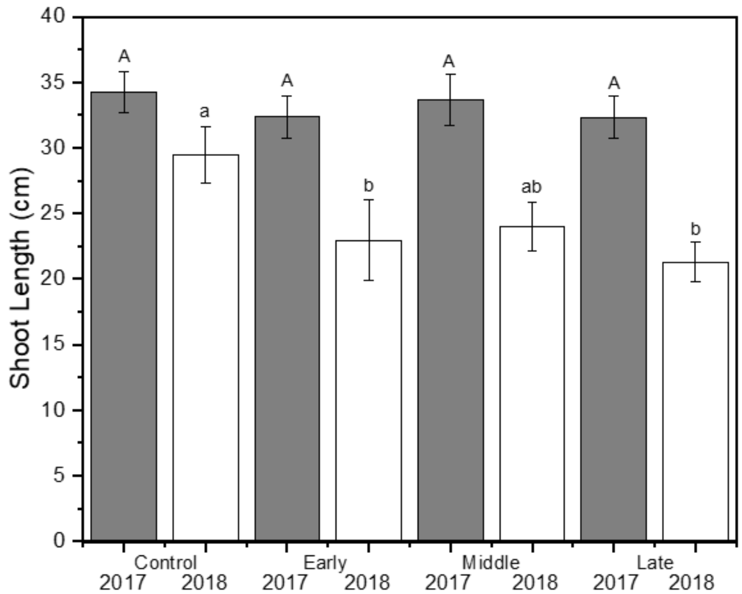


Figure 4. Mean shoot length (cm) for trees exposed to early, middle, or late summer water limitations compared to a well-watered control. Letters denote significant differences determined using Fisher's LSD test (α=0.05).

In 2017, red color was greater in fruit from trees that were water limited compared to the well-watered control. This was also true in 2018 but the differences were not significantly different. Fruit from trees that were exposed to water deficits late in the season had an average overall red color classification of 2.94 in 2017, 3.04 in 2018, and 3.59 in 2019. A color classification of 3 is where 50-75% of the fruit is red. Firmness, and soluble solids content were also highest in fruit harvested from trees that were exposed to water deficits late in the season (Table 1). This was also observed in 2018 but were not significantly different than the fully irrigated control. In contrast, fruit from trees within the well-watered control had the lowest firmness, and soluble solids content. Fruit from trees exposed to water deficits either early or mid-season were in-between fruit from the well-watered control and fruit from trees that were water-limited later in the season.

Mean fruit weight was always the greatest for the fully watered control. However, differences were only significantly different in 2017. In 2018, differences among treatments in fruit weight were different than 2017, particularly under the early deficit irrigation treatment. Because crop load was lower in 2018 than in 2017, overall fruit weight was greater in 2018. In 2019, when crop load was higher again, fruit size was more similar to that observed in 2017. Despite showing similar patterns in stem water potential during the early period, fruit weight was the smallest for trees exposed to early water deficits. June 2017 was much warmer than June 2018 which could have altered fruit growth during this stage. Since cooler temperatures were present when the trees under early deficit irrigation were returned to full irrigation, fruit expansion may have been slower at this time as well.

Table 1: Fruit quality after storage averages for each treatment from 90 fruits per treatment.

Treatment	Weight (g)	Color Class (1-4)	Firm (lb)	Brix (%)
		2017		
Control	255 a	2.6 b	17.1 a	13.8 a
Early	247 ab	2.7 ab	17.4 a	15.3 c
Middle	226 b	2.3 b	18.1 a	14.5 b
Late	209 c	2.9 a	19.6 b	15.6 c
		2018		
Control	326 a	2.7 a	16.0 a	14.9 a
Early	269 a	2.9 a	16.4 ab	15.7 a
Middle	299 a	2.8 a	17.4 b	15.4 a
Late	305 a	3.0 a	16.3 ab	15.2 a
		2019		
Control	290 a	3.6 a	14.1 a	13.5 a
Early	276 a	3.2 a	14.0 a	13.6 a
Middle	278 a	3.6 a	14.1 a	13.2 a
Late	274 a	3.8 a	14.1 a	14.1 a

