The Effect of Irrigation Frequency, Phosphorus Fertigation, and Cultivar on Levels of Phenolic Compounds in Sweet Cherries

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Abstract. This work examined the effect of irrigation frequency and phosphorus (P) fertigation on the levels of phenolic compounds present in two sweet cherry cultivars, ‘Skeena’ and ‘Cristalina’, over three growing seasons (2012–14). Two irrigation treatments were tested: a high irrigation frequency (I1) and a low irrigation frequency (I2). Both irrigation treatments applied the same quantities of water [100% evapotranspiration (ET)], but the high irrigation frequency applied water four times daily (0300, 0900, 1500, and 2100 hours) whereas the low irrigation frequency was applied at one time (0900 hours) every second day. Three soil management treatments were investigated, including 1) an unmulched control receiving no P, 2) a 10-cm waste wood mulch receiving no P, and 3) a treatment involving annual fertigation of 20 g P/tree at full bloom as ammonium polyphosphate. It was determined that cultivar was the most important factor affecting levels of phenolic compounds in sweet cherries, with generally greater levels associated with ‘Skeena’. The effect of different irrigation and fertilization strategies showed less promising results in terms of influencing levels of phenolic compounds. Both severe and mild water stress did not show an appreciable influence on increasing levels of phenolic compounds in cherries. Furthermore, severe water stress, which occurred during 2012, was associated with the lowest annual concentration of phenolic compounds and an economically unacceptable reduction in fruit size. Phosphorus fertigation influenced cherry phosphorus status positively by increasing leaf and fruit P concentrations consistently, yet these fruit exhibited lower levels of phenolic compounds.

There is growing interest in consuming a diet enriched with naturally occurring phytochemicals, such as a diet high in fruits and vegetables. High intake of fruit and vegetables is reported to be beneficial to human health as a result of the reductions in the risks of developing cancer (Bovin et al., 2009) and cardiovascular disease (Erdman et al., 2007). Phytochemicals with antioxidants activity reduce the detrimental effects of reactive oxygen species produced from normal plant metabolic processes (Munns and Tester, 2008) and are stimulated when plants encounter environmental stresses (Atkinson et al., 2005). As such, the biochemical and molecular mechanisms that plants have developed to ensure their growth result in the acquisition and formation of components that may benefit human health. Consumption of phytochemical/bioactive compounds present in plants may limit oxidative damage in human cells (Foyer and Fletcher, 2001; Li et al., 2007). Therefore, supplementing our body’s capability to eliminate free radicals by the consumption of foods high in antioxidants may be beneficial, and studies have implicated phenolic compounds to be important phytochemicals because of their antioxidant activities (Boyner and Liu, 2004; Rice-Evans et al., 1997).

Different fruits and vegetables contain different types and concentrations of phytochemical/bioactive compounds (Ali et al., 2012; Boivin et al., 2009; Lutz et al., 2015; Valavanidis et al., 2009), which has stimulated research with the aim of assessing the types and levels of phenolic compounds and antioxidant activities of common vegetables (Lutz et al., 2015) and different fruits (Lutz et al., 2015; Valavanidis et al., 2009). Phenolic compounds have been reported to be a major group of phytochemicals in sweet cherries with antioxidant activity (McCune et al., 2011), and types of phenolic compounds include anthocyanins, flavonols, phe- nolic acids, and tartaric esters (Gao and Mazzu, 1995; McCune et al., 2011; Seeram et al., 2001). The quality and bioactive attributes of fresh fruits can be affected by different preharvest factors such as genetic variability, mineral application, irri- gation, seasonal and environmental variation, canopy position, pruning (Ali et al., 2012; Anttonen and Karjalainen, 2009; Boyner and Liu, 2003), crop load (Stopar et al., 2002), and rootstock (Bartolini et al., 2014). However, despite the recent appearance of many new sweet cherry cultivars, there have been relatively few studies determining the effects of sweet cherry cultivar on levels of phenolic compounds (Ballisteri et al., 2013; Liu et al., 2011). Seasonal variation has been shown to affect cherry yield, crop load, and quality (Caprio and Quamme, 2006; Engin et al., 2009; Measham et al., 2012; Neilsen et al., 2014). The work of Ušenik et al. (2010) noted that the canopy leaf area-to-fruit ratio influenced fruit color, fruit mass, total soluble solids, and the sugars-to-acid ratio of sweet cherries. It has been reported that lower crop loads are related to greater levels of phenolic compounds in apples (Stopar et al., 2002). Also, in general, crop production factors such as irrigation and fertilization have been reported to affect the chemical composition of fruits, which impacts nutritional and bioactive compositions along with sensory quality (taste, color, texture/firmness) at harvest and during shelf life (Ali et al., 2012; Ferretti et al., 2010; Kader, 2002). Regulated water stress has been proposed as a mechanism to achieve high levels of bioactive compounds in fruits (Atkinson et al., 2005), yet there have been few studies that have investigated the potential role of cultural and environmental factors on levels of phenolic compounds in cherries. A recent review called for increased research to clarify the impact of environmental stresses on crop quality (Wang and Frei, 2011). In the irrigated fruit-growing region of the Pacific Northwest of North America, extreme climatic events including drought are expected consequences of global climate change (Neilsen et al., 2006). This has stimulated interest in the consequences of various conservation irrigation strategies on plant performance, including fruit mineral concentrations (Neilsen et al., 2015). Limited information is available concerning how novel irrigation approaches affect the production of secondary metabolites in fruit despite the inevitability of water shortage. Furthermore, the widespread adoption of altered, potentially more stressful, conservation irrigation methods is of emerging importance (Ripoll et al., 2014). Recent research on sweet cherry, a crop of growing importance in the region, has identified several nutrient and water management strategies, including I1 and P fertigation (Neilsen et al., 2010, 2014), that can improve cherry fruit yield and quality, but effects on levels of different types of phenolic compounds in cherries have not been assessed.

