**FINAL PROJECT REPORT**

**Project Title:** Effect of near-harvest irrigation on fruit quality


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**Cooperators**: Denny Hayden, Russ LeSage


**Total Project Request:** **Year 1:** $24,503 **Year 2:** $21,330

**Other funding sources**

**Notes:** M.S. student (Nadia Valverdi) in Whiting's lab is supported by a Fulbright scholarship, covering stipend and tuition to work on this project.

**Budget 1**
**Organization Name:** WSU **Contract Administrator: Amanda Yager**
**Telephone: 509-786-9204** **Email address: ayager@wsu.edu**

| Item | 2014 | 2015 |
|---|---|---|
| **Salaries** | $3,000 | $3,120 |
| **Benefits** | $1,290 | $1,342 |
| **Wages** | $3,520 | $3,661 |
| **Benefits** | $341 | $355 |
| **Equipment** | $3,000 | |
| **Supplies** | $3,000 | $3,000 |
| **Travel** | $1,000 | $1,000 |
| **Miscellaneous** | | |
| **Plot Fees** | | |
| **Total** | $15,151 | $12,478 |

**Footnotes: Salary is one month for technician support + associated benefits; wages are for student timeslip assistance with data collection**

**Budget 2-Einhorn**

**Organization Name: OSU-MCAREC** **Contract Administrator: L.J. Koong**
**Telephone: 541 737-4866** **Email address: l.j.koong@oregonstate.edu**

| Item | 2014 | 2015 |
|---|---|---|
| **Salaries** | | |
| **Benefits** | | |
| **Wages**[1] | $4,810 | $4,810 |
| **Benefits** | $388 | $388 |
| **Equipment** | | |
| **Supplies**[2] | $1,000 | $500 |
| **Travel**[3] | $850 | $850 |
| **Miscellaneous**[4] | $2,304 | $2,304 |
| **Plot Fees** | | |
| **Total** | $9,352 | $8,852 |

**Footnotes:**

**[1] Wages are for 370 hours for temporary employee support at $13/hr. Benefit rate is 8.31%.**

**[2] Supplies include nitrogen gas, rental fee for N gas cylinder; Irrigation tubing and supplies; pvc access tubes for neutron probe installation.**

**[3] Travel to sites in The Dalles, OR 1,440 miles (240 per week x 6 weeks) at 0.59 per mile.**

**[4] IrriNet, LLc. neutron probe readings at $4/measurement tube * 48 tubes [i.e., 16 per site x 3 sites] x 3 measurements per week x 4 weeks.**

**OBJECTIVE:**
Improve fruit quality by understanding the role of near-harvest irrigation on key quality traits (firmness, size, soluble solids) and fruit susceptibility to splitting.

**SIGNIFICANT FINDINGS:**

- Irrigation can be reduced prior to harvest without harming sweet cherry fruit yield or quality
- Withholding irrigation in the weeks prior to harvest does not consistently improve quality nor reduce susceptibility to splitting
- Preharvest termination of irrigation has varied effects on sweet cherry fruit quality, the most consistent response being an increase in soluble solids, and slight decrease in firmness
- Withholding irrigation up to 24, 21 and 15 dbh did not affect yield of mature 'Chelan', 'Lapins' and 'Skeena' trees, respectively
- Withholding irrigation beginning 15 dbh, but not 10- or 5-dbh, led to a significant reduction in fruit growth and final fruit size of Skeena
- Stem water potential is a good indicator of plant water status and responded sensitively and rapidly to irrigation withholding
- A stem water potential value of less than -1.5 MPa one week before harvest resulted in growth limiting conditions for cherry fruit.
- Withholding irrigation water from 'Skeena' trees for up to 9 days before harvest (dbh) had no quantifiable effects on tree yield, fruit size or quality at harvest or after cold storage
- Withholding irrigation for 5 dbh had no effect on fruit growth or quality of 'Sweetheart'/'Gisela6' trees
- Withholding irrigation water from 'Sweetheart' for 10 and 15 days resulted in a significant reduction in fruit size and weight
- Withholding irrigation up to 24 days before harvest (dbh) did not affect splitting susceptibility on 'Chelan' and 'Lapins'
- Sweetheart fruit from 10 and 15 dbh treatments had significantly greater cracking resistance (i.e., ~50% less cracking), compared to control and 5 dbh fruits
- Across cultivars+sites, differences in soil water content among withholding treatments were apparent throughout the 3-foot soil profile measured – tree roots of 'Gisela 6' and Mazzard were clearly extracting water from the 3 ft depth

**RESULTS AND DISCUSSION:**

This research project has investigated the effects of withholding near-harvest irrigation on fruit quantity and quality, soil water content, and tree physiology for 4 cultivars ('Chelan', 'Lapins', 'Skeena', and 'Sweetheart') over two years and in 3 locations (Brewster, Dufur, and Pasco). The following summary is organized by cultivar/location, and emphasizes results from 2015. Please see our previous report for detailed descriptions of 2014 results.

