FINAL PROJECT REPORT

Project Title: Improving sweet cherry yield security and fruit quality

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Other funding sources

Agency Name: Horticulture Australia Limited (HAL)
Amt. awarded: $231,000
Notes: this funding supported a highly-rated counter-seasonal research project with similar objectives in Australia

Budget 1
Organization Name: WSU **Contract Administrator: Mary Lou Bricker/Lisa Bruce**
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Item	(2010)	**(2011)**	
Salaries	28,914	**35,071**	
Benefits	4,365	**4,539**	
Wages	24,264	**25,235**	
Benefits	3,301	**3,433**	
Equipment	6,500		
Supplies	2,000	**2,000**	
Travel	5,000	**7,500**	
Miscellaneous			
Total	74,344	**77,778**	

Footnotes: Salaries is for Ph.D. student salary and benefits (include health insurance and 1.5% med aid), Research Assistant Allyson Leonhard (0.15 FTE benefits at 36%); Wages are for equivalent of 3 students for the summer months (15.0% benefits) and Ph.D. student summer wages (9.6% benefits); supplies includes EM center microscopy fee and lab consumables. Travel is for domestic, to plots ($5000) and international ($2500 for 1 trip annually to Tasmania).

OBJECTIVES

This research project is a logical evolution from previous research by PI Whiting and other TFRC-funded work that have highlighted the need to achieve yield security, develop precision thinning strategies, and better understand components of fruit size. Towards achieving these goals, this project has the following key objectives:

1. Understand role of environment on fruit set and effective pollination period.
2. Identify the best time to thin.
3. Investigate potential post-bloom thinners.
4. Understand timing of mesocarp cell division & expansion cycles and their relative role in fruit quality.
5. Develop counter-seasonal collaboration with University of Tasmania and leverage WTFRC/OSCC funding via Horticulture Australia Limited.

SIGNIFICANT FINDINGS

- Daily, fruit set varies significantly
- Natural fruit set is low when flowers open during windy, hot conditions
- Pollen germination rate and growth rate don't appear to limit fruit set in cultivars with low productivity
- Short period of ovule longevity appears to limit productivity (fruit set) in Regina, Benton
- Fruit set in Regina, Tieton, Benton can be improved with PGRs applied during bloom
- Fruit quality potential is related to timing of flowering at high crop load
- Fruit quality potential is unrelated to timing of flowering at low crop load
- Fruit quality potential is similar for all buds in a spur
- Fruit quality is highest for single-fruit 'clusters' (i.e., 1 fruit set per floral bud) compared with multiple-fruit 'clusters' (i.e., several fruit set per floral bud)

- The earlier the thinning, the better the fruit quality response
- The benefit of thinning on fruit quality depends on the fruit density – there are benefits from thinning after pit hardening if crop density if high
- Trials with BA, ABA, methyl jasmonate, and NAA showed no efficacy as post-bloom thinners
- Ethephon and PCa + ABA show potential as post-bloom thinners applied 2 – 3 weeks after full bloom

- Counter-seasonal collaboration with University of Tasmania is established – we have project funded by Horticulture Australia Limited for complementary work

RESULTS & DISCUSSION

1. Role of environment on fruit set and effective pollination period

Field studies All previous studies of fruit set have been accomplished by counting flowers on a single day early in bloom, and counting final fruit numbers near harvest – a technique that reveals nothing about the variability in fruit set nor the underlying causes. From tagging individual flowers on the day of opening we were able to study fruit set on a daily basis, throughout the flowering

period. In addition, we have a preliminary dataset for modeling flowering progression with key environmental parameters. Across both years, we documented tremendous variability in fruit set under field conditions in Lapins, Kordia, Van, and Sweetheart throughout the bloom period. For example, fruit set varied from a low of 10% to 100% in Lapins, across the 18-day bloom period (Fig. 1). At this stage we are analyzing variability in fruit set with daily weather conditions to identify patterns and key environmental factors. Preliminary analyses show no relationship between temperature on the day a flower opens and fruit set. Interestingly, fruit set from hand pollinations was similar to that of open pollinated flowers on most days. This suggests there weren't many days when pollinator activity was limiting to fruit set.

