POSTHARVEST DEFECIT IRRIGATION FOR IMPROVED RESILIENCE OF CHERRY TO CLIMATE CHANGE & MODELLING SWEET CHERRY COLD HARDINESS

FARM ADAPTATION INNOVATOR PROGRAM | RESEARCH SUMMARY | JUNE 2019 - DECEMBER 2022

Geographic Applicability

- Research location: Coldstream, Kelowna, Summerland, and Meadow Valley, BC
- Applicability: Okanagan Valley, BC

Commodity Relevance

- This study was conducted on commercial 'Sweetheart' sweet cherry orchards in the Okanagan Valley, BC but findings may apply to other varieties and other stone fruit and in other semi-arid fruit growing regions

Practical benefits

- Findings from this study may contribute to the development of more sustainable irrigation management practices in sweet cherry production in the Okanagan Valley through improved understanding of plant water requirements in the postharvest period
- Cost-benefit analysis of adopting postharvest deficit irrigation (PDI) in Okanagan cherry orchards revealed the costs of implementing PDI are minimal but bring benefits for the grower and society in conserving water
- A web application based on sweet cherry cold hardiness models developed using data from this PDI project has been created and made openly accessible for use by growers and extension workers as a frost management decision support tool

Project lead

- Louise Nelson, Professor Emerita, University of British Columbia, Okanagan Campus

Research Team

- Julien Picault, Professor of Teaching, University of British Columbia, Okanagan Campus
- Kirsten Hannam, Research Scientist, Agriculture and Agri-Food Canada, SuRDC
- Denise Neilsen, Retired Research Scientist, Agriculture and Agri-Food Canada, SuRDC
- Elizabeth Houghton, PhD student, University of British Columbia, Okanagan Campus
- Kirsten Bevandick, MSc student, University of British Columbia, Okanagan Campus

PROJECT OVERVIEW

Cherry production in the southern interior of British Columbia is expanding northward and to higher elevations than previously possible as a result of climate change. Additionally, the timing and availability of water supply is changing in the Okanagan Valley, and the availability of irrigation water in the late summers is a growing concern. Overall, annual water use and irrigation water demand are projected to increase in this region due to climate change, population growth, and expanding agriculture. Therefore, it is important to research and adopt irrigation practices that will reduce water consumption while minimizing adverse effects on crop production.

Postharvest deficit irrigation (PDI) is a strategy that can be used to reduce water demands in sweet cherry orchards and is a more sustainable irrigation strategy that will support agricultural resilience to climate change. Previous studies in this region have reported no change in plant physiology or tree growth with irrigation volume reductions of up to 25 %, postharvest. However, the effects of more severe postharvest reductions in irrigation volume were unknown. We compared the effects of three irrigation treatments; (i) a control of full irrigation, irrigated according to conventional growers' practice at each orchard, (ii) PDI-30 with 27-33 % reduction in irrigation volume, after harvest (67-73 % of control) and

(iii) PDI-50 with 47-52 % reduction in irrigation volume, after harvest (48-53 % of control) over a three-year period (2019-2021) in five commercial sweet cherry orchards that ranged in elevation and latitude across the Okanagan Valley, BC, Canada. Soil moisture, plant stem water potential, photosynthesis, tree growth, flower bud spring phenology, flower bud moisture content and cold hardiness, and fruit yield and quality (at harvest and after cold storage and shelf-life conditions) were assessed to determine if PDI altered plant and fruit development over the subsequent growing season. A cost-benefit analysis of PDI implementation in the Okanagan Valley was also completed. Furthermore, cold hardiness data collected during this study were used to develop and validate models that predict the temperatures that cause lethal damage to the sweet cherry cultivars 'Sweetheart' and 'Lapins' throughout the dormant season. These cold hardiness predictive models will provide a decision support tool for growers. This tool will be beneficial when faced with making potentially costly frost management decisions and may be especially useful to growers interested in expanding sweet cherry production into more extreme growing sites in the face of a changing climate.