***'Chelan'/Mazzard - Pasco*** We documented no effect of early termination of irrigation treatments (i.e., 24 and 14 dbh) on stem water potential nor fruit growth rates in the 'Chelan' trial in Pasco (Fig ). Stem water potential remained above ca. -0.75 MPa at all sampling dates for 2014 and above ca -1.2 in 2015, irrespective of treatment. Importantly, fruit quality was unaffected by early termination of irrigation (Table 1). In addition, there was no effect of irrigation treatment on yield in either year (Fig. 3).

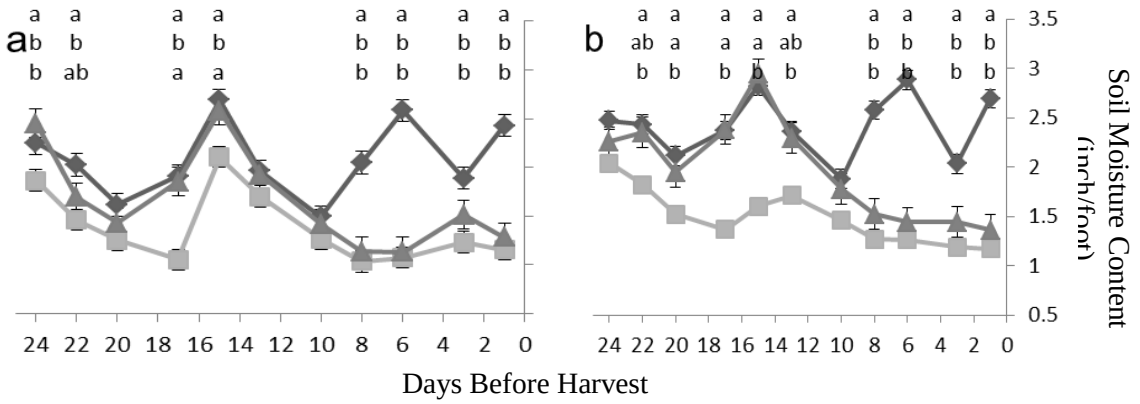


**Figure 1**. Soil water content at a = 6' depth and b = 12' for 'Lapins'/Mazzard trees on 2015.

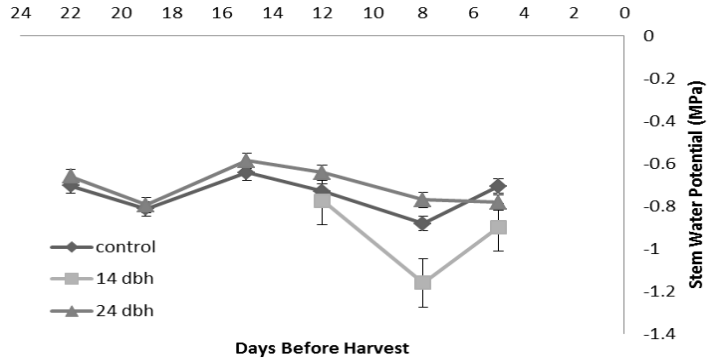


**Figure 2**. The influence of early termination of irrigation on 'Chelan' fruit for midday xylem stem water potential on 2015. Harvest was on 28 May.

**Table 1.** The effect of early irrigation termination on 'Chelan' fruit quality. Irrigation was terminated on 4 May (24 dbh) and 14 May (14 dbh), harvest was 28 May. T.A.= titratable acidity; S.S.=soluble solids; PFRF = pedicel-fruit retention force. n=75 for all quality assessments

| Treatment | Firmness g/mm | Weight g | Diameter mm | T.A. | S.S. % | Color CTIFL | PFRF g |
|---|---|---|---|---|---|---|---|
| control | 313 | 10.4 | 27.8 | 2.8 | 16.3 | 5.07 | 1.09 |
| 14 dbh | 319 | 11.0 | 28.4 | 2.8 | 17.2 | 5.27 | 1.08 |
| 24 dbh | 297 | 10.6 | 28.0 | 2.6 | 16.7 | 5.21 | 1.10 |
| p-value | 0.497 | 0.259 | 0.344 | 0.850 | 0.427 | 0.647 | 0.886 |

