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Pruning Strategies for High Density 'Montmorency' Tart Cherry

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PRUNING STRATEGIES FOR HIGH DENSITY
‘MONTMORENCY’ TART CHERRY

by

Sheriden M. Hansen

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Plant Science

Approved:

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UTAH STATE UNIVERSITY
Logan, Utah

2017

ABSTRACT

Pruning Strategies for High Density ‘Montmorency’ Tart Cherry

by

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Utah State University, 2017

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The tart cherry (*Prunus cerasus*) is the most significant fruit crop in Utah, accounting for approximately 51% of total statewide fruit acreage. Conventional low-density (LD) tart cherry plantings are designed to accommodate large trunk-shake mechanical harvesters. Availability of canopy-shake harvesters adapted to smaller trees could facilitate transitioning to high density (HD) systems, where continuous fruiting walls are highly efficient at light capture, and are more precocious than LD systems. HD systems would require specialized pruning techniques to maintain long-term productivity while maximizing the efficiency of a limited labor supply. In order to maintain tree health and crop quality, these systems must not compromise chemical protectant application. Experimental HD orchards with multiple rootstocks, training systems and tree densities were used for investigating both renewal pruning and mechanical pruning strategies. Pruning cuts of varying lengths (0 cm to 25 cm) were made on different diameter branches (0.6 to 4.7 cm), and renewal growth was monitored for shoot number, length and growth angle. In a separate study, mechanical hedging was carried out at bloom and 45 days after bloom, and plant response was compared based on yield, fruit quality and uniformity of spray distribution. It was found that leaving at least 10 cm of branch when making renewal pruning cuts was more likely to regenerate appropriate fruiting wood, but that rootstock and diameter both influenced the critical length needed for generating at least one renewal shoot. Mechanical hedging at bloom or 45 days after bloom did not affect yields or fruit quality when carried out in an orchard that had received adequate renewal pruning. In a second orchard that had not received sufficient renewal pruning, hedging initially reduced yield, but second-year yields of hedged trees were equivalent to or greater than unhedged controls. Spray pattern analysis with water sensitive targets suggested that hedging creates a more consistent canopy density resulting in improved spray coverage compared to unhedged HD trees. A survey of light distribution and fruit quality in conventional commercial tart cherry orchards did not provide conclusive results for determining optimum light microenvironment to meet fruit quality minimum standards. Additional research on light distribution in commercial orchards is needed. Maintaining long-term productivity of tart cherry orchards with an increasingly expensive labor supply is critical to the sustainability of fruit production. This research provides distinct guidelines on renewal pruning of HD plantings to maintain productivity. Results also indicate that mechanical hedging strategies can be a viable option for growers to reduce costs and time spent pruning the orchard, while still obtaining high yields. These results can help improve tart cherry production by reducing labor costs, and improving production of high quality fruit in Utah orchards.

(100 pages)

PUBLIC ABSTRACT

Pruning Strategies for High Density ‘Montmorency’ Tart Cherry’

Sheriden M. Hansen

The tart cherry (*Prunus cerasus*) is the most significant fruit tree crop in Utah, accounting for roughly 51% of the total statewide commercial fruit acreage. In order to accommodate harvesting equipment, tart cherries are grown in conventional orchards with large trees spaced up to 5.5 meters apart. New methods of harvest are adapted to smaller trees in tighter spaced high density (HD) orchards. HD orchards bear fruit earlier in the orchard life than conventional orchards, but likely require different pruning and management strategies, which have not yet been determined for tart cherry. Experimental HD orchards were used to determine the type of renewal pruning cuts to maintain orchard productivity, and to determine whether mechanical pruning (hedging) could be used to maintain tree size. It was found that when removing branches during pruning, leaving the branch stub at least 10 cm long greatly increases the likelihood of getting adequate renewal growth. Mechanical hedging at bloom or 45 days after bloom did not change yields or fruit quality when applied to a well-pruned and maintained orchard. Spray pattern analysis in these canopies suggested that hedging creates a more consistent canopy density than unhedged HD canopies. This research provides distinct guidelines on renewal pruning of tart cherry to maintain productivity, and shows that mechanical hedging strategies can be a viable option for maintaining tree size in HD plantings without increasing pruning costs.

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Sheriden M. Hansen

CONTENTS

Page

CHAPTER

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

LITERATURE REVIEW

Introduction

The tart cherry (*Prunus cerasus*) is the most significant commercial fruit tree crop in Utah and was officially made Utah's state fruit in 1997. Utah County accounts for most tart cherry production where 1,254 ha are dedicated solely to tart cherry. Acreage in Utah County accounts for forty-nine percent of Utah's dedicated fruit growing land. Utah produces roughly eight percent of the nation's total tart cherry crop and is typically ranked second in tart cherry production in the U.S. In 2014, Utah growers produced 23,200 Mg, in 2015, 18.3 million kg, and in 2016, 22.5 million kg of tart cherries (USDA, 2017).

Historically, tart cherries were tediously harvested by hand. A labor crisis in the 1960's led to the need for mechanized harvests resulting in the development and use of the trunk shaker harvester. This type of harvester clamps rubber drums onto the trunk of a single tree and shakes the trunk. Fruit falls from the canopy onto tarps beneath the tree where it is moved to cold water tanks and transported to packing facilities. Trunk shaker harvesters are large, cumbersome, and can be difficult to manipulate in the orchard. The need to accommodate these large pieces of equipment creates a low-density orchard environment with 6-meter alleyways and 4.3 to 5.5 meters between-tree spacing (Nugent, 2002). Scaffold branches in this system cannot be lower than 1 to 1.2 meters to accommodate the shaker head.

This system has seemingly served growers well, ultimately producing quality, high yields of fruit in a timely manner with minimal labor. However, there are some limitations to this system. Shakers can only be used with trunks that are larger than 12 cm in diameter to avoid lethal damage to trees, which means growers are forced to wait six to seven years after initial planting to harvest. Shaking done on less mature trees with smaller trunk circumference, 3.8 to 12 cm, results in up to two-thirds of trees being significantly damaged (Schulte et al., 1992). Trunk damage consists of cracking and shearing of the bark, resulting in diminished vascular flow of water and nutrients in the tree. Tart cherry trees can withstand a one-time injury where 50% of the circumference of the trunk bark is sheared off with no decrease in subsequent shoot growth or yield (Layne and Flore, 1991). Tree death occurs when 75 to 100 percent of the circumference of the tree bark is damaged; death is delayed by two to three years after injury (Layne and Flore, 1991). Vigorous trees are typically able to form callus and reestablish vascular flow to some extent when the bark is left on the tree. However, the damage that occurs with tart cherry harvest is repetitive at a yearly interval (Layne and Flore, 1991). This reduces the tree’s ability to form callus and heal, which leads to tree decline and ultimately diminishes the life of the orchard. The life expectancy of a tart cherry orchard is between 25 and 30 years, but decline from damage done at harvest often shortens orchard life to 15 to 20 years (Schulte et al., 1992). Low density spacing to accommodate harvest equipment in the orchard also creates other problems. Trees in this system do not significantly bear fruit until approximately 3 to 6 years after planting and typically reach full production at roughly 12 years (Papenfuss, unpublished). This lack of precocity coupled with shortened orchard life means that growers face a narrow window of productivity in their trees before decline.

These described conventional systems have been standard throughout the world for decades. Changes to the system started in Poland and Serbia where rotary-tine-tower harvesters were used on bush-type cherry trees. In the 2000's, researchers in Canada and the United States began experimenting with over-the-row harvesters for use with more traditionally shaped trees. Over-the-row harvesters are equipped with two drums with vibrating horizontal fingers that vibrate the tree canopy from each side of the tree, releasing fruit (Monroe, 1982). This type of harvester requires some careful considerations to tree form and pruning (Holownicki, 2013). Scaffold limbs can be started as low as 0.3 meters off the ground, which is much lower than the traditional system. Trees are no more than 2.4 to 3 meters high to accommodate the harvester tunnel. Also, limbs should be malleable and able to flex as they pass through the harvester, while carrying a high fruit load, in order to maximize tree potential.

These advances in harvest techniques are driving the industry to consider the development and use of a high density (HD) system for tart cherries. HD systems are typically used in apple production on trees with dwarfing rootstocks. The same principles used in apple production are now being applied to tart cherries with some adjustment. Spacing in the HD tart cherry system is tighter than the conventional low density (LD) system with alleyways of 3 meters or less. Development of dwarfing rootstocks for cherries has allowed between-tree spacing of 0.9 meters. This tighter spacing allows for a continuous canopy form for tart cherry and the development of a pyramidal shaped fruiting wall to maximize sunlight capture and accommodate the over-the-row harvester. The HD system benefits from improved precocity, with trees bearing and being harvested as early as the second or third year after planting, which could potentially increase grower revenue.

New advancements can be overwhelming to growers and may be met with some reservation, until it is shown that the benefits outweigh the costs. HD systems potentially mean smaller and simpler trees which can reduce labor costs and possibly give growers an economic edge. Longer orchard life, more precocious trees, higher economic gains, and higher yields of quality fruit are all potential benefits of the HD system.

High yields of quality fruit can largely be attributed to optimizing light capture and distribution in the HD canopy. Increased ability for the canopy to capture light due to canopy architecture and the development of a fruiting wall may contribute to more photosynthates, directly increasing fruit production and quality.

Light Microenvironment and Fruit Quality

Fruit quality is important to the tart cherry industry as it sets parameters against which a product can be measured. Quality for tart cherries is not as well defined as for some other crops. In apples, quality is defined as fruit that contains intense color, high dry matter mass, and high soluble solid levels (Palmer, 2007). It has been well documented over the last 30 years with apples that dry matter production, fruit size, color, soluble solids concentration, as well as total fruit yield are directly related to the amount of sunlight intercepted in the tree (Campbell and Marini, 1992; Flore and Layne, 1999; Palmer 1997; Wünsche et al., 1996). Centuries ago it was noted by growers that limitations on light, either by self-shading or from neighboring trees, limited fruit yield. Light interception consists of several factors: whole tree light interception, distribution of light through the canopy and the effect it has on fruit, and individual leaf light interception and its relationship to adjacent fruit quality.

Overall tree light interception is crucial to the plant's ability to produce both reproductive and vegetative tissues. Fruit quality is dependent on the amount of irradiation the tree can intercept and convert to biomass (Palmer, 2007). Light interception in the canopy is defined as the difference between irradiation above the canopy and the mean irradiance beneath the canopy (Flore and Layne, 1990). Not only is light intercepted from above the canopy, a small percentage of light also reflects off the orchard floor, contributing to the overall canopy interception of light.

As light filters through the canopy layers, a gradient of light interception is established that contributes to both whole tree light interception and light microenvironment. This gradient is determined by tree shape and size and can be manipulated by changing certain orchard design factors such as row spacing and orientation, tree height and shape, and tree spacing (Atwell et al., 1999). Traditionally, tart cherry is grown with a dense rounded canopy form. As light filters through the canopy, a gradient is established with the highest light levels in the top of the canopy and successively lower light levels moving toward the base. With apples grown in the same form as tart cherries, it has been shown that the upper third of the canopy has the greatest density of leaves, flowers, and fruit, as well as the highest light interception levels. Apple fruit quality, where fruit is exposed to more light at the edges and high in the canopy, has higher levels of soluble solids, increased size, and more intense fruit color (Tustin et al., 1989; Ferree and Hall, 1989). The lower third of the apple canopy makes the smallest contribution to the tree in terms of leaf area, flowers and fruit, and is correlated with the lowest light interception in the canopy (Ferree et al., 1980). Gradually decreasing fruit quality is also observed lower in the canopy with increased shade (Palmer, 2014). In apples that have been artificially shaded, there is a direct relationship between available light and fruit quality, including fruit size, dry matter mass, soluble solid concentration, and coloration (Campbell and Marini, 1992; Jackson, 1970; Palmer, 2014). It can be assumed that shading in the canopy can be detrimental to tart cherry yields in the same way. It is known that excessive shading in tart cherry leads to premature fruit drop (Flore and Layne, 1999). A linear relationship between the percent of light intercepted and the overall yield (Jackson 1978; Flore and Layne, 1990; Palmer, 2007) has been found in fruit including apple and tart cherry. Because light is critical for quality fruit growth and development, a canopy must be shaped and formed to capture as much light as possible.

Light microenvironment refers to the individual leaf capturing light and the contribution it makes to the quality of the adjacent fruit. Light at extremely high levels is not necessarily beneficial for fruit production. The light saturation point for a tart cherry leaf is ~600 to 800 μmol m^{-2} s^{-1} (Beckman et al., 1992) which is typically between 30 and 50% full sunlight (Flore and Layne, 1990). Allowing light to filter through the canopy at this range would theoretically create high yields of high quality fruit. The amount of light distribution through the tart cherry canopy at light saturation levels is not well documented, and may vary due to pruning practices that determine tree canopy density.

Measures of fruit quality such as color and dry matter mass are related to light microenvironment. Fruit color is possibly the most sensitive indication of light penetration in the canopy. Color indication of ripeness is a phenomenon among many fruit, including apple and peach (Atwell and Kriedmann, 1999), and is an important parameter for determination of ripeness and commercial harvest date for cherries (Milosevic and Milosevic, 2012). Both fruit size and proportion of red skin on apples is reduced if grown in shaded areas of the canopy, meaning that these characteristics are directly related to light interception (Jackson, 1970) by the fruit and the associated leaves. Because of this relationship, intense fruit color and fruit size are good indicators of quality fruit and can indicate the proportion of light the canopy is receiving at the location of the fruit.

Light microenvironment and specific light distribution also contribute to the partitioning of dry matter to fruit throughout the canopy (Wünsche et al., 1996). Dry matter mass is defined as total biological yield (Palmer, 2007) and is closely related to fruit size. The net total dry matter productivity of an apple orchard is related to light availability, light interception, photosynthesis, and respiration. The ability of a plant to capture light and increase dry matter mass in fruit is a function of the orchard system, leaf area index (LAI), and growing season (Wünsche et al., 1996). Creating a dense canopy with a high LAI to capture sunlight, does not necessarily increase dry matter mass; dense foliage in the tree canopy creates internal shading and can prohibit uniform light distribution in the tree. Dry matter is considered an important part of apple fruit quality as it contributes to the taste and eating experience of the fruit (Palmer, 2014). Dr. John Palmer noted, “Initial purchase is based on eye appeal, but repeat purchase is based on eating experience. Our production target should therefore be yield, fruit size, appearance, and eating quality, in other words: maturity and dry matter concentration.” (Palmer, 2014).

Creating an optimal canopy for light interception can be labor intensive. For a processed crop such as tart cherry, it can be difficult to justify labor-intensive training and pruning. One possible way to create an environment that will increase light capture in the canopy is the application of mechanical summer pruning to the HD tart cherry system. This may increase light capture and in turn create high yields of high quality fruit. Mechanization of pruning would simplify the pruning process, potentially saving time and money, making the system more economically feasible.

Response of ‘Montmorency’ Tart Cherry to Renewal Pruning Strategies

Fruiting in tart cherries occurs primarily from spurs on two-year-old and older wood, but may also occur on one-year-old wood. Precocious buds that form on one-year-old wood can contribute to branches that are bare and do not produce fruit (blind wood; Perry et al., 1998). ‘Montmorency’ tart cherries on Gisela rootstocks have a tendency to produce a considerable amount of blind wood. This can be treated with the application of gibberellic acid (Anderson et al., 1996) which stimulates the formation of spurs and increases bloom potential (Anderson, 1998). Renewal pruning is important in tart cherries to not only open the canopy, but to allow a continual supply of healthy fruiting spurs to be developed in the canopy (Cain, 1972). This technique replaces older rigid branches with thinner flexible branches. In apple and peach, short 2 cm long bevel cut stubs are left when renewal pruning. This is referred to as a Dutch or stub cut. From this short stub, a bud will break, typically on the underside of the stub. The resulting shoot will grow with a wide crotch angle and at a flatter angle, effectively replacing or renewing the cut branch (Robinson, 2003). Preliminary results indicate that tart cherries do not respond to short renewal cuts the same way apples and peaches do. Cherries appear to need longer lengths of stubs to regrow fruiting wood. However, an optimum length is not yet known. It is suggested that in addition to hedging, one-fifth of the largest scaffolds in the tree be renewed annually to keep scaffolds small, flexible, and fruitful (Crandall, 1979).