Overall, fruit size profiles were similarly reduced in both middle and late summer deficit periods compared to the control. Bitter pit incidence was higher immediately after harvest in fruit from trees that were water-limited early in the summer where 23% of the fruit had bitter pit. This was consistent across all three years of the project. Bitter pit incidence at harvest was lowest in the well-watered control and for fruit from trees that were exposed to water deficits in either the middle or later part of the growing season with 13%, 9%, and 14%, respectively. After 3 months of RA storage at 33°F, bitter pit incidence increased in all treatments. Periodic water limitations had a significant impact on bitter pit incidence. Overall, middle and late-summer deficits reduced bitter pit incidence compared to the control. Bitter pit averaged approximately 51% for the well-watered control in all years. Late summer water limitations limited bitter pit to approximately 42%. Fruit from trees exposed to middle summer irrigation deficits had the lowest bitter pit incidence with 35% of the fruit affected. Bitter pit was the highest in 2017 and decreased on average from 2017-2019 (Figure 5), Despite calcium sprays in 2018, the low crop load strongly stimulated bitter pit development. 2019had the lowest bitter pit incidence when the crop load was full again,. Environmental differences between 2017 and 2018, particularly during the early and middle season treatments, may have contributed to the differences in post storage bitter pit incidence between 2017 and 2018. In 2019, conditions were cooler, particularly late in the summer and fruit size and bitter pit incidence were lower as a result.

Fruit size affected bitter pit incidence and bitter pit was the greatest in 2017 all fruit diameter classes (Figure 6). Fruit that had a diameter of less than 80 mm had 38, 30, and 14% of fruit affected by bitter pit for 2017, 2018, and 2019, respectively. Fruit that had a diameter of greater than 90 mm had 77, 52, and 48% of fruit affected by bitter pit for 2017, 2018, and 2019, respectively. Fruit that had a diameter between 80 and 90 mm had bitter pit incidence between the smallest and largest fruit categories. Trees that were treated with either middle or late summer deficit irrigation had a larger proportion of fruit with diameters less than 80 mm (Figure 7) which largely accounts for differences in bitter pit between the irrigation treatments.