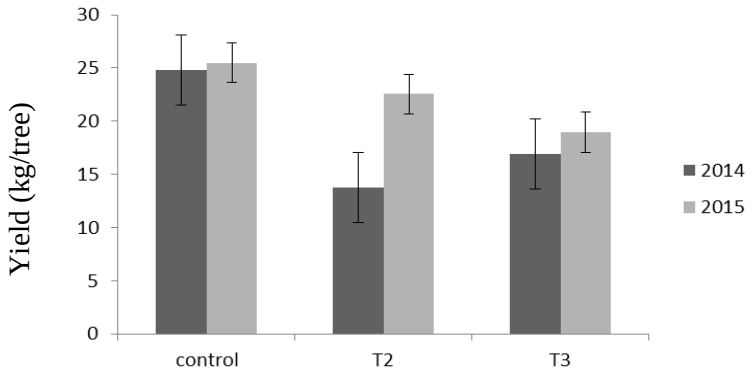


**Figure 3.** The influence of early termination of irrigation on 'Chelan' fruit yield in 2014 and 2015. T2= 7 dbh and 14 dbh for 2014-2015; T3= 17 dbh and 24 dbh for 2014-2015. Each column is the mean of X trees +/- the standard error.

There was no effect of irrigation treatment on the susceptibility of 'Chelan' fruit to splitting (Fig. 4) when assessed by a bench-top immersion test – this was consistent in both years. 'Chelan' is regarded as a split-resistant cultivar – a contention supported by our research. The cracking index was never greater than 25 in 2014, although in 2015 values peaked about two weeks prior to harvest, between 40 and 50. This is attributed to a heavy rain (1.03 inches) that fell the day we sampled fruit. The dramatic increase in sensitivity to splitting following the rain is likely due to greater turgor in fruit (i.e., less ability to withstand water uptake) and, perhaps, a loss of protection from protective coatings. We sampled additional fruit to assess natural cracking in the field, following the rainfall 14 dbh (>1 inch). The percent of cracked fruit was 14% for control, 17% for 14 dbh and 8.5% for 24 dbh irrigation treatments, differences were not statistical significant.

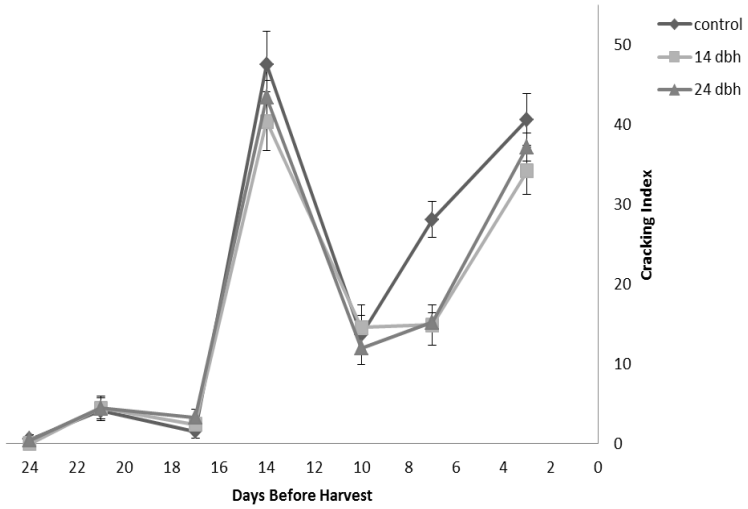


**Figure 4**. Cracking index (i.e., relative susceptibility) of 'Chelan' fruit to preharvest termination of irrigation treatment on 2015. Harvest was on 28 May.

***'Lapins'/Mazzard - Brewster*** In both years we conducted two separate trials in mature commercial 'Lapins' orchards near Brewster; one being similar to the Pasco 'Chelan' trial in which the full suite of soil and tree testing was conducted regularly (intensive trial); the other being a larger scale trial established in two (2014) or four (2015) contiguous 4 acre blocks in which only fruit quality data were evaluated (extensive trial).

***Intensive trial*** In 2015 we observed a decline in stem water potential in trees receiving less irrigation compared to the regularly-irrigated control, though water potential never fell below ca. -1.2 MPa in 2014 or ca. -1.6 MPa in 2015 from trees unwatered for 16 days. These results suggest that trees were not under significant stress at any point – previous research has suggested that midday stem water

potential needs to drop to below -1.5 to have negative impacts (which it did in 'Sweetheart' in Dufur – see below). The inability to induce significant stress in mature 'Lapins'/Mazzard trees suggests that these trees are accessing water resources deep in the soil profile. Our soil texture analysis revealed a sandy clay loam in the upper 8 inches, transitioning to sandy loam and loam textures. Analyses of soil water content revealed a consistent withdrawal of water from 3 feet deep (our deepest sampling site), further indication that trees were supporting the lack of irrigation with water from soil reserves.

