FINAL PROJECT REPORT
WTFRC Project Number: CH-05-506

Project Title: Understanding N requirements for sweet cherry production

PI: Denise Neilsen
Organization: Agriculture &Agri-Food Canada
Telephone/email: 250-494-6417/neilsend@agr.gc.ca
Address: 4200 Highway 97
City: Summerland
State/Province/Zip BC V0H 1Z0

Co-PI(2): Gerry Neilsen
Organization: AAFC
Telephone/email: 250-494-6377/ neilseng@agr.gc.ca
Address: 4200 Highway 97
City: Summerland
State/Province/Zip: BC V0H 1Z0

Co-PI(3): Peter Millard
Organization: Macaulay Land Use Research Institute
Telephone/email: +44 1224 318611/ p.millard@macaulay.ac.uk
Address: Craigiebuckler
City: Aberdeen
State/Province/Zip Scotland UK AB15 8QH

Other funding Sources

Agency Name: Agriculture &Agri-Food Canada Matching Investment Initiative (MII) Program.
Amount awarded: Matched Commission funds as below ($15,000US)
Notes: With match, total budget is basically double the numbers below.

Total Project Funding: approx $30,000 US *exact dollar value depends upon the value of the US dollar

Budget History: Washington Tree Fruit Research Commission Funds

Item	**Year 1:**	**Year 2:**	**Year 3:**
Salaries	$4,500 US	$4,500 US	$4,500 US
Benefits			
Wages			
Benefits			
Equipment			
Supplies			
Travel			
Miscellaneous			
Total	$5000 US	$5000 US	$5000 US

SIGNIFICANT FINDINGS

1. A rating system was developed to summarize experience with different sap flow systems as to accuracy, consistency, flexibility, field effectiveness, longevity and system cost (see Table 1).

2. Sap flow measurements are highly sensitive to small changes in environmental conditions and soil moisture content and offer long term, continuous monitoring of tree performance.

3. Sap flow systems were useful for understanding cherry tree response to environmental factors and indicated:

    a. a pronounced daily pattern in tree water use (sap flow) related to increased light and temperature.
    b. reduced sap flow above 95 F (35 C) indicating a high probability of water stress in cherries above this temperature regardless of irrigation strategy.
    c. large decreases in sap flow during precipitation events due to reduced transpiration and low light

4. Sap flow systems were useful for understanding the impact of management practices on transpiration and by inference on fruit growth and development.

    a. Through sap flow monitoring, imposed water deficits were shown to reduce transpiration which affected fruit size in an experiment block of Lapins/Gi.5.
    b. Transpiration limitations associated with a 2-3 day irrigation cycle could be identified through sap flow monitoring in a commercial orchard of Sweetheart/Mazzard where irrigation was not scheduled to meet evaporative demand.
    c. Transpiration limitations associated with a two day irrigation compared with a daily cycle could be identified through sap flow monitoring in an experimental block of Skeena/Gi.6 where irrigation was scheduled to meet evaporative demand.

5. The major advantage of the technique is continuous monitoring which enables the timing and magnitude of the effects of either environmental or management factors on plant performance to be identified

6. There is a pronounced withdrawal of N from cherry leaves in the 6-8 week period prior to leaf loss regardless of tree N status.

7. Disruption of the normal cycle of leaf N removal via premature leaf loss depressed subsequent yield of Lapins on Gisela 5 rootstock until 3 year’s after the triggering event.

