Title

Factors affecting within orchard variability of nutrition,yield and quality of sweet cherry (Prunus avium L.)

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Introduction

Sweet cherry (*Prunus avium* L.) is a high value horticultural crop with good potential for increased production in the irrigated, temperate fruit growing region of southern British Columbia (Kappel, 2006). Cherry production is known to exhibit large annual variation in yield (Proebsting and Mills, 1981). Recently, Caprio and Quamme (2006) have identified statistical associations between cherry yield and daily precipitation and temperature patterns during the growing season. They speculated that response of sweet cherry to historical weather events might be useful in assessing responses to climate change. Climate change scenarios for southern BC predict increased air temperature and crop water demand in association with greater uncertainty concerning snowpack accumulation for subsequent irrigation use (Neilsen et al., 2006). Advances in sensor technology can improve understanding of the spatial and temporal variation of environmental variables such as temperature (Tarara and Hoheisel, 2007). This information may improve precision management of high value horticultural crops when combined with improved understanding of the spatial variation of economically important plant characteristics including yield and quality of fruit (Coates et al., 2006).

A study was therefore undertaken to characterize variation in tree performance in a commercial sweet cherry orchard which was intensively monitored for the important climate change variable, air temperature. Emphasis was placed upon yield, tree vigor, fruit quality and tree nutrition.

Materials and Methods

In May 2006, 30 pairs of 10-year-old ‘Sweetheart’ sweet cherry trees on Mazzard rootstock were selected in a commercial orchard near Kelowna, BC, Canada. Each set of trees was distributed throughout the block to represent the range of slopes and elevations. Midway between each tree pair, an i-button temperature sensor logger (Dallas Semi-conductor Inc., Dallas TX.) which recorded hourly temperature 2006-2008 was installed within Gill radiation shields at a consistent 1.25m height above the soil surface. Throughout the 2006-2008 growing seasons, average cherry volume was calculated approximately bi-weekly based on fruit length and width (2 directions) measurements made on 20 randomly selected cherries at mid-tree height around the tree canopies (and the centrally located temperature sensors). Each year, just prior to commercial harvest, a randomly selected sample of cherries (n>200) was collected at each location. These fruit were analyzed for fruit mineral composition (N, P, Ca, Mg, K and B) and quality characteristics (fruit mass, fruit firmness, stem pull force, soluble solids content (SSC), titratable acidity, splits and color). Trunk cross-sectional area (TCSA) was calculated from trunk diameter measurements at 0.3m height in Apr. 2007 and Nov. 2008. Commencing in 2007, annual composite 30-leaf samples from the mid third portion of extension shoots of current year’s growth were collected per location in mid-July and leaf N, P, K, Ca, Mg, B, Zn, Fe, Mn and Cu were determined. Tissue chemical analyses and fruit quality analyses were made by standard techniques as described in Neilsen et al. (2007). Yield was estimated in 2007 and 2008 by counting the number of fruit, post-June drop, on two large representative limbs located on the north and south side of each measurement tree. Yield was extrapolated to whole trees in proportion to limb cross sectional area and using average fruit weight at harvest. Analysis of variance using locations as reps was used to determine the effects of years. Correlation analysis was undertaken to determine the degree of association between variables at the 30 sensor locations.

In an adjacent ‘Sweetheart’/Mazzard block, Granier style sap flow probes, constructed according to the procedures of James et al. (2002) were installed in the trunks of 10 same aged trees at 0.3m above the graft on the opposite side to the rootstock. Two probes were installed in each tree and the pair insulated appropriately. Changes in temperature due to sap flow were sampled every 10 seconds and averaged each 10 minutes. Calculations of sap velocity and flux were made using Granier's equation (Granier, 1987). Sap flow probes were installed by June 8, 2006 and were used to record tree sap flow for the next 3 growing seasons.

Results and Discussion

The 2006-2008 study period represented progressively cooler years as indicated by degree day accumulation above 5C (DD5) by harvest (Table 1). The coldest year, 2008, was characterized by a cold spring, low degree day accumulation by bloom, and frost overnight April 20/21 when blossoms were at open cluster. This event severely reduced harvestable yield in 2008. The minimum temperature occurred at 6 AM, April 21st and ranged from -4.9C to -5.8C among sensors, all values below a critical -4C threshold. Neither minimum temperature nor duration of cold (degree hours below 0C) were significantly correlated with estimated yield in 2008 (data not shown). Each growing season, average fruit volume of 'Sweetheart' cherry for all of the 30 temperature monitoring locations within the orchard showed a similar pattern (Fig.1). Volume change was slower in the fruit cell division period immediately following bloom, followed by more rapid growth prior to a decline in rate of volume increment approximately 3 weeks prior to harvest (day of the year (DOY) 195 in 2006-07 and 190 in 2008). Change in cherry volume was particularly inhibited in 2006, immediately pre-harvest, when DD5 at harvest exceeded the other years. Average fruit volume at harvest in 2006 was less than the immediately preceeding sample time although the decrease was within sampling variation. Despite a warm harvest period in 2006, fruit were harvested later than any other year, suggesting the possibility of overripe and dehydrating fruit. Furthermore largest fruit weight was not positively related to temperature since smallest average fruit size occurred in the warmest year (2006).

