THE IMPACTS OF ARTIFICIAL SPUR EXTINCTION
AND LEAF REMOVAL ON YIELD AND FRUIT QUALITY OF ‘GALA’

A Thesis in
Horticulture
by
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ABSTRACT

Crop load and early season leaf area are believed to be strong indicators of yield and fruit quality at harvest. Managing crop load generally consists of removing fruit; the earlier in the season excess fruit is removed, the greater the improvements at the end of the season, particularly with reference to fruit size. Early season thinning strategies are currently limited for Mid-Atlantic growers. Spur leaves are viewed at a vital carbohydrate source, contributing to initial fruit set and therefore final fruit quality. Trials conducted in 2017 and 2018 at the Fruit Research and Extension Center in Biglerville, PA examined how 3 levels of Artificial Spur Extinction (ASE) and spur leaf removal impacted end of season fruit quality and within cluster competition on ‘Crimson Gala’/M.9 trees planted in 2009.

Artificial spur extinction lowered crop density only in the second season, and then only the two most intense spur removal treatments were effective. Average fruit size was increased, but fruit size distribution was not shifted to larger sizes, and overall yield was not improved. In both seasons, crop value was highest in the untreated control with intact lateral clusters. In the first season there was a greater impact on fruit set by total cluster count than by treatment, while this reversed in 2018, suggesting the level of variability decreased, and that branch level impacts were more applicable to whole-tree crop load. The lack of separation between of crop density levels suggests that branch level manipulations don’t accurately predict yield in Pennsylvania growing systems. Additionally, ASE cannot be recommended to Mid-Atlantic growers, due to the negative effects of treatments on yield and orchard profitability.

Spur leaves did not impact fruit size or quality in either season, but did impact fruitlet growth and drop rates for one week in both seasons. However, this did not result in differences in size of fruit or number of fruit per cluster at harvest. Fruit nutritional status was also not impacted by spur leaf removal. This experiment confirmed that having intact spur leaves subtending the flower cluster is not critical for fruit set as long as phloem remains intact. The setting of fruits
seems to be supported by other spur leaves due to the high efficiency with which photosynthates are moved throughout the canopy.
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Dedication

This thesis is dedicated to my parents, Deborah and Gregory Wiepz. Gregory taught me that education is a continual journey born of curiosity, and Deborah taught me that patience and determination are critical elements of any successful endeavor.
Chapter 1

Introduction

Apples are grown on more than 5 million hectares on six continents, making them one of the most widely produced horticultural crops. In 2016, The United States alone produced 4.6 million tons, of which 222,000 came from Pennsylvania (USDA/NASS, 2017; Food and Agriculture Organization of the United Nations, 2016). The importance of this crop in the local and national economies makes it an important and necessary horticultural research subject.

Crop load management

Crop load management in apples plays an important role in fruit quality and tree health (Batjer LP, Billingsley HD 1957; Byers 2003). Management primarily focuses on reducing fruit number to optimal levels: between one and one and a half kilograms of fruit per square centimeter trunk cross sectional area. This can maximize fruit quality, yield, and tree health and decrease biennial bearing, thus maximizing the profitability of present and future harvests (Byers 2003; Dennis 2000; Lafer 1998).

Internal and external factors determine fruit quality, these impact the appearance of the fruit, as well as its taste and longevity. External factors such as; size, blush coverage and intensity, and a lack of defects are the primary determinants of crop value. However, internal factors, including starch, sugar, and acid concentration, among others, are critical for the taste and storability of the crop (Amarante et al. 2008; Byers 2003). Larger, defect free fruit with greater blush coverage tend to sell at a higher price point for most cultivars. Although the impacts of thinning on yield and profit vary by cultivar, the increased price of larger, higher quality fruit is
believed to offset lower fruit numbers. Below a certain size threshold, apples sell for as little as 30% of the fresh market price (Byers 2003). Some cultivars show a high correlation between fruit number and yield, thus leading to decreased income in the year of thinning (Forshey and Elfving 1977). However, increased return bloom the season following thinning often causes the orchard to be more reliably profitable. Consistent profit margins are partially due to reduced biennial bearing. A heavy crop in an “on” year can prevent the initiation of some or all floral buds for the following season (Dennis 2000). Therefore, this trait can mostly be managed by decreasing crop load in heavy seasons (Janick 2003).

Tree health is heavily influenced by crop load, as carbohydrate availability influences fruiting, vegetative growth, and seasonal reserves (A N Lakso et al. 1999). Additionally, limb breakage and reduced cold hardiness can occur due to over cropping (Dennis 2000). Thinning young trees also prevents stunting of tree growth and other long term issues with tree health. Once trees are of a size to support a full crop load, thinning results in greater seasonal tree growth and a greater number of spurs with growing bourse shoots (Byers 2003). Early thinning, at or before bloom, leads to greater impacts on fruit size and firmness (Johnson 1995). Final fruit weight decreased by 5g for every 7 day delay in thinning until impacts ceased four weeks before June drop (McArtney, Palmer, and Adams 1996); (Menzies 1980).

Into the early 1900s it was largely concluded that thinning of fruit would not impact return bloom in the following year. However, Harley (1935) showed that early thinning increased the percentage of spurs blooming the following season, from as low as 3% to as high as 47%. Timing of thinning application to create the greatest impact on return bloom was debated between pre-bloom (Bobb and Blake 1938; Crow 1920) and June drop (Auchter and Schrader 1923). While the specific timeframe to impact return bloom varies with cultural conditions and cultivar, early thinning conclusively has an impact.
Excess fruit can be removed in numerous ways, but is typically done using chemical, manual, or mechanical thinning. Each of these techniques carry their own advantages and disadvantages (Table 1-1).

Chemically thinning apples has been investigated since the early 1900’s with widespread use beginning approximately fifty years later (M. Williams 1979). The initial thinning chemicals were corrosives, including tar oil distillate, lime sulfur and iron sulfate. While some corrosive agents are still used today in the Western and Midwestern United States (Domoto et al. 2012; Schwallier and Irish-Brown 2013; Washington State University 2018), they are currently not registered for use in Pennsylvania (J. Schupp 2017). Pennsylvania growers primarily use post bloom hormonal thinners including synthetic auxins and cytokinins. Ethephon is used only as a “rescue” thinner due to its efficacy when fruits are too large to thin with other chemistries. Caustic materials are not used in the Mid-Atlantic region due to potential phytotoxic damage in humid conditions. Lime sulfur did not produce these effects on certain cultivars (Washington State University 2018; MW Williams 1994). The thinning response to plant growth regulators (PGRs) can be highly unpredictable, and is influenced by numerous environmental and cultural factors, potentially requiring multiple applications, or follow-up hand thinning: both of which quickly become economically limiting. This variation can also cause over thinning, resulting in an abundance of large, low quality, fruit prone to post-harvest disorders (Dennis 2000; J. Schupp 2017; M. Williams 1979). Aside from corrosive compounds and synthetic PGRs, two carbamate insecticides, carbaryl and vidate, are labelled for use as thinners in Pennsylvania (J. Schupp 2017). These materials are considered to be effective mild thinners. While carbamates are used in the US, the European Union repealed their registration as thinners in 2006, citing potential deleterious effects on growers, pollinators, insectivorous birds, herbivorous mammals, and aquatic organisms (Health & Consumer Protection Directorate-General 2006). Recently, some retailers in the US have begun to follow suit, potentially signaling a shift away from carbamate
use here as well (Whole Foods Market® Prohibited and Restricted Pesticides for Fresh Produce and Flowers 2014). Chemical thinners are currently the most practical and widely used tool available for decreasing crop load. However, their unpredictability, potential high economic cost, and changing regulations leave room for additional means of decreasing cropload.

From as early as the 1600s until the implementation of chemical thinners in the mid-1900s, manual removal of excess fruit was the recommended means of decreasing crop load (Dennis 2000). Although the returns on quality of manual thinning have been well established, it is not a common practice due to high labor requirement, making it economically viable only for high value cultivars (O’Rourke 2003). Delaying fruit removal to after final fruit set minimizes the chances of over-thinning but, due to the time necessary to manually thin trees, decreases potential fruit size and return bloom impacts (Kon and Schupp 2013; McArtney, Palmer, and Adams 1996).

While progress has been made in ease of application of hand-thinning there are still many limitations. The Equillifruit hand thinning gauge was designed to simplify the practice of hand thinning and maximize efficiency for treatment. Kon and Schupp (2013) found that the gauge, when used at final fruit set in Pennsylvania, adequately set crop load for high quality fruit. However, the time necessary to manually remove fruit resulted in poor fruit size at harvest. Labor cost is a primary concern of growers, and the delay in crop manipulation limits increases in fruit size and return bloom. While manual thinning is a useful tool to supplement other strategies or for growers that do not have chemical options available to them, it is not a practical primary thinning strategy for most growers.

In an effort to minimize chemical inputs, due to higher governmental regulation regarding sustainability and fruit quality, researchers and producers are investigating ways to make the physical removal of fruit more economic. While mechanical methods of removing fruit are relatively common with stone fruit, including club thinning, string thinning, shaking, and high
pressure spray guns, they are not often used on apples due to the propensity of early season bruises appearing at harvest (Dennis 2000). Schupp et. al., (2008) investigated the used of the Darwin string thinner, developed in Germany, in Mid-Atlantic apple orchards beginning in 2007 (J. R. Schupp et al. 2008). The string thinner reduced labor requirements between 50% and 81% when compared with hand thinning and led to a net economic gain from $175/ha to $1966/ha (J. R. Schupp et al. 2008). However, the impacts of the string thinner on yield and fruit size in ‘Gala,’ were limited by the damage to spur leaves (Kon, 2012). Aside from the incidence of bruising and damage to early photosynthetic tissue, mechanical thinning can introduce other risks, including the transfer of disease. Ngugi and Schupp (2009) demonstrated that the use of mechanical string thinners under conditions conducive to infection increased the risk of spreading *Erwinia amylovora* (Ngugi and Schupp 2009).

The variability of cultural systems, cultivar-specific responses, governmental regulation, and consumer preference illustrate the need for multiple cropload management strategies. Each of the existing strategies has deficiencies, whether it is cost of labor or chemicals, predictability of final fruit set, or maximization of thinning response. The addition of another strategy that could work alone or in conjunction with existing strategies could be highly beneficial to Mid-Atlantic growers (Table 1-1).

**Spur removal**

The term ‘spur’ refers to the complex of a mixed vegetative and fruiting bud, and the short branch that attaches it to a limb. Studies on spur removal as a pruning or thinning method originally focused on managing the “spur-bound condition” of ‘Delicious’ type apples, where older trees fail to develop high quality spurs, producing smaller fruit and becoming insensitive to chemical thinners. Therefore the primary focus was on spur and fruit quality impacts (David C. Ferree & Forshey, 1988; Rom, 1992). Spur quality is often correlated with large bud size and large initial leaf area which are potential indicators of “good fruit set, satisfactory fruit size and
high fruit Ca levels” (Ferree, Schmid, Schupp, & Warrington, 1990). More recently studies have focused on apple spur removal as a crop load management strategy for various cultivars and training systems. Eliminating the “spur-bound condition” was most effectively achieved by combining spur pruning with heading cuts or stubbing spurs (David C. Ferree and Forshey 1988). While intense spur removal treatments induced lateral buds to become fruitful (Pierre-Eric Lauri and Terouanne 1999), fruit size was not significantly increased in the first season, unless combined with other pruning methods (Ferree & Forshey, 1988). However, after two years spur pruning increased the portion of the crop in the largest size category from 3% to 10%. Due to the impacts seen with other treatments the study concluded that spur pruning alone is not an economic option for improving fruit quality in ‘Delicious’ cultivars (Ferree et al., 1990).

Artificial spur extinction was designed to mimic the fruit set tendency of type IV apple trees which naturally abort spurs, causing them to bear more regularly each season (Lauri et al., 1995). Based on results from a study examining the year to year evolution of fruiting points it was proposed to stimulate return bloom on axillary branches (Pierre-Eric Lauri et al. 1995; Pierre-Eric Lauri and Lespinasse 1999). Early work on spur extinction examined three training systems with ‘Gala’: Solaxe, Centrifugal training (CT), and total extinction on 1-year-old wood. The authors reported that the necessity of extinction decreased greatly the season following treatment, as there was very little regrowth on the extinction sites. Additionally, the CT system, the most extreme spur removal treatment, increased the number of flowering clusters, regardless of the length of the spur shoot (Lauri, Willaume, Larrive, & Lespinasse, 2004).