Increased air flow and light penetration in the canopy from renewal pruning is important not just for fruit yield and quality, but may facilitate effective spray application of crop protectants. It has been well documented that the canopies of well-pruned trees have greater spray penetration when compared to the canopies of lightly pruned trees (Sutton and Unrath, 1984). Hedgerow trees with dense canopies were found to have low deposits of spray materials (Ferree and Hall, 1980). Adequate spray penetration in the canopy is important as chemical application has a direct impact on fruit quality, fruit yields, and reduces insect and disease incidence. Using renewal pruning techniques coupled with hedging techniques may reduce the density of the outer canopy and increase spray penetration in the hedged canopy to facilitate the production of quality fruit.

Mechanical Summer Pruning

Tart cherry pruning by mechanically hedging has been tested in the United States since the 1960’s, although the practice never gained popularity with growers, possibly because it was thought to damage the canopy. Hedging creates a proliferation of shoot growth in the outer canopy just beneath the hedging cut (Kessner, 1990) which may reduce tree stature while improving light capture and increase fruiting area in the canopy

(Cain, 1972). Hedging may potentially reduce the amount of labor in the orchard and could be correlated to a specific timing for hedging in the summer months.

Summer hedging should be light, meaning removal of 10 to 50% of the current season's growth and should not cut into 2-year-old wood (Kessner, 1990). Heavy hedging or the removal of more than 2-feet of growth is considered a severe heading back and is often followed by vigorous shoot growth and a reduction in yield (Forshey, 1969). Trees should be hedged at an angle, this is crucial to light capture in the canopy and to avoid self-shading. Kessner (1990) suggests hedging at a 60º angle to be most beneficial for tart cherry production. In HD apple orchards, a steeper hedging angle is being used. High density apples 3.4 to 4.0 m tall are being hedged so that the top of the tree is 0.6 m wide and the lower canopy is no more than 1.2 m wide (Sazo, 2015). This results in a 9-11º angle from vertical, depending on tree height. Narrow apple canopies with a depth of 0.9 meters or less may have greater light interception than traditional canopies (Robinson et al., 2013). Dwarfing rootstocks planted in a high density system are ideal for hedging as smaller trees have a higher percent surface area exposed for sunlight capture than a large non-dwarfing rootstock (Cain, 1972). High density orchards, with their narrow canopies, have the potential to not only intercept high levels of light, especially when trees are young, but distribute light more evenly throughout the canopy than LD orchards (Roper, personal communication). More light captured by the canopy results in more formation of fruiting wood, higher quality spurs, better fruit coloration, possibly higher percent soluble solids, and more products of photosynthesis to partition to production of fruit. A potential concern with hedged trees is that it may create a dense outer wall to the overall tree form, and may create more internal shading in the canopy. The effect of hedging on the tart cherry canopy, light interception, and internal shading requires further research.

Timing of hedging is important as it impacts fruit production and development. It has been suggested in an early study conducted in Washington state, that earlier summer hedging done in June produced higher yields than late summer hedging (July and August) (Crandall, 1979). Early spring hedging may also create higher numbers of flower buds in the canopy. Crandall reported 93% and 98% of buds being flower buds when hedged June and July, with only 50% of buds being floral when hedged in August (Crandall, 1979). The number of flowers per bud do not diminish with summer pruning (Kessner, 1977). This is important to production because tart cherry buds are simple buds, meaning that they can only produce flower tissue or leaf tissue, but not both in the same bud. Having an adequate supply of both vegetative and floral buds to produce new growth of fruiting wood and fruit is important to yield.

Fruit set may be improved with summer hedging. Kessner (1977) saw a 20% increase in fruit set in summer hedged tart cherry trees, and when hedged 15 to 18 days before harvest, additionally a 20% increase in fruit size may be observed. It is interesting to note that leaf size may be greater by 20 to 30% in hedged trees as well, increasing surface area to potentially capture sunlight (Kessner, 1977).

Trees should initially be hedged just prior to bloom to establish a fruiting wall; a second hedging should then be carried out around 45 days after full bloom for best results. Kessner (1990) recommended the optimum timing for yearly hedging is 45 days after full bloom ± 2 to 3 days. Hedging at this critical point of development can change the direction of growth to promote shoot and spur development, increasing yields of good quality fruit (Kessner, 1990), and can stimulate flower bud formation, increasing yields for future crops. Preliminary results from a HD tart cherry planting in Michigan show that summer hedging at 45 days post full bloom, can yield an average of 5.4 kg/tree (roughly 9,761 kg·ha^{-1}). In contrast, winter hedging done on dormant trees in the same study was shown to be a less successful timing with yields averaging 1.7 kg/tree (2,913 kg·ha^{-1}) (Perry, 2015). It is important to note that these yields are unusually low and are not comparable to commercial yields, particularly in Utah.

Hedging creates a dense outer shell to the canopy by stimulating buds below the hedging cut to break and grow. This can create some unique problems including increased pathogen populations. Hedged trees in a 10-year study conducted in Washington had higher frequency of brown rot (Crandall, 1979). The dense outer wall created with hedging techniques may also change the way spray applications distribute within the canopy. The movement to smaller trees in the HD system could facilitate spray coverage, counteracting this potentially negative effect. Differences in spray distribution may warrant the need for changes to spray program protocol for HD and hedged trees. These potential problems may also be remedied with renewal pruning to open the canopy and increase air flow and sunlight penetration (Palmer, 2014).

Implications of Altering Pruning and Training Strategies on Crop Protection Needs

Pesticide and growth regulator recommendations are based on application in a standard orchard (Sutton et al., 1984.) Canopies can vary in depth and density and can be variable within and between orchards. Changes in orchard structure, moving from the traditional LD to the more modern HD system, requires reassessment of the effects on pests, as well as distribution uniformity of crop protectant applications. Applications of crop protectants must be made at the appropriate time, with material directed to the appropriate part of the canopy. Failure to cover the canopy adequately can result in poor outcomes and may leave fruit and leaves unprotected and susceptible to pest or pathogen damage. Additionally, applications should be made in an economic and environmentally sustainable manner.

Current technology for air blast sprayers uses high volume, fan generated air currents that force spray material through the tree canopy (Stansly et al., 1996) replacing air in the canopy with chemical laden air. Nozzle size and pressure applied during application determine droplet size and spray uniformity. The problem with air blast sprayers is that canopy layers can receive unequal spray distribution. Outside surfaces of the canopy often receive higher amounts of spray. In one study, fruit surfaces that faced the outside of the canopy received up to five times more spray than the inside surfaces (Stansly et al, 1996). Black et al. (1995) found in apple that less spray was captured at the bottom center position in the tree than at positions near the spray alley and at the top center of the tree. Based on the type of sprayer being used, bottom and top layers of canopy distribution can be widely variable. Each type of sprayer comes with a set of advantages and challenges, for example, some sprayers tend to favor the bottom and middle of the canopy.

The quality and uniformity of the spray can also be affected by air turbulence. Turbulence causes leaves to flutter, exposing leaves to spray on both the top and bottom surfaces. Greater air turbulence has the ability to carry spray to the backside of fruit and is a desirable feature for spray application (Stansly et al., 1996). High density systems may react differently to turbulence and spray uniformity due to smaller, more narrow, and more planar canopies. Non-turbulent air blast sprayers can carry material a greater distance from the sprayer, which can be useful in penetration of larger canopies or for multiple row distribution (Black, 2017).

Sutton et al. (1984) and Ferree et al. (1980) found that differences in apple canopy structure may account for variation in the deposition of crop protectants in orchards with different pruning and training. Canopy density is influenced by training and pruning and can contribute to the penetration of spray in the canopy. Higher density of spray deposits in well-pruned tree canopies compared to low deposits in lightly pruned trees is well documented. Deposits are also more uniform in well pruned trees. Well pruned trees require 30-50% less spray to achieve adequate coverage when compared to lightly-pruned trees (Sutton et al., 1984). Other factors that can affect spray deposits are row spacing, tree height, and canopy spread (Manktelow and Praat, 1997). In the HD tart cherry system, canopy shape and density are modified from the LD system. High density systems have narrower, more planar canopy shapes created by smaller trees spaced closer together to create a continuous canopy in the row, and the canopy is typically dense in tart cherry. Reduction in tree size means that trees are easier to prune, spray and thin (Palmer, 2014), increasing orchard management efficiency (Ferree and Hall, 1989). It has been suggested that trees that are hedged may make spraying easier, less expensive, and provide better control of insects and diseases (Crane, 1967), however, this may not be entirely accurate. As hedging creates a dense proliferation of shoots formed at the outer edge of the canopy, it is entirely possible that application of crop protectants may not penetrate the canopy as easily as with unhedged traditional trees.

Dense canopies in apples have been found to require higher spray volumes to achieve complete canopy coverage (Herrera-Aguirre and Unrath, 1980.) Pyramid hedgerow apple systems have a lower canopy volume than slender spindle and trellis systems and have been found to have the lowest distribution of spray deposits when compared to trellis and spindle systems (Ferree and Hall, 1989). Well-pruned trees that are less dense have been found to have better distribution of droplets than trees that are lightly pruned (Sutton et al., 1984). Deposits of spray materials have also been found to be more uniform in well-pruned apple trees than in lightly pruned trees (Travis, 1981). These findings may be applicable to the naturally dense canopy of the tart cherry. In HD tart cherry systems, the canopy is likely to be more dense than traditional tart cherry systems. Well-pruned HD orchards are likely to have higher and more uniform deposits on the outside edge of the canopy due to the canopy structure, but may require higher spray volumes to reach the middle of the canopy. Because of changes in canopy architecture, it is important for growers to know how to adjust spray volume and sprayer calibration to provide correct dosages of chemicals (Herrera-Aguirre and Unrath, 1980).

Objectives

The objective of this thesis was to test the following: First, to determine the response of ‘Montmorency’ tart cherry to pruning strategies including: renewal pruning (Chapter 2) and mechanical hedging (Chapter 3). Second, to assess the implications of altering pruning and training strategies on application of crop protectants (Chapter 3). Finally, to determine the relationship between light micro-environment and fruit quality in tart cherry (Appendix 1).

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CHAPTER 2

THE RESPONSE OF ‘MONTMORENCY’ TART CHERRY TO RENEWAL PRUNING STRATEGIES

Introduction

Renewal pruning is important in fruit production to promote the continual formation of new healthy fruiting spurs in the canopy (Cain, 1972). Renewal pruning also opens up the canopy to improve light penetration, to improve air circulation, and to maintain the productivity and health of the tree.

In many temperate fruit tree species, renewal pruning is used to replace large, rigid branches with smaller, flexible branches with healthy, young spurs and fruiting shoots. In apples and peaches, renewal pruning often involves leaving short, 2 cm long, bevel cut stubs, referred to as a Dutch or stub cuts (Fig. 2.1). From this short stub, a bud will break, typically on the underside of the stub. The resulting shoot will grow with a wide crotch angle and at a flatter angle, effectively replacing or renewing the cut branch (Robinson, 2003).

Tree canopies are complex systems that interact with light to ultimately achieve the production of high quality fruit. Fruit quality is largely dependent on the amount of light distribution to the location of fruiting spurs within the canopy. It has been well documented over the last 30 years in multiple fruit crops, that dry matter production, fruit size, color, soluble solids concentration and total fruit yield are directly related to the amount of sunlight intercepted in the tree (Campbell and Marini, 1992; Flore and Layne, 1999; Palmer, 1997; Wünsche et al., 1996). As light filters through the canopy, a gradient of light interception is established that contributes to both whole tree light interception and light microenvironment around the fruiting spur. Renewal pruning can influence the way light interacts with the canopy; by selectively renewing the largest branches in the canopy, light penetration may be increased. This increased light in the canopy promotes tree health, increased flower bud formation, and the development of quality fruit.

Renewal pruning for increased light interception can impact air circulation through the canopy as well. Air circulation is important to reduce the incidence of disease, such as fungal infections in the canopy. Tart cherry is susceptible to a host of fungal infections, such as powdery mildew (*Podosphaera clandestine*), as well as arthropod pests that thrive in dense canopies where air circulation is poor. The application of crop protectants is essential to maintain tree health and for the production of quality fruit that meets consumer standards. Selective renewal pruning can improve air circulation, decrease canopy humidity, decrease the prevalence of disease, and at the same time may make crop protectant applications more effective by increasing distribution through the canopy.

It has been well documented that the canopies of well-pruned trees have greater spray penetration when compared to the canopies of lightly pruned trees (Sutton and Unrath, 1984). Hedgerow trees with dense canopies were found to have low deposits of spray materials (Ferree and Hall, 1980). Adequate spray penetration in the canopy is important as chemical application has a direct impact on fruit quality, fruit yields, and insect and disease incidence. Some growers are using mechanical hedging to efficiently prune and reduce labor costs in the orchard, this practice can create a more dense outer canopy in the trees (Nugent, 2002). Using renewal pruning techniques may reduce the density of the outer canopy and increase spray distribution through the hedged canopy to facilitate the production of quality fruit.

This may be particularly important if mechanical pruning (hedging) is also used. It is suggested in current literature that, one-fifth of the largest scaffolds in the tree be renewed annually to keep scaffolds small, flexible, and fruitful if hedging is also used (Crandall, 1979).

Fruiting in tart cherries occurs primarily on spurs on two-year-old and older wood, but in certain circumstances, may also occur at the base of one-year-old wood. Cherries have simple buds, either flowering or vegetative, and fruiting buds that form on one-year-old wood result in blind nodes after the first fruiting year. In contrast, vegetative buds formed on one-year-old wood result in spurs that will fruit for several years (Perry et al., 1998). Any management practice that promotes more precocious fruiting, potentially risks excessive flower bud formation on one-year-old wood, further contributing to the amount of blind wood in the canopy. This can be managed with the application of gibberellic acid (Anderson et al., 1996) which suppresses flower bud formation in favor of vegetative bud formation, resulting in less blind wood formation in the canopy. However, renewal pruning is also required to replace blind wood with spur wood.

Although apples and peaches respond best to cutting branches to at least 2 cm stubs (Robinson, 2003), the stub length for tart cherry branch renewal is a topic that has not been well researched. Preliminary results indicate that tart cherries do not respond to short renewal cuts the same way apples and peaches do. Cherries appear to need longer stub lengths to regrow fruiting wood. Nugent (2002) recommended 10 to 15 cm stub lengths to promote renewal growth, but did not report data from which this recommendation was based.

The objective of this research was to find the minimum stub length to generate at least one new shoot on ‘Montmorency’ tart cherry in a high density orchard, and to determine whether this critical length was affected by rootstock vigor.

Materials and Methods

Renewal pruning strategies were applied to a high density (HD) tart cherry orchard planted in 2010 at the Utah Agricultural Experiment Station research farm in Kaysville, Utah (41°01’16°N latitude, 1328 m elevation, 165 freeze-free days). Experimental design was a randomized complete block with a 3 rootstock x 3 training system factorial treatment structure. The scion cultivar was ‘Montmorency’ tart cherry on three rootstocks: Gisela® 3 (Gi.3) and Gisela® 5 (Gi.5) dwarfing rootstocks, and the commercial standard ‘Mahaleb’ rootstock. Trees were trained to three different systems: single leader, double leader, and quad leader, with scaffolds oriented in line with the row to facilitate machine harvest. Tree spacing was 1.8, 2.4 and 3.0 m with alleyways spaced 3.8 m apart. Experimental units consisted of uniform 9.1 m long plots with varying numbers of trees per plot to facilitate machine harvest and allow for direct comparison of systems. Orchard soil was a Kidman fine sandy loam with 0 to 1 percent slopes. Fertility application rates differed between years, with nitrogen application rates of 55 $kg \cdot ha^{-1}$ in 2015 and 25 $kg \cdot ha^{-1}$ in 2016 banded within the tree row.