In the growing season following treatment application, PDI had no effect overall on stem water potential or photosynthesis in any year and at any site; there were also no effects of PDI treatment on tree growth. Additionally, neither PDI- 30 nor PDI-50 caused changes in the timing of flower bud phenology, cold hardiness or moisture content relative to the control. PDI treatments also had no overall effect on fruit yield or fruit quality at harvest or after storage and shelf-life conditions. Furthermore, the cost-benefit analysis revealed that the costs of implementing PDI are minimal but bring benefits for the grower and society in conserving water. Therefore, postharvest deficit irrigation shows potential as an effective water-saving measure in sweet cherry orchards in the Okanagan Valley.

Figure 1. Photograph of a 'Sweetheart' sweet cherry study block located at a high elevation orchard near Summerland, BC.

KEY FINDINGS

EFFECTS OF POSTHARVEST DEFICIT IRRIGATION ON SWEET CHERRY IN FIVE OKANAGAN ORCHARDS

Climate:

There was substantial inter-annual variability in precipitation and temperature over the postharvest period in 2019, 2020 and 2021. In 2019, higher than average precipitation fell in August and September. In 2020 and 2021, more seasonal precipitation fell over the same period. All sites experienced similar monthly mean temperatures from June to September each year.

Soil Moisture:

Soil moisture was measured postharvest in 2019 at four of the five sites, preharvest and postharvest in 2020 and 2021 at all sites, and preharvest in 2022 at all sites. Significantly lower mean weekly soil moistures in response to reduced irrigation treatments were observed in some sites in some years. However, significant treatment differences in mean weekly soil moisture were also observed over the preharvest period when treatments were uniformly irrigated at some sites in some years. These results indicated a variability in soil moisture content which could not be attributed to postharvest deficit irrigation (PDI) treatments. In general, soil moisture content was higher in the preharvest period than the postharvest period.

Stem Water Potential:

The stem water potential (Ψstem) of cherry trees was measured at both preharvest and postharvest periods in 2020 and 2021 and at the preharvest period in 2022 at all study sites. Contrary to expectations, data analysis of stem water potential in the preharvest period, when irrigation treatments were not being applied, revealed some differences between irrigation treatment at one study site in 2021 and one study site in 2022. In the postharvest period, when PDI treatments had been applied, more treatment differences were observed. In general, the PDI treatments showed increased water stress at three of the five sites during the postharvest period (Fig. 2).