Since 2004, much of the research on ASE has been done in New Zealand and Australia pertaining to specific cultivars, including ‘Scifresh’, ‘Gala’, ‘Honeycrisp’, ‘Scilate’, ‘Kalei’ and ‘Cripps Pink.’ ASE enhanced fruit set in weakly flowering cultivars, specifically ‘Scilate’ and ‘Granny Smith’ (Breen et al. 2014; D. S. Tustin et al. 2011, 2012). Improved fruit set was correlated with decreased bienniality as well as enhanced fruit quality and color of ‘Scilate,’
‘Kalei,’ and ‘Honeycrisp’ (Embree et al. 2007; Van Hooijdonk et al. 2014; Nichols, Embree, and Fillmore 2011; Tabing et al. 2016). Improved fruit size, dry matter content, and coloration are purported to be beyond those that would be caused by the observed crop load decrease. This may be due to increased light penetration into the canopy, although studies on both water use and light interception did not show significant differences (Breen et al. 2016; Green et al. 2016; Van Hooijdonk et al. 2014; Tabing et al. 2016).

Although spur thinning as a technique has been around for a number of years, the use of ASE in modern production systems is still being investigated. This is evidenced by the wide variety of cultivar specific trials on new and currently popular cultivars. Examination of different levels of ASE is needed to expand the applicable regions and cultivars. One study conducted by Breen et al. (2016) on ‘Gala’ examined ASE levels of two, four, and six buds per cm² branch cross sectional area, showing a bud density of four would achieve the commercial target per tree for an orchard. Most of the studies conducted in New Zealand were further thinned after initial bud removal, limiting the investigations’ applicability to all production systems (Breen et al. 2016).

Artificial spur extinction research in Pennsylvania was focused on application technique, to minimize the labor required for treatment application. After the thinning treatments were applied in 2016, blossom cluster density and fruit set per cm² limb cross-sectional area in 2017 for ASE and mechanical ASE (performed with a Darwin string-thinner), were reduced. However, fruit set was still higher than recommended for optimum fruit size and quality, suggesting that the industry standard of thinning to 6 buds cm² limb cross sectional area is insufficient to improve fruit size and quality in Pennsylvania (J. Schupp 2016).

*Spur leaves*

Spur leaves play an important role in early season fruit development when these leaves are a vital source of carbon for fruit until the bourse shoots expand (Hansen 1971). Removing
spur leaves, ringing spurs, and removing bourse shoots on some of the spurs impacted early photosynthate availability, dry weight, mineral content, and fruit size (Ferree and Palmer, 1982). The Ca concentration and dry weight of the fruit were linearly related to the spur leaf area, suggesting that the transpiration of the spur leaves is crucial to the importation of resources into the fruit in the early season. All of these response variables were affected only when spurs were isolated by ringing, suggesting that carbohydrates are highly mobile throughout the tree (Ferree & Palmer, 1982).

**Objectives**

The objectives of this project are to evaluate the efficacy of four different levels of spur extinction in the Mid-Atlantic region on fruit set, size, yield, and quality, and to determine an effective spur removal level for optimizing crop load. Additionally, we assessed the impacts of spur leaf removal on fruitlet growth rate, fruit set, and bourse shoot length, as well as fruit size, weight, blush percentage, seed number, and dry weight percentage.

**Conclusion**

Artificial spur extinction potentially offers growers in the Mid-Atlantic Region an additional tool for improving fruit quality. Spur extinction performed during dormancy, earlier than other chemical or hand thinning treatments, can potentially maximize responses to thinning (McArtney, Palmer, and Adams 1996). ASE also has potential in production systems where chemical thinning is less effective or isn’t an option. Cultivars which are difficult to thin chemically may benefit from reduced hand thinning time, and orchards managed with organic practices where there are few chemical thinning options available could utilize ASE as an effective crop load management strategy (Breen et al. 2015). Finally, ASE provides a unique opportunity to better understand the physiology of fruit set. Manipulating the balance of fruiting and vegetative tissues by removing a portion of both, alters the carbon balance in the plant at a critical time in growth and development. By changing other key components of the plant at that
time, one can explore the impacts on fruit growth and quality. Additionally, the altered cropload status could potentially improve the efficacy of predictive models, something that commercial growers could certainly benefit from (Breen et al. 2014, 2015; Nichols, Embree, and Fillmore 2011).
Literature Cited


Disasters.


Marini, Richard P, James R Schupp, Tara Auxt Baugher, and Robert Crassweller. “Sampling Apple Trees to Accurately Estimate Mean Fruit Weight and Fruit Size Distribution.”


Table 1-1. Characteristics of three modes of thinning

<table>
<thead>
<tr>
<th>Thinning strategy</th>
<th>Manual</th>
<th>Mechanical</th>
<th>Chemical</th>
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<tr>
<td>Reliability</td>
<td>H</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Regulation (and consumer preference)</td>
<td>L</td>
<td>L</td>
<td>H</td>
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<tr>
<td>Weather Dependency</td>
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<td>Phytotoxic Risk</td>
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<tr>
<td>Labor Intensive</td>
<td>H</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Return Bloom Impacts</td>
<td>L</td>
<td>L</td>
<td>M</td>
</tr>
</tbody>
</table>

H=high or yes
M=medium or sometimes
L=low or none
Chapter 2

Impacts of five levels of artificial spur extinction on fruit yield and quality of ‘Gala’ apples in tall spindle orchard systems in Pennsylvania

Introduction

Apple trees have a strong propensity to set more fruit at the beginning of the season than can be grown to marketable size and quality by harvest. Thinning the crop to reduce yield to optimum levels of one to one-and-a-half kilograms of fruit per square centimeter trunk cross sectional area improves fruit size and quality and tree health, decreasing biennial yield fluctuations (Batjer LP, Billingsley HD 1957; Byers 2003; Dennis 2000; Lafer 1998). Thinning improves marketable yield and reduces yearly yield fluctuations leading to greater and more reliable profits for growers.

In addition to overall fruit size, fruit quality is determined by various internal and external factors that impact the appearance, taste and storability of the fruit. External factors such as blush coverage, red color intensity, and lack of defects are the primary determinants of crop value. Internal factors, including starch, sugar, and acid concentration, among others, are critical for the taste and storability of the crop (Amarante et al. 2008; Byers 2003). Large, defect free fruit with greater blush coverage tend to sell at a higher price.

Crop load heavily influences tree health, as carbohydrate availability affects fruiting, vegetative growth, and seasonal reserves, as well as limb breakage (Byers 2003; Dennis 2000; A N Lakso et al. 1999). In young trees, thinning prevents stunting of tree growth and other long-term issues with tree health. The impacts of thinning on yield and profit vary by cultivar, with the increased price of larger, higher quality fruit offsetting lower fruit numbers for some, with smaller fruit selling for as little as 30% of the fresh market price (Byers 2003). For others, a high correlation between fruit number and yield leads to decreased income the year of thinning, but return bloom the following season can cause the orchard to be more consistently profitable (Forshey and Elfving 1977). Reliable profits are partially due to
a decreased biennial bearing. Decreasing crop load in heavy seasons can mostly manage this issue, as excess crop can prevent the initiation of some or all floral buds for the following season (Dennis 2000; Janick 2003).

Early studies on spur removal primarily focused on managing the “spur-bound condition” of ‘Delicious’ type apples where older trees produce smaller fruit and become insensitive to chemical thinning with age (David C. Ferree & Forshey, 1988; Rom, 1992). More recent spur removal research has focused on improvements in spur quality, and its physiological ramifications. High quality spurs are associated with large bud size and initial leaf area, potential indications of “good fruit set, satisfactory fruit size and high fruit Ca levels” (Ferree, Schmid, Schupp, & Warrington, 1990). When combined with heading cuts or stubbing spurs, spur pruning helped to eliminate the “spur-bound condition,” but was not effective when used as a solo treatment (David C. Ferree and Forshey 1988).

While intense spur removal treatments caused lateral buds to become fruitful (Pierre-Eric Lauri and Terouanne 1999), it did not increase fruit size significantly in the first season, unless combined with other pruning methods (Ferree and Forshey, 1988). After two years spur pruning increased the portion of the crop in the largest size category from 3% to 10%. Due to the impacts of other treatments it was concluded that spur pruning alone was not an economic option for improving fruit quality in ‘Delicious’ cultivars (Ferree et al., 1990).

Artificial spur extinction is a version of spur removal proposed to stimulate return bloom on axillary branches (Pierre-Eric Lauri et al. 1995; Pierre-Eric Lauri and Lespinasse 1999). Based on a previous study that traced the evolution of fruiting spurs from year to year, ASE mimicked the growth habit of type IV apple trees which naturally abort spurs inside of the canopy, bearing a regular crop of high quality fruit on the tips of their branches each season (Lauri et al., 1995).

Early research on ASE examined its impacts on ‘Gala’ grown in Solaxe and Centrifugal training (CT) training systems, and total extinction on 1-year-old wood. Research showed that the necessity of additional extinction decreased greatly in the season following treatment. CT, the most extreme spur removal treatment, increased the number of flowering clusters on the outer part of the canopy (Lauri,
Willaume, Larrive, & Lespinasse, 2004). In addition to establishing the practice of ASE on tall spindle trees, researchers in New Zealand and Australia examined its impacts on specific cultivars, including ‘Scifresh’, ‘Gala’, ‘Honeycrisp’, ‘Scilate’, ‘Kalei’ and ‘Cripps Pink.’


Increases in fruit size, dry matter content, and coloration in these studies were purported to be beyond those that would be caused by the observed reduction in crop load. This may be due to increased light penetration into the canopy, although studies on both water use and light interception showed slight but nonsignificant differences (Breen et al. 2016; Green et al. 2016; Van Hooijdonk et al. 2014; Tabing et al. 2016).

With certain cultivars the response to ASE increased with ASE severity. Breen et al. (2016) examined ASE levels of two, four, and six buds per cm² branch cross sectional area, (lc1sa) and reported that a bud density of four would achieve the commercial target per ‘Gala’ tree.

All previously mentioned studies included hand thinning following initial bud removal. This application of a second thinning method limits the investigations’ applicability to all production systems and could potentially mask the effects of ASE (Breen et al. 2016).

Artificial spur extinction offers growers a potential additional tool for improving fruit quality. Spur extinction is performed during tight cluster, which is earlier than chemical or hand thinning, potentially maximizing thinning impacts (McArtney, Palmer, and Adams 1996). ASE also has potential in production systems where chemical thinning is less effective or isn’t an option. Cultivars which are difficult to thin chemically could benefit from reduced hand thinning time. Organic production, which lacks chemical thinning options, could also benefit from an additional way to manipulate crop load (Breen et al. 2015).
‘Gala’ apples are an economically important variety in Pennsylvania and the United States as a whole, appearing in the top five varieties for both production and sales (U.S. Apple Association 2018). Presently, ASE research in Pennsylvania has focused on application technique, seeking to minimize the labor required for treatment application. Thinning treatments applied in 2016, reduced the blossom cluster density for ASE and mechanical ASE (performed with a Darwin string-thinner). The same results were seen in 2017, coupled with lower fruit set per cm² lcsa. However, fruit size and quality were not improved. Suggesting that, in Pennsylvania, the industry standard of thinning to 6 buds cm² limb cross sectional area is insufficient to optimize crop load (J. Schupp 2016). The objectives of this study were to determine if a more severe level of spur removal improves fruit size and quality in mature ‘Gala’ trees, and to determine if improvements in quality improve crop value under current Pennsylvania market conditions.

**Materials and Methods**

*Experimental Design*

In 2017 and 2018, experiments were conducted at the Penn State Fruit Research and Extension Center in Biglerville, PA. Mature ‘Crimson Gala’/ M.9 NAKB337 trees planted in 2009 at 0.9 x 3.66 m spacing were selected for this experiment. Aside from thinning protocols, trees were maintained to industry standards for pesticide regimens. Trees were trained to a tall spindle system to fill all available space in the fruiting wall, and no permanent scaffolds were maintained. Twenty trees with trunk circumferences between 11.9 and 16.5 cm. were selected for use in this experiment, based on measurement 30cm above the graft union.