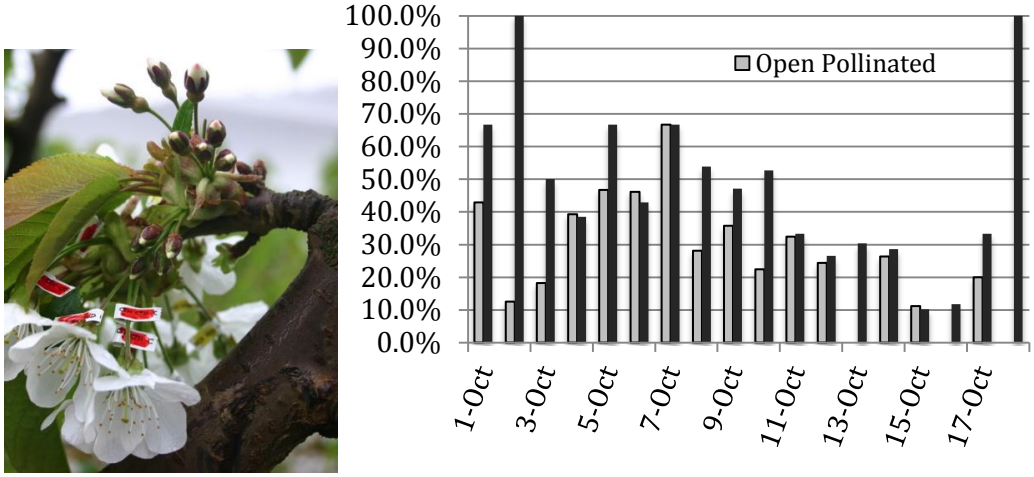

Figure 1. Variability in fruit set (% available flowers) throughout the bloom period in 'Sweetheart' sweet cherry in a commercial orchard in the Huon valley, Tasmania. Individual pedicels were labeled on the day of opening (photo).

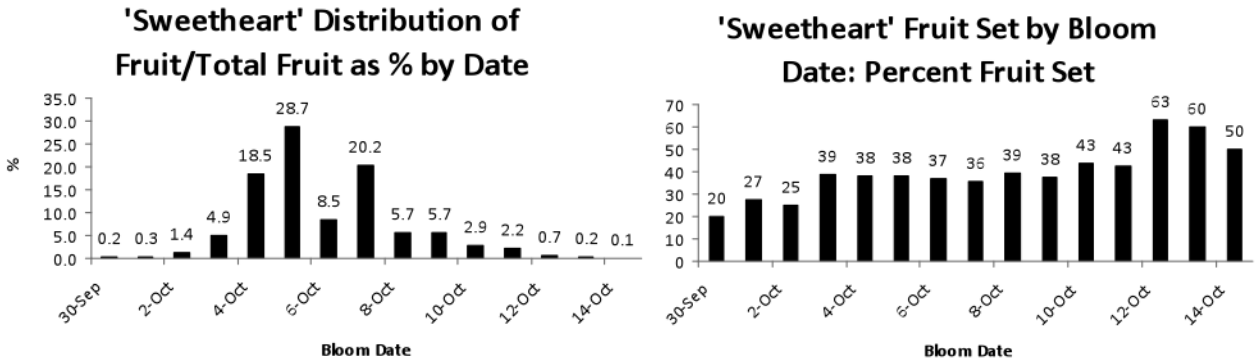

Figure 2. The percent of final fruit count by date of flowering (Left) and the daily variation in fruit set (% available flowers) (Right) for 'Sweetheart' in 2011.