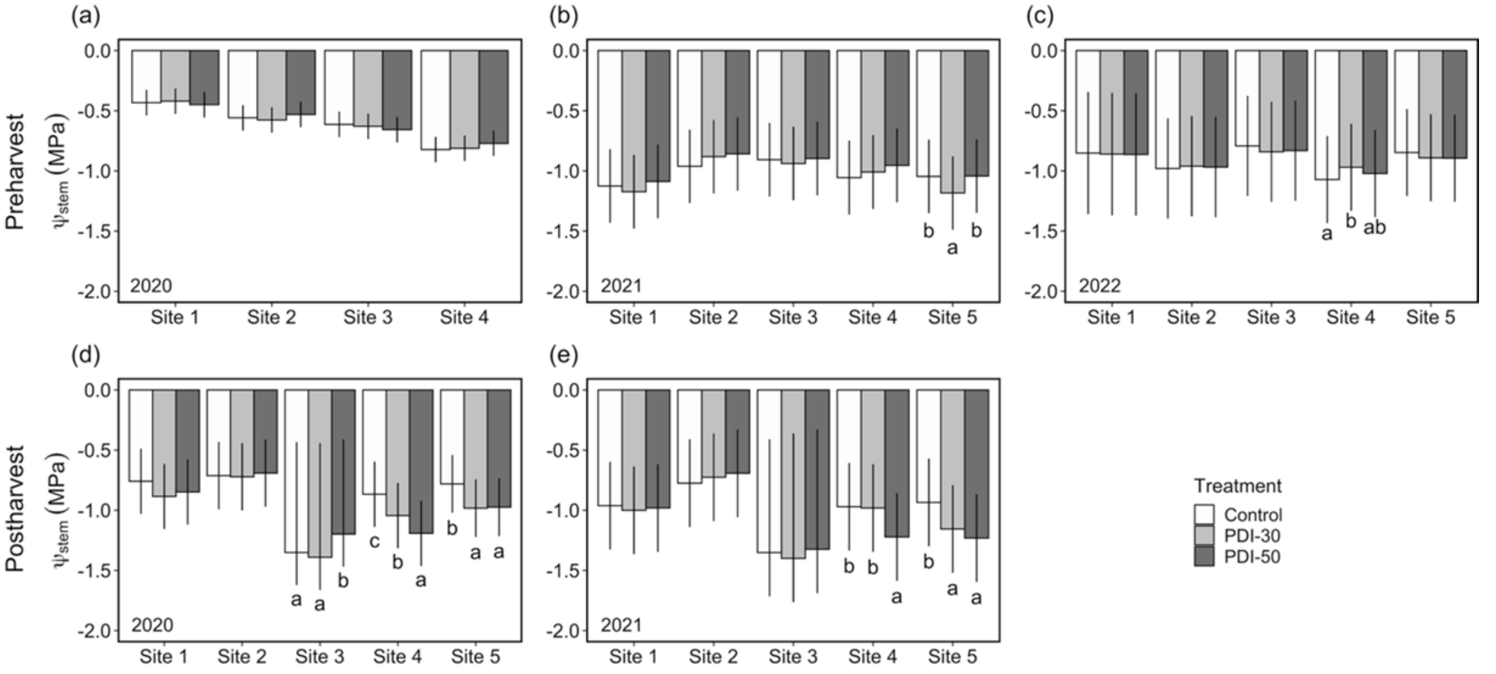


Figure 2. Estimated marginal mean Ψstem ((a) preharvest 2020 Ψstem, (b) preharvest 2021 Ψstem, (c) preharvest 2022 Ψstem, (d) postharvest 2020 Ψstem, (e) postharvest 2021 Ψstem). Error bars indicate 95 % confidence levels of estimated marginal means. The preharvest and postharvest periods were analyzed separately. Values within the same parameter and site that share the same letter or have no letters do not differ significantly ($p \leq 0.05$).

Photosynthesis and Water Use Efficiency:

Differences in preharvest net rates of photosynthesis (An), transpiration (E), and stomatal conductance (gs) and water use efficiency (WUEintrinsic) were not observed between PDI treatments with the exception of preharvest E and gs in 2021 at site 5 only, PDI-30 had significantly lower E and gs than the control and the PDI-50 treatment (data not shown). Significant differences in postharvest An, E, and gs were observed at two of the five study sites in some study years. In general, An, E, and gs were higher in treatments receiving more water. Additionally, WUEintrinsic was found to be lower in the control (full irrigation) than in the PDI treatments in some years, at some sites.

Tree Growth:

Overall, irrigation treatment did not significantly affect any measured indicators of growth, including annual measures of tree cross sectional area (TCSA) during the dormant season, new wood pruning weight, or leaf area at all study sites (Fig. 3). However, differences between sites were observed.

Fall Leaf Abscission Rate and Leaf Nitrogen:

No effect of PDI was observed on leaf abscission rate or leaf nitrogen when measured at site 4 in the fall of 2021.

Flower Bud Spring Phenology, Cold Hardiness and Moisture:

Treatment did not significantly affect spring phenology in any year of this study at any site. Treatment also did not affect flower bud cold hardiness nor moisture in the fall, winter, or spring seasons at all sites throughout the three years of this study.