Trees were assigned in four single tree replications to one of five treatments in a completely random design using a random number generator in Excel. To obtain an understanding of the cumulative effects of the thinning treatment, the same treatments were applied to each tree in both 2017 and 2018.

1. Two buds remaining per cm² lcsa (ASE2)
2. Four buds remaining per cm² lcsa (ASE4)
3. Six buds remaining per cm² lcsa (ASE6)
4. All spurs and terminals remaining, with lateral buds removed (Control A)
5. All spurs, terminals, and laterals unaltered (Control B)

All thinning treatments were applied in mid to late March, at or before the green tip stage (Figure 2-1). Each branch was assigned 2, 4, or 6 buds per cm² lcsa to reflect their respective treatment (1-3) using a modified MAFCOT 6 Equillifruit disc (Figure 2-2). Potential fruiting buds were retained along the branch and were evenly spaced, well exposed to light, and included the terminal bud in the total floral bud count. All other buds were broken off as close to the main branch as possible by hand or with pruning shears (Figure 2-1). Approximately three weeks after green tip, fruiting and lateral buds on one-year old wood were removed on treatments 1-4 by holding the terminal bud in one hand while running the thumb and forefinger of the other down the branch to the previous season’s leaf scar.

*Environmental and Treatment Assessment*

Blossom cluster counts were recorded for each tree at full bloom, each tree was counted twice to ensure accuracy. Total cluster count per tree was analyzed to ensure an increasing number by treatment. When fruit were approximately 30mm in diameter, and fruitlet abscission had ceased, final fruit set (ffs) was recorded. All ffs were converted to frequency counts, indicating the number of clusters holding each number of fruitlets.

*Vegetative and Fruit Impacts*

Canopy light environment was measured using a 1 m light meter (LI-COR LI-250A) placed perpendicular to the row at 1.5m height in the canopy as an indicator of vegetative growth. Ambient light was measured every five trees and the percentage of radiation within the canopy was calculated. Trunk diameters were measured at 30 cm above the graft union at the beginning of the experiment and annually following cessation of seasonal growth. The trunk cross-sectional area (TCSA) increase was calculated annually.
Fruit were harvested based on optimal background color and starch-iodine tests from adjacent non-data trees indicating fruit was mature. In 2017 trees were harvested twice to ensure optimal ripeness and all harvest analyses were conducted after the second harvest. Trees were harvested once in 2018, due to low fruit numbers, and all analyses were performed following harvest. Individual fruit weight was measured using an electronic single-lane fruit sizer (Durand-Wayland, Ind., LaGrange, GA). Total yield was analyzed as fruit size distribution, crop density, and average fruit size. Additionally, yields were converted to crop value by sizing the fruit based on a subsample taken from each treatment to convert individual apple weight to diameters. The analysis confirmed the following relationship:

\[ \text{diameter(cm)} = 0.00628 \times \text{fruit weight(g)} + 1.75486 \] with an \( \text{adjusted } R^2 = 0.8912 \).

After apple weights were converted to sizes, they were assigned to boxes or bags based on size and prices per pound were used for each category. Prices were then obtained from a local packing house with the assistance of the Penn State Ag Economist Lynn Kime (Table 1.1). A 20 fruit sample from each tree was used to assess treatment effects on fruit quality. For trees with less than 20 fruit available, the entire harvest was used as the sample. The apple surface was measured at two points to represent zones of high and low blush on the apple with a spectrophotometer (CM-2600D; Konica Minolta Sensing Inc., Osaka, Japan). Color characteristics were analyzed using hue, chroma, and lightness, as indicated in the CIELAB color space (CIE Recommendations on Uniform Color Spaces, Color-Difference Equations, and Metric Color Terms 1977). Two photographs per apple were taken and analyzed using digital image analysis in Image J software to calculate the percentage of blush on the skin (Winzeler and Schupp 2011).

Two discs of peel were removed on opposite sides of each apple, and firmness of the subtending flesh was measured with a fruit texture analyzer (Güss GS-14, QA Supplies, LLC, Norfolk, VA). An equatorial slice of each apple was reserved for starch analysis. The cut surface was dipped into a chlorine-iodine solution and allowed to sit in the open air before being photographed to determine percentage of surface stained by iodine using digital image analysis using Image J software (H. Edwin Winzeler, Personal Communication). Stain percentage is inversely correlated with ripeness. Juice samples were
taken from each apple and analyzed for soluble solids using a digital refractometer (Atago model PR-32 alpha, Bellevue, WA). In 2018, juice titratable acidity was measured with a mini-titrator and pH meter (HI 84432; Hanna Instruments, Woonsocket, RI), and total polyphenol content of the juice measured (Tannin in Cider Apples 2013; Waterhouse 2012).

**Statistics**

Initially the two years of data were pooled with the intent to evaluate the interaction between treatment and years. However, the great variation between the two years due to early bloom followed by freezes in 2017, and normal bloom date followed by hail and carbon stress in 2018 gave significantly different results by year even when interactions were not significant. Therefore, data were analyzed by year.

All data were analyzed with SAS software (version 9.3; SAS Institute, Cary, NC). Data for each response variable were subjected to a one-way analysis of variance using Proc GLM. Regression using PROC REG was performed using whole tree cluster count as the regressor variable. Regression examines the relationship between number of flowering spurs per tree and response variables, whereas ANOVA tests the hypothesis that all treatments are equal. Significance, when discussed in this paper is at the P<0.1 level, on the recommendation of my committee, based on the amount of variability.

Analysis of covariance was performed with Proc Mixed with trunk diameter as a covariate. The nonsignificant covariate indicated that a completely randomized design was preferable to blocking on initial TCSA. Fruit set was analyzed by assessing the fraction of clusters setting each number of fruitlets.

Fruit size distributions were compared using the non-parametric Kolmogorov-Smirnov test with SAS’s NPAR1WAY procedure to perform pairwise comparisons of empirical distribution functions (EDF) for each treatment. EDF is a non-parametric estimate of the cumulative distribution function for each variable. Therefore, its value at a given point is equal to the proportion of observations from the sample that are less than or equal to that point (Marini et al., n.d.; Marini, Personal Communication). The existence of ten comparisons and desired experiment-wise error rate of 0.1, lead to comparison-wise error rate of 0.01.
Results

Fruit set and canopy environment

At ffs in 2017 and 2018 respectively, the accumulated growing degree days (GDD) were 80 and 324 (Figure 1.4) while the cumulative radiation was 1935.4 MJ/M²/s and 1143.2 MJ/M²/s (Figure 1.3). Analysis of variance showed the number of fruit set per 100 blossom clusters (percent) was impacted by treatment in 2018, when ASE 2 was 133% lower than Control B, but was unaffected in 2017. The total number of clusters that set fruit was strongly influenced by treatment in both seasons, with Control B higher than ASE 2 and ASE 4 in both years. Treatment impacted the proportion of clusters holding 5 fruit in 2017, and 1, 3, and 4 fruit in 2018 (Table 2-3). Light environment was influenced by treatment only in 2018 with ASE2 light levels 118% higher than Control B. Relationships with total cluster count were not identical to treatment impacts. Percent fruit set was negatively related to total cluster count in 2017 but not in 2018 (Figure 2-6). The number of clusters that set fruit was positively related to total cluster count in both seasons, accounting for 93% and 64% of the variability in 2017 and 2018, respectively. Total cluster count and proportion of clusters holding 2 fruit were positively related in 2017 while a negative relationship existed between clusters holding 3, 4, or 5 fruit per cluster. In 2018, number of fruit set per cluster was not impacted at any level by total cluster count (Table 2-4). The 2018 hail damage assessment showed no relationship between any indicator of damage and tree location (data not shown).

Yield and Fruit Quality

Crop density in 2018 was higher in control B than ASE 2 or ASE 4. In 2017 treatment impacted fruit size, crop value and soluble solid concentrations (Table 2-7 and 2-5). Control A and B had smaller average fruit size than ASE 2 in 2017 (Table 2-7). Texture, all characteristics of blush, and starch were not affected by treatment in either season. Titratable acidity was greater in ASE 2 and ASE 4 trees than Control B in 2018 (Table2-5). Crop value was 62% and 164% higher in Control B than ASE2 in 2017 and 2018 respectively (Table 2-7). At harvest in 2018, crop value dropped by an average of 93% for all treatments (Figure 2-5). Crop density was positively related to cluster count in 2018. Fruit size decreased
with cluster count in 2017, but not in 2018 (Table 2-8). Fruit firmness, blush and starch were unrelated to total cluster count in both seasons (Table 2-6) Soluble solids concentration was negatively related to cluster count in 2017, accounting for 44% of the variability, but not in 2018 (Table 2-6). Crop value was positively related to cluster count in both years, with R² values of 0.72 2017 and 0.59 in 2018 (Table 2-7). Fruit size distributions for ASE2 and ASE4 differed from Control B in 2018. Both thinned treatments were shifted to smaller sizes categories, in addition to having lower yield overall (Table 2-1).

Discussion

Environmental conditions heavily influenced results both seasons. A late frost in 2017 and a hail storm at petal fall in 2018 caused early season stress on the trees. In 2018, the event was more significant and was closely followed by a carbon deficit that lasted multiple months. Therefore, data from the two seasons are markedly different and comparisons between the two are limited.

While results suggesting whether or not ASE lowers crop load may vary, likely by the definition of crop load, it is purported to be a highly replicable system (Kon and Schupp 2018). However, the difference between impacts of crop load and treatment suggest that the level of ASE, even when not combined with the recommended pruning pattern, was not directly translatable to crop load (S. Tustin et al. 2014).

In four of the previous studies ASE treatment increased the number of fruit set per spur, which is expected when crop load is decreased. Despite the research with ‘Scilate’ and ‘Granny Smith’ the fruit set was in no way enhanced on the thinned trees in the second season (Breen et al. 2014; Embree et al. 2007; Van Hooijdonk et al. 2014; Nichols, Embree, and Fillmore 2011; Tabing et al. 2016; D. S. Tustin et al. 2011, 2012). Percent fruit set showed that the first season impacts were attributed to cluster count on the trees rather than level of spur extinction. In 2018, ASE did alter percent fruit set, but it lowered the fruit set overall. The negative relationship between cluster count and percent fruit set in 2017 suggests that in
tall spindle does confirm that higher crop load causes decreased fruit set, however the translation of ASE level to crop load is not direct. Fruit set was also not enhanced within clusters. Again, in 2017 clusters were positively related to within cluster fruit set, however, this did not translate directly to treatment. There were impacts of treatment in 2018, suggesting that the variability of each treatment declined in the second season. ASE in New Zealand decreased bienniality and fluctuation in fruit set from year to year (Breen et al. 2014, 2015; Nichols, Embree, and Fillmore 2011). While this appeared to be true, based on the results in 2018, the mean separations showed that spur removal did not improve fruit set, as Control B set more fruit per cluster than any of the thinned treatments.

Number of fruit per cluster is an indicator of harvest and fruit quality, and fruit size. Fruit size plays a key role in crop value and yield for many cultivars. The unchanged fruit size distribution the first season supports results of Ferree and Forshey (1988) where spur removal did not increase fruit size significantly in the first season, unless combined with other pruning methods (Ferree and Forshey, 1988). However after two years spur pruning increased the portion of the crop in the largest size category (Ferree et al., 1990). Our experiment project showed little difference in size distributions. The only differences occurred in 2018 and Control B not only had higher yield, but more large fruit as well. Size distribution was not increased in either season, while average fruit size increased with fewer clusters on the tree, as would be expected for an early season thinning method. Removing excess crop, particularly early in the season, such as when the treatments were applied in this experiment, increased fruit size at harvest (Johnson 1995; Kon and Schupp 2018; Mcartney et al. 2006; Menzies 1980). Again, this effect wasn’t attributable to treatment. In 2018 treatments did not affect fruit size and cluster count, due to the further reduction in crop load that occurred at and after petal fall. Crop density in 2017 wasn’t impacted by treatment or total cluster count on the tree, concurring again with Ferree’s (1988) findings on the lack of response in the first year of application. The positive relationship between cluster count and crop density in 2018 is also likely due to the environmental stress that occurred early in the season.

