Final Report

Reducing the impact of late season rainfall

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Contents

Figures 5

Tables 5

Summary 6

Keywords 7

Summary of trials 8

- Connective vascular tissue within the fruit stem 8
- Ground cover impact of water uptake 13
- Root pruning impact on fruit water uptake 17
- Soil fungi (AM) impact on root water uptake 19
- Rapid expansion phases of fruit development 21
- The role of calcium on fruit integrity 25
- The role of plant growth regulators on cuticle integrity 26
- Root pruning as a strategy to increase fruit set and crop load 27

Outputs 30

- Industry articles 30
- Industry presentations 30
- Fact sheets 30
- Theses 31
- Scientific presentations 31
- Scientific publications 31

Outcomes 32

- Research 32
- Capacity 32
- Adoption 32
- Evidence of adoption and understanding of research outcomes 32
- Collaboration 33

Scientific refereed publications 34

IP/Commercialisation 35

Acknowledgements 36

Appendices – published/accepted papers 37

- The role of Arbuscular Mycorrhizal Fungi in Establishment and Water Balance of Tomato Seedlings and Sweet Cherry Cuttings in Low Phosphorous Soil 37
- Calcium Application and Impacts on Cherry Fruit Quality 38
- Flowers to Fruit; Early fruit formation and late fruit quality 39

Preharvest application of biofilm leads to reliable supply of high quality cherry fruit after storage 40

The Permeability Concept: A Useful Tool in Analyzing Water Transport through the Sweet Cherry Fruit Surface 41

Tree Water Relations; Flow and Fruit. 42

Figures

Figure 1 Mean cherry diameter (mm) measured each day at 0500hrs at Old Beach and Huonville, adjusted for continuity to account for changes in measurement between individual cherries. Linear regressions were performed for each stage of development at Old Beach (Stage 1 =y = 0.3212x + 5.222, p=<0.01 R^2 = 0.924; Stage 2 showed no significant change; Stage 3 y = 1.3059x - 49.338, p<0.01 R^2 = 0.9344; Post-Ripe showed no significant change) As well as Huonville (Stage 3 y = 0.0407x + 31.689 p=0.01 R^2 = 0.9252; Post-Ripe y = -0.0407x + 31.689 p<0.01 R^2 = 0.9252). . 10
Figure 2 Change in cross-sectional area of the entire pedicel (blue diamond) and xylem (red square) over time (DAFB). 10
Figure 3 Representative examples of pedicel cross sections, taken from Old Beach. Top row images are of pedicel samples taken proximally to fruit, at stages 1, 2 and 3 respectfully. Middle row images are of samples taken from the middle of the pedicel at stages 1, 2 and 3 respectfully. Bottom row images are pedicel samples taken proximally to the spur, at stages 1, 2 and 3 respectfully. Scale shown on individual images. 11
Figure 4 Cross-sectional nuclear magnetic resonance images of cherry pedicels at different dates. White pixels indicate areas of high signal indicating water saturation. 11
Figure 5 Visible leaf-curling symptoms of slight water stress in trial trees 14
Figure 6 Percentage of side cracks in fruit from trees with weeded or bare rows. 15
Figure 7 Side cracking in fruit 16
Figure 8 Site preparation for root pruning trials 18
Figure 9 Cherry rootstock cuttings with and without AM fungi 19
Figure 10 Hend Mohamed searching for fungal spores 20
Figure 11 Daily maximum expansion (MDE) divided by initial (5am) diameter, and maximum daily shrinkage divided by initial (5am) diameter (MDS) of cherries at Old Beach at each stage of development. Different letters represent significant differences at p<0.05. 23
Figure 12 Change in size relative to initial size of detached fruit, with stage 2 control fruit for comparison 24
Figure 13 Inspecting fruit in the calcium trial 25
Figure 14 Project work being presented at the 7th International Cherry Symposium in Spain 25
Figure 15 Monitoring rate of change from flower to fruit 26
Figure 16 The incidence (%) of fruit cracking from trees with no root pruning (C), Late root pruning on 1 (LRP1) or 2 (LRP2) sides of the row. Error bars represent standard error of the mean (SEM). 29
Figure 17 The size (mm) of fruit from trees with no root pruning (C), Late root pruning on 1 (LRP1) or 2 (LRP2) sides of the row. Error bars represent standard error of the mean (SEM). 29

Tables

Table 1 Diversity of plants found in the non-herbicided orchard rows 15

Summary

This project - Reducing the impact of late season rainfall - has generated important results regarding cherry cracking that are directly applicable with current orchard practice. It has provided information on which to base risk management decisions in seasons with late season rainfalls; providing information with which to improve fruit integrity, and consequently fruit quality. The broad research aims of the project were to reduce crop damage and the impact of late season rainfall by:

1. Preventing rapid and excess water uptake to fruit following rainfall events and;

2. Building fruit resilience before a rainfall event.

A number of trials were undertaken in order to achieve of these two aims; as follows;

1. Preventing rapid and excess water uptake to fruit following rainfall events
    a. Connective vascular tissue within the fruit stem
    b. Ground cover impact of water uptake
    c. Root pruning impact on fruit water uptake
    d. Soil fungi (AM) impact on root water uptake
2. Building fruit resilience before a rainfall event
    a. Rapid expansion phases of fruit development
    b. The role of calcium and irrigation on fruit integrity
    c. The role of plant growth regulators on cuticle integrity
    d. Root pruning as a strategy to increase fruit set and crop load

These trials build on the results of an earlier project (CY09002) and show that there are a number of strategies that can be employed within current orchard management practices to reduce the impact of late season rainfall. Building resilience in fruit through irrigation, nutrition, and crop load management helps reduce the impact of rainfall late in the season when fruit is most susceptible to cracking. However, there are no practical options to reduce the rapid uptake of rainfall late in the season; ground covers will slow uptake but are not suited to current systems, vascular tissue stays connected and functional throughout fruit maturation, and root pruning late in the season was not viable. Therefore, building resilience into the fruit early in the season is vital. Building resilience is possible through maintaining cuticular and skin integrity and strength. This is enhanced by a comprehensive calcium program which allows calcium uptake early in fruit development. Also by maintaining irrigation to reduce excessive diurnal shrinking and swelling of fruit during development,

and to avoid trees being water stressed coming into a rainfall event. Managing crop load, and considering the growth rate of fruit early in fruit development is also advised.

This project shifts the thinking of cracking management from a reactive approach when rain is imminent to a holistic year-round approach.

"Penny's research has changed the way we think about rainfall" Peter Smith, Eversley Cherries, Legana, Tasmania.

This project also supported the training of two students through an Honours study and a Masters study. This has resulted in successful qualification and desire to continue working in discipline. Matthew Calverley gained first class Honours, and has secured a position with the Department of Agriculture. Hend Mohamed gained a Masters degree (graduating 2015) and is now seeking a PhD project in horticulture. This project also introduced a plant pathologist into the industry to build experience and expertise with cherries. Dr. Karen Barry now leads a much-needed project investigating optimal management of pre-harvest rot in sweet-cherry.

The project has also contributed to improved management through regular communication of results via a number of channels; direct discussion with growers, fact sheets, industry articles and presentations and the imminent release of a user-friendly manual about cherry cracking.

This project has also supported the building of scientific understanding internationally through peer-reviewed publications, presentations at international conferences, international collaborations, and the provision of advice to international trials regarding cracking management.

Keywords

Cherry, cracking, vascular, calcium, cytolin, crop load, irrigation, nutrition

Summary of trials

Summaries of trials are provided below. Some summaries will be brief where there is an associated publication (provided as an Appendix to this report), or draft in preparation for publication. Those trials associated with the Honours project will be covered in more detail.

Connective vascular tissue within the fruit stem

This work was generated through the honours project attached to the project

Introduction

The long term expansion of the cherry industry in Tasmania depends heavily on the production of high quality fruit to exploit premium prices in domestic and international markets (James, 2011). In both markets, fruit quality is based on size, taste and appearance (Kappel, 1996, Demirsoy, 2004, Dever, 1996), all three of which may all be influenced by water supply to trees (Marsal et al., 2010, Simon, 2006, Sekse, 1995). Thus, understanding water movement through the plant and to the fruit is fundamental to attaining these quality traits.

A significant source of water contribution to the fruit water budget is the internal vascular system via the pedicel. The chief components of a plants vascular system are the phloem and xylem, and their function is highly dependent on water potential gradients (Boyer, 1985, Tyree, 2003).

Water drawn from organs with a more strongly negative water potential is postulated to have a major influence on vascular supply and cherry fruit expansion patterns. Investigation of the flow through vascular tissues to cherry fruit by Measham et al (2011) observed considerable differences between days with and days without rainfall, as well as vascular efflux on dry days. Influx to the fruit resumed when the water potential gradients were reversed. This indicates competition for water via the xylem between the fruit and leaves, with the leaves representing the stronger draw on water, perhaps because of less flow resistance (Measham et al., 2011, Oyarzun et al., 2010).