Fruit Yield and Quality:

Treatment and site significantly influenced fruit yield in 2020 and site significantly influenced measures of yield in all years. In 2020, a significant difference in yield was observed between treatments only at one of the five sites; yield was significantly higher in the PDI-30 treatment than the control; however, the PDI-30 and PDI-50 treatment did not differ significantly. Treatment did not significantly affect any measures of fruit quality taken at harvest (fruit firmness, size, colour, stem pull force, or the ratio of soluble sugar content to titratable acidity [SSC:TA]) in 2020, 2021, or 2022. However, site significantly affected all measures of fruit quality at harvest. Overall, treatment also did not affect measures of fruit quality taken after six weeks of cold storage or six weeks of cold storage followed by shelf-life conditions at 20 ˚C for five days.

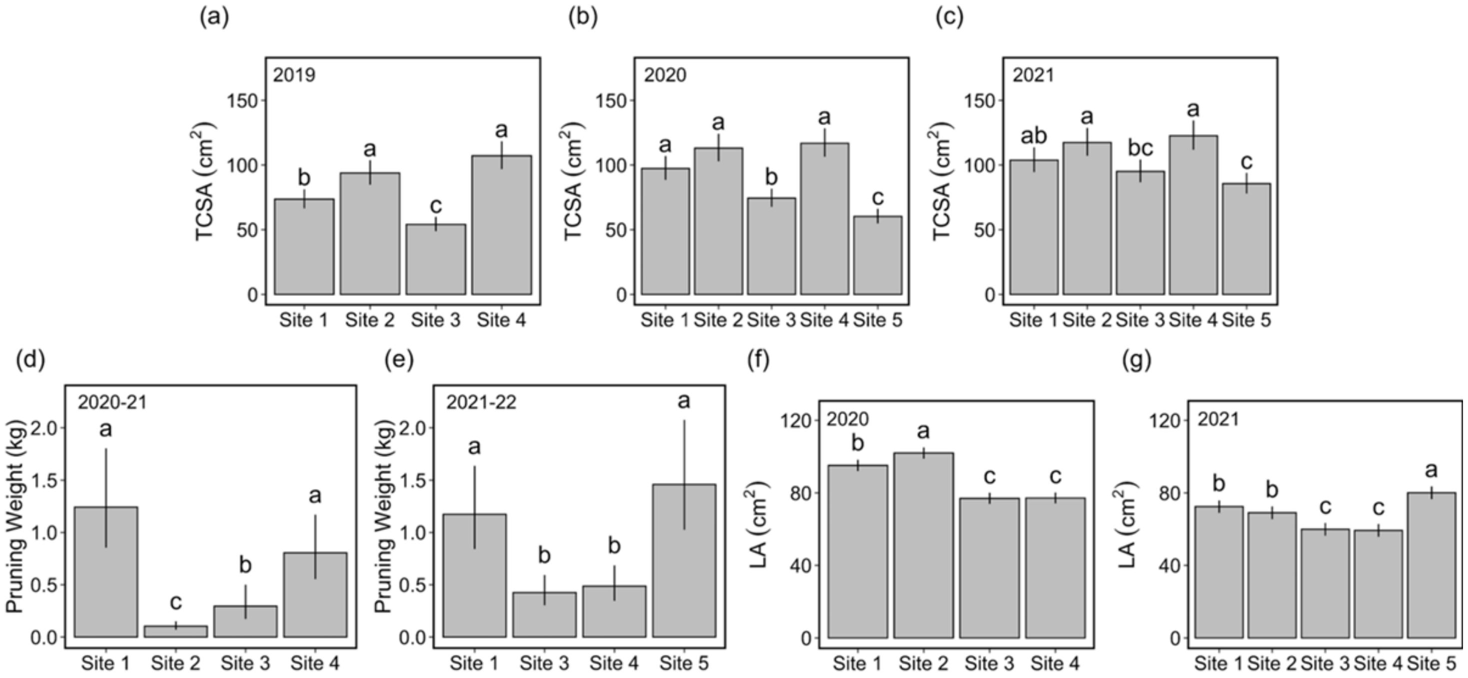


Figure 3. Estimated marginal mean TCSA, pruning weight, and leaf area ((a) 2019 TCSA, (b) 2020 TCSA, (c) 2021 TCSA, (d) 2020-21 dry new wood winter pruning weight, (e) 2021-22 dry new wood winter pruning weight, (f) 2020 leaf area, (g) 2021 leaf area. No significant differences among irrigation treatments were found for all three indicators of growth. Values within the same parameter and year that share the same letter do not differ significantly ($p \leq 0.05$).