Within orchard variation. DD5 accumulation by harvest varied by sensor location within the block each year with the range between warmest and coldest sensors at 393, 182 and 187 DD5 by harvest 2006-2008, respectively (Table 1). Site values were significantly ($p<0.001$, ***) correlated over the three years including 2006 and 2007 ($r=0.77$), 2007 and 2008 ($r=0.60$) and 2006 and 2008 ($r=0.63$) implying that there are warm and cold locations within the orchard that are stable over years.

Highest within block variability, as indicated by coefficients of variation (CV) exceeding 25%, was measured for tree yield, trunk cross-sectional area (TCSA), per cent split fruit (PSP), leaf Zn and Mn in both 2007 and 2008 when these parameters were measured (Table 1). Most leaf and fruit nutrient concentrations and harvest fruit quality parameters had CV values ranging between 5-20%, as typified by leaf and fruit K (Table 1). Fruit firmness, harvest DD5 accumulation and SSC in 2008 had lowest within orchard variation with CV value less than 5%. Variation in yield (or its component average fruit size) was not consistently correlated with DD5 accumulation, growth or leaf and fruit nutrition in any year. In contrast, in both measurement years, TCSA was significantly positively associated with leaf K (Fig.2b) and negatively associated with DD5 by harvest (Fig.2a) indicating that smaller trees had lower leaf K concentrations and were located on warmer sites. This did not reflect differences in soil K status on the warmer sites since leaf and soil K values were not correlated. PSP was associated with elevated fruit K concentration in each year (2006 $r=0.48^{**}$, 2007 $r=0.55^{**}$, 2008 $r=0.46^{*}$).

Within orchard variation in yield for high value crops such as sweet cherry are of direct and immediate economic importance for growers. Large year to year variations in annual yield of orchards are well known in cherry production (Proebsting and Mills, 1981). The large variations in per tree yield within orchards, as observed in this study, are less well documented. It is noteworthy that it was not possible to use correlation analysis to identify important factors associated with tree to tree yield variation. It appeared that catastrophic factors involving the killing frost of April 2008 dominated effects on yield. The association of TCSA, which presumably integrates growth effects over multiple seasons, with seasonal variation in temperature and leaf K nutrition is surprising, unless it is assumed that these variables are symptomatic of some long term growth controlling factors. Normally the average and range of midsummer leaf K concentrations measured in 2007-2008 would be considered sufficient for cherry growth (Hanson and Proebsting, 1996). In contrast, the association of elevated fruit cracking and high fruit K concentration are consistent with results from apple which suggest high fruit K adversely affects fruit Ca concentration and cell wall stability (Vang-Petersen, 1980).

Irrigation. In 2006, the warmest study year, sap flow in the 'Sweetheart' cherry trees fluctuated in an apparent 3-4 day cycle regardless of estimated ET. In 2007 this fluctuation was attributed to irrigation management which apparently affected transpiration rates, potentially limiting photosynthesis, tree and fruit growth (Fig.3). A number of heavy rainfall events scattered throughout the period between full canopy development (~DOY 140, May 20th) and harvest (DOY 210, July 29th) moderated the effect of dry intervals between irrigation applications. However, there were a number of instances where sap flow did not follow ET, likely because of restricted soil moisture availablility. In 2007, (Fig.3) in the period covered by oval a, sap flow did not increase in response to increased ET on day 172, until irrigation was applied the next day. Similarly, in Fig.3 – oval b, a period of relatively constant potential ET was characterized by a sap flow pattern which responded to irrigation applications. In Fig.3 – oval c, the effect of rainfall and cloudiness on sap flow is illustrated. In 2007 this pattern was also observed on days 156, 168 and 176. In 2008, irrigation was much more frequent, the year cooler and there was only one period, between days 193-202, when the pattern of sap flow did not correspond to the pattern of potential ET (Fig.3).