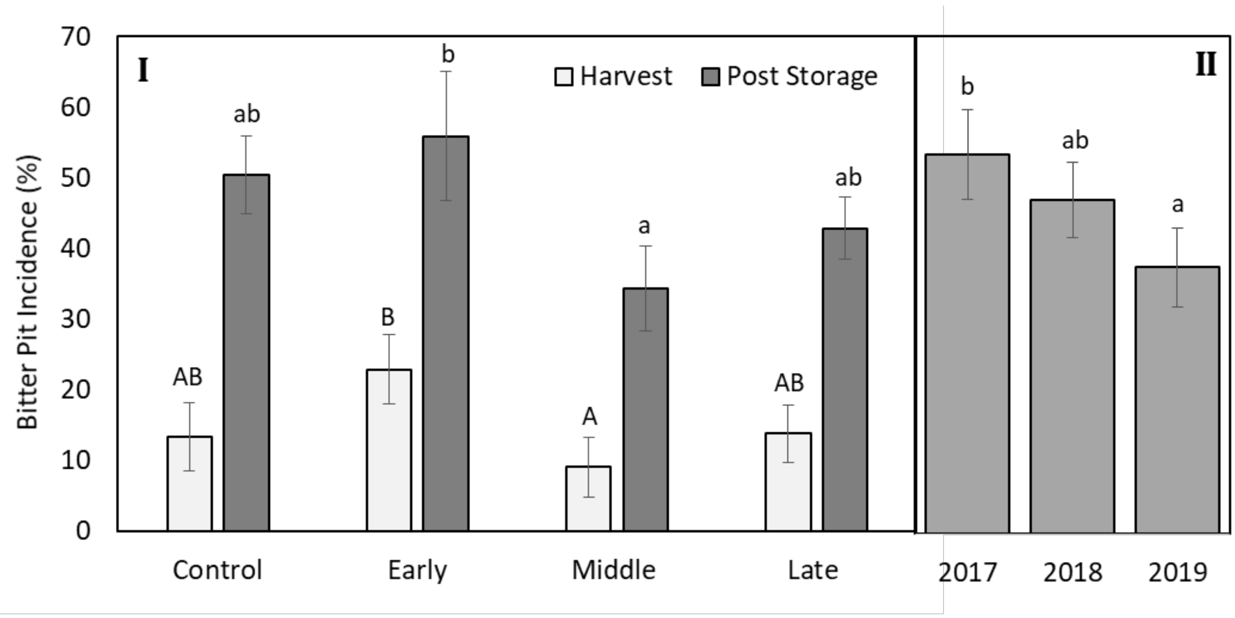


Figure 5. I. Mean bitter pit incidence (%) for 2017, 2018, and 2019 at harvest and after three months storage for fruit sampled from trees exposed to early, middle, or late summer water limitations compared to a well-watered control. II. Mean bitter pit incidence for 2017, 2018, and 2019 after three months of regular atmosphere storage. Vertical bars represent the SE of the total (N=12). Letters denote significant differences determined using Fisher's LSD test (α=0.05). There were no significant interactions between treatment and year (P=0.51).

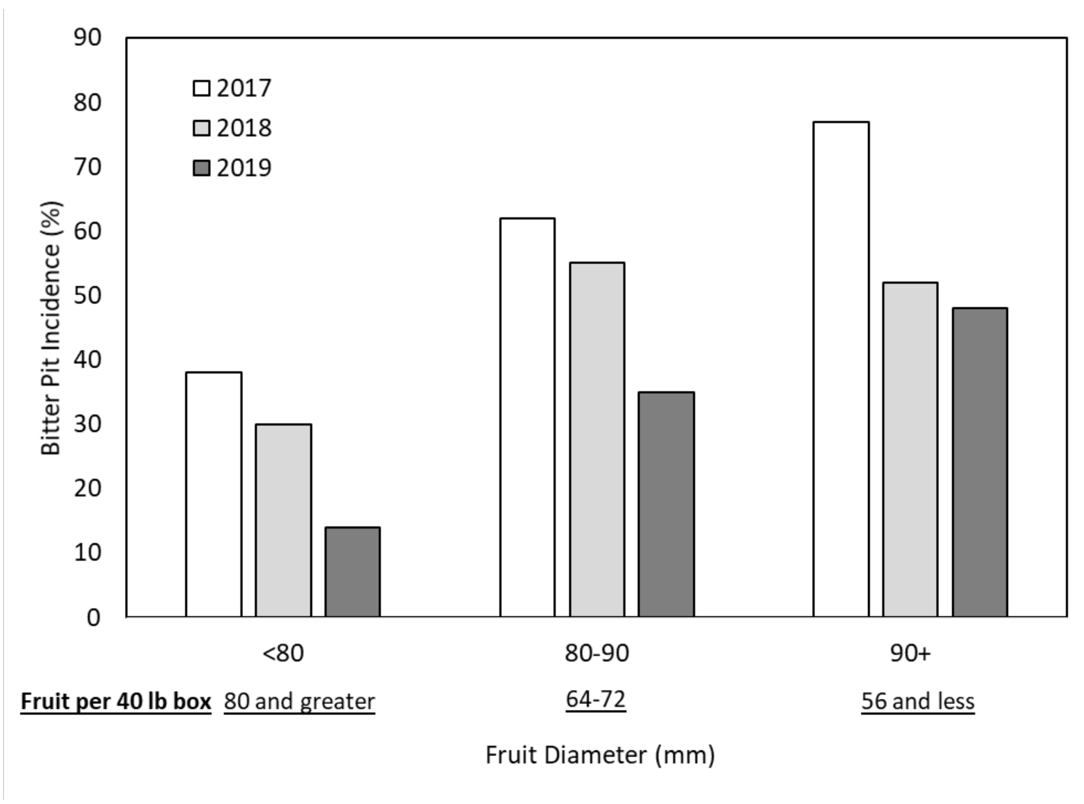


Figure 6. Bitter pit incidence for each size category in 2017, 2018, and 2019. Fruit per 40 lb box is presented below each diameter category

