Virginia Cooperative Extension
Virginia Tech • Virginia State University

Publication SPES-134P

Crop Load Management in Commercial Apple Orchards: Chemical Fruit Thinning

W. Chester Allen, Graduate Research Assistant, Horticulture,
Alson H. Smith Jr. Agricultural Research and Extension Center, Virginia Tech
Dr. Sherif M. Sherif, Assistant Professor, Horticulture,
Alson H. Smith Jr. Agricultural Research and Extension Center, Virginia Tech

Introduction

Chemical fruit thinning is commonly practiced in commercial apple orchards to manage and regulate the number of fruit per tree (crop load), which improves fruit quality and production. In this management practice, growers typically apply several sprays of chemical thinners to orchard blocks in the spring when the fruit is small and just beginning to develop. These thinning spray applications result in the abscission, or detachment, of some of the fruit. This intentional fruit abscission or shedding is commonly referred to as "thinning."

Currently, chemical fruit thinning is the major means and standard practice of crop load management in apple orchards on the East Coast. However, results can occasionally be variable due to many factors, including temperature, solar radiation, and cultivar, which can affect the efficacy of the chemical thinners. These variations can cause either under-thinning or overthinning. As a result, proper chemical fruit thinning has come to be referred to as an "art" by many growers.

Successful chemical fruit thinning in apple orchards depends on multiple factors but still relies heavily upon a grower's knowledge and experience. The purpose of this publication is to provide commercial apple growers with more insight into the predictability of using chemical thinners to increase the chances of achieving their desired thinning outcomes.

Purpose of Chemical Fruit Thinning

Chemical fruit thinning improves crop production in several ways. First, thinning increases the fruit size of the current season's crop. This occurs by allowing carbohydrates produced in the trees to be channeled to fewer fruit which, in turn, increases the fruit size. As a result, proper chemical fruit thinning prevents the production of small and poor-quality fruit that would otherwise occur. Second, adequate thinning can improve fruit quality traits such as color. This occurs by increasing light and nutrient availability for improved color development. Third, thinning increases long-term crop production by improving the return bloom for the following year. In apple, as with many other deciduous fruit trees, initiation and differentiation of flower buds for the following growing season occurs soon after bloom in the current season. Therefore, reducing the number of fruit by chemical thinning allows more photoassimilates (nutrients) to be targeted toward the formation of more flower buds for the next year. Fourth, chemical fruit thinning is also used to prevent biennial bearing, which occurs when trees produce a heavy crop one year, thereby taking photoassimilates away from the forming flower buds for next year. This in turn causes the following year to have a light crop since the flower buds did not receive adequate nutrients for proper development and formation. Some varieties such as Fuji and York Imperial are more prone to biennial bearing than other varieties. Chemical fruit thinning breaks the biennial bearing cycle by causing the tree to develop a sufficient number of fruiting spurs for the following year. With proper chemical fruit thinning, growers can expect to optimize the current season's crop with regard to yield, fruit size, and color while ensuring the following year's crop by enhancing return bloom and annual bearing.

www.ext.vt.edu

Produced by Virginia Cooperative Extension, Virginia Tech, 2019

VT/0519/SPES-134P

Effectiveness of Chemical Fruit Thinning

Many factors collectively influence the effectiveness of a thinning spray. Such factors include but are not limited to the chemistry of thinning materials, application rates, fruit diameter at the time of application, use of oils and surfactants in thinning sprays, weather, cultivar, tree age, and previous pruning. Since all of these factors influence the effectiveness of thinning spray applications, they all should be carefully considered beforehand.

Chemical Selection and Rates

The selection of chemicals for thinning has a significant influence on thinning effectiveness. The efficacy of chemical thinners varies according to the fruit diameter at application time. The most effective chemical thinners can be very aggressive, causing the most thinning, while the least effective chemical thinners are only slightly aggressive, causing the least thinning. Consequently, chemical thinners should be selected according to the diameter of the fruit at the time of application and the desired level of thinning.