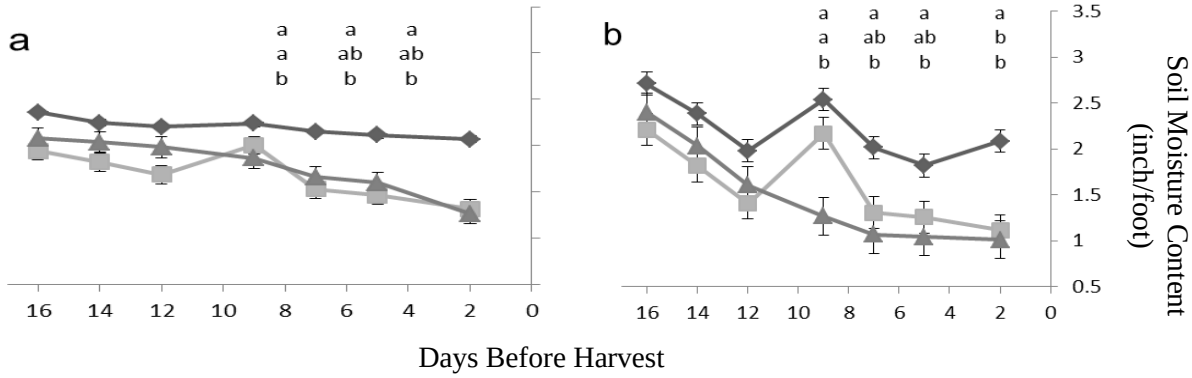


**Figure 5**. The influence of early termination of irrigation on soil water content at a = 6' depth and b = 12' for 'Lapins' trees on 2015.

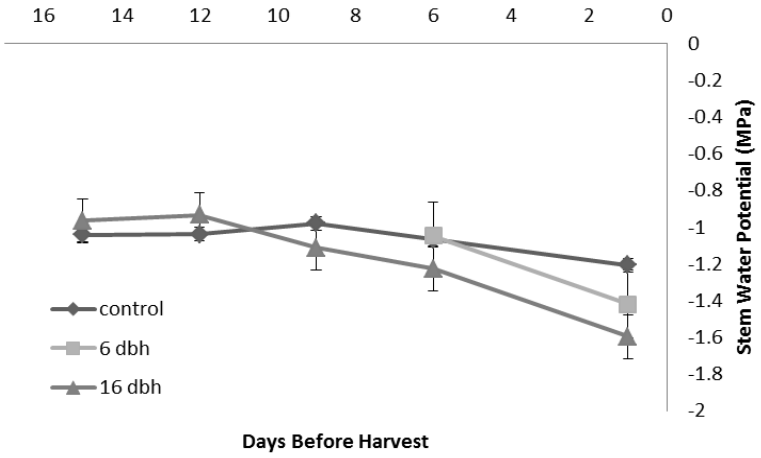


**Figure 6**. The influence of early termination of irrigation on 'Lapins' fruit for midday xylem stem water potential on 2015. Harvest was on 1 July .

Despite a decline in stem water potential near harvest in deficit irrigation treatments, there was no effect of irrigation treatment on fruit growth (data not shown) nor final diameter (Table 2). Again, this is not unusual for the range of stem water potentials observed across treatments. The only consistent effect on fruit quality attributes across both years was an improvement in fruit soluble solids, which were significantly improved (+10 to 14%) by both early irrigation termination treatments in 2014 and (+14%) for withholding irrigation from 6 dbh in 2015. The increase in soluble solids may be due to fruit dehydration but there was no observable fruit shrivel. An increase of 2% soluble solids is significant and likely sufficient to improve the consumer appeal of the fruit. In 2015 we observed a reduction in fruit firmness of a ca. -6% in response to irrigation being withheld for 16 dbh (Table 2), similar to the results for 'Skeena' in Dufur in 2014. Yield wasn't affected by treatments at any year of study (Fig. 6).