Annual dormant pruning was based on a columnarized system with renewal cuts made back to the main leader in a 3-4 year cycle. The targeted result was permanent leaders with weaker fruiting lateral shoots that are frequently replaced. During dormant winter months, trees were pruned by hand using protocols for tall spindle apples (Robinson et al., 2006) to facilitate light penetration in the canopy and to accommodate an over-the-row harvester. Briefly, the tall spindle apple protocol calls for annual renewal pruning of 2 to 3 of the largest branches in the canopy. Renewal pruning treatments were assigned by first selecting branches for removal and then cutting each of these to ~25 cm long. The diameter of each cut branch was then measured using hand held calipers, and categorized by diameter class: small <1.5 cm diameter, medium 1.5 to 2.5 cm diameter, and large >2.5 cm diameter. Stubs were flagged, numbered, and diameter recorded. Stub cut length was then assigned and cut based on stub diameter, rootstock, and training system. Stub length treatments varied slightly between 2015 and 2016. In 2015, target stub lengths were 0, 10, 18, and 25 cm. In order to better determine optimum stub length, the number of treatments was increased in 2016 to 0, 5, 10, 15, 20, and 25 cm. Stubs were cut to the assigned length on 23-27 March 2015 and 11-15 April 2016 and assessed for growth in early September in both years. Growth was evaluated by number and length of new shoots. In 2016, the growth habit, or angle of growth of these new shoots was also assessed. A growth angle less than 45º from horizontal was classified as horizontal, with angles greater than 45º classified as vertical.

Data for the number and length of regrowth were analyzed as a completely randomized design with 3 branch diameter × 5 branch length × 3 rootstock × 3 training system factorial treatment structure, using the GLM procedure in SAS statistical analysis software (Cary, NC). Shoot growth angle was analyzed using a generalized linear model performed on a logit scale that analyzed proportion of horizontal shoots to all renewal growth shoots.

Results

Shoot number

The amount of renewal growth, as determined by the number of new shoots originating from a renewal stub cut, was affected by the length of stub cut and the diameter of the cut branch in both 2015 and 2016 (Table 2.1). In 2016, the tree training system and rootstock also affected new shoot number. Except for a marginally significant interaction between rootstock and stub diameter, there was generally no significant interaction among these factors, and the data are presented as main effects for each factor.

In both study years, the number of new shoots per renewal cut was linearly related to the length of the stub cut (Fig. 2.2). In both years, the 25 cm stub lengths resulted in more than 2.5 new shoots per cut stub, with stub lengths approximately 10 cm in length resulting in an average of one new shoot per renewal cut.

In both years, regrowth was directly related to branch diameter. However, the magnitude of this diameter effect depended somewhat on the rootstock (diameter × rootstock $P > 0.075$; Table 2.1). This interaction is illustrated in Fig. 2.3. In both years, the largest diameter cuts on ‘Mahaleb’ rootstock had disproportionately more new shoots when compared to large diameter cuts on the other rootstocks. A representative example of medium and large diameter stub, and the resulting proliferation of new shoots is shown in Fig. 2.4.

A significant effect of training system on number of new shoots was found in 2016, but not 2015. Mean number of shoots per stub in the single leader system in 2016 was 1.45 shoots, compared to 1.02 shoots per stub in the double leader system, and 1.26 shoots per stub in the quad leader system (data not shown). This difference in training system effect between the two years may be due to severity of dormant pruning. In order to accommodate the interior space in the over-the-row harvester, tree height had to be reduced in the single leader system between the 2015 and 2016 seasons, resulting in more severe pruning. This may have led to increased regrowth for this system resulting in the significant system effect found in 2016.

Shoot length

The average length of new shoots is another way to quantify renewal growth response. Average shoot length was affected by rootstock, diameter, and stub length in both 2015 and 2016 (Table 2.1). There was a significant interaction between branch diameter and training system as well as between system and stub length in 2016, but no significant interaction in 2015. The data are presented as main effects of each factor.

The interaction between training system and stub length observed in 2016 appears to be the result of disproportionately longer new shoots originating in the single-leader system, particularly at intermediate stub lengths (Fig. 2.5). This may be due to the more intense pruning severity required in this system. In general, average new shoot length increased with length of the branch stub, but the effect diminished with longer stub length

(Fig. 2.6). In both years, 10 cm length stub cuts resulted in new average shoot lengths of 32.6 cm, whereas leaving stubs 2.5 times longer only resulted in average shoot lengths of 47.5 and 41.2 cm in 2015 and 2016, respectively.

The number of new shoots was also related to stub diameter and rootstock, with larger diameter and higher vigor rootstocks producing greater numbers of new shoots. Linear regression was used to calculate the critical stub length for each rootstock and branch diameter combination (Table 2.2). In order to regrow a single renewal shoot, smaller diameter stubs on Gi.3 rootstocks required 14 cm stub length as compared to Gi.3 large diameter stubs that required 8 cm. ‘Mahaleb’ large diameter stubs could be as short as 5 cm in order to regrow a single shoot. Larger diameter stubs on more vigorous rootstocks needed less length to promote appropriate renewal growth.

The effect of rootstock on new shoot length differed slightly between years, but was also related to branch diameter (Table 2.1). This rootstock × diameter interaction is illustrated in Fig. 2.6. In general, large diameter renewal stubs and vigorous rootstocks, such as ‘Mahaleb’, consistently resulted in longer new shoots than smaller diameter stubs and less vigorous rootstocks. The one exception to this trend was for large diameter stubs on Gi.3 rootstocks in 2016, where average length of regrowth shoots was 45.2 cm/branch, compared to 38.3 and 39.3 cm/branch for Gi.3 and ‘Mahaleb’, respectively (Fig. 2.6).

The fraction of new shoots that had a horizontal growth patterns was significantly influenced by branch diameter ($p < 0.001$; Table 2.3), where larger diameter stubs tended to produce a higher proportion of vertical shoots than smaller stubs (Table 2.3).

Discussion

Renewal pruning cuts in fruit trees are advantageous as they provide greater infiltration of light and opportunity to renew growth and fruiting spurs in the canopy (Robinson, 2006; Schupp et al., 2017). It is well known that short stub cuts lead to renewal growth in apple and peach. However, critical length of renewal pruning cuts to provide adequate new growth in tart cherry or sweet cherry is not well documented. Nugent (2002) recommended that renewal stub lengths be left between 10 and 14 cm for tart cherry, but this recommendation was not based on any published data. This study confirms that recommendation as lengths greater than 10 cm generally produced one new renewal shoot per cut in the season following pruning. However, this critical length was influenced somewhat by rootstock and diameter. The rootstock effect on regrowth are predictable based on the relative tree vigor. ‘Mahaleb’ is the most vigorous rootstock included here, producing large trees that are 90% of full sized seeding Mazzard trees (Long and Kaiser, 2010), where dwarfing Gi.3 and Gi.5 produce trees less than 50% of the size of full-size trees (Long et al., 2014). The higher number of new shoots and the longer average shoot length would be expected for a higher vigor rootstock.

Training system also affected regrowth, but only in 2016. To facilitate the use of a mechanical over-the-row harvester in the orchard, tree height and width had to be considered during dormant pruning. Height of trees could not exceed 3.4 meters in order to fit through the harvester. Trees in all systems were pruned to fit through the predetermined space. However, the single leader trees had a tendency to be taller than that of the other training systems, which required more severe dormant pruning in this system. Pruning protocols followed typical spindle pruning developed for apples with 2 to 3 of the largest limbs being renewed annually. This renewal pruning strategy, coupled with the height reduction cuts contributed to an overall higher severity of dormant pruning in the single leader trees. Schupp et al. (2017) found that severity of whole-tree pruning had an effect on the number of new renewal shoots in apple, with greater numbers of new shoots in more heavily pruned trees and recommend a pruning severity index to compare severity. In the present study, data were not collected to compare severity among treatments, but the results of this study may suggest that a severity index could also predict regrowth response in tart cherry.

Conclusion

Results indicate that to produce at least one new shoot, renewal pruning cuts in ‘Montmorency’ tart cherry should be 10 cm long, which is considerable longer than the lengths required for apple and peach. It is important to note that critical length can be impacted by the diameter of the renewal stub as well as the rootstock vigor associated with the tree. Regrowth is likely impacted by pruning severity, but further work is needed in order quantify this effect in tart cherry.

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Tables

Table 2.1. Analysis of variance for regrowth at stub cuts for number of new shoots, and the average length of new shoots.

	Number New Shoots		Average Shoot Length	
Source	2015	2016	2015	2016
Rootstock	-	0.081	0.011	0.029
System	-	0.005	-	-
Diameter	< 0.001	< 0.001	< 0.001	<0.001
Stub Length	< 0.001	< 0.001	< 0.001	<0.001
Rootstock*System	-	-	-	-
Rootstock*Diameter	0.064	0.073	-	-
Rootstock*Length	-	-	0.064	-
System*Diameter	-	-	-	0.038
System*Length	-	-	-	0.001
Diameter*Length	-	-	0.065	-
Rootstock*System*Diam	-	-	0.013	-
Rootstock*System*Length	-	-	-	-
Rootstock*Diameter*Length	-	-	-	-
System*Diameter*Length	-	-	-	-
Rootstock*System*Diameter*Length	-	-	-	-

Table 2.2. Critical stub length required to regrow one shoot for each rootstock and branch diameter category. Linear regressions were calculated for each combination. Asterisks indicate the R^2 of the regression.

	Stub Diameter		
Rootstock	Small (<1.5 cm)	Medium (1.5-2.5 cm)	Large (>2.5 cm)
	Length of stub cut (cm)		
G3	14.1**	10.6***	7.8**
G5	11.5***	10.2***	8.4***
MAH	10.2**	8.6*	5.1***

* R^2 = 0.80-0.89, ** R^2 = 0.90-0.94, ***R^2 = 0.95-1.00

Table 2.3. Factors affecting angle of regrowth. The proportion of total new shoots with horizontal (<45°) orientation was compared using a generalized linear model performed on the logit scale. Variables tested were trunk cross-sectional area (TCSA), rootstock, training system, stub diameter and stub length.

Factor	*P* > F
TCSA	-
Rootstock	-
Training System	-
Stub Diameter	<0.001
Stub Length	-

Figures

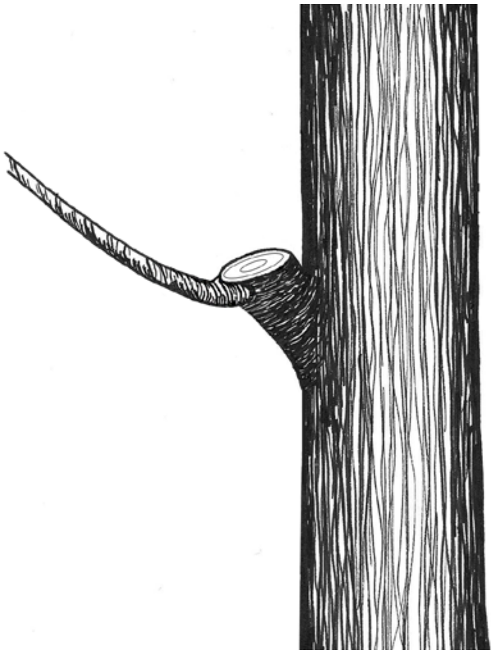

Fig. 2.1. Illustration of a typical favorable regrowth response to a beveled renewal cut. Leaving the lower side of the branch cut longer than the upper side encourages regrowth from the underside of the cut, creating new growth with wide branch angles and a more horizontal growth angle suited to fruit production. (Illustration by A. Spranger, USU.)

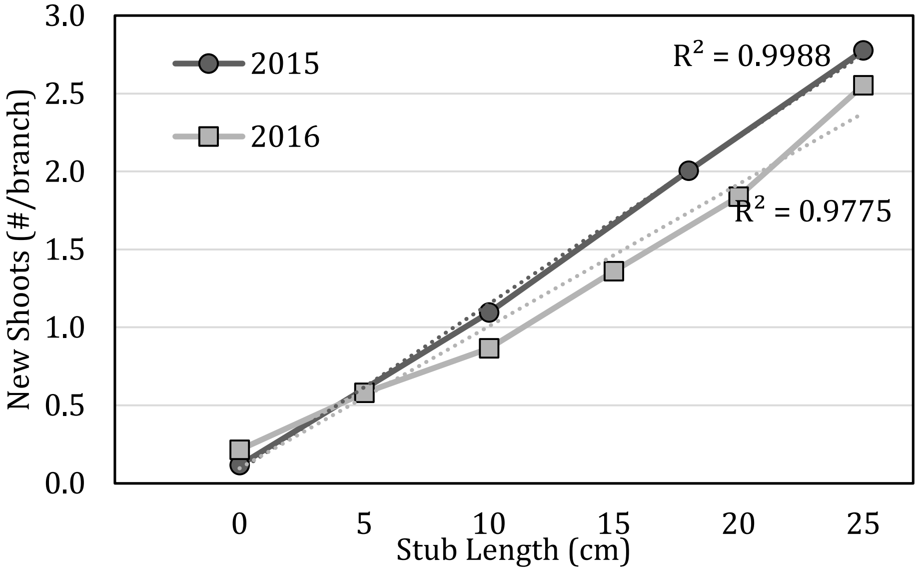

Fig. 2.2. The effect of stub length on regrowth as determined by the number of new shoots formed per branch cut. Values are averaged across rootstock, training system and stub diameter to show general trends so that each value represents the mean of at least 200 and 100 observed renewal stubs in 2015 and 2016, respectively. R^2 values are for a linear regression model. Within the various treatment combinations, the relationship between stub length and new shoot number remained linear.