RESULTS AND DISCUSSION

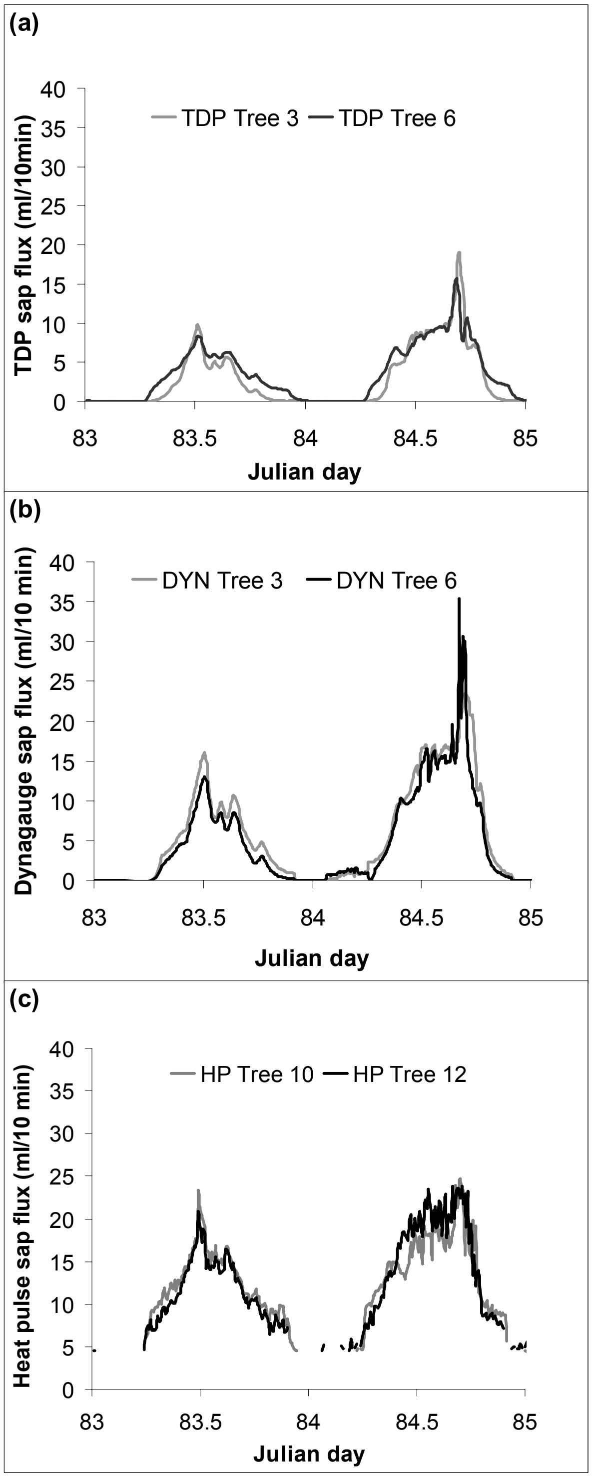

Figure 1. Daily sap flow traces for a) TDP b) Dynagage and c) HP gauges in 2007

The initial objectives of this proposal were to determine sap composition and N requirements for sweet cherry, based on xylem N flux and the use of ^{15}N labelled fertilizer. In 2005 funding was re-targeted to a) the assessment of sap flow gauges in greenhouse and field experiments and b) the effects of intervening in Fall N withdrawal and spring remobilization to determine their contribution to cherry nutrition and production.

Assessment of sap flow gauges

Sap flow gauges have been tested to determine:

1. accuracy and precision in the measurement of whole tree transpiration
2. responsiveness to environmental variables
3. usefulness as a tool for irrigation management

1. *Measurement of whole tree transpiration*

Greenhouse tests were carried out in 2005, 2006 and 2007 with consistent results. In the greenhouse, the three types of sap flow gauges tested – PARC thermal dissipation probes (TDP), Dynagage heat balance probes (DYN) and Tranzflo heat pulse probes (HP) had similar responses to tree transpiration requirements over the day. This is illustrated by the similarity in the shapes of the graphs of sap flux, measured every 10 minutes, for representative Stardust/Mazzard cherry trees on two contrasting days (Fig 1). TDP and DYN probes were apparently more responsive to high transpiration demands (Julian day 84.75 - Fig. 1a, b) than HP probes (Fig. 1c). The HP probe signal was 'noisier' than the TDP and DYN probes. The amount of sap flux measured by the probes differed with TDP< DYN < HP.

The accuracy of the different probes was assessed by comparing the calculated sap flux values with weight loss due to transpiration from the pots, which were permanently located on weighing platforms fitted with shear beam force transducers (Omega). The TDP probes underestimated transpiration and were the least accurate, as indicated by how closely the slopes