**Table 2.** The effect of preharvest irrigation termination on 'Lapins' fruit quality and yield. Irrigation was terminated on 15 June (16 dbh) and 25 June (6 dbh), harvest was on 1 July. T.A.=titratable acidity; S.S.=soluble solids; PFRF=pedicel-fruit retention force (n=25) for all the traits.

| Treatment | Firmness g/mm | Weight g | PFRF kg | Diameter mm | T.A. | Color CTIFL | S.S. % |
|---|---|---|---|---|---|---|---|
| control | 282 a | 9.2 | 0.7 | 25.4 | 2.5 | 4.8 | 17.0 a |
| 6 dbh | 286 a | 9.3 | 0.7 | 25.5 | 2.1 | 4.6 | 19.3 b |
| 16 dbh | 266 b | 9.2 | 0.7 | 25.7 | 2.1 | 4.9 | 18.8 ab |
| p-value | <0.0001 | 0.832 | 0.711 | 0.870 | 0.534 | 0.732 | 0.078 |

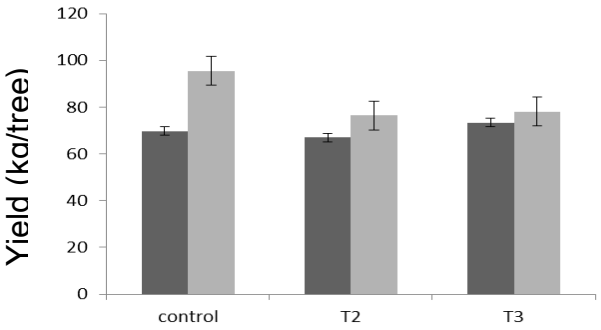


**Figure 7.** The influence of early termination of irrigation on 'Lapins' fruit yield in 2014 and 2015. T2= 11 dbh and 6 dbh for 2014-2015; T3= 21 dbh and 16 dbh for 2014-2015. Each column is the mean of 9 trees +/- the standard error.

We observed an inconsistent and largely insignificant effect of irrigation treatment on 'Lapins' fruit susceptibility to cracking (Fig. 8). Clearly 'Lapins' is more susceptible to splitting than 'Chelan' – the lowest 'Lapins' cracking index was about the same as the highest cracking index for 'Chelan' in the 2014 trials. Further, the pattern of susceptibility to cracking differed between these two cultivars. For 'Chelan', the index was extremely low, exhibiting nearly complete resistance until the final week before harvest. In 'Lapins' susceptibility increased throughout the final weeks of stage III of fruit development and exhibited a decline at the point of harvest, irrespective of irrigation treatment (Fig.8). In 2015, the trend in fruit susceptibility to splitting was similar to the previous year but fruit the cracking index was consistently about 20 points lower, nearly half of the values in 2014. This supports the conclusion that there is a strong effect of environment on susceptibility to splitting. No irrigation treatment had a significant effect on fruit susceptibility to splitting in 2015.

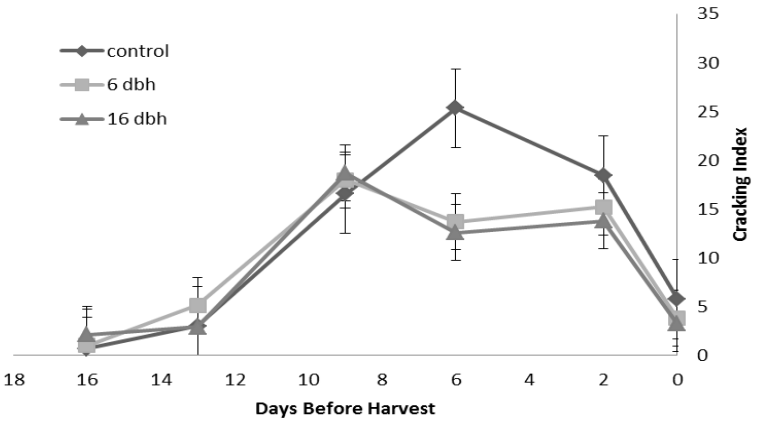


**Figure 8**. Cracking index (i.e., relative susceptibility) of 'Lapins' fruit to preharvest termination of irrigation treatment on 2015. Harvest was on 28 May.

***Extensive trial*** In 2015, the four irrigation treatments compared were: 1) irrigated every 4-5 days for 5-6 hours (control-lo) 2) irrigating every 2 days for 6 hr sets (control-hi), 3) withholding irrigation from 19 dbh, and 4) withholding irrigation from 9 dbh. We imposed the 19 dbh termination treatment and the over irrigated treatment on 15 June, the 9 dbh termination treatment was imposed on 25 June. Fruit were harvested on 4 July. Fruit from the over irrigated treatments and withhold of 19 dbh shows an increase of (ca. +8 and 6%) in firmness respectively, but it shows a decrease of 11% in soluble solids compared to the control-high treatment.