Despite not altering the crop load in 2017, treatments influenced some aspects of fruit quality. Fruit quality is determined by internal and external factors that impact the fruit appearance, taste, and
storability. External factors such as size, blush coverage and intensity, and a lack of defects are the primary determinants of crop value. However, internal factors, including starch, sugar, and acid concentration, among others, are critical for the taste and storability of the crop (Amarante et al. 2008; Byers 2003). Much of the research on ASE suggests that improved fruit size, dry matter content, and coloration are beyond those caused by the decrease in crop load. This may be due to increased light penetration into the canopy, although the lack of difference in texture, blush, or starch in 2018 suggests that increasing light interception in this growing system does not dramatically alter the quality of the fruit in tall spindle systems in Pennsylvania (Breen et al. 2016; Green et al. 2016; Van Hooijdonk et al. 2014; Tabing et al. 2016). The difference in acidity in 2018 was attributed to treatment but not to cluster count, potentially suggesting that the removal of buds at different levels does affect fruit quality more than crop load alone. The differences in acid in 2018 and soluble solid concentration in 2017 were also not associated with any differences in starch, meaning that the fruit was not under or over ripe. These differences in flavor compounds, could be due to environmental factors or, in the case of 2018, in spur quality differences from the previous season. It’s difficult to conclude anything about spur quality without another season of data.

Over the last 50 years extreme environmental events, including flooding, harsher than normal winters, and early springs, along with many others, have become more common (Doocy et al. 2013; Kunkel et al. 2013; Peterson et al. 2013). Observing the impacts of crop load management strategies in various environmental conditions is more important than ever because of this. Particularly in the Northeastern U.S. where the frequency of winter storms has dramatically increased, even in the last 20 years (Vose et al. n.d.). In an environment where winter temperatures were not as extreme as those of the northeast, this may not impact the reliability of this thinning strategy.

Environmental conditions in Pennsylvania influenced the crop both seasons. In 2017, a late frost occurred before full bloom. At petal fall in 2018 a hail storm damaged woody tissues, young fruit, and any open leaf area. Additionally, weather from initial to final fruit set was markedly different between the
two seasons. Cumulative solar radiation levels were much lower (Figure 1.3), and cumulative growing degree days, calculated with a base temperature of 14°C, were much higher in 2018 (Figure 1.4).

Given that ‘Gala’ does not have strong dominance of king blossoms, 2017’s early frost was presumed to have little impact on yield or final fruit set (D.C. Ferree et al. 2001). A damage assessment following the hail storm in 2018 showed that all trees were evenly impacted by the storm. The combination of high temperatures and low radiation following the storm likely caused carbon stress in 2018, causing the trees to drop a substantial amount of fruit, resulting in the 93% decrease on average of crop value (A. N. Lakso 2011). The damage to leaves and woody tissue also caused a flush of vegetative growth, further skewing the carbon balance in the trees and affecting the canopy environment (Greene and Autio 1994; Alan N Lakso, Greene, and Palmer 2006).

Early-season spur removal removed potential vegetative tissue, as well as fruit. In New Zealand this caused a four percent increase in light penetration in tall spindle trees (Breen et al. 2016; P.-E. Lauri et al. 2004; Willaumé Pierre-Éric Lauri Hervé Sinoquet 2004). During the first season we measured no difference in canopy light environment for thinned trees, suggesting that the proportion of potential vegetative tissue that was removed was not critical to yield or fruit quality. The 118% higher light levels in ASE2 the second season, are most likely attributable to the damage from the hail storm (Figure 2-7). Damaged woody tissues, similar to the nursery practice of notching, can cause a flush of vegetative growth when formerly dormant lateral buds break (Greene and Autio 1994). The openness of the canopy on ASE treated trees, shown in Figure 2-8, made the woody tissues of those trees more vulnerable to damage. Additionally, many of the bourse shoots on those trees were removed meaning that any vegetative growth that occurred would have been from dormant lateral buds. McArtney (2015) found that only 4% of buds that broke due to notching grew to be more than one centimeter long (Mcartney and Obermiller 2015). The combination of less damage and growth from bourse shoots could lead to the greater photosynthetic interception of the control trees, which then resulted in the maintenance of more, larger fruit to the end of the season.
Although the impacts of thinning on quality and yield vary by cultivar, the increased price of larger, higher quality fruit generally offsets lower fruit numbers (Byers 2003). In 2016, a carton of 80-count extra fancy ‘Gala’ apples sold for $0.18 more per apple than those in a 198 count wholesale carton in southern Pennsylvania. The data from this project showed a positive relationship between cluster count and crop value in both years, with $R^2$ values of 0.72 and 0.59 in 2017 and 2018, respectively. The value of Control B was 62% and 164% higher than ASE2 in 2017 and 2018 respectively, suggesting that for ‘Gala’ the number of fruit is a better indicator of crop value than the size of the fruit. The 93% drop in crop value for 2018 suggests these data are not particularly applicable to a grower, but the relationship is very similar to the previous years (Figure 2-5).

ASE research in Pennsylvania has focused on minimizing the labor required for treatment application and concluded that in Pennsylvania, the ASE standard of thinning to 6 buds per cm$^2$ lcsa is insufficient to optimize yield and fruit quality (J. Schupp 2016). Ferree (1990) stated that spur removal alone is not an economic option for improving fruit quality in ‘Delicious’ type apples. Based on previous research in Pennsylvania and the results of this study ‘Gala’ apples would fall into this recommendation as well. This practice currently cannot be recommended to Pennsylvania growers.

**Summary**

The purpose of this study was to determine the applicability of ASE in Pennsylvania orchards by examining the impacts of five levels of spur extinction on yield and fruit quality. Spur removal has been studied for years but much of the research done on ASE, has been conducted in Australia and New Zealand. The results there have been very promising, suggesting ASE as a new and highly beneficial form of cropload management for growers around the world. The timing of application, decreased labor requirement, increased reliability, and lack of chemical regulation have the potential to make ASE highly useful for Pennsylvania growers, making it a great asset to growers looking to decrease the amount of chemical thinners they are using for any reason. Previous ASE research in Pennsylvania has concluded that the industry standard of 6 buds per centimeter squared lcsa does not maximize impacts on fruit
quality and yield. Therefore this experiment was designed to further investigate if a level of ASE exists that would lower crop load to optimal yield levels.

Mature ‘Crimson Gala’ apple trees in Pennsylvania were assigned to one of five treatment levels. Thinned treatments were set to 2, 4, or 6 buds remaining per cm² lcsa while Control A had no spurs removed. Control B also had no spurs removed, additionally, the second step of ASE was not conducted, and so all lateral buds on one year old wood were left intact. To examine the trees beforehand and immediate impacts of the thinning treatments trunk diameter and whole tree cluster count were taken. As an indicator of harvest yield, final fruit set was taken as a distribution count. Vegetative impacts were investigated by looking at the canopy light environment. Impacts on fruit were analyzed using blush, starch, texture, soluble solids, acidity, acidity and tannin content. Yield measurements included crop value, fruit size, crop density, and fruit size distribution.

This combination of high temperatures and low available radiation resulted in a carbon stress in 2018, altering the yield and fruit quality data from that season. Carbon stress occurred after a hail event and many trees dropped additional fruit causing crop value to be 93% lower on average for all of the treatments. In addition to the lower crop value, light levels were altered in the second season with more light intercepted in control trees, and no enhancement to fruit set.

The impacts that were seen in 2017 were among the expected impacts of thinning. Regression by total cluster count showed a higher percent fruit set in thinned trees and a negative relationship of the proportion of clusters setting more than two fruit per cluster. These impacts, however, did not translate to treatment, suggesting spur removal is not as effective unless combined with the recommended pruning style. Results in 2018 showed no differences based on cluster count, but did have some treatment impacts, suggesting that variability within the treatments was less in the second season.

While distribution of fruit size was not increased in either season by thinning treatment, average fruit size was increased in 2017 by lower cluster numbers. Much of the research into ASE suggests that improvements in fruit size, dry matter content, and coloration are beyond those caused by the decrease in crop load. While the differences in quality that were seen in 2018 may be attributed to changes in canopy
environment or changes in spur quality from the previous season, they are minor, only pertaining to acidity.

Despite the dramatically lower crop value in 2018, both years saw a direct relationship between clusters on the tree and crop value, suggesting that in ‘Gala’ the number of fruit is a better indicator of crop value than the size of the fruit. Due to the nature of spur formation and the unusual environmental conditions that occurred in the 2018 season, at least one more season of research would be beneficial to investigate the impacts of spur quality on fruit flavor characteristics.

While ASE did alter the canopy and some fruit quality factors in both seasons, it did not enhance profit in either season. Up until this point ASE research in Pennsylvania concluded that the ASE standard level of thinning to 6 buds cm² limb cross sectional area is insufficient to optimize yield and fruit quality impacts (J. Schupp 2016). Based on the data from the last two years, this study would conclude that in a Pennsylvania environment, no level of Artificial Spur Extinction improves size of ‘Gala’ fruit to the point that crop value is improved.
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industry-at-a-glance/ (December 10, 2018).


Figure 2-1. Removal of a dormant spur by hand

Figure 2-2. Mafcot 6 Equilli-fruit disc

Figure 2-3. Cumulative radiation at final fruit set 2017 and 2018

Figure 2-4. Cumulative growing degree days at final fruit set 2017 and 2018
Table 2-1. Effect of artificial spur extinction on yield empirical distribution functions

<table>
<thead>
<tr>
<th>2017/2018</th>
<th>ASE4</th>
<th>ASE6</th>
<th>Control A</th>
<th>Control B</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASE2</td>
<td>0.7634 / 0.8625</td>
<td>0.9375 / 0.2676</td>
<td>0.1514 / 0.1514</td>
<td>0.0796 / 0.0002</td>
</tr>
<tr>
<td>ASE4</td>
<td>X</td>
<td>0.9375 / 0.8625</td>
<td>0.4375 / 0.5412</td>
<td>0.1514 / 0.0018</td>
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<tr>
<td>ASE6</td>
<td>X</td>
<td>0.5412 / 0.9375</td>
<td>0.2676 / 0.0390</td>
<td>0.09375 / 0.0562</td>
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<tr>
<td>Control A</td>
<td>X</td>
<td>0.9375</td>
<td>0.0562</td>
<td>0.0562</td>
</tr>
</tbody>
</table>

*Kolmogorov Smirnov test result

Comparisonwise error rate = 0.01

Table 2-2. Prices for extra fancy 'Gala' apples in southern Pennsylvania, 2016

<table>
<thead>
<tr>
<th>Diameter (in)</th>
<th>Pack (category)</th>
<th>Size (in)</th>
<th>Value ($/pound)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.13</td>
<td>Juice Unsized</td>
<td>2.5</td>
<td>-0.002619048</td>
</tr>
<tr>
<td>2.50</td>
<td>8/3# Bags RPC</td>
<td>2.5&quot;</td>
<td>0.345</td>
</tr>
<tr>
<td>2.63</td>
<td>8/3# DRC</td>
<td>2.625&quot;</td>
<td>0.193</td>
</tr>
<tr>
<td>2.75</td>
<td>3# Bag/Bin</td>
<td>2.75&quot;</td>
<td>0.234375</td>
</tr>
<tr>
<td>3.00</td>
<td>Traypack 113</td>
<td>3.00</td>
<td>0.224</td>
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<td>3.13</td>
<td>Traypack 100</td>
<td>3.13</td>
<td>0.408</td>
</tr>
<tr>
<td>3.25</td>
<td>Traypack 88</td>
<td>3.25</td>
<td>0.438</td>
</tr>
<tr>
<td>3.38</td>
<td>Traypack 80</td>
<td>3.38</td>
<td>0.431</td>
</tr>
<tr>
<td>3.50</td>
<td>Traypack 72</td>
<td>3.50</td>
<td>0.41</td>
</tr>
<tr>
<td>3.63</td>
<td>Traypack 64</td>
<td>3.63</td>
<td>0.411</td>
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</table>
Table 2-3. Effect of 5 levels of artificial spur extinction on canopy environment, fruit set and vegetative growth indicators

