Evaluating Application Timing Strategies, Suitability, and Efficacy of Apple Blossom Thinning Chemicals for Commercial Use

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ABSTRACT

With post-bloom chemical fruit thinning responses being heavily influenced by tree carbohydrate reserves and weather conditions, there is a need for alternative thinning practices such as chemical blossom thinning in the Mid-Atlantic apple growing region. This project sought to 1) evaluate timing strategies for lime sulfur + Stylet-Oil blossom thinning sprays and 2) screen chemical agents for their suitability and efficacy as blossom thinners. In the first study, two ‘Gala’/‘M.9’ blocks in different states (North Carolina and Virginia) were utilized in 2019 to compare between pollen tube growth model-guided blossom thinning sprays and those that are based on fixed time intervals between the initial application and subsequent thinning sprays. It was generally found that model-guided blossom thinning sprays and sprays applied at 20% open bloom and 48 hours after reduced fruit set, crop load, and improved fruit weight. In the second study, a ‘Honeycrisp’/‘B.9’ and ‘Cripps Pink’/‘M.9’ apple block in Virginia were used in 2018 and 2019 to evaluate multiple chemical agents with and without Stylet-Oil. Most of the treatments under-thinned compared to untreated control trees. However, it was determined that ammonium thiosulfate with and without Stylet-Oil was the most effective thinning agent. Potassium bicarbonate + Stylet-Oil was observed to cause excessive fruit russeting and phytotoxicity. This project demonstrated that optimum apple crop loads can be obtained if lime sulfur + Stylet-Oil blossom thinning sprays are applied at the proper time, and that multiple chemical agents offer potential use for chemical blossom thinning in the Mid-Atlantic region.

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GENERAL AUDIENCE ABSTRACT

For apple trees to produce high quality fruit, a proportion of the flowers and/or fruit must be removed in a practice known as “thinning”. Chemical blossom thinning is a relatively new method of thinning in the Mid-Atlantic apple growing region. This project sought to 1) evaluate spray timing of blossom thinning sprays and 2) evaluate different chemicals for their suitability in blossom thinning. In the first study, two ‘Gala’ apple orchards in two states (North Carolina and Virginia) were utilized in 2019 to compare a computer model-guided spray timing to structured spray timings based on the amount of time between the first and second sprays. It was found that the model-guided sprays, and sprays occurring once 20% of the blossoms had opened and reapplied 48 hours after, were the most effective in thinning the flowers. In the second part of the study, a ‘Honeycrisp’ orchard and a ‘Cripps Pink’ orchard in Virginia were used in 2018 and 2019 to evaluate different chemicals for their potential as blossom thinners. Unfortunately, most of the treatments did not achieve sufficient thinning results compared to untreated trees. However, it was determined that ammonium thiosulfate with and without Stylet-Oil was the most effective thinning chemical. Potassium bicarbonate with Stylet-Oil was found to cause excessive injury to the fruit and foliage. This project demonstrated that blossom thinning can be effective when the sprays are applied at the correct time and that multiple chemical agents offer potential for blossom thinning in the Mid-Atlantic.

Dedication

I am honored to dedicate my thesis and dissertation to the three most influential individuals in my life. I would like to first dedicate this work posthumously to my great-grandfather W. Chester Ayers of Cana, Virginia. He made an outstanding impact on my life. By starting and expanding the family apple and peach orchard, Ayers Orchard, I have no doubt he is the reason why I have embraced agriculture not only as a career but as a way of life. To me, he passed on a lasting legacy of honest hard-work, tree fruit production knowledge, and a love for farming which I obtained in the early years of my life by working in the very orchard blocks he planted in his time. I also wish to dedicate this work to my grandfather Billy H. Allen, also of Cana, Virginia, whom sadly passed away while I was completing this very research work. I would like to thank him for his generosity, encouragement, and words of wisdom. I cannot thank him enough for his support and generosity in helping me start my own farming enterprise. My grandfather Billy and great-grandfather Chester were each a true *Small Town Southern Man* as the country singer Alan Jackson would have said.

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The Lord will send a blessing on your barns

and on everything you put your hand to.

The Lord Your God will bless you in the land

He is giving you.

Deuteronomy 28:8

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Chapter I

Introduction, Literature Review, & Research Proposal

Introduction

Commercial apple production growers make many important annual management decisions which directly impact the production and sustainability of their orchards. Thinning decisions are considered to be among the most important since they directly impact yield, fruit quality, profitability, and growing habit. Since the 1960s, post-bloom chemical fruit thinning using plant growth regulators and carbamate insecticides were the main thinning methods to reduce the crop load in Virginia apple orchards (Rollins et al., 1964; Pfeiffer et al., 2019). Although post-bloom thinning has been widely adopted, multiple external factors such as weather conditions (i.e. temperature and solar radiation) can greatly impact the efficacy of post-bloom fruit thinning spray applications (Byers and Carbaugh, 1991). The effect of these external factors on the efficacy of post-bloom chemical fruit thinning sprays has resulted in much difficulty for growers to obtain desired crop load levels from thinning. Consequently, there is a need for an alternative thinning practice which possesses the following properties: 1) results in desired crop loads, 2) does not have adverse effects on tree health and overall fruit quality, 3) is practical/efficient, and 4) is economical. One alternative thinning practice is chemical blossom thinning. Unlike post-bloom chemical fruit thinning, chemical blossom thinning uses chemicals applied during bloom to reduce the crop load by preventing the fertilization of a percentage of the flowers (Schupp and Kon, 2019). With the need to find a suitable alternative method to post-bloom chemical fruit thinning, the recent registration of lime sulfur for blossom thinning in multiple states including Virginia, and the availability of the Pollen Tube Growth Model (PTGM) for growers, there is a need to address practical questions and concerns regarding blossom thinning in order to promote it as an alternative thinning practice to Virginia apple growers.

Justification for Thinning (Crop Load Reduction)

Under natural conditions, 8-10% of apple blossoms will develop into fruit; however, an ideal crop is obtained when approximately 5% of the blossoms set fruit (Way, 1978). In circumstances when fruit set is heavy, as much as 80% of the fruit may need to be removed (Pfeiffer et al., 2019). When proper thinning is implemented, the crop load is reduced to an acceptable level which balances tree carbohydrate usage between developing fruit in the current year and flower bud development for the following crop. Consequently, thinning improves return bloom for the following year which promotes annual bearing (Pfeiffer et al., 2019). Additionally, thinning will improve fruit quality traits such as size and coloration by allowing carbohydrates to be channeled into fewer fruit and increasing fruit spacing to improve color development (Allen and Sherif, 2019). Detailed attention to crop load management is required for optimal annual production in commercial apple orchards.

History of Thinning in Virginia's Apple Industry

17th, 18th, & 19th Centuries

Cultivated apple trees were first planted in Virginia and surrounding states during the colonial period, 17th and 18th centuries, as the region became settled by immigrants from Europe. During this time, apple orchards were commonly planted for local fruit production and consumption. At the time of the establishment of these small orchards, the benefits of hand fruit thinning were known of in Europe and practiced to some extent. It is noted by Lawson, a 17th century English Horticulturist, that pulling off fruit (hand thinning) would result in better quality fruit (Lawson, 1683; Dennis, 2000). As a result, it was likely that at least some of the early American apple growers knew of the benefits of hand-thinning. However, the extent and frequency to which hand-thinning was implemented, if at all, during this time is largely unknown. The first recorded reference to hand-thinning by an American author, Andrew Downing, comes in the 1845 book "The Fruit and Fruit Trees of America…" where hand-thinning is referenced as a method to induce fruitfulness (Downing, 1845).

First Half of 20th Century

As the market for Virginia apples began to grow and prosper in the 20th century, the early commercial producers began to intensify management of orchards to improve fruit quality, production, and returns. Consequently, hand-thinning recommendations became very common in Virginia by state agriculture and extension professionals in the early 20th century. One of the first articles to recommend hand-thinning in Virginia apple orchards was the Report of the State Board of Agriculture of Virginia in 1900 (Virginia State Board of Agriculture, 1900). Within the report, the section "Thin Out Your Fruit" goes into detail recommending hand-thinning during June in order to improve fruit size, quality, and color (Virginia State Board of Agriculture, 1900). Additionally, other extension and government documents during this time recommended hand thinning. For instance, a 1939 USDA bulletin, Apple Growing East of the Mississippi River, also recommended thinning apple fruits to improve fruit size, color, and returns and further stated that there were no other suitable methods of thinning at the time (Gould, 1939). Many extension bulletins on hand-thinning to improve fruit quality and yield became available in major production areas across the nation in the early 20th century (Dennis, 2000). In the 1921 book "The Commercial Apple Industry of America", it was referenced that once producers performed thinning, they would be convinced that it was a highly important orchard management practice and could positively increase returns from its associated benefits (Folger and Thomson, 1921). With the availability of many extension bulletins addressing the benefits of hand-thinning and grower interest in improving fruit quality and profitability, it is likely that hand-thinning became a common orchard management practice in Virginia apple orchards during the early 20th century when labor sources permitted.

To improve fruit quality for export and domestic markets, orchard spraying for disease and insect suppression also started to become very common during the early 20th century. One of the most common products used for early season disease and insect pest suppression at this time was lime sulfur. The 1923 Orchard Spraying in Virginia extension bulletin recommended lime sulfur

sprays at the pink and petal fall stages for the control scab, mildew, curculio, etc. (Virginia Polytechnic Institute, 1923). The recommendation of lime sulfur as the main component in pink and petal fall sprays for early season disease and insect suppression was continued by Virginia Spray Bulletins until the late 1950s. Starting in the early 1950s, lime sulfur sprays at pink and petal fall sprays started becoming displaced by more effective insecticides, fungicides, and other sulfur-based products such as wettable sulfur and sulfur paste. The 1958 Virginia Spray bulletin was one of the last spray bulletins to recommend lime sulfur as a pre-bloom (pink stage) spray (Rollins et al., 1958).

While lime sulfur sprays were effective for early season disease and insect pest suppression in the 19th century, reduced fruit set was observed. The effect of lime sulfur as a thinner was first noted in Great Britain when lime sulfur sprays for the control of apple scab was being studied (Bagenal et al., 1925; Dennis, 2000). Additionally, the 1953 Virginia Spray Bulletin cautioned apple growers that lime sulfur sprays during the bloom period could thin the crop (Virginia Polytechnic Institute, 1953). Intentional thinning with lime sulfur sprays was not referenced in any of the 20th century Virginia Orchard Spray Bulletins published by Virginia Polytechnic Institute & State University Cooperative Extension Service. However, it is possible that growers were obtaining some level of thinning due to the frequent use of lime sulfur sprays before and after bloom.

Second Half of 20th Century to Present

With a surge in agriculture research and a need to find an alternative method to replace the high labor costs of hand fruit thinning, chemicals for post-bloom fruit thinning were identified and became available and labelled for fruit thinning starting in the 1950s through 1960s. The 1964 Virginia Spray Bulletin was the first Virginia spray bulletin to contain a section on fruit thinning (Rollins et al., 1964). In the bulletin, 1-naphthaleneacetic acid (NAA), 1-naphthylacetamide (NAD), and 1-naphthyl methylcarbmate (carbaryl) were recommended for post-bloom chemical fruit thinning (Rollins et al., 1964).

By 2019, post-bloom chemical fruit thinning had become the main method for managing crop load and an important requirement for profitable commercial apple production in Virginia and other apple producing states. A total of six chemistries of post-bloom chemical thinners were labelled for fruit thinning in Virginia Orchards by 2019. These chemistries included: 1-naphthaleneacetic acid (NAA), 1-naphthylacetamide (NAD), 6-benzyladenine (6-BA), 2-chloroethyl phosphonic acid (ethephon), 1-naphthyl methylcarbmate (carbaryl), and methyl N'N'-dimethyl-N-[(methylcarbamoyl)oxy]-1-thiooxamimidate (oxamyl) (Pfeiffer et al., 2019). An extensive level of research and field testing has allowed specific recommendations in Virginia Cooperative Extension Spray Bulletins for each thinner with regards to rates, (based on developmental stage and fruit diameter), and external factors on thinner efficacy (weather, cultivar, etc.) (Pfeiffer et al., 2019). Additionally, a predictive model was made available to assist growers in adjusting thinning rates according to weather data (Cornell University, 2019). Within a few decades of the introduction of post-bloom chemical fruit thinners, chemical post-bloom thinning had become the primary method of crop load management and a requirement for profitable commercial apple production in Virginia.

Challenges of Post-bloom Chemical Fruit Thinning

Although post-bloom thinning is currently the main method of thinning for commercial apple producers in Virginia and the Mid-Atlantic region, many external factors impact post-bloom thinner efficacy to reduce the crop load precisely. A range of factors such as temperature, light (solar radiation), variety, location, etc. can cause variability in thinning responses from year to year (Byers and Carbaugh, 1991).

Influence of Weather on Tree Carbohydrate Metabolism & Thinning

Many external factors, mentioned above, indirectly impact the level of thinning response by affecting tree carbohydrate balance. Tree carbohydrate balance is important during thinning since fruit cell division and fruit respiration chiefly occurs early in the season following bloom (Lakso and Goffinet, 2013). When carbohydrate supply is not limited, fruit will experience a high cell division rate, high growth rate, and will continue to stay on the tree and grow; while in carbohydrate deficient situations, fruit will experience a low cell division rate, low growth rate, and will abort and drop (Lakso and Goffinet, 2013).

With the fruit being supported almost entirely by carbohydrates from photosynthesis after bloom (Lakso and Goffinet, 2013), solar radiation and temperature are the main factors regulating the carbohydrate production and supply within trees during fruit set (Lakso et al., 2007). This carbohydrate supply is a significant factor in determining tree response to chemical fruit thinners since it can affect the response of trees to thinning materials (Lakso et al., 2007). With regards to solar radiation, continuous periods of cloudy weather, as little as three days, can greatly reduce the amount of photoassimilates available to the developing fruit, making them more sensitive to thinning sprays (Byers et al., 1990); whereas sunny weather decreases the degree of thinning of post-bloom chemical thinners.

Similarly, temperature indirectly influences chemical thinner efficacy by affecting carbohydrate production. Thinners will be less effective at lower temperatures (Forshey, 1986), but more effective at higher temperatures due to the stress of increased competition between sinks (fruit and vegetative growth) for carbohydrate usage (Greene, 2002).

However, temperature may also impact post-bloom chemical thinner efficacy by affecting the absorption and uptake of the chemical thinner. Although studies, such as Jones and Koen, 1985, show a correlation between higher temperatures and increased thinning action and suggested that higher temperatures increased chemical absorption (Kon and Schupp, 2019), it was alternatively proposed that it is not the warm temperatures that increase chemical absorption, but rather cool temperatures inhibiting/delaying the chemical action of thinners such as carbaryl or NAA due to a slower plant metabolism at the lower temperatures (Byers, 2002).

In summary, post-bloom chemical thinning sprays would be less effective in situations where high carbohydrate production and/or low carbohydrate demand exists (i.e. sunny and cool weather) but will be more effective in situations where the carbohydrate production is low and/or high carbohydrate demand exists (i.e. cloudy and warm weather). This can make post-bloom chemical fruit thinning a challenge for growers since they will not only need to consider the

weather (temperature and solar radiation) at the time of application but also the weather a few days before and after thinning sprays in order to adjust the chemical thinner rates needed to achieve the optimum thinning response.

Fruit Size

Fruit size at the time of thinning is another important factor which greatly influences the efficacy of post-bloom chemical thinners. In most cases, post-bloom chemical thinners are applied between petal fall and fruit diameter of 15 millimeters. However, the susceptibility of fruitlets to post-bloom chemical thinners can vary within in this range with some thinners being more effective at a certain fruit diameter than others due to the mode of action of the thinner (Green, 2002). For example, NAA and 6-BA can be used as a thinner between petal fall and 17mm fruit diameter, but the optimal thinning response will be obtained when it is applied between 10-12 mm fruit diameter (Crassweller et al., 2016). Consequently, growers must pay close attention to fruit size when using post-bloom chemical fruit thinners.

Variety Responses

Variety responsiveness to chemical thinners is an additional factor which makes post-bloom thinning difficult. Some varieties such as Cripps Pink and Granny Smith can be considered highly sensitive to chemical thinners while other varieties such as Fuji and Rome can be considered less sensitive to chemical thinners (Pfeiffer et al., 2019). Varietal differences can make post-bloom thinning even more challenging due to the need to change rates, thinners, and application numbers between blocks.

Early History of Chemical Blossom Thinning in the United States

Early 19th Century Research

Chemical blossom thinning was first evaluated as a thinning method in the United States during the early 20th century. Since hand thinning was the primary method of fruit thinning in the early 20th century, much research went into identifying potential blossom/flower thinners which could effectively reduce the crop load during this time (Kon and Schupp, 2019). One of the first recorded research efforts at intentional chemical blossom thinning was performed by Drain, in 1924 when he found that iron sulphate was capable of thinning the blossoms of apple trees (Drain, 1924; Dennis, 2000). In response to growers' requests, extensive blossom thinning tests were conducted across six states with eight cultivars and multiple chemicals (i.e. calcium polysulfide, copper sulphate, sodium nitrate, zinc sulphate, and oil emulsion) from 1933 to 1935 (Auchter and Roberts, 1933; Auchter and Roberts, 1935; Dennis, 2000). In their first series of tests, it was concluded that none of the treatments performed well due to overthinning and excessive phytotoxicity in the foliage of the treatments (Auchter and Roberts, 1933; Dennis, 2000). Expanding the experiment with additional cultivars and new treatments in 1935, it was found that many of the treatments once again caused excessive phytotoxicity and/or fruit russeting, and that tar oil performed the best for blossom thinning (Auchter and Roberts, 1935; Dennis, 2000).

The Use of DNOC

In 1940, it was found that dinitro-ortho-cresol (DNOC, tradename Elgetol) could potentially be used as a blossom thinner since it prevented the germination of pollen (MacDaniels and Hildebrand, 1940; Dennis, 2000). Consequently, DNOC came into use as a blossom thinner for commercial apple orchards. However, the use of DNOC had several negative attributes. DNOC applications were often accompanied by phytotoxicity and pedicel injury (Kon and Schupp, 2019). Standard West Coast apple thinning spray programs consisted of two main parts during the mid to late 20th century: 1) blossom thinning with DNOC and 2) post-bloom chemical fruit thinning with NAA and carbaryl (Washington State University, 1975). One application was commonly applied at the rate of 2.7 pints to 6 pints per acre in dilute, 400 gallon/acre, sprays (Washington State University, 1975). With regards to application timing, DNOC applications were made according to the percentage of open bloom. The 1975 Washington State Tree Fruit Spray Guide recommended that DNOC applications occur when three blossoms were open per cluster on the north side of the tree which was defined as full bloom (Washington State University, 1975). This equates to approximately 60% open bloom. The 1980 Elgetol (DNOC) label called for applications to be made when 70% to 80% of the blossoms were open and not to apply after 90% of the blossoms were open (Elgetol Label, 1980). If the DNOC thinning sprays were not sufficient to obtain the desired level of thinning, then post-bloom thinning sprays with NAA, NAD, and/or carbaryl would be applied (Washington State University, 1975). Despite standard and common use on the West Coast for blossom thinning, DNOC was not utilized by growers on the East Coast, due to the high humidity and frequent precipitation which caused overthinning and injury (Dennis, 2000). The use of DNOC as a blossom thinner on the West Coast continued until its termination in 1989 due to high re-registration costs and environmental concerns (Dennis, 2000). Consequently, this led to an increase in research which sought to find a blossom thinner replacement for DNOC (Dennis, 2000).

Blossom Thinning Research Following DNOC Label Cancellation

Search for DNOC Replacements

Many different compounds were evaluated at the end of the 20th century and the beginning of the 21st century in the search for an effective blossom thinning agent which could replace DNOC and not produce any detrimental effects such as phytotoxicity, fruit russeting, etc. Since 1989, over 150 different chemicals have been tested and evaluated for blossom thinning in apples (Kon and Schupp, 2019).

Only a few chemicals obtained a label for blossom thinning in apples. One of the first chemicals to receive a label shortly after the cancellation of DNOC's label was sulfcarbamide, since it was found to be an effective blossom thinning agent (Williams, 1993; Kon and Schupp, 2019). However, fruit russeting (Greene, 2004) associated with late sulfcarbamide applications prohibited widespread adoption and eventually led to its label cancellation in 2006 (Kon and Schupp, 2019). Additionally, pelargonic acid received a label for blossom thinning in 1996 from research which demonstrated that it was effective as a blossom thinning agent (Williams, 1994). However, phytotoxicity issues, variability in thinning efficacy, and spray tank mixing issues led

to its cancellation later in 2003 (Kon and Schupp, 2019). Furthermore, endothall was also evaluated and found to be effective at reducing the crop load as a chemical blossom thinner (Williams et al., 1995) and received a label for blossom thinning in Washington state briefly between 2014 and 2017 (Kon and Schupp, 2019).