In 2010/2011 flower tagging studies revealed that 'Sweetheart' fruit set was about 37% overall. Daily range in fruit set ranged from about 20 to 63%. Flowering began slowly, peaking on day 6 and declining slowly thereafter (Fig. 2). Nearly 30% of all fruit at harvest were set from flowers that opened on a single day (Fig. 2). If only the flowers that opened on that day were to have set fruit, overall fruit set would have been about 12%, only slightly less than we estimate being a desirable balance for 'Sweetheart'. This flowering pattern was common for most cultivars studied and suggests that a commercial crop may be set within a day or two, if conditions are favorable. We anticipate

developing targeted crop load management strategies with this knowledge combined with data from our pollen tube growth studies (see below). This may include removal of pollinators past peak bloom or application of caustic thinners. Rigorous models of bloom progression and a clear understanding

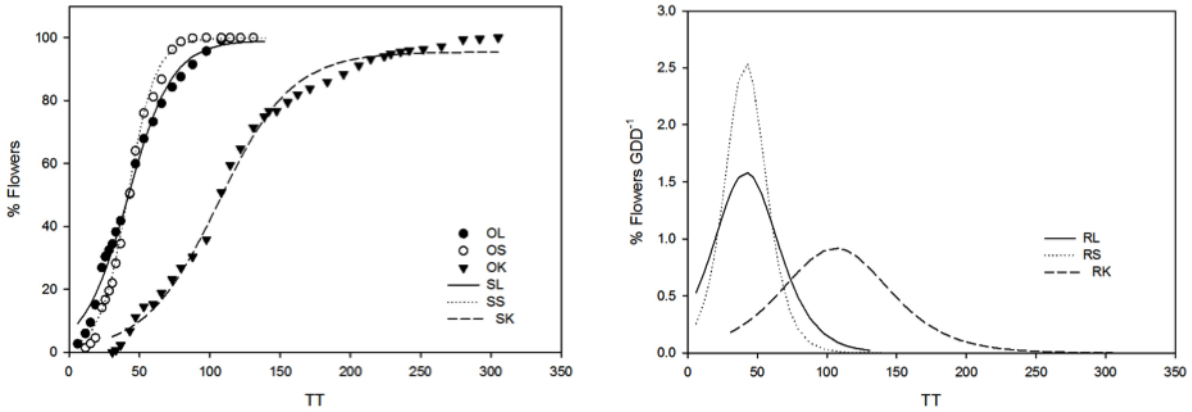

Figure 3. Logistic model for flowering of 'Lapins' (OL), 'Sweetheart' (OS), and 'Kordia' (OK) as a function of thermal time (TT) (left). Rate of flowering (flowers/growing degree day) as a function of thermal time (TT) (right).

of effective pollination period will facilitate the development of effective crop load management strategies. Our preliminary attempts to model flowering of sweet cherry with thermal time reveal a sigmoidal curve with Lapins and Sweetheart blooming earlier than Attika (Fig. 3). We are currently including growth chamber studies with field observations to strengthen these flowering models. In addition, we are pursuing funding from USDA to continue the effort.

At commercial harvest there was no apparent relationship between fruit quality (any attribute evaluated) and the date that the flower opened during bloom (Fig. 5). This was true for each cultivar evaluated and contradicts one dataset collected in Prosser that showed that quality potential was highest in the earliest-opening flowers. We believe this is due to differences in crop load, which was heavy in Prosser and light in Tasmania. Trials established in Tasmania evaluated the role of crop load on the effect of timing of flowering on fruit quality potential, however, fruit load was light overall and we observed no effect. Regardless, the variability among fruit at 'commercial' harvest maturity is tremendous, even among fruit from flowers that opened on the same day (Fig. 5). We recorded nearly a 3-fold variability (e.g., 5 to 15 g per fruit) in fruit weight that is obviously not related to timing of flowering. Variability in other key attributes was significant as well. Combined, these data suggest fruit quality potential is determined, in part, at the time of flowering (a possibility we are investigating) and not by the timing of anthesis. A preliminary investigation into the potential for bud hierarchy within cherry spurs revealed no consistent difference in fruit quality between fruit from the apical-most fruit bud (i.e., that nearest the vegetative bud) vs. the basal-most bud (Table 1).