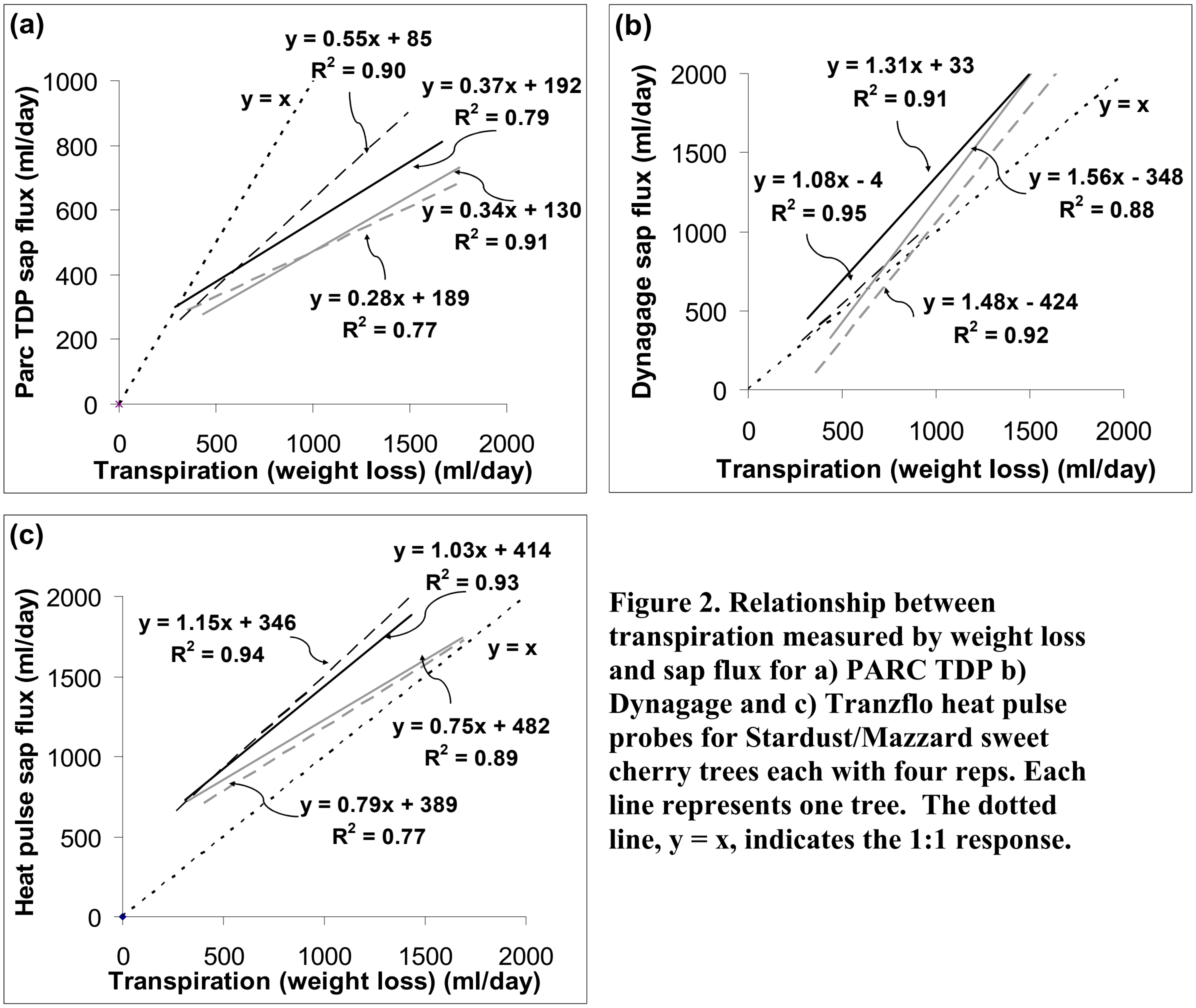

Figure 2. Relationship between transpiration measured by weight loss and sap flux for a) PARC TDP b) Dynagage and c) Tranzflo heat pulse probes for Stardust/Mazzard sweet cherry trees each with four reps. Each line represents one tree. The dotted line, y = x, indicates the 1:1 response.

of the lines for different probes were to the dotted 1:1 line (y = x) (Fig. 2a). The most accurate type of probe was the DYN heat balance probe (Fig. 2b), and the HP probes were intermediate in accuracy, tending to overestimate actual transpiration.

Figure 3. Irregular xylem function in cherry demonstrated using safranin dye solution

The consistency of the relationship between measured and estimated transpiration for individual probes over the course of the experiment is indicated by the magnitude of the R^2 values given on the graphs (Fig. 2). The closer the values are to 1.0 (a perfect correlation) the more consistent the relationship for that particular probe. All of the correlations were strong for individual probes indicating good consistency in their ability to estimate transpiration over time. Between-probe consistency, (similarity in the line equations) was about the same for the replicates of the three different probe types (Fig. 2).

Overall, Dynagage (DYN) heat balance probes are better for estimates of actual transpiration losses than the other two probe types and for xylem N transport studies would be the system of choice. The DYN probes heat the outside of the trunk and measure thermal losses due to sap flow thus sampling the whole of the trunk circumference. The other two probe types are needles

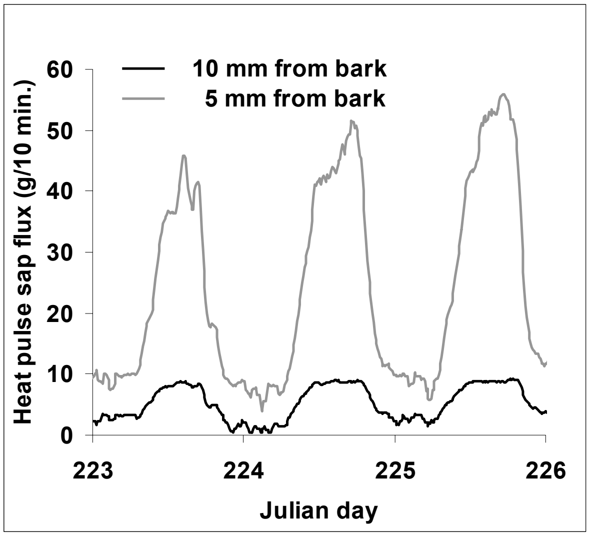

Figure 4. Spatial distribution of sap flow across the trunk measured using Tranzflo probes.

inserted into the xylem and hence only sample a small portion of the total flow. Circumferential xylem inconsistency (Fig. 3) and radial differences in xylem conductive tissue (Fig. 4) contribute to the errors in the TDP and HP estimates of sap flow. This is offset, to some degree in HP probes by ability to take measurements at different depths within the trunk.