<table>
<thead>
<tr>
<th>Thinning Treatment</th>
<th>Canopy Light Environment (MJ/M²/s)</th>
<th>Fruit set per 100 clusters</th>
<th>Clusters with fruit number</th>
<th>1 fruit per cluster(^y)</th>
<th>2 fruit per cluster(^y)</th>
<th>3 fruit per cluster(^y)</th>
<th>4 fruit per cluster(^y)</th>
<th>5 fruit per cluster(^y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE 2</td>
<td>24.50a</td>
<td>212a</td>
<td>47b</td>
<td>0.26a</td>
<td>0.30a</td>
<td>0.24a</td>
<td>0.13a</td>
<td>0.06a</td>
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<td>ASE 4</td>
<td>23.29a</td>
<td>216a</td>
<td>61b</td>
<td>0.24a</td>
<td>0.29a</td>
<td>0.30a</td>
<td>0.14a</td>
<td>0.02b</td>
</tr>
<tr>
<td>ASE 6</td>
<td>23.63a</td>
<td>180a</td>
<td>72ab</td>
<td>0.35a</td>
<td>0.33a</td>
<td>0.22a</td>
<td>0.08a</td>
<td>0.02b</td>
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<td>Control A</td>
<td>22.85a</td>
<td>190a</td>
<td>101a</td>
<td>0.26a</td>
<td>0.38a</td>
<td>0.25a</td>
<td>0.09a</td>
<td>0.02b</td>
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<td>Control B</td>
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<td>127a</td>
<td>101a</td>
<td>0.36a</td>
<td>0.36a</td>
<td>0.21a</td>
<td>0.04a</td>
<td>0.02b</td>
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<tr>
<td>P-value from ANOVA</td>
<td>0.9906</td>
<td>0.1272</td>
<td>0.0017</td>
<td>0.2458</td>
<td>0.1565</td>
<td>0.2679</td>
<td>0.1821</td>
<td>0.0217</td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE 2</td>
<td>20.16a</td>
<td>15.31b</td>
<td>7b</td>
<td>0.83a</td>
<td>0.18a</td>
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<td>21.49b</td>
<td>12b</td>
<td>0.81a</td>
<td>0.19a</td>
<td>0.00b</td>
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<td>ASE 6</td>
<td>14.40a</td>
<td>33.15b</td>
<td>20b</td>
<td>0.76a</td>
<td>0.20a</td>
<td>0.04ab</td>
<td>0.00b</td>
<td>-</td>
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<tr>
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<td>10.57b</td>
<td>46.70a</td>
<td>29ab</td>
<td>0.67a</td>
<td>0.30a</td>
<td>0.03ab</td>
<td>0.00b</td>
<td>-</td>
</tr>
<tr>
<td>Control B</td>
<td>5.16b</td>
<td>75.61a</td>
<td>52a</td>
<td>0.62a</td>
<td>0.25a</td>
<td>0.11a</td>
<td>0.03a</td>
<td>-</td>
</tr>
<tr>
<td>P-value from ANOVA</td>
<td>0.0163</td>
<td>0.0074</td>
<td>0.0026</td>
<td>0.0934</td>
<td>0.3715</td>
<td>0.0154</td>
<td>0.0008</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^x\) Means of 4 Observations

\(^y\) Calculated as proportion of total clusters setting fruit

Tukey’s adjusted mean separation used

No clusters set 5 fruit per cluster in 2018
Table 2-4. Effect of total cluster count on canopy environment, fruit set and vegetative growth indicators<sup>z</sup>

<table>
<thead>
<tr>
<th>Canopy Light Environment (MJ/M²/s)</th>
<th>Fruit set per 100 clusters</th>
<th>Clusters with fruit number</th>
<th>1 fruit per cluster&lt;sup&gt;y&lt;/sup&gt;</th>
<th>2 fruit per cluster&lt;sup&gt;y&lt;/sup&gt;</th>
<th>3 fruit per cluster&lt;sup&gt;y&lt;/sup&gt;</th>
<th>4 fruit per cluster&lt;sup&gt;y&lt;/sup&gt;</th>
<th>5 fruit per cluster&lt;sup&gt;y&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2017</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>21.7701</td>
<td>258.5268</td>
<td>12.5411</td>
<td>0.2109</td>
<td>0.2592</td>
<td>0.3096</td>
<td>0.1656</td>
</tr>
<tr>
<td>Slope</td>
<td>0.0200</td>
<td>-0.7928</td>
<td>0.6859</td>
<td>0.0009</td>
<td>0.0008</td>
<td>-0.0007</td>
<td>-0.0007</td>
</tr>
<tr>
<td>Slope P-value</td>
<td>0.4476</td>
<td>0.0099</td>
<td>&lt;.0001</td>
<td>0.1298</td>
<td>0.0178</td>
<td>0.0642</td>
<td>0.0601</td>
</tr>
<tr>
<td>R²</td>
<td>0.0324</td>
<td>0.3157</td>
<td>0.9368</td>
<td>0.1228</td>
<td>0.2744</td>
<td>0.1777</td>
<td>0.1827</td>
</tr>
</tbody>
</table>

| **2018**                          |                             |                           |                   |                   |                   |                   |                   |                   |
| Intercept                         | 21.5673                     | 19.2822                   | -12.0941          | 0.8147            | 0.1960            | -0.0065           | -0.0039           | -                 |
| Slope                             | -0.0947                     | 0.2380                    | 0.4481            | -0.0009           | 0.0003            | 0.0005            | 0.0001            | -                 |
| Slope P-value                     | **0.0524**                  | 0.1949                    | <.0001            | 0.2534            | 0.5970            | 0.1323            | 0.206             | -                 |
| R²                                | 0.1934                      | 0.0915                    | 0.6435            | 0.0718            | 0.0158            | 0.1214            | 0.0871            | -                 |

<sup>z</sup>Total tree cluster count used as regressor variable

<sup>y</sup>Calculated as proportion of total clusters setting fruit

No clusters set 5 fruit per cluster in 2018
Table 2-5. Effect of 5 levels of artificial spur extinction on fruit quality characteristics

<table>
<thead>
<tr>
<th>Thinning Treatment</th>
<th>Blush (%)</th>
<th>L</th>
<th>Chroma (%)</th>
<th>hue*</th>
<th>Anthocyanin Index (%)</th>
<th>Starch (%)</th>
<th>Fruit Firmness (N)</th>
<th>Sugar (brix)</th>
<th>pH</th>
<th>TA (g/L)</th>
<th>Tannins</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE2</td>
<td>43.00a</td>
<td>54.69a</td>
<td>35.29a</td>
<td>48.17a</td>
<td>5.21a</td>
<td>31.71a</td>
<td>9.493a</td>
<td>13.28a</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ASE4</td>
<td>39.98a</td>
<td>55.69a</td>
<td>34.88a</td>
<td>50.22a</td>
<td>4.94a</td>
<td>33.39a</td>
<td>9.481a</td>
<td>12.73a</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ASE6</td>
<td>44.62a</td>
<td>55.58a</td>
<td>35.17a</td>
<td>52.40a</td>
<td>5.25a</td>
<td>44.42a</td>
<td>9.597a</td>
<td>12.4ab</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Control A</td>
<td>47.33a</td>
<td>53.35a</td>
<td>34.12a</td>
<td>48.22a</td>
<td>5.82a</td>
<td>45.58a</td>
<td>9.697a</td>
<td>11.80b</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Control B</td>
<td>32.16a</td>
<td>57.92a</td>
<td>34.39a</td>
<td>59.40a</td>
<td>4.00a</td>
<td>28.84a</td>
<td>9.635a</td>
<td>11.65b</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P-value from ANOVA</td>
<td>0.2868</td>
<td>0.2162</td>
<td>0.3255</td>
<td>0.3253</td>
<td>0.1594</td>
<td>0.227</td>
<td>0.9544</td>
<td><strong>0.0008</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE2</td>
<td>35.38a</td>
<td>58.77a</td>
<td>32.86a</td>
<td>57.24a</td>
<td>2.97a</td>
<td>45.76a</td>
<td>9.304a</td>
<td>12.13a</td>
<td>3.56a</td>
<td>0.51a</td>
<td>0.43a</td>
</tr>
<tr>
<td>ASE4</td>
<td>37.36a</td>
<td>60.43a</td>
<td>31.67a</td>
<td>59.64a</td>
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<td>43.14a</td>
<td>8.898a</td>
<td>11.60a</td>
<td>3.58a</td>
<td>0.52a</td>
<td>0.41a</td>
</tr>
<tr>
<td>ASE6</td>
<td>49.22a</td>
<td>58.80a</td>
<td>32.34a</td>
<td>57.38a</td>
<td>3.00a</td>
<td>39.84a</td>
<td>9.06a</td>
<td>11.90a</td>
<td>3.64a</td>
<td>0.49ab</td>
<td>0.41a</td>
</tr>
<tr>
<td>Control A</td>
<td>57.19a</td>
<td>56.80a</td>
<td>32.00a</td>
<td>49.98a</td>
<td>3.19a</td>
<td>36.45a</td>
<td>8.699a</td>
<td>11.75a</td>
<td>3.58a</td>
<td>0.49ab</td>
<td>0.36a</td>
</tr>
<tr>
<td>Control B</td>
<td>32.59a</td>
<td>61.25a</td>
<td>31.51a</td>
<td>60.20a</td>
<td>2.15a</td>
<td>52.24a</td>
<td>9.199a</td>
<td>11.70a</td>
<td>3.64a</td>
<td>0.43b</td>
<td>0.41a</td>
</tr>
<tr>
<td>P-value from ANOVA</td>
<td>0.2143</td>
<td>0.2977</td>
<td>0.4402</td>
<td>0.3813</td>
<td>0.3968</td>
<td>0.419</td>
<td>0.3616</td>
<td><strong>0.0947</strong></td>
<td>0.0398</td>
<td>0.5822</td>
<td></td>
</tr>
</tbody>
</table>

*Means of 4 Observations

Tukey’s adjusted mean separation used

pH, Titratable Acidity, Tannins not measured in 2017
Table 2-6. Effect of total cluster count on fruit quality characteristics

<table>
<thead>
<tr>
<th></th>
<th>Blush (%)</th>
<th>L</th>
<th>Chroma</th>
<th>hue°</th>
<th>AIM</th>
<th>Starch (%)</th>
<th>Texture (N)</th>
<th>Sugar (brix)</th>
<th>pH</th>
<th>TA (g/L)</th>
<th>Tannins</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2017</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Intercept</td>
<td>46.8598</td>
<td>54.4509</td>
<td>35.0185</td>
<td>45.4967</td>
<td>5.5543</td>
<td>36.1250</td>
<td>9.40873</td>
<td>13.29376</td>
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<tr>
<td>Slope</td>
<td>-0.0516</td>
<td>0.00944</td>
<td>-0.00235</td>
<td>0.05871</td>
<td>-0.0043</td>
<td>0.00631</td>
<td>0.00163</td>
<td>-0.00863</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Slope P-value</td>
<td>0.2227</td>
<td>0.458</td>
<td>0.5415</td>
<td>0.0577</td>
<td>0.2664</td>
<td>0.9074</td>
<td>0.347</td>
<td><strong>0.0014</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>R²</td>
<td>0.0814</td>
<td>0.031</td>
<td>0.0211</td>
<td>0.1859</td>
<td>0.0681</td>
<td>0.0008</td>
<td>0.0493</td>
<td>0.4424</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<p>| | | | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2018</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>43.4974</td>
<td>58.71616</td>
<td>33.1850</td>
<td>55.6261</td>
<td>3.0862</td>
<td>37.49</td>
<td>9.11844</td>
<td>12.19798</td>
<td>3.56074</td>
<td>0.52185</td>
<td>0.43876</td>
</tr>
<tr>
<td>Slope</td>
<td>-0.0143</td>
<td>0.0061</td>
<td>-0.0138</td>
<td>0.0045</td>
<td>-0.0048</td>
<td>0.0744</td>
<td>-0.0011</td>
<td>-0.005</td>
<td>0.0005</td>
<td>-0.0004</td>
<td>-0.0004</td>
</tr>
<tr>
<td>Slope P-value</td>
<td>0.8998</td>
<td>0.7758</td>
<td><strong>0.04</strong></td>
<td>0.9247</td>
<td>0.4347</td>
<td>0.3299</td>
<td>0.7162</td>
<td>0.1204</td>
<td>0.1551</td>
<td>0.1325</td>
<td>0.2005</td>
</tr>
<tr>
<td>R²</td>
<td>0.0009</td>
<td>0.0046</td>
<td>0.2141</td>
<td>0.0005</td>
<td>0.0343</td>
<td>0.0528</td>
<td>0.0075</td>
<td>0.1287</td>
<td>0.109</td>
<td>0.1212</td>
<td>0.0893</td>
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</tbody>
</table>