Lime Sulfur

With the known ability of lime sulfur to reduce fruit set, research interest in evaluating lime sulfur as a blossom thinning agent in apples began to increase in the early 21st century following the discontinuation of other blossom thinners (i.e. sulfcarbamide) which were intended to replace DNOC. Consequently, Washington state growers were the first to receive a label for blossom thinning with lime sulfur in 2003 (Schupp, et al. 2005).

Recent Mid-Atlantic Blossom Thinning Research

Shortly after the labelling of lime sulfur for blossom thinning on the West Coast, multiple research projects in the Mid-Atlantic growing region were implemented to investigate the details of its mode of action, application timing, and efficacy as an alternative thinning method for the East Coast. To investigate the thinning efficacy of lime sulfur, Schupp et al (2005) found that the thinning response of lime sulfur sprays was increased by the use of surfactants, with petroleum oil-based surfactants considered the best under Mid-Atlantic conditions. In an attempt to investigate the mode of action of lime sulfur sprays, research from Yoder suggested that lime sulfur sprays with surfactants caused flower and fruitlet abscission (a reduction in fruit set) chiefly by inhibiting pollen germination, pollen tube growth in the style, and fertilization (Yoder et al., 2009). In order to find a method to determine optimum application timings, another line of research was initiated by researchers at Virginia Tech who invested into developing a decision making aid. The work of Yoder and colleagues in 2009 demonstrated that pollen tube growth rates were regulated by genotype and temperature (Yoder et al., 2009). Further work by DeLong et al (2016) showed that a three-factor relationship between paternal pollen tube growth rates, maternal cultivar style lengths, and temperature collectively determined the time required for fertilization. From this and other research, the pollen tube growth model (PTGM) was developed for seven varieties (Red Delicious, Golden Delicious, Honeycrisp, Granny Smith, Cripps Pink, Gala, and Fuji). Although much research from Virginia went into developing the PTGM, the model was first tested in commercial Washington State orchards in 2008 and 2011 (Yoder et al., 2010). From these early experiments, it was found that the application timing guided by the PTGM resulted in the desired effect of allowing the fertilization of the majority of the king blooms (85% fertilized) and preventing the fertilization of the majority of the side blooms (20% fertilized) in Gala orchard blocks (Yoder et al., 2013). Consequently, the model was made available on the AgWeatherNet webpage for field tests using several hundred beta-test orchard sites between 2012 and 2014 in Washington State (Yoder et al., 2014). From these extensive beta-tests and grower feedback, alternations were made to the model prior to its public release on the AgWeatherNet website for West Coast producers (Yoder et al., 2014). In 2014 and 2015, a Pennsylvania trial evaluating lime sulfur, stylet oil, ammonium thiosulfate, and endothall for blossom thinning utilized the PTGM as a timing aid and found that none of the treatments overthinned nor resulted in excessive fruit injury (Kon et al., 2018). As of April 2019, the PTGM

is currently available to United States apple growers on both the AgWeatherNet website (West Coast) and NEWA website (East Coast).

Advantages & Disadvantages of Chemical Blossom Thinning

From previous research with blossom thinning, several key advantages of blossom thinning over post-bloom chemical fruit thinning have been identified. Since blossom thinning occurs earlier, it has the greater potential to increase fruit size when compared to post-bloom chemical fruit thinning (Greene, 2002). Additionally, blossom thinning has been shown to result in increased return bloom the following year (Batjer, 1965; Kon and Schupp, 2019). Finally, some formulations of lime sulfur are approved for organic production and registered for chemical blossom thinning; thereby, allowing lime sulfur blossom thinning to be used as a thinning practice for organic apple orchards. Post-bloom chemical fruit thinners (NAA, NAD, Carbaryl, etc.) are not approved for organic production.

Adverse weather conditions (i.e. frost, freeze, low temperatures, excessive wind, etc.) during the blossom period can inhibit fruit set by inhibiting pollination or damaging blossoms (Kon and Schupp, 2019). Consequently, blossom thinning can result in over-thinning when adverse weather conditions occur. Additionally, fruit russeting and foliar phytotoxicity can occur depending on the chemical rates, chemical materials, application weather conditions, and application timing (McArtney and Obermiller, no date). Finally, blossom thinning requires the utmost attention to determine the application timing needed to achieve the intended thinning response. Consequently, applications on large acreage and across multiple varieties are often difficult.

Research Proposal

Justification

Although post-bloom chemical fruit thinning has been the main method of crop load management used by Virginia and Mid-Atlantic apple producers since the 1960s, variability in thinning results has sparked interest in alternative thinning methods. Virginia apple producers would greatly benefit from having a more reliable practice of thinning which: 1) is suitable for different production systems, 2) results in desired crop loads, 3) does not have adverse effects on vegetative health and fruit quality, 4) is practical/efficient, and 5) is economical. One such possible alternative practice to post-bloom chemical fruit thinning is chemical blossom thinning. Despite the promising attributes of chemical blossom thinning and extensive use already on the West Coast**,** the practice of chemical blossom thinning in Virginia and other East-Coast states has been rather limited. However, several recent developments may allow the adoption of chemical blossom thinning by Virginia apple growers. For instance, Rex Lime Sulfur Solution and NovaSource Lime Sulfur Solution recently obtained labels as the first materials registered for blossom thinning in Virginia in 2018. Additionally, the PTGM was made available to Virginia and other East Coast states in the Spring of 2019. Consequently, there is a need for applied blossom thinning research projects which address the practical questions and concerns of blossom thinning in Virginia and the surrounding Mid-Atlantic states.

Research Goal & Objectives

The chief goal of this study is to investigate key limitations of chemical blossom thinning in Virginia. The main objectives of this project are: 1) investigate practical application strategies (application timing) of currently registered blossom thinning materials and 2) evaluate the suitability (crop safety) and efficacy (degree of thinning) of potential unregistered materials for commercial use.

The first objective is to evaluate application strategies of lime sulfur blossom thinning sprays for blossom thinning with regards to application timing. This objective seeks to determine the optimum application timing of initial sprays and subsequent repeat sprays. Although the PTGM is already available to assist growers in timing blossom thinning applications, there are multiple limitations to the model. First, the model does not compensate for the varying efficacy and modes of actions of different blossom thinning agents and/or surfactant combinations. The research tests for the PTGM utilized liquid lime sulfur combined with Crocker fish oil, since it was the preferred blossom thinning material and surfactant at the time, and did not account for the possibility that other chemical thinners with different modes of action to stopping pollen tube growth could be utilized as well (Yoder et al., 2013). Additionally, the model is only currently available for seven different varieties and many growers in Virginia and other growing regions have more than the seven standard varieties planted. Although growers could attempt to match varieties not listed on the PTGM to closely-related varieties based on parentage, different varietal responses have been recognized which could result in inaccurate model predictions (Yoder et al., 2013). Another factor impeding the use of the model is the need for data collection and input. The PTGM requires a significant amount of time for the growers to collect flowers, measure style length, input necessary data, and frequently monitor the model. This can be especially challenging for growers who have multiple varieties and/or blocks which are spread out. Finally, grower response to the PTGM has been very mixed. Additionally, Washington state apple growers utilizing the PTGM have had varying opinions with some growers having success and others not having success using the model (Dininny, 2017). Although the PTGM can assist progressive growers with larger contiguous acreages of few varieties, the issues which impede its use warrant that an alternative system for determining application timing and frequency be investigated. One possible alternative is scheduled based application timings where applications would be made after a certain percentage of blossoms were open, and then re-applied continually (i.e. every three days) thereafter. By investigating schedule-based application timing, growers who are unable to use the PTGM, due to the reasons described previously, could have a sound alternative method to assist them in timing blossom thinning sprays. In this project, two main application strategies will be assessed. One strategy will be based on model-guided bloom thinning applications using the PTGM to determine application timing and frequency. The other strategy will be based on scheduled applications. For the schedule-based treatments, initial spray application timing (e.g. first application at 20% open bloom vs. 80% open bloom) and application frequency (e.g. repeat applications every two days vs. every three days) will be evaluated. The purpose of this objective is to provide growers with recommendations on the optimum initial application timing and the required frequency of re-application.

The second objective of this research project is to investigate the suitability (crop safety) and efficacy (degree of thinning action) of non-labeled materials for chemical blossom thinning. The goal of this objective is to identify potential blossom thinning materials which could be superior blossom thinning agents compared to the currently registered lime sulfur solution materials. For instance, although lime sulfur is well documented to be an effective blossom thinner, fruit russeting issues associated with its use can impede usage (McArtney and Obermiller, no date). To meet this objective, potential blossom thinning agents will be evaluated based upon their effect on fruit quality and foliar phytotoxicity (crop safety). The impact the chemicals have on fruit quality factors such as color, russeting, and maturation (starch index, brix, etc.) will be evaluated in addition to foliar phytotoxicity ratings. Additionally, the efficacy of the blossom thinning agents will also be evaluated. To accomplish this, fruit set data will be collected in the form of percentage fruit set, fruit number per branch cross-sectional area (BCSA), and/or fruit number per trunk cross-sectional area (TCSA). The purpose of this objective is to identify potential chemical agents which are equally and/or more effective than the currently labeled lime sulfur blossom thinning materials in order for new superior blossom thinning products to be made available to growers in Virginia and the surrounding Mid-Atlantic region.

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Chapter II

Lime Sulfur Blossom Thinning Spray Timing Strategies in Apple

Introduction

Chemical blossom thinning is one new alternative thinning method with much merit that recently became available to apple growers in several states on the East Coast (i.e. North Carolina, Virginia, and Pennsylvania). The capability of chemical blossom thinning with lime sulfur for several East Coast states resulted due to the recent label registration of lime sulfur products for blossom thinning in apples. Liquid lime sulfur products became available for apple crop thinning in several eastern states in 2019 (Schupp and Kon, 2019). Although chemical blossom thinning with lime sulfur can be seen as a new method of thinning for East Coast producers; West Coast producers in Washington state have utilized lime sulfur for blossom thinning since receiving a label in 2003 (Schupp et al., 2005). Additionally, West Coast producers had historically utilized other products such as dinitro-o-cresylate (DNOC) (Childers, 1973) and are more familiar with the practice of blossom thinning in comparison to East Coast growers. Consequently, there is a need for current applied research which addresses the questions and challenges of lime sulfur blossom thinning on the East Coast.

One immediate challenge facing East Coast growers wishing to adopt lime sulfur blossom thinning is determining initial spray application timing and reapplication frequency. Timing is critical if optimum thinning results are to be obtained from blossom thinning sprays (Dennis, 2000). Currently, there are two major methods of timing blossom thinning sprays: 1) visual observation of the percentage of open blossoms and 2) model guided spray method using the pollen tube growth model (PTGM).

Prior to the availability of the PTGM, timing blossom thinning sprays from visual observation of open blooms was the sole method of determining appropriate application timing. Using the visual observation method requires growers to visually estimate the percentage of open bloom frequently during the bloom period. Common spray applications timings with visual observation method include 20%, 40%, 60%, 80%, 100% open bloom with single or multiple applications occurring (Kon et al., 2018). However, the recommended percentage of open bloom for triggering a spray application can vary depending on the chemical blossom thinner used and the source of information.

For instance, the 1975 Washington State Tree Fruit Spray Guide recommended that DNOC applications occur once three blossoms were open per cluster on the north side of the tree which was defined as full bloom (Washington State University, 1975). This equates to approximately 60% open bloom. However, the 1980 Elgetol label (active ingredient DNOC) called for applications to be made when 70% to 80% of the blossoms were open and not to apply after 90% of the blossoms were open (Elgetol Label, 1980). The DNOC label allowed only one application per year for blossom thinning (Washington State University, 1975).

With regards to lime sulfur blossom thinning, modern extension sources recommend the use of the PTGM (Peck and Olmstead, 2018; Allen and Sherif, 2019; Schupp and Kon, 2019). However, in cases where growers are not using the PTGM, it is currently recommended that one application of lime sulfur be sprayed at 20-30%, followed by a second application at 80-100% open bloom (Schupp and Kon, 2019).

Although the visual observation is easy for growers to utilize, variable thinning outcomes can result since pollen tubes are capable of reaching the base of the style within 48 hours (Yoder et al., 2009); thereby resulting in fertilization and rendering the blossom thinning spray ineffective. As a result, the visual observation method for timing blossom thinning sprays is a subjective method compared to model guided bloom thinning (Kon et al., 2018).

To develop a more precise method of timing blossom thinning sprays, research was invested into developing a model to assist in timing blossom thinning sprays. Some of the early research work in forming the modern pollen tube growth model (PTGM) demonstrated that pollen tube growth rates were regulated by genotype and temperature (Yoder et al., 2009). Further work showed that a three-factor relationship between paternal pollen tube growth rates, maternal cultivar style lengths, and temperature collectively determine the time required for fertilization (DeLong et al., 2016). Using the prototype PTGM, it was found that the application timing dictated from the preliminary model resulted in the desired effect of allowing the fertilization of the majority of the king blooms (85% fertilized) and preventing the fertilization of the majority of the side blooms (20% fertilized) in Gala orchard blocks (Yoder et al., 2013). After extensive field testing in Washington State, and necessary adjustments were made (Yoder et al., 2014), the PTGM was publicly made available on the AgWeatherNet website in 2014 for West Coast producers (Johnson and Courtney, 2018). As of 2019, the PTGM is available on both the AgWeatherNet website for West Coast producers and the NEWA website for East Coast producers and can be used for seven different major varieties.

The PTGM requires frequent monitoring and data input from the user. Before starting the model, growers must carefully monitor the stage of blossom development in their blocks. The model should be started when the number of open blossoms is equal to the desired crop load (Schupp and Kon, 2019). Once enough blossoms are open to set the intended crop load, flowers must be sampled from the block(s) and the styles measured in order to determine the average style length. The model can then be started by selecting the variety, entering the average style length, and selecting the date at which the number of open blossoms were present to develop into the intended crop load. Once the model is started, it will track pollen tube growth down the style and provide a prediction of the future date/time at which fertilization of the open blossoms will occur. The pollen tube growth rates for each variety are tracked according to hourly temperature data (Schupp and Kon, 2019). It is recommended that the first blossom thinning spray application be made shortly after the pollen tube length has reached 100% the length of the styles. Once the first spray is applied, the model can be reset by entering a spray date and time. Subsequent sprays should then be applied when the pollen tube length is 60-80% the length of the style. This will ensure that the remaining blossoms are not fertilized. Subsequent sprays should be continued until the end of the blossom period; however, it must be noted that current

labeled lime sulfur formulations restrict blossom thinning to a maximum of three sprays per season (Rex Lime Sulfur Solution Label, 2019; NovaSource Lime-Sulfur Solution Label; 2019).

Although the PTGM can assist growers in applying blossom thinning sprays with precision, there are several limitations which must be noted. First, the model does not compensate for the varying efficacy and modes of actions of different blossom thinning agents and/or surfactant combinations. The research tests for the PTGM utilized liquid lime sulfur combined with fish oil, because it was the preferred blossom thinning combination at the time, and did not account for the possibility that other chemical thinners with different modes of action to stopping pollen tube growth could be utilized as well (Yoder et al., 2013). Additionally, the current model utilizes the pollen tube growth rate of the pollinizer 'Snowdrift' for making fertilization timing predictions (DeLong et al., 2016). With many apple orchards on the East Coast relying on many different pollinizer cultivars (i.e. 'Manchurian', 'Indian Summer', 'Evereste', etc.) and even production cultivars (i.e. 'Golden Delicious', 'Fuji', etc.) for pollen sources, the accuracy of the PTGM will vary from block to block depending on the dominant pollen source. Furthermore, the PTGM is currently only available for seven different varieties (Allen and Sherif, 2019). Many growers in the Mid-Atlantic have more than the seven standard varieties planted. Although growers could attempt to match varieties not listed on the PTGM to the closest variety based on parentage, different varietal responses have been recognized which could result in inaccurate model predictions (Yoder et al., 2013). Finally, the proper use of the PTGM requires time for growers to collect data and run the model. The PTGM requires a significant amount of time for the growers to sample flowers, measure style length, input necessary data, and frequently monitor the model. This can be especially challenging for growers who have large acreages, multiple varieties, and/or blocks which vary in location and bloom development.

With limitations to model-guided bloom thinning and few sound science-based guidelines for using the visual observation of open blooms to time thinning sprays, there is a warranted need for alternative lime sulfur blossom thinning timing strategies. One possible alternative strategy would be a schedule-based application timing method which utilizes the percentage of open blossoms to determine the initial spray timing and time-intervals (i.e. 48 hours vs 72 hours) for timing subsequent blossom thinning sprays. By investigating schedule-based application timing such as this, growers who wish not to use and/or are unable to use the PTGM, could have a sound alternative method to assist them in timing blossom thinning sprays.

In this project, two main lime sulfur blossom thinning application timing strategies were evaluated and compared. One strategy was based on model-guided bloom thinning applications using the PTGM to determine application timing and frequency. The other strategy was based on scheduled applications. For the schedule-based treatments, initial spray application timing was based on the percentage of open bloom (i.e. 20% open bloom vs. 80% open bloom) and subsequent blossom thinning spray timing was based on fixed time intervals (i.e. 48 hours vs. 72 hours). This research projects sought to evaluate how: 1) initial lime sulfur blossom thinning sprays applied according to the percentage of open bloom and 2) subsequent lime sulfur blossom thinning sprays applied according to time intervals collectively impact fruit set, crop density yield, fruit russet, etc., and compare these to the PTGM-based applications. The purpose of this

study is to provide Mid-Atlantic growers with scientific based recommendations on the optimum initial application timing and the required frequency of reapplication of blossom thinning sprays.

Materials & Methods

Research Sites & Blocks

This project was undertaken in the 2019 growing season at two geographically separate sites. At both sites, the exact same experiment was performed with each site having the same protocol, treatments, number of replicates, experimental design, and data collection procedures. Site #1 was located at the Alson H. Smith Jr. Agricultural Research and Extension Center in Winchester, Virginia (Virginia Tech). The Winchester site utilized Crimson Gala/M.9 apple trees planted in the year 2000. The trees were planted at a 10 ft. by 18 ft. spacing and trained to a central leader system. Site #2 was located at the Mountain Horticultural Crops Research and Extension Center in Mills River, North Carolina (North Carolina State University). The Mills River site utilized Ultima Gala/M.9 apple trees planted in the year 2012. These trees were planted at a 3 ft. by 13.3 ft. spacing and trained to a tall spindle system.

Treatment Structure

A total of five different treatments and one non-thinned control were utilized at both sites for this project. The treatment schemes differed according to the application timing of two blossom thinning sprays during bloom. In treatment #1 the PTGM was started at ~20% open king bloom and the application timing of the first and second blossom thinning sprays was determined based on the model's predictions for both sites. For treatment #2, the first blossom thinning spray was targeted at 20% open bloom (king and side bloom) and the second spray was targeted 48 hours thereafter. In treatment #3 the first blossom thinning spray was targeted at 20% open bloom and the second spray was targeted 72 hours thereafter. For treatment #4, the first blossom thinning spray was targeted at 80% open bloom and the second spray was targeted 48 hours thereafter. In treatment #5 the first blossom thinning spray was targeted at 80% open bloom and the second spray was targeted 72 hours thereafter. For the control group the trees were not thinned (no blossom thinning sprays, no post-bloom fruit thinning, no hand thinning, etc.). Table 2-1 summarizes the treatment schemes**.**

Experimental Design

Both sites utilized a complete randomized design (CRD). Each treatment and the control consisted of five replicate trees. Consequently, 30 trees were used at each site. At Winchester, a single buffer tree was used to separate treatments and minimize spray drift. At Mills River, 3 to 5 buffer trees were used to separate treatment trees and minimize spray drift due to the closer in-row tree spacing.