Additionally, the rates of chemical thinners can also have an impact. For most chemical fruit thinners, higher rates will result in a greater thinning action, and lower rates will cause less fruit to be thinned. When selecting chemical thinners and rates, always read and follow the label. Furthermore, it is important to note that the proper rate is also determined by the carbohydrate status of the tree and the variety, which will be covered below.

Fruit Diameter and Application Timing

The diameter of the fruit at the time of application is one of the most important factors in determining the efficacy of thinning sprays. Chemical thinners vary in their efficacy according to different fruit size. Minor differences in fruit diameter can often determine if a chemical thinner is effective or ineffective. Chemical fruit thinning sprays are generally applied and completed between petal-fall and 25-millimeter fruit diameter. However, most fruit thinning sprays should be completed by the time fruits reach 15 millimeters in diameter; larger fruits are hard to thin with most chemical thinners.

Use of Oils and Surfactants in Thinning Sprays

The addition of spray oils or surfactants to tank mixtures of chemical thinners can significantly improve the effectiveness of thinning sprays. Oils and surfactants increase the leaf absorption of the chemical thinners, which increases the thinning response. Consequently, growers should use oils and surfactants with caution in thinning sprays unless heavy thinning is desired

Weather

Weather conditions immediately before, during, and after chemical thinner spray applications can have a profound impact on the efficacy of chemical thinners. The two main weather conditions that impact thinning sprays are light and temperature. Low levels of sunlight (cloudy weather) for several days before and after applications can greatly increase the thinning response. The occurrence of continuous cloudy weather after thinning spray applications has a significant potential to increase the level of thinning action (Forshey, 1986), while sunny weather will decrease the impact of thinning sprays. With regard to temperature, warm temperatures (greater than 85 degrees F) around the time of application will result in a greater thinning action, since warmer temperatures increase chemical absorption of the thinners into the foliage and fruit (Byers, 2002). However, cooler temperatures (lower than 65 degrees F) around the time of application will decrease absorption and consequently reduce the level of thinning action.

Light and temperature also influence the effectiveness of thinning sprays through an indirect process. Together, light and temperature affect carbohydrate production within the trees. In turn, the trees' carbohydrate levels impact the efficacy of the chemical thinners, with lower carbohydrate levels causing an increase in the thinning action. The impact of sunlight and temperature on tree carbohydrate production and the ability to thin orchard blocks is described in table 1. In addition, table 2 demonstrates the combined influence of sunlight and temperature on the level of difficulty in thinning based on weather conditions at the time of thinning spray applications. Combined light and temperature effects can lead to some of the most challenging situations, with warm and cloudy conditions leading to easy-to-thin situations, and cool and sunny conditions leading to very-hard-to-thin situations.

Table 1. Impact of light and temperature on tree carbohydrate production and the ability to thin fruit with chemical thinners.

Weather	Carbohydrate Production	Ability to Thin
Sunny	High	Hard to Thin
Cloudy	Low	Easy to Thin
Cool (< 65° F)	High	Hard to Thin
Warm (> 85° F)	Low	Easy to Thin

Table 2. Combined influence of light and temperature on the ability to thin fruit with chemical thinners.

	Cool (< 65° F)	Warm (> 85° F)
Sunny	Very Hard to Thin	Moderate Ability to Thin
Cloudy	Moderate Ability to Thin	Very Easy to Thin

Fruit Variety

The variety can also have a large impact on the effectiveness of thinning sprays. Certain varieties are more responsive to chemical thinners; other varieties are less responsive. Table 3 categorizes several major varieties according to ease of thinning.

Table 3. Easy, moderate, and hard-to-thin apple varieties.