**Table 3**. The effect of early irrigation termination on 'Lapins' fruit quality and yield from the large-scale (4 acre) plots. Irrigation was terminated on 15 June (19 dbh), 25 June (9 dbh) . T.A.=titratable acidity; S.S.=soluble solids; PFRF=stem pull force. (n=75).

| Treatment | Firmness g/mm | Weight g | Diameter mm | T.A. | S.S. % | Color CTIFL | PFRF kg. |
|---|---|---|---|---|---|---|---|
| Control-lo | 257 b | 11.4 | 27.4 | 2.2 | 17.6 a | 4.9 | 0.6 |
| Control-high | 277 a | 10.5 | 26.0 | 2.1 | 15.9 b | 4.7 | 0.6 |
| 9 dbh | 268 ab | 10.3 | 26.6 | 2.1 | 16.6 ab | 4.9 | 0.6 |
| 19 dbh | 273 a | 9.9 | 26.6 | 2.2 | 17.7 a | 4.8 | 0.6 |
| p-value | 0.0070 | 0.116 | 0.397 | 0.620 | 0.103 | 0.854 | 0.121 |

***'Skeena'/'Gisela6' – Dufur*** High temperatures resulted in much earlier harvest dates than expected (June 24). This was partly due to Skeena's inherent sensitivity to heat stress. Thus, our 9 and 3 dbh treatments were intended to be 15 and 10 dbh, respectively. The 5 dbh treatment had not yet been initiated. Irrespective, our data support that Skeena trees could handle no irrigation for 10 dbh without negative effects on growth or quality, as similarly observed in 2014. Fruit size was not affected by water withholding, therefore we did not evaluate the relative water content and dry matter of fruit. Stem water potential values were close to critical levels (< -1.5 MPa), but not low enough for long enough to reduce fruit growth.

**Table 4**. Effects of early irrigation withholding for 3 or 9 days before harvest (dbh) on yield and fruit quality attributes of 'Skeena' sweet cherry trees.

| Treatment | Yield kg/tree | Fruit diameter mm | Fruit wt. g | FF g/mm | Skin color ctifl | PRF g | SSC % | TA % |
|---|---|---|---|---|---|---|---|---|
| Control | 34.85 | 28.35 | 10.01 | 339.6 | 5.7 | 276 b | 18.6 | 0.88 |
| 3-dbh | 38.06 | 27.75 | 9.45 | 340.4 | 5.5 | 422 a | 18.1 | 0.91 |
| 9-dbh | 34.76 | 28.25 | 9.94 | 343.4 | 5.5 | 356 ab | 18.7 | 0.91 |
| *Pr>F* | *0.659* | *0.469* | *0.496* | *0.834* | *0.083* | *0.016* | *0.533* | *0.241* |

Yield (n=2); fruit diameter and weight (n=400);
fruit firmness (FF) (n=400); skin color (n=100); pedicel retention force (PRF) (n=25);
titratable acidity (TA) and soluble solids content (SSC) (n=2).
Data assigned different letters within columns signifies significant difference at $P < 0.05$ by Fisher's Protected LSD test.

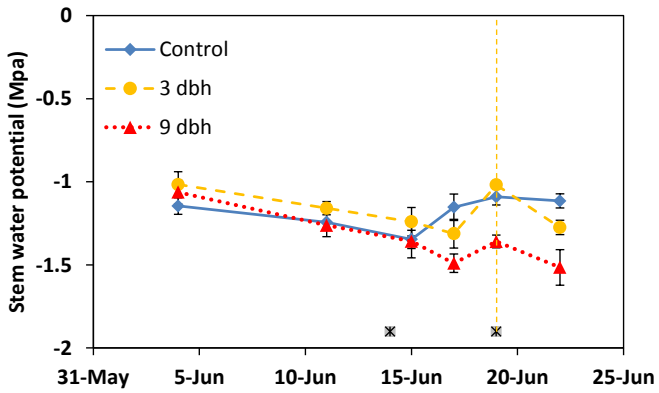


**Figure 9**. Stem water potential of Skeena trees cut-off from irrigation 3 or 9 days before harvest (dbh), compared to control trees. Asterisks above x-axis signify start date of withholding for each treatment with hashed vertical line. Harvest date was 4-July. For water potential, 4 leaves per replicate were bagged ~1hr prior to measurement. Measurements bracketed solar noon (±1.5 hrs).