In Prosser in 2011 we harvested fruit from several cultivars at commercial maturity, selecting fruit borne from the same floral bud but with different numbers of fruit. These were categorized as single-, double-, triple-, or quadruple-fruit 'clusters'. This observational study's results are currently being analyzed but a notable trend is apparent – there is a negative relationship between the number of fruit set in a bud and the size/weight of those fruit (Table 2). When only one flower in a bud set fruit, the quality of those fruit was always better than quality of fruit from multiple-fruit clusters, regardless of cultivar. Previous work funded by the WTFRC in PI Whiting's lab showed that applications of GA during floral bud initiation could reduce the density of flowers per bud without impacting the number of buds per spur. This may be a practical strategy to achieve improvements in quality by favoring fewer flowers per bud. We will investigate this further along with other analyses into fruit quality potential that are needed to elucidate factors accounting for the tremendous

variability.

Table 1. Quality attributes of 'Sweetheart' sweet cherry fruit borne on apical or basal floral buds. Data are means from individual fruit analyses, N = 22 (apical), N= 24 (basal), N=48 (apical-thinned), N=42 (basal-thinned).

	Weight (g)	Diameter (mm)	Skin colour	Soluble solids
Apical	12.4	30.0	5.5	17.1
Basal	13.3	31.3	5.6	18.5
Apical – thinned	12.2	30.1	5.3	15.9
Basal – thinned	11.9	29.7	5.3	16.3

Table 2. Fruit weight of sweet cherry cultivars harvested at commercial maturity from either a single-, double-, triple-, or quadruple-fruit cluster.

	Fruit weight (g)				
Cluster type	'Benton'	'Chelan'	'Cowiche'	'Rainier'	'Tieton'
Single	9.88	7.11	11.15	8.46	11.59
Double	8.90	6.55	10.15	7.64	10.70
Triple	7.00	6.53	9.56	7.25	9.59
Quadruple		5.68		4.67	7.78

In another field experiment we covered limbs of emasculated flowers with bee exclusion netting and populations of flowers were hand pollinated at 1-day intervals to study stigma receptivity/ovule longevity. Results indicate an extended period of stigma receptivity/ovule viability in all cultivars – 'Tieton', 'Benton, 'Rainier', and 'Sweetheart', with fruit being set from pollinations made 5 days after emasculation (roughly equivalent to 4 days after the flower opened).

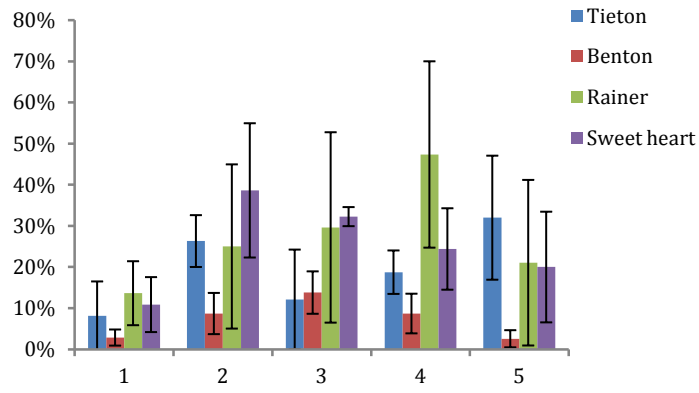

Figure 4. Fruit set (% available flowers) from hand pollinations made at daily intervals. Day 1 – flowers emasculated at full white. Day 2 – date of opening. Flowers were isolated from bees so that pollination was initiated manually. Data are means +/- SE.