The objective of this study was to determine the effects of irrigation frequency, P fertigation, and cultivar (Skeena and Cristalina) on the size (quality parameter) and levels of different types of phenolic compounds in sweet cherries at harvest. In addition, this work provides data on the levels of phenolic compounds for two cherry cultivars, Skeena and Cristalina, grown in the Okanagan region of British Columbia as affected by different
irrigation and fertilization strategies that can serve as a resource for other comparative work.

**Materials and Methods**

**General orchard information.** This study was conducted over three growing seasons in a sweet cherry (Prunus cerasus × Prunus canescens) orchard of ‘Cristalina’ and ‘Skeena’ cultivars. The trees were planted on Gisela 6 rootstock in Mar. 2005 at the Summerland Research and Development Center in Summerland, British Columbia, Canada. The orchard was maintained in a split–split plot experimental design with two main plot irrigation treatments, two cultivars as subplots, and three soil management treatments as sub-subplots with six replicates in 2006–14. Sub-subplots, the smallest experimental unit, consisted of two measurement units separated from adjacent subplots within the row by a shared guard tree at each end. Trees were planted at a spacing of 2 m (between trees) × 4 m (between rows), representing a planting density of 1250 trees/ha.

**Irrigation treatments.** For nine growing seasons (2006–14), irrigation was scheduled to replace 100% of the previous day’s evapotranspiration (ET) based on evaporation from an automatic atmometer (ET gauge Co.). The crop coefficient, fitted to data from Allen et al. (1998), was used to calculate ET. For all treatments, a 2-m-wide weed-free herbicide strip was maintained in the tree row and a 4-m-wide weed-free strip centered on the tree row. A 2-m-wide weed-free strip centered on the tree row, representing a planting density of 1250 trees/ha.

Table 1. Summary of statistically significant interactions a among irrigation (I), P fertigation (PF), and cultivar (CV) for fruit weight and phenolic compounds during the 2014 growing season.

| Interaction | Fruit wt (Folin-Ciocalteu method) | Total phenolics (Glories method) | Tartaric esters | Flavonols | Total anthocyanins |
|-------------|----------------------------------|---------------------------------|-----------------|-----------|-------------------|
| I × CV      | NS                               | NS                              | NS              | NS        | NS                |
| I × PF      | NS                               | NS                              | NS              | NS        | NS                |
| PF × CV     | ****                             | ***                             | ***             | ****      | *                 |
| I × CV × PF | *                                | *                               | *               | NS        | NS                |

aSignificant interactions between main effects at P ≤ 0.05 (*), P ≤ 0.01 (**), P ≤ 0.001 (***) or P ≤ 0.0001 (****); or not significant (NS).