Changes in vascular function in later maturity is reported in many fruit, and may be connected to water supply regulation, although the details are different for different species (Bondada et al., 2005, Chatelet et al., 2008, Choat, 2009, Greenspan, 1994, Guichard et al., 2005, Keller, 2006, Morandi et al., 2009, Tilbrook and Tyerman, 2009, Windt et al., 2006). Diminished xylem flow in apples has been linked to improved mineral supply via the phloem, and is thought to occur due to physical breakdown of the xylem (Lang, 1994, Drazeta, 2004). Grapes also exhibit reduced xylem flow once ripe, however, evidence produced using a variety of methods indicate that the xylem in grapes remains fully intact (Bondada et al., 2005, Chatelet et al., 2008, Keller, 2006). Some authors suggest that phloem influx is driven by apoplastic/symplastic solute partitioning which enhances phloem tissue and impairs xylem flow (Bondada et al., 2005, Chatelet et al., 2008, Keller, 2006).

This study seeks to address the question of the function of phloem and xylem within cherry pedicels in relation to fruit water status during maturation. Anatomy of pedicels will be examined and considered for any effect anatomical change may have on vascular function.

Materials and Methods

Pedicel samples were collected weekly during fruit development and maturation from mature 'Sweetheart' trees in Southern Tasmania. Samples were immersed in either ethanol or formaldehyde solutions for preservation. Different solutions were used for compare the quality of the two methods of preservation. Subsequently, samples were processed at the Menzies Centre (UTAS) using a toluidine blue stain to elucidate vascular structures. The integrity of vascular tissue was visually assessed and the vascular areas occupied were measured using a Leica electronic microscope and imaging software, and subsequently compared over fruit development as well as with NMR images.

Samples for NMR imaging were taken directly to the University of Tasmania central sciences laboratory subsequent to collection for analysis. Pedicels which were excised, where necessary, from the fruit with a small amount of residual tissue remaining to maintain structural integrity at the fruit junction, before insertion into 2.5mm solenoid coil for imaging using an Agilent/Varian Unity-Inova wide-bore spectrometer. 0.03x0.03mm resolution images were achieved.

Results

No anatomical changes in the xylem or phloem were observed in the pedicel samples taken at different stages. Images of representative cross sectional anatomy of pedicels are presented in figure 1. However, a significant negative correlation was found between maturity (DAFB) and total cross sectional area of pedicels ($p<0.001$, $N=-.809$, $n=9$), as well as between maturity and xylem area proximal to the spur ($p<0.001$, $N=-0.802$, $n=11$), (figure 2) indicating a reduction in pedicel diameter at the spur end over time. The pedicel diameter was observed to increase in diameter slightly over time at the fruit end and also in the middle, although the trend was not statistically significant. Nuclear magnetic resonance images indicated that water was present in both phloem and xylem tissues at all stages of growth (figure 3), implying continuity of function of both xylem and phloem at all stages.

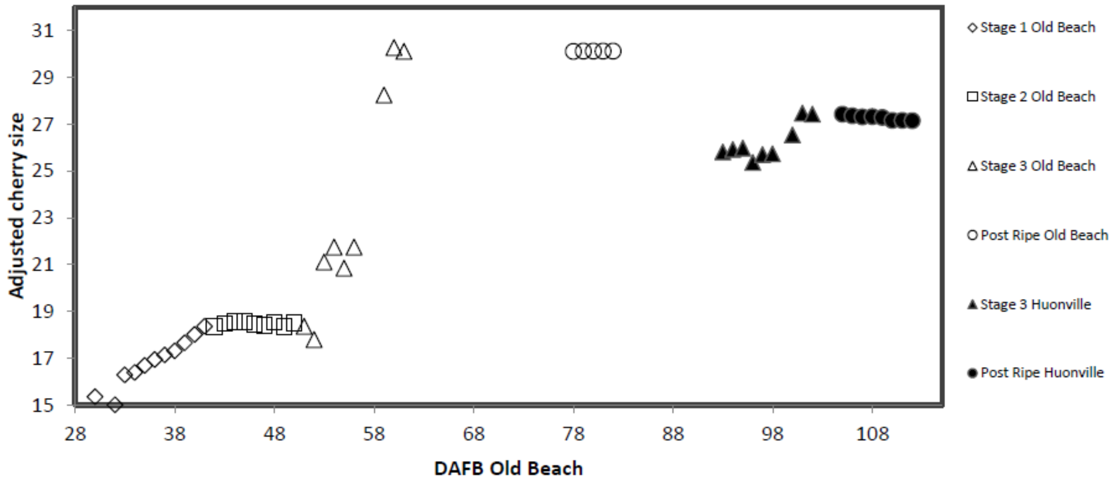

Figure 1 Mean cherry diameter (mm) measured each day at 0500hrs at Old Beach and Huonville, adjusted for continuity to account for changes in measurement between individual cherries. Linear regressions were performed for each stage of development at Old Beach (Stage 1 =y = 0.3212x + 5.222, p=<0.01 R^2 = 0.924; Stage 2 showed no significant change; Stage 3 y = 1.3059x - 49.338, p<0.01 R^2 = 0.9344; Post-Ripe showed no significant change) As well as Huonville (Stage 3 y = 0.0407x + 31.689 p=0.01 R^2 = 0.9252; Post-Ripe y = -0.0407x + 31.689 p<0.01 R^2 = 0.9252).

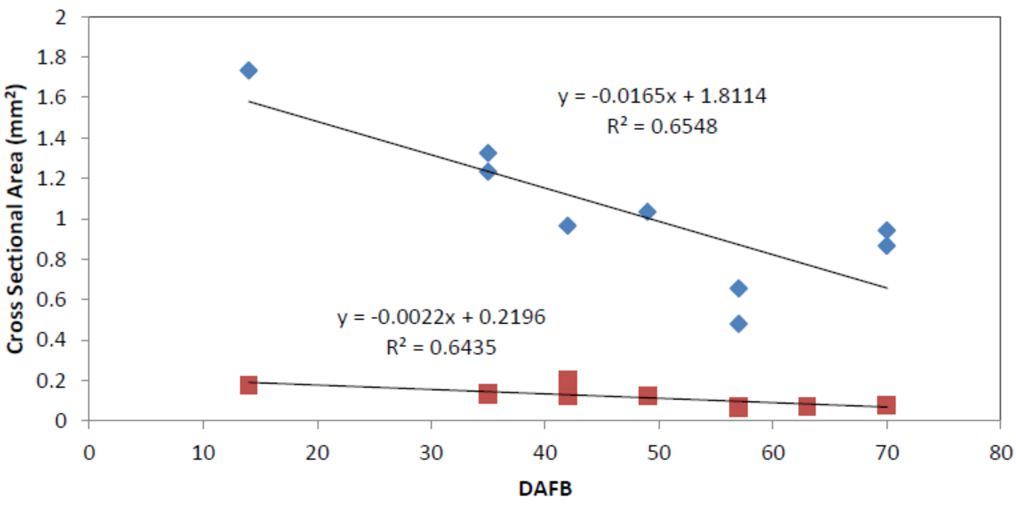

Figure 2 Change in cross-sectional area of the entire pedicel (blue diamond) and xylem (red square) over time (DAFB).