Spray Applications (Methodology, Chemicals, & Sprayers)

All treatment spray applications were made using dilute sprays. The first and second blossom thinning sprays for all treatments consisted of a spray solution containing: 2% NovaSource Lime Sulfur (active ingredient: 29% calcium polysulfide) and 2% JMS Stylet Oil (active ingredient:

97.1% paraffinic oil). This equated to the rate of 2.56 fluid ounces of NovaSource Lime Sulfur and 2.56 fluid ounces of JMS Stylet Oil per gallon of water. In the applications, both sides of the trees were sprayed resulting in thorough coverage of the entire tree canopy. Once the entire coverage of the tree canopy was achieved, spraying was ceased for each respective tree. At the Winchester site, treatment spray applications started with an electric powered handgun sprayer (custom fabricated) mounted on the bed of a utility vehicle. However, after completing the first applications for treatments #2 and #3 on April 18th, an equipment breakdown occurred. Consequently, the remaining sprays were applied using a handpump backpack sprayer (The Fountain Head Group, Inc., New York Mills, NY) at the Winchester site. At the Mills River site, a CO_2 gas pressurized hand-gun sprayer (Bellspray, Inc., Opelousas, LA) mounted on the bed of a utility vehicle was used to apply the blossom thinning sprays.

Treatment #1: PTGM and Spray Applications

For treatment #1, the PTGM was utilized to determine the application timing of the first and second sprays. At both sites the PTGM was started once ~20% of the king blossoms were open. This was determined by daily visual observation. Prior to starting the model, 50 blossoms were collected at random at each site in order to determine the average style length to be entered into the model. At the Winchester site, the average style length was measured to be 12.96 mm and at the Mills River site the average style length was 9.77 mm. The model was started on April 17, 2019 at 10:00 AM at the Winchester site and on April 7, 2019 at 7:00 PM at the Mills River site. Once the PTGM was started, the first spray application timing was targeted at the time when the cumulative pollen tube growth reached 100% the length of the style indicating that the open blossoms present at the time the model was started had been fertilized. After the first application occurred and the model was reset, the second spray application timing was targeted when the cumulative pollen tube growth reached 60% to 70% the length of the style in order to prevent the fertilization of the remaining flowers. At the Winchester site the first application occurred on April 21, 2019 at 12:30 AM when the pollen tube was predicted to have reached 114% the length of the style. The second application at the Winchester site occurred on April 23, 2019 at 2:37 PM when the pollen tube reached 57% the length of the style. At the Mills River site, the first application occurred on April 10, 2019 at 1:07 PM when the pollen tube was predicated to have reached 95% the length of the style. The second application at the Mills River site occurred on April 12, 2019 at 8:25 AM when the pollen tube reached 76% the length of the style. Table 2-1 summarizes the application timings of all the treatments.

Treatments #2-5: Spray Applications

Treatments #2, #3, #4, and #5 utilized pre-structured blossom thinning spray timings based upon the percentage of open bloom for initial sprays and fixed time intervals for subsequent sprays. In order to determine the percentage of open bloom, ten representative branches uniformly distributed in the research block at each site were selected. At the pink stage, all the pre-mature flower clusters on each branch were counted and multiplied by five (five flowers per cluster) in order to determine the theoretical total number of flowers which had not yet opened. Daily counts of the open flowers on each branch were performed starting at the late pink stage. The

daily count of open flowers was then divided by the theoretical total number of flowers to determine the percentage of open flowers for each day.

At the Winchester site, ~20% open bloom was reached on April 18, 2019 and the first blossom thinning sprays for treatments #2 and #3 were applied at 12:48 PM on April 18, 2019. The second spray for treatment #2 was applied on April 20, 2019 at 8:47 PM. The second spray for treatment #3 was applied on April 21, 2019 at 5:21 PM.

At the Winchester site, ~80% open bloom was reached on April 20, 2019 and the first blossom thinning sprays for treatments #4 and #5 were applied at 8:47 PM on April 20, 2019. The second spray for treatment #4 was applied on April 22, 2019 at 7:40 PM. The second spray for treatment #5 was applied on April 23, 2019 at 7:36 PM.

At the Mills River site, ~20% open bloom was reached on April 9, 2019 and the first blossom thinning sprays for treatments #2 and #3 were applied at 8:45 AM on April 9, 2019. The second for treatment #2 was applied on April 11, 2019 at 8:43 AM. The second spray for treatment #3 was applied on April 12, 2019 at 8:25 AM.

At the Mills River site, ~80% open bloom was reached on April 13, 2019 and the first blossom thinning sprays for treatments #4 and #5 were applied at 5:00 PM on April 13, 2019. Unfavorable wind for spraying caused the second spray target application time to be missed for treatments #4 and #5 at the Mills River site. The second spray for treatment #4 was applied on April 16, 2019 at 9:07 AM. The second spray for treatment #5 was applied on April 17, 2019 at 9:50 AM. Consequently, the spray application timing for treatments #4 and #5 was extended forward but still had an approximate 24-hour difference between the treatments.

After treatment applications, the timing was considered to be precise enough to validate the experiment. However, when drawing conclusions, it must be taken into consideration that the timing of the second blossom thinning sprays for both treatments #4 and #5 at the Mills River location were extended by ~24 hours. Table 2-1 lists the actual application timing for all the treatment sprays used in the experiment.

Data Collection Methods: Fruit Set

Fruit set differences between treatments were evaluated by flagging representative limbs to obtain approximately 100 flower clusters per replicate tree. At the Winchester site, three uniform branches per replicate tree were selected to obtain the ~100 flower clusters. At the Mills River site, 3-7 uniform limbs per replicate tree were selected to obtain the ~100 flower clusters. From the flagged flower clusters, the cluster count (i.e. 103 flower clusters) was multiplied by five (the average number of blossoms per cluster) to obtain the theoretical maximum fruit set (i.e. 515 fruit) on the flagged limbs of each replicate tree. Counts of the number of fruits on the flagged limbs of each replicate tree were performed two weeks, four weeks, six weeks, and eight weeks after petal fall and immediately prior to harvest. To obtain fruit set percentages, the fruitlet/fruit count from each respective time interval was divided by the theoretical maximum fruit set (i.e. 515 fruit).

Data Collection Methods: Crop Density

Differences in crop density between the treatments were evaluated using the fruit number per cm^2 of branch cross sectional area (BCSA) at the Winchester site and the fruit number per cm^2 of limb cross sectional area (LCSA). In the Spring of 2019, the diameter of the flagged branches/limbs used in evaluating fruit set were measured. From the branch diameter and the previous fruit counts, the fruit number per BCSA/LCSA at each respective time interval was determined.

Harvest Methods

In order to obtain crop yield data (i.e. Kg. fruit/tree), whole tree harvests were utilized. Two pick harvests were utilized at both sites to optimize fruit maturation at harvest. In the first pick, only fruit which had developed sufficient color indicating ripeness were harvested. After the first pick, approximately one week was left to allow the remaining fruit to ripen and develop color. In the second pick all the remaining fruit were harvested. For both picks at both sites, all the fruit on each replicate tree was harvested except for any fruit which had obvious visual damage from excessive rot, herbicide injury, mechanical injury, etc. The percentage of unharvested fruit due to damage was very minimal and visually estimated to be less than 1% of the entire crop load at both sites.

At the Winchester site, the first pick occurred on August 16, 2019 and the second pick occurred on August 22, 2019. The harvested fruit from both sites was placed into bushel crates. All the harvested fruit was placed into cold storage immediately after harvest. On August 25, 2019 the fruit was loaded onto a non-refrigerated truck (International, Co., Lisle, IL) and then transported to Mills River, NC. The box truck arrived at Mills River on August 26, 2019 and all the Virginia fruit were run through the fruit sorter on the same day.

At the Mills River site, the first pick occurred on August 15, 2019 and the second pick occurred on August 21, 2019. The harvested fruit from each pick was placed in bushel crates which were stored in cold storage overnight. The fruit from the first pick was run through the sorter on August 16, 2019 and the fruit from the second pick was run through the sorter on August 22, 2019.

Data Collection Methods: Fruit Weight, Diameter, Length, Blush, Yield (Kg. Fruit per Tree), Fruit No. per Tree, and Yield Estimate (Bushels/Acre)

An electronic fruit sorter (Durand-Wayland, Inc., LaGrange, GA) equipped with a color and infrared camera system and full transmittance spectrometer (TrueSort Electronics; Ellips, Eidhoven, Netherlands) was used to determine: 1) individual fruit weight, 2) individual fruit diameter, 3) individual fruit length, and 4) the percentage of blush present on each fruit. From this data, the yield (kg. fruit/tree) per treatment and fruit count (# fruit/tree) was calculated and determined. The crop yield per acre was estimated using tree density (Winchester: 242 trees per acre; Mills River: 1,092 trees per acre), the kilograms of harvested fruit per replicate tree, and a fixed bushel weight of 48 lbs. From the Winchester site, a total of 18,815 individual fruits from all treatment and control trees were harvested from both picks and run through the sorter. At the

Mills River site, a total of 6,040 individual fruits from the treatment trees and control trees were harvested from both picks and run through the sorter.

Data Collection Methods: Fruit Russeting

Fruit russet data was collected from both the Winchester and Mills Rivers sites to determine if there was a treatment effect on fruit finish. After running the fruit through the sorter, twenty fruit from each replicate were randomly pulled at the end of the line. These fruits were rated for russet. A russet rating scale adapted from the United States Standards for Grades of Apples was used (United State Department of Agriculture, 2002). Using the scale, the fruit were placed into one of three grade categories: Category 1 (US. Extra Fancy & U.S. Fancy grades) 0% russeting; Category 2 (U.S. No. 1 grade) 1-25% smooth net like russeting and/or 1-10% smooth solid russeting; and Category 3 (U.S. Utility Grade) >25% smooth net like russeting and/or >10% smooth solid russeting.

Data Collection Methods: Raised Lenticels

At the Mills River site, it was observed that a significant portion of the fruit showed raised lenticels. However, none of the Winchester fruit were observed to have raised lenticels. Consequently, a raised lenticel rating was performed on the fruit from the Mills River site. A rating scale of yea vs. nay with regards to the presence of raised lenticels on each fruit was used with the same 20 fruit subsample used in the fruit russet ratings.

Data Collection Methods: Foliar Phytotoxicity

Visual foliar phytotoxicity ratings were used at both sites in this project to determine if there was any treatment effect on foliar phytotoxicity. At both sites a 0-100 foliar phytotoxicity rating scale was utilized with 0 indicating that 0% of the leaf surface was necrotic/chlorotic and 100 indicating that 100% of the leaf surface was necrotic/chlorotic. At both the Winchester site and the Mills River site, four representative leaf spurs (2 from each side of the tree) were used for the foliar phytotoxicity ratings. When generating the phytotoxicity ratings, the entire surface area of all the leaves of each spur were considered. The collective leaf surface area of all the leaves on each spur served as each data point. Phytotoxicity ratings were performed May 7, 2019 at Winchester and on May 8, 2019 at Mills River.

Research Block Maintenance

In the course of the experiment, standard orchard management tasks were carried out in the research blocks. Both research blocks received a standard insecticide and fungicide spray program during the course of the experiment. Additionally, both research blocks received a standard nutrient management program during the course of the experiment. Furthermore, both research blocks received standard pruning/training procedures during the winter of 2018/2019. No other thinning methods (hand, chemical, nor mechanical) were implemented on the treatment nor control trees in the research blocks other than the treatment sprays.

Statistical Analysis

JMP Pro 14 was used for all statistical analyses in this project. Tukey's Honestly Significantly Difference Test was used as the sole statistical method in evaluating significant difference between means with regards to fruit set, crop density, yield, foliar phytotoxicity, fruit russeting, etc.

Results

Fruit Set (Winchester, Virginia & Mills River, North Carolina)

The majority of the blossom thinning treatments were found to be effective at reducing fruit set at the Winchester site. (Table 2-2). Most of the treatments had a mean fruit set at harvest which was significantly different from the control. Treatments with the first blossom thinning sprays occurring at 20% open bloom had the lowest mean fruit set compared to the other treatments. However, this difference was not significant. Differences in fruit set at harvest between treatments were more variable and less concise at the Mills River site. (Table 2-2). Only the PTGM treatment and 20% open bloom + 48 hour treatment, were found to have a mean fruit set at harvest which was both lower and significantly different from the control at Mills River. At both sites the level of significant difference between treatments and the control was generally constant from two weeks after petal fall until the time at harvest. (Table 2-2).

Crop Density (Winchester, Virginia & Mills River, North Carolina)

The mean crop density (fruit no./cm^2 BCSA) in all the Winchester treatments was lower than the control but without a significant difference being observed between thinning treatments and the control. (Table 2-3). However, at the Mills River site, the PTGM treatment and the 20% open bloom + 48 hour treatment were the only treatments found to both be effective in reducing the crop density (fruit no./cm^2 LCSA) and be significantly different from the control. (Table 2-3).

Kg Fruit/Tree (Winchester, Virginia & Mills River, North Carolina)

All treatments at the Winchester site had a lower mean weights of fruit per tree when compared to the control, but none were significantly different from the control. (Table 2-4). At the Mills River site, the PTGM, 20% open bloom + 48 hour, and 20% open bloom + 72 hour treatments had lower mean weights of fruit per tree when compared to the control. Surprisingly, none of the treatments at the Mills river site were significantly different from the control.

Fruit No./Tree (Winchester, Virginia & Mills River, North Carolina)

All the treatments at the Winchester site had a lower fruit number per tree that was not significantly different from the control. (Table 2-4). Most of the treatments at the Mills river site had a lower fruit number per tree compared to the control. The PTGM treatment at the Mills River site was the only treatment which was significantly different from the control.

Estimated Yield in Bushels/Acre (Winchester, Virginia & Mills River, North Carolina)

The estimated yield per acre was lower in all treatments at the Winchester site with no significant difference between the treatments and control. At the Mills River site, none of the treatments

were significantly different from the control with regards to estimated yield per acre. However, the PTGM treatment was significantly different from the 80% open bloom + 48-hour treatment and 80% open bloom + 72-hour treatment in Mills River.

Individual Fruit Weight, Diameter, Length (Winchester, Virginia & Mills River, North Carolina)

At the Winchester site and the Mills River site, each treatment was significantly different from the control with regards to fruit weight, diameter, and length. (Table 2-6). Furthermore, the significant differences of fruit weight, diameter, and length were all co-related in each treatment at each respective site. Despite the presence of significant differences between treatments and the control, there was no clear relation between initial spray application timing (20% open bloom vs. 80% open bloom) nor reapplication frequency (48 hours vs. 72 hours) and fruit size, diameter, and weight at either location.

Fruit Blush (Winchester, Virginia & Mills River, North Carolina)

The treatments at the Winchester site did not have a substantial effect on increasing or decreasing fruit blush. (Table 2-6). However, it was found that both the 20% open bloom + 72-hour treatment and the 80% open + 48-hour treatment slightly decreased the percentage of fruit blush and where significantly different from the control. At the Mills River site, all the treatments increased the occurrence of fruit blush with each treatment having a higher mean percentage of blush compared to the control. (Table 2-6). Additionally, all the treatments at Mills River, except for the 80% open bloom + 72-hour treatment, were significantly different from the control. Furthermore, the Mills River data collectively showed that fruit blush increased with earlier initial application timing and more frequent reapplication frequencies.

Fruit Russet Incidence/Severity Influence on Packout (Winchester, Virginia & Mills River, North Carolina)

All the treatments from the Winchester site had lower mean packouts of U.S. Extra Fancy/U.S. Fancy grade fruit and higher proportions of U.S. No. 1 grade fruit due to the incidence and severity of russet. (Table 2-7). The PTGM treatment and the 20% open bloom + 48 hour treatment both had lower mean percentages of U.S. Extra Fancy/U.S. Fancy grade fruit and higher mean percentages of U.S. No. 1 grade fruit which were significantly different from the control at the Winchester site. There was no significant difference in the proportion of fruit classified in the U.S. Utility grade due to russet at the Winchester site. At the Mills River site, the treatment means of the percentages of fruit categorized into the U.S. Extra Fancy/U.S. Fancy grade, U.S. No. 1 grade, and U.S. Utility grade were not significantly different and not consistent enough to establish a concise relation between lime sulfur spray timing and fruit russet incidence/severity. (Table 2-7).

Raised Lenticel Occurrence (Winchester, Virginia & Mills River, North Carolina)

All treatments at the Mills River site had a higher mean percentage of fruit with raised lenticels. (Table 2-8). None of the treatments were significantly different compared to the control. Raised lenticels were not observed at Winchester, so no data located at this site.

Foliar Phytotoxicity (Winchester, Virginia & Mills River, North Carolina)

At the Winchester site, all the treatments increased the incidence of phytotoxicity with most of them being significantly different from the control. (Table 2-9). The Winchester treatments suggested that phytotoxicity incidence increased with later initial applications. However, there was no significant difference between the phytotoxicity ratings of earlier initial applications when compared to the later initial applications. At the Mills River site most of the treatments increased phytotoxicity incidence. (Table 2-9). However, only the PTGM treatment had a significantly higher level of phytotoxicity compared to the control.

Discussion & Conclusions

The purpose of this project was to investigate the optimal initial application timing and the required frequency of reapplication of lime sulfur blossom thinning sprays best suited for commercial apple growers in the Mid-Atlantic Region. Consequently, this project collected yield data (i.e. fruit set, crop density, etc.), fruit quality data (i.e. weight, diameter, blush, etc.), and crop safety data (i.e. russet incidence, phytotoxicity) on the cultivar 'Gala' at two separate sites (Winchester, VA, and Mills River, NC) in the 2019 growing season.

Fruit Set, Crop Density, Kg Fruit/Tree, Fruit No./Tree, and Estimated Bu./Acre

When evaluating treatment effect on yield factors, the data from this project demonstrated that the PTGM treatment was able to effectively reduce fruit set, crop density, Kg. fruit/tree, fruit no./tree, and estimated bu./acre at both sites in most cases. (Tables 2-2, 2-3, 2-4, and 2-5). This is in agreement with other previous studies (Kon et al., 2018; Peck et al., 2017) which demonstrate that the PTGM is a reliable method for timing blossom thinning sprays. Additionally, it was found that lime sulfur sprays applied at 20% open bloom and 48 hours later performed near equally well as the PTGM treatment in reducing fruit set, crop density, kg. fruit/tree, fruit no./tree, and estimated yield per acre in most situations. (Tables 2-2, 2-3, 2-4, and 2-5). The 20% open bloom + 48-hour treatment likely performed as well as the PTGM since the initial application was early enough to prevent excessive fruit set. Blossom thinning sprays need to be applied early enough to prevent excessive fruit set (Bound and Jones, 2004). It also performed well likely due to the short reapplication frequency (48 hours). Since temperature directly impacts pollen tube growth which, in turn, influences the time required for fertilization (Yoder et al., 2009), shorter spray intervals are more likely to decrease the chances of flower fertilization and preventing fruit set. The other treatments with more delayed reapplication frequencies and later initial sprays were found to be not as effective in reducing the factors affecting yield such as fruit set, crop density, etc.

With regards to reapplication frequency of the treatments with an initial application at 20% open bloom, it was found that the treatment at 20% open bloom + 72 hours thereafter was only effective in reducing fruit set and crop density at the Winchester site but not the Mills River site. Although temperature plays a major role in determining fertilization timing (Yoder et al., 2009), there was only minor difference in mean hourly temperature between the time of the first and second sprays for the 20% open bloom + 72-hour treatment at the two sites (Winchester 62.9°F and Mills River 61.3°F). Consequently, the ability of the 20% open bloom + 72-hour treatment

to reduce the fruit set as well as the 20% open bloom + 48-hour treatment at the Winchester site but not the Mills River site was likely due to other variable(s) affecting the time required for flower fertilization such as style length. At the Winchester site, the mean style length was found to be 12.96 mm compared to the shorter 9.77 mm style length at the Mills River location. Since longer style length has been shown to be associated with more time required for flower fertilization (DeLong et al., 2016; Jahed and Hirst, 2017), it is likely that the shorter style length at the Mills River site allowed the pollen tubes to reach the base of the style resulting in flower fertilization prior to the second spray in the 20% open bloom treatment; thereby, rendering the second spray ineffective in thinning the flowers and causing the treatment to have a higher fruit set, crop density, etc. Consequently, it is suggested that second blossom thinning sprays occurring ~72 hours after the initial spray can be too late in preventing fertilization and reducing the crop load in some situations. Additionally, pollen tube growth rates and the associated time required for fertilization have shown to be influenced by other factors such as paternal pollen source (DeLong et al., 2016; Jahed & Hirst, 2017). With the research sites having different adjacent blocks containing different production and pollinizer cultivars, the dominant paternal pollen source was likely different between the two sites and may have also had a role in affecting the time required for flower fertilization.