Table 2. Average fruit weight and dry weight concentration of selected phenolic compounds as affected by high-frequency (I1) and low-frequency (I2) irrigation during the 2012–14 growing seasons.

| Irrigation treatment | Fruit wt (g) | Total phenolics (Folin-Ciocalteu method, mg gallic acid eq/100 g dry wt) | Total phenolics (Glories method, mg gallic acid eq/100 g dry wt) | Tartaric esters (mg caffeic acid eq/100 g dry wt) | Flavonols (mg quercetin eq/100 g dry wt) | Total anthocyanins (cyanidin 3-rutinoside/100 g dry wt) |
|----------------------|--------------|------------------------------------------------------------------------|-----------------------------------------------------------------|-----------------------------------------------|------------------------------------------|-------------------------------------------------|
| 2012                 |              |                                                                       |                                                                 |                                               |                                           |                                                 |
| I1                   | 10.5         | 643                                                                    | 650                                                             | 218                                           | 171                                       | 381                                             |
| I2                   | 10.5         | 720                                                                    | 666                                                             | 224                                           | 173                                       | 344                                             |
| Significance         | NS           | NS                                                                    | NS                                                              | NS                                            | NS                                        | NS                                              |
| 2013                 |              |                                                                       |                                                                 |                                               |                                           |                                                 |
| I1                   | 11.8         | 617                                                                    | 535                                                             | 207                                           | 110                                       | 296                                             |
| I2                   | 10.8         | 605                                                                    | 518                                                             | 209                                           | 106                                       | 259                                             |
| Significance         | **           | **                                                                    | **                                                              | **                                            | **                                        | **                                              |
| 2014                 |              |                                                                       |                                                                 |                                               |                                           |                                                 |
| I1                   | 10.5         | 643                                                                    | 650                                                             | 218                                           | 171                                       | 381                                             |
| I2                   | 10.5         | 720                                                                    | 666                                                             | 224                                           | 173                                       | 344                                             |
| Significance         | NS           | NS                                                                    | NS                                                              | NS                                            | NS                                        | NS                                              |

a1 I1 irrigation applied four times daily or once every second day (I2) with the same quantities of water (100% ET replacement).

ns = paired means not significantly different.
samples, a 60-fruit sample was collected from each plot and the cherries were destemmed, pitted, and added to a blender with water in a 1:1 fruit-to-water ratio (w/w). This resulted in a fruit slurry that was subsequently freeze-dried, which allowed for a homogeneous freeze-dried product to be obtained. The freeze-dried cherry material was then placed in polyethylene bags and its particle size was reduced by crushing the freeze-dried material into a powder with a marble rolling pin. For P analysis, 0.500 ± 0.002 g ground dried leaf or fruit sample were weighed into crucibles. Lids were put on the crucibles and the crucibles were “ashed” in a programmable muffle furnace. The samples were ashed at 525 °C for 8 h. To the ashed crucibles, 10 mL of 1.2 N HCl was added and allowed to sit for 60 min. Samples were analyzed by P using an ICP-OES spectrophotometer (Spectroblue Ti; Spectro, Kleve, Germany). P results for the leaf samples were expressed on a dry weight basis whereas results for cherry samples were expressed on a fresh weight basis.