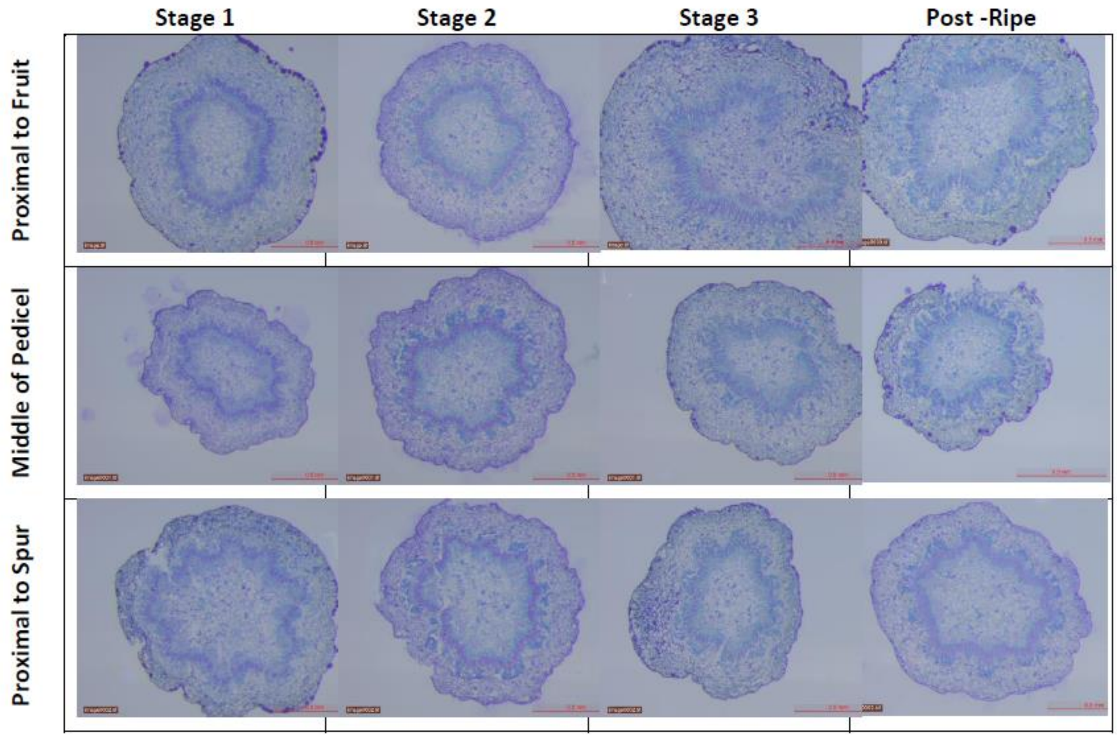

Figure 3 Representative examples of pedicel cross sections, taken from Old Beach. Top row images are of pedicel samples taken proximally to fruit, at stages 1, 2 and 3 respectfully. Middle row images are of samples taken from the middle of the pedicel at stages 1, 2 and 3 respectfully. Bottom row images are pedicel samples taken proximally to the spur, at stages 1, 2 and 3 respectfully. Scale shown on individual images.

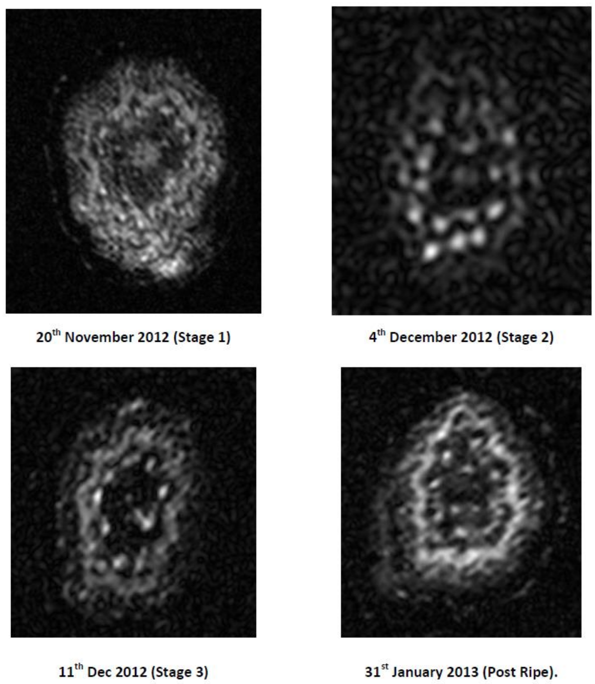

Figure 4 Cross-sectional nuclear magnetic resonance images of cherry pedicels at different dates. White pixels indicate areas of high signal indicating water saturation.

Discussion

The findings in this study do not imply that the proportion of xylem to phloem flux necessarily changes at later stages as it is known to in grapes. Rather, it is posited that the xylem remains fully in-tact and continues to make important contributions to the water balance of the fruit. An analogous model is seen in peaches, whose growth relies on transpiration in combination with carbohydrate import to replenish water losses and facilitate growth primarily via the xylem (Morandi, 2007).

Such a mechanism is in contrast with apple fruit, which appear to become phloem dominant as a result of physical xylem breakdown (Lang, 1994). Evidence gathered in this study does not support the notion of xylem breakdown in cherry fruit pedicels. Firstly, the magnitude of shrinkage was not increased by girdling, implying that xylem was still providing sufficient water supply to counter atmospheric water losses. In addition, detailed histological slides did not show evidence of xylem breakdown, and this was confirmed by magnetic resonance imaging that indicated there was fluid in both xylem and phloem tissues at all stages of development.

Furthermore, the histological measurements in this study did show that the cross sectional area of the pedicel proximal to the spur becomes significantly smaller throughout development, as does the xylem specifically, despite a general non-statistically significant trend of increase in other parts of the pedicel. It is speculated that stretching due to the weight of the fruit causes this phenomenon, which may potentially cause a kind of vascular bottle neck. Xylem vessel frequency to size ratio measurements may be necessary to rule out xylem diminished patency (Lang, 1994).

Ground cover impact of water uptake

This work is in preparation for scientific publication.

Introduction

Cracking in sweet cherries is a generic term used to describe rain induced fracturing of the cherry fruit skin, sometimes associated with rupturing of underlying flesh. Some studies on fruit cracking noted differences in cracking patterns (Sawada 1934; Christensen 1972) but most published work has not differentiated cracks in terms of size, shape, depth or location on the fruit surface. Sawada (1934) suggested that different forms of cracking might be related to fruit shape and Christensen (1972) noted varietal differences in cracking type and incidence. More recently Measham et al. (2009) examined cracking patterns more closely comparing varieties across seasons and suggested that the crack types, previously defined by Christensen (1996), may be driven by separate mechanisms. This work showed that the cracking incidence and the development of different crack types is influenced by both genotype and season, but importantly that large longitudinal 'side' cracks result from water supplied to the root zone which causes an influx of flow to the fruit via the internal tree system. This trial investigates the impact of water flow from the root zone under the conventional herbicided 'bare row' compared to rows that were allowed to support a natural weed ground cover by the cessation of herbicide.

Materials and Methods

Mature 'Lapins' trees were used in this trial, grown on F12/1 rootstock to a Spanish bush style, and subjected to commercial industry standard orchard practices. From harvest of 2013 no herbicide was applied to 5 plots of 10 trees, and by the 2013/14 season these plots were compared to untreated (no herbicide) plots of 10 trees. The diversity and density of plats in the treatment plots was recorded using 50cm quadrats just prior to harvest; all above ground dry matter was removed, dried and weighed.

Assessments taken close to harvest included pre-dawn leaf water potential (as an indication of soil moisture difference) and midday leaf water potential using a 'scholander' type pressure instrument (Model 615 PMS Instrument Company, Albany, USA). Gas exchange was measured using an infra-red gas analyser (LI-6400 XT LI-COR Inc., Lincoln, NE) with the midday photosynthetic photon flux density (PPFD set at 1500 µmol m^{-2} s^{-1}). Three measurements were taken from fully expanded leaves of two trees from each replicate plot and averaged (n=5). At harvest, the number of cracks was assessed as per Measham et al (2009).

Results

The no-herbicide treatment was considered successful with each plot showing a combination of at least 6 different plant types. The full list of plants is provided in Table 1. The mean fresh and dry weight of plants in each quadrat was 1166g ± 104g and 209.9g ± 22g respectively. The pre-dawn water potentials showed no significant ($P<0.01$) difference indicating that soil moisture and tree water status was equivalent between the herbicided and non-herbicided rows. However, by midday, the herbicided bare row trees were showing signs of water stress compared to the non-herbicided rows. Physiological indicator (stomatal function and gas exchange) and water potential values were significantly lower.

A small rainfall event occurred just prior to harvest allowing fruit cracking to be assessed; fruit from trees on the herbicided bare rows experienced a significantly ($P<0.01$) higher proportion of ground-water induced side cracks (Figure 5). No significant difference was noted for apical or stem-end cracks. No significant difference was noted in fruit quality characteristics.

Data were subject to ANOVA using PROC GLM. Treatment means were compared using Fisher's protected LSD. Statistical software SPSS (version 17) and SAS (version 9.1) were used for the analyses. Unless otherwise specified, all results quoted as 'significant' are at probability level of 0.05.