Regarding later initial applications at 80% open bloom, the data suggested that these treatments were not reliably effective in reducing fruit set, crop density, kg fruit/tree, fruit no./tree, nor estimated bu./acre. (Tables 2-2, 2-3, 2-4, 2-5). This likely resulted from the additional time allowed for the majority of the blossoms to open and become fertilized, thereby rendering the blossom thinning sprays less effective. Bound and Jones (2004), using ammonium thiosulfate as a blossom thinner found applications made later during bloom are not as effective as applications made earlier during bloom in reducing fruit set**.** Finally, there was no concise difference in fruit set, crop density, kg fruit/tree, fruit no./tree, and estimated bu./acre (tables 2-2, 2-3, 2-4, 2-5) between the reapplication frequencies (48 hours vs. 72 hours) of the treatments with an initial application at 80% open bloom. This likely resulted from the increased crop load which could have minimized significant difference. The windy conditions which caused the second applications in the 80% open bloom treatments at the Mills River site to be delayed, could have also contributed to this. (Table 2-1).

Fruit Weight, Diameter, and Length

Despite the large number of data points (18,815 fruit from the Winchester site and 6,040 fruit from the Mills River site) and the presence of significant difference between treatments and the control, there was no clear and concise relationship effect of initial application timing (i.e. 20% open bloom vs. 80% open bloom) nor application frequency (i.e. 48 hours vs. 72 hours) on individual fruit weight, diameter, or length across both sites. (Table 2-6). At the Winchester site, all of the treatments had higher mean fruit weights, diameters, and lengths which were significantly different from the control suggesting that all of the treatments had a thinning effect. This is in agreement with other recent studies (Marchioretto et al., 2019; Bound, 2010; Stopar, 2008; Peck et al., 2017; Kon et al., 2018) which have also shown that increased thinning (i.e. reduced fruit set, reduced crop load, etc.) results in increased fruit weight/size when lime sulfur

is used as a blossom thinner. At the Mills River site all the treatments with the exception of the 20% open bloom + 72-hour treatment and 80% open bloom + 72-hour treatment had significantly higher mean weights, diameters, and lengths than the control. (Table 2-6). This occurrence likely resulted from the short style length (9.77 mm). At both sites, the PTGM treatment and the other treatments with a reapplication interval of 48 hours, all had significantly higher mean fruit weights, diameters, and lengths compared to the control. With effective thinning applications shifting the fruit weight distribution curve from lower size categories to higher size categories (Link, 2000), it is suggested that the PTGM and 48 hour reapplication treatments had an effective thinning effect.

Fruit Blush

There was no concise treatment effect on fruit blush across both sites. At the Winchester site, most of the treatments had no significant impact on fruit blush compared to the control. (Table 2-6). The 20% open bloom + 72 hour and 80% open bloom + 48 hour treatments slightly decreased fruit blush at the Winchester site, but at Mills River fruit blush increased with earlier initial application timing and more frequent reapplication frequencies. (Table 2-6). When studying lime sulfur blossom thinning sprays with different adjuvants, Bound demonstrated that the lime sulfur blossom thinning sprays with heavier thinning (decreased fruit and crop density) increased fruit background color (Bound, 2010). With a positive linear relationship existing between decreased crop load and increased fruit color (Link, 2000) it is suggested that the earlier initial application time (i.e. 20% open bloom) and more frequent reapplication frequencies (i.e. 48 hours) of blossom thinning sprays can result in more thinning thereby increasing fruit color. Evidence of this trend is generally supported by the Mills River crop density data, Kg. fruit/tree data, fruit no./tree, and estimated bu./acre. (Tables 2-3, 2-4, 2-5). However, this relation between application timing and fruit blush was not observed at the Winchester site. This could have resulted from sub-clonal differences (‘Ultima Gala’ vs. ‘Crimson Gala’) and/or the training system differences (tall spindle vs. central leader) between the two sites.

Packout According to Fruit Russet Incidence/Severity

The occurrence of fruit russeting from lime sulfur blossom thinning sprays likely results since chemical thinning is performed during the most sensitive time for the induction of russeting (Link, 2000). Fruit packout from russet incidence/severity was not conclusive between the two sites. At the Winchester site, all the treatments had lower mean packouts of U.S. Extra Fancy/U.S. Fancy grade fruit and higher proportions of U.S. No. 1 grade fruit due to the incidence and severity of russet, though not always significant. (Table 2-7). On the contrary, the Mills River data suggested that the lime sulfur sprays had no impact on fruit russeting incidence/severity and consequential impact on the packout of higher grade fruit. The ability of lime sulfur to result in increased fruit russeting has varied between different studies and is likely collectively dependent on multiple factors. Stopar found that increasing concentrations of lime sulfur did not induce the occurrence of fruit russet (Stopar, 2008). Peck found that model guided lime sulfur blossom thinning sprays resulted in a significant increase of fruit russet incidence (Peck et al., 2017). Bound found that the selection of the adjuvant to be used in lime sulfur sprays can have significant impacts on fruit russet incidence (Bound, 2010). Furthermore, it has

been suggested that climatic factors such as humidity can have an influence on russet incidence/severity from lime sulfur blossom thinning sprays (McArtney & Obermiller, no date). The results from this study suggested that there was no conclusive effect of lime sulfur blossom thinning spray timing on russet incidence/severity. (Table 2-7). It is likely that environmental variables such as humidity were different between the two sites which could explain the difference in fruit russet incidence/severity between the Winchester and Mills River. The ability of lime sulfur blossom thinning sprays to result in fruit russeting is likely caused by a collective and complex interaction of multiple factors including but not limited to concentration, adjuvant selection, number of sprays, and weather factors (i.e. humidity, temperature). From the data of this study, it is suggested that the timing lime sulfur blossom thinning can possibly have an impact on fruit russet incidence/severity.

Raised Lenticels

The occurrence of raised lenticels was observed on the fruit from the Mills River site but not on the fruit from the Winchester site. Consequently, a raised lenticel rating was only performed at the Mills River site. Although the average mean of raised lenticels was higher in all the treatments compared to the control, there was no significant difference among treatments. (Table 2-8). The occurrence of raised lenticels at the Mills River site but not the Winchester site, likely resulted due to difference in weather conditions between the two sites. Fruit disorders, such as raised lenticels, are related to dysfunctions or aberrations in the development of the epidermal tissue which are often linked to climatic conditions during the growing season (Cury et al., 2008).

Phytotoxicity

In most cases, the treatments in this project had slight increased incidences of foliar phytotoxicity compared to the control. (Table 2-9). However, the PTGM treatment at the Mills River site had a significant level of phytotoxicity compared to the other treatments at both sites. This could have resulted from inadequate weather conditions during the time of application. Slow drying conditions caused by low light, high humidity, and temperatures above 85°F around the time of application have the most potential for causing foliar phytotoxicity from lime sulfur blossom thinning sprays (Schupp and Kon, 2019). Overall, the data does not suggest a clear relationship between lime sulfur blossom thinning spray timing and phytotoxicity incidence. Although lime sulfur blossom thinning sprays have been associated with increased foliar phytotoxicity in some studies (Stopar, 2008), other studies (Kon et al., 2018) have shown that lime sulfur results in minimal foliar phytotoxicity and other blossom thinners, such as ammonium thiosulfate, can result in more phytotoxicity. From the results of this study it can be suggested that lime sulfur sprays applied during bloom have the potential to result in increased foliar phytotoxicity with little to no influence from the application timing. Furthermore, it can be suggested that other variables such as drying time, influence phytotoxicity incidence more extensively than application timing of lime sulfur blossom thinning sprays as indicated by the data from this project.

Summary & Final Conclusions

With current post-bloom thinner applications being used as the main crop load management practice for East Coast producers since the 1960's and associated thinning results being variable (Byers and Carbaugh, 1991), there is a need for alternative and/or improved thinning practices. One such possible alternative is chemical blossom thinning. An immediate challenge facing growers interested in adopting chemical blossom is the proper timing of spray applications. The timing of blossom thinning sprays is critical if optimum results are to be obtained (Dennis, 2000). Although much work was invested in developing a model to guide blossom thinning spray timing, there are multiple limitations to the model. For instance, the current model utilizes the pollen tube growth rate of the pollinizer Snowdrift for making fertilization timing predictions (DeLong et al., 2016). Additionally, other factors relating to grower's ability to use the model can limit its use in some situations. Consequently, this project was undertaken to evaluate lime sulfur blossom thinning timing strategies using pre-structured sprays times based on the percentage of open bloom (20% and 80%) and reapplication time-intervals (48 hours and 72 hours) in addition to the model.

From this project it was found that the PTGM was effective in timing sprays which resulted in reduced fruit set, crop density, kg/fruit tree, etc. and increasing fruit weight and size. These results are in agreement with other studies using the PTGM at the field level (Kon et al., 2018; Peck et al., 2017). Additionally, it was found that treatments with an initial application applied at 20% open bloom and 48 hours thereafter were nearly equally effective as the PTGM treatment in reducing fruit set, crop density, etc. and increasing individual fruit weight and size. Other treatments with later initial application at 80% open bloom and more delayed second sprays (i.e. 72 hours after the initial spray) were generally not effective in reducing fruit set, crop density and improving fruit weight/size in most circumstances. This likely resulted because initial applications applied later in bloom allow the majority of the blossoms to become fertilized thereby rendering later blossom thinning spray less effective (Bound and Jones, 2004) and longer reapplication intervals allow more pollen tubes to reach the base of the style due to differences in style length (DeLong et al., 2016; Jahed and Hirst, 2017), paternal pollen source (DeLong et al., 2016; Jahed & Hirst, 2017), and temperature (Yoder, 2009) may all be factors in blossom thinning effectiveness.

With regard to crop safety, the data from this project did not conclusively suggest that a relationship exists between lime sulfur blossom thinning spray timing and fruit russet incidence/severity, raised lenticel occurrence, and phytotoxicity. It is likely that other factors such as humidity (McArtney & Obermiller, no date), drying time (Schupp and Kon, 2019), and climate (Cury et al., 2008) have a greater impact on the crop safety of lime sulfur blossom thinning sprays compared to application timing. This would explain why fruit russet incidence/severity, raised lenticel occurrence, and phytotoxicity results were not consistent between the two sites of this study.

The data from this project collectively demonstrated that lime sulfur blossom thinning sprays can be an effective and safe method thinning in fresh-market apple production depending on spray application timing. From this study, it is suggested that growers wishing to adopt chemical

blossom thinning as a main thinning practice should use the PTGM if feasible. However, if growers are not able to use the PTGM this project demonstrates that lime sulfur sprays applied at 20% open bloom and 48 hours thereafter will result in a similar and effective thinning outcome. Although this project only evaluated lime sulfur blossom thinning spray timing, growers must also take into consideration other variables such as rates, surfactant, and the number of applications when planning a lime sulfur blossom thinning spray program. These additional considerations are very important and should be thoroughly evaluated in future applied research studies at the field level.

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Table 2-1: Blossom Thinning Spray Timing Strategies and Actual Application Timing in 'Gala' (Virginia & North Carolina, 2019).

No.	Spray Timing Strategies[z]		*Winchester, Va.*[y]		*Mills River N.C.*[x]	
	Spray #1	Spray #2	Spray #1	Spray #2	Spray #1	Spray #2
1[w]	PTGM	PTGM	Apr. 21	Apr. 23	Apr. 10	Apr. 12
			12:30 AM	2:37 PM	1:07 PM	8:25 AM
2[v]	20% OB	48 hr.	Apr. 18	Apr. 20	Apr. 9	Apr. 11
			12:48 PM	8:47 PM	8:45 AM	8:43 AM
3[v]	20% OB	72 hr.	Apr. 18	Apr. 21	Apr. 9	Apr. 12
			12:48 PM	5:21 PM	8:45 AM	8:25 AM
4[v]	80% OB	48 hr.	Apr. 20	Apr. 22	Apr. 13	Apr. 16
			8:47 PM	7:40 PM	5:00 PM	9:07 AM
5[v]	80% OB	72 hr.	Apr. 20	Apr. 23	Apr. 13	Apr. 17
			8:47 PM	7:36 PM	5:00 PM	9:50 AM
6[u]	Control		-	-	-	-

[z]Each treatment received two blossom thinner spray applications. Both spray applications contained 2% NovaSource Lime Sulfur and 2% JMS Stylet-Oil. Treatments differed according to application timing.

[y]Actual application timing of blossom thinning sprays at Winchester, Va.

[x]Actual application timing of blossom thinning sprays at Mills River, N.C.

[w]Spray application timing of treatment number 1 utilized the pollen tube growth model. The model was started once ~ 20% of the king blossoms were open. The model was started on April 17, 2019 at 10:00 AM in Winchester, Va. and on April 7, 2019 at 7:00 PM in Mills River, N.C. The first spray application was targeted at the date/time when the pollen tube reached 100% the length of the style as predicted by the model. The second spray application was targeted at the date/time when the pollen tube reached 60-70% the length of the style as predicted by the model.

[v]Spray application timings for treatment numbers 2-5 were determined by pre-structed timing intervals. The first applications were targeted when 20% or 80% open bloom (king and side bloom) occurred and second applications where targeted at the 48-hour or 72-hour time marks following the first spray.

[u]Non-thinned control. No blossom thinning sprays, no fruit thinning sprays, no hand-thinning, etc.

Table 2-2: Blossom Thinning Spray Timing Strategy Influence on Fruit Set (%) in 'Gala' (Virginia and North Carolina, 2019).[z,y]

Treatment	2 WAPF[x]	4 WAPF[x]	6 WAPF[x]	8 WAPF[x]	Harvest[w]
		Winchester, Va.			
PTGM	30.0 bc	17.6 a	13.4 b	12.7 b	11.7 b
20% OB + 48 hr.	25.7 c	12.0 b	10.2 b	9.8 b	9.6 b
20% OB + 72 hr.	25.6 c	11.9 b	10.1 b	9.4 b	9.1 b
80% OB + 48 hr.	37.6 ab	17.5 a	14.3 ab	13.6 ab	13.2 ab
80% OB + 72 hr.	32.9 abc	17.2 a	14.1 ab	13.4 ab	11.5 b
Control	44.0 a	21.4 a	18.6 a	17.5 a	16.3 a
		Mills River, N.C.			
PTGM	29.4 b	10.8 c	8.4 b	8.3 b	7.8 b
20% OB + 48 hr.	38.2 ab	16.0 bc	10.0 b	9.2 b	8.8 b
20% OB + 72 hr.	45.5 a	22.5 a	16.1 a	15.6 a	14.9 a
80% OB + 48 hr.	39.8 ab	22.7 a	15.3 a	15.0 a	14.5 a
80% OB + 72 hr.	41.8 ab	17.8 ab	12.0 ab	11.8 ab	10.9 ab
Control	46.1 a	20.3 ab	14.3 a	13.6 a	13.2 a

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.

[y]Fruit set was determined by selecting ~100 flower clusters on 3 branches per replicate tree at the Winchester, Virginia site, and 3-7 branches per replicate tree at Mills River, North Carolina site, multiplying the flower cluster count by five (average number of blossoms per cluster) to obtain maximum theoretical fruit set, and then dividing the fruit set counts at varying time intervals by the maximum theoretical fruit set.

[x]Fruit set at 2, 4, 6, and 8 two weeks after petal fall (WAPF).

[w]Fruit set at harvest.

Table 2-3: Blossom Thinning Spray Timing Strategy Influence on Crop Density in 'Gala' (Virginia and North Carolina, 2019).[z,y]

Treatment	2 WAPF[x]	4 WAPF[x]	6 WAPF[x]	8 WAPF[x]	Harvest[w]
		Winchester, Va. (Fruit No./cm² BCSA)			
PTGM	12.8 a	8.1 a	6.2 a	5.9 a	5.4 a
20% OB + 48 hr.	14.0 a	6.8 a	5.7 a	5.5 a	5.4 a
20% OB + 72 hr.	11.7 a	5.3 a	4.4 a	4.2 a	4.0 a
80% OB + 48 hr.	12.1 a	6.1 a	4.6 a	4.3 a	4.2 a
80% OB + 72 hr.	15.4 a	8.4 a	6.9 a	6.6 a	5.7 a
Control	20.8 a	10.3 a	8.9 a	8.4 a	7.6 a
		Mills River, N.C. (Fruit No./cm² BCSA)			
PTGM	29.6 a	10.5 b	8.0 b	7.9 b	7.4 b
20% OB + 48 hr.	33.7 a	14.4 ab	8.9 b	8.1 b	7.9 b
20% OB + 72 hr.	42.0 a	20.4 a	14.4 a	14.1 a	13.6 a
80% OB + 48 hr.	32.3 a	18.0 a	11.9 ab	11.7 ab	11.4 ab
80% OB + 72 hr.	43.4 a	18.2 a	12.3 ab	12.3 ab	11.7 ab
Control	37.6 a	16.4 ab	11.4 ab	10.6 ab	10.4 ab

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.

[y]Crop density determined by using 3 branches per replicate tree at Winchester, Virginia Site, and 3-7 branches per replicate tree at Mills River, North Carolina site. Crop density expressed as fruit number per cm^2 of branch cross-sectional area at Winchester, Virginia site and at Mill River, North Carolina site.

[x]Crop density at 2, 4, 6, and 8 weeks after petal fall (WAPF).

[w]Crop density at harvest.

Table 2-4: Blossom Thinning Timing Strategy Influence on Kilograms Fruit per Tree and Number of Fruit per Tree in 'Gala' (Virginia and North Carolina, 2019).[z]

Treatment	*Winchester, Va.*		*Mills River, N.C.*	
	Kg Fruit/Tree[y]	Fruit No./Tree[z]	Kg Fruit/Tree[y]	Fruit No./Tree[z]
PTGM	72.4 a	596 a	16.3 b	119 c
20% OB + 48 hr.	65.5 a	518 a	19.5 ab	153 bc
20% OB + 72 hr.	79.6 a	572 a	23.8 ab	207 ab
80% OB + 48 hr.	84.8 a	657 a	28.2 a	217 ab
80% OB + 72 hr.	66.8 a	564 a	28.5 a	284 a
Control	93.8 a	855 a	27.2 ab	228 ab

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Kilograms of fruit/tree determined by entire tree harvest (two separate picks at both sites) and running fruit through sorter to obtain total weight of harvested fruit per replicate tree.
[z]Number of fruit/tree determined by entire tree harvest (two separate picks at both sites) and running fruit through sorter to obtain the total number of fruit per replicate tree.

Table 2-5: Blossom Thinning Spray Timing Strategy Influence on Estimated Yield (Bushels/Acre) in 'Gala' (Virginia and North Carolina, 2019).[z]

Treatment	*Winchester, Va.*[y]	*Mills River, N.C.*[x]
PTGM	805 a	820 b
20% OB + 48 hr.	728 a	978 ab
20% OB + 72 hr.	885 a	1,193 ab
80% OB + 48 hr.	943 a	1,415 a
80% OB + 72 hr.	742 a	1,429 a
Control	1,042 a	1,363 ab

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Estimated yield calculated using tree density (242 trees per acre, 10 ft. x 18 ft. spacing), kilograms of harvested fruit per replicate tree, and a fixed bushel weight of 48 lbs.
[x]Estimated yield calculated using tree density (1,092 trees per acre, 3 ft. x 13.3 ft. spacing), kilograms of harvested fruit per replicate tree, and a fixed bushel weight of 48 lbs.

Table 2-6: Blossom Thinning Spray Timing Strategy Influence on Fruit Weight, Diameter, Length, and Blush in 'Gala' (Virginia and North Carolina, 2019).[z]

Treatment	Weight (g)[y]	Diameter (mm)[y]	Length (mm)[y]	Blush (%)[y]
		Winchester, Va.[x]		
PTGM	121 d	64.2 d	60.8 d	56.7 a
20% OB + 48 hr.	126 c	65.1 c	61.5 c	57.1 a
20% OB + 72 hr.	139 a	67.5 a	64.2 a	54.2 bc
80% OB + 48 hr.	129 b	65.7 b	62.5 b	53.5 c
80% OB + 72 hr.	118 e	63.7 e	60.2 e	56.0 ab
Control	110 f	61.8 f	58.74 f	56.7 a
		Mills River, N.C.[w]		
PTGM	138 a	67.0 a	64.5 a	65.9 a
20% OB + 48 hr.	127 b	65.2 b	62.5 b	66.7 a
20% OB + 72 hr.	115 d	62.4 d	59.9 d	53.0 c
80% OB + 48 hr.	130 b	65.6 b	62.8 b	59.2 b
80% OB + 72 hr.	100 e	59.0 e	56.7 e	49.2 d
Control	119 c	63.5 c	61.1 c	47.7 d

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Individual fruit weight, diameter, length, and blush determined by entire tree harvests (two separate picks) at both sites and running all harvested fruit through sorter.
[x]Data obtained from a total of 18,815 individual fruits harvested from all treatment trees and control trees at Winchester, Virginia site.
[w]Data obtained from a total of 6,040 individual fruits harvested from all treatment trees and control trees at Mills River, North Carolina site.