Easy to Thin	Moderate Ability to Thin	Hard to Thin
Granny Smith, Jonagold, Jonathon, Cripps Pink, McIntosh, Idared, Cortland, Ginger Gold, Mutsu, Northern Spy, Zestar	Ambrosia, Honeycrisp, Cameo, Empire, Red Delicious, Braeburn, Stayman-Winesap	Gala, Golden Delicious, Rome, Fuji, Newton Pippin, York Imperial, Winesap, Lodi, Macoun

Block Health and Age

The characteristics of individual blocks can also have a bearing on the efficacy of chemical thinners. In general, healthy, well-maintained, and vigorous orchard blocks are more difficult to thin than blocks that suffer from pest infestation, disease, improper nutrient management, winter injury, or other stresses. Additionally, thinning is typically harder to achieve in mature blocks than in young blocks, which can be easily overthinned. Younger trees are more susceptible to overthinning because they have proportionally fewer leaves, or vegetative structures, compared with fruits, or reproductive structures. This in turn results in carbohydrate deficiency and high sensitivity to thinning materials when compared with older trees.

Pruning

Previous dormant pruning can also affect the efficacy of thinning sprays. Extensive dormant pruning could leave very few fruit buds on a tree. Consequently, less fruit will set during the blossom period, and thinning sprays may not even be necessary. If thinning is needed, it could be more difficult to achieve after previous dormant pruning because the carbohydrate reserves will be relatively higher. However, refraining from dormant pruning could result in a heavy fruit set in which multiple thinning sprays would likely be needed to achieve an appropriate fruit load.

Chemicals Suitable for Fruit Thinning

Many chemicals are available for use in chemical fruit thinning (table 4). Most of the chemicals used in post-bloom fruit thinning are plant growth regulators (PGRs). However, insecticides, such as carbaryl, for example, that interfere with carbohydrate metabolism and accumulation are also used in combination with PGRs to boost thinning efficacy. In most cases, thinning spray applications consist of several chemical thinners used in combination with each other.

Table 4. Common chemical thinners, trade names, and manufacturers.

Common Name	Common Trade Names	Manufacturer
NAA	PoMaxa	Valent USA
	Fruitone L	Valent USA
	Refine 3.5 WSG	Fine Americas
6-BA	Maxcel	Valent USA
	Exilis 9.5 SC	Fine Americas
NAD	Amid-Thin W	Valent USA
Carbaryl	Sevin 4F	NovaSource
	Sevin XLR Plus	NovaSource
	Carbaryl 4L	Drexel Chemical Company
Ethephon	Motivate	Fine Americas
	Ethephon 2SL	Adama Essentials

1-Naphthalenacetic Acid (NAA)

Naphthalenacetic acid (NAA) is a plant growth regulator commonly used for thinning apples. Common trade names of NAA include PoMaxa, Fruitone L, and Refine 3.5 WSG. It is currently believed that NAA applications cause fruit abscission by reducing synthesis of the hormone auxin in the fruit, which limits seed development and carbohydrate demand, resulting in fruit abortion (Kolaric, 2010). This thinner is most effective when applied between petal fall and 15-millimeter fruit diameter. Little or no thinning action results when applied after fruit grows beyond 15 millimeters. For best results, NAA is commonly combined with carbaryl or 6-benzyladenine (6-BA) and applied when fruit is between 7 and 12 millimeters in diameter.

To prevent the formation of pygmy fruits (small misshapen fruit), the combination of NAA and 6-BA should not be applied to Red Delicious or Fuji. Furthermore, this combination should not be applied when temperatures are too cool for thinning.

Another important characterization of NAA is its ability to reduce the size of mature fruit. Studies have shown that NAA can reduce overall fruit size of the harvested crop when compared with other chemicals used in fruit thinning (Greene and Lakso, 2013). Growers should therefore consider using another chemical thinner, such as 6-BA, when thinning small-fruited cultivars, such as Gala and Ginger Gold, to maximize fruit size if desired by current markets.