Phenolics content assessment. A randomly harvested 100-fruit subsample for each sampled plot was used to determine average fruit weight. For measurement of levels of phenolic compounds present in the cherries, another randomly harvested 100-fruit subsample for each sampled plot was used to obtain a composite sample from which phenolic compounds were extracted. Before extraction, cherries were destemmed, pitted, and added to blender with water in a 1:1 fruit-to-water ratio (w/w). This resulted in a fruit slurry that was subsequently freeze-dried in the same manner as noted earlier. The freeze-dried cherry powder was then subjected to solvent extraction, and the extracts were assessed to determine the types and levels of phenolic compounds present because studies have shown that phenolic compounds derived from plants are effective antioxidants (Rice-Evans et al., 1997). Total phenolics content was assessed using both the Folin-Ciocalteu and Glories methods. The use of the Glories method also allowed for the determination of levels of total tartaric esters, flavonols, and anthocyanins. The extracts used for testing in these methods were obtained using a procedure based on the work of Velioglu et al. (1998). An aliquot of 1 g sample (freeze-dried cherry powder) was weighed into a centrifuge tube and 20 mL 70% MeOH was added to the tube (1:20 ratio). Tubes were vortexed to ensure wetting of all solids, then were placed on a shaker (VWR 3500 Analog Shaker; VWR, Mississauga, ON) and shaken on shaker speed 4 for (VWR 3500 Analog Shaker; VWR, Mississauga, ON). The system was vortexed again to ensure adequate mixing, then was allowed to sit for 60 min before reading absorbance. Quantification was determined based on a standard curve for gallic acid by measuring absorbance at 765 nm on a spectrophotometer (Cary 50; Agilent Technologies, Mississauga, ON). The total amount of phenolic content was expressed as milligrams gallic acid equivalent per gram sample on a dry weight basis. Experiments were performed in duplicate. Measurement of total phenolics, tartaric esters, flavonols, and anthocyanins using the Glories method was performed using a procedure based on the method provided by Harrison et al. (2013). An aliquot of 0.1 mL sample extract or standard was added to a test tube. Gallic acid, caffeic acid, quercetin, and cyanidin-3-rutinoside were used as the standards for quantification of total phenolics, tartaric esters, flavonols, and anthocyanins, respectively. To the sample or standard, 0.1 mL 0.1% HCl in 95% EtOH along with 1.82 mL 2% HCl was added. The system was vortexed and allowed to sit for ~15 min before reading the absorbance. Quantification was determined based on a standard curve for each standard by measuring absorbance at 280, 320, 360, and 520 nm on a spectrophotometer (Cary 50; Agilent Technologies) for determination of total phenolics, tartaric esters, flavonols, and anthocyanins, respectively. The total amount of phenolic content was expressed at milligrams standard equivalent per gram sample on a dry weight basis. Experiments were performed in duplicate.

Soil moisture measurements. Volumetric soil moisture was measured using depth-integrated (0–20 cm) time domain reflectometry periodically from June to Oct. 2012–14 (Topp and Reynolds, 1998). Volumetric soil moisture content was expressed as percent total available water (TAW) averaged over the 0–20 cm depth. TAW = (SW − PWP)/(FC − PWP) × 100, where SW is percent volumetric soil moisture content, PWP is soil moisture content at the permanent wilting point (15 bars, 8% volumetric soil moisture content), and FC is soil moisture content after soil drainage (0.1 bar, 18% volumetric soil moisture content). Moisture measurements were made at 24 locations [both cultivars × two irrigation treatments (I1 and I2) × two soil management treatments (no P control and mulch) × three replicates]. Probes were located 0.3 m from the south side of the measurement trees midway between the two emitters. Measurements were made just before the 0900 h irrigation of the I2 irrigation, which maximized the difference between the I1 and I2 irrigation treatments. In 2014, midday stem water potential measurements were made on DOY 182 (12 July), 205 (25 July), and 216 (5 Aug.). Measurements were made between 1100 and 1400 h on the 24 plots where soil moisture measurements were made. Each time, midday stem water potential was determined on three leaves per treatment and replicate after shielding the leaf with black plastic covered with aluminum foil for 2 to 3 h to avoid leaf temperature increase during measurement of water potential using a pressure chamber model 610 (PMS Instrument Co., Albany, OR) (McCutchan and Shackel, 1992).

Statistical analysis. Analysis of variance was performed on all measured soil and plant variables using the GLM procedure (SAS, 2006). The analysis was undertaken separately for each year because of differences in plots sampled and environmental conditions.
in 2012. Volumetric soil measurement and leaf water potential measurements were analyzed on 24 plots [two cultivars × two irrigation frequencies (I1 and I2) × two soil management treatments (No P control and mulch)] × three replicates.

### Results and Discussion

In 2012 and 2013, statistically significant effects were observed only for main effect treatments (irrigation, P fertigation, and cultivar). Significant interactions were observed only in 2014 (Table 1). That year, there was a significant two-way interaction between P fertigation and cultivar for fruit size and the concentration of all phenolic compounds, and a significant three-way interaction for fruit weight, total phenolics (both methods), and tartaric acid concentrations. These complex three-way interactions are not discussed subsequently.