Significance to the industry

Given the variation that we have observed among different tree/probe combinations, it is apparent that deriving a universal conversion factor for estimating actual transpiration from sap flow for TDP and HP would not be possible. However, accuracy of measurement (closeness of sap flow estimates to actual transpiration losses) is only important if quantification of xylem flux is required. Below, we will discuss other uses of sap flow gages which are based on relative responses to either environmental or orchard management factors. For this use, given that the probes have similar self consistency, other factors such as cost, robustness and longevity need to be considered (Table 1). We have chosen to use the TDP probes for field studies based on the lower energy inputs required, easier set-up, longevity and lower system cost.

Table 1. Comparison of sap flow measurement systems

Sapflow system	Accuracy	Consistency	Flexibility	Field efficiency	Longevity	System Cost
Parc TDP		✓	✓	✓	✓	✓
Tranzflo HP	✓	✓	✓		✓	
Dynagage	✓	✓				

*accuracy rating based on proximity to y = x for calibration (transpiration/ sap flow)

*consistency based on closeness of R^2 values to a perfect relationship (R^2 =1.0) for calibration

*flexibility based on applicability of the sensor design to a range of tree sizes/shapes. Dynagage collars are specific for trunk size.

*field efficiency based on ease of set up in field, power requirements, maintenance requirements. TDP probes require less set-up and have much lower power requirements.

*longevity based on potential for long-term observations on the same tree (full season or multi-season monitoring). Dynagage heaters damage the bark after 1-2 months.

*system cost - all require datalogger control. Differences in the cost of sensor/systems are significant

2. Use of TDP sap flow probes to understand and measure tree response to environmental factors

Graphs of sap flow measured over the day (Figs. 1 and 4) indicate that transpiration is primarily governed by the availability of light which controls stomatal opening and carbon acquisition for growth. Even in the greenhouse, where conditions are controlled, daily patterns may vary, largely due to differences in sunlight – e.g. the difference between day 83 and 84 (Fig. 1). However, other factors are also important and these are associated with the ability of the soil/plant system to support the transpiration requirements at the leaf/air interface. In the greenhouse, there was an increase in sap flow in response to increasing temperature up to 35°C (95°F) and decline thereafter (Fig. 5). This indicates that even well-watered soils may not be able to supply sufficient water to meet the high evaporative demand associated with high temperatures. A similar response can be seen in the field when estimates of evapotranspiration, adjusted for canopy development and rainfall, are compared with daily sap flow (Fig. 6). In a well-watered soil there was no increase in sap flow beyond a daily ET of around 7.0 mm (0.28 in).

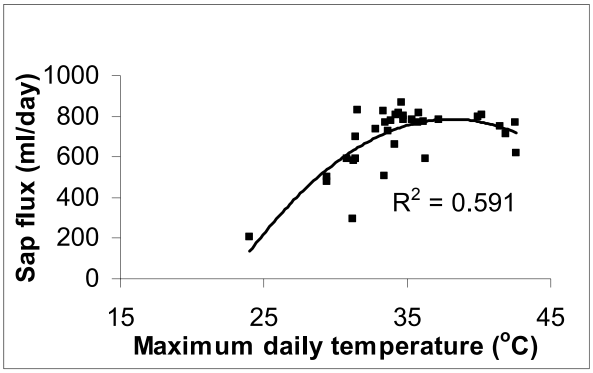

Figure 5. The relationship between maximum daily temperature and sap flux in the greenhouse (mean of 8 plants).

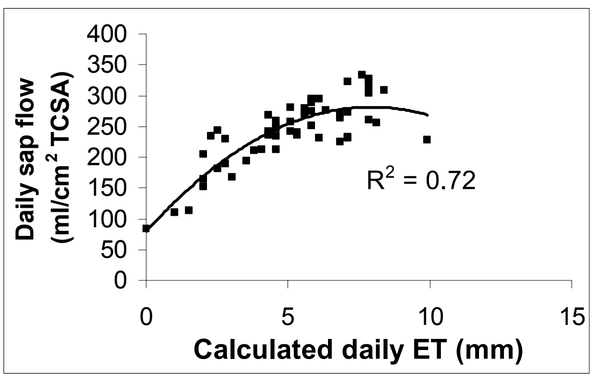

Figure 6. Daily sap flow, adjusted for TCSA compared with ET for well-watered Skeena/Gi.5 cherry trees at the PARC lysimeter in 2007 (mean of 4 plants).