KEY FINDINGS

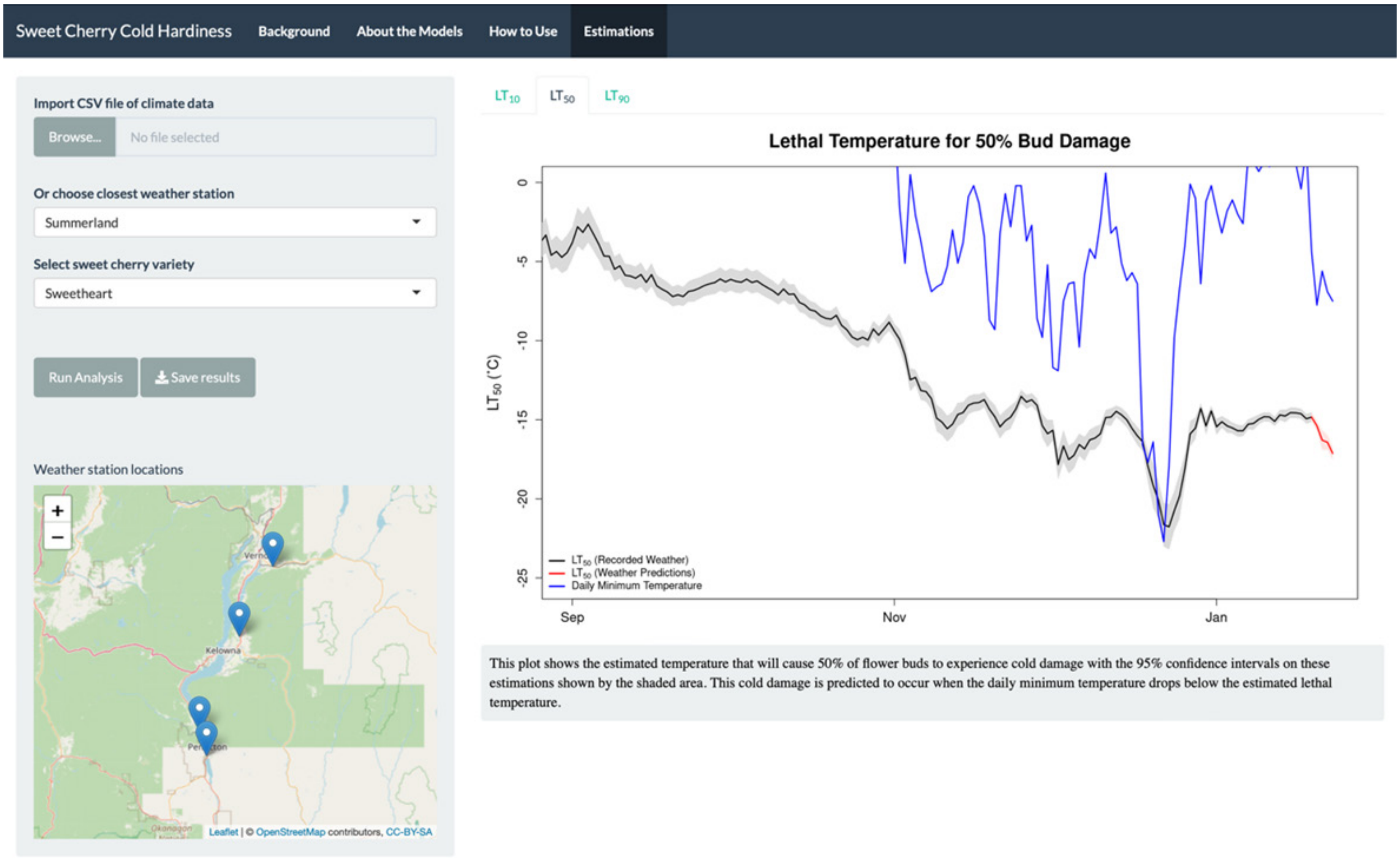
COST-BENEFIT ANALYSIS OF ADOPTING POSTHARVEST DEFICIT IRRIGATION IN OKANAGAN CHERRY ORCHARDS