6-Benzyladenine (6-BA)

Another common plant growth regulator used in thinning is 6-BA. This chemical thinner stimulates fruit drop by enhancing the length of the shoot, leading to increased competition for carbohydrate between shoots and fruits, between clusters, and between fruits of the same cluster. Trade names for 6-BA include Maxcel and Exilis 9.5 SC. For the best results, 6-BA should be combined with carbaryl and applied when fruit is between 7 and 15 millimeters in diameter. Growers should avoid using 6-BA when temperatures are below 68 degrees F because the efficacy of 6-BA decreases significantly with cooler temperatures (Peter, 2018). In a recent study conducted at the University of Massachusetts, 6-BA was rated as the weakest chemical thinner when used alone (Clements and Autio, 2011). Unlike NAA, 6-BA has been observed to increase cell division and consequently fruit size as compared with other chemical fruit thinners (Wismer, Proctor, and Elfving, 1995).

1-Naphthaleneacetamide (NAD)

NAD is another plant growth regulator that can be utilized for thinning. The most available and common trade name is Amid-Thin W. It is typically applied alone between petal fall and 15-millimeter fruit diameter. To prevent the chances of pygmy fruit formation, NAD should not be applied to Red Delicious or Fuji after petal fall (Pfeiffer, 2019). Furthermore, NAD should not be used in thinning spray applications where the spray volume is less than 100 gallons per acre, as decreased efficacy may result (Peter, 2018).

Carbaryl

Carbaryl is a carbamate insecticide that also functions as a thinning agent. Common trade names for carbaryl include Sevin 4F, Sevin XLR Plus, and Carbaryl 4L. Carbaryl is commonly applied as a chemical thinner in one of two ways. First, it can be applied as a carbaryl-only thinning spray between petal fall and 15-millimeter fruit diameter. However, it is more commonly applied in combination with either NAA or 6-BA when the fruit is between 7 and 15 millimeters in diameter. Unlike growth regulator thinners such as

NAA, carbaryl is not very rate responsive when used alone; increases in carbaryl rates will not increase thinning activity (Forshey, 1986). It is also important to recognize that because carbaryl is an insecticide, it must not be applied for thinning when bees are still in the orchard or when any flowers remain open (Pfeiffer, 2019).

Ethephon

Ethephon is a plant growth regulator that can be used as a thinning spray on larger fruit. Common trade names for ethephon include Motivate and Ethephon 2SL. Most commonly, ethephon is applied as a "rescue thinning" treatment if the first thinning sprays are not sufficient. It is most commonly used when fruit size is between 18 and 26 millimeters in diameter. When aggressive thinning is needed, it can be combined with carbaryl or NAA. Growers should use caution when applying ethephon as it can result in severe overthinning, particularly if high temperatures (greater than 90 degrees F) or heavy cloud cover occur after application.

Deciding When and How to Apply Thinning Sprays

Deciding when to apply thinning sprays, which ones to use, and at what rates are among the most important decisions affecting the crop load in each season. Consequently, it is vital to seriously consider and work through the details of application for successful thinning.

Application Timing

The timing of chemical thinning spray application should be determined primarily according to fruit growth stage. Tables 5, 6, and 7, below, list thinning sprays according to fruit growth stage. To obtain successful thinning results, growers should use chemical thinners or combinations thereof that are effective at the appropriate growth stage at the time of application.

Selection of Chemical Thinners

The selection of chemical thinners should be first determined according to the growth stage of the fruit. Because chemical thinner efficacy is highly dependent on the growth stage, this is the most important selection criteria. Additionally, the post-application thinning response of different chemical thinners should be evaluated by the grower because some chemical thinners, or combinations thereof, are more aggressive than others. Chemical thinners should be carefully selected according to the effectiveness at application time, the intended level of thinning action desired, and past experience in carefully monitored blocks.