Figure 5 Visible leaf-curling symptoms of slight water stress in trial trees

Table 1 Diversity of plants found in the non-herbicided orchard rows

Common Name	**Scientific Name**
Grasses:	
Ryegrass	*Lolium perenne*
Speargrass	*Bromus diandrus or Bromus maximus*
Winter grass	*Poa annua*
Herbacious weeds:	
Common Chickweed	*Stellaria media*
Dandelion	*Taraxacum officinale*
Groundsel	*Senecio vulgare*
Milk Thistle	*Silybum marianum*
Musky Storksbill	*Erodium moschatum*
Plantain	*Plantago major*
Wild Radish	*Raphanus raphanistrum*
Willow Herb	*Epilobium ciliatum*
Wireweed	*Polyganum viticulare*
Clover:	
Red	*Trifolium pratense*
White	*Trifolium repens*

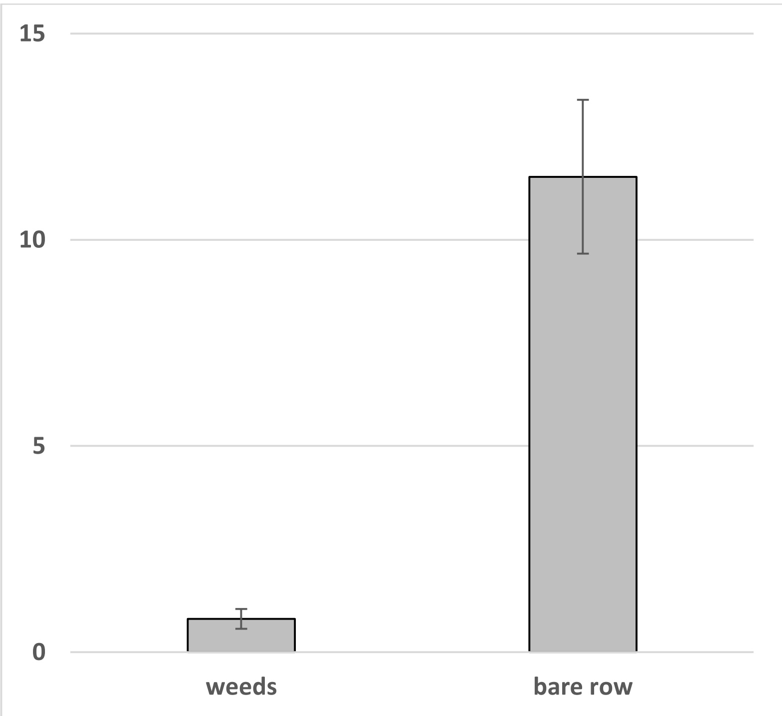

Figure 6 Percentage of side cracks in fruit from trees with weeded or bare rows.

Discussion

That water stressed trees resulted in greater numbers of cracked fruit after rainfall supports the theory (Measham et al. 2014) that water potential is the driving force of water movement within the tree. It also confirms that water supplied to stressed leaves then enters the fruit; this aligns with the work showing that phloem flow is predominant when fruit is mature, and explains the results shown by Measham et al. (2013) that leaf removal during rainfall will reduce the incidence of cracked fruit. That there was negligible difference in fruit quality shows that the tree is allocating water according to demand under normal orchard, but that the system is compromised when extra water is added during a rainfall event.

It cannot be confirmed from this study that ground covers are able to prevent the uptake of water into the tree system after rainfall, but results imply that uptake is at least slowed to such an extent that cracking is reduced.

Figure 7 Side cracking in fruit

Root pruning impact on fruit water uptake

To prevent water uptake after rainfall without the use of covers, the potential for reducing root capacity is often discussed with many growers keen to investigate. Additionally, identifying whether soil water and root location coincide would be valuable information.

It has been established that cherry fruit will still crack under covers (where the fruit surface remains dry) and that cracking incidence can be dependent on rootstock (Cline et al. 1995b). Although limited in number, these findings clearly implicate root water uptake and movement via the vascular system in crack development.

In a previous project (CY09002) the authors noted that water uptake occurred even when irrigation had been turned off and the expected location of the root zone had dried out considerably. This suggested that roots were extending into the inter row and accessing water delivered during rainfall events.

This trial intended to prune roots immediately prior to a rainfall event late in the growing season in order to assess the impact on water flow reaching the fruit after rainfall. The trial was set up in each year of the project, with soil moisture monitors in place, and sap flow equipment installed on trees.

However, each year the trial was aborted for a number of reasons;

- A wet season meant the ground was too wet/treacherous for machinery to be used
- Machinery was damaged
- Competition for labour resources during the harvest period

It was concluded that this method was not practical. Despite the best of intentions and support, this work could not be achieved.

Figure 8 Site preparation for root pruning trials

Soil fungi (AM) impact on root water uptake

This work was generated through the Masters study associated with this project and has been accepted for publication in *Acta Horticulturae (appendix A).*

Figure 9 Cherry rootstock cuttings with and without AM fungi

Figure 10 Hend Mohamed searching for fungal spores

Rapid expansion phases of fruit development

This work was generated through the honours project attached to the project

Introduction

Expansion of individual fruit must overcome losses through transpiration, so contraction often occurs through the day when transpiration increases, such that diameter measurements tend to display gradual increase with a diurnal spike and trough (Coombe, 1976, Kozlowski, 1968, Measham et al., 2011, Treder et al., 2004).

Stomata are generally the main avenue for transpiration (Boyer, 1985, Blanke and Lenz, 1989), however cherries have relatively few stomata and these decrease per unit area as well as becoming less functional over time. External water flux in mature cherries is therefore probably mainly directly via the cuticle (Christensen, 1972b.).

Flow through vascular tissues to cherry fruit shows considerable differences between days with and days without rainfall, as well as vascular efflux on dry days. Influx to the fruit resumed when the water potential gradients were reversed. Evidence that regular water supply prevents extremes of fruit expansion and contraction may also be explained in terms of water competition (Sekse, 1995).

Vascular efflux may be an important adaptive mechanism where water is scarce. It has been suggested that in soft skinned fruit prone to splitting, water recycling like this may serve as a mechanism to prevent excess water accumulation (Greenspan, 1994).

This study seeks to address the question of the function of phloem and xylem within cherry pedicels in relation to fruit water status during maturation. To do so, fruit growth stages will be defined and diurnal patterns of expansion within each stage will be assessed.

Materials and Methods

Diurnal growth patterns of fruit taken from early development through to post-ripe were measured using electronic calliper diameter sensors (Phytomonitor, SK224, 4-30mm). The diameter of six randomly selected fruit, within the reach of the sensor cables, was recorded at half hourly intervals.

Additional diameter data were captured using a Phytomonitor PM-11 automatic data logging system installed in the field and used to calculate the daily fluctuation patterns of fruit, including maximum daily expansion (MDE), maximum daily shrinkage (MDS) and net daily growth (NDG). These descriptors of growth patterns were correlated with climatic parameters of humidity, VPD, temperature and dew point which were also recorded at the experimental site using the in-built functions of the same data-logging system.

To assess the contribution of the phloem and xylem components to fruit water balance, an experiment comprising two treatments and an untreated control was implemented in a completely randomised design. The two treatments were:

1) Disabling phloem function of the pedicel using a custom built steam girdling device (see appendix A) to isolate xylem flow and, 2) Complete severance of the pedicel at the spur junction and thus vascular function, followed by repositioning of the fruit within the tree using tape, to determine transpiration from the fruit/pedicel.

Over the course of the trial, sensors were methodically removed and reapplied to new, randomly-selected cherries and treatments were replicated. Each time the sensors were moved, measurements of fruit diameter were taken for calibration of the diameter sensors. A minimum of 2/3 cherries per treatment period.

A value for Net Daily Growth over 24 hours, i.e. NDG, was calculated by subtracting the last diameter value for a given 24 hour period from the initial 5am diameter. A value for Maximum Daily Shrinkage over 24 hours, i.e. "MDS", was calculated where fruit diameter exhibited a growth pattern incorporating a period of shrinkage. MDS was derived by ascertaining the highest value in the morning, or first diameter peak, and the temporally subsequent lowest value was subtracted (figure4a). A value for Maximum Daily Expansion over 24 hours, i.e. "MDE", was calculated by subtracting the maximum diameter for a day and subtracting the 5am diameter value.

SPSS (v.21.0.0.0; IBM Corporation 1989, 2012) was used to assess obtained measurements. Initial identification of extreme values was performed, as well as assessment for data distribution. Distribution of MDE, MDS and NDG data did not meet parametric assumptions of normality or homoscedasticity therefore non-parametric tests were performed. Non-parametric tests used were Kruskal-Wallis and Man-Whitney U comparisons of medians depending on experimental design. Spearman's correlations were performed to assess the relationship of environmental data with growth measurements.

Results

A notable difference among cherries at the different stages of development was the degree of fluctuation in size, recorded as the maximum daily expansion (MDE) and shrinkage (MDS) (figure 7). MDE of cherries at stage 2 (9.8mm) was over ten times higher than at stage one (0.9mm), and over one hundred times greater than post-ripe cherries (0.1mm). MDE of cherries at stage 3 (8.4mm) were also considerably greater than cherries during stage one as well as cherries when post ripe, although significantly less so ($p<0.01$) than during stage 2. MDS of cherries at stage 2 (19.5mm) and

3 (12.6mm) was significantly greater ($p<0.01$) than during stages 1 (0.04mm) or when post ripe (0.04mm).

No significant correlations were found between recorded weather data and fruit growth measurements.