**Irrigation treatments.** Levels of the different types of phenolic compounds [total phenolics (Folin-Ciocălteu method), total phenolics (Glories method), tartaric esters, flavonols, and total anthocyanins] were unaffected in 2012–14 by variation in irrigation frequency (Table 2). As noted earlier, there were no interactions for irrigation effects over the three growing seasons. I1 had been previously advantageous, improving initial growth and establishment of these sweet cherries (Neilsen et al., 2010) as a consequence of maintaining greater surface soil moisture content when measured just before I2 irrigation. The same favorable moisture regime was maintained for I2 trees in the three growing seasons during which fruit phenolic concentrations were measured (Fig. 1). However, in 2012, there was a mechanical problem with the automated irrigation system that occurred during netting of the block to avoid bird damage to the early-ripening ‘Cristalina’ cherries at the end of June. As a consequence, both treatments experienced low soil water contents (expressed as percent available water), with values reaching zero available water (the permanent wilting point) on DOY 194 (12 July) before correction of the problem on DOY 205 (23 July) (Fig. 1). Thus, both irrigation treatments were subjected to considerable water stress in 2012 during the critical preharvest period. In contrast, during 2013–14, I1 maintained soil moisture readings at or greater than field capacity whereas I2 resulted in available water content ranging from 60% to 80% and 70% to 80% of maximum immediately preharvest during 2013–14, respectively. This was assumed to represent a mild water stress difference between treatments during these years, and contrasts with the severe stress observed for both treatments in 2012. Midday stem water potentials, as measured on 3 d in 2014, when significant soil moisture differences were observed between I1 and I2, confirmed this. There were significant differences (\( P \leq 0.10 \)) between stem potential for I1 trees (−0.7 to −1.0 MPa) relative to I2 trees (−0.8 to −1.1 MPa) (Fig. 1). It is noteworthy that midday stem water potential declined later in the growing season despite TAW remaining relatively constant. This is consistent with measurements on midday drip-irrigated ‘Ambrosia’ apple and has been attributed to plant water stress being affected by high evaporative demand midsummer and reduced soil hydraulic conductivity rather than reduced soil water potential (Neilsen et al., 2016). None of the values for either treatment approached midday stem potential values of −1.5 MPa associated previously with detrimental stress in sweet cherry (Neilsen et al., 2017). Unfortunately, stem potential measurements were made only in a single year. It would have been informative to have performed plant water measurements during the period of severe water stress in 2012.

No differences in levels of the different types of phenolic compounds were observed between I1 and I2 throughout the study, and concentrations of phenolic compounds were at their lowest values in 2012, when both treatments were significantly water stressed. In 2012, average fruit size over all treatments was a commercially unacceptable 8.3 g compared with 11.3 g in 2013 and 10.5 g in 2014 (Table 2). Thus, there would appear to be limited scope to manipulate cherry fruit phenolic compound levels by application of mild or severe water stress.

**P fertigation.** All measurements of levels of the different types of phenolic compounds in cherry fruit were affected significantly by the soil management treatment involving P fertigation (Table 3). In 2012, when only control and P-fertigated fruit were assessed, the measured levels of phenolic compounds were always reduced in harvested fruit that had received P. Similarly, in 2013, P-fertigated fruit had lower levels of phenolic compounds than fruit from mulch and control treatments, which did not receive P. The single exception was flavonol concentration, which did not differ between control and P-fertigated fruit. In 2014, there was a significant cultivar-by-soil management interaction with ‘Cristalina’, but not ‘Skeena’, fruit exhibiting the pattern of the two previous years, with minimum levels of phenolic compounds occurring in P-fertigated fruit (Tables 1 and 3). In contrast, for ‘Skeena’, all concentrations of phenolic compounds in P-fertigated fruit exceeded values for control

### Table 3. Average fruit weight and dry weight concentration of selected phenolic compounds as affected by P fertigation during the 2012–14 growing seasons.