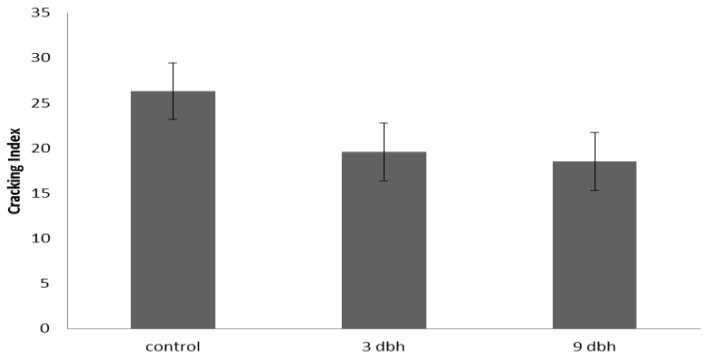


**Figure 10**. Cracking susceptibility of 'Skeena'/Gisela6 fruit in response to near-harvest deficit irrigation treatments. dbh = days before harvest.

***'Sweetheart'/'Gisela6' – Dufur*** For each withholding treatment, stem water potential declined in synchrony with the irrigation termination date (Fig.11). Within ~1 week of harvest, critical water potential values (i.e., relative to the process of fruit growth) are ≤ -1.5 MPa. These data agree with 2014 results from 15 dbh Skeena. Fruit growth also responded sensitively to water withholding; a ~9% reduction of fruit size was observed (approximately a ½ row size reduction). Photosynthesis of 10 and 15 dbh trees was reduced by 50%, compared to controls and 5 dbh, but only at 2 days before harvest. Dry matter (carbon) of fruit was not reduced by irrigation treatments indicating that growth resources under water stress conditions remained sufficient for growth. In fact, relative water content was reduced in stressed treatments indicating that evaporation at the fruit surface, and/or water flow out of the fruit to organs with lower water potential were responsible for the weight loss. The fact that sugar concentration was higher in these fruit supports that they were slightly dehydrated (ssc represents the percent sugar (predominantly) in solution, therefore processes which cause dehydration increase the ssc). Cracking data support this observation. Less cracking could have been due to changes in the cuticle and/or epidermal layer as a result of water stress, but is more likely associated with the fruit's ability to draw in more water. We would have expected a significant reduction in water content to result in softer fruit, but this was not supported by firmtech data. Interestingly, all treatments of Sweetheart were observed to have 'lost' size in the last few days prior to harvest-presumably due to dehydration. Temperatures were ~100°F several days to 1 week prior to harvest. Despite a reduction in fruit size, all treatments attained an average fruit size at harvest of ~10 row (Table 5). Soil moisture was low in the top 1 foot of soil for 10 and 15dbh trees, but roots were clearly extracting water from lower depths. While soil moisture provides an indication of the stress it is an indirect measure of plant stress. An ample volume of available water in the soil profile (even for the course soils evaluated herein) can compensate for irrigation deficits over a period of 1 week.

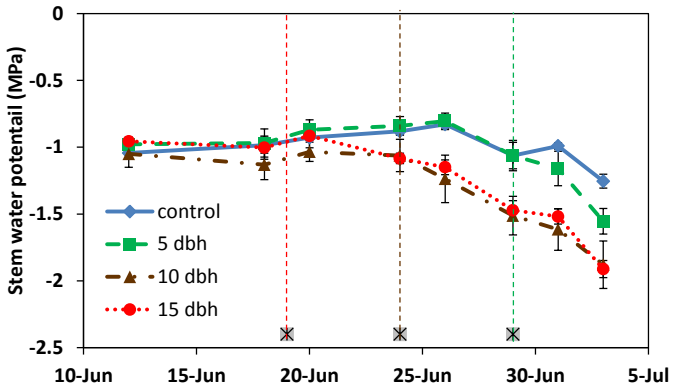


**Figure 11**. Stem water potential of Sweetheart trees cut-off from irrigation 5, 10 or 15 days before harvest (dbh), compared to control trees. Asterisks above x-axis signify start date of withholding for each treatment with hashed vertical line. Harvest date was 4-July. For water potential, 4 leaves per replicate were bagged ~1hr prior to measurement. Measurements bracketed solar noon (±1.5 hrs).