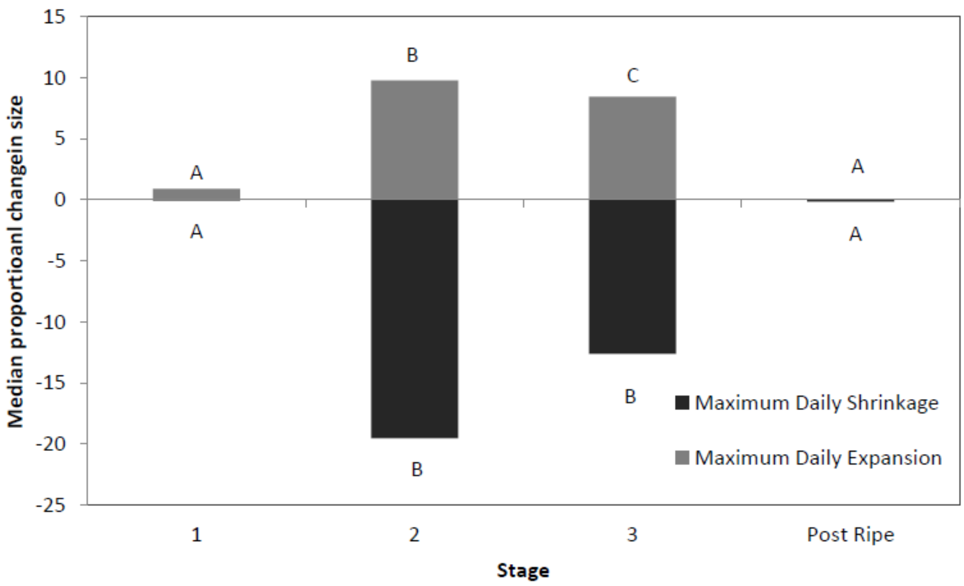

Figure 11 Daily maximum expansion (MDE) divided by initial (5am) diameter, and maximum daily shrinkage divided by initial (5am) diameter (MDS) of cherries at Old Beach at each stage of development. Different letters represent significant differences at p<0.05.

Disabling phloem by girdling did not significantly influence maximum daily expansion (MDE), maximum daily shrinkage (MDS) or net daily growth (NGD) of fruit during stages one and two of growth (table2). Neither did girdling significantly affect cherry growth or size fluctuation during stage three at Old Beach or Huonville, however MDE was found to be significantly less in girdled cherries during stage four at Old Beach. The diurnal growth pattern of girdled cherries was not observed to be significantly different from control cherries in the timing of size fluctuations. Detached cherries, however, were observed to have a considerably different diurnal growth pattern than control cherries (figure 8). Detachment of cherries reduced MDE to 0 in all cases, as well as significantly increasing MDS and reducing NDG compared to control cherries.

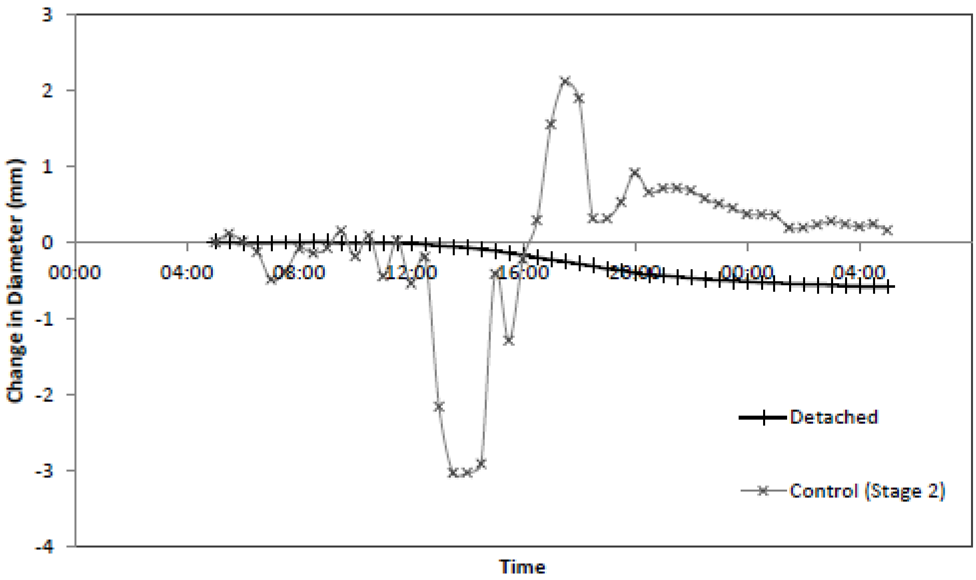

Figure 12 Change in size relative to initial size of detached fruit, with stage 2 control fruit for comparison

Discussion

This study has shown that water flow to cherry fruit becomes phloem-dependant in the final phases of growth. This finding is evidenced by a significant reduction of maximum daily expansion of cherries with girdled pedicels compared with untreated cherries during the post-ripe phase. Girdling disables phloem, so this difference points to the dependence of ripe cherries on phloem to supply water and maintain turgor despite water loss through transpiration. It indicates that cherries may have a similar physiological mechanism of water budget balance as grapes, which are believed to employ apoplastic/symplastic solute partitioning in order to enhance phloem unloading once ripe, excluding passive xylem flow by creating an excessively high hydrostatic pressure within the fruit (Greenspan, 1994, Keller, 2006, Bondada et al., 2005). The finding is also supported by observations in kiwi fruit, which are unable to support growth once the phloem was severed (Clearwater et al., 2012, Morandi et al., 2009).

Hence, cherry fruit in the first stage of growth are able to generate enough negative water potential to facilitate growth through passive xylem flow. During maturation, water uptake shifts to phloem flow, supporting photoassimilate supply. This leaves a non-viable option for cracking prevention (removing leaves and photoassimilate supply would reduce fruit quality).

The role of calcium on fruit integrity

This work has been accepted for publication in Acta Horticulturae (Appendix B)

Figure 13 Inspecting fruit in the calcium trial

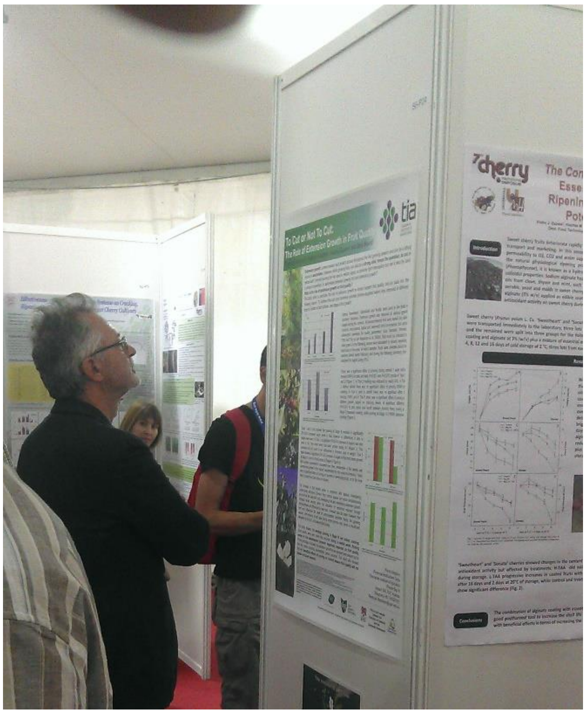

Figure 14 Project work being presented at the 7th International Cherry Symposium in Spain

The role of plant growth regulators on cuticle integrity

This work has been accepted for publication in Acta Horticulturae (appendix C)