\(^z\)Total tree cluster count used as regressor variable
pH, Titratable Acidity, Tannins not measured in 2017
Table 2-7. Effect of 5 levels of artificial spur extinction on fruit size, crop value and crop density*

<table>
<thead>
<tr>
<th>Thinning Treatment</th>
<th>Average Fruit Size (g)</th>
<th>Crop Value¹</th>
<th>Crop Density (Crop/TCSA'y)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2017</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE2</td>
<td>185.56a</td>
<td>11.52b</td>
<td>5.64a</td>
</tr>
<tr>
<td>ASE4</td>
<td>173.87ab</td>
<td>14.09b</td>
<td>7.19a</td>
</tr>
<tr>
<td>ASE6</td>
<td>154.84abc</td>
<td>12.75b</td>
<td>8.99a</td>
</tr>
<tr>
<td>Control A</td>
<td>146.51bc</td>
<td>19.4a</td>
<td>9.98a</td>
</tr>
<tr>
<td>Control B</td>
<td>128.39c</td>
<td>21.86a</td>
<td>7.88a</td>
</tr>
<tr>
<td><strong>P-value</strong></td>
<td></td>
<td>0.0042</td>
<td>.0001</td>
</tr>
<tr>
<td><strong>2018</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE2</td>
<td>157.81a</td>
<td>0.29b</td>
<td>0.45b</td>
</tr>
<tr>
<td>ASE4</td>
<td>153.13a</td>
<td>0.49b</td>
<td>0.75b</td>
</tr>
<tr>
<td>ASE6</td>
<td>151.11a</td>
<td>0.90b</td>
<td>1.73ab</td>
</tr>
<tr>
<td>Control A</td>
<td>153.43a</td>
<td>1.50b</td>
<td>2.62ab</td>
</tr>
<tr>
<td>Control B</td>
<td>157.61a</td>
<td>3.01a</td>
<td>4.17a</td>
</tr>
<tr>
<td><strong>P-value</strong></td>
<td>0.4884</td>
<td><strong>0.0014</strong></td>
<td><strong>0.0084</strong></td>
</tr>
</tbody>
</table>

* Means of 4 Observations
¹Total yield from all treated trees converted to dollars using Table 2-2
'yTCSA: Trunk cross sectional area (cm²)
Tukey’s adjusted mean separation used

Table 2-8. Effect of total cluster count on fruit size, crop value and crop densityz

<table>
<thead>
<tr>
<th>Average Fruit Size (g)</th>
<th>Crop Value¹</th>
<th>Crop Density (Crop/TCSA'y)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2017</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>200.7572</td>
<td>8.9765</td>
</tr>
<tr>
<td>Slope</td>
<td>-0.40742</td>
<td>0.06594</td>
</tr>
<tr>
<td>Slope P-value</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>R²</td>
<td>0.7743</td>
<td>0.7239</td>
</tr>
<tr>
<td><strong>2018</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>152.7098</td>
<td>-0.82259</td>
</tr>
<tr>
<td>Slope</td>
<td>0.0237</td>
<td>0.0256</td>
</tr>
<tr>
<td>Slope P-value</td>
<td>0.5553</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>R²</td>
<td>0.0197</td>
<td>0.5867</td>
</tr>
</tbody>
</table>

zTotal tree cluster count used as regressor variable
¹Total yield from all treated trees converted to dollars using Table 2-2
'yTCSA: Trunk cross sectional area (cm²)
Figure 2-5. Decrease in crop value by treatment

Figure 2-6. Effect of total cluster count on percent fruit set, 2017 and 2018
Figure 2-7. Hail damage on woody tissue, 2018

Figure 2-8. Artificial spur extinction treatment levels at full bloom, showing flower cluster density.
Chapter 3
Interaction between spur leaf removal and crop load on within cluster competition and fruit quality

Introduction

Early season manipulations of crop density of fruit trees can have a great impact on fruit quality and tree health. Due to the strong propensity of fruit trees to set excess fruit at the beginning of the season, reducing the number of fruit is necessary to achieve optimum yields (Batjer LP, Billingsley HD 1957; Byers 2003; Dennis 2000; Lafer 1998). In addition to improving fruit size, removing excess crop load improves appearance, taste and storability, as well as decreasing yearly yield fluctuations (Amarante et al. 2008; Byers 2003). These improvements lead to greater and more reliable profits.

The earlier excess fruit is removed, the greater will be the impacts on fruit size and quality. Thinning at or before bloom leads to greater impacts on fruit size and firmness (Johnson 1995; Kon and Schupp 2018). Final fruit weight decreased by 5g for every 7-day delay in thinning until impacts ceased four weeks before June drop (McArtney, Palmer, and Adams 1996; Menzies 1980). Harley (1935) showed that early thinning increased the percentage of spurs blooming the following season, from as low as 3% to as high as 47% (Harley CP 1935). Timing of thinning application to create the greatest impact on return bloom seems to vary by cultivar between pre-bloom (Bobb and Blake 1938; Crow 1920) and June drop (Auchter and Schrader 1923). Although the impact of early thinning on return bloom seems to vary with cultural conditions and cultivar, it does improve return bloom.

Many of the impacts of early season crop density adjustments are attributed to the balance of carbohydrates throughout the tree. Current crop load management decisions are based on the assumptions of the ‘Carbon Balance Model’ which attribute ‘June drop’ to the fruit’s demand for carbohydrates outweighing the tree’s ability to produce them (A. N. Lakso 2011). The complex of a potential fruiting bud and the short branch that connects the bud and limb is often referred to as a spur. The first leaves to
unfold during the season arise from these buds and are often called spur leaves. During initial fruit, spur leaves are considered a vital source of current season carbohydrates. Research suggests that these leaves are the main source of carbon for fruit until the bourse shoots expand (Hansen 1971). By performing spur leaf removal, ringing of the spurs, and bourse shoot removal on apple tree spurs, Ferree and Palmer (1982) examined the impact of early-season photosynthates on dry weight, mineral concentration, and fruit size. The Ca concentration and dry weight of the fruit were linearly related to spur leaf area, suggesting that the transpiration of the spur leaves is crucial for importing resources into the fruit in the early season. Additionally, the bourse shoot competed directly with fruit early in the season while contributing to fruit size later in the season. Only spurs that were ringed to isolate them from the rest of the tree were affected. When spurs were not ringed, carbohydrates from elsewhere in the tree filled the role of any removed parts (Ferree & Palmer, 1982).

Bourse shoots also play an intricate role in fruit competition. Early season shoot removal promoted heavier initial fruit set, followed by a heavier ‘June drop’ (Quinlan and Preston 1971). Contrary to suggesting this is due to carbohydrate competition, Quinlan and Preston (1971) proposed an impact from hormonal balance within the branches, attributed to the impacts of ‘tipping’ bourse shoots being equal to removal of the whole shoot.

Interactions between thinning and spur leaf removal are complex, which include timing, climate variation, and crop density among others. To minimize application and environmental variation, a thinning technique that can be performed before initial fruit set is highly replicable is preferred and artificial spur extinction (ASE) fills this role.

Artificial spur extinction is a version of spur removal proposed to stimulate return bloom on axillary branches by manipulating the potential crop load of a tree (Pierre-Eric Lauri et al. 1995; Pierre-Eric Lauri and Lespinasse 1999). Based on a previous study that traced the evolution of fruiting spurs from year to year, ASE mimics the growth habit of type IV apple trees which naturally abort spurs inside the canopy, bearing a regular crop of high quality fruit on the tips of their branches each season (Lauri et
Researchers examined the impacts of ASE with different training systems and cultivars (Lauri, Willaume, Larrivée, & Lespinasse, 2004). ASE enhanced fruit set, improved return bloom, increased fruit size and quality, and regulated crop load variability (Breen et al. 2014, 2015; Embree et al. 2007; Van Hooijdonk et al. 2014; Nichols, Embree, and Fillmore 2011; Tabing et al. 2016; D. S. Tustin et al. 2011, 2012). Intensity levels of ASE were examined with certain cultivars and improved size and quality at more intense levels of spur removal. Breen et al. (2016) examined ASE levels of two, four, and six buds per cm² branch cross sectional area on ‘Gala’, showing increased fruit size with fewer spurs remaining on a tree and an optimal crop density at 4 buds per cm² branch cross sectional area. ASE has potential for adjusting crop loads in production systems where chemical thinning is less effective or isn’t an option.

‘Gala’ apples are an economically important variety in Pennsylvania and the United States as a whole, appearing in the top five varieties for both production and sales (U.S. Apple Association 2018). Research on ASE in Pennsylvania showed that it lowered crop density (J. Schupp 2016). Unpublished data from 2017 and 2018 showed that ASE altered the potential crop load of mature ‘Crimson Gala’ trees when applied at increasingly intense rates. This experiment used ASE to create a range of crop densities and to study the interaction with spur leaf removal. The objectives of this study were: 1) to investigate the impacts of spur leaf removal on within cluster competition and fruit size and quality, and 2) to examine the interaction between crop density and spur leaf removal as related to carbohydrate mobility in a small fruited cultivar.

**Materials and Methods**

**Experimental Design**

In 2017 and 2018, experiments were conducted at the Penn State Fruit Research and Extension Center in Biglerville, PA. Mature ‘Crimson Gala’/M.9 NAKB337 trees planted in 2009 at 0.9 x 3.66 m spacing were selected for this experiment. Aside from applied treatments, trees were maintained to...
industry standards for pesticide regimens. Trees were trained to a tall spindle system to fill all available space in the fruiting wall, no permanent scaffolds were maintained. Twenty trees with trunk circumferences between 11.9 and 16.5 cm. were selected for use in this experiment, based on measurement 30cm above the graft union.

Trees were assigned to one of four treatments in a completely random design using a random number generator in Excel® software with four single-tree replications. To understand the cumulative effects of the thinning treatment, the same treatments were applied to each tree in both 2017 and 2018.

1. Two buds remaining per cm$^2$ limb cross sectional area, (lcsa) (ASE2)
2. Four buds remaining per cm$^2$ lcsa (ASE4)
3. Six buds remaining per cm$^2$ lcsa (ASE6)
4. All spurs and terminals remaining, with lateral buds removed (Control)

Following thinning treatments twenty spurs in 2017 and 10 spurs in 2018 were randomly selected on each tree and divided into two spur leaf removal treatments. Both treatments were randomized throughout the canopy.

a. Spur leaves removed
b. Spur leaves intact

All thinning treatments were applied in mid to late March, at or before the green tip stage (Figure 3.1). Each branch was assigned 2, 4, or 6 buds per cm$^2$ lcsa to reflect their respective treatment (1-3) using a modified MAFCOT 6 Equillifruit disc (Figure3.2). Potential fruiting buds, evenly spaced along the branch with good light exposure, were retained and included the terminal bud in the total floral bud count. All other buds were broken off as close to the main branch as possible by hand or with pruning shears (Figure3.1). Approximately three weeks after green tip, fruiting and lateral buds on one-year-old wood were removed on all branches by holding the terminal bud in one hand while running the thumb and forefinger of the other down the branch to the previous season’s leaf scar.

At full bloom the secondary treatment was applied to half of the selected spurs. Spurs were labeled with numbered orange tags and half were labeled with numbered white tags, 10 of each in 2017
and 5 of each in 2018. The spur leaves on the orange tagged spurs were gently removed with a small shears as close to the base of the spur as possible. Each flower was then labeled with numbered tape. Label 0 representing the king bloom and increasing out to the lateral blossoms.

**Cluster Competition**

Fruitlets were measured once a week for 6 weeks, beginning at initial fruit set, when fruit were approximately 6mm in diameter, and continuing until fruit reached approximately 30mm in diameter and fruit abscission had ceased. Fruit were harvested when they developed optimal background color and starch-iodine tests from adjacent non-data trees indicated that fruit maturity was appropriate. In 2017 and 2018 a single harvest was conducted, and all analyses were performed following that harvest.