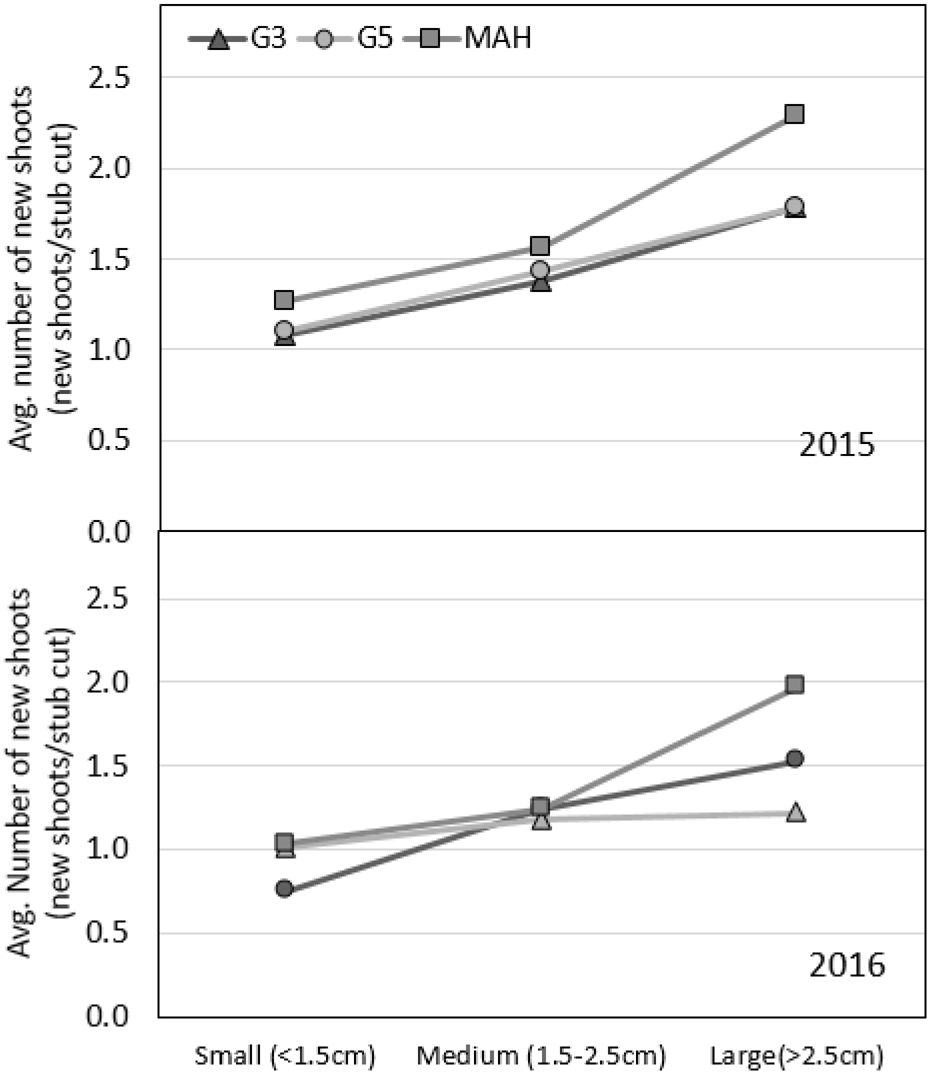

Figure 2.3. The effect of rootstock and branch diameter on regrowth as determined by the number of new shoots formed per cut branch in 2015 (A) and 2016 (B). Values are averaged across training system and stub length, and represent the means of at least 80 and 50 stubs per branch diameter and rootstock combination in 2015 and 2016, respectively.

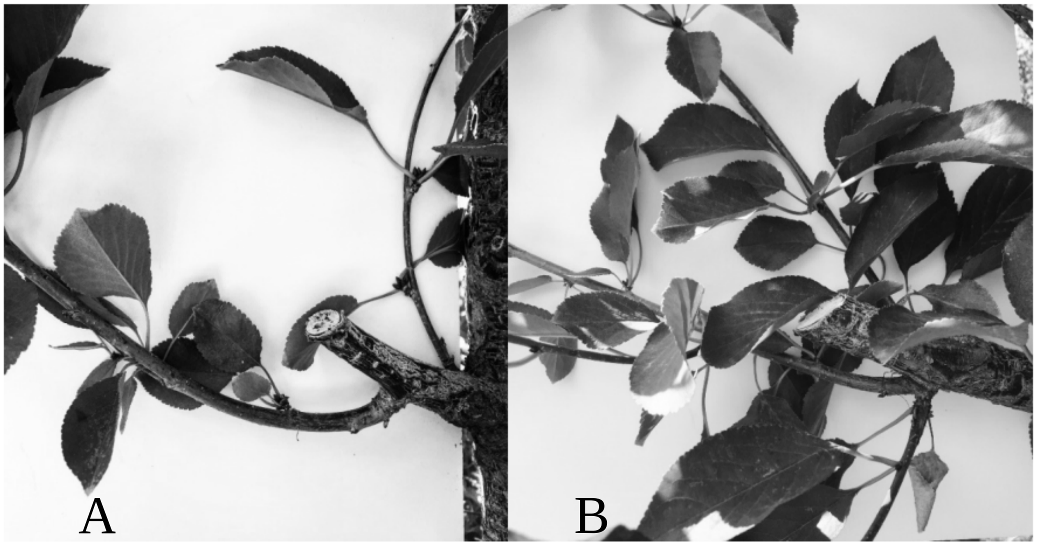

Fig. 2.4. The effect of stub diameter on shoot regrowth for a medium (A) and a large diameter stub (B). Both are on Gi.5 rootstock trained to a single leader. The medium diameter cut shown in A resulted in regrowth of one shoot, compared to four new shoots on the large diameter stub (B). Note that the smaller shoot in the background (A) originates from the base of the stub cut branch and is not current year regrowth.

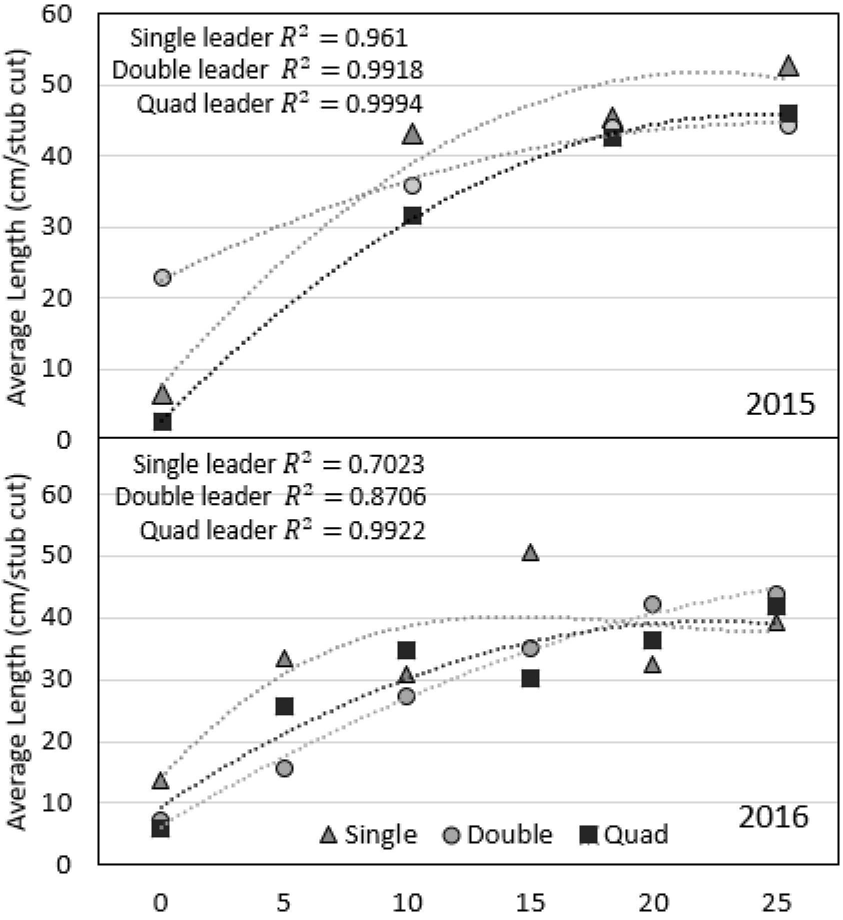

Fig. 2.5. The effect of branch stub length and training system on renewal growth as measured by the average length of renewal shoots. Values are averaged across rootstock and stub diameter and represent the means of at least 70 and 30 renewal stubs observed per treatment in 2015 and 2016, respectively. Values of R^2 are for a quadratic regression model.

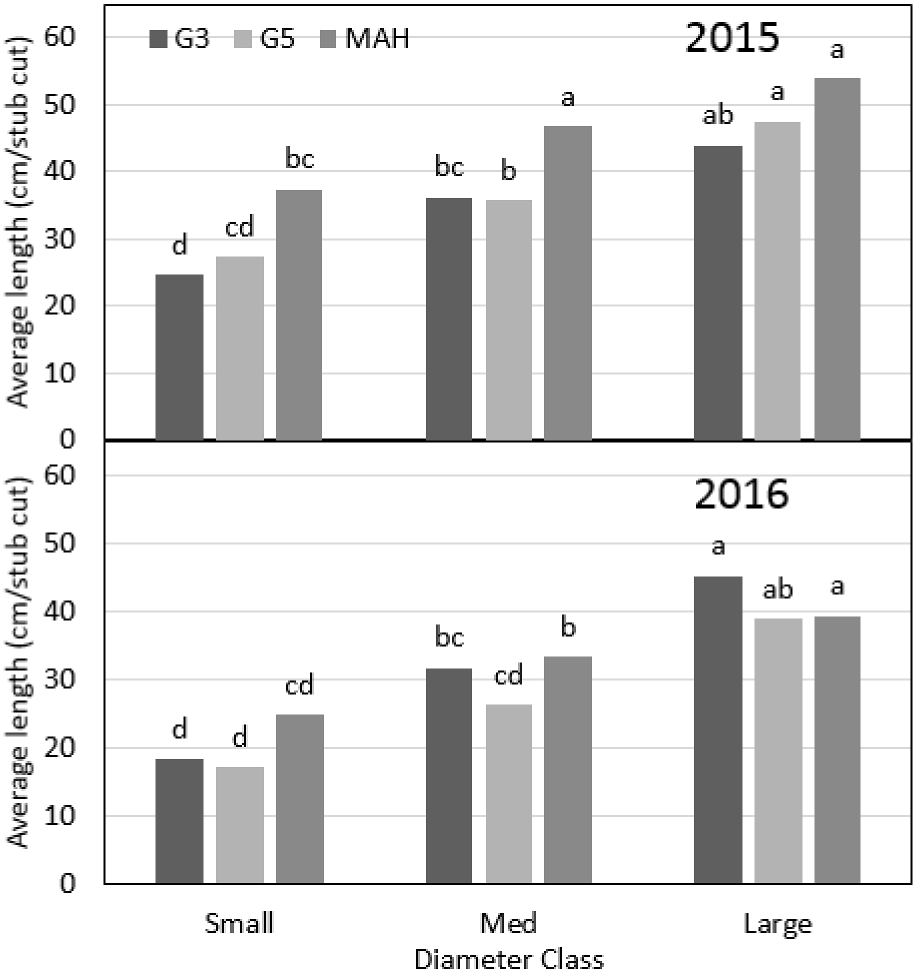

Fig. 2.6. The effect of rootstock and diameter on regrowth, as measured by the average length of shoots formed per renewal cut. Branch diameter was classified into small (<1.5 cm), medium (1.5-2.5 cm) and large (>2.5 cm) categories. Values are the means of at least 105 (2015) and 61 (2016) renewal stubs observed per rootstock.

CHAPTER 3

THE RESPONSE OF ‘MONTMORENCY’ TART CHERRY TO SUMMER MECHANICAL HEDGING

Introduction

Tart cherry is the most important commercial fruit crop in Utah, both in acreage and in financial value. Fifty-one percent of Utah’s dedicated fruit growing land is used for tart cherry production and Utah produces about eight percent of the nation’s total tart cherry crop. Utah produced 18,300 Mg of tart cherries in 2015 and 22,500 Mg in 2016 (USDA, 2017).

Roughly 95% of tart cherries grown in Utah are processed (USDA, 2017). As with other fruit destined for processing, the value per kg of this crop is relatively low compared to tree fruit crops that go to fresh markets. Tart cherries produced in Utah are valued at \$0.55-1.12/kg (UDAF, 2017), considerably less than \$0.94-2.74/kg for fresh market sweet cherries and \$0.74-1.19/kg for fresh market peaches. One of the largest production costs in tart cherry production is labor to prune. A recent budget put together by Michigan State University estimates that \$499/ha is spent on hand pruning annually, which represents 77% of the total annual labor cost and 10% of the total production annual production costs for a mature orchard (MSU, 2016). Tart cherry canopies require hand pruning and renewal of branches every one to three years to facilitate light penetration and distribution through the canopy, ensure uniform application of crop protectants, and to ensure overall tree health. Because pruning must be done by hand, and agricultural labor is in limited supply, mechanical pruning in tart cherry has become of interest to tart cherry growers.

Mechanical pruning has the potential to reduce labor costs in tart cherry orchards. The time required for dormant pruning of mature high density (HD) apple trees can reach 50-75 h/ha, and can be decreased with the use of mechanical pruning to 10-20 h/ha (Zimmer and Schwender, 2016). In Michigan, the time required to both hand prune and mechanically hedge a tart cherry orchard averages 37 hours/ha. Of that 37 hours, 35 hours are allocated to hand pruning. In contrast, mechanical hedging requires less than 2 hours per hectare (MSU, 2016).

Traditionally, hand labor in grapes has been costly and is needed for pruning, thinning, and harvesting. Rising labor costs and labor shortages pushed the industry to look at mechanization as a means of cost and labor force reduction. Mechanization of vineyards began in the early 1950's and has progressed to where the entire system is now mechanized for multiple growing styles (Morris, 2007). Grapes are pruned and suckered, shoots and leaves are removed, clusters are thinned, and fruit is harvested by mechanical means. Mechanization of canopy and crop load management can reduce labor costs by 44 to 80% in vineyards (Kutural et al., 2012).

Apples, like grapes, have historically been pruned and harvested by hand and have faced the same challenges with labor costs and shortages. Orchard design has changed greatly in the last 50 years. The movement from low density (LD) to HD systems has been observed in multiple fruit crops, but perhaps most dramatically in apples. Apple systems have evolved from a traditional LD system to a supported and trellised ultra high density system utilizing dwarfing rootstocks and focusing on precocious yields of high quality fruit, rather than vegetative growth and woody tissue formation. This movement from LD to HD systems has opened up opportunities for mechanization. Robotics are now in the forefront of orchard mechanization research, as they are incorporated into orchard design and growing techniques. HD and narrow incline training systems in apple look to be compatible with mechanical harvesting systems (Peterson, 2005). Imaging systems and software development are being incorporated in machinery with the ability to locate and harvest the fruit, making total mechanization in the orchard a near possibility.

Tart cherry pruning by mechanical hedging has been tested in the United States since the 1960's, although the practice never gained widespread use with growers. The ongoing shortage of labor has driven tart cherry growers to think about systems better suited to further mechanization, including HD systems that may lend themselves to mechanical hedging. These advances could also include the use of over-the-row canopy shake harvesters (Holownicki, 2013) to replace traditional trunk shake harvest in addition to pruning mechanization. However, mechanized pruning could present some potential problems.

One of the key reasons mechanical hedging did not gain more widespread use in tart cherry management is that the growth response to hedging was thought to be detrimental to the canopy. Hedging primarily involves heading cuts, which stimulates a proliferation of shoot growth in the outer canopy just beneath the hedging cut (Kessner, 1990). This proliferation can decrease light penetration into the canopy, which reduces fruiting potential in the lower part of the tree canopy and may also impact crop protectant application success in the canopy.

Pesticide and growth regulator recommendations are based on application in a standard orchard (Sutton and Unrath, 1984). However, not all canopies are the same, varying in volume and density within and between orchards. Differences in canopy width and density between LD and HD orchards can be significant and could have dramatic effects on the distribution uniformity of crop protectants (Sutton and Unrath, 1984; Ferree et al., 1980). LD canopies tend to be large and rounded with more volume to cover than HD orchards, which are typically narrow and planar in design. Dense canopies in apples have been found to require higher spray volumes to achieve complete canopy coverage (Herrera-Aguirre and Unrath, 1980). The tree-row-volume concept uses canopy volume to adjust spray-dosage volume per hectare (Sutton and Unrath, 1984). However, it may not account for drastic changes in canopy architecture that significantly alter other characteristics such as canopy density. Changes in orchard structure, moving from the traditional LD to HD system may not be adequately reflected in spray coverage requirements by using tree-row-volume adjustments.

As the development of new training and pruning systems for tart cherries continues, an assessment of the effects of these altered canopy characteristics on pests, as well as distribution uniformity of crop protectant application becomes necessary.
The objectives of this study were to evaluate the effectiveness of mechanical pruning techniques and to determine optimum timing of hedging applications for high density tart cherry in Utah, as well as evaluation of canopy density in a HD system using spray distribution uniformity as a measure of density.