The daily time course of sap flow in well-watered trees is highly responsive to a number of environmental factors (Fig. 7). In general, sap flow increased in response to increased temperature and ET. Large reductions in sap flow occurred during precipitation events on day 175, 180 and 200. This was likely caused by high relative humidity (low vapour pressure deficits) reducing transpiration requirements and low light conditions reducing stomatal conductance.

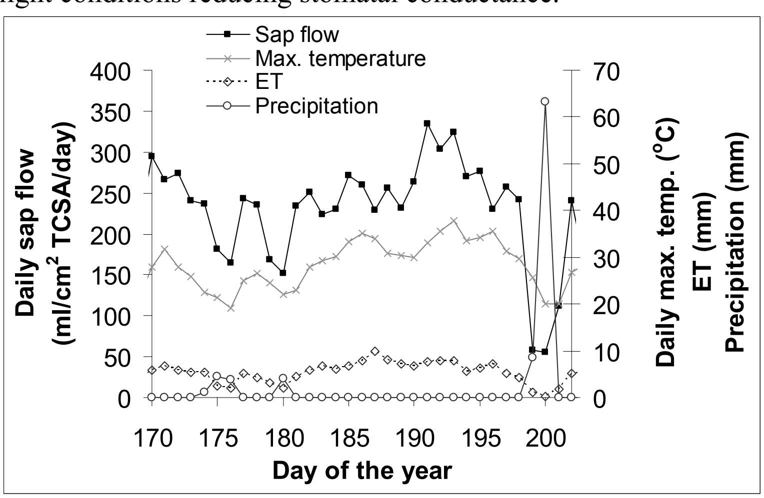

Figure 7. Sap flow as affected by air temperature, calculated ET and precipitation for well-watered Skeena/Gi.5 cherry trees at the PARC lysimeter in 2007 (mean of 4 plants)

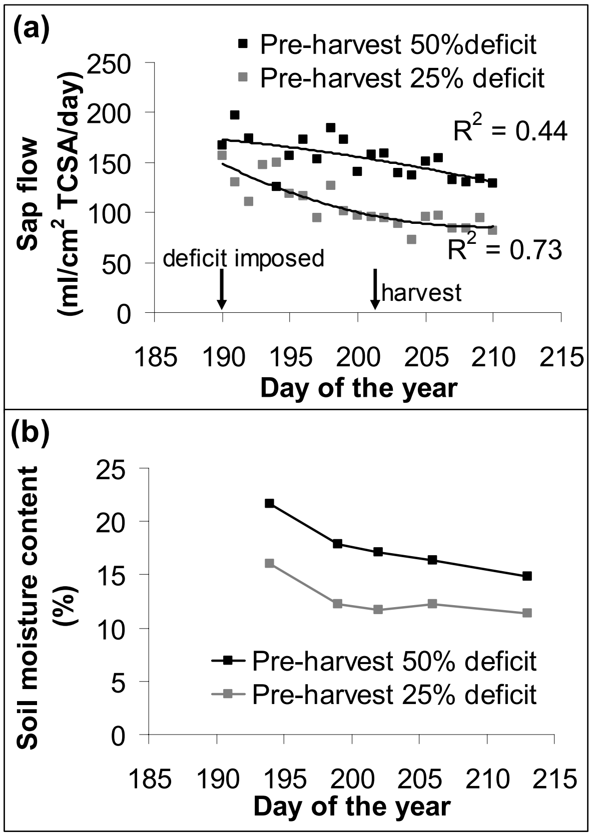

Figure 8. Effects of drought on a) sap flow and b) soil moisture in field grown Lapins/Gi.5

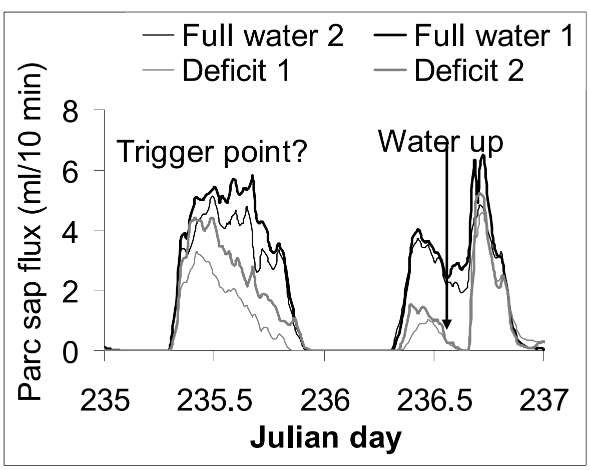

Figure 9. Response of TDP sap flow probes to severe imposed drought.