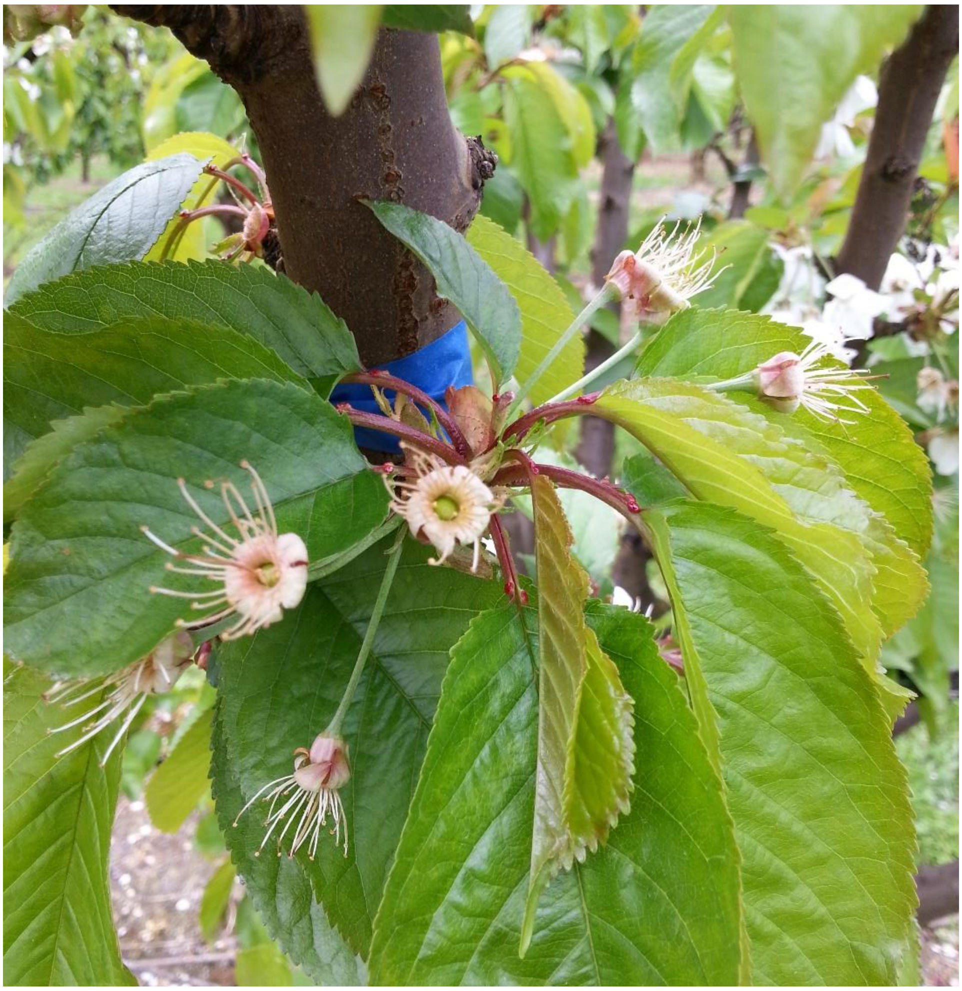

Figure 15 Monitoring rate of change from flower to fruit

Root pruning as a strategy to increase fruit set and crop load

This work is in preparation for scientific publication.

Introduction

These trials are additional to the original project proposal. This project had access to a commercial root pruner for other trials, and it was decided in consultation with the owner and grower, to make additional use of the pruner and investigate the impact of root pruning on fruit set. The previous project (CY09002) highlighted the beneficial impact of higher crop loads on reducing the incidence of cracking. An aligned project (CY12003) used these results as the basis to investigate plant growth regulators, and carbohydrate allocation through trunk girdling for improving fruit set.

Increasing fruit set through root pruning is much discussed anecdotally, but there is no scientific evidence for this approach. It is supported by scientific literature regarding resource allocation. The project team (CY12000) offered this trial for collaboration with the carbohydrate work of CY12003 but unfortunately resources were not available.

Throughout the growing season carbohydrate levels continuously vary within a tree, following a seasonal pattern (Chu et al., 1980; Keller and Loescher, 1989a; Luu and Getsinger, 1990). For example, the spurs have enough stored carbohydrate reserves to supporting the initial growth stages (budburst) until the developed leaves can support fruit development via photosynthetic processes (Chu et al., 1980; Keller and Loescher, 1989b). Therefore stored carbohydrates are a critical component in the success of bud burst and subsequent pollination and fruit set. The theory behind root pruning is to temporarily divert the carbohydrate resources to developing fruit rather than root growth.

Materials and Methods

Two field trials were undertaken in the southern hemisphere on a commercial sweet cherry orchard in Southern Tasmania. Trials used mature fruit-bearing trees of cultivar 'Lapins' on Mazzard rootstock, trained to a bush system. In trial 1 and trial 2 treatments were applied randomly to 5 target plots of 12 trees. Random allocation was undertaken prior to trial commencement and selected trees marked with flagging tape. Treatments consisted of an early (post-harvest April) and late (pre-bloom August) root pruning on either 1 side of the row, or both sides of the row.

Fruit set, calculated as the percentage of fruit remaining from the original number of flowers was assessed as fruit entered stage II of development (determined from visual assessment of pit-hardening). At harvest, a subsample of 25 randomly selected fruit from non-tagged branches of each trial tree was collected, returned to the laboratory and assessed for quality).

Analysis was undertaken using SPSS software (version 20). Differences between means (lsd) were considered significant at $P < 0.05$. Unless otherwise specified, all results quoted as significant are at probability level of 0.05. Figures were produced in Microsoft excel.

Results

Late root pruning (LRP) prior to bud burst significantly ($P<0.05$) increased crop load compared to no root pruning, irrespective of whether 1 or 2 sides of the row were pruned (Figure 16); from 66% fruit set to almost 80%. Early root pruning (ERP) did not significantly affect fruit set or final crop load or yield (Figure 16).

Root pruning on both sides resulted in significantly lowered fruit size (Figure 17) but there was no significant difference in quality of fruit from trees with one row side being pruned. In the first year of trials there was no rainfall event and thus the impact on cracking from the changed crop load and fruit quality could not be assessed.

In the second year, however, results were similar with fruit set increasing by 25% with late root pruning. Interestingly, these trees also showed fruit of improved quality; fruit size was increased (from 14.5 g to 15.7 g) with no impact on fruit sugars or firmness. Following rainfall, root-pruned trees showed reduced cracking incidence (12% compared to 9%).

Discussion

The results showed variable responses to root pruning indicating that there is additional knowledge required before this can be recommended as a reliable option to increase fruit set. The trials do however show that it has potential for manipulation of crop load.

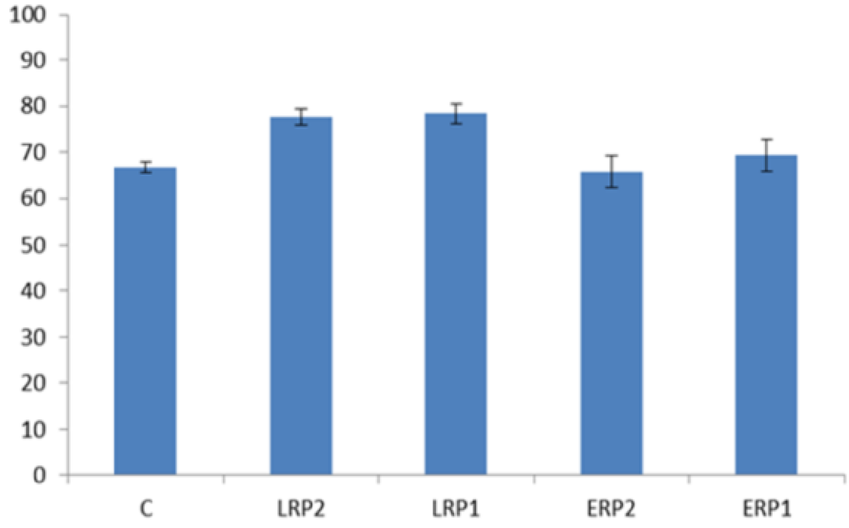

Figure 16 The fruit set on trees with no root pruning (C) or late root pruning on 1 (LRP1) or 2 (LRP2) sides of the row. Error bars represent standard error of the mean (SEM).

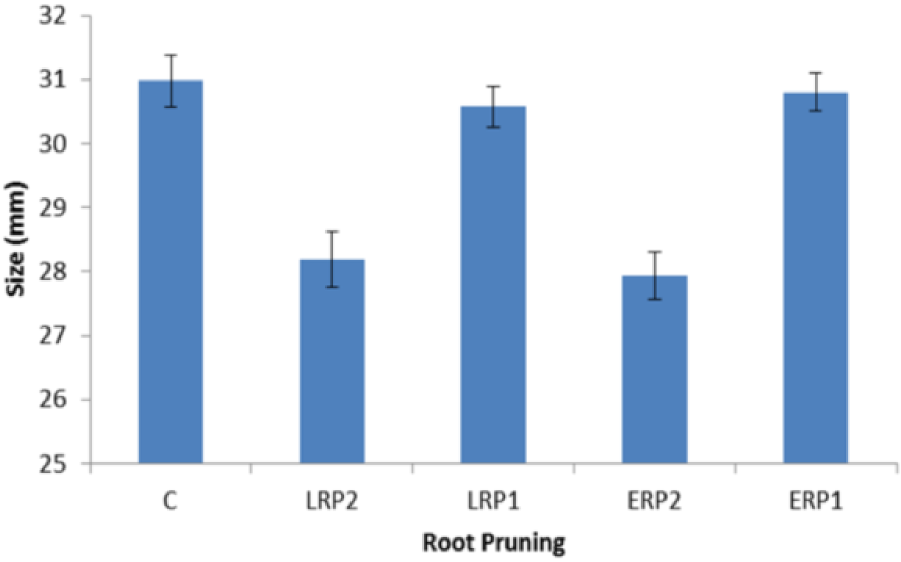

Figure 17 The size (mm) of fruit from trees with no root pruning (C), Late root pruning on 1 (LRP1) or 2 (LRP2) sides of the row. Error bars represent standard error of the mean (SEM).