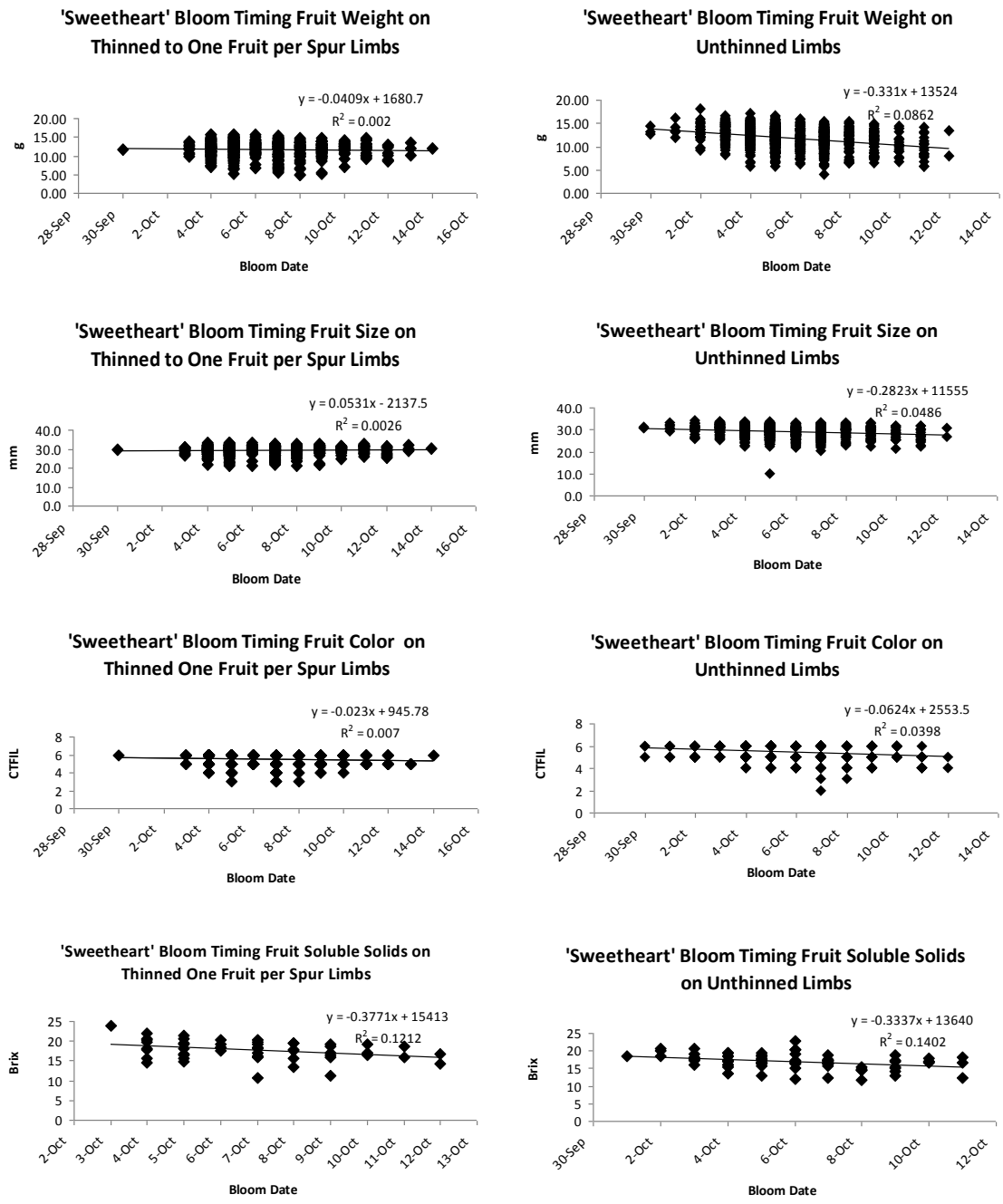

Figure 5. Relationship between fruit quality attributes and date of flowering for 'Sweetheart' trees that were thinning to 1 bud/spur (left) or unthinned (right).

Growth chamber studies In 2011 we conducted several studies in plant growth chambers to evaluate the effective pollination period for sweet cherry and to understand the role of temperature on fundamental elements of fertilization. Our assessments of pollen germination, pollen tube growth, stigma receptivity, and ovule viability of 'Benton', 'Bing', 'Regina', and 'Sweetheart' reveal differences between 'productive' cultivars (e.g., 'Bing' and 'Sweetheart') and unproductive cultivars (e.g., 'Benton' and 'Regina'), though our analyses are ongoing. It appears that pistil factors are important in cultivars with low fruit set – we observed lower receptivity of the stigma and faster degeneration of the ovule in 'Benton' and 'Regina' compared with 'Bing' and 'Sweetheart'. Low