Table 2-7: Blossom Thinning Spray Timing Strategy Influence on Fruit Packout (%) According to Fruit Russet Incidence/Severity in 'Gala' (Virginia and North Carolina, 2019).[z, y]

Treatment	U.S Extra Fancy and U.S Fancy[x]	U.S. No. 1[w]	U.S. Utility[v]
		Winchester, Va.	
PTGM	51 c	48 a	1 a
20% OB + 48 hr.	58 bc	42 a	0 a
20% OB + 72 hr.	70 abc	29 ab	1 a
80% OB + 48 hr.	77 ab	22 b	1 a
80% OB + 72 hr.	63 abc	36 ab	1 a
Control	82 a	18 b	0 a
		Mills River, N.C.	
PTGM	48 a	44 a	8 a
20% OB + 48 hr.	54 a	41 a	5 a
20% OB + 72 hr.	36 a	61 a	3 a
80% OB + 48 hr.	39 a	53 a	8 a
80% OB + 72 hr.	52 a	45 a	3 a
Control	46 a	49 a	5 a

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Packout according to fruit russet incidence/severity was determined using a 20-fruit subsample per replicate and assigning each individual fruit into a USDA apple grade based upon the incidence/severity of russet on the fruit as according to the USDA apple grade standards.
[x]U.S. Extra Fancy and U.S. Fancy Grades criteria: 0% russeting.
[w]U.S. No. 1 Grade criteria: 1-25% smooth net like russeting and/or 1-10% smooth solid russeting.
[v]U.S. Utility Grade criteria: greater than 25% smooth net like russeting and/or greater than 10% smooth solid russeting.

Table 2-8: Blossom Thinning Spray Timing Strategy Influence on Fruit (%) with Raised in 'Gala' (Virginia and North Carolina, 2019).[z, y]

Treatment	*Winchester, Va.*[x]	*Mills River, N.C.*
PTGM	-	96 a
20% OB + 48 hr.	-	96 a
20% OB + 72 hr.	-	92 a
80% OB + 48 hr.	-	92 a
80% OB + 72 hr.	-	95 a
Control	-	86 a

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Occurrence of raised lenticels evaluated using 20 fruit subsample per replicate tree and visual raised lenticel rating of yay or nay. Occurrence of raised lenticels expressed as the percentage of fruit with raised lenticels.
[x]No data collected from Winchester, Virginia location.

Table 2-9: Blossom Thinning Spray Timing Strategy Influence on Leaf Surface Area (%) Affected by Phytotoxicity in 'Gala' (Virginia and North Carolina, 2019).[z, y]

Treatment	*Winchester, Va.*	*Mills River, N.C.*
PTGM	1.8 a	16.0 a
20% OB + 48 hr.	1.8 a	8.0 b
20% OB + 72 hr.	1.7 ab	5.8 b
80% OB + 48 hr.	2.6 a	6.5 b
80% OB + 72 hr.	3.0 a	4.3 b
Control	0.2 b	5.0 b

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Phytotoxicity evaluated by selecting four leaf spurs per replicate and visually assessing the percentage of chlorotic/necrotic leaf area present on the upper surface area of the leaves present on each spur. Phytotoxicity expressed as the percentage of leaf area affected by chlorosis and/or necrosis.

Chapter III

Evaluation of Chemical Agent Suitability & Efficacy for Blossom Thinning in Apples

Introduction

With much labor needed for hand-thinning and the associated benefits of thinning being well known, much research went into identifying potential blossom/flower thinners which could effectively reduce the crop load during the first half of the 20th century (Kon and Schupp, 2019). In 1924 Drain made one of the first intentional research attempts at thinning via chemical blossom thinning with iron sulfate (Drain, 1924). Shortly after, Autcher and Roberts performed extensive research in evaluating multiple chemical agents (e.g. sodium, calcium polysulfide, copper sulfate, sodium nitrate, zinc sulfate, and oil emulsion) for chemical blossom thinning in multiple apple cultivars (Auchter and Roberts, 1933; Auchter and Roberts, 1935). Although partial crop load reduction was often achieved in these early trials, excessive phytotoxicity and/or fruit russeting was frequently observed in the treatments (Auchter and Roberts, 1935).

In 1940, MacDaniels discovered that dinitro-ortho-cresol (DNOC) was suitable as a blossom thinner since it prevented the germination of pollen (MacDaniels and Hildebrand, 1940; Dennis, 2000). However, it was not without its drawbacks. It was common for leaf phytotoxicity and pedicel injury to occur with DNOC applications (Kon and Schupp, 2019). Furthermore, leaf wetting could result in excessive thinning and additional leaf phytotoxicity (Williams, 1994; Kon and Schupp, 2019). As a result, DNOC came into regular use for blossom thinning by commercial growers in the arid tree fruit production regions of the Western United States during the mid and into the late 20th century where the negative effects of phytotoxicity and fruit injury were less severe than in the Eastern United States. Despite standard and common use on the West Coast for blossom thinning, DNOC was not utilized by growers on the East Coast, due to the high humidity and frequent precipitation which caused overthinning and injury (Dennis, 2000). Moreover, the use of DNOC as a blossom thinner on the West Coast continued until its cancellation in 1989 due to high re-registration costs and environmental concerns (Dennis, 2000). Consequently, this led to an increase in research which sought to find a blossom thinner replacement for DNOC (Dennis, 2000).

Many different compounds and chemical agents were evaluated at the end of the 20th century and the beginning of the 21st century in the search for an effective blossom thinning agent which could replace DNOC and not produce any detrimental effects such as phytotoxicity, fruit russeting, etc. From the extensive screening efforts, over 150 different chemicals were tested and evaluated for blossom thinning in apples since 1989 (Kon and Schupp, 2019). From the vast level of blossom thinning research following the cancellation of DNOC's label, only a few chemicals obtained a label for blossom thinning in apples. One of the first chemicals to receive a label shortly after the cancellation of DNOC's label was sulfcarbamide, since it was found to be an effective blossom thinning agent (Williams, 1993; Kon and Schupp, 2019). However, fruit russeting (Greene, 2004) associated with late sulfcarbamide blossom thinning spray applications was a negative drawback which prohibited its widespread adoption and eventually led to its label

cancellation in 2006 (Kon and Schupp, 2019). Additionally, pelargonic acid received a label for blossom thinning in 1996 (Kon and Schupp, 2019) from research which demonstrated that it was effective as a blossom thinning agent (Williams, 1994). However, phytotoxicity issues, variability in thinning efficacy, and spray tank mixing issues led to its cancellation later in 2003 (Kon and Schupp, 2019). Furthermore, endothall (3,6-endoxohexahydrophythalic acid) was also evaluated and found to be effective at reducing the crop load as a chemical blossom thinner (Williams et al., 1995) and received a label for blossom thinning in Washington state briefly between 2014 and 2017 (Kon and Schupp, 2019).

Out of the many chemical agents evaluated following DNOC's cancellation, lime sulfur (calcium polysulfide) emerged to be one of the most promising. West Coast producers in Washington state were the first to receive a label for blossom thinning with lime sulfur in 2003 (Schupp, et al. 2005). Since then, lime sulfur has also become labelled for blossom thinning in several East Coast and Midwest states.

Although current blossom thinning programs in the United States chiefly rely on lime sulfur in combination with adjuvants/surfactants such as paraffinic oil (Stylet-Oil) or fish-oil, several disadvantages have been observed with life sulfur's use as a chemical blossom thinner in apple. Lime sulfur has shown to cause significant russeting in some studies (Peck et al., 2017) but not others (Kon et al., 2018). Furthermore, the ability of lime sulfur to adequately achieve a sufficient thinning response has varied with some studies demonstrating a significant thinning response (Peck et al., 2017) and other studies demonstrating a non-significant and less than ideal thinning response (Kon et al., 2018).

With lime sulfur blossom thinning sprays demonstrating an ability to produce variable thinning responses and cause fruit russeting in different production situations within the Mid-Atlantic production region of the United States, there is a need for evaluating alternative chemical agents for blossom thinning. Several other agents which have demonstrated the potential for effective chemical blossom thinning include: ammonium thiosulfate (Kacal et al., 2019; Marchioretto, 2018; Maas, 2016; Milić, 2011), potassium bicarbonate (Wiebel et al, 2012; Bound, 2010), potassium thiosulfate (Kacal et al., 2019; Milić et al., 2011; Bound and Wilson, 2004), and extract of giant knotweed (*Reynoutria sachalinensis*) (Peck et al., 2017).

This research project seeks to evaluate and screen potential chemical agents and compounds for chemical blossom thinning. In this study the chemical agents and compounds were evaluated on the basis of the following: 1) suitability: potential to cause negative attributes such as phytotoxicity and fruit russeting and 2) efficacy: ability to sufficiently thin the crop by lowering fruit set and crop density while raising fruit quality parameters such as color and weight compared to the control. The purpose of this research project is to identify chemical agents and compounds which could be suitable for mid-Atlantic apple to utilize in chemical blossom thinning on a commercial basis.

Materials & Methods

Research Sites & Blocks

This study was undertaken in the 2018 and 2019 growing seasons at the Alson H. Smith Jr. Agricultural Research and Extension Center in Winchester, Virginia. In both years, a Honeycrisp block and a Cripps Pink block were utilized for evaluating the same blossom thinning treatments. The Honeycrisp block consisted of Honeycrisp/B.9 apple trees planted at a 11.5 ft. by 3 ft. spacing in 2015 and trained to a tall spindle training system. The Cripps Pink block consisted of Cripps Pink/M.9 apple trees planted at an 18 ft. by 9 ft. spacing in 2000 and trained to a central leader training system.

Chemical Agents

Multiple different chemical agents were evaluated for their suitability and efficacy in blossom thinning. In the 2018 trials, ammonium thiosulfate (Sigma-Aldrich, 98.0% ai.), calcium polysulfide (Tessenderlo Kernley Inc., NovaSource Lime Sulfur Solution, 29.0% ai.), calcium polysulfide (Or-Cal Inc., Rex Lime Sulfur Solution, 28.0% ai.), potassium bicarbonate (H & I Agritech Inc., GreenCure Fungicide, 85.0% ai.), potassium thiosulfate (Sigma-Aldrich Inc., 95.0% ai.), and *Reynoutria sachalinensis* (Marrone Bio Innovations Inc., Regalia Biofungicide, 5.0% ai.) were each evaluated alone and in combination with paraffinic oil (JMS Flower Farms Inc., JMS Stylet-Oil, 97.1% ai.). Additionally, paraffinic oil was evaluated alone. Two industry standard post-bloom chemical fruit thinning treatments were also evaluated to serve as positive controls: one using 1-naphthaleneacetic acid (Valent Biosciences Inc., Pomaxa, 3.5% ai.) and the other using 6-benzyladenine (Valent Biosciences Inc., Maxcel, 1.9% ai.) were also evaluated to serve as positive controls. Both post-bloom treatments also contained carbaryl (Loveland Products Inc., Carbaryl 4L, 43.0% ai.) and a nonionic surfactant (Kalo Inc., Regulaid, 90.6% ai.). A non-thinned control was also utilized for comparison. Table 3-1 outlines the treatment schemes and rates used in 2018.

In the 2019 trials the same treatments and controls were evaluated. However, the rates of ammonium thiosulfate, calcium polysulfide, and potassium thiosulfate were increased since these treatments were not observed to have a sufficient thinning effect in the 2018 season. Additionally, the rate of potassium bicarbonate was reduced in the 2019 season since excessive fruit russeting was observed in the 2018 season. Potassium nitrate (Yara Inc., Yara Krista-K, 59.7% ai.) and urea (generic, feed grade, 47.0% ai.) alone and in combination with paraffinic oil were added to the 2019 season treatment list. However, these new treatments and the potassium bicarbonate + paraffinic oil treatment were not evaluated in the 2019 Honeycrisp trial due to a lack of trees with sufficient and uniform bloom. Table 3-1 outlines the treatment schemes and rates used in 2019.

Trial Design

The Honeycrisp and Cripps Pink trials in both years utilized a complete randomized design (CRD). All treatments and controls consisted of three replicate trees. In the Honeycrisp block a

minimum of three buffer trees were utilized to separate treatment trees. In the Cripps Pink block one buffer tree was utilized to septate the treatment trees.

Pollen Tube Growth Model

The Pollen Tube Growth Model (PTGM) was utilized to determine the spray application timing of all the blossom thinning treatments in both trials each year. In each trial, the PTGM was started once ~ 20% of the King Blossoms were open and appropriate weather for proper pollinator activity occurred. This was determined by daily visual observations. Prior to the starting the model, 50 blossoms were collected at random at each site in order to determine the average style length and were entered into the model. In the 2018 season, the Honeycrisp trees were found to have an average style length of 7.90 mm and the Cripps Pink trees were found to have an average style length of 7.94 mm. For the 2019 season, the Honeycrisp trees were found to have an average style length of 10.30 mm and the Cripps Pink trees were found to have an average style length of 10.76 mm. Once the PTGM was started, the first spray application timing was targeted at the time when the cumulative pollen tube growth reached 100% the length of the style indicating that the open blossoms present at the time the model was started had been fertilized. Once the first application occurred and the model was reset, the second spray application timing was targeted between the time when the cumulative pollen tube growth reached 60% to 70% the length of the style in order to prevent the fertilization of the remaining flowers. Only two applications of each treatment were applied in each trial for each year. All treatments were applied near the same time according to the PTGM's predictions. In most cases, all the treatments of any given trial were applied within a 3-hour period.

Spray Timing

In the 2018 Honeycrisp trial, the model was started on April 26, 2018 at 10:00 AM. The first blossom thinning spray occurred on April 30, 2018 at 1:00 PM when the pollen tube reached 107% the length of the style. The second spray occurred on May 2, 2018 at 8:00 AM when the pollen tube reached 79% of the style length.

In the 2018 Cripps Pink trial, the model was started on April 23, 2018 at 5:00 PM. The first blossom thinning spray occurred on April 28, 2018 at 8:00 AM when the pollen tube reached 114% the length of the style. The second spray in the 2018 Cripps Pink trail occurred on May 1, 2018 at 4:00 PM when the pollen tube reached 70% of the style length.

In the 2019 Honeycrisp trial, the model was started on April 18, 2019 at 12:00 PM. The first blossom thinning spray occurred on April 20, 2019 at 11:00 PM when the pollen tube reached 108% the length of the style. The second spray occurred on April 23, 2019 at 1:00 PM when the pollen tube reached 63% of the style length.

For the 2019 Cripps Pink trial, the model was started on April 16, 2019 at 10:00 AM. The first blossom thinning spray occurred on April 20, 2019 at 5:00 PM when the pollen tube reached 115% the length of the style. The second spray occurred on April 23, 2019 at 8:00 PM when the pollen tube reached 66% of the style length.

Spray Application Methodology

All treatment applications were made as dilute sprays. In the applications, both sides of the trees were sprayed resulting in thorough coverage of the entire tree canopy. Once the entire coverage of the tree canopy was achieved, spraying was ceased for each respective tree. In the 2018 season, applications were applied with an electric powered handgun sprayer (custom fabricated) mounted on the bed of a utility vehicle. In the 2019 season, treatment sprays were applied using a handpump backpack sprayer (The Fountain Head Group, Inc., New York Mills, NY).

Data Collection Methods: Fruit Set

Fruit set differences between treatments were evaluated in both cultivars in both years. In the 2018 Honeycrisp trail, data collection error caused the fruit set counts to be unsuitable for analysis and comparison. In the 2018 Cripps Pink trial, fruit set was determined by selecting approximately ~50 flower clusters on 1-3 representative branches per replicate tree. In the 2019 Honeycrisp trial whole tree flower cluster counts on each replicate tree were utilized. For the 2019 Cripps Pink trial fruit set was determined by the selection of ~100 flower clusters on three representative branches per replicate tree.

From the selected flower clusters, the cluster count (i.e. 103 flower clusters) was multiplied by five (the average number of blossoms per cluster) to obtain the theoretical maximum fruit set (i.e. 515 fruit) on the selected branches of each replicate tree. Counts of the number of fruits on the selected branches of each replicate tree (Cripps Pink) or entire tree (Honeycrisp) were performed two weeks, four weeks, six weeks, and eight weeks after petal fall and immediately prior to harvest. To obtain fruit set percentages, the fruitlet/fruit count from each respective time interval was divided by the theoretical maximum fruit set (i.e. 515 fruit).

Data Collection Methods: Crop Density

Differences in crop density between the treatments were evaluated in both cultivars in both years of the study. For the 2018 and 2019 Honeycrisp trials, the fruit number per cm^2 of trunk cross sectional area (TCSA) was utilized. In the 2018 and 2019 Cripps Pink trials, the fruit number per cm^2 of branch cross sectional area (BCSA) was utilized. Branch diameter measurements were taken in the Spring at the start of each experiment. Trunk diameter measurements were taken in the Fall at the end of each experiment. Using the branch/trunk diameters and the fruit counts, the fruit number per BCSA/TCSA were calculated at two weeks, four weeks, six weeks, and eight weeks after petal fall and immediately prior to harvest. Crop density at harvest was the only usable crop density measurement in the 2018 Honeycrisp trial due to data collection errors.

Harvest Methods

In order to obtain fruit quality data (i.e. individual fruit weight, pressure, starch, russet ratings, etc.) a harvest subsample was taken from each trial when the crop reached maturity. In the 2018 Honeycrisp trial, a subsample of 5 fruit per replicate tree were harvested on August 20, 2018. For the 2019 Honeycrisp trial a subsample of 20 fruit per replicate tree were harvested on August 17, 2019. In the 2018 Cripps Pink trial, a subsample of 5 fruit per replicate tree were harvested on October 29, 2019. For the 2019 Cripps Pink trial, a subsample of 20 fruit per replicate tree were

harvested on October 25, 2019. All fruit was harvested into corrugated tray pack boxes and then placed in cold storage for 24-96 hours prior to fruit quality data collection.

Data Collection Methods: Fruit Diameter, Weight, & Pressure

The diameter, weight, and pressure of each individual fruit was measured using a fruit texture analyzer (Guss Inc., Jennings, South Africa). Two pressure readings were taken from each fruit with one reading being taken on the blush side and the other on the green side of the fruit.

Data Collection Methods: Color

In this study, the color of each fruit was measured using a DA-Meter (TR Turoni Inc., Forli, Italy). Two readings were taken of each fruit with one reading taken on the blush side and the other reading taken on the green side of the same fruit.

Data Collection Methods: Starch

Starch ratings were performed on all the fruit evaluated in this study. For Honeycrisp, the Honeycrisp Starch Iodine Index (Washington Tree Fruit Research Commission, Wenatchee, Washington) with a scale of 1-6 was utilized for ratings. For Cripps Pink, the Standard Iodine Index (Cornell University, Ithaca, New York) with scale of 1-8 was utilized.

Data Collection Methods: Brix, TA, & pH

Individual juice samples were obtained from a composite sample representing all the sampled fruit of each replicate-tree (5 fruit/replicate in 2018 experiments, and 20 fruit/replicate in 2019 experiments). From each juice sample, the sugar content (Brix), titratable acidity (TA), and pH were determined. Soluble solids (Brix) was determined using a pocket refractometer (ATAGO Inc., Tokyo, Japan). TA and pH were evaluated using a titrino (Metrohm Inc., Herisau, Switzerland).

Data Collection Methods: Fruit Russeting

Fruit russet data was collected from the 2019 Honeycrisp and 2019 Cripps trials but not the 2018 trials. A russet rating scale adapted from the United States Standards for Grades of Apples was used (United State Department of Agriculture, 2002). Using the scale, each fruit was assigned into one of three grade categories: Category 1 (US. Extra Fancy & U.S. Fancy grades) 0% russeting; Category 2 (U.S. No. 1 grade) 1-25% smooth net like russeting and/or 1-10% smooth solid russeting; and Category 3 (U.S. Utility Grade) >25% smooth net like russeting and/or >10% smooth solid russeting.

Data Collection Methods: Foliar Phytotoxicity

Visual foliar phytotoxicity ratings were used to determine if there was any treatment effect on foliar phytotoxicity in this study. A 0-100 foliar phytotoxicity rating scale with 0 indicating that 0% of the leaf surface was necrotic/chlorotic and 100 indicating that 100% of the leaf surface was necrotic/chlorotic was utilized in this project. Four representative leaf spurs (2 from each side of the tree) were used for the foliar phytotoxicity ratings. When generating the phytotoxicity

ratings, the entire surface area of all the leaves of each spur were considered. The collective leaf surface area of all the leaves on each spur served as each data point.