A cost-benefit analysis (CBA) of postharvest deficit irrigation implementation in the Okanagan Valley was completed. Through this CBA, it was concluded that the adoption of PDI in Okanagan orchards has many benefits and very few costs. The value of adopting PDI comes from the value of water saved in the Okanagan. The value of these savings is dependent on the supply of water, which can fluctuate from year to year. The CBA showed that adopting PDI has more benefits in years of drought. The majority of the benefits from adopting PDI in the Okanagan are for society and not for the farmers.

The authors suggest putting in place incentives to encourage water saving practices in cherry production.

MODELS FOR ESTIMATING THE COLD HARDINESS OF SWEET CHERRY

Models that predict the lethal temperature that causes 10 %, 50 %, and 90 % damage (LT10, LT50, LT90) to two cultivars of sweet cherry ('Sweetheart' and 'Lapins') flower buds from the early fall through to spring were developed. Model evaluation and validation using several seasons of lethal temperature data not included in model development showed good agreement between model lethal temperature estimations and observed lethal temperature values for both sweet cherry cultivars. Additionally, an open-access, interactive, web-based application (Fig. 4) was developed to access the outputs of these models in real-time (https://sweetcherry.shinyapps.io/cherrycoldhardiness/).



Import CSV file of climate data: No file selected

Or choose closest weather station: Summerland

Select sweet cherry variety: Sweetheart

This plot shows the estimated temperature that will cause 50% of flower buds to experience cold damage with the 95% confidence intervals on these estimations shown by the shaded area. This cold damage is predicted to occur when the daily minimum temperature drops below the estimated lethal temperature.

Figure 4. 'Estimations' page of interactive web application designed for simplified and open access to cold hardiness model estimations made from either user uploaded weather data or the current season's data accessed from the Government of Canada's Historic Climate database and three days of weather forecasts from OpenWeather (https://openweathermap.org).

RESEARCH METHODS

EFFECTS OF POSTHARVEST DEFICIT IRRIGATION ON SWEET CHERRY IN FIVE OKANAGAN ORCHARDS

Study Sites, Experimental Design and Treatments:

The study sites were located at five commercial sweet cherry orchards that varied in both elevation and latitude across the Okanagan Valley, BC (referred to as sites 1-5). Irrigation treatments were applied to sites 1-4 in 2019 and to sites 1-5 in 2020 and 2021. Three Irrigation treatments were applied by modifying microsprinkler flow rates: a control of growers' standard practice, irrigation volumetric reductions of 27-33 % postharvest (PDI-30) and irrigation volumetric reductions of 47-52 % postharvest (PDI-50).

Meteorological Data and Soil Moisture:
HOBO® data loggers were used to record hourly ambient air temperatures in or close to each study orchard. Soil moisture probes were installed at each site and volumetric soil moisture data were recorded hourly.
Stem Water Potential Photosynthesis, and Water Use

Efficiency:

Stem water potential (Ψstem) was measured at mid-day approximately every two weeks from June through September in 2020 and 2021, and from June through to harvest in 2022, at all sites using a Scholander Pressure Chamber. Net rates of photosynthesis (An), transpiration (E), and stomatal conductance (gs) were measured approximately every two weeks using a LCi T Photosynthesis Meter from June through September in 2020 and 2021 and from June through to harvest in 2022, at all sites. Water use efficiency (WUEintrinsic) was calculated as An/gs.

Tree Growth:

Plant growth was assessed by measuring annual TCSA, new wood pruning weight, and average leaf area.