Materials and Methods

Mechanical hedging

Renewal pruning strategies using mechanical hedging were applied to a HD orchard planted in 2010 at the Utah Agricultural Experiment Station Research Farm in Kaysville, Utah. The orchard consisted of ‘Montmorency’ tart cherry on Gi.3, Gi.5, and ‘Mahaleb’ rootstocks, with 1.8 m between-tree spacing, and 3.8 m between-row spacing. The number of trees available varied by rootstock, and so the experiment was laid out as a randomized block design, with three replicate blocks of Gi.5, 2 replicate blocks of Gi.3 and a single block of Mahaleb. Data for Gi.5 and Gi.3 were analyzed as a randomized complete block with 2 rootstock x 4 hedging factorial treatment structure. Since Mahaleb was unreplicated, results are shown solely for comparison. Within each replicate block, 3-tree plots were assigned to one of four hedging treatments. Treatments included: hedging both sides prior to leaf bud break (20 Apr 2015 and 1 Apr 2016, ‘dormant’), hedging both sides of the tree 45 days after bloom (29 May 2015 and 6 Jun 2016, ‘mid’) and pruning one or the other side of the tree in alternate years (‘alternate’), where the north side of the plots were hedged in 2015, and the south side in 2016 following the timing protocol of the ‘mid’ treatment (29 May 2015 and 6 Jun 2016, Gi.3 and Gi.5 rootstocks only). A control treatment was left unhedged. All trees also received standard renewal pruning based on a columnarized system with renewal cuts made back to the main leader in a 3 to 4 year cycle. Trees were pruned by hand when dormant using protocols for tall spindle apples (Robinson et al., 2006) renewing 2 to 3 of the largest branches in the canopy. All applications of hedging treatments in this orchard were carried out with a commercial sickle bar hedger (Topper Hedger, Gillison Variety Fabrication, Benzonia, MI.). Trees were hedged at an angle approximately 9° from vertical, with the base of the hedger kept at approximately 0.7 meters from the trunk of the tree.

Bloom count and fruit set data were collected in 2016 and 2017 from similarly sized branches in each plot in Kaysville. One branch with a diameter of 5 to 8 mm was flagged on three trees per treatment. Blossom clusters were counted in early April 2016 and 2017. In May, the same branches were reassessed for number of developing fruit. Bloom density (blossom cluster # / cm^2 stem cross sectional area; SCSA) and initial crop load (fruit # / cm^2 SCSA) were calculated and compared across treatments.

Fruit quality and size at harvest was determined on a 10-fruit sample taken at random from each plot in 2015, 2016, and 2017. Samples were weighed and soluble solids were measured using a handheld refractometer (Test Products Intl., Beaverton, OR). Yields were taken from the Kaysville site using a prototype over-the-row harvester based on a modified commercial blueberry harvester (BEI, International, South Haven, MI). Machine harvested yields were weighed and recorded for comparison. One tree per plot was then harvested by hand to determine the amount of fruit missed by the harvester and to compare the effectiveness of the harvester among treatments.

Additional plots were established in a commercially managed orchard established in 2010 in Santaquin, Utah that consisted of Gi.5 and 'Mahaleb' rootstocks at 2.1 x 5.5 m spacing. Plots varied in tree number with 4 to 5 trees per plot. A wooden jig was used to facilitate a 9° angle for hedging. The jig was placed at the base of the tree and leveled, providing 0.7 m of space from the trunk to the bottom of the canopy. A gas-powered hand-held hedger (Model HS45, Stihl Incorporated, Virginia Beach, VA) with a 46 cm blade was used to hedge along the jig. Hedging was done approximately 45 days after full bloom on 27 May 2015 and 13 June 2016. Yields in the Santaquin trial were measured by hand harvesting two representative trees per plot in 2015, 2016, and 2017. In the fall of 2017, light interception was measured with a trailer mounted ceptometer system. The system consisted of a GPS antenna, 50-cm light bars with sensors at 5-cm intervals (MQ-301 Apogee Line Quantum Sensor, Apogee Instruments, Logan, UT), and a data logger (CR1000, Campbell Scientific, Logan, UT). Data are taken that integrate light reading across each 50 cm light bar and at time intervals equivalent to approximately 15 cm distances down the row. Light readings were calculated as fraction of ambient sunlight (measured at the ends of the row) and mean light levels were calculated for each 3-tree plot. Mean and SD of all light readings within a plot were calculated to compare canopy density and uniformity. Row orientation in this experiment are East-West, and measurements were taken in September when the mid-day canopy shadow extended across the alleyway so that measurements taken on the north side of the row represented light interception for that row.

Application of crop protectants

Comparison of spray patterns in plots with alternate pruning and training strategies was assessed in 2016 and 2017 in a high density ‘Montmorency’ tart cherry orchard established at the Utah Agricultural Experiment Station research farm in

Kaysville, Utah in 2010. A hedged and unhedged treatment with an in-row tree spacing of 1.8 m and alleyway spacing of 3.8 m were also compared.

In 2016, water sensitive targets (TeeJet water sensitive paper 52 x 76 mm, Syngenta International AG, Greensboro, NC) were held at specific locations within the canopy of each orchard training system using adjustable clips attached to metal conduit posts. Target locations were placed 0.6 m behind the tree row at tree center (C) and at the center of the row between trees (D), with targets placed 0.6 (C_1, D_1), 1.2 (C_2, D_2), and 1.8 m (C_3, D_3), above the orchard floor at each location (Fig.3.1). A water application was then made to one side of the row with an air blast sprayer (Turbo Mist H.D. Tower, Model 30P, Slimline Manufacturing Ltd, Penticton, BC, Canada) at a speed of 1.56 meters sec^{-1} calibrated to apply 935 L/ha. Targets were carefully removed from clips and allowed to dry. Targets were scanned and the digital images analyzed to determine droplet size and the percentage of card covered (Image J software, National Institutes of Health, Bethesda, MD).

In 2017, additional locations were added for target placement in the same plots that were used in 2016. In addition to the placement in 2016, targets were placed in the center of the tree row adjacent to the trunk (A) and centered directly between trees (B) (Fig.3.1), also a different air blast sprayer was used (Pak Blast Model KB425 P5028, Rears Mfg. Co., Eugene, OR). Target heights remained the same at 0.6 (A_1, B_1), 1.2 (A_2, B_2), and 1.8m (A_3, B_3) above the orchard floor.

Statistical analysis

The mechanical hedging study was a randomized block design with 4 hedging treatments and 3 rootstocks, where blocking was by field location and by rootstock. Due to the limited availability of trees, the Gi.5 rootstock had 3 replicates of each hedging treatment, compared to 2 replicates of Gi.3 and a single block of hedging treatments for 'Mahaleb' which were not included for statistical analysis, but for general comparison. Yield (kg/tree), fruit weight (g), and soluble solids (%) were measured in each plot over three years, and the data analyzed as repeated measures (over years) using the GLM procedure of SAS software. Single year analysis was also performed to compare differences within each year. Light readings and spray distribution data were both carried out as randomized block design for hedged and unhedged treatments on a single rootstock (Gi.5).

Results

Mechanical hedging

The overall effect of hedging treatment on yield showed no significant difference over the three years of this research (Table 3.1, Fig. 3.2) in the Kaysville trial. Repeated measure analysis was performed for Gi.3 and Gi.5 rootstocks ('Mahaleb' trees were excluded from the repeated measures analysis as they were not replicated). Yields were highly variable from year to year in the Santaquin trial (Table 3.2). In the initial year, yields following mechanical hedging appeared to be lower than unhedged, but differences were not statistically significant. In the second and third year of the study, yields in the hedged treatments were as high, or higher than the unhedged controls (Fig. 3.3).

The effect of hedging treatment on fruit size varied by year, as indicated by a significant year × hedging treatment interaction (Table 3.1). Fruit size did not differ significantly among hedging treatments in 2015 or 2017. In 2016, fruit weighed between 8.0 and 10.6 grams, and the alternate hedging treatment had significantly larger fruit than the other treatments (Figure 3.4). ‘Mahaleb’ fruits were not included in this analysis.

The effect of rootstock on fruit sugar content (soluble solids %) also differed among years. In 2017, Gi.3 and Gi.5 soluble solids differed significantly, with values of 15.9% and measuring 18.1% (Fig. 3.5). Fruit from trees on ‘Mahaleb’ rootstocks tended to have lower levels of soluble solids (%) in all three years, but data were not included in the analysis.

Bloom density (bloom/cm^2 SCSA) did not show any differences among hedging treatments, or between Gi.3 and Gi.5 rootstocks in 2017 (Table 3.3). There was a significant hedging treatment effect in 2016, but this response was affected by rootstock. It is interesting to note that bloom density appeared to be much lower for ‘Mahaleb’ (23.9 clusters/ cm^2 SCSA) than for Gi.3 (67.3 clusters/cm^2 SCSA) or Gi.5 (59.0 clusters/cm^2 SCSA; Fig. 3.6). The hedging treatment × rootstock interaction for 2016 is shown in Fig. 3.7. Differences in bloom density were most pronounced between the hedging treatments and the unhedged control. The difference in bloom density between rootstocks appeared slightly more pronounced in dormant hedging than for the other hedging treatments, but rootstock differences for a given level of hedging treatment were not statistically significant.

Crop load was measured as number of fruit/cm^2 SCSA. There was no difference observed among hedging or rootstock treatments in 2017. However, in 2016, there was a significant difference between the ‘alternate’ treatment and all other hedging treatments (Table 3.3, Fig. 3.8). The ‘alternate’ treatment had a mean crop load of 60.7 fruit/cm^2 SCSA, compared to 38.6, 46.7, and 48.9 fruit/cm^2 SCSA for the ‘dormant’, ‘mid’ and unhedged control treatments, respectively (Fig. 3.8). This may be due to the fact that the ‘alternate’ treatment was hedged only on the north side of the tree in 2015, leaving unhedged canopy on the south side of the tree, reducing the impact of hedging, and possibly contributing to the increase in fruit density in 2016. Fruit set showed similar trends where the ‘alternate’ treatment showing the highest number of fruits per flower cluster in 2016 (Table 3.3, Fig. 3.9).

Analysis of light readings taken under the plot canopies showed no significant difference in transmitted light between the hedged and unhedged plots, where the hedged trees had light transmission of 26% ambient light and the unhedged trees had 25% transmission of ambient light (Figure 3.10). A standard deviation of all the light readings within each plots was calculated as a measure of the uniformity of canopy density. Standard deviation was 4% in hedged trees and 3% in unhedged trees, indicating similar canopy uniformity between treatments.

Application of Crop Protectants

One measure of the effect of hedging on canopy density was to assess the penetration and distribution of crop protectant applications in the canopy of hedged and unhedged trees. 2016 results indicated that spray penetration through the lower center of the tree was poor in both hedged and unhedged trees (Fig. 3.11, position C1). Higher in the tree, penetration at the tree center was greater in hedged than unhedged trees (C3). Between-tree penetration at the lowest position (D1) was greater in the unhedged treatment than the hedged treatment. Analysis of variance show that hedging treatment was a significant factor in spray distribution uniformity (Table 3.4).

In 2017, spray penetration showed greater uniformity across positions in the hedged than the unhedged treatments. Target coverage ranged from 41% to 61% in the hedged treatments, compared to 21% and 79% for the unhedged treatments (Fig. 3.12). The difference between 2016 and 2017 may be due to the proliferation of shoot growth beneath hedging cuts, creating a more uniformly dense canopy.

Discussion

Mechanical hedging

We did not see significant yield differences among hedging treatments. Previous work suggested that trees be initially hedged just prior to bloom to establish a fruiting wall, with a second hedging carried out at 45 ± 3 days after full bloom ('mid' treatment) repeated annually (Kessner, 1990). Preliminary results from a HD tart cherry planting in Michigan show that summer hedging at 45 days post full bloom ('mid' treatment), can yield an average of 5.4 kg/tree (9,760 kg·ha^{-1}). In contrast, winter hedging done on dormant trees in the same study was shown to be a less successful timing with yields averaging 1.7 kg/tree (2,910 kg·ha^{-1}; Perry, 2015). It is important to note that these yields are low relative to commercial yields of conventional spaced orchards in Utah, where statewide average yields are 17,000 kg·ha^{-1} (USDA, 2017), with young productive orchards routinely exceeding 28,000 kg·ha^{-1} (Papenfuss, personal communication).

‘Dormant’ hedging in this study was not executed as precisely as hoped. Protocols dictated that hedging be done prior to bud break. However, equipment availability was limiting, and hedging was carried out in 2016 prior to leaf bud break, but during bloom. This may have contributed to variability in results, and additional studies should be carried to verify the effect of ‘dormant’ mechanical hedging in tart cherry.

In this study, fruit size was not affected by hedging treatments, but did differ among rootstocks. ‘Mahaleb’ fruits tended to be larger than Gi.5 fruit, although this difference was only statistically significant in 2016. This was likely due to lower fruit set in ‘Mahaleb’ compared to the other rootstocks, resulting in higher leaf:fruit ratio which would be expected to contribute to larger fruit with higher sugar content. Fruit weight increase has been noted in previous mechanical hedging studies. Kessner (1978) saw a 20% increase in fruit set in summer hedged tart cherry trees, and when hedged 15 to 18 days before harvest, an additional 20% increase in fruit size was observed.

Fruit sweetness was found to be a consistent function of rootstock in this study. ‘Mahaleb’ rootstocks showed lower soluble solid than other rootstocks over three consecutive years. ‘Mahaleb’ is a vigorous rootstock (Anderson et al., 1996) and is known for vigorous vegetative growth and a lack of precocity. It is likely that ‘Mahaleb’ utilizes more carbon resources to produce vegetative growth, partitioning less resources to increase fruit quality. Further, the Mahaleb trees had more dense canopies than trees on either of the Gisela rootstocks. Differences were noted in the total light interception when comparing ‘Mahaleb’, Gi. 3 and Gi.5 rootstocks. ‘Mahaleb’ trees showed greater than 90% total light interception, where the Gi.3 and Gi.5 rootstocks showed near optimal total light interception ranging from 72% to 74% (Shafer, unpublished). High total light interception in the 'Mahaleb' trees suggests that canopy density in these trees is too high. This high density impedes light penetration in the canopy and creates an environment with high internal shading that leads to loss of fruiting wood, reduced yields, and increased incidence of foliar disease, which were all observed in this study.

Hedging has been documented as creating higher numbers of buds in the canopy, with an increase in the percentage of floral buds. Crandall reported 93% and 98% of total buds being flower buds when hedged in June and July, with only 50% of buds being floral when hedged in August (Crandall, 1979). The number of flowers per bud do not diminish with summer pruning (Kessner, 1978). Results from this study did not reflect a consistent increase in number of flower buds by treatment, but found a correlation between rootstock and number of flower buds present. Trees on 'Mahaleb' rootstocks had lower numbers of flower bud clusters counted per SCSA cm^2 than the Gisela rootstocks. 'Mahaleb' canopies tend to be more vegetative and therefore more dense than the canopies of the smaller Gi.3 and Gi.5 trees. This contributes to increased internal shading in the canopy which likely contributed to the decreased number of buds formed in the canopy. Light levels below 20% full sunlight have a negative effect on floral bud formation (Flore and Layne, 1999). Internal shading caused by hedging is a concern and can affect the distribution of crop protectants in the canopy. Differences in canopy density and spray distribution may warrant the need for changes to spray program protocol for HD and mechanically pruned trees.

Powdery mildew is a common concern in tart cherry, especially where the canopy becomes dense. Disease incidence was not formally rated across treatments, but powdery mildew incidence appeared somewhat higher in the hedged ‘Mahaleb’ plots, where the canopies were particularly dense compared to that of the Gi.3 and Gi.5. This may have had some impact on productivity.