**Table 5**. Effects of early irrigation withholding for 5, 10 or 15 days before harvest (dbh) on yield and fruit quality attributes of 'Sweetheart' sweet cherry trees.

| Treatment | Yield kg/tree | Fruit diameter mm | Fruit wt. g | DMC g/fruit | RWC % | FF g/mm | Skin color ctifl | PRF g | SSC % | TA % |
|---|---|---|---|---|---|---|---|---|---|---|
| Control | 19.4 | 27.7 a | 9.8 a | 2.29 | 76.98 a | 341.8 | 4.7 a | 277 | 22.1 | 1.07 |
| 5-dbh | 20.7 | 27.4 a | 9.5 ab | 2.23 | 77.3 a | 343.2 | 4.4 b | 277 | 21.1 | 1.08 |
| 10-dbh | 19.9 | 26.5 b | 9.0 b | 2.3 | 75.03 b | 329.6 | 4.8 a | 205 | 23.6 | 1.01 |
| 15-dbh | 19.3 | 26.9 ab | 9.2 b | 2.28 | 75.92 ab | 328.3 | 4.6 a | 212 | 22.4 | 1.05 |
| *Pr>F* | *0.948* | *0.042* | *0.024* | *0.851* | *0.031* | *0.587* | *0.008* | *0.109* | *0.098* | *0.195* |

Yield (n=2); fruit diameter and weight (n=400); fruit relative water content (RWC) and dry matter content (DMC) (n=60); fruit firmness (FF) (n=400); skin color (n=100); pedicel retention force (PRF) (n=25); titratable acidity (TA) and soluble solids content (SSC) (n=2);
Data assigned different letters within columns signifies significant difference at $P < 0.05$ by Fisher's Protected LSD test.

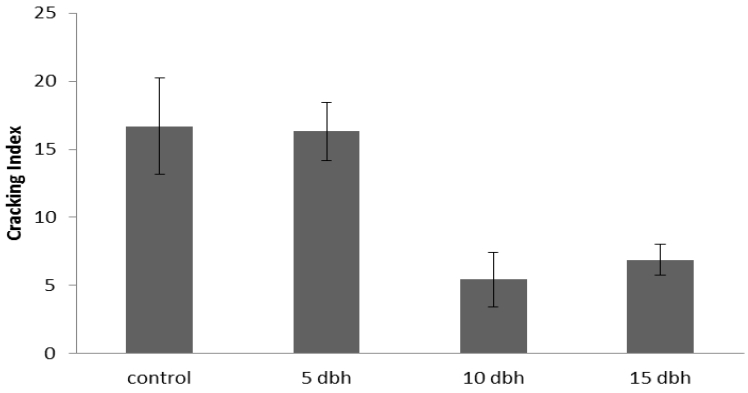


**Figure 12**. Effect of early irrigation termination on 'Sweetheart' fruit cracking susceptibility. N=100

EXECUTIVE SUMMARY

***Effect of near-harvest irrigation on fruit quality***

This project has evaluated, over two years, and for four cultivars in three locations (all commercial collaborators), the effects of withholding irrigation prior to harvest on sweet cherry fruit quality and quantity. Combined, our results reveal an apparent resilience of sweet cherry to the reductions in the quantity of water normally applied in the weeks preceding harvest. We found no consistent negative effect of withholding irrigation, up to 3 weeks before harvest. Neither did we discover a consistent effect of pre-harvest irrigation treatments on the fruits' susceptibility to splitting. For example, in 2015, 'Sweetheart' fruit splitting at harvest was 50% lower when trees received no irrigation from 10 or 15 days before harvest (dbh), but these fruit were slightly smaller than fruit from trees receiving 'normal' irrigation.

The greatest risk from withholding irrigation in the weeks prior to harvest appears to be primarily a slight loss in firmness (1 of 5 trials in 2015) or size (1 of 5 trials in 2015). In both cases, midday stem water potential reached levels below -1.5 MPa.

The obvious benefit from withholding irrigation water prior to harvest is clear – the savings of water, particularly important in drought years such as 2015 and predicted for 2016. For example, in 'Skeena', the savings of 3 preharvest irrigation sets (i.e., 9 dbh termination) would have saved that grower an estimated 21,600 gallons per acre with no negative effects on fruit quality. In addition, we have observed fruit quality improvements from withholding near-harvest irrigation: increase in pedicel-fruit retention force (1 of 5 trials in 2015), increase in soluble solids (1 of 5 trials in 2015).

Importantly, midday measurements of stem water potential, using a portable pressure bomb, integrated soil and tree water status, and may be used to predict, and avoid stress. Our results suggest that maintaining midday stem water potential above -1.5 is important for avoiding deleterious stress effects on fruit quality. Utilizing regular assessments of stem water potential to schedule irrigation has been suggested previously and is an area worthy of further investigation.