Changes in irrigation management and ET from 2006-2008 apparently reduced periods of potential detrimental stress due to irrigation management. However the limited water holding capacity of the gravelly sandy loam orchard soil suggest that historical irrigation management practices would have been inadequate for elimination of water stress. The problem would have been more acute in warm years and at warm locations within the orchard and also resulted in reduced uptake of nutrients such as K which are sensitive to water stress. It is therefore hypothesized from within orchard observations at this location that spatial variations in irrigation effectiveness have caused the variation in TCSA (and ultimately yield) within the experimental block.

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Table 1. Annual mean, range and coefficient of variation for selected temperature, tree and nutrition parameters, 2006-2008 in a 'Sweetheart' cherry orchard, Kelowna, BC (n=30 locations).

Parameter	Year	Mean	Range	C.V. (%)
Degree day accumulation above 5C				
by harvest	2006	1750*a*	(1554-1947)	5.0
	2007	1557*b*	(1454-1636)	3.0
	2008	1341*c*	(1255-1402)	2.8
by bloom	2007	216*a*	(200-240)	4.2
	2008	151*b*	(135-162)	5.2
Average fruit size (g)	2006	9.4*c*	(8.0-10.6)	6.7
	2007	11.3*a*	(10-12)	11.8
	2008	10.6*b*	(9.4-11.8)	5.3
Splits (%)	2006	7*b*	(1-17)	60
	2007	36*a*	(8-72)	42
	2008	4*b*	(0-16)	90
Yield (kg/tree)	2007	91*a*	(34-231)	52
	2008	41*b*	(3-126)	75
Trunk cross-sectional area (cm^2)	2007	113*b*	(60-166)	25
	2008	141*a*	(68-221)	29
Leaf Zn (mg/kg dw)	2007	30.9*a*	(16-93)	57
	2008	20.9*b*	(13-52)	33
Leaf Mn (mg/kg dw)	2007	168*a*	(74-337)	42
	2008	113*b*	(62-210)	33
Leaf K (% dw)	2007	2.11	(1.22-2.82)	16
	2008	2.03	(1.53-2.92)	17
Fruit K (mg/100g FW)	2006	238	(195-322)	12
	2007	228	(202-267)	6
	2008	233	(205-252)	6

Annual means statistically different at p=0.0001 (****) except for leaf Zn (p=0.01,**) and leaf and fruit K (NS).

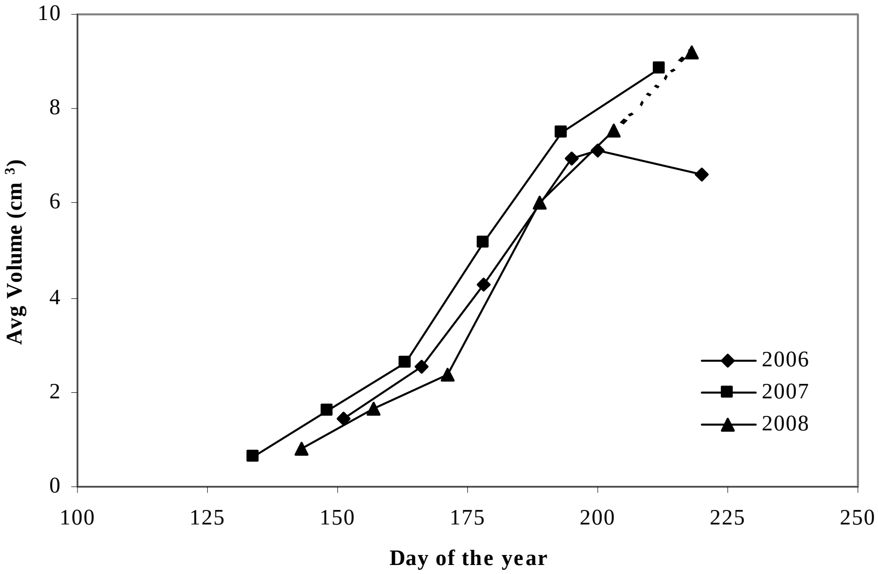

Fig. 1. **Average 'Sweetheart' cherry volume at all sensor locations (n=30 locations, n=20 cherries/location) during the 2006-2008 growing seasons, Kelowna orchard.**