Data Collection Methods: Return Bloom

Return bloom data was collected from the 2018 Honeycrisp and 2018 Cripps Pink trials during the Spring of 2019. The return bloom for each treatment was determined by selecting 50 buds at the early-pink stage on 3-8 representative 2-year old limb/branch sections per replicate tree. Out of the 50 buds, the number of floral buds was recorded. The percentage of return bloom was then calculated by dividing the number of floral buds by the total number of buds (50) per replicate. The return bloom from the 2019 Honeycrisp and 2019 Cripps Pink trials is yet to be determined.

Research Block Maintenance

In the course of the project, standard orchard management tasks were carried out in the research blocks. Both research blocks received a standard insecticide and fungicide spray program and standard pruning/training procedures during the course of the study. Additionally, both research blocks received a standard nutrient management program. Furthermore, both research blocks received standard pruning/training procedures. However, the 2018 Honeycrisp and 2018 Cripps Pink replicate and control trees were not pruned during the winter of 2018/2019, so return bloom measurements could be recorded. No other thinning methods (hand, chemical, nor mechanical) were implemented on the treatment nor control trees in the research blocks other than the treatment sprays.

Statistical Analysis

JMP Pro 14 was used for all statistical analysis in this project. Tukey's Honestly Significantly Difference was used as the sole statistical method in evaluating significant difference between the treatments with regards to fruit set, crop density, fruit color, foliar phytotoxicity, fruit russeting, etc.

Results

Fruit Set

The majority of the blossom thinning chemicals evaluated did not significantly reduce fruit set compared to the non-thinned control. (Tables 3-2, 3-3). Both ATS + SO and Regalia reduced fruit set 8 weeks after petal and at harvest in Honeycrisp during the 2019 growing season and were comparable to the NAA + C + R post-bloom treatment. (Table 3-2). Additionally, ATS + SO reduced fruit set 2, 4, and 6 weeks after petal in the Honeycrisp 2019 trial. Neither ATS + SO, Regalia, nor any other blossom thinning treatment reduced fruit set in the 2018 Cripps Pink nor 2019 Cripps Pink trials. (Table 3-3). Although significant differences between the blossom thinning treatments and control was not generally observed, it is important to note that the majority of blossom thinning treatments did have lower mean fruit sets compared to the control. All the post-bloom fruit thinning treatments (NAA + C + R and 6-BA + C + R) had lower mean fruit sets compared to the controls. (Tables 3-2, 3-3). However, it was found that only NAA + C + R significantly reduced fruit set in the 2019 Honeycrisp trial and that only 6-BA + C +R

significantly reduced in 2019 Cripps Pink trial at the time of harvest. None of the blossom thinning nor post-bloom thinning treatments were significantly different from the control in the 2018 Cripps Pink trial. (Table 3-3).

Crop Density (Fruit No./BCSA or TCSA)

None of the blossom thinning treatments had significantly lower crop densities compared to the non-thinned control in the 2018 Honeycrisp, 2019 Honeycrisp, 2018 Cripps Pink, and 2019 Cripps Pink trials (Tables 3-4, 3-5). However, several blossom thinning treatments such as KB + SO and KN had a lower mean crop density compared to the control in most cases. Additionally, it was found that the LSS 1 + SO treatments had lower mean crop densities compared to the non-thinned control at 2, 4, 6, and 8 weeks after petal fall and at harvest in all four trials. Both post-bloom fruit thinning treatments, NAA + C + R and 6-BA + C + R, were not significantly different from the non-thinned control but did have lower mean crop densities compared to the control (Tables 3-4, 3-5).

Fruit Diameter & Weight

In most cases there was no significant effect on fruit diameter nor weight from the blossom thinner chemicals evaluated (Tables 3-6, 3-7). None of the blossom thinning treatments increased fruit diameter nor weight in the 2018 Honeycrisp, 2018 Cripps Pink, nor 2019 Cripps Pink trials. In the 2019 Honeycrisp trial only the ATS and KTS + SO treatments were found to have both higher mean fruit diameters and weights which were significantly greater than the control. The LSS 2 + SO treatment had significantly higher weight but not diameter compared to the control. In the 2019 Honeycrisp and 2019 Cripps Pink trials, both post-bloom chemical thinning treatments had a significantly higher fruit diameter and weight compared to the control. For 2018, only the 6-BA + C + R treatment was found to significantly increase fruit diameter and size in the 2018 Honeycrisp trial (Tables 3-6, 3-7).

Fruit Color

None of the blossom thinning treatments nor post-bloom thinning treatments were found to increase fruit color (blush) with the DA meter in the 2018 Honeycrisp, 2019 Honeycrisp, and 2018 Cripps Pink trials. In the 2019 Cripps Pink trial LSS 2, KB, KN, Regalia, and LSS 2 + SO in addition to both post-bloom treatments were found to significantly increase fruit color compared to the control. (Table 3-7).

Fruit Pressure

It was observed that several blossom thinning treatments had pressure (pressure) which was significantly greater than the control (Tables 3-8, Table 3-9). However, there was no concise relationship between any specific treatment's ability to increase fruit pressure between years (2018 vs. 2019) nor cultivars (Honeycrisp vs. Cripps Pink). It was also observed that the LSS 1 treatment in the 2019 Honeycrisp had a significantly lower pressure compared to the control. The remaining blossom thinning and post-bloom thinning treatments had pressure values which were comparable to the control.

Fruit Starch

It was observed that a minor selection of blossom thinning treatments significantly lowered starch index ratings indicating a certain level of delayed ripeness compared to the control (Tables 3-8, 3-9). However, this observation was minor, and no specific treatment consistently lowered the starch index across years nor cultivars.

Fruit Brix

Only the blossom thinning KB + SO treatment and the post-bloom 6-BA + C + R treatment were found to significantly raise sugar levels, expressed as Brix, compared to the control in the 2018 Honeycrisp treatment (Table 3-8). None of the other treatments in the other trials were found to significantly influence sugar content (Tables 3-8, 3-9).

Fruit TA

In the 2018 Cripps Pink trial it was found that the majority of the blossom thinning treatments significantly increased fruit TA compared to the control (Table 3-9). This phenomenon was not observed in the 2019 Cripps Pink trial nor any of the Honeycrisp trials (Tables 3-8, 3-9). KB + SO was the only treatment which was found to consistently and significantly increase fruit TA in both cultivars, but only in 2018.

Fruit pH

The 2018 Cripps Pink trial was also the only trial with several treatments to have a significantly lower fruit pH compared to the control (Table 3-9). These treatments with a significantly lower pH also had significantly higher TA. None of the other treatments in the other three trials had significantly different pH values compared to the control.

Fruit Packout from Russeting Incidence & Severity

In the 2019 Honeycrisp trial it was found that both LSS + SO treatments significantly decreased the packout of U.S. Extra Fancy and U.S. Fancy grade fruit compared to the control due to russet incidence and severity (Table 3-10). Additionally, LSS 1 + SO significantly increased the proportion of U.S. Utility grade fruit in the 2019 Honeycrisp trial. However, in the 2019 Cripps Pink trial none of the LSS treatments impacted fruit packout from russet incidence or severity; instead it was found that the KB and KB + SO treatment significantly reduced the packout of U.S. Extra Fancy and U.S. Fancy grade fruit (Table 3-10). It was also found that KB + SO significantly increase the proportion of U.S. No. 1 grade fruit compared to the control. Both KB and KB + SO significantly increased the proportion of U.S. Utility grade fruit compared to the control.

Foliar Phytotoxicity

In both the 2019 Honeycrisp and 2019 Cripps Pink trials it was found that ATS and ATS + SO significantly increased the incidence of foliar phytotoxicity compared to the control (Table 3-11). It was also found that KB + SO significantly increased foliar phytotoxicity in the 2019 Cripps Pink trial.

Return Bloom

It was found that both post-bloom fruit thinning treatments and the KB + SO blossom thinning treatment significantly increased return bloom in the 2018 Honeycrisp trial (Table 3-12). None of the treatments in the 2018 Cripps Pink trial were found to significantly increase return bloom compared to the control.

Discussion & Conclusions

Fruit Set & Crop Density

In this project most of the blossom thinning treatments evaluated did not significantly reduce fruit set nor crop density compared to the control and resulted in severe under-thinning. ATS + SO and Regalia were identified as the only blossom thinning treatments which could significantly reduce fruit set in the 2019 Honeycrisp trial (Tale 3-2). Although no other treatments were found to significantly reduce fruit set and/or crop density in any of the trials (Tables 3-2, 3-3, 3-4, 3-5), several of the blossom thinning chemicals did generally have lower, but not significantly different, mean fruit sets and crop densities compared to the control (α=0.05). It is suggested that the primary cause of this observation was due to low rates of the chemical agents being evaluated. Other additional factors causing this outcome could have included cultivar characteristics and insufficient subsample and replicate numbers.

With regards to ammonium thiosulfate, several recent studies have demonstrated that ATS can used as an effective blossom thinning agent (Kon et al., 2018; Fallahi & Willemsen, 2002; Kacal et. al., 2019; Maas, 2016; Marchioretto et al., 2018; Milić, 2011). The results of our study generally contradict the findings of most ATS blossom thinning studies since none of the ATS treatments significantly reduce fruit set nor crop load – with the exception of ATS + SO in the 2019 Honeycrisp trial. Research by Irving was the first to demonstrate a liner relationship between increased ATS rates and increased thinning capability (Irving et al., 1989). Further work by Marchioretto suggested that ATS needed to be applied at 2.5% to achieve an effective thinning response in Gala (Marchioretto et al., 2018) while another study indicated that ATS applied at the rate of 3.0% was the rate needed to effectively reduce crop load in Red Delicious (Kacal et. al., 2019). With the ATS rates of 1.0% (2018) and 1.5% (2019), it is likely that the failure of the ATS blossom thinning treatments to significantly reduce fruit set and/or crop density was associated with the lower rates used in this study.

The degree of thinning by lime sulfur solution (calcium polysulfide) blossom thinning sprays has shown to be concentration dependent (Stopar, 2008) much like ATS. With other research work demonstrating that lime sulfur based blossom thinning is effective when lime sulfur is used at concentrations of 2.0% (Kon et al., 2018; Bound, 2010); it is suggested that the lime sulfur rates used in this study (1.0% in 2018, 1.5% in 2019) were not sufficient to trigger a significant reduction in fruit set nor crop density.

In this study potassium bicarbonate did not result in a significantly decreased fruit set nor crop density compared to the control despite the KB + SO treatment having a lower crop density of 1.5 fruit/TCSA compared to the control crop density of 10.0 fruit/TCSA in the 2018 Honeycrisp

trial. (Table 3-4). Recent research in Switzerland has shown that two applications of 15 kg of Armicarb (85.0% potassium bicarbonate) per hectare (calculated to be 1.5% Armicarb) resulted in a satisfying thinning outcome in most cultivars (Weibel et al., 2012). Other research work has also demonstrated that blossom sprays containing 2% Ecocarb (95.0% potassium bicarbonate) significantly lowered fruit set and crop density when applied as a blossom thinner (Bound, 2010). With this research project using rates of 1.05% in 2019, it is suggested that lower rates of potassium bicarbonate products in the 1.0% range are generally insufficient to obtain an adequate thinning response. However, with the higher 2018 rates of 1.58% it is suggested that the subsample size and replicate numbers were insufficient to establish significant difference in the 2018 trials.

With regards to potassium nitrate, none of the KN treatments with or without oil were not found to effectively reduce fruit set nor crop density. With most nitrogen based foliar fertilizers lacking a substantial blossom thinning effect (Handschack and Alexander, 2002), it is suggested that KN is not effective as a blossom thinning agent at the tested rates; however, higher rates may have the potential to increase the thinning capability of KN.

The data from this research also suggested that KTS and KTS + SO was insufficient in decreasing fruit set and crop density at the rates selected (0.5% in 2018 and 1.0% in 2019). In a study by Bound and Wilson it was found that KTS is effective as a chemical agent for blossom thinning when used at the rates of 0.5%, 1.0%, and 1.5% in Red Delicious and Gala cultivars (Bound and Wilson, 2004). However, another study has demonstrated that blossom thinning sprays with 1%, 2%, and 3% were all incapable of significantly reducing fruit in the RedChief Delicious cultivar (Kacal et al., 2019). As a result, effective blossom thinning with KTS is likely cultivar dependent and it is suggested that higher rates of KTS are likely needed to obtain desired thinning outcomes in Honeycrisp and Cripps Pink.

In this project the Regalia and Regalia + SO treatments were not generally effective in significantly reducing fruit set and crop density. A previous study using an organically managed Honeycrisp block at the same research facility that this project took place demonstrated that two blossom thinning sprays with Regalia combined with Stylet-Oil significantly reduced crop load (Peck et al., 2017). However, the results of this previous study are contrary to our study which demonstrated that Regalia + SO was ineffective in significantly reducing fruit set and crop density in both years on Honeycrisp and Cripps Pink. This likely resulted due to a difference in rates. In Peck's study 9.4 L of Regalia were combined with 9.4 L of JMS Stylet-Oil (Peck et al., 2017), equating to an approximate spray concentration calculated to be 2.5% Regalia and 2.5% Stylet-Oil whereas in this study a concentration of 0.5% Regalia (2018), 1.0% Regalia (2019), and 1.0% Stylet-Oil (2018 and 2019) was utilized. Nonetheless, this does not explain why the Regalia treatment without Stylet-Oil significantly reduced fruit set in the 2019 Honeycrisp trial and the Regalia + SO treatment did not.

This study also found 1% urea blossom thinning sprays, with and without Stylet-Oil, were ineffective at reducing fruit set and crop density. Research by Handschack and Alexander demonstrated that blossom thinning using 6% urea could result in a slight difference in fruit set compared to the control (Handschack and Alexander, 2002). From our study it is suggested that

urea applied at low rates does not have a flower thinning capability suitable for commercial use. However, higher rates of urea could possibly produce significant thinning outcomes if evaluated.

In this study, the majority of the blossom thinning treatments did not result in significant reduction of fruit set nor crop density compared to the control. It is suggested that this is mostly attributed to the low rates of the selected chemical agents whereas the majority of other studies demonstrate effective thinning with the same chemical agents used at higher rates. Additionally, it is important to note that the majority of the post-bloom chemical fruit treatments did not significantly reduce fruit set and crop density; however, from the visual observation of the treatment trees and blocks, it was noted that the blossom thinning treatments generally under-thinned and the post-bloom treatments generally overthinned. This suggests that the subsample size (branches and flower clusters) and replicate size (number of trees) was insufficient to account for variability in the block.

Fruit Diameter and Weight

From this study it was found that the blossom thinning treatments evaluated did not significantly increase fruit diameter nor weight in most cases (Tables 3-6, 3-7). The 2019 Honeycrisp trial was the only trial to have treatments with significantly higher mean fruit weights and/or weights compared to the control. ATS and KTS + SO treatments were found to have both significantly higher mean fruit diameters and weights and the LSS 2 + SO treatment had significantly higher weight compared to the control. With higher fruit weight/size being associated with greater thinning (Link, 2000), it can be suggested that these treatments achieved a certain level of thinning. This theory can be supported by other studies which found that blossom thinning using ATS (Milić et al., 2011) and KTS (Bound and Wilson, 2004) increased fruit weight/size at certain rates. Most recent LSS blossom thinning studies (Kon et al., 2018; Peck et al., 2017: Bound, 2010) have demonstrated that LSS increases mean fruit weight and or size at certain rates but not always enough to result in a significant difference from the control. However, it must be noted that ATS + SO and Regalia were the only treatments capable of reducing fruit set significantly (Table 3-2). This implies that the sub-sample size (5 fruits per replicate in 2018 and 20 fruits per replicate in 2019) was not sufficient to fairly detect significant fruit diameter and weight distributions.

Fruit Color

In this study no conclusive treatment effect on fruit color was observed. No significant increases or decreases in fruit color were observed in any of the treatments compared to the control in the 2018 trials (Tables 3-6, 3-7). In the 2019 Cripps Pink trial, both post-bloom thinner applications and several blossom thinning treatments (LSS 2, LSS 2 + SO, KB, KN, and Regalia) had increased coloration (Table 3-7). Although increased coloration is often associated with greater thinning (Link, 2000) and it has been demonstrated that blossom thinning sprays with agents such as LSS can increase fruit color (Bound, 2010), it is not likely that the treatments were responsible for the increased coloration in the 2019 Cripps Pink trial since these treatments were not effective in significantly reducing crop density nor crop load (Tables 3-2, 3-3, 3-4, 3-5) and most were not found to increase fruit weight and size (Tables 3-6, 3-7). Furthermore, Regalia

was found to significantly increase fruit color in the 2019 Cripps Prink trial (Table 2-7) but also a significantly decreased fruit color in the 2019 Honeycrisp trial (Table 3-6). Due to the inconsistency of the mean color value, there is no conclusive evidence showing that blossom thinning treatments increased fruit coloration.

Fruit Quality Factors (Pressure, Starch, Brix, TA, pH)

Although several treatments had both significantly higher and lower pressure, starch, Brix, TA, and pH values compared to the control in different trials, there was no definitive and specific treatment which was determined to have a major and clear impact on any specific fruit quality trait (Tables 3-8, 3-9). Although effective thinning has generally been shown to increase fruit firmness, soluble solids, and titratable acidity (Link, 2000), recent research on chemical blossom thinning agents had demonstrated variable impacts on fruit quality factors much like this research project. For instance, Bound and Wilson found that KTS blossom thinning sprays significantly increased soluble solids (Brix) and significantly decreased pressure in Red Delicious as KTS concentration increased (Bound and Wilson, 2004). On the contrary Kacal and others determined that blossom thinning with similar KTS rates did not significantly impact soluble solids (Brix) nor pressure (Kacal et al., 2019). One possible cause of this confliction of results could be due to varietal differences. However, subsample size could have also contributed to this. Bound and Wilson used a fruit subsample size of 25 fruits per tree (Bound and Wilson, 2004) while Kacal and others used a subsample size of 20 fruits per tree (Kacal et al., 2019). This study used a subsample size of 5 fruits per tree in 2018 and subsample size of 20 fruits per tree in 2019. It is possible that the small fruit subsample size in 2018 could have contributed to this observation. With the treatments not demonstrating the ability to influence fruit quality traits (e.g. pressure, starch, Brix, TA, pH) consistently between varieties nor years and recent blossom thinning studies demonstrating conflicting results, it is suggested that none of the treatments in this study had a valid impact on fruit quality traits.

Fruit Russeting Incidence & Severity

Many caustic type blossom thinners have shown to cause excessive russeting to fruit (Greene, 2002). From this study it was found that several blossom thinning treatments significantly reduced fruit packout from russet incidence/severity. It was found that both LSS + SO treatments significantly decreased the packout of U.S. Extra Fancy and U.S. Fancy grade fruit compared to the control due to russet incidence and severity in the 2019 Honeycrisp trial (Table 3-10). Additionally, LSS 1 + SO significantly increased the proportion of U.S. Utility grade fruit in the 2019 Honeycrisp trial. In the 2019 Cripps Pink trial, none of the LSS treatments significantly influenced fruit packout from russet incidence or severity. This suggests that russet incidence from LSS could be cultivar dependent. In an earlier study at the same research center a few years prior, it was found that that LSS + SO significantly increased fruit russet occurrence and significantly reduced pack-out in Honeycrisp (Peck et al., 2017). However, another recent study in Pennsylvania using similar concentrations found that LSS + SO did not significantly increase fruit russet occurrence in Gala (Kon et al., 2018). In the Cripps Pink trial, it was found that the KB and KB + SO treatments significantly reduced the packout of U.S. Extra Fancy and U.S. Fancy grade fruit (Table 3-10). It was also found that KB + SO significantly increased the

proportion of U.S. No. 1 grade fruit compared to the control. Both KB and KB + SO significantly increased the proportion of U.S. Utility grade fruit compared to the control. Although KB was tested in the 2019 Honeycrisp trial and reduced the mean fruit packout of U.S. Extra Fancy and U.S. Fancy grade fruit by ~50% compared to the control, there was no significant difference. KB + SO was not tested in the 2019 Honeycrisp trial due to lack of trees with sufficient and uniform bloom. From this data, it can also be suggested that KB's ability to cause detrimental russet incidence is also cultivar dependent like LSS. In an extensive study using multiple different cultivars it was found that KB could result in russeting in some cultivars more than others (Wiebel et al., 2012). This study and other research strongly suggest that fruit russet occurrence from LSS and KB blossom thinning sprays is likely strongly dependent on the cultivar. However, there are also likely other variables such as adjuvant selection (Bound, 2010) and possibly rates (Stopar, 2008) which also collectively influence fruit russet incidence in chemical blossom thinning.