| P treatments | Fruit wt (g) | Total phenolics (Folin-Ciocălteu method, mg gallic acid eq/100 g dry wt) | Total phenolics (Glories method, mg gallic acid eq/100 g dry wt) | Tartaric esters (mg caffeic acid eq/100 g dry wt) | Flavonols (mg quercetin eq/100 g dry wt) | Total anthocyanins (cyanidin 3-rutinoside/100 g dry wt) |
|--------------|--------------|-------------------------------------------------|-------------------------------------------------|---------------------------------|---------------------------------|-------------------------------------------------|
| **2012**     |              |                                                 |                                                 |                                 |                                 |                                                 |
| No P         | 8.2          | 523                                             | 473                                             | 203                             | 107                             | 134                                             |
| P            | 8.3          | 464                                             | 425                                             | 192                             | 94                              | 90                                              |
| Significance | NS           | ***                                             | **                                              | *                               | **                               | ****                                            |
| **2013**     |              |                                                 |                                                 |                                 |                                 |                                                 |
| Mulch        | 11.2         | 638 a                                           | 551 a                                           | 214 a                           | 113 a                           | 304 a                                           |
| No P         | 11.2         | 629 a                                           | 540 a                                           | 213 a                           | 110.3 ab                        | 289 a                                           |
| P            | 11.6         | 570 b                                           | 491 b                                           | 199 b                           | 110 b                           | 239 b                                           |
| Significance | NS           | ***                                             | **                                              | *                               | **                               | ****                                            |
| **2014**     |              |                                                 |                                                 |                                 |                                 |                                                 |
| Cristalina   |              |                                                 |                                                 |                                 |                                 |                                                 |
| Mulch        | 9.2 b        | 653 a                                           | 603 a                                           | 198 a                           | 166 a                           | 354 a                                           |
| No P         | 9.2 b        | 674 a                                           | 621 a                                           | 198 a                           | 172 a                           | 386 a                                           |
| P            | 10.6 a       | 518 b                                           | 464 b                                           | 164 b                           | 128 b                           | 212 b                                           |
| Significance | ns           | ***                                             | **                                              | *                               | **                               | ****                                            |
| Skeena       |              |                                                 |                                                 |                                 |                                 |                                                 |
| Mulch        | 11.8 a       | 836 a                                           | 788 a                                           | 258 b                           | 194 a                           | 531 a                                           |
| No P         | 12.2 a       | 759 b                                           | 709 b                                           | 238 b                           | 177 b                           | 434 b                                           |
| P            | 10.1 b       | 802 a                                           | 765 a                                           | 272 a                           | 194 a                           | 422 b                                           |
| Significance | ns           | ***                                             | **                                              | *                               | **                              | ****                                            |

Significant interaction between P treatments and cultivar in 2014.

Means significantly different at \( P = 0.05 (*) \), \( P = 0.01 (**) \), \( P \leq 0.001 (****) \), or \( P \leq 0.0001 (***) \); or not significantly different (ns). For P treatments, means are ns when followed by the same letter within cultivars.
fruit. Both measures of ‘Skeena’ total phenolics and flavonoids were similar to mulched fruit. Concentrations of tartaric esters were greater and anthocyanin concentrations were lower in P-fertilized fruit relative to fruit from trees that had been mulched. Fruit were a similar size between and among treatments in both 2012 and 2013 (Table 3). In 2014, there was an interaction between cultivar and soil management treatments for fruit size (Table 1) as a result of P-fertilized fruit being largest for ’Cristalina’ and smallest for ’Skeena’. The small ’Skeena’ fruit in 2014 may have resulted in greater fruit levels of phenolic compounds reversing the patterns observed during previous years.

P fertigation at bloom time was effective at augmenting cherry tree P status as indicated by consistent increases in midsummer leaf P and fruit P concentrations at harvest in trees receiving spring P applications relative to mulched and control trees, which received standard NKB fertigation without P (Table 4). Fertigation of high rates of P coincident with bloom was shown previously to be effective and desirable by increasing leaf and fruit P concentration while improving establishment of sweet cherry in this block (Neilsen et al., 2010). Delayed crop maturity—as indicated by reduced harvest color and soluble solids contents, and greater stem pull force—were other previously observed consequences of P fertigation. In general, the data indicate that P fertigation acts to reduce levels of phenolic compounds at harvest, which may reflect the previously observed delayed cherry maturity associated with P applications. Improved subtropical peach fruit quality and elevated fruit phytochemical composition has been associated recently with low N fertilization rates, although effects varied by cultivar (Vashisth et al., 2017). In a previous study involving P fertigation of apple cultivars, elevated fruit P was associated with reduced incidence of water core on some cultivars at harvest, increased resistance to browning, and elevated antioxidant activities (Neilsen et al., 2008). This collective information is further evidence that fertilization can influence the levels of phenolic compounds in fruit, but there are likely to be important differences across horticultural crops and cultivars.