temperature reduces the rate of pollen germination and growth through the style and extends the viability of the ovule whereas high temperature accelerates these components. Under low temperatures, we observed no pollen germination by 8 hours after hand pollination, irrespective of cultivar. In contrast, more than 60% of the pollen grains had germinated on 'Sweetheart' stigmas after 8 hours of high temperature treatment. Under our average temperature regime, designed to mimic 'normal' spring conditions, we recorded pollen tube growth to the base of the style by 96 hours in 'Bing' and by 72 hours in 'Sweetheart'. In contrast, in 'Benton' and 'Regina', we did not record similar pollen growth until 120 hours post pollination. Our observations from lab and field studies, as well as anecdotal evidence from growers, indicate that low temperature conditions are favorable for achieving high fruit set. This is likely due to prolonged viability of the ovules.

Complete results of our growth chamber trials will be posted on our program's website once complete – please visit http://fruit.prosser.wsu.edu for more information.

Our investigations into practical strategies for improving fruit set have been based upon our discovery that ovule longevity appears important to cultivars exhibiting low fruit set. In 2010 we treated 'Tieton' at about 75% full bloom with 4-CPA (a synthetic auxin), GA_3+GA_{4+7}, and AVG (Retain®). Each treatment improved final fruit set significantly (Table 3). Both GA treatment and CPA have yielded inconsistent results. Two years of field trials in Tasmania have also confirmed the efficacy of AVG for improving fruit set of 'Regina'. We have anecdotal evidence from two orchards that two applications of AVG, made at about 20% and 50% of full bloom are effective for improving fruit set. At this stage the most promising program for improving fruit set is two applications of AVG made during early stages of flowering (ca. 10-20% and 40-60%).

Treatment	Fruit set (%)
Control	25 a
4-CPA	36 b
AVG	40 b
GA_3+GA_{4+7}	44 b

Table 3. Effect of PGRs applied to whole trees at about 75% full bloom on fruit set of 'Tieton' sweet cherry. Data with different letters are significantly different at P < 0.01)

2. Timing of thinning - we investigated the effects of the timing of thinning at key phenological stages of fruit development on fruit yield and quality relationships for Bing and Sweetheart in 2010, and Van and Sweetheart in 2011. In addition, we investigated target crop loads by thinning entire trees to leave 1, 2, or 4 floral buds per spur. This work is intended to answer a few simple questions – when is the best time to thin, and, to what targets should we thin?

In every case, earlier thinning was beneficial compared with thinning later in the season. For example, when crop load was adjusted by thinning dormant buds or flowers at full bloom, 'Sweetheart' fruit weight was about 17% heavier compared to later thinning timings, which were similar (Table 4). The results with 'Sweetheart' contradict slightly our previous results that showed benefits from thinning up to early stage II of fruit development (see previous reports). This may be due to the relatively light crop load in the 'Sweetheart' trial – when crop load is heavier, later thinning may be beneficial, as late as early stage III in heavily cropped trees. However, our results do underscore the importance for thinning programs to be imposed as early as possible in the fruiting timeline. The significant challenge of course is not knowing what fruit set is until well past full bloom. Our future work will continue to investigate post-bloom thinning strategies.

Interestingly, we observed a clear relationship between crop load and susceptibility to cracking – incidence of split fruit was dramatically higher in trees with low fruit density and large fruit size.

Table 4. Effects of fruit bud density and time of thinning on yield and fruit quality attributes of 'Sweetheart' sweet cherry.