Foliar Phytotoxicity

In this study, several blossom thinning treatments were identified to significantly increase phytotoxicity following application. Both ATS and ATS + SO significantly increased foliar phytotoxicity compared to the control in both the 2019 Honeycrisp trial and the 2019 Cripps Pink trial. KB + SO also significantly increased foliar phytotoxicity in the 2019 Cripps Pink trial; it was not evaluated in the 2019 Honeycrisp trial. Many caustic blossom thinners have shown to cause unacceptable phytotoxicity in foliage (Greene, 2002). Kon found that ATS significantly increased phytotoxicity in Gala but only significantly increased phytotoxicity one year out of two in Golden Delicious (Kon et al., 2018). Kon also found that LSS + SO did not result in significant phytotoxicity (Kon et al., 2018). Wiebel found that KB blossom thinning sprays with no surfactant/adjuvant did not result in phytotoxic effects (Wiebel et al., 2012). The data from this project agrees with both Kon's and Wiebel's studies. It can be concluded that ATS based sprays can result in excessive phytotoxicity when ATS is used as a blossom thinning agent. It can also be suggested that LSS + SO can cause a small but not significant phytotoxic effect. With regards to KB, it is suggested that KB can cause a phytotoxic effect when applied alone; but KB will cause a more severe phytotoxic effect when combined with Stylet-Oil.

Return Bloom

With regards to return bloom, it was found that both post-bloom fruit thinning treatments and the KB + SO blossom thinning treatment significantly increased return bloom in the 2018 Honeycrisp trial (Table 3-12). None of the treatments in the 2018 Cripps Pink trial were found to significantly increase return bloom compared to the control. This observation was likely directly related to the crop density of the treatments. In the 2018 Honeycrisp trial, none of the treatments had a significantly lower crop density compared to the control. However, the KB + SO treatment had a crop density 85% lower than the control (Table 3-4). With lower crop density being associated with greater return bloom in the following year (Marini et. al., 2013), it is likely that the high level of thinning exhibited in the KB + SO treatment in the 2018 Honeycrisp resulted in the high level of return bloom. This conclusion can be supported by other research studies. Bound also found that very high return bloom could be achieved when Ecocarb (potassium

bicarbonate) is used as a blossom thinning agent alone at the rate of 5% (Bound, 2010). However, Bound found that when 5% Ecocarb was used as a blossom thinner excessive thinning occurred resulting in a crop density of 0 fruit/TCSA (Bound, 2010). This is comparable to our research where KB + SO resulted in a very low crop density of 1.5 fruit/TCSA compared to the control which had a crop density of 10 fruit/TCSA. Consequently, the high level of return bloom in the KB + SO treatment of the 2018 Honeycrisp trial most likely resulted from excessive overthinning.

Summary & Final Conclusions

While lime sulfur is the most widely available and labelled blossom thinning product for growers in Virginia and the East Coast, there are several drawbacks associated with its use such as fruit russeting (Peck et al., 2017) and ineffective thinning results (Kon et al., 2018) occurring in certain situations. Commercial apple growers in Virginia and the surrounding Mid-Atlantic who are interested in adopting chemical blossom would benefit from having alternative chemical agents which are safe and effective for blossom thinning. Consequently, this research study was undertaken to screen multiple chemical agents for their suitability (crop safety) and efficacy (thinning ability) as chemical blossom thinners in Mid-Atlantic conditions.

From this project it was found that the majority of the chemical agents severely under thinned and did not significantly reduce the fruit set nor crop load compared to the control. The cause of this was likely due to the selection of low rates. However, it could have also resulted from low subsample and replicate numbers used in determining fruit set and crop density. Of the chemical agents evaluated, ATS and ATS + SO arguably demonstrated the most promise to effectively reduce the crop load since these treatments lowered the mean fruit set and crop density while having a higher mean fruit diameters and weights in most cases. This agrees with other recent studies (Kacal et al., 2019; Marchioretto et. al., 2019; Maas, 2016; Milić, 2011) which demonstrated that ATS has an ability to effectively reduce the crop load. Several other chemical agents evaluated (i.e. LSS + SO and KB + SO) also demonstrated lower mean fruit sets and crop densities with higher mean fruit diameters and weights compared to the control in some cases; thereby, suggesting their capability of effective thinning if the rates were increased. Incremental increases in rates have shown to increase the thinning efficacy of multiple chemical agents including the following: ATS (Kacal et al. 2019), KB (Wiebel et al., 2012), KTS (Bound and Wilson, 2004). It can be assumed that many of the chemical agents evaluated in this study are cable of achieving an adequate thinning response provided that proper rates are identified and utilized.

With regards to suitability, several chemical agents demonstrated an ability to cause significant crop harm in the form of excessive fruit russeting and/or phytotoxicity. LSS + SO demonstrated a strong ability to reduce packout in Honeycrisp from excessive fruit russeting, while KB and KB + SO demonstrated an ability to reduce packout in Cripps Pink from excessive fruit russeting. This suggests that blossom thinning chemical agents vary in their capability to cause excessive fruit russeting between apple cultivars. The use of Armicarb (potassium bicarbonate) can increase fruit russeting in some cultivars (Wiebel et al., 2012). This study also found that ATS, ATS + SO, KB and KB + SO caused significant phytotoxicity in both Honeycrisp and

Cripps Pink suggesting that ATS and KB based blossom thinning sprays will likely result in foliar phytotoxicity in most situations. This is in general agreement with another recent study in the Mid-Atlantic which demonstrated that ATS significantly increased phytotoxicity in Gala but only significantly increased phytotoxicity one year out of two in Golden Delicious (Kon et al., 2018). Regarding fruit quality parameters (i.e. color, pressure, soluble solids, etc.), no conclusive trend was observed nor established in this study. From the 2018 trials, none of the treatments demonstrated a conclusive ability to significantly enhance return bloom. Although KB + SO was found to increase return bloom in the 2018 Honeycrisp trial, this was likely associated with an isolated incidence of over thinning in the respective trial.

The data from this study implies that blossom thinning chemical agents can vary in their ability to effectively reduce the crop load. It is also suggested from this study that the rate selection of blossom thinning chemical agents is very important to obtain adequate thinning responses and is the reason why the majority of the treatments did not significantly reduce the fruit set nor crop density. Consequently, it is recommended that future research studies focus on evaluating and identifying proper rates of chemical agents for blossom thinning. The data from this project also demonstrated that ATS and KB based blossom thinning sprays will likely result in foliar phytotoxicity, particularly when mixed with oil, which should be considered if these reagents are to become widely available and labelled for blossom thinning in the future in the Mid-Atlantic area. Furthermore, the data from this study demonstrates that LSS + SO, KB, and KB + SO based blossom thinning treatments vary in their ability to induce fruit russeting between cultivars. This observation should be considered in future research studies and in commercial production situations. In summary, it is suggested that multiple chemical agents (i.e. ATS, LSS, KB) can be utilized for chemical blossom thinning in Virginia and the Mid-Atlantic region provided that the ideal rates are identified which result in sufficient thinning and minimize associated crop safety hazards such as fruit russeting.

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Table 3-1: Blossom Thinning Agents and Rates Evaluated for Suitability and Efficacy in 'Honeycrisp' and 'Cripps Pink' (Virginia, 2018 and 2019)

#	Treatment	Thinner Products[z]	2018 Rates[yx]	2019 Rates[yx]
1	ATS	Ammonium Thiosulfate	1.00%	1.50%
2	LSS 1	Calcium Polysulfide (1)	1.00%	1.50%
3	LSS 2	Calcium Polysulfide (2)	1.00%	1.50%
4	KB	Potassium Bicarbonate	1.58%	1.05%
5	KN	Potassium Nitrate	-	1.00%
6	KTS	Potassium Thiosulfate	0.50%	1.00%
7	Regalia	*Reynoutria sachalinensis*	1.00%	1.00%
8	Urea	Urea	-	1.00%
9	ATS + SO	Ammonium Thiosulfate	1.00%	1.50%
		Stylet-Oil	1.00%	1.00%
10	LSS 1 + SO	Calcium Polysulfide (1)	1.00%	1.50%
		Stylet-Oil	1.00%	1.00%
11	LSS 2 + SO	Calcium Polysulfide (2)	1.00%	1.50%
		Stylet-Oil	1.00%	1.00%
12	KB + SO	Potassium Bicarbonate	1.58%	1.05%
		Stylet-Oil	1.00%	1.00%
13	KN + SO	Potassium Nitrate	-	1.00%
		Stylet-Oil		1.00%
14	KTS + SO	Potassium Thiosulfate	0.50%	1.00%
		Stylet-Oil	1.00%	1.00%
15	Regalia + SO	*Reynoutria sachalinensis*	1.00%	1.00%
		Stylet-Oil	1.00%	1.00%
16	Urea + SO	Urea	-	1.00%
		Stylet-Oil		1.00%
17	SO	Stylet-Oil	1.00%	1.00%
18	NAA + C + R	NAA	0.02%	0.02%
		Carbaryl	0.12%	0.21%
		Nonionic Surfactant	0.06%	0.11%
19	6-BA + C + R	6-BA	1.00%	0.42%
		Carbaryl	0.12%	0.21%
		Nonionic Surfactant	0.06%	0.11%
20	Control	-	-	-

[z] Ammonium thiosulfate (Sigma-Aldrich, 98.0% ai.), calcium polysulfide (Tessenderlo Kernley Inc., NovaSource Lime Sulfur Solution, 29.0% ai.), calcium polysulfide (Or-Cal Inc., Rex Lime Sulfur Solution, 28.0% ai.), potassium bicarbonate (H & I Agritech Inc., GreenCure Fungicide, 85.0% ai.), potassium thiosulfate (Sigma-Aldrich Inc., 95.0% ai.), *Reynoutria sachalinensis* (Marrone Bio Innovations Inc., Regalia Biofungicide, 5.0% ai.), paraffinic oil (JMS Flower Farms Inc., JMS Stylet-Oil, 97.1% ai.), 1-naphthaleneacetic acid (Valent Biosciences Inc., Pomaxa, 3.5% ai.), 6-benzyladenine (Valent Biosciences Inc., Maxcel, 1.9% ai.), carbaryl (Loveland Products Inc., Carbaryl 4L, 43.0% ai.), nonionic surfactant (Kalo Inc., Regulaid, 90.6% ai.).

[y] Rates of product per unit volume of spray water. **NOT** expressed as active ingredient (ai.) per unit of spray mixture.

[x] Potassium Nitrate with and without Stylet-Oil, and Urea with and without Stylet Oil were not tested on Honeycrisp and Cripps Pink in 2018. Potassium Nitrate with and without Stylet-Oil, Urea with and without Stylet-Oil, and Potassium Bicarbonate with Stylet-Oil were not tested on Honeycrisp in 2019 due to a lack of trees with sufficient return bloom required for experimentation.

Table 3-2: Blossom Thinning Agent Influence on Fruit Set (%) in 'Honeycrisp' (Virginia, 2019)[z,y]

Treatment	2 WAPF[x]	4 WAPF[x]	6 WAPF[x]	8 WAPF[x]	Harvest
		'Honeycrisp' 2019			
ATS	25.4 ab	23.1 ab	22.1 ab	22.0 ab	18.6 ab
LSS 1	35.7 ab	27.7 ab	26.0 ab	25.7 ab	21.0 ab
LSS 2	42.2 ab	35.9 ab	30.9 ab	30.6 ab	26.2 ab
KB	32.8 ab	25.1 ab	23.2 ab	22.0 ab	17.5 ab
KN	-	-	-	-	-
KTS	22.7 ab	20.2 ab	16.5 ab	16.4 ab	15.0 ab
Regalia	18.9 ab	12.4 ab	10.5 ab	9.9 b	8.4 b
Urea	-	-	-	-	-
ATS + SO	12.5 b	8.6 b	8.2 b	8.1 b	7.8 b
LSS 1 + SO	32.6 ab	30.0 ab	26.1 ab	25.3 ab	23.6 ab
LSS 2 + SO	45.0 ab	35.7 ab	32.8 ab	31.8 ab	27.4 ab
KB + SO	-	-	-	-	-
KN + SO	-	-	-	-	-
KTS + SO	36.4 ab	30.6 ab	28.3 ab	27.1 ab	23.8 ab
Regalia + SO	24.7 ab	20.5 ab	19.5 ab	18.9 ab	17.4 ab
Urea + SO	-	-	-	-	-
SO	44.2 ab	36.2 ab	33.5 ab	32.6 ab	22.0 ab
NAA + C + R	27.5 ab	13.4 ab	10.0 ab	9.1 b	9.1 b
6-BA + C + R	35.3 ab	15.8 ab	10.8 ab	10.6 ab	10.6 ab
Control	54.5 a	42.6 a	40.2 a	39.5 a	31.2 a

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.

[y]Fruit set determined by whole tree blossom cluster counts and whole tree fruit counts.

[x]Weeks after petal fall (WAPF).

Table 3-3: Blossom Thinning Agent Influence on Fruit Set (%) in 'Cripps Pink' (Virginia, 2018 and 2019)[z,y]

Treatment	2 WAPF[x]	4 WAPF[x]	6 WAPF[x]	8 WAPF[x]	Harvest
		'Cripps Pink' 2018			
ATS	18.5 a	16.6 a	15.7 a	14.6 a	11.8 a
LSS 1	16.3 a	11.5 a	10.6 a	9.1 a	8.3 a
LSS 2	18.4 a	14.0 a	13.5 a	12.0 a	11.4 a
KB	23.4 a	17.8 a	17.0 a	16.3 a	13.5 a
KN	-	-	-	-	-
KTS	25.5 a	20.5 a	19.6 a	18.8 a	14.9 a
Regalia	27.1 a	19.3 a	19.3 a	13.4 a	13.4 a
Urea	-	-	-	-	-
ATS + SO	22.8 a	14.5 a	13.9 a	13.7 a	11.7 a
LSS 1 + SO	10.6 a	7.1 a	6.5 a	6.5 a	4.9 a
LSS 2 + SO	21.6 a	17.5 a	16.1 a	15.7 a	12.1 a
KB + SO	17.6 a	8.0 a	7.4 a	6.8 a	5.3 a
KN + SO	-	-	-	-	-
KTS + SO	30.7 a	22.1 a	21.1 a	20.2 a	17.0 a
Regalia + SO	19.1 a	15.6 a	14.7 a	11.3 a	11.7 a
Urea + SO	-	-	-	-	-
SO	23.3 a	18.8 a	18.2 a	17.7 a	14.6 a
NAA + C + R	12.4 a	12.0 a	10.9 a	10.4 a	8.4 a
6-BA + C + R	14.6 a	14.2 a	13.4 a	11.5 a	8.9 a
Control	28.9 a	21.8 a	20.8 a	17.4 a	15.1 a
		'Cripps Pink' 2019			
ATS	23.9 ab	17.3 ab	14.1 abc	13.2 abc	10.6 abc
LSS 1	27.0 ab	15.8 abc	14.4 abc	13.6 abc	12.8 ab
LSS 2	27.4 ab	17.7 ab	15.9 ab	15.0 ab	13.0 ab
KB	17.2 b	15.1 abc	13.9 abc	12.7 abc	11.1 abc
KN	16.0 b	11.7 abc	10.3 abc	9.7 abc	7.5 abc
KTS	27.9 ab	19.6 ab	17.4 ab	16.5 ab	14.0 ab
Regalia	21.7 b	16.0 ab	14.5 ab	13.2 abc	12.4 abc
Urea	23.3 ab	16.0 ab	14.0 abc	14.0 ab	12.5 abc
ATS + SO	22.6 ab	13.6 abc	11.7 abc	11.2 abc	10.7 abc
LSS 1 + SO	21.6 b	16.0 ab	15.2 ab	14.5 ab	12.8 ab
LSS 2 + SO	21.6 b	15.9 ab	14.9 ab	14.2 ab	11.6 abc
KB + SO	18.2 b	12.2 abc	11.2 abc	11.2 abc	9.6 abc
KN + SO	21.2 b	15.8 abc	14.1 abc	13.8 abc	12.3 abc
KTS + SO	25.7 ab	15.0 abc	13.6 abc	12.5 abc	9.5 abc
Regalia + SO	32.6 ab	20.2 ab	19.7 a	19.2 a	17.1 a
Urea + SO	41.4 a	22.9 a	20.9 a	20.1 a	16.9 a
SO	25.6 ab	15.6 abc	14.6 ab	13.9 abc	9.9 abc
NAA + C + R	17.8 b	9.8 bc	8.4 bc	6.9 bc	6.4 bc
6-BA + C + R	21.0 b	4.3 c	3.8 c	3.4 c	2.7 c
Control	32.3 ab	22.5 a	19.4 a	19.0 a	15.4 ab

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Fruit set determined by the selection of ~50 flower clusters on 1-4 branches in 2018 and ~100 flower clusters on 3 branches in 2019 for each replicate tree and fruit counts on the respective branches.
[x]Weeks after petal fall (WAPF).

Table 3-4: Blossom Thinning Agent Influence on Crop Density (Fruit No./TCSA) in 'Honeycrisp' (Virginia, 2018 and 2019)[z,y]

Treatment	2 WAPF[x]	4 WAPF[x]	6 WAPF[x]	8 WAPF[x]	Harvest
		'Honeycrisp' 2018			
ATS	-	-	-	-	11.4 a
LSS 1	-	-	-	-	11.3 a
LSS 2	-	-	-	-	9.9 ab
KB	-	-	-	-	5.5 ab
KN	-	-	-	-	-
KTS	-	-	-	-	14.2 a
Regalia	-	-	-	-	10.7 ab
Urea	-	-	-	-	-
ATS + SO	-	-	-	-	11.4 a
LSS 1 + SO	-	-	-	-	8.0 ab
LSS 2 + SO	-	-	-	-	7.8 ab
KB + SO	-	-	-	-	1.5 b
KN + SO	-	-	-	-	-
KTS + SO	-	-	-	-	8.7 ab
Regalia + SO	-	-	-	-	9.8 ab
Urea + SO	-	-	-	-	-
SO	-	-	-	-	9.8 ab
NAA + C + R	-	-	-	-	-
6-BA + C + R	-	-	-	-	-
Control	-	-	-	-	10.0 ab
		'Honeycrisp' 2019			
ATS	4.7 b	4.2 ab	4.0 ab	4.0 ab	3.4 a
LSS 1	13.5 ab	10.0 ab	9.4 ab	9.2 ab	7.2 a
LSS 2	11.7 ab	10.7 ab	9.8 ab	9.7 ab	7.2 a
KB	13.5 ab	9.7 ab	8.8 ab	8.6 ab	7.4 a
KN	-	-	-	-	-
KTS	15.0 ab	12.8 ab	10.7 ab	10.6 ab	9.9 a
Regalia	25.4 a	16.8 a	14.8 a	14.1 a	12.2 a
Urea	-	-	-	-	-
ATS + SO	12.5 ab	8.5 ab	8.1 ab	8.0 ab	7.7 a
LSS 1 + SO	8.0 ab	7.3 ab	6.3 ab	6.1 ab	5.8 a
LSS 2 + SO	9.1 ab	7.7 ab	7.0 ab	6.8 ab	6.0 a
KB + SO	-	-	-	-	-
KN + SO	-	-	-	-	-
KTS + SO	7.2 b	6.1 ab	5.6 ab	5.4 ab	4.7 a
Regalia + SO	6.9 b	5.5 ab	5.3 ab	5.2 ab	4.9 a
Urea + SO	-	-	-	-	-
SO	10.1 ab	8.3 ab	7.2 ab	7.0 ab	5.3 a
NAA + C + R	12.3 ab	5.7 ab	4.3 ab	3.8 ab	3.8 a
6-BA + C + R	6.0 b	2.8 b	2.0 b	1.9 b	1.9 a
Control	12.5 ab	8.8 ab	8.4 ab	8.3 ab	6.9 a

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Crop density determined by whole tree fruit counts.
[x]Weeks after petal fall (WAPF).