Flower Bud Spring Phenology:

The proportion of select tree flower bud developmental stage progression was monitored approximately weekly through the spring from the side green stage to full bloom. Spring phenology was monitored at site 4 in 2020 and at all sites in 2021 and 2022.

Flower Bud Cold Hardiness, Moisture, and In-Field Cold Damage:

Flower bud cold hardiness was determined at sites 1-4 from October 2019 to January 2020 and from November 2020 to April 2021, and at sites 1-5 from November 2021 to March 2022. Cold hardiness of flower buds was measured using differential thermal analysis (DTA) in the fall and winter months and controlled freezing tests in the spring. Flower bud moisture and in-field flower bud cold damage were also evaluated.

Fruit Yield and Quality Determinations:

Fruit yield assessments were conducted on the day of commercial harvest. Fruit quality was assessed from 300 cherries harvested from each plot in 2020 and 2021. One hundred cherries were subjected to one of three conditions prior to assessing fruit quality: immediately after harvest, after six weeks under commercial cold storage conditions, after six weeks under commercial storage conditions followed by "shelf-life conditions" at 20˚C, for 5 days. In 2022, only 100 cherries were sampled, and fruit quality was only assessed immediately after harvest. The cherries were assessed for fruit firmness (FF), row size, colour, stem pull force (SPF), soluble solids concentration (SSC), and titratable acidity (TA).

Statistical Analysis:

Generalized least squares (GLS) models and linear mixed-effects models (LMMs) were used to test for significant effects of irrigation treatment on all measured variables. Akaike's information criterion adjusted for small sample sizes (AICc) was used to identify fixed effects that improved model fit for non-Gaussian GLS models fitted using maximum likelihood (ML). Analyses of variance were completed on the Gaussian GLS models and LMMs to determine which parameters significantly influenced model fit. Tukey- adjusted pairwise comparisons between treatments and sites were completed on the estimated marginal means of the GLS and LMM using the 'emmeans' function from the 'emmeans' package in R. Gaussian model assumptions of normality and homoscedasticity were validated.

RESEARCH METHODS

COST-BENEFIT ANALYSIS OF ADOPTING POSTHARVEST DEFICIT IRRIGATION IN OKANAGAN CHERRY ORCHARDS

The CBA was conducted by completing the following ten steps: 1) Explain the purpose of the CBA, 2) Specify the set of alternative projects, 3) Decide whose benefits and costs count, 4) Identify the impacts categories, catalogue them, and select measurement indicators, 5) Predict the impacts quantitatively over the life of the project, 6) Monetize all impacts, 7) Discount benefits and costs to obtain present values, 8) Compute the net present value of each alternative, 9) Perform sensitivity analysis, 10) Make a recommendation.

DYNAMIC MODELS FOR ESTIMATING THE COLD HARDINESS OF SWEET CHERRY

Using lethal temperature data collected in Summerland, BC over six seasons for ‘Sweetheart’ and three seasons for ‘Lapins’ we parameterized dynamic models using the GLS method. These models incorporate parameters based on a series of equations that describe chill and heat accumulation and rely on measures of hourly air temperature. Model evaluation and validation using several seasons of lethal temperature data not included in model development were also completed. Additionally, an open-access, interactive, web-based application to access and apply these models was developed using the R package ‘Shiny’.

ACKNOWLEDGEMENTS

We are grateful to the BC Cherry Growers who allowed us to conduct these studies in their orchards. We acknowledge the help of numerous undergraduate students from The University of British Columbia’s Okanagan campus as well as the technical staff from Agriculture and Agri-Food Canada’s Summerland Research and Development Centre, particularly Shawn Kuchta.

Funding for this project has been provided in part by an anonymous private foundation, Agriculture and Agri-Food Canada, the BC Cherry Association and in part by the Governments of Canada and British Columbia through the Canadian Agricultural Partnership, a federal-provincial-territorial initiative. The program is delivered by the Investment Agriculture Foundation of BC.

Delivered by:
Investment Agriculture Foundation

Funding provided by:
Canadian Agricultural Partnership
BC Cherry Association
British Columbia
Canada