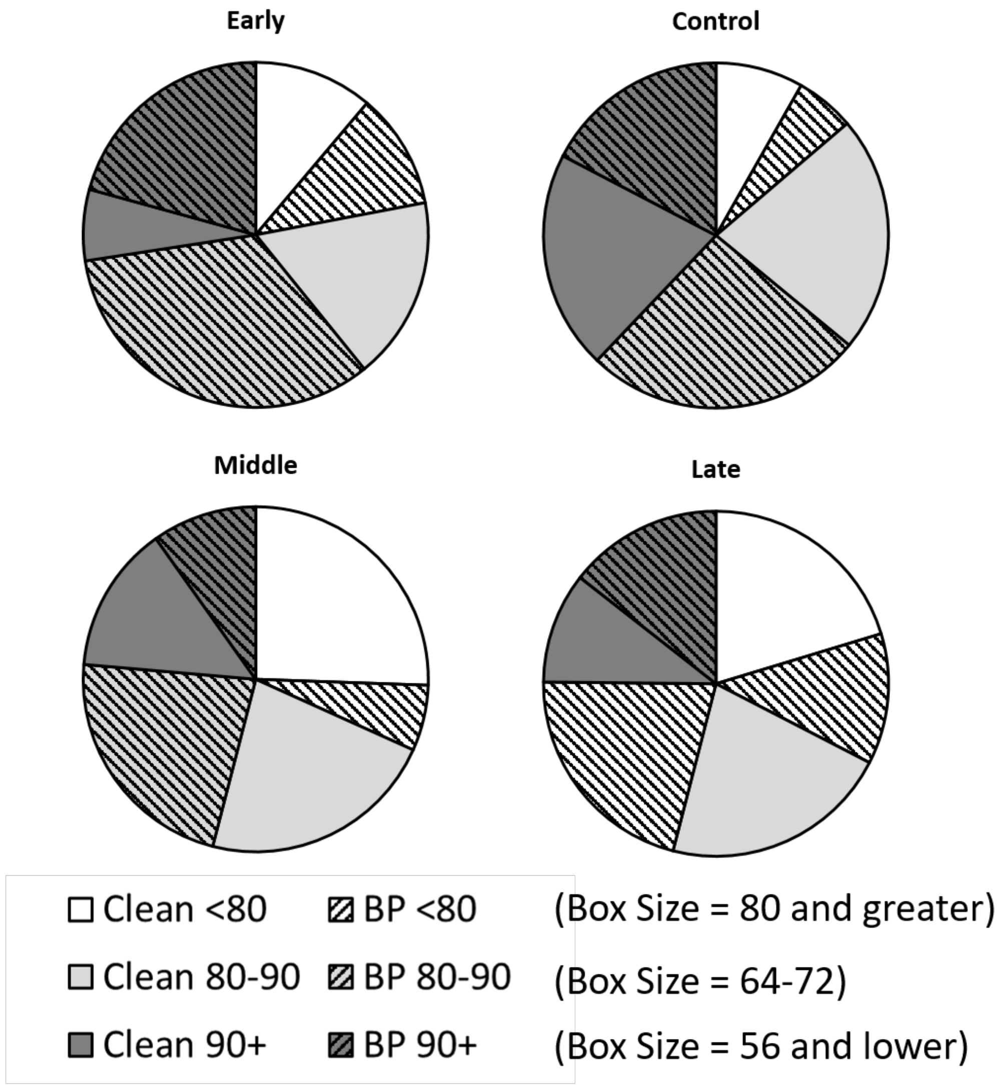


Figure 7. Mean proportions of fruit with a diameter of <80 mm (white), 80-90mm (light grey), or 90+ mm (dark grey) that is either healthy (solid color) or with bitter pit (diagonal lines) harvested from trees exposed to either early, middle, or late summer water limitations compared to a fully watered control.