Application of crop protectants

Pesticide and growth regulator recommendations are based on application in a standard orchard (Sutton and Unrath, 1984). Spray patterns in hedged tart cherries lack research for comparison, however, in hedged apples, well pruned canopies have better spray distribution throughout the canopy (Travis, 1981). More consistent spray pattern and coverage were observed in the hedged trees, particularly in 2017, suggesting more uniform density throughout the hedged canopy. Black et al. (1995) found varying results of spray coverage based on location in the tree with significantly less spray captured at the bottom center position in the tree than at positions near the spray ally and top center of the tree. This study noted more spray penetration between trees and typically higher in the tree, but these differences were more pronounced in the first year. The difference in penetration uniformity may be a function of canopy architecture as the fruiting wall continued to fill in, but may also be related to design differences in the two sprayers.

Dense canopies in apples have been found to require higher spray volumes to achieve complete canopy coverage (Herrera-Aguirre and Unrath, 1980), and as hedging continues in these orchards, further research may be needed to assess spray patterns and determine methods for maintaining adequate spray coverage uniformity.

Conclusion

Results of this work show that yields were not significantly impacted by hedging, indicating that hedging is a viable pruning option for maintaining a fruiting wall in an HD tart cherry system. Hedging creates a proliferation of growth that can increase the amount of young fruiting wood in the canopy and may create a uniformly dense canopy. Comparison of spray distribution patterns suggest that hedging resulted in more uniform canopy density. However, light interception uniformity did not differ between hedged and unhedged canopies, and was near the levels thought to be optimum for the development of high quality fruit.

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Tables

Table 3.1 Analysis of variance for yield, fruit weight and soluble solids for the Gi.3 and Gi.5 rootstocks in the Kaysville hedging study for 2015 to 2017. Data combined across years were analyzed as a repeated measures design. Data for Mahaleb rootstocks were not included in analysis as hedging treatments on this rootstock were not replicated.

Source	Yield (kg/tree)	Fruit Weight (g)	Soluble Solids (%)
Treatment	-	0.061	-
Rootstock	0.074	-	0.012
Block	-	0.001	0.028
Treatment*Rootstock	-	-	-
Treatment*Rootstock*Block	-	-	-
Year	-	0.049	<0.001
Treatment*Year	-	0.047	-
Rootstock*Year	-	-	0.030
Treatment*Rootstock*Year	-	-	-

Table 3.2 Repeated measures analysis for yield for Gi.5 rootstocks in the Santaquin hedging study for 2015 to 2017. Hedging treatments on Mahaleb rootstocks were not included in analysis as they were not replicated.

Source	Yield (kg/tree)
Treatment	-
Block	0.048
Treatment*Block	-
Year	<0.001
Treatment*Year	-

Table 3.3. Analysis of variance for bloom density (#/scsa), crop load (fruit #/cm^2 SCSA) and fruit set (%) for 2016 and 2017, analyzed separately for each year.

	Bloom Density (#/cm^2 SCSA)		Crop Load (#/ cm^{2}SCSA)		Fruit Set (%)	
Source	2016	2017	2016	2017	2016	2017
Treatment	0.002	-	0.014	-	0.009	-
Rootstock	-	-	-	-	-	-
Treatment × Rootstock	0.029	-	-	-	-	-

Table 3.4. Analysis of variance for spray distribution uniformity as compared by target coverage in 2016.

	Card Coverage (%)	
Source	2016	2017
Hedging	0.047	0.010
Position	<0.001	0.001
Hedging × Position	0.020	0.012

Figures

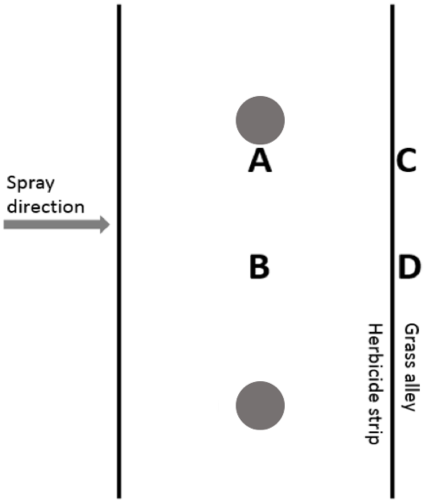

Fig. 3.1. Ariel view diagram of spray target placement in the orchard. In-row tree spacing is 1.83m. Targets were placed at three heights in each location: 0.61, 1.22, and 1.83m above the ground. In 2016, location C and D were used. In 2017, locations A, B, C, and D were used.

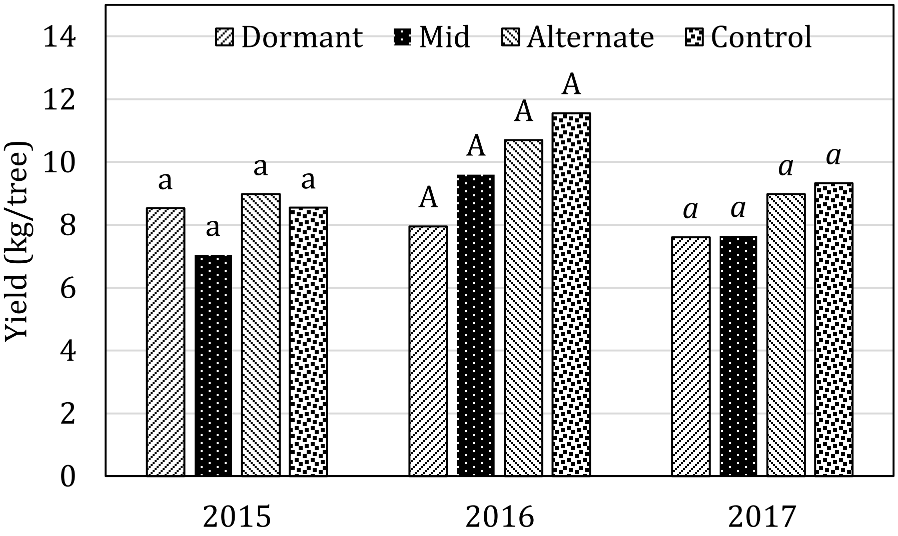

Fig. 3.2. Yield response of hedging treatments for the Kaysville study over three seasons (2015 to 2017). Yield was based on machine harvest of replicate 3-tree plots, and are averaged across rootstocks, excluding ‘Mahaleb’.

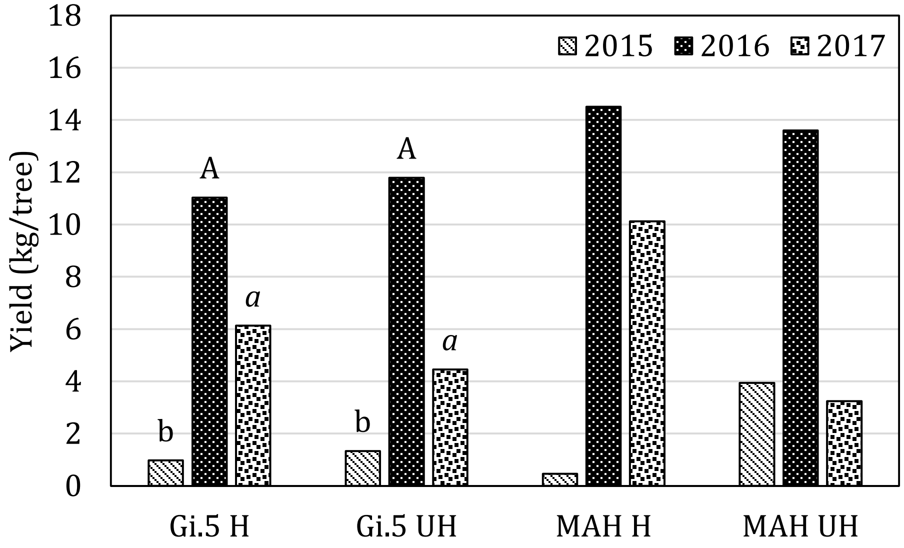

Fig. 3.3. The effect of hedging on tart cherry yields in Santaquin, Utah, in the 2015 to 2017 seasons. Yields were highly variable from year to year, and were initially lower after hedging, but showed recovery in the following two years. Mahaleb trees were represented in a single plot and were not included in repeated measures analysis. Mean values are from a single hand-harvested data tree in three replicated plots in the Gi.5 trees and a single plot in the 'Mahaleb' trees.

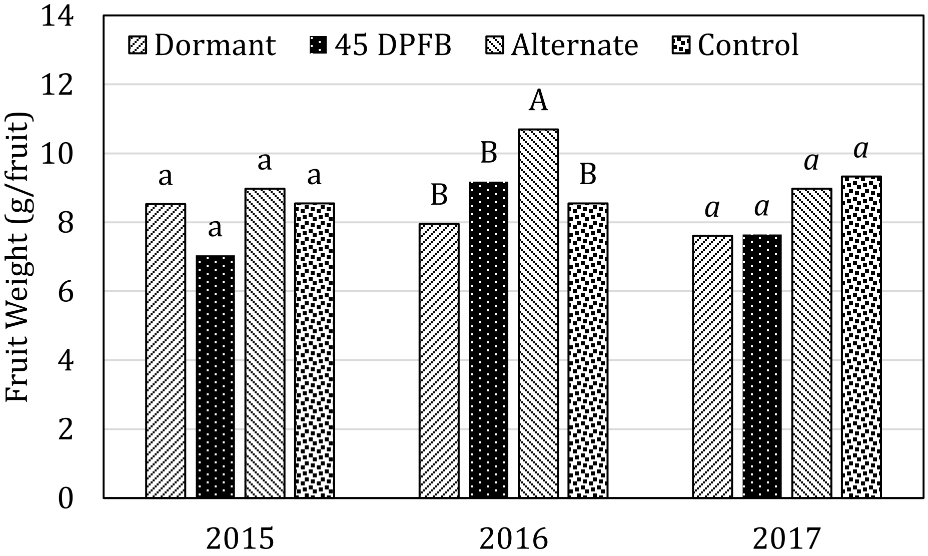

Fig. 3.4. The effect of hedging on average fruit size (g) in the Kaysville study from 2015 to 2017. Values are from 20-fruit samples from at least three replicated plots with three trees per plot, and averaged over Gisela rootstocks.

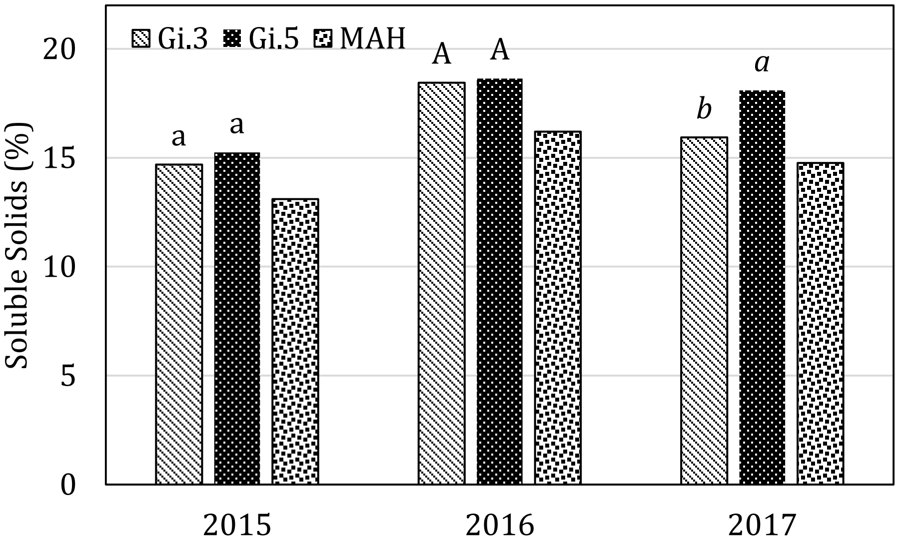

Fig. 3.5. The effect of rootstock on fruit soluble solids in the Kaysville hedging study for the 2015 to 2017 seasons. Mahaleb was not included in the analysis as hedging treatments were not replicated on this rootstock, but results are shown for reference. Values are the means of refractometer measurement taken from 20 fruit samples from at least three replicated plots and averaged across hedging treatments.

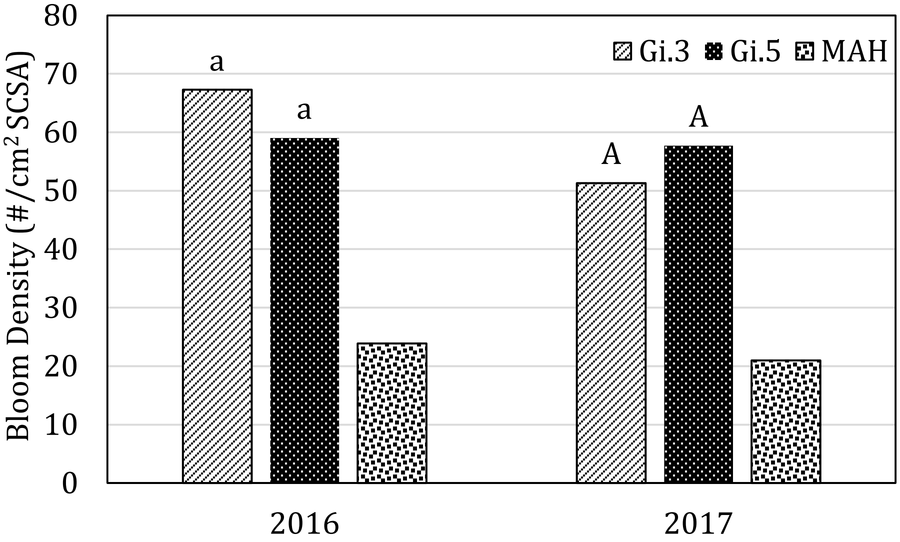

Fig. 3.6. The effect of rootstock on bloom density (cluster number per cm^2 SCSA) in 2016 and 2017. Values are the means of at least 9 similar sized branches with an SCSA of 2.4 to 4.5 (cm^2). 'Mahaleb' rootstocks are included for reference, but not analyzed because the hedging treatments were not replicated on this rootstock.

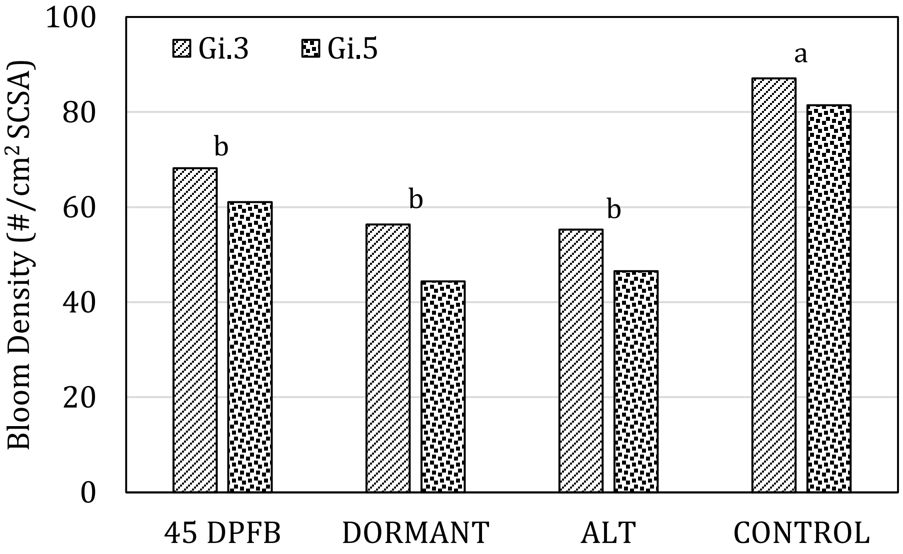

Fig. 3.7. The effect of hedging treatment on bloom density (#/cm^2 SCSA) on Gi.3 and Gi.5 rootstocks in 2016. Values are the means of counts on at least 3 similar sized branches with an SCSA of 2.4 to 4.5 (cm^2) measured in each replicate plot. Treatments were hedged 45 days post full bloom (45 DPFB), prebloom, 45 DPFB on alternate sides of the row (alt), and an unhedged control.