3. *Use of sap flow probes to understand and measure tree response to water management*

Our initial trials examined the effects of imposed moisture deficits on sap flow in an attempt to define a protocol for integrating sap flow measurements into automated irrigation management. The sap flow signal in response to pre-harvest water deficits was quite clear in field grown Lapins/Gi.5 indicating both the timing and magnitude of the drought (Fig. 8a). This was supported by differences in soil moisture content which were evident within three days of the drought imposition in this sandy soil and were cumulative over time (Fig. 8b). The practical outcome of the relative water deficits were significantly smaller fruit (8.2 vs 9.7g) but with greater firmness (71.6 vs 70.4 durometer units) and fewer splits (0% vs 6%) for the more severely droughted trees.

In pursuit of an electronic signal that might be used to control irrigation systems, we examined daily sap flow graphs to identify potential trigger points for watering up. While these signals are quite evident visually (Figure 9), it was not possible to find a pattern that could be reliably used. There were several reasons for this. Sap flow responses to drought were not consistent in shape and varied between the early morning peak followed by a rapid reduction in flow seen for droughted trees in Fig. 9 and an overall reduction in flow with no difference in shape between well-watered and droughted trees. Consequently, a simple mathematical relationship between expected and actual sap flow to be used in a datalogger could not be determined. Similarly, relationships with environmental variables such as maximum daily temperature (Fig. 5) or ET (Fig. 6), although strong, are too variable to be used for calculations of 'expected' daily sap flow.

The high sensitivity of the probes to instantaneous changes in environmental

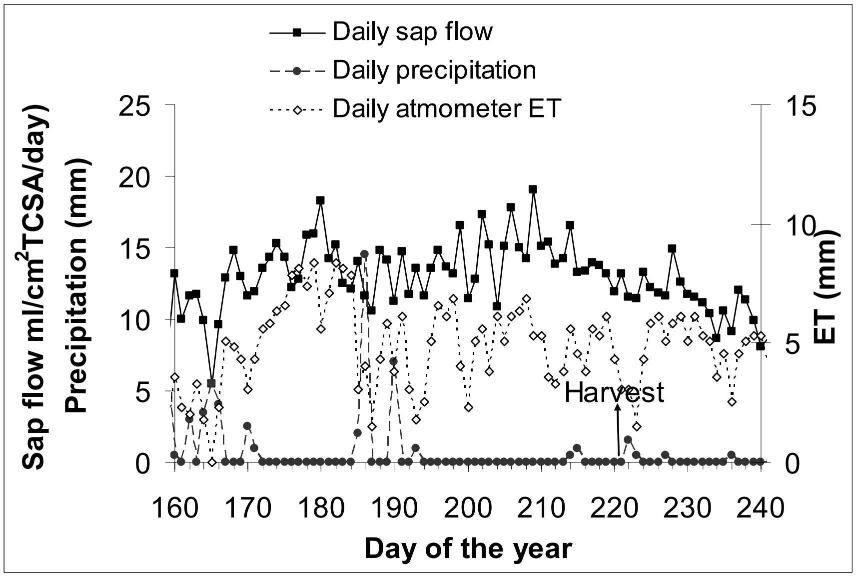

Figure 10. Daily sap flow, precipitation and atmometer ET for field grown Sweetheart/Mazzard sweet cherries. Mean of 5 trees.

conditions makes them difficult to use, on a short term basis, to determine soil moisture limitations to transpiration and for automated irrigation control. However, no other method of measurement allows such long term detailed analysis of plant water relations in the field and visual examination of sap flow traces over time can yield valuable information. For example, seasonal water use patterns were identified from sap flow measured in a commercial orchard in 2006 (Fig. 10). The daily sap flow graph varied systematically regardless of ET and precipitation effects. The orchard receives micro-sprinkler irrigation on a 2-3 day cycle and this is reflected in the pattern of sap flow and hence transpiration, particularly in the 30 days before harvest. The decline in sap flow after harvest likely reflects lower stomatal conductance associated with a reduced demand for carbon once the fruit has been removed. The implication of the relationship between sap flow and carbon acquisition before harvest is that transpiration limitations on stomatal conductance may affect fruit development and