COMMERCIAL ORCHARDS

7 out of 10 orchards deploying deficit irrigation had bitter pit incidence lower than 10% (Figure 8). Fruit weight mostly fell within the size category of 72-88s in these orchards with few fruit belonging to larger size categories. For the three orchards with bitter pit incidence above 10%, the K:Ca ratio was above 25, whereas the K:Ca ratio for the other three sites was below or equal to 20 (Table 2). These differences in ratio were driven by both low levels of Ca and high levels of potassium. This demonstrates that irrigation cannot be used as a tool to control bitter pit when nutrients are not correctly balanced. Potassium: calcium ratios for the three orchards with bitter pit incidence greater than 10% were greater than 25:1 indicating nutrient imbalances increasing bitter pit risk.

Table 2. Fruit calcium, potassium, and magnesium concentrations and associated ratios for ten commercial orchard sites deploying deficit irrigation in 2018 and 2019

Year	Orchard	Ca (%)	K (%)	Mg (%)	K/Ca	K+Mg/Ca	Fruit Size (g)
2018	A	0.045	0.611	0.033	13.6	14.3	177
2018	B	0.018	0.817	0.042	45.4	47.7	271
2018	C	0.042	0.625	0.03	14.9	15.6	277
2018	D	0.036	0.708	0.039	19.7	20.8	213
2018	E	0.027	0.674	0.033	25.0	26.2	263
2019	F	0.106	0.916	0.042	8.6	9.0	226
2019	G	0.046	0.834	0.040	18.2	19.0	219
2019	H	0.058	1.019	0.046	17.6	18.4	249
2019	I	0.030	0.989	0.044	33.1	34.5	226
2019	J	0.042	0.998	0.044	23.8	24.8	216

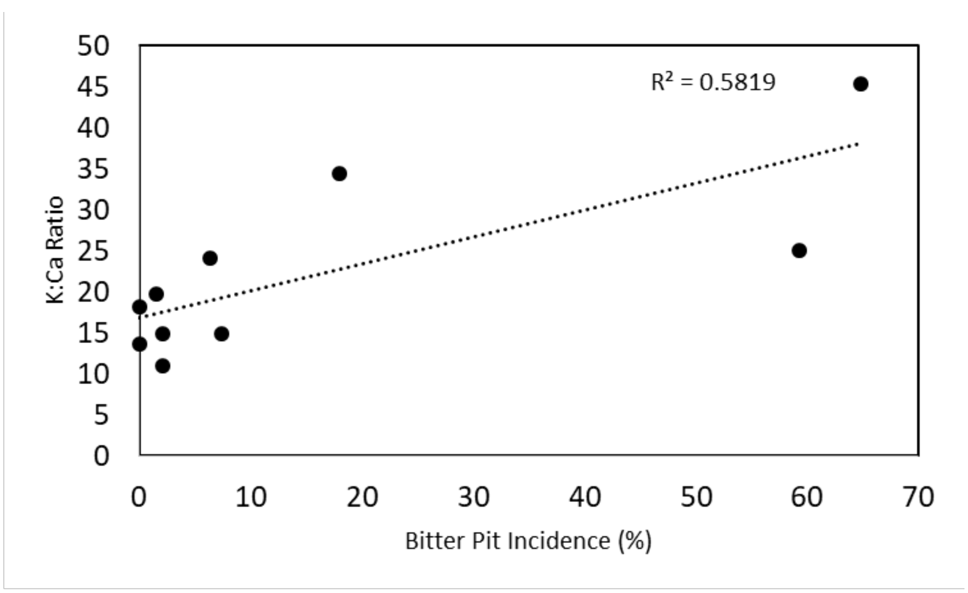


Figure 8. The relationship between bitter pit incidence (x-axis) and the potassium: calcium (K:Ca) ratio in the peel and cortex for fruit from 10 commercial orchards using calcium sprays, careful crop load management, and deficit irrigation to control bitter pit.