Cultivar. The levels of phenolic compounds were consistently greater in ’Skeena’ compared with ’Cristalina’ for 2012–14 (Tables 3 and 5). These concentration differences were independent of fruit size because they were measured regardless whether ‘Skeena’ cherries were smaller (2012), larger (2014), or the same size (2013) as ’Cristalina’ cherries. Only anthocyanin concentrations differed from this pattern, with similar values between cultivars during the first two growing seasons and greater values associated with ’Skeena’ cherries in 2014, the last year of the study. Similarities in anthocyanin concentration were expected because harvest time for each dark-skinned cultivar each year differed from this pattern, with similar values (2012) associated with lowest annual concentration of phenolic compounds and an economically unacceptable reduction in fruit size. P fertigation was highly effective at increasing cherry P status, elevating leaf and fruit P concentrations consistently. However, these fruit had lower levels of phenolic compounds, possibly indicating a role for P in the retardation of fruit maturity and the accumulation of phenolic compounds and antioxidant activity. Finally, this work

Table 4. Leaf and fruit P concentration as affected by P treatments, 2012–14.

| P treatments | Leaf P (g/kg dry wt) | Fruit P (mg/100 g fresh wt) |
|--------------|---------------------|-----------------------------|
|              | 2012 | 2013 | 2014 | 2012 | 2013 | 2014 |
| Mulch        |      |      |      |      |      |      |
| No P         | 2.2 b | 2.2 b | 0.23 b | 21.8 b | 24.7 b | 19.0 c |
| P            | 3.3 a | 3.3 a | 0.28 a | 25.7 a | 29.9 a | 22.7 a |
| Significance | **** | **** | **** | **** | **** | **** |

Means within columns followed by different letters are significantly different at \( P \leq 0.0001 \).

Table 5. Average fruit weight and dry weight concentrations of selected phenolic compounds as affected by sweet cherry cultivar, 2012–14.

| Cultivar | Fruit wt (g) | Total phenolics (Folin-Ciocalteu method, mg gallic acid eq/100 g dry wt) | Total phenolics (Glories method, mg gallic acid eq/100 g dry wt) | Tartaric esters (mg caffeic acid eq/100 g dry wt) | Flavonoids (mg quercetin eq/100 g dry wt) | Total anthocyanins (mg cyanidin 3-rutinoside/100 g dry wt) |
|----------|--------------|-----------------------------------------------------------------------|------------------------------------------------------------------|---------------------------------------------|----------------------------------------|--------------------------------------------------|
| 2012     |              |                                                                       |                                                                  |                                             |                                        |                                                   |
| Cristalina | 8.8 | 412 | 349 | 145 | 78 | 111 |
| Skeena   | 7.6 | 575 | 549 | 249 | 122 | 113 |
| Significance | ** | **** | **** | **** | **** | NS |
| 2013     |              |                                                                       |                                                                  |                                             |                                        |                                                   |
| Cristalina | 11.3 | 554 | 477 | 176 | 104 | 272 |
| Skeena   | 11.3 | 667 | 576 | 240 | 111 | 282 |
| Significance | NS | **** | **** | **** | * | NS |
| 2014*    |              |                                                                       |                                                                  |                                             |                                        |                                                   |
| Cristalina | 9.7 | 615 | 563 | 187 | 155 | 317 |
| Skeena   | 11.4 | 799 | 754 | 256 | 188 | 462 |
| Significance | * | **** | **** | **** | ** | *** |

*It should be noted that a significant interaction was observed between P fertigation and cultivar for the 2014 growing year. Interaction means are reported in Table 3. Means between cultivars within years significantly different at \( P \leq 0.05 (*)\), \( P \leq 0.01 (**), P \leq 0.001 (***)\), or \( P \leq 0.0001 (****)\); or not significantly different (NS)
provides data on the levels of total phenolics, tartaric esters, flavonols, and total anthocyanins for two cherry cultivars (‘Skeena’ and ‘Cristalina’) grown in the Okanagan region of British Columbia as affected by different irrigation and fertilization strategies, and can serve as a resource for other comparative work.

**Literature Cited**

Ali, L., B.W. Alsanuis, A.K. Rosberg, B. Svensson, T. Nielsen, and M.E. Olsen. 2012. Effects of nutrition strategy on the levels of nutrients and bioactive compounds in blackberries. Eur. Food Res. Technol. 234:33–44.

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. FAO, Rome, Italy.

Anttonen, M.J. and R.O. Karjalainen. 2009. Evaluation of means to increase content of bioactive phenolic compounds in soft fruits. Acta Hort. 839:309–314.

Atkinson, C.J., R. Nestby, Y.Y. Ford, and P.A.A. Dodds. 2005. Enhancing beneficial antioxidants in fruits: A plant physiological perspective. Biofactors 23:229–234.

Ballisteri, G., A. Conti, A. Gentile, M. Amenta, S. Fabroni, and P. Rapisarda. 2013. Fruit quality and bioactive compounds relevant to human health of sweet cherry (Prunus avium L.) cultivars grown in Italy. Food Chem. 140:630–638.