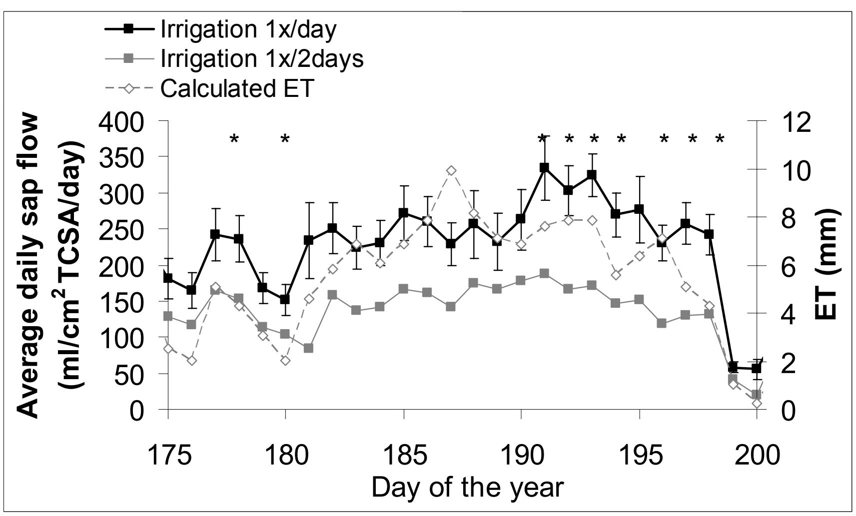

Figure 11. Sap flow in response to ET and two irrigation regimes – scheduled daily drip irrigation and the same volume of water applied every two days for well-watered Skeena/Gi.6 cherry trees at the PARC lysimeter in 2007 (mean of 4 plants).

*** sign. at p<0.05**

quality as noted earlier for field grown Lapins/Gi.6. These findings suggest that a change in irrigation practice may be warranted and potentially lead to improved fruit size (average fruit weight = 9.8 g). This type of analysis is useful where irrigation scheduling to meet evaporative demand is not being practiced.

Sap flow patterns can also be used to assess the impacts of new management practices on tree performance. In an experiment at the PARC lysimeter the effect of two irrigation strategies on Skeena/Gi.6 is being assessed. Irrigation was delivered through four 4L/hr (1 gal/hr) drip emitters per tree either daily or once every two days and scheduled to meet evaporative demand. The trees receiving water once every two days had lower sap flow that trees receiving daily irrigation (Fig. 11). The differences in sap flow, between the treatments increased as ET increased (days180-199) indicating that daily irrigation helped to overcome soil moisture limitations to transpiration and potentially stomatal conductance, carbon acquisition and fruit water status. These trees will be cropped for the first time next season. Other management practices that are currently under investigation using sap flow gauges in cherries and other crops include differential crop loads, partial root zone drying, mulching and foliar spray programs.

Significance to the industry and economic significance

Needle type probes such as the PARC-TDP probes which are inserted into the xylem of the tree can provide a continuous record of tree sap flow over multiple seasons. Sap flow measured in this way is an estimate of relative transpiration rates within an individual day or from day to day. The probes are exceedingly sensitive to small changes in air temperature, relative humidity and soil moisture availability. Because transpiration rates are closely linked to stomatal conductance, carbon acquisition and plant water status, factors which limit transpiration may also affect fruit growth and water status. We have identified upper limits for transpiration based on ET (7 mm/day) and temperature (95° F ; 35° C). Sap flow probes may also be used to assess overall tree performance in response to a range of management practices. Experimental water deficits imposed 30 days before harvest caused reduced transpiration and associated reductions in fruit size. In a commercial orchard, sap flow measurements indicated that transpiration was reduced in synchrony with the irrigation cycle, with potential detrimental effects on fruit size. In another trial, with young non-fruiting trees, sap flow was lower when irrigation was applied on a two day rather than a daily cycle.

The potential economic significance of this type of knowledge relates to the ability to identify management practices which may enhance or limit the production of high quality fruit. We have identified irrigation management factors which limit transpiration and fruit growth. Assessment of any current or new management practices with this technique would likely prove beneficial. The major advantage of the technique is continuous monitoring which enables the timing and magnitude of the effects of either environmental or management factors on plant performance to be identified.

Fall N supply and spring remobilization

Seasonal pattern of N remobilization for "Lapins" sweet cherry on Gisela 5 rootstock.

Leaf N concentration of new-year, mid-shoot extension leaves of sweet cherry declines very slowly after harvest until the end of September, as indicated by two sets of trees receiving contrasting N treatments over a two year period (Fig. 12). However for both N treatments there was a rapid decline in leaf N concentration during the month of October, at a rate averaging about 10% (of the original concentration) per week, which represents the remobilization of nitrogen from leaves to woody storage prior to normal leaf fall. Normally leaf fall is usually completed by December in this region, ensuring sufficient time for the normal processes of nitrogen recycling. This normal process is critical to insure adequate N to support good tree growth the next spring.