**Vegetative and Fruit Impacts**

In 2017 number and length (cm) of bourse shoots on each labeled spur was recorded in late July, after bourse shoots set terminal bud. Due to the damage of the hail storm in 2018, this measurement could not be taken. In addition to measuring trunk diameters in early spring of 2017, trunk diameters were measured again in spring of 2018 to estimate tree growth. Trunks were measured with cloth measuring tape thirty centimeters from the graft union.

Number and size of fruit were recorded at harvest. Fruit growth was estimated by weighing each individual fruit using an electronic scale, as well as measuring diameter and length of each individual fruit. All fruit from each spur were used for quality analyses.

Seed count, and dry matter content were recorded for each individual apple and averaged by spur. Dry matter content was estimated using an equatorial slice approximately 4mm thick, dried for 48 hours to a constant weight. Soluble solids concentration and nutritional status of the fruit were pooled over spur leaf removal treatment and tree so two samples were taken from each tree. Juice samples were analyzed for soluble solids using a digital refractometer (Atago model PR-32 alpha, Bellevue, WA). Peel samples were removed from the calyx end of each apple (Baugher et al. 2014) and freeze dried before being sent to the Penn State Agricultural Analytics laboratory for acid digestion and nutrient content analysis.
2018 some samples were too small to perform both nitrogen and standard mineral analyses, so Nitrogen was omitted.

Statistics

Initially the two years of data were pooled with the intent of separating response variables that had an interaction between treatment and year. However, due to the large amount of variation, even data where the interaction was not significant, did have significant differences by year. Therefore, all data were separated by year. All statistical analyses were run using SAS software (version 9.3; SAS Institute, Cary, NC). All analyses were run as a two-way analysis of variance using the glm procedure. Means were compared with Tukey test and a significance level of p=0.1.

Trunk diameter was examined as a covariate and found to be insignificant, supporting the decision for a completely randomized design rather than a blocked design rather than blocking on TCSA.

Results

Early Season

In 2017, spur leaf removal did not significantly impact growth rate in any week and thinning rate was only significant in week three. At this time, ASE 2 was 18% greater than the control. In 2018, thinning rate was significant every week. In week three it was highly significant and was coupled with significant difference by spur leaf removal treatment, all spur leaves removed being 17% greater than no spur leaves removed. ASE2 had a lower growth rate than the control in all but week 5 when there was no difference. In weeks one through four, ASE2 was, on average 29% lower than the control. ASE 4 and ASE6 did not differ, except in week 3, when ASE4 was 52% greater (Table 3-1). Drop rate, calculated as the number of fruit fallen/day showed significant differences between spur leaf removal treatment at two weeks in 2017 and three weeks in 2018. In week one of 2017, all spur leaves removed was 25% greater than no spur leaves removed, while in week three it was 52% lower. Thinning treatment was significant in weeks one and four in 2017. In week 1, ASE6 was significantly higher than all other treatments, 87%
greater than the control. In week four, control and ASE 4 were significantly higher than ASE 2 and ASE 6, with control 76% higher than ASE2. In 2018, spur leaf impacted drop rate in 3 out of 5 weeks. In week one all spur leaves removed was 43% higher than no spur leaves removed. In weeks two and four that relationship reversed with all being 53% and 106% lower, respectively. Thinning treatment was only significant in week one during 2018, which showed ASE2 dropping 35% more fruit than the control (Table 3-2). In week four a significant interaction between thinning and spur leaf removal occurred (Figure 3-4). The impacts of thinning treatment did not have any pertinent impacts on spur quality in either season (Appendix).

Late season

Thinning treatment and spur leaf removal in 2017 did not influence fruit size or number. Thinning did impact the number of seeds per fruit with both ASE 4 and the control being significantly greater than ASE2. In 2018 thinning, but not SLR, treatment impacted all fruit size and number variables. Control had more fruit per cluster, larger size fruit, and more seeds per fruit than the thinned treatments. Fruit size was, on average, 78% greater in control trees than ASE 2 trees. Fruit from the control trees also had 81% greater dry matter content than ASE6, which had the lowest dry matter content (Table 3-3). Spur leaf removal had no impact on fruit nutrient status in either 2017 or 2018. Thinning treatment impacted fruit nutrient status in 2017. Control trees had 20% less potassium and 89% more calcium than ASE 6 trees, which were at the opposite extremes of these nutrients. ASE 6 had significantly higher magnesium than ASE 4 and the control trees. The ratio of calcium to magnesium was impacted by thinning treatment in both 2017 and 2018, it was 59% and 32% greater in control than ASE 2, respectively. Calcium concentrations were, overall, lower in 2018, averaging 48% less than those of 2017 (Table 3-4).

Discussion

The early season conditions of 2017 and 2018 were remarkably different, with significantly less radiation and greater growing degree days accumulated at final fruit set in 2018. These high temperatures
and low cumulative radiation levels led to the development of a carbon stress event (Figure 3-2 and 3-3). There was also a severe hail event on May 10, 2018 that caused a considerable amount of damage to the trees, causing changes in the canopy environment and a significant amount of fruitlet abscission (Figure 3-6).

Spur leaves purportedly play an important role in early season fruit development. Most historic research suggests that these leaves are the main source of carbon for fruit until bourse shoot expansion (Hansen 1971). However, the data from this project suggested quite the opposite. The removal of spur leaves did not affect fruit growth rate in any weeks in 2017 and only in week three of 2018, when spur leaf removal caused fruitlets to grow faster. Spur leaf removal affected fruit drop rate in both years, but they varied. In both years, the drop rate was increased by spur leaf removal (SLR) in the first week. Later in the season, week 3 in 2017 and weeks 2 and 4 in 2018 that trend was reversed and the drop rate of spurs with spur leaves surpassed that of SLR spurs. End of season impacts on fruit number in both seasons showed that this fluctuation of drop rate resulted in no differences in fruit number per spur because of spur leaf removal, suggesting they do not play a major role in within-cluster competition. Additionally, it has been proposed that transpiration of spur leaves plays a vital role in moving nutrients into growing fruit early in the season (Lang and Volz 1998). However, the results of this experiment also did not show differences in nutrient status of fruit because of spur leaf removal. This concurs with research by Ferree and Palmer (1982), who showed that, while Ca content and dry weight of the fruit were linearly related to the presence of spur leaves, suggesting that the transpiration of the spur leaves is crucial to the importation of resources into the fruit in the early season, they found these impacts only occurred when spurs were ringed, isolating them from the remainder of the tree (Ferree & Palmer, 1982). Both Ferree’s work and the results of this experiment conclude that spur leaves subtending the blossom cluster do not play a vital role in early fruit development, when phloem surrounding the spur is uninterrupted. This suggests that available carbohydrates are highly mobile throughout the tree, and are being provided by intact spur leaves elsewhere in the canopy.
Thinning treatment impacted fruit growth rate in one week of 2017, where ASE 2 grew significantly faster than the control trees. In 2018 thinning treatment was significant in all 5 weeks, but unlike the first week in 2017, ASE 2 grew slower than control trees in all but one week. Drop rate was impacted by thinning treatment in both 2017 and 2018, in week one 2017, ASE 6 and the control dropped the most fruit while in the first week of 2018, ASE2 dropped the most fruit. This may trace back to the hail storm that occurred at petal fall in 2018. Week one of growth rate and drop rate measurements occurred approximately a week after that. The most intensely thinned trees had a more open canopy (Figure 3-5) which may have allowed the hail stones to cause more damage throughout the canopy, increasing the impact of the stress event. Additionally, removal of spurs augments the vegetative density of the canopy as well as the potential crop load, meaning that control trees may had greater vegetative growth (evidenced in the other study that looks at canopy light environment) and were able to more efficiently utilize available radiation. Less damage and greater photosynthetic capability would explain greater numbers of larger fruit that also had greater dry matter content at harvest (Table 3-3). Crop load is a strong indicator of nutrient status (Ferguson and Watkins 1992) and in both 2017 and 2018 thinning treatment influenced nutrient status of the fruit. In both seasons the ratio of calcium to magnesium was higher in control trees than in ASE 2 trees. This suggests that the control trees were closer to an optimal crop density for ‘Gala’ trees. Mean separations did not show increases with increased crop load (ASE2, ASE4, ASE6, Control) in either year. This is likely due to a lack of separation in tree level crop density by the branch level treatments as well as the large amount of variability in the data set. The ratio of potassium and magnesium to calcium reached maximums in 2017 and 2018 of 14.25 and 18.48, respectively. These levels are much lower than those shown to cause bitter pit in Pennsylvania, where a ratio value of 45 was linked to between 30% and 90% incidence (Auxt Baugher et al. 2017).

Of all the variables that were measured, the interaction between thinning treatment and spur leaf removal (Table 3-2) was significant for only week 4 in 2018 (Figure 3-5). The higher drop rate of ASE 6 for the fruit without spur leaves removed is likely due to the large amount unexplained variability.
Overall the data from this project confirmed the findings of Ferree and Palmer (1982) that carbohydrates are highly mobile within the tree, and therefore for individual spurs with uninterrupted phloem, having spur leaves on each flower cluster is not critical to fruit set and yield, as carbohydrates seem to be translocated from elsewhere in the canopy. Crop load plays an important role in fruit size and quality, but it is not a direct relationship in ‘Gala’ apples. The environmental stress of the 2018 season presented a unique opportunity to understand that the importance of crop density and spur leaves exists not in their presence or absence but rather the balance of the tree overall. In a typical season, it’s possible that the ratio of photosynthetic tissue to crop load is the true indicator of yield and fruit quality.

Summary

Early season crop load manipulation is crucial for maximizing fruit size and quality as well as return bloom (Johnson 1995; Kon and Schupp 2018; McArtney, Palmer, and Adams 1996; Menzies 1980). The interaction of crop density and the carbon balance influence in yield and fruit quality (A. N. Lakso 2011). The first leaves to unfold, known as spur leaves, are considered a vital source of carbohydrates for developing fruitlets (Hansen 1971). However, other researchers found that spur leaves were only vital in spurs that had been ringed to isolate them from the rest of the tree, suggesting that, carbohydrates are highly mobile throughout the tree (Ferree & Palmer, 1982).

Artificial spur extinction is a version of spur removal designed to decrease potential crop load and improve regularity of bearing and quality of fruit (Pierre-Eric Lauri et al. 1995; Pierre-Eric Lauri and Lespinasse 1999). Researchers have tested ASE in training systems and on specific cultivars (Lauri, Willaume, Larrive, & Lespinasse, 2004), where it enhanced fruit set, improved return bloom, increased fruit size and quality, and regulated crop load variability (Breen et al. 2014, 2015; Embree et al. 2007; Van Hooijdonk et al. 2014; Nichols, Embree, and Fillmore 2011; Tabing et al. 2016; D. S. Tustin et al. 2011, 2012). Intensity levels of ASE were examined in certain cultivars, showing improved size and quality at more intense levels of spur removal. Breen et al. (2016) examined ASE levels of two, four, and
six buds per cm² branch cross sectional area with ‘Gala’, showing increased fruit size with fewer spurs remaining on a tree and an optimal crop density at 4 buds per cm² branch cross sectional area. Spur extinction is performed during tight cluster; earlier application than any chemical or hand thinning, potentially maximizing thinning impacts (McArtney, Palmer, and Adams 1996). ASE also has potential in production systems where chemical thinning is less effective or isn’t an option.

Research in Pennsylvania showed that ASE reduced crop density (J. Schupp 2016). This experiment used ASE to create a range of crop densities to study the interaction with spur leaf removal. The objectives of this study were: 1) to investigate the impacts of spur leaf removal on within cluster competition and fruit size and quality, 2) to examine the interaction between crop density and spur leaf removal and what it means regarding carbohydrate mobility in a small fruited variety.

Sixteen mature ‘Crimson Gala’ trees on M.9 NAKB337 were assigned in four single tree replications to one of four treatments: 2, 4, or 6 buds remaining per centimeter² limb cross sectional area, (lcsa) and a control. Thinning treatments were applied during dormancy, in mid-March. At full bloom, twenty spurs in 2017 and 10 spurs in 2018 were randomly selected on each tree and all spur leaves were removed from half of the spurs. Fructlet growth rate was measured for the first five weeks following initial fruit set, ending when fruit reached approximately 30mm in diameter and fruit abscission had ceased. Fruit size and nutrition factors were measured on all fruit at harvest.