Bartolini, S., A. Lecese, C. Lacona, L. Andreini, and M.J. Anttonen, M.J. and R.O. Karjalainen. 2009. Evaluation of means to increase content of bioactive phenolic compounds in soft fruits. Acta Hort. 839:309–314.

Atkinson, C.J., R. Nestby, Y.Y. Ford, and P.A.A. Dodds. 2005. Enhancing beneficial antioxidants in fruits: A plant physiological perspective. Biofactors 23:229–234.

Ballisteri, G., A. Conti, A. Gentile, M. Amenta, S. Fabroni, and P. Rapisarda. 2013. Fruit quality and bioactive compounds relevant to human health of sweet cherry (Prunus avium L.) cultivars grown in Italy. Food Chem. 140:630–638.

Bartolini, S., A. Lecese, C. Lacona, L. Andreini, and R. Viti. 2014. Influence of rootstock on fruit entity, quality and antioxidant properties of fresh apricots (cv. ‘Pisana’). New Zeal. J. Crop Hort. 42:265–274.

Boivin, D., S. Lamy, S. Lord-Dufour, J. Jackson, E. Bartolini, S., A. Leccese, C. Lacona, L. Andreini, and M. Serrano. 2008. Sensory, nutritive and antioxidant activities of common vegetables: A comparative study. Food Chem. 106:165–172.

Boivin, D., S. Lamy, S. Lord-Dufour, J. Jackson, E. Bartolini, S., A. Leccese, C. Lacona, L. Andreini, and M. Serrano. 2008. Sensory, nutritive and antioxidant activities of common vegetables: A comparative study. Food Chem. 106:165–172.

Bortolin, S., A. Lecese, C. Lacona, L. Andreini, and R. Viti. 2014. Influence of rootstock on fruit entity, quality and antioxidant properties of fresh apricots (cv. ‘Pisana’). New Zeal. J. Crop Hort. 42:265–274.

Boivin, D., S. Lamy, S. Lord-Dufour, J. Jackson, E. Bartolini, S., A. Leccese, C. Lacona, L. Andreini, and M. Serrano. 2008. Sensory, nutritive and antioxidant activities of common vegetables: A comparative study. Food Chem. 106:165–172.

Bormann, J.E., B.D. Oomah, M.S. Diarra, and C. Oomah. 2006. Antioxidants in fruits: A plant physiological perspective. Crit. Rev. Food Sci. Nutr. 51:1–12.

Bourquin, N., N. Stendell-Hollis, and C.A. Thomson. 2011. Cherries and health: A review. Crit. Rev. Food Sci. Nutr. 51:1–12.

Bouquet, H. and K.A. Shackell. 1992. Stem-water potential as a sensitive indicator of water stress of prune tree (Prunus domestica L. cv. French). J. Amer. Soc. Hort. Sci. 117:607–611.

Bouquet, H. and K.A. Shackell. 1992. Stem-water potential as a sensitive indicator of water stress of prune tree (Prunus domestica L. cv. French). J. Amer. Soc. Hort. Sci. 117:607–611.

Bouquet, H. and K.A. Shackell. 1992. Stem-water potential as a sensitive indicator of water stress of prune tree (Prunus domestica L. cv. French). J. Amer. Soc. Hort. Sci. 117:607–611.

Bouquet, H. and K.A. Shackell. 1992. Stem-water potential as a sensitive indicator of water stress of prune tree (Prunus domestica L. cv. French). J. Amer. Soc. Hort. Sci. 117:607–611.

Bouquet, H. and K.A. Shackell. 1992. Stem-water potential as a sensitive indicator of water stress of prune tree (Prunus domestica L. cv. French). J. Amer. Soc. Hort. Sci. 117:607–611.

Bouquet, H. and K.A. Shackell. 1992. Stem-water potential as a sensitive indicator of water stress of prune tree (Prunus domestica L. cv. French). J. Amer. Soc. Hort. Sci. 117:607–611.

Bouquet, H. and K.A. Shackell. 1992. Stem-water potential as a sensitive indicator of water stress of prune tree (Prunus domestica L. cv. French). J. Amer. Soc. Hort. Sci. 117:607–611.

Bouquet, H. and K.A. Shackell. 1992. Stem-water potential as a sensitive indicator of water stress of prune tree (Prunus domestica L. cv. French). J. Amer. Soc. Hort. Sci. 117:607–611.