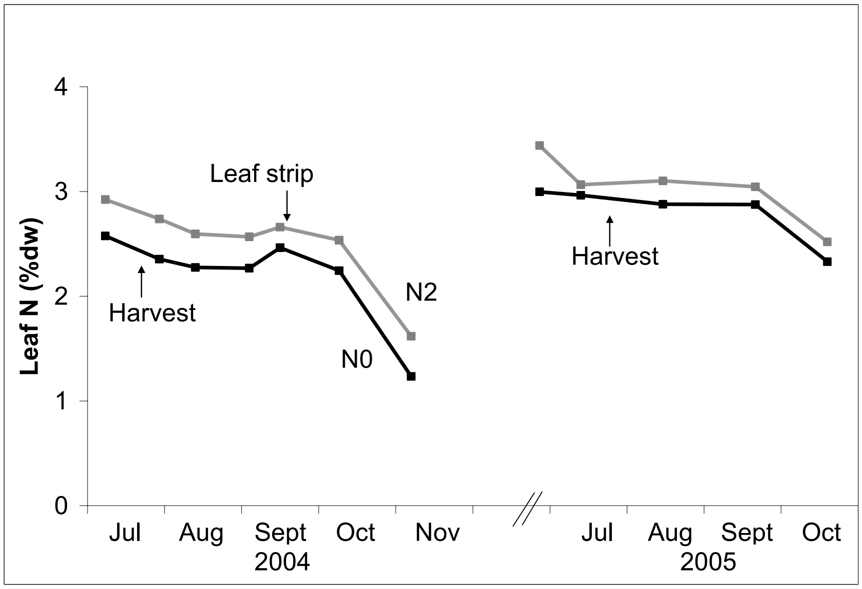

Figure 12. Effect of N application rate and leaf stripping on leaf N concentration of Lapins/Gi.5 cherry trees.

Implications of disruption of the normal N remobilization processes

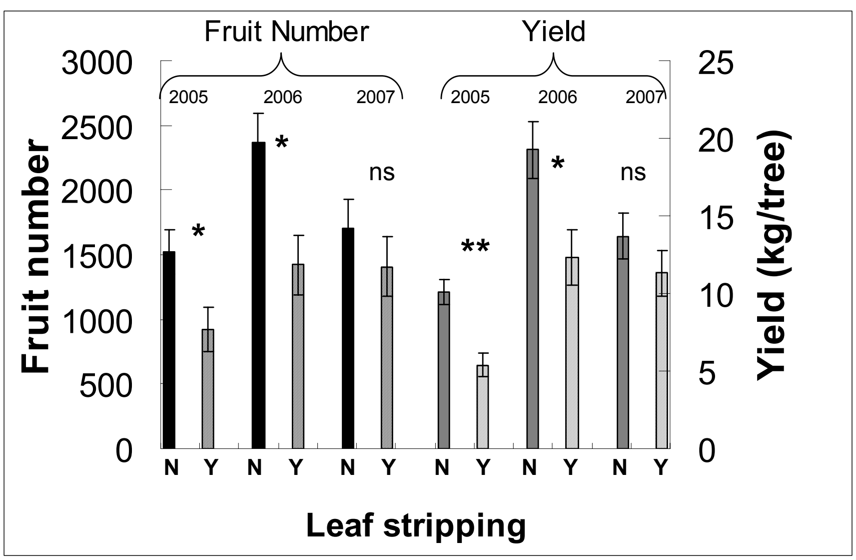

Figure 13. Effect of leaf removal on Sept. 17th, 2005 on fruit number and yield of Lapins/G.5, 2005-2007.

*,**,ns Significant at $p<0.05$, 0.01 and not significant respectively.

In mid September 2004, the normal remobilization cycle was disrupted by imposing a leaf stripping treatment which was enacted to prevent the movement of N from leaves back into storage (Fig. 12). The importance of effects resulting from disruption of the normal N remobilization cycle was indicated by its pronounced effect on tree yield performance in subsequent years (Fig.13). Yield was significantly decreased in 2005 (46.5%) and 2006 (35.9%). By the third year following the treatment (2007), the effect was no longer statistically significant, although yield was still lower. The yield reduction occurred because of significant reduction in fruit number (2005-2006, Fig. 13) rather than average fruit size which was unaffected (data not shown).

Significance to the industry and economic significance

Disruption of the normal N remobilization cycle for young sweet cherry trees on dwarfing rootstocks, such as these “Lapins” on Gi 5 rootstock, can have large, negative effects on yield performance for several growing seasons. Since fruit size was not statistically affected, the economic impact directly relates to yield reduction and would have decreased income for an experimental block by 46.5 % and 35.9% one and two years, respectively, after the causal event. Trees seem to have the capacity to recover from this stress with normal fertilization and management practices by the third year.

Although the treatment represents an extreme treatment (removal of all leaves), the results suggest that factors leading to premature defoliation of leaves, including insect damage and early freezes could seriously depress fruit production for several years. As the month of October was a critical time for cherry trees to replenish N storage supplies by removing N from leaves, detrimental effects on leaf function during this important time period are particularly serious. It would be prudent for growers with orchards so affected to consider supplementary foliar sprays in the years immediately following the stress event. For example, early spring (in March to dormant trunks) and post harvest urea sprays can augment depleted N storage reserves, as has been previously demonstrated for apple.