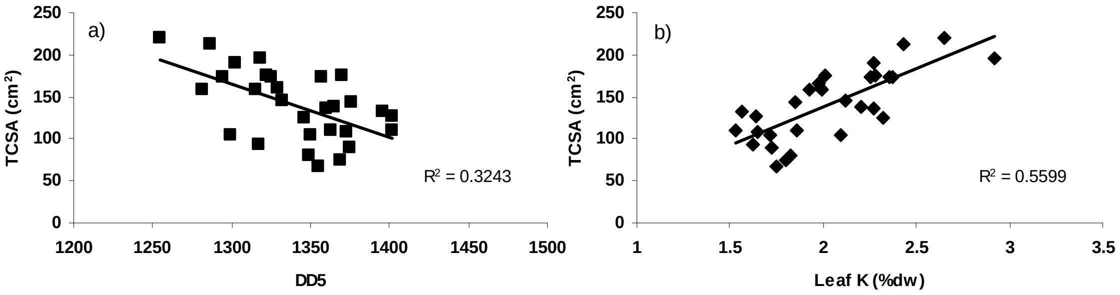

Fig. 2. **Within orchard average trunk cross-sectional area (TCSA) as related to a) degree day accumulation above 5C (DD5) and b) leaf K concentration; 2008 at n=30 locations.**

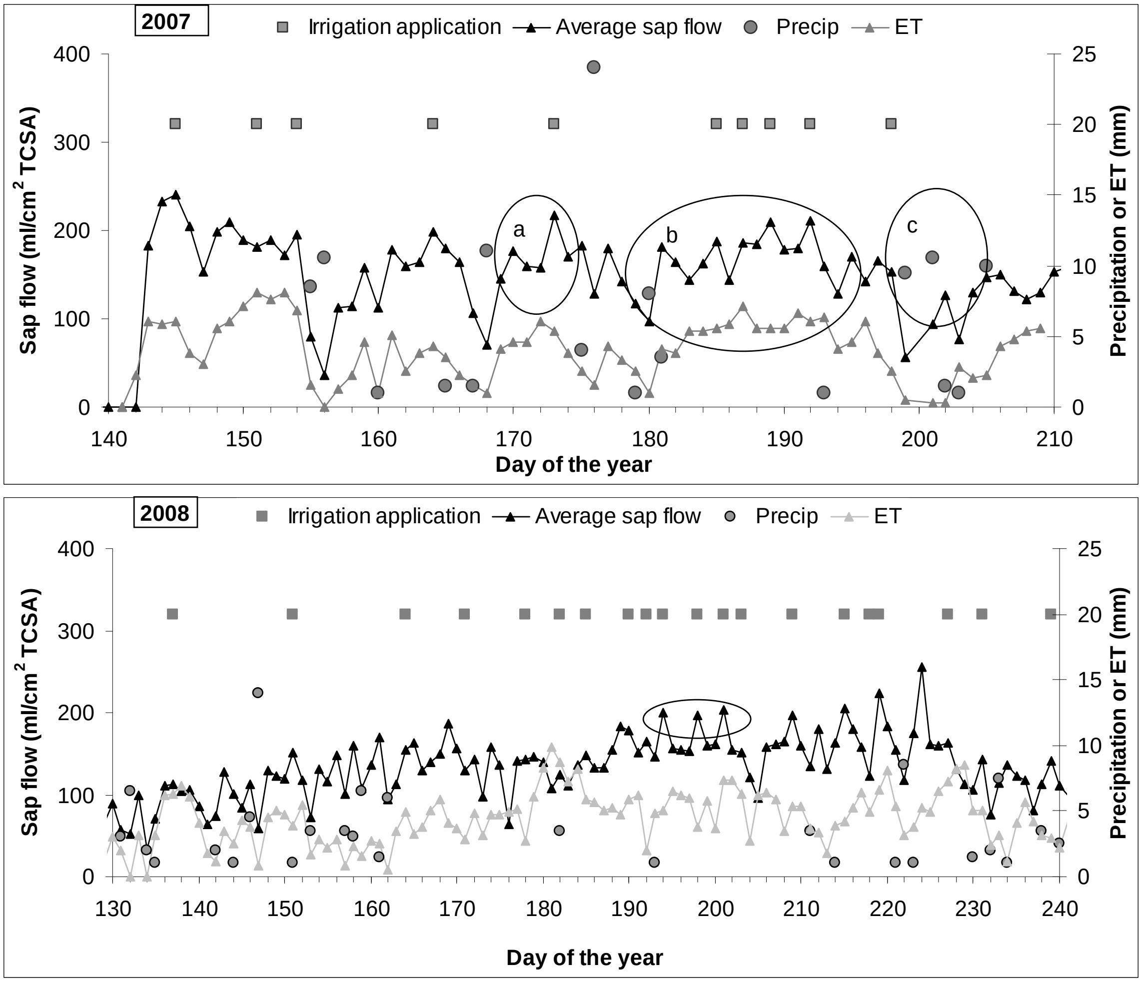

Fig. 3. Effect of water supply (precipitation and irrigation) on sap flow in Sweetheart/Mazzard sweet cherry in response to evaporative demand (ET) measured by an atmometer.