The data from this project suggested very little impact of spur leaves on within cluster competition, while spur leaf removal did impact growth and drop rates, at the end of the season, the impacts seemed to even out, with no differences in fruit number or size based of spur leaf removal. Similarly, no differences were seen in nutrient status of the fruit at the end of the season due to spur leaf removal. Thinning treatment had more impacts, leading to differences in growth rate, drop rate, and fruit size and number in the second season.

Overall the data from this project confirmed the findings of Ferree and Palmer (1982) that carbohydrates are highly mobile within the tree. Therefore, spur leaves subtending the blossom cluster are not critical to fruit set and yield, in clusters with uninterrupted phloem. Whether available photosynthates
are being translocated from carbon stores or other spur leaves has not been determined. Crop load plays an important role in fruit size and quality but was not a direct relationship in this experiment.
Literature Cited


Marini, Richard P, James R Schupp, Tara Auxt Baugher, and Robert Crassweller. “Sampling Apple Trees to Accurately Estimate Mean Fruit Weight and Fruit Size Distribution.”


Mcartney, Steven, John Palmer, Sue Davies, and Shona Seymour. 2006. “Effects of Lime Sulfur and Fish Oil on Pollen Tube Growth, Leaf Photosynthesis and Fruit Set in Apple.”


nia (March 5, 2018).
Figure 3-1. Removal of a dormant spur by hand

Figure 3-2. Cumulative radiation at final fruit set 2017 and 2018

Figure 3-3. Cumulative growing degree days at final fruit set 2017 and 2018
Figure 3-4 Effect of thinning and spur leaf removal on drop rate, week 4 2018

Figure 3-5. Artificial spur extinction treatment levels at full bloom, showing flower cluster density
Figure 3-6. Hail damage on woody tissue, 2018
### Table 3-1. Effect of artificial spur extinction and spur leaf removal on weekly fruitlet growth rate for 5 weeks after initial fruit set

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Week1 (mm/day)</th>
<th>Week2 (mm/day)</th>
<th>Week3 (mm/day)</th>
<th>Week4 (mm/day)</th>
<th>Week5 (mm/day)</th>
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<td>0.64bc</td>
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<sup>x</sup> Measurements taken from all fruitlets in labeled clusters and averaged by factorial combination

<sup>y</sup> Means within columns, treatments, and years by Tukey’s HSD at the 10% level of significance
Table 3-2. Effect of artificial spur extinction and spur leaf removal on weekly fruitlet drop rate for 5 weeks after initial fruit set.

<table>
<thead>
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<th>Treatment</th>
<th>Week1 (fruit/day)</th>
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<th>Week3 (fruit/day)</th>
<th>Week4 (fruit/day)</th>
<th>Week5 (fruit/day)</th>
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<td></td>
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<td>Thinning</td>
<td>0.0413</td>
<td>0.5925</td>
<td>0.2224</td>
<td>0.1031</td>
<td>0.5677</td>
</tr>
<tr>
<td>Thinning * SLR</td>
<td>0.3804</td>
<td>0.2710</td>
<td>0.2899</td>
<td>0.0056</td>
<td>0.6828</td>
</tr>
</tbody>
</table>

<sup>a</sup> Measurements taken from all fruitlets in labeled clusters and averaged by factorial combination

<sup>y</sup> Means within columns, treatments, and years followed by common letters do not differ significantly by Tukey’s HSD at the 10% level.
Table 3-3. Effect of artificial spur extinction and spur leaf removal on fruit quality indicators

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fruit (per spur)</td>
<td>Weight (g)</td>
</tr>
<tr>
<td><strong>Thinning</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE2</td>
<td>1a</td>
<td>129.43a</td>
</tr>
<tr>
<td>ASE4</td>
<td>2a</td>
<td>129.13a</td>
</tr>
<tr>
<td>ASE6</td>
<td>1a</td>
<td>117.16a</td>
</tr>
<tr>
<td>Control</td>
<td>1a</td>
<td>106.71a</td>
</tr>
<tr>
<td><strong>Spur leaves removed (SLR)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>1a</td>
<td>120.95a</td>
</tr>
<tr>
<td>None</td>
<td>1a</td>
<td>120.26a</td>
</tr>
<tr>
<td><strong>P-value from ANOVA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLR</td>
<td>0.2982</td>
<td>0.9284</td>
</tr>
<tr>
<td>Thinning</td>
<td>0.2648</td>
<td>0.1327</td>
</tr>
<tr>
<td>Thinning * SLR</td>
<td>0.8013</td>
<td>0.1157</td>
</tr>
<tr>
<td><strong>Thinning</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE2</td>
<td>0b</td>
<td>49.03b</td>
</tr>
<tr>
<td>ASE4</td>
<td>0b</td>
<td>79.78b</td>
</tr>
<tr>
<td>ASE6</td>
<td>0b</td>
<td>49.26b</td>
</tr>
<tr>
<td>Control</td>
<td>1a</td>
<td>115.62a</td>
</tr>
<tr>
<td><strong>Spur leaves removed (SLR)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>1a</td>
<td>74.08a</td>
</tr>
<tr>
<td>None</td>
<td>1a</td>
<td>85.29a</td>
</tr>
<tr>
<td><strong>P-value from ANOVA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLR</td>
<td>0.7039</td>
<td>0.9089</td>
</tr>
<tr>
<td>Thinning</td>
<td>0.0282</td>
<td>0.0030</td>
</tr>
<tr>
<td>Thinning * SLR</td>
<td>0.3100</td>
<td>0.7648</td>
</tr>
</tbody>
</table>

\(^{x}\) Measurements taken from all harvested apples and averaged by factorial combination. Means within columns, treatments and years followed by common letters do not differ at the 10% level, by Tukey's HSD.

\(^{y}\) Calculated as a percentage.
Table 3-4. Effect of artificial spur extinction and spur leaf removal on fruit peel nutrient status *

<table>
<thead>
<tr>
<th>Treatment</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Ca:Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinning</td>
<td></td>
<td>2017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE2</td>
<td>0.47a</td>
<td>0.09bc</td>
<td>0.07ab</td>
<td>1.30bc</td>
</tr>
<tr>
<td>ASE4</td>
<td>0.40b</td>
<td>0.11b</td>
<td>0.07b</td>
<td>1.68b</td>
</tr>
<tr>
<td>ASE6</td>
<td>0.47a</td>
<td>0.06c</td>
<td>0.08a</td>
<td>0.80c</td>
</tr>
<tr>
<td>Control</td>
<td>0.38b</td>
<td>0.16a</td>
<td>0.07b</td>
<td>2.39a</td>
</tr>
<tr>
<td>Spur leaves removed (SLR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>0.43a</td>
<td>0.11a</td>
<td>0.07a</td>
<td>1.56a</td>
</tr>
<tr>
<td>None</td>
<td>0.43a</td>
<td>0.10a</td>
<td>0.07a</td>
<td>1.53a</td>
</tr>
<tr>
<td>P-value from ANOVA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLR</td>
<td>0.7080</td>
<td>0.7626</td>
<td>1.0000</td>
<td>0.9242</td>
</tr>
<tr>
<td>Thinning</td>
<td>&lt;.0001</td>
<td><strong>0.0007</strong></td>
<td><strong>0.0086</strong></td>
<td><strong>0.0005</strong></td>
</tr>
<tr>
<td>Thinning * SLR</td>
<td>0.8805</td>
<td>0.9764</td>
<td>0.4610</td>
<td>0.9949</td>
</tr>
<tr>
<td>Thinning</td>
<td></td>
<td>2018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE2</td>
<td>0.59a</td>
<td>0.05b</td>
<td>0.08a</td>
<td>0.60b</td>
</tr>
<tr>
<td>ASE4</td>
<td>0.51a</td>
<td>0.06a</td>
<td>0.08a</td>
<td>0.77a</td>
</tr>
<tr>
<td>ASE6</td>
<td>0.59a</td>
<td>0.06ab</td>
<td>0.09a</td>
<td>0.69ab</td>
</tr>
<tr>
<td>Control</td>
<td>0.59a</td>
<td>0.07a</td>
<td>0.09a</td>
<td>0.83a</td>
</tr>
<tr>
<td>Spur leaves removed (SLR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>0.56a</td>
<td>0.06a</td>
<td>0.08a</td>
<td>0.70b</td>
</tr>
<tr>
<td>None</td>
<td>0.58a</td>
<td>0.07a</td>
<td>0.09a</td>
<td>0.80a</td>
</tr>
<tr>
<td>P-value from ANOVA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLR</td>
<td>0.8144</td>
<td>0.7114</td>
<td>0.9349</td>
<td>0.3257</td>
</tr>
<tr>
<td>Thinning</td>
<td>0.4378</td>
<td><strong>0.0473</strong></td>
<td>0.6983</td>
<td><strong>0.0413</strong></td>
</tr>
<tr>
<td>Thinning * SLR</td>
<td>0.6902</td>
<td>0.1563</td>
<td>0.2931</td>
<td>0.4176</td>
</tr>
</tbody>
</table>

* Measurements taken from all harvested apples and averaged by factorial combination. Means within columns, treatments and years followed by common letters do not differ at the 10% level, by tukey’s HSD.

<sup>y</sup>Calculated as a percentage
Appendix

Thinning is believed to improve spur quality in the following season. Ferree et. al. (1990) stated that spur quality is often correlated with large bud size and large initial leaf area. To investigate changes in spur quality characteristics of spur leaves were measured at full bloom, when the spur leaf removal treatment was applied to experiment two: “Interaction between spur leaf removal and crop load on within cluster competition and fruit quality.”

Materials and Methods

Sixteen mature ‘Crimson Gala’/M.9 NAKB337 trees planted in 2009 at 0.9 x 3.66 m were used in this experiment. In 2017 and 2018, after being completely randomized using a random number generator, trees were thinned using artificial spur extinction at or before green tip to represent the following treatments:

1. Two buds remaining per cm² limb cross sectional area, (lcsa) (ASE2)
2. Four buds remaining per cm² lcsa (ASE4)
3. Six buds remaining per cm² lcsa (ASE6)
4. All spurs and terminals remaining, with lateral buds removed (Control)

Spur leaves were then removed at full bloom from 10 tagged spurs in 2017 and 5 tagged spurs in 2018. Leaves from each spur were counted and their area recorded (LI-COR 3100, Lincoln, NE). Samples were then dried using a forced-air drier for 48 hours before weighing for calculation of dry matter content.
Results and Discussion

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of Leaves</th>
<th>Leaf Area</th>
<th>Specific Leaf Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE2</td>
<td>7.57a</td>
<td>47.95ab</td>
<td>179.03a</td>
</tr>
<tr>
<td>ASE4</td>
<td>10.20a</td>
<td>57.56a</td>
<td>145.61a</td>
</tr>
<tr>
<td>ASE6</td>
<td>7.05a</td>
<td>44.09b</td>
<td>153.62a</td>
</tr>
<tr>
<td>Control</td>
<td>7.48a</td>
<td>37.281b</td>
<td>155.52a</td>
</tr>
<tr>
<td>P-value from ANOVA</td>
<td>0.2388</td>
<td><strong>0.0147</strong></td>
<td>0.6920</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of Leaves</th>
<th>Leaf Area</th>
<th>Specific Leaf Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE2</td>
<td>8.80a</td>
<td>66.27a</td>
<td>189.41a</td>
</tr>
<tr>
<td>ASE4</td>
<td>7.80b</td>
<td>61.89a</td>
<td>192.62a</td>
</tr>
<tr>
<td>ASE6</td>
<td>7.55b</td>
<td>61.67a</td>
<td>188.47a</td>
</tr>
<tr>
<td>Control</td>
<td>7.00b</td>
<td>57.30a</td>
<td>191.10a</td>
</tr>
<tr>
<td>P-value from ANOVA</td>
<td><strong>0.0013</strong></td>
<td>0.2610</td>
<td>0.8800</td>
</tr>
</tbody>
</table>

In 2017 ASE 4 had greater leaf area than ASE 6 and the Control. However, this difference was not sustained into 2018. Leaf number was greater in ASE 2 than all other treatments in 2018, but was not correlated with increased leaf area. No differences occurred in specific leaf area in either season. While some differentiated did occur due to thinning treatment, none of these differences can be attributed to an increase in spur quality without further repetition of the study.