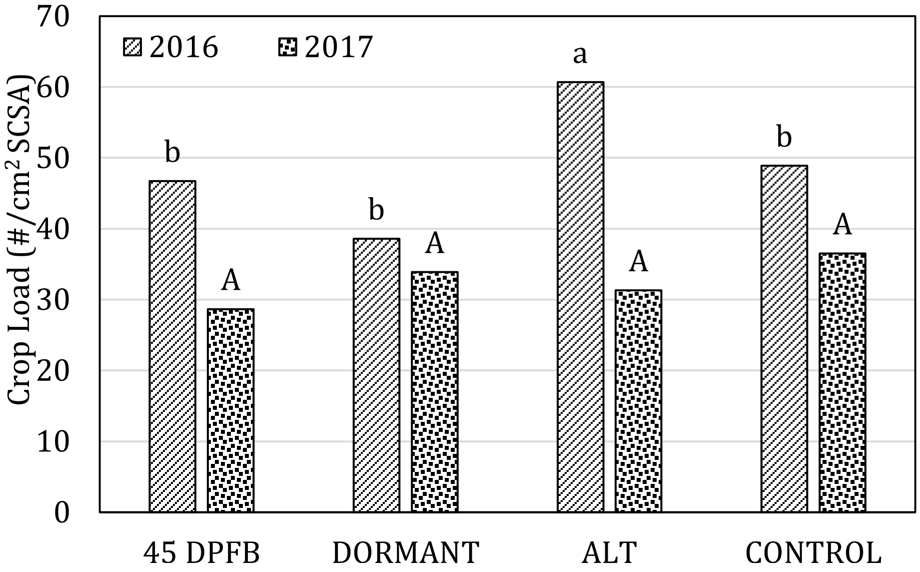

Fig. 3.8. The effect of hedging treatment on crop load (number of fruit/SCSA) in 2016 and 2017. Values are the means of at least three similar sized branches (SCSA of 2.4 to 4.5 cm^2) counted in each of three replicate plots.

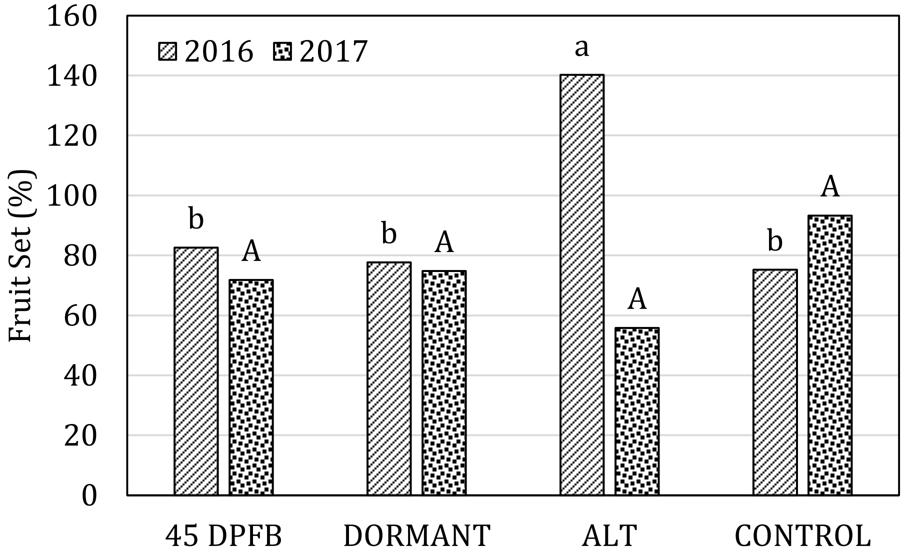

Fig. 3.9. The effect of hedging treatment on fruit set (based on fruit # per flower cluster) in 2016. Values are calculated from the number of flower clusters and the fruit counts taken on at least three similar sized branches (SCSA of 2.4 to 4.5 cm^2) in three replicate plots.

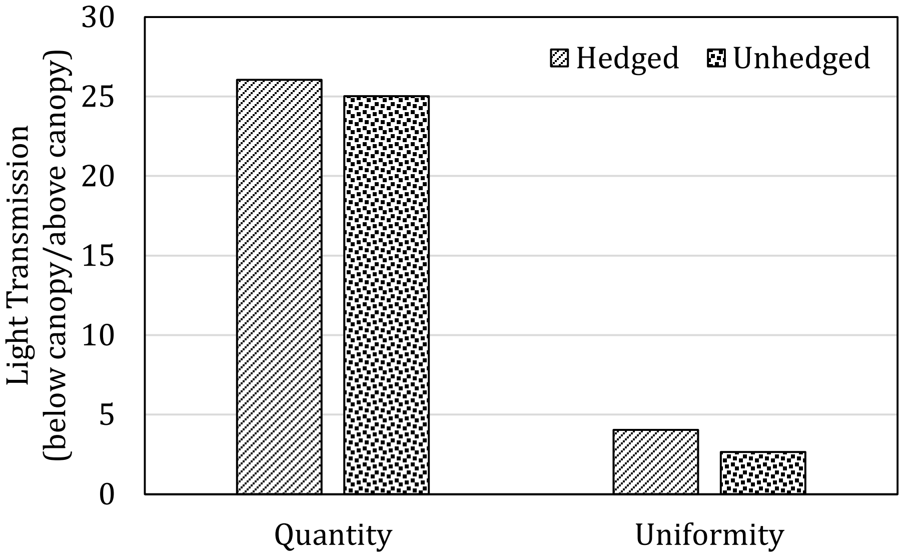

Fig. 3.10. The effect of hedging in a HD system on canopy light transmission quantity and uniformity. Values were obtained by measuring the PAR light levels below the canopy as a percentage of light levels taken outside the orchard. Quantity is the mean for all measurements taken within the plot, and uniformity is the standard deviation (SD) of the same measurements. No significant difference was noted between hedging treatments for quantity (*P* = 0.86) or uniformity (*P* = 0.42). Values are the means of three replicate 3-tree plots.

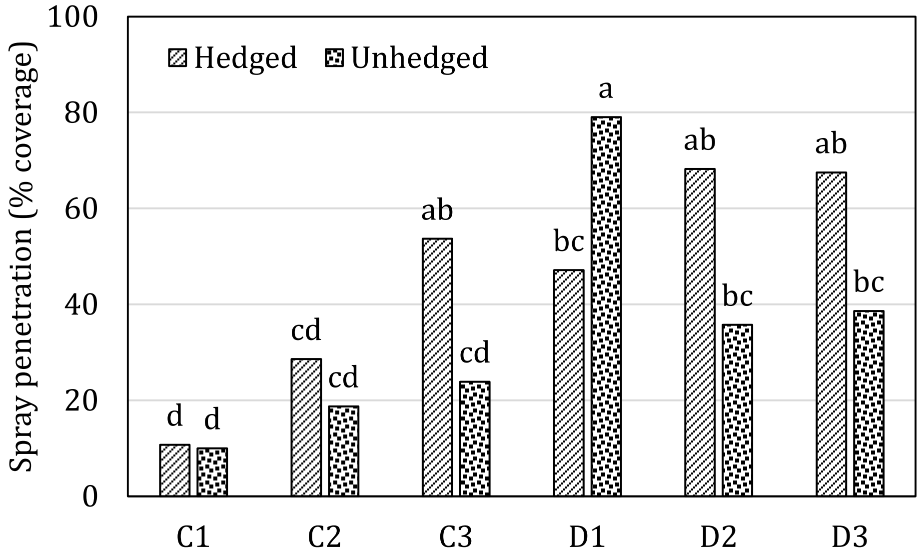

Fig. 3.11. Comparison of spray penetration in hedged and unhedged treatments in 2016. Distribution uniformity was measured as target coverage (%) at 6 positions (illustrated in Fig.1). Values are the means of three replicate plots with one data collection site for specific height and location per plot. Target coverage was measured using Image-J software.

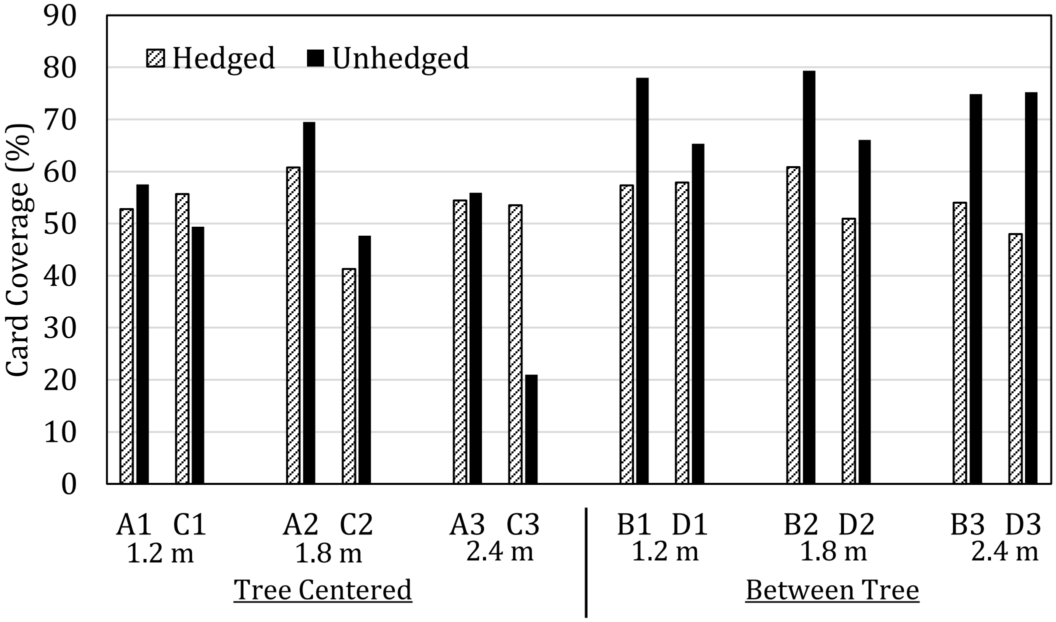

Fig. 3.12. Comparison of spray distribution uniformity in hedged and unhedged treatments in 2017. Distribution uniformity was measured as target coverage (%). Values are the means of three replicate plots with one data collection site for each specific height and location per plot (for card placement see Fig. 1). Target coverage was measured using Image-J software.

CHAPTER 4

CONCLUSION

There is interest in developing new high density (HD) systems for the production of tart cherries in Utah. These studies investigated factors that need to be considered in the development of HD systems, including: renewal pruning strategies for maintaining tree productivity, the viability of mechanical pruning approaches, and how these systems may influence distribution uniformity of crop protectants.

As seen in Chapter 2, renewal pruning can be used in orchards to stimulate healthy, young wood that is highly fruitful as a means of replacing large, aging branches. Longer and larger diameter renewal stubs produced greater numbers of new shoots. Overall critical length of renewal stubs was determined to be 10 cm to support the regrowth of at least one renewal shoot. This is much longer than the 2 to 5 cm stubs required for adequate renewal growth in apple (Robinson, 2003) and peach. However, rootstock also had an effect on renewal growth, with the more dwarfing Gisela ® 3 (Gi.3) and Gisela ® 5 (Gi.5) rootstocks requiring longer stubs than the vigorous ‘Mahaleb’ rootstock. For example, small diameter branches in cuts in Gisela ® 3 should be left 14 cm long to ensure regrowth. .

As discussed in chapter 3, mechanical hedging techniques were applied to a HD ‘Montmorency’ tart cherry orchard in Kaysville, UT. Four different hedging treatments were applied: ‘dormant’ (prior to bud break), ‘mid’ (45 days after full bloom), ‘alternate’ (45 days after full bloom applied to north side of the row in 2015 and south side of the row in 2016), and an unhedged control treatment. No hedging treatment differences were seen in yield, bloom density or fruit set in any of the three years of the study. Rootstock did affect bloom density and fruit set, where ‘Mahaleb’ rootstocks consistently showed lower bloom density in both 2016 and 2017 and lower crop load in 2017.

Fruit quality, as indexed by fruit sugar content (% soluble solids) was also affected by rootstock. In three consecutive years, trees on ‘Mahaleb’ rootstocks produced fruit with lower soluble solids than those of Gi.3 and Gi.5 with the highest percentage of soluble solids consistently found in Gi.5 rootstock trees. ‘Mahaleb’ trees are highly vigorous and tend to produce larger amounts of vegetative growth than Gi.3 and Gi.5. This likely contributed to internal shading, reducing number of fruiting buds produced in the canopy of ‘Mahaleb’ trees, and lower sugar content in the developing fruit. This indicates that pruning to open the canopy to support light distribution is important for the production of fruiting buds and high yields, and that using rootstocks with the appropriate level of vigor and precocity is critical.

A post bloom hedging treatment was also applied to a HD ‘Montmorency’ orchard in Santaquin, UT. Results differed from those in Kaysville. Initial yields (2015) tended to be lower than the unhedged treatments, but showed increases in the two years following. This suggests that initial hedging removes fruiting buds from the tree, but creates a proliferation of fruitful growth beneath the hedging cut, contributing to recovery of yield.

Canopy density was indirectly measured in the mechanical hedging study by comparing spray distribution patterns in canopies of hedged and unhedged trees in 2016 and 2017. In 2016, hedged trees showed higher spray penetration through the canopy than unhedged trees, suggesting lower canopy density. In 2017, results showed more even spray distribution in the hedged canopies where unhedged canopies showed more variability. Canopies were not hedged in 2017, this fact coupled with the results from the spray pattern analysis suggest that the hedged canopy developed a more evenly dense canopy than the unhedged canopy. These results suggest that uniform distribution of crop protectants could be facilitated by hedging. However, measurements of light interception did not show any differences between hedged and unhedged treatments. This suggests that additional research is needed to determine how these hedged treatments affect canopy density and to test the correlation between spray distribution uniformity and light distribution.

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APPENDIX

APPENDIX

LIGHT MICRO-ENVIRONMENT AND FRUIT QUALITY

Introduction

Markets for high value crops, such as temperate tree fruits, are based on consistent high quality. Quality in apples is defined as fruit that contains intense color, high dry matter mass, and high soluble solid levels (Palmer, 2007). Quality for tart cherries is not as well defined and setting quality standards is important as it sets parameters against which a product can be measured. It has been well documented over the last 30 years with apples that dry matter production, fruit size, color, soluble solids concentration and total fruit yield are directly related to the amount of sunlight intercepted in the tree (Campbell and Marini, 1992; Flore and Layne, 1999; Palmer, 1997; Wunsche et al., 1996).

Whole canopy light interception is crucial to the plant's ability to produce both reproductive and vegetative tissues. Whole canopy light interception is defined as the difference between irradiance above the canopy and mean irradiance beneath the canopy (Flore and Layne, 1990). Not only is light intercepted from above the canopy, a small percentage of light reflects off the orchard floor, contributing to the overall canopy light interception.

Light microenvironment refers to the individual leaf capturing light and the contribution it makes to the quality of the adjacent fruit. Light at extremely high levels is not necessarily beneficial for fruit production. The light saturation point for a tart cherry leaf is ~600 to 800 μmol m^{-2} s^{-1} (Beckman et al., 1992) which is typically between 30 and 50% full sunlight (Flore and Layne, 1990). Allowing light to filter through a canopy at this range would theoretically create high yields of high quality fruit. The amount of light distribution through the tart cherry canopy is not well documented and may vary due to pruning practices that determine tree canopy density.