Outputs

Industry information

1. Measham, PF, “Calcium and Sweet Cherries”, Horticulture Australia Limited, Tree Fruit Magazine, Australia, October (2013)
2. Measham, PF, “Trends in Cherry research”, Australian Cherries, Horticulture Australia Limited, Australia, December (2014)
3. Measham, PF, “Reducing the impact of late season rainfall in cherries”, Tree Fruit, Fruit Tree Media, Australia, October, pp. 3-5. (2015)
4. Measham, PF, “How well do fruit from highly irrigated trees perform post-harvest?” Australian Cherries, Cherry Growers Australia Inc, Hobart, Tasmania, April (2013)
5. Measham, P, “Reducing the impact of late season rainfall CY12000”, Australian Cherries, Cherry Growers Australia Inc, Hobart, Tasmania, 20, pp. 13-14. (2015)
6. Measham, PF, “Cherry Cracking” Cherry Growers Australia (2016)

Industry presentations

1. Measham, PF and Cover, IP and Rix, KD and Bound, SA, “Cytolin and nose cracking”, Victorian Cherry Association Conference 2015, 14-15 May 2015, Healesville, Australia (2015)
2. Measham, PF, “TIA: Cherry fruit quality”, Victorian Cherry Association Field Day, 15 October 2015, Victoria, Australia (2015)
3. Measham, PF, “TIA: Cherry fruit quality”, South Australian Cherry pre-season seminar night, November, South Australia, Australia (2015)
4. Measham, PF and Wilson, SJ and Bound, SA and Gracie, AJ and Cover, S, “Reducing the impact of late season rainfall - Rain and cracking”, Poster/Oral Presentation at the Fruit Growers of Tasmania May Conference, May, Hobart, Tasmania (2013)
5. Measham PF, “Understanding the permeability concept” Invited presentation to Fruit Growers Victoria (2014)
6. Measham, PF, “Yield and Quality in Perennial Agriculture”, TIA Showcase, August, Launceston, Tasmania (2013)

Fact sheets

1. FS28 Cracking and calcium
2. FS27 Apical-end scarring and cracking
3. FS9 Fruit water uptake
4. FS8 Giving fruit a helping hand
5. FS7 Arbuscular mycorrhiza (AM) and sweet cherry
6. FS5 Reducing the impact of late season rainfall
7. FS3 Yield and Quality

Fact sheets are available on the Tasmanian Institute of Agriculture (TIA) web site,

http://www.utas.edu.au/tia/centres/perennial-horticulture-centre/fact-sheets-and-tools/fact-sheets-and-tools2

There is also a link to the TIA fact sheet section of the website from the Cherry growers Australia website.

Theses

1. Honours

Diurnal Growth Patterns of Sweet Cherry Fruit and the Function of Pedicel Phloem and Xylem

By Matthew Calverley (supervised by Dr Penny Measham and Dr Alistair Gracie)

2. Masters

Arbuscular mycorrhizal fungi and their influence on growth and water relations of sweet cherry rootstock and tomato plants

By Hend Mohamed (supervised by Dr Penny Measham and Dr Karen Barry)

Scientific presentations

1. Measham, PF and Cover, IP and Bound, SA, "Flowers to fruit; early fruit formation and late fruit quality", 28th International Horticulture Congress, 17-24 August 2014, Brisbane, Australia (2014)
2. Mohamed, H and Barry, K and Measham, P, "The role of arbuscular mycorrhiza in establishment and water balance of tomato seedlings and sweet cherry cuttings in low phosphorous soil", International Horticultural Congress 2014, 17-22 August 2014, Brisbane, Australia (2014)
3. Knoche, M* and Measham, PF, "The permeability concept: A useful tool in analyzing water transport through the sweet cherry fruit surface", Proceedings of the 7th International Cherry Symposium, 23-27 June 2013, Plasencia, Spain (2013)
4. Measham, PF, "The when and where of calcium uptake", Proceedings of the 7th International Cherry Symposium, 23-27 June 2013, Plasencia, Spain (2013)
5. Measham, PF, "Impacts of irrigation volume on bloom and fruit set of sweet cherry (Prunus avium L.)", Proceedings of the 7th International Cherry Symposium, 23-27 June 2013, Plasencia, Spain (2013)
6. Calverley, M, "Sweet cherry growth patterns" Ag Institute student forum, Hobart (2012)

Scientific publications

See section "Scientific refereed publications"

Outcomes

Research

- Type of calcium application changes distribution of calcium within the fruit (and changes susceptibility to different crack types)
- Foliar calcium application increased fruit skin calcium levels
- Calcium application can be manipulated to build resilience to different crack types
- Water-stressed trees are more likely to experience fruit cracking with rainfall events
- Irrigation can be utilised to build resilience into fruit by maintaining structural integrity
- Ground covers impact on root water uptake by fruit trees
- Ground water uptake can be manipulated to reduce side cracks
- Root pruning near harvest is not practical in wet seasons
- Root pruning can impact on fruit set in one year
- Manipulating crop load can promote resilience to rainfall
- Permeability concept explained to growers
- Early applications of Cytolin reduce apical-end scarring, and subsequent cracking, in regions with cool springs
- Fruit pedicels (stems) are functional throughout the growing season, and do not have the potential to restrict water uptake after rainfall
- Soil fungi, arbuscular mycorrhiza (AM) improve cutting establishment in 'Colt' rootstock
- AM fungi promoted seedling growth, and have potential to alter water use in mature trees

Capacity

- Two trained horticultural scientists
- Research assistant now employed by Industry (Fruit Growers Tasmania)
- Increased research exposure to cherry industry (plant pathologist)
- Growers with user-friendly reference materials

Adoption

- Calcium application occurring earlier
- Orchards trialling root pruning for fruit set
- Orchards trialling use of PGRs for cracking prevention
- Continued engagement with growers allows for discussion of this and previous project results

Evidence of adoption and understanding of research outcomes

http://www.abc.net.au/news/2015-01-14/farmers-assessing-rain-damage-to-fruit-crops/6016918

In January 2015 southern Tasmania experienced a very high rainfall event; up to 145mm overnight. Several growers were interviewed about the event, and revealed a good understanding of cracking mechanisms, factors of influence and management options. Specifically comments revealed an understanding of;

- The impact of seasonal timing on cracking

  (Late season rainfall is more damaging, and fruit close to harvest most susceptible)

- The impact of diurnal timing of rainfall on cracking

  (Overnight rainfall is not as damaging as day time)

- The different water pathways that result in cracking damage

  (Direct absorption across the fruit skin, and uptake from the soil through the vascular tissue)

- The different susceptibilities of varieties

  (Lapins is highly susceptible)

- The benefits of carrying a higher crop load
- The benefits of cover sprays
- The timing of water exposure on fruit and impact on cracking

  (Understanding the permeability concept, and how fruit regulates water status on overcast and humid days)

Collaboration

The prevention of cracking internationally has been bolstered by a collaboration with Turkish and American researchers facilitated through scientific discourse while undertaking this project – leading to the provision of guidance and advice on cracking management, and the combining of data to jointly publish results. Additionally, presenting work from this project in the international realm precipitated a theoretical discussion and new approach to the ability of cherries to self-regulate water status – leading to the joint publication of a permeability concept. These discussions also allowed data from a previous cracking project to be revisited and analysed for publication; an output that would not have occurred without this project being undertaken.

Scientific refereed publications

1. Measham, PF, Wilson, SJ, Gracie, AJ and Bound, SA. (2014) Tree water relations: Flow and fruit. *Agricultural Water Management* 137 59-67
2. Mohamed, H, Measham, PF and Barry, KM. The role of arbuscular mycorrhizal fungi in establishment and water balance of tomato seedlings and sweet cherry cuttings in low phosphorous soil, accepted *Acta Horticulturae*
3. Measham, PF, Cover, I and Bound, SA. Early fruit formation and late fruit quality, accepted *Acta Horticulturae*
4. Knoche, M* and Measham, PF. The permeability concept: A useful tool in analyzing water transport through the sweet cherry fruit surface, accepted *Acta Horticulturae*
5. Measham, PF, Townsend, A and Richardson, A. The where and when of calcium uptake, accepted *Acta Horticulturae*
6. Bound SA, Close DC, Quentin AG, Measham PF, Whiting MD. Regulating crop load of Sweetheart and Van sweet cherry for optimal quality, accepted *Acta Horticulturae*
7. Measham, PF, Long, L, Ağlar, E and Kaiser, C. Post-harvest benefits of pre-harvest cracking treatments, under review, *Fruits*
8. Measham, PF, Cover, I, Bound, SA and Rix, K. Reducing scar tissue and subsequent fruit cracking with early PGR applications, submission 2016 to Journal of Agricultural Science
9. Measham PF, Cover, I and Wilson SJ. Ground cover and water uptake in sweet cherry; implications for fruit cracking, submission 2016 to HortScience.