Table 3-5: Blossom Thinning Agent Influence on Crop Density (Fruit No./BCSA) in 'Cripps Pink' (Virginia, 2018 and 2019)[z,y]

Treatment	2 WAPF[x]	4 WAPF[x]	6 WAPF[x]	8 WAPF[x]	Harvest
		'Cripps Pink' 2018			
ATS	4.3 a	4.0 a	3.7 a	3.5 a	2.8 a
LSS 1	3.1 a	2.5 a	2.2 a	1.9 a	1.7 a
LSS 2	2.9 a	2.5 a	2.3 a	2.1 a	2.0 a
KB	7.7 a	5.9 a	5.7 a	5.5 a	4.6 a
KN	-	-	-	-	-
KTS	5.5 a	4.3 a	4.2 a	3.9 a	3.1 a
Regalia	15.9 a	8.9 a	8.9 a	8.0 a	6.4 a
Urea	-	-	-	-	-
ATS + SO	6.1 a	4.0 a	3.9 a	3.8 a	3.2 a
LSS 1 + SO	1.5 a	1.0 a	0.9 a	0.9 a	0.7 a
LSS 2 + SO	5.1 a	4.1 a	3.8 a	3.7 a	2.8 a
KB + SO	2.3 a	1.7 a	1.6 a	1.5 a	1.2 a
KN + SO	-	-	-	-	-
KTS + SO	28.8 a	17.3 a	17.1 a	16.9 a	13.0 a
Regalia + SO	2.9 a	2.2 a	2.1 a	1.5 a	1.9 a
Urea + SO	-	-	-	-	-
SO	5.0 a	4.0 a	3.9 a	3.8 a	3.1 a
NAA + C + R	1.4 a	1.4 a	1.3 a	1.2 a	0.9 a
6-BA + C + R	2.3 a	2.3 a	2.1 a	1.9 a	1.5 a
Control	4.5 a	3.5 a	3.4 a	2.8 a	2.4 a
		'Cripps Pink' 2019			
ATS	7.0 a	4.7 ab	3.7 a	3.5 a	3.1 a
LSS 1	14.6 a	8.8 ab	8.1 a	7.5 a	6.9 a
LSS 2	15.5 a	9.3 ab	8.3 a	7.8 a	7.1 a
KB	10.5 a	9.4 ab	8.9 a	8.3 a	7.1 a
KN	5.9 a	4.2 ab	3.6 a	3.5 a	2.6 a
KTS	17.5 a	12.6 a	11.3 a	10.8 a	9.0 a
Regalia	7.3 a	5.4 ab	4.8 a	4.5 a	4.2 a
Urea	11.1 a	7.7 ab	7.1 a	6.7 a	5.8 a
ATS + SO	10.0 a	5.5 ab	4.8 a	4.5 a	4.4 a
LSS 1 + SO	9.7 a	7.0 ab	6.8 a	6.4 a	5.8 a
LSS 2 + SO	12.3 a	9.1 ab	8.5 a	8.3 a	6.4 a
KB + SO	8.5 a	5.8 ab	5.4 a	5.4 a	4.5 a
KN + SO	8.6 a	6.0 ab	5.5 a	5.5 a	4.9 a
KTS + SO	21.2 a	12.5 a	11.2 a	9.8 a	7.3 a
Regalia + SO	17.3 a	10.4 ab	10.3 a	10.0 a	8.4 a
Urea + SO	19.9 a	11.0 ab	10.0 a	9.6 a	8.0 a
SO	14.6 a	9.0 ab	8.3 a	7.9 a	6.0 a
NAA + C + R	9.8 a	4.6 ab	3.7 a	3.3 a	3.3 a
6-BA + C + R	4.2 a	1.1 b	1.0 a	0.9 a	0.8 a
Control	20.0 a	12.1 a	10.2 a	10.0 a	8.8 a

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Crop density determined by fruit counts on 1-4 branches per replicate tree.
[x]Weeks after petal fall (WAPF).

Table 3-6: Blossom Thinning Agent Influence on Fruit Diameter, Weight, and Color in 'Honeycrisp' (Virginia, 2018 and 2019)[z,y]

Treatment	Diameter (mm)	Weight (g)	Color (I_{AD})
		'Honeycrisp' 2018	
ATS	81 a	216 a	0.63 a
LSS 1	81 a	212 a	0.73 a
LSS 2	78 a	194 a	0.60 a
KB	80 a	204 a	0.65 a
KN	-	-	-
KTS	77 a	186 a	0.60 a
Regalia	81 a	214 a	0.73 a
Urea	-	-	-
ATS + SO	79 a	204 a	0.84 a
LSS 1 + SO	77 a	183 a	0.60 a
LSS 2 + SO	81 a	212 a	0.73 a
KB + SO	82 a	224 a	0.87 a
KN + SO	-	-	-
KTS + SO	78 a	189 a	0.71 a
Regalia + SO	80 a	197 a	0.67 a
Urea + SO	-	-	-
SO	80 a	210 a	0.64 a
NAA + C + R	83 a	232 a	0.76 a
6-BA + C + R	82 a	224 a	0.59 a
Control	79 a	194 a	0.78 a
		'Honeycrisp' 2019	
ATS	86 a	254 a	0.78 bcd
LSS 1	79 e	204 f	0.82 bcd
LSS 2	75 cde	180 def	0.73 d
KB	79 bcde	196 cdef	0.89 bc
KN	-	-	-
KTS	74 de	161 fg	0.73 d
Regalia	66 f	121 g	1.08 a
Urea	-	-	-
ATS + SO	77 cde	186 def	0.90 b
LSS 1 + SO	79 bcd	203 cde	0.77 cd
LSS 2 + SO	79 bc	208 bcd	0.79 bcd
KB + SO	-	-	-
KN + SO	-	-	-
KTS + SO	83 ab	232 abc	0.74 d
Regalia + SO	79 bcd	200 cde	0.72 d
Urea + SO	-	-	-
SO	76 cde	177 def	0.75 d
NAA + C + R	84 a	242 ab	0.77 cd
6-BA + C + R	86 a	256 a	0.82 bcd
Control	76 cde	172 ef	0.79 bcd

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Subsample of 5 fruit per replicate tree used in 2018. Subsample of 20 fruit per replicate tree used in 2019.

Table 3-7: Blossom Thinning Agent Influence on Fruit Diameter, Weight, and Color in 'Cripps Pink' (Virginia, 2018 and 2019)[z,y]

Treatment	Diameter (mm)	Weight (g)	Color (I_{AD})
		'Cripps Pink' 2018	
ATS	66 c	135 bc	0.61 ab
LSS 1	71 abc	157 abc	0.62 ab
LSS 2	69 abc	156 abc	0.63 ab
KB	69 bc	148 bc	0.86 a
KN	-	-	-
KTS	69 abc	153 abc	0.83 a
Regalia	69 abc	149 abc	0.61 ab
Urea	-	-	-
ATS + SO	68 bc	143 bc	0.72 ab
LSS 1 + SO	68 bc	142 bc	0.64 ab
LSS 2 + SO	68 bc	149 abc	0.57 b
KB + SO	72 ab	171 ab	0.77 ab
KN + SO	-	-	-
KTS + SO	67 c	134 c	0.66 ab
Regalia + SO	66 c	130 c	0.71 ab
Urea + SO	-	-	-
SO	68 bc	145 bc	0.75 ab
NAA + C + R	69 abc	154 abc	0.58 b
6-BA + C + R	74 a	185 a	0.84 a
Control	68 bc	141 bc	0.61 ab
		'Cripps Pink' 2019	
ATS	69 c	150 c	0.67 abc
LSS 1	66 cde	136 cd	0.64 abcd
LSS 2	65 de	131 d	0.43 g
KB	66 de	135 cd	0.47 fg
KN	66 de	132 d	0.48 efg
KTS	66 cde	137 cd	0.64 abcd
Regalia	68 c	151 c	0.55 cdefg
Urea	65 de	131 d	0.66 abcd
ATS + SO	66 cde	138 cd	0.59 abcdef
LSS 1 + SO	66 cde	139 cd	0.71 ab
LSS 2 + SO	64 e	127 d	0.55 cdefg
KB + SO	67 cde	136 cd	0.72 a
KN + SO	65 de	132 d	0.59 abcdef
KTS + SO	65 de	131 d	0.62 abcd
Regalia + SO	67 cde	141 cd	0.61 abcde
Urea + SO	65 de	131 d	0.66 abcd
SO	67 cde	143 cd	0.58 bcdef
NAA + C + R	73 b	184 b	0.57 cdef
6-BA + C + R	77 a	209 a	0.53 defg
Control	67 cd	142 cd	0.71 ab

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Subsample of 5 fruit per replicate tree used in 2018. Subsample of 20 fruit per replicate tree used in 2019.

Table 3-8: Blossom Thinning Agent Influence on Fruit Pressure, Starch, °Brix, TA, and pH in 'Honeycrisp' (Virginia, 2018 and 2019)[z,y]

Treatment	Pressure (lbs.)	Starch (0-6)	°Brix	TA	pH
		'Honeycrisp' 2018			
ATS	15.4 cd	4.3 a	12.9 ab	5.7 b	3.37 a
LSS 1	15.6 bcd	3.5 ab	12.9 ab	6.1 b	3.32 a
LSS 2	15 cd	3.7 ab	12.9 ab	5.9 b	3.37 a
KB	17.1 ab	2.6 b	13.9 ab	7.6 ab	3.38 a
KN	-	-	-	-	-
KTS	15.6 bcd	4.5 a	13.0 ab	6.0 b	3.38 a
Regalia	15.7 bcd	4.2 a	13.0 ab	5.8 b	3.37 a
Urea	-	-	-	-	-
ATS + SO	16.1 bc	3.4 ab	12.8 ab	6.8 ab	3.27 a
LSS 1 + SO	16.3 bc	3.8 ab	13.4 ab	6.0 b	3.37 a
LSS 2 + SO	15.6 bcd	3.5 ab	12.6 ab	6.2 b	3.38 a
KB + SO	18.3 a	3.3 ab	14.5 a	8.8 a	3.26 a
KN + SO	-	-	-	-	-
KTS + SO	15.6 bcd	3.2 ab	13.0 ab	6.6 b	3.93 a
Regalia + SO	15.4 cd	4.5 a	12.5 ab	5.9 b	3.37 a
Urea + SO	-	-	-	-	-
SO	15.4 cd	4.4 a	13.0 ab	6.0 b	3.31 a
NAA + C + R	15.5 cd	4.2 a	13.4 ab	6.4 b	3.26 a
6-BA + C + R	15.5 bcd	4.7 a	14.3 a	6.1 b	3.33 a
Control	14.4 d	4.2 a	12.0 b	5.9 b	3.40 a
		'Honeycrisp' 2019			
ATS	16.5 bc	3.8 de	13.8 a	6.7 a	3.49 a
LSS 1	15.4 e	5.0 ab	12.3 a	4.1 a	3.51 a
LSS 2	15.9 cde	4.2 bcde	12.8 a	5.3 a	3.44 a
KB	16.0 cde	5.1 a	13.0 a	5.1 a	3.46 a
KN	-	-	-	-	-
KTS	16.2 cde	4.1 bcde	13.0 a	5.0 a	3.45 a
Regalia	18.0 a	2.9 f	13.1 a	5.4 a	3.40 a
Urea	-	-	-	-	-
ATS + SO	16.1 cde	3.9 de	13.2 a	5.7 a	3.48 a
LSS 1 + SO	16.3 cd	3.5 ef	13.7 a	6.0 a	3.43 a
LSS 2 + SO	15.7 cde	5.1 a	13.1 a	5.0 a	3.50 a
KB + SO	-	-	-	-	-
KN + SO	-	-	-	-	-
KTS + SO	15.6 de	3.9 de	13.8 a	5.8 a	3.43 a
Regalia + SO	16.4 cd	3.6 ef	14.1 a	7.0 a	3.41 a
Urea + SO	-	-	-	-	-
SO	17.4 ab	4.9 abc	13.3 a	5.3 a	3.52 a
NAA + C + R	16.3 cd	4.1 cde	14.4 a	6.5 a	3.50 a
6-BA + C + R	15.9 cde	5.0 abc	13.9 a	6.5 a	3.53 a
Control	16.5 cd	4.7 abcd	12.9 a	5.4 a	3.45 a

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Subsample of 5 fruit per replicate tree used in 2018. Subsample of 20 fruit per replicate tree used in 2019.

Table 3-9: Blossom Thinning Agent Influence on Fruit Pressure, Starch, °Brix, TA, and pH in 'Cripps Pink' (Virginia, 2018 and 2019)[z,y]

Treatment	Pressure (lbs.)	Starch (0-8)	°Brix	TA	pH
		'Cripps Pink' 2018			
ATS	22.4 abc	3.6 a	13.9 a	11.6 ab	3.40 abc
LSS 1	21.6 abcd	2.8 abc	12.5 a	9.6 abc	3.40 abc
LSS 2	22.1 abc	3.1 abc	16.6 a	13.1 a	3.38 bc
KB	21.4 bcd	3.0 abc	14.0 a	9.4 abc	3.39 abc
KN	-	-	-	-	-
KTS	22.0 abc	3.0 abc	15.4 a	10.5 ab	3.42 abc
Regalia	22.8 ab	2.4 c	14.6 a	11.4 ab	3.40 abc
Urea	-	-	-	-	-
ATS + SO	20.6 cd	2.9 abc	15.9 a	9.5 abc	3.43 ab
LSS 1 + SO	22.1 abc	2.5 bc	14.3 a	12.5 a	3.33 c
LSS 2 + SO	23.4 a	2.9 abc	16.6 a	11.3 ab	3.39 abc
KB + SO	20.6 cd	3.0 abc	14.5 a	11.6 ab	3.36 bc
KN + SO	-	-	-	-	-
KTS + SO	21.6 abcd	3.3 ab	13.5 a	10.0 abc	3.41 abc
Regalia + SO	21.7 abcd	3.1 abc	15.7 a	8.3 bc	3.42 ab
Urea + SO	-	-	-	-	-
SO	21.5 bcd	3.0 abc	14.3 a	10.9 ab	3.41 abc
NAA + C + R	21.5 bcd	3.2 abc	14.8 a	10.6 ab	3.37 bc
6-BA + C + R	19.9 d	3.0 abc	16.5 a	9.5 abc	3.42 abc
Control	21.0 bcd	3.1 abc	13.2 a	6.2 c	3.47 a
		'Cripps Pink' 2019			
ATS	21.2 cde	3.6 cde	13.8 ab	6.4 a	3.52 ab
LSS 1	20.9 cde	3.8 bcde	13.8 ab	5.7 a	3.56 ab
LSS 2	21.5 bcd	4.6 a	14.0 ab	6.6 a	3.56 ab
KB	22.3 ab	3.7 bcde	14.0 ab	7.2 a	3.58 a
KN	22.8 a	3.5 de	14.0 ab	7.3 a	3.52 ab
KTS	21.0 cde	4.0 abcd	13.5 b	6.0 a	3.58 a
Regalia	21.3 bcd	3.7 cde	13.8 ab	6.8 a	3.57 a
Urea	21.8 bc	4.2 abcd	13.7 ab	6.5 a	3.55 ab
ATS + SO	21.1 cde	3.8 bcde	13.9 ab	6.7 a	3.51 ab
LSS 1 + SO	20.8 def	4.0 abcd	13.6 b	6.0 a	3.52 ab
LSS 2 + SO	20.8 def	4.1 abcd	14.0 ab	5.7 a	3.53 ab
KB + SO	21.1 cde	3.2 e	14.0 ab	6.4 a	3.55 ab
KN + SO	21.5 bcd	3.7 bcde	14.1 ab	6.3 a	3.51 ab
KTS + SO	21.5 bcd	4.2 abcd	13.9 ab	6.3 a	3.52 ab
Regalia + SO	21.2 cde	4.2 abcd	13.7 b	6.4 a	3.50 ab
Urea + SO	19.9 f	4.4 ab	13.8 ab	5.5 a	3.50 ab
SO	20.4 ef	4.3 abc	13.7 ab	5.9 a	3.49 ab
NAA + C + R	21.1 cde	3.6 cde	14.6 ab	7.6 a	3.46 ab
6-BA + C + R	21.5 bcd	3.8 bcde	14.8 a	8.1 a	3.49 b
Control	20.3 ef	4.3 abcd	13.8 ab	5.8 a	3.50 ab

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Subsample of 5 fruit per replicate tree used in 2018. Subsample of 20 fruit per replicate tree used in 2019.

Table 3-10: Blossom Thinning Agent Influence on Packout (%) from Fruit Russet Incidence/Severity in 'Honeycrisp' and 'Cripps Pink' (Virginia, 2019)[z,y]

Treatment	U.S. Extra Fancy & U.S. Fancy Grades	U.S. No. 1 Grade	U.S. Utility Grade
		'Honeycrisp' 2019	
ATS	47 abc	50 a	3 ab
LSS 1	32 abc	60 a	8 ab
LSS 2	52 abc	48 a	0 b
KB	31 abc	60 a	9 ab
KN	-	-	-
KTS	68 a	32 a	0 ab
Regalia	32 abc	63 a	5 ab
Urea	-	-	-
ATS + SO	52 abc	48 a	0 b
LSS 1 + SO	22 bc	58 a	20 a
LSS 2 + SO	15 c	70 a	15 ab
KB + SO	-	-	-
KN + SO	-	-	-
KTS + SO	53 abc	47 a	0 b
Regalia + SO	42 abc	53 a	5 ab
Urea + SO	-	-	-
SO	38 abc	56 a	6 ab
NAA + C + R	57 ab	40 a	3 ab
6-BA + C + R	55 ab	45 a	0 b
Control	63 a	37 a	0 b
		'Cripps Pink' 2019	
ATS	87 a	13 bc	0 c
LSS 1	97 a	3 c	0 c
LSS 2	87 a	13 bc	0 c
KB	37 bc	55 ab	8 b
KN	57 abc	43 abc	0 c
KTS	83 a	17 bc	0 c
Regalia	58 abc	42 abc	0 c
Urea	77 ab	23 abc	0 c
ATS + SO	80 a	20 bc	0 c
LSS 1 + SO	87 a	13 bc	0 c
LSS 2 + SO	77 ab	23 abc	0 c
KB + SO	18 c	64 a	18 a
KN + SO	88 a	12 c	0 c
KTS + SO	88 a	12 c	0 c
Regalia + SO	77 ab	22 abc	1 bc
Urea + SO	90 a	10 c	0 c
SO	85 a	15 bc	0 c
NAA + C + R	75 ab	25 abc	0 c
6-BA + C + R	68 ab	32 abc	0 c
Control	85 a	15 bc	0 c

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Packout according to fruit russet incidence/severity was determined using a 20-fruit subsample per replicate and assigning each individual fruit into a USDA apple grade based upon the incidence/severity of russet on the fruit as according to the USDA apple grade standards.

Table 3-11: Blossom Thinning Agent Influence on Leaf Area (%) Affected by Phytotoxicity in 'Honeycrisp' and 'Cripps Pink' (Virginia, 2019)[z,y]

Treatment	*'Honeycrisp' 2019*	*'Cripps Pink' 2019*
ATS	3.6 a	8.0 a
LSS 1	0.0 b	0.3 b
LSS 2	0.1 b	0.3 b
KB	0.0 b	0.5 b
KN	-	0.3 b
KTS	0.1 b	0.8 b
Regalia	0.2 b	1.3 b
Urea	-	0.7 b
ATS + SO	4.2 a	8.5 a
LSS 1 + SO	0.3 b	0.3 b
LSS 2 + SO	0.0 b	0.4 b
KB + SO	-	8.6 a
KN + SO	-	0.5 b
KTS + SO	0.5 b	1.3 b
Regalia + SO	0.5 b	0.3 b
Urea + SO	-	0.4 b
SO	0.0 b	0.2 b
NAA + C + R	0.1 b	0.0 b
6-BA + C + R	0.1 b	0.3 b
Control	0.0 b	0.3 b

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.
[y]Phytotoxicity evaluated by selecting four leaf spurs per replicate and visually assessing the percentage of chlorotic/necrotic leaf area present on the upper surface area of the leaves present on each spur. Phytotoxicity expressed as the percentage of leaf area affected by chlorosis and/or necrosis.

Table 3-12: Blossom Thinning Agent Influence on Return Bloom (%) in 'Honeycrisp' and 'Cripps Pink' (Virginia, 2018)[z,y]

Treatment	*'Honeycrisp' 2018*	*'Cripps Pink' 2018*
ATS	3 de	63 a
LSS 1	15 bcde	53 a
LSS 2	0 e	76 a
KB	43 abcd	60 a
KN	-	-
KTS	0 e	67 a
Regalia	1 de	72 a
Urea	-	-
ATS + SO	12 bcde	44 a
LSS 1 + SO	7 cde	58 a
LSS 2 + SO	4 de	69 a
KB + SO	65 a	68 a
KN + SO	-	-
KTS + SO	5 de	63 a
Regalia + SO	4 de	71 a
Urea + SO	-	-
SO	2 de	65 a
NAA + C + R	50 ab	69 a
6-BA + C + R	49 abc	59 a
Control	1 de	64 a

[z]Mean separation within columns by Tukey's honest significant difference test in JMP Pro 14 at $\alpha = 0.05$.

[y]Return bloom determined by selecting 2-9 limbs/branches and counting 50 buds on 2-year wood per replicate and evaluating the portion of buds which were floral vs. vegetative. Return bloom expressed as the percentage of buds which were floral.