As light filters through the canopy layers, a gradient of light interception is established that contributes to both whole tree light interception and light microenvironment. This gradient is determined by tree shape and size and can be manipulated by changing certain orchard design factors such as row spacing and orientation, tree height and shape, and tree spacing (Atwell and Kriedmann, 1999). Apples grown in a rounded canopy form, similar to tart cherries, have shown that the upper third of the canopy has the greatest density of leaves, flowers, and fruit, as well as the highest light interception levels. A linear relationship between the percent of light intercepted and overall yield has been found in apple (Jackson, 1978; Palmer, 2007) and tart cherry (Flore and Layne, 1990). Apples in the outer edge of the canopy have higher levels of soluble solids, increased size, and more intense fruit color. Fruit color is one of the most sensitive measures of light in the canopy and is an indication of ripeness in apple and peach (Atwell and Kreidmann, 1999). Color is also an important parameter for ripeness and commercial harvest date determination in tart cherry (Milosevic and Milosevic, 2012). Fruit dry matter mass is defined as total biological yield (Palmer, 2007) and is closely related to fruit size. The net total dry matter productivity of apple is related to light availability, interception, photosynthesis, and respiration.

The lower third of the apple canopy makes the smallest contribution to the tree in terms of leaf area, flowers and fruit, and is correlated with the lowest light interception in the canopy (Ferree et al., 1980), and decreased fruit quality (Campbell and Marini, 1992;

Jackson, 1970; Palmer, 2014). Both fruit size and proportion of red exocarp on apples is reduced if grown in shaded areas of the canopy (Jackson, 1970). It can be assumed that shading in the canopy can be detrimental to tart cherry in the same way it is in apple. Excessive shading in tart cherry leads to premature fruit drop (Flore and Layne, 1999). Because light is critical for fruit growth and development, a canopy must be shaped and formed to optimize light interception and distribution within the canopy.

Creating an optimal canopy for light interception can be labor intensive. Practices such as trellising, training, branch angle manipulation, and intensive pruning are commonly used in apple production, but require expensive labor inputs that are difficult to justify in a lower-value processed crop such as tart cherry. There is interest in growing tart cherries in high density (HD) systems that mimic HD apple production, and it seems logical to apply the same management practices in tart cherry that have been applied in apple. One possible way to create an environment that will increase light capture in the canopy is the application of mechanical summer pruning to the HD tart cherry system. This may increase light capture and in turn create high yields of high quality fruit. Mechanization of pruning would simplify the pruning process, making the system more economically feasible. An additional practice being used in commercial HD apple production is to make 2-3 renewal pruning cuts on the largest branches annually to open up the canopy and allow better light distribution. This practice focuses on limb renewal pruning that renews large diameter branches that are greater than 50% the diameter of the trunk (Robinson et al., 2006). Conventional tart cherry pruning practices focus on large diameter branch renewal every second or third year to improve light distribution in the canopy. This practice allows for regrowth of healthy fruiting wood in the canopy. To design the most efficient tart cherry management systems including implementing renewal and mechanical pruning strategies, a greater understanding of the relationship between light microenvironment and fruit quality is needed, particularly for Utah conditions.

The objectives of this research were to determine the relationship between light micro-environment and fruit quality in tart cherry and to understand minimum localized light requirements to produce fruit of marketable quality.

Materials and Methods

Commercially planted ‘Montmorency’ tart cherries on ‘Mahaleb’ rootstocks were sampled from four mature orchards during 2015, and five orchards during 2016, near Genola, Utah. Orchard age, in-row and between-tree spacing, soil type, and slope varied among sites, with orchard establishment ranging from 1996 to 2005 (Table A.1.). Pruning practices varied between orchards due to grower preference, however, trees were generally trained to a traditional multiple steep leader. Fertility and irrigation practices were typical of commercial orchard management for Utah.

Two trees each week were sampled at random throughout selected orchards over four weeks prior to harvest, to establish fruit quality parameters related to fruit ripeness (Figure 1). In 2015, orchards ‘A’, ‘B’, ‘C’, and ‘D’ were sampled. Fruit samples of 10 individual fruits were taken in 2015 on the east (X) and west (Y) sides of the canopy at approximately 2.5 (X_1, Y_1), 3.3 (X_2, Y_2), and 4.3 (X_3, Y_3) meters above the ground (Fig. A.1). Samples were labeled and numbered at time of sampling and placed in a cooler to preserve freshness. A reading was taken of photosynthetically active radiation (PAR) at each fruit sampling location, using a hand-held meter (MQ-200 Quantum Light Sensor, Apogee Instruments, Logan, UT). Light readings were also measured above the canopy and at the center of the canopy. Samples and readings were taken mid-day.

Sampling differed slightly from 2015 to 2016. In addition to the four orchards sampled in 2015, orchard 'E' was added. The grid system and sampling protocol was changed to facilitate more accurate light readings in the canopy (Fig. A.1). Readings and samples were taken at dusk in diffuse light weekly in the four weeks prior to harvest. Two samples and correlating light readings were taken in the canopy on the east and west sides from 2.7 to 3.0 (X_1, Y_1) meters and from 4.3 to 4.6 (X_3, Y_3) meters above the ground. An additional sample and light reading was taken on the north side (Z) of the tree from 2.7 to 3.0 meters (Z_1) above the ground. In-tree and above-tree light readings were recorded at time of sampling. Samples of 6 fruit were taken, labeled, and kept on ice until later sample analysis.

Samples were processed within 24 hours of collection. Fresh whole fruit and fresh pit weights were recorded. LCH color readings were taken at two points on the fruit on half of the samples using a handheld spectrophotomer (Model CM-2600d, Konica Minolta Sensing Americas, Inc., Ramsey, NJ,). Pits and remaining whole fruits were then frozen to a temperature of -62º C and lyophilized (Freezone 12, Labconco Freeze Dry System, Kansas City, MO). Dry whole fruit and dry pit weight were then recorded. Fruit dry matter content, fruit color, fruit fresh weight, percent soluble solids, and flesh to pit ratio were compared among tree locations and across orchards.

Results

Survey results suggest some relationship between fruit quality and the light micro-environment in the canopy immediately surrounding the fruit. Light readings in the canopy were positively correlated with fruit sugar content in areas of the canopy with lower light levels (< 20% of ambient; Fig. A.2). Fruit quality did not diminish as much as expected where the light microenvironment dropped below 10% of ambient, suggesting that fruit quality in tart cherry may be attainable at lower light microenvironments than that of apple.

Measurements of fruit color using a spectrophotometer suggested a negative correlation between light microenvironment and fruit color, as determined by lightness or darkness of the epidermis or outer layer of the fruit. Results suggest that fruit that has higher levels of light in the micro-environment had darker color than fruit that received lower levels of light (Fig. A.3). However, this relationship was again less pronounced at light levels greater than 20% of ambient.

Discussion

Fruit quality has historically been associated with light micro-environment and interception. Parameters such as soluble solids, size, and color have been related to light interception in apples (Atwell and Kreidmann, 1999). Fruit color is an important measure for determining ripeness in apple and harvest date in tart cherry (Milosevic and Milosevic, 2012). This study showed that soluble solids and fruit color are correlated with light interception, but suggest that critical light levels for adequate fruit quality may be lower than those of other fruit crops.

Results from this study were highly variable. Instantaneous light readings proved to be difficult to collect as conditions varied. Leaf flutter made it difficult to determine representative light levels. In an attempt to reduce variability in data collection, light readings were taken in diffuse light at dusk in 2016, instead of mid-day full sunlight. There was some reduction in variability in 2016, but light readings remained difficult to obtain again due to leaf flutter. Better methods are needed to obtain light measurements that represent daily light integral at specific locations within the canopy.

Conclusion

Fruit quality parameters, such as color and soluble solids can be correlated with light micro-environment. Color in tart cherries has been used as a key indicator of harvest date and should continue to be used for this purpose. Soluble solids is positively correlated with the amount of light interception in the micro-environment immediately surrounding fruit. Care should be taken by growers to create a canopy environment conducive to light distribution to produce quality fruit in the whole canopy, not just in the outer canopy layers.

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Tables

Table A.1. Summary information for commercial orchards used for fruit samples and correlating light readings taken in 2015 and 2016 in Genola, Utah.

Orchard	Est.	Spacing	Soil Type	Slope	Elevation
A	1996	3.7 x 5.5 m	Sanpete gravelly fine sandy loam	4 to 15%	1386 m
B	2003	4.0 x 5.5 m	Hiko peak stony, sandy loam	4 to 8%	1397 m
C	2002	4.3 x 5.5 m	Hiko peak stony, sandy loam	4 to 8%	1408 m
D	2002	4.3 x 5.5 m	Linoyer very fine sandy loam	2 to 5%	1378 m
E	2005	4.0 x 5.2 m	Medburn fine, sandy loam	2 to 4%	1438 m

Figures

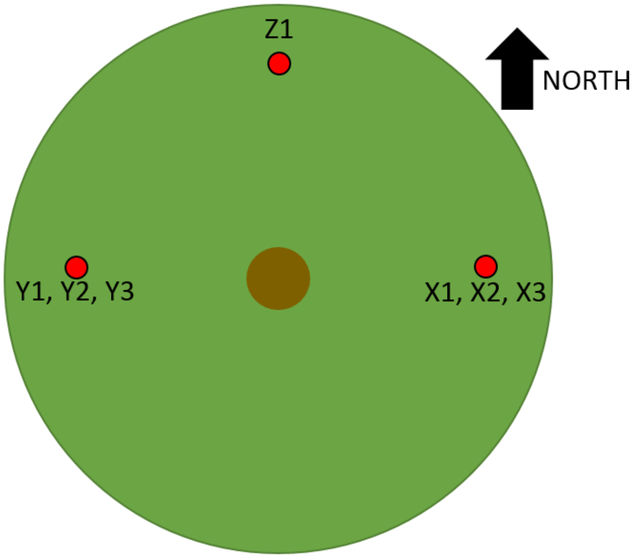

Fig. A.1. Illustration of fruit sampling positions. Samples were taken in 2015 on east and west sides of the canopy, at locations X_1 (2.5 m), X_2 (3.3 m), X_3 (4.3 m), Y_1 (2.5 m), Y_2 (3.3 m), and Y_3 (4.3 m). In 2016, samples were taken on the east, west, and north sides of the canopy at locations X_1 (2.7 to 3.0 m), X_3 (4.3 to 4.6 m), Y_1 (2.7 to 3.0 m), Y_3 (4.3 to 4.6 m), and Z_1 (2.7 to 3.0 m).

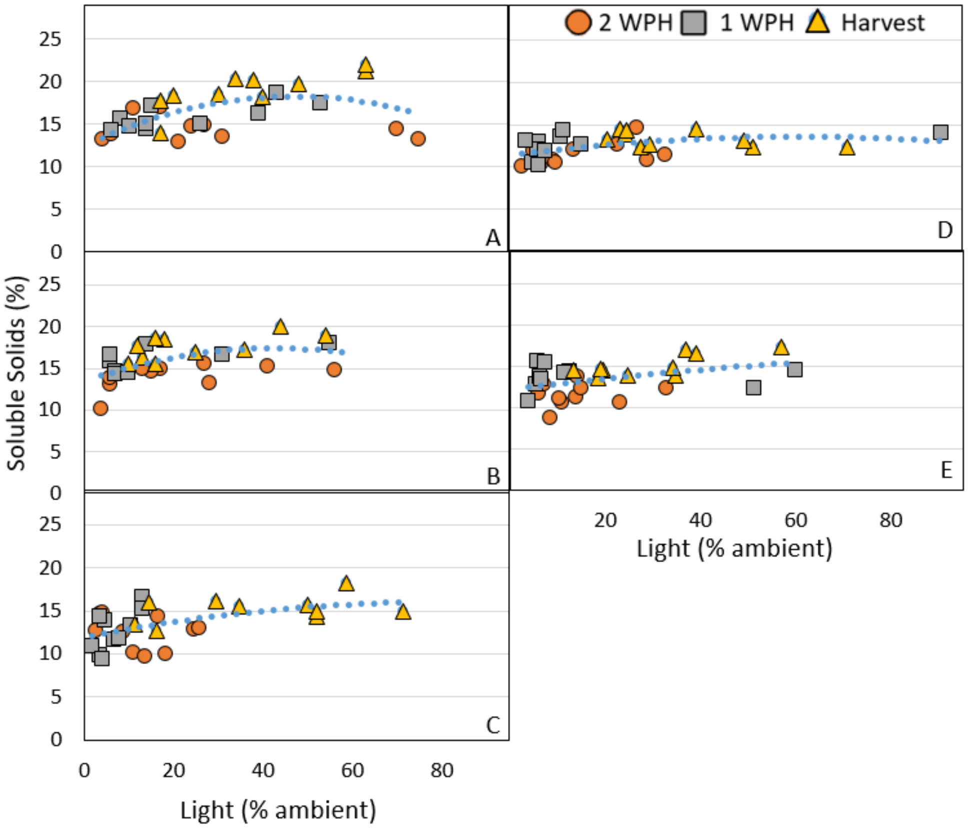

Fig. A.2. The relationship between light microenvironment and fruit quality, as measured by soluble solids (%). Measurements were taken weekly from two weeks pre-harvest to harvest at 5 locations in the tree. Samples consisted of six fruits and a correlating light reading at each sample location in the canopy.

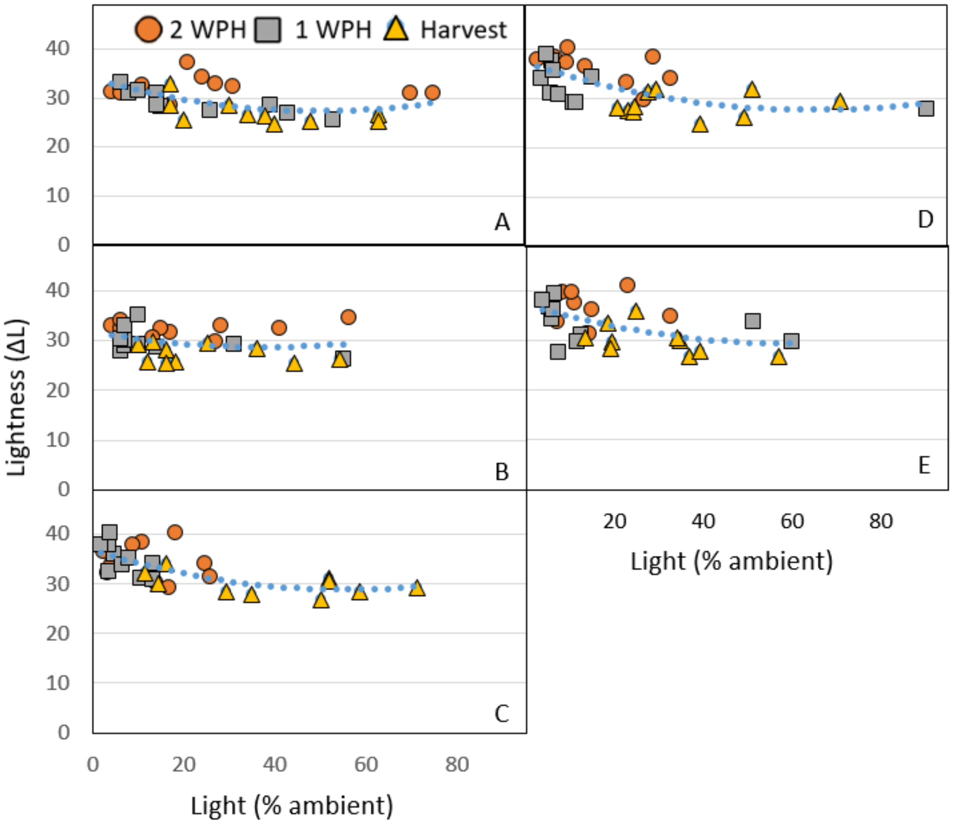

Fig. A.3. The relationship between light microenvironment and fruit color (lightness; Δ L). Measurements were taken weekly from two weeks pre-harvest to harvest at 5 locations in the tree. Samples consisted of six fruits and a correlating light reading at each sample location in the canopy.