IP/Commercialisation

Nil

Acknowledgements

This research was carried out with funding from Horticulture Innovation Australia Limited using the Cherry industry levy, with co-investment from Hansen Orchards and funds from the Australian Government. The authors would like to thank those from Hort Innovation that provided guidance, advice and support throughout the project; in particular Stuart Burgess and Kathryn Young. We also wish to acknowledge the support of industry bodies; Cherry growers Australia and Fruit Growers Tasmania. The generous support of growers enabled the research to be undertaken on representative commercial operations. Thank you to Howard Hansen, Ryan Hankin, Tim Reid, Nick Owens, Nic Hansen, Wayne Thompson, Matt Griggs, Shane Hutcheon, and Neil Polley. For technical and research assistance we would also like to thank Ian Cover, Alistair Gracie, Caroline Claye and Justin Direen.

Appendices – published/accepted papers

The role of Arbuscular Mycorrhizal Fungi in Establishment and Water Balance of Tomato Seedlings and Sweet Cherry Cuttings in Low Phosphorous Soil. *Acta Hoticulturae (in press)*

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Keywords: *Rhizophagus irregularis*, *Glomus intraradices*, photosynthesis, water potential, survival

Abstract

Extreme variability in water availability during the growing season makes sweet cherry fruit more prone to cracking. Therefore, experiments were designed to explore how mycorrhizal colonization of cherry roots may influence water regulation, as well as enhanced growth performance. Arbuscular mycorrhizal fungi (AMF) are obligate mutualists from the Order *Glomale*s and most fruit trees establish associations with AMF naturally when transplanted to the field, particularly in low phosphorous conditions. Although plants benefit from this symbiotic relationship through increased nutrients uptake especially phosphate, management practices influence the presence of mycorrhizal colonization in the field. This project has investigated the early growth rate and establishment of cherry (and tomato plants as a model system) inoculated with *Rhizophagus irregularis* (syn.*Glomus intraradices)*. After one month of growth, the number of leaves of mycorrhizal tomato seedlings was significantly increased and the height was approximately doubled in response to inoculation compared with non-inoculated tomatoes. In addition, a significant effect of AM fungi on cutting survival was observed, where 65% of inoculated cherry rootstocks survived after two months from striking, compared to 45% of non-mycorrhizal cherries. The effect of AMF on water uptake is currently being investigated in both sweet cherries and tomatoes to determine how colonization affects water uptake and photosynthesis during periods of drought and excess water conditions.

Calcium Application and Impacts on Cherry Fruit Quality. *Acta Horticulturae (in press)*

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Key words; Cherry, Cracking, Calcium, Fertigation

Abstract

The most common mineral employed in the management of fruit cracking is calcium (Ca). Ca is a xylem mobile mineral, and as fruit xylem connections and pathways are thought to be reduced during maturation, so early accumulation is vital. Ca has been implicated in building resilience to cracking into fruit, with many studies exploring the impact of late season calcium chloride ($CaCl_2$) spray applications on cracking. These trials have produced inconsistent results but early and repeated spray patterns for calcium uptake are supported by studies in apples.

Enhanced Ca uptake rates have been recorded in the sweet cherry variety 'Van' with the use of thickeners and surfactants. A major limitation of using direct Ca application to prevent cracking is the unsightly residue left on the fruit, therefore the benefits must outweigh this disadvantage. To assess from where Ca was incorporated into fruit (vascular supply, or directly across the fruit skin) trials were undertaken in Southern Tasmania, Australia which included Ca applications supplied via fertigation and/or foliar spray applications. Foliar sprays commenced either before or after Stage II (pit-hardening) of fruit development to assess when any uptake occurred. Ca levels were assessed using ICP-MS at both Stage II and at harvest maturity. It was expected that increased calcium would strengthen fruit tissue and reduce cracking resulting from rain. Relationships between fruit Ca and fruit quality (firmness) were explored, and the potential for continued use of Ca in mediating fruit cracking after rainfall discussed.

Flowers to Fruit; Early fruit formation and late fruit quality. *Acta Horticulturae (in press)*

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Keywords: *Prunus avium*, apical-end scar, fruit cracking, cytolin

Abstract

Early fruit development (from bloom to stage II) was followed in the current season on variety 'Lapins'; this variety has previously been exposed as susceptible to apical-end skin blemishes such as cracking and woody scar tissue. It has been shown that skin cracking at the apical-end of the fruit in response to late season rainfall is increased by water uptake across the fruit skin, which in turn is encouraged by water droplets forming in the apical-end depression in some varieties. This condition could be further exacerbated by the presence of growth scars. Anecdotal information and industry reports support the development of apical-end skin blemishes in regions which experience a long cool spring and a protracted period of development. To explore this problem, regular flower and fruit monitoring early in the season was undertaken at two sites. The relationship between floral part retention, scarring and the development of larger cracks following late season rainfall was investigated. Style retention was found to increase both scarring and apical-end cracking. Furthermore, to determine if timely progression (rate of development) from floral through to fruit formation affected the formation of apical-end scarring, floral closure was promoted using a growth promoting spray applied at 50%, 100% and 2 weeks after full bloom. Preliminary results showed that style retention is increased under a slower progression of flower to fruit.

Preharvest application of biofilm leads to reliable supply of high quality cherry fruit after storage *(submitted)*

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Abstract

The production of sweet cherry fruit is intensive and high-risk. A major challenge throughout the growing period is rain-induced fruit cracking. A new copolymer of stearic acid, cellulose and calcium (SureSeal) and a related product by the same developers with palm oil replacing the stearic acid (Parka®), has shown that anti-transpirants may have considerable potential in reducing cracking at harvest, thereby increasing yield of marketable fruit. However, sweet cherry fruit are a thin-skinned, soft fruit and the major challenge post-harvest is maintaining quality for greater than a few weeks. Maintaining fruit quality through to the retailer starts with producing optimum fruit at harvest, and reducing water loss during post-harvest storage. Coatings applied postharvest have been shown to retard water loss, and we now provide evidence of continued benefit of pre-harvest applications during post-harvest storage. Trials were undertaken on fruit from eight different orchards from tree different countries; Australia, the United States of America and Turkey. Reductions (20 – 77%) in cracking were seen in all trials, and fruit quality remained at a marketable level at harvest and through to 2 weeks post-harvest. The results of this study provide confidence that the increased yield and marketable quality of cherry fruit produced under management for rain-induced cracking are not diminished during storage.

Keywords; hydrophobic, elasticity, fruit coating, fruit cracking, rainfall

The Permeability Concept: A Useful Tool in Analyzing Water Transport through the Sweet Cherry Fruit Surface. *Acta Horticulturae (in press)*

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Keywords: *Prunus avium*, uptake, transpiration, pedicel, xylem, phloem

Abstract

Rain cracking of sweet cherry fruit is thought to be related to a net transport of water into the fruit. This net transport may occur along various pathways and in different directions, i.e., through the fruit surface and along the pedicel/fruit juncture as uptake into the fruit or transpiration from the fruit surface. In addition, vascular transport through the pedicel may contribute to rain cracking. Water transport through the fruit surface may be described quantitatively using Fick’s law of diffusion, where the amount of water taken up into or transpired from the fruit surface is expressed as the product of the fruit surface area, the driving force for water transport and the permeability of the fruit surface. Analyzing water transport on this basis allows prediction of the effect of selected fruit factors on net water transport; the leakiness of the pedicel/fruit juncture, the effect of fruit size, the magnitude of the driving force, the skin permeability or the effect of environmental variables such as relative humidity or the percentage of the fruit surface area wet. This modeling approach may be extended and a complete fruit water balance established by including estimates for vascular transport through the fruit pedicel. Examples using literature sources are provided of how these calculations may be used to identify important determinants in the fruit’s water balance.

Tree Water Relations; Flow and Fruit. *Agricultural Water Management, 137 pp. 59-67.*

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ABSTRACT

This study explores vascular influx of water in sweet cherry (*Prunus avium* L.) fruit because water is a key component of fruit quality and has been implicated in cherry fruit cracking. Flow to fruit is influenced by changing water potential of the fruit, and of potential gradients between the fruit and the spur. Water potential was influenced by vapour pressure deficit. In all seasons of this study, the most negative fruit water potential occurred in mid-afternoon when the magnitude of fruit water potential (Ψ_F) was greater than leaf water potential (Ψ_L) and analysis showed that there was a significant difference in this potential gradient between days with and without rainfall. Frequency analysis of days monitored over seasons further showed a significant association between the incidence of natural or simulated rainfall and the direction of sap flow to the fruit. This implies that manipulation of the driving forces within sweet cherry trees could be a viable management strategy for the prevention of cracking in cherry fruit. Furthermore, it suggests a role for orchard irrigation, in avoiding development of water potential gradients of fruit that favour rapid vascular influx of water following rainfall.

Key words: sap flow, fruit growth rate, water potential, water movement