Industry Outreach

Since the start of this project, Lee Kalcsits has given 19 presentations to the Washington State apple producers. These have included state, regional, and grower-specific discussions. Additionally, Tianna DuPont organized an irrigation field day in June 2017 attended by approximately 50 industry members that Lee Kalcsits presented at. In 2019, WSU Wenatchee Tree Fruit Research and Extension Center hosted a field day to more than 100 industry members and this research was showcased here. Michelle Reid completed her M.S. working on this project and has presented this research at national and international and also provided 10 talks in 2018 and 2019 to industry members. At the completion of this project, the team will continue to work with the industry including producers and irrigation service providers to provide unbiased information on soil moisture and plant water status monitoring. This will include working with extension to increase the output of online and personally-delivered information to the industry.

EXECUTIVE SUMMARY

Project title: Control of fruit size and bitter pit in Honeycrisp using irrigation

Key words: Bitter pit, Honeycrisp, Irrigation

Abstract: *Malus* x *domestica* cv. 'Honeycrisp' produces large fruit that is susceptible to bitter pit. This project tested the use deficit irrigation for limiting fruit growth and bitter pit. Middle to late summer deficit irrigation during fruit expansion reduced bitter pit by decreasing the proportion of large fruit.

As the acreage of planted 'Honeycrisp' apples continues to expand across the entire United States, the market will become more selective in size and quality. 'Honeycrisp' apples have a propensity to grow oversized fruit. Fruit with larger diameters are more susceptible to the development of bitter pit. To remain competitive, the Washington apple industry must find ways to limit bitter pit occurrence and increase the amount of premium packed fruit per bin. One approach that can be used is controlling the water supply to the orchard to limit fruit size and subsequently, limit bitter pit occurrence. Washington State has the advantage of relying on irrigation for water supply and therefore has much tighter control over water delivery than other growing regions.

Deficit irrigation has been shown to decrease fruit size and subsequently, increase fruit quality. For many varieties, a decrease in fruit size would be a limitation of deficit irrigation. However, for 'Honeycrisp', where oversized fruit is common, particularly in young orchards, controlled deficit irrigation has the potential to allow growers in irrigated environments to control fruit size in accordance to their projected crop load and market demand. However, there are risks with deficit irrigation. Over stressing the tree or applying stress at the wrong time could lead to early fruit drop or losses in final fruit quality. There is a strong potential to develop advanced water management strategies as a tool to improve quality and help growers reach higher value size classes than would be possible using normal irrigation strategies.

The objectives of this project were to test how irrigation timing affects fruit size and bitter pit incidence in 'Honeycrisp' and to develop indicators to make irrigation decisions. Over three years, we show that reducing irrigation during middle and late summer during cell expansion can limit fruit size and shift the proportion of fruit in smaller, more marketable size categories. These smaller fruit were also much less susceptible to bitter pit. However, to adopt these strategies, growers need soil and plant based indicators that allow them to accurately deliver water at the right developmental stages to ensure proper sizing, development and quality. Soil moisture and stem water potential remain the two best indicators of stress in apple and closely followed the drying cycles in the orchard. It is key to make sure soil moisture sensors are placed within the root zone each orchard. Fruit quality was largely unaffected by summer water restrictions except red color development was greater when late summer water limitations were applied. Middle and late summer water limitations are effective at reducing bitter pit by 10-15% compared to non-limiting irrigation applications. However, in commercial orchards that have adopted these irrigation strategies, bitter pit incidence remained high in orchards that had not achieved optimal nutrient balance. In orchards where nutrient and crop load balance were achieved, bitter pit incidence was below 10% when irrigation deficits were used in 2018 and 2019.