Treatment	Estimated fruit per tree	Estimated fruit per cm^2 TCSA	Mean fruit weight (g)	Yield efficiency (kg/cm^2 TCSA)	% cracked fruit
Crop load (CL)					
1 bud/spur	1441 a ***	9.53 a ***	11.75 b **	0.109 a ***	58.6 c ***
2 buds/spur	2157 b	13.54 b	11.56 b	0.149 b	39.5 b
4 buds/spur	3810 c	22.58 c	10.29 a	0.222 c	18.0 a
Thinning time (TT)					
Dormant	2192 ab *	13.62 ns	12.28 b ***	0.155 ns	34.0 a **
Full bloom (FB)	2135 a	13.01	12.11 b	0.152	40.8 ab
2 wAFB	2679 c	16.36	10.52 a	0.161	33.0 a
4 wAFB	2792 c	17.32	10.26 a	0.163	35.8 a
6 wAFB	2613 bc	15.78	10.83 a	0.170	50.1 b

ns, *, **, ***, non significant or significant at P≤0.05, P≤0.01, P≤0.001. Within a single column and main effect only, means sharing the same letter are not significantly different at P=0.05 using the LSD test. Main effects of CL, or TT represent data averaged TT, or CL, respectively.

3. Investigate potential post-bloom thinners In 2011 we repeated trials of various PGRs as post-bloom thinners for sweet cherry. Trials were conducted on 'Sweetheart', 'Bing', and 'Rainier', all on 'Gisela' rootstocks. Single applications were made at about 3 weeks after full bloom, approximately the stage I – stage II transition (i.e., pit formation was beginning in some fruit). In contrast to 2010 results, we documented effective thinning with Ethephon in all cultivars (Fig. 5). None of the other PGRs (BA, ABA, methyl jasmonate, NAA) were effective though BA did improve fruit size slightly without inducing any thinning. There did not appear to be any collateral damage to the Ethephon-treated trees – leaves did not abscise and shoot growth continued. Thinning was clearly excessive with Ethephon – we propose to investigate rate and timing response for multiple cultivars in the new proposal. The development of an effective post-bloom thinner for sweet cherry would give growers a convenient tool for managing crop load.

Figure 5. Comparison of limbs shortly after treatment with Ethephon (left) and about one month following treatment with Ethephon (right).

4. Understand timing of mesocarp cell division & expansion cycles and their relative role in fruit quality – see report from Einhorn and Gibeault for progress on this collaboration.

5. Develop counter-seasonal collaboration with University of Tasmania and leverage WTFRC/OSCC funding via Horticulture Australia Limited – considerable effort was made this year to work through contract negotiations for the collaboration. A project that complements the current project was submitted to HAL with PIs Whiting and Close. The full amount of funding from the WTFRC awarded to the current project was sent to HAL as a 'voluntary contribution' to the HAL project. These funds will be matched with HAL funds at about 41% (i.e., the $74,344 funded in year 1 will be leveraged to about $104,000). These matched funds will then be returned to the WTFRC to be issued to WSU. The HAL proposal has been funded fully for 2 years and puts in place technical support in Tasmania to work on issues of concern common to Tasmania, Washington, and Oregon.

EXECUTIVE SUMMARY

This research has improved our understanding of factors that limit fruit set in sweet cherry. Cultivars characterized as poor producers appear to be so from short viability of the ovules. With this knowledge we have begun research into practical strategies to increase productivity in key cultivars. Field trials have shown promise for AVG applications made early in flowering to improve fruit set.

Every element of fruit set/pollination is affected by temperature – pollen tube growth rates increase with temperature, but so does the rate of ovule senescence. Our results suggest that fruit set will be greater in cool springs due to delayed ovule senescence despite slower pollen tube growth. Warm, and windy weather during bloom will decrease fruit set due to accelerated ovule senescence, despite increased pollen tube growth rates.

If crop load is balanced, timing of flowering does not affect fruit quality (i.e., fruit from the earliest and latest opening flowers will be similar quality). However, if crop load is high, fruit set from the earlier opening flowers will be better quality than those from late-opening flowers.

Thinning early in fruit development (e.g., dormant buds, flowers) is more beneficial than later thinning (e.g., post pit hardening) for improving fruit quality.

For most cultivars, a well-balanced crop load is 2 – 4 fruit per spur. Fruit quality from single-fruit clusters is better than from multiple-fruit clusters (i.e., several fruit set from same bud). There appears to be no effect of flower bud position on fruit quality potential in sweet cherry.

Ethephon applied 2 to 3 weeks after full bloom shows promise as a post-bloom thinning agent.