Rates of Chemical Thinners

The rate of chemical thinners is another important aspect that growers need to carefully consider. Most chemical thinners except for carbaryl and ethephon have rates listed in parts per million (ppm) and fluid ounces (fl oz) according to the spray volume. The labels for each chemical thinner commonly supply a conversion chart from ppm to fluid ounces based on the spray volume (gallons per acre). The labels for most chemical thinners typically list a broad range of rates. In most instances, the level of thinning action is dependent on the rates. When lower rates are used, a reduced thinning action can be expected, and when

Table 5. Effective thinning sprays at petal fall to 5 mm fruit diameter.

Effective thinning sprays at petal fall to 5 mm fruit diameter.		
Thinning Sprays	Application Rates/Acre	Thinning Action
1) NAA	0.5-4.0 fl oz	Moderately Aggressive
2) NAD	0.25-0.5 lbs	Moderately Aggressive
3) Carbaryl	1-3 quarts	Moderately Aggressive
Effective thinning sprays at petal fall to 5 mm fruit diameter.		
Thinning Sprays	Application Rates/Acre	Thinning Action
1) NAA + 6-BA	0.5-4.0 fl oz + 48-128 fl oz	Moderately Aggressive
2) NAA + Carbaryl	0.5-4.0 fl oz+ 1-3 quarts	Very Aggressive
3) 6-BA + Carbaryl	48-128 fl oz + 1-3 quarts	Moderately Aggressive
4) NAA	0.5-4.0 fl oz	Moderately Aggressive
5) 6-BA	48-128 fl oz	Slightly Aggressive
6) NAD	0.15-0.5 lbs	Slightly Aggressive
7) Carbaryl	1-3 quarts	Slightly Aggressive
Effective thinning sprays at 16 mm-25 mm fruit diameter.		
Thinning Sprays	Application Rates/Acre	Thinning Action
1) Ethephon	0.5-4.0 pints	Moderately Aggressive
2) Ethephon + Carbaryl	0.5-4.0 pints + 1-3 quarts	Very Aggressive

Application rates are based upon a concentrate spray volume of 100 gallons per acre and product labels at the time of publication. When applying chemical thinners, follow the rates indicated on the labels of the products that you are using. Always follow the label when applying chemical thinners. The degree of thinning action is listed according to the authors' personal field experiences. The degree of thinning action may vary from orchard to orchard and block to block. Addition of oil and/or non-ionic surfactants to tank mixtures can significantly increase the efficacy of thinning materials. Growers should use oils and surfactants with caution unless heavy thinning is desired.

higher rates are used, a greater thinning action occurs. When deciding the rates to apply, carefully consider the number of set fruit (crop load), factors that can affect the efficacy (such as variety, light, temperature, etc.), and always follow the label.

Carbohydrate Thinning Model

A tool that can aid growers in making chemical thinning decisions is the Cornell Apple Carbohydrate Thinning Model (Cornell University, 2018). This model was generated by scientists at Cornell University, and it works to improve thinning sprays by mathematically accounting for the carbohydrate balance of the trees caused by influence of weather factors (solar radiation and temperature). The model can be easily operated and used by growers, and is accessible at the Network for Environment and Weather Applications (NEWA) webpage hosted by Cornell University. It is available at the following web address: http://newa.cornell.edu/index.php?page=apple-thin. To use the model, you should have a representative weather station located close to your orchard. When using the model, first select your state from the drop-down menu. Next, select the weather station closest to your orchard blocks. If you wish to use your own weather station, there are detailed instructions on the NEWA webpage on how to upload your weather station data. After selecting the closest weather station to your orchard, enter your current date and click the "continue" button. This will take you to a new page where you will then need to enter the green tip date and bloom date of the orchard block you wish to run the model for. Finally, click the "calculate" button to access the model's thinning recommendations. This will take you to a new page with a table. The column on the far right titled "thinning recommendations" will provide chemical thinner rate recommendations based upon the weather forecast. Figure 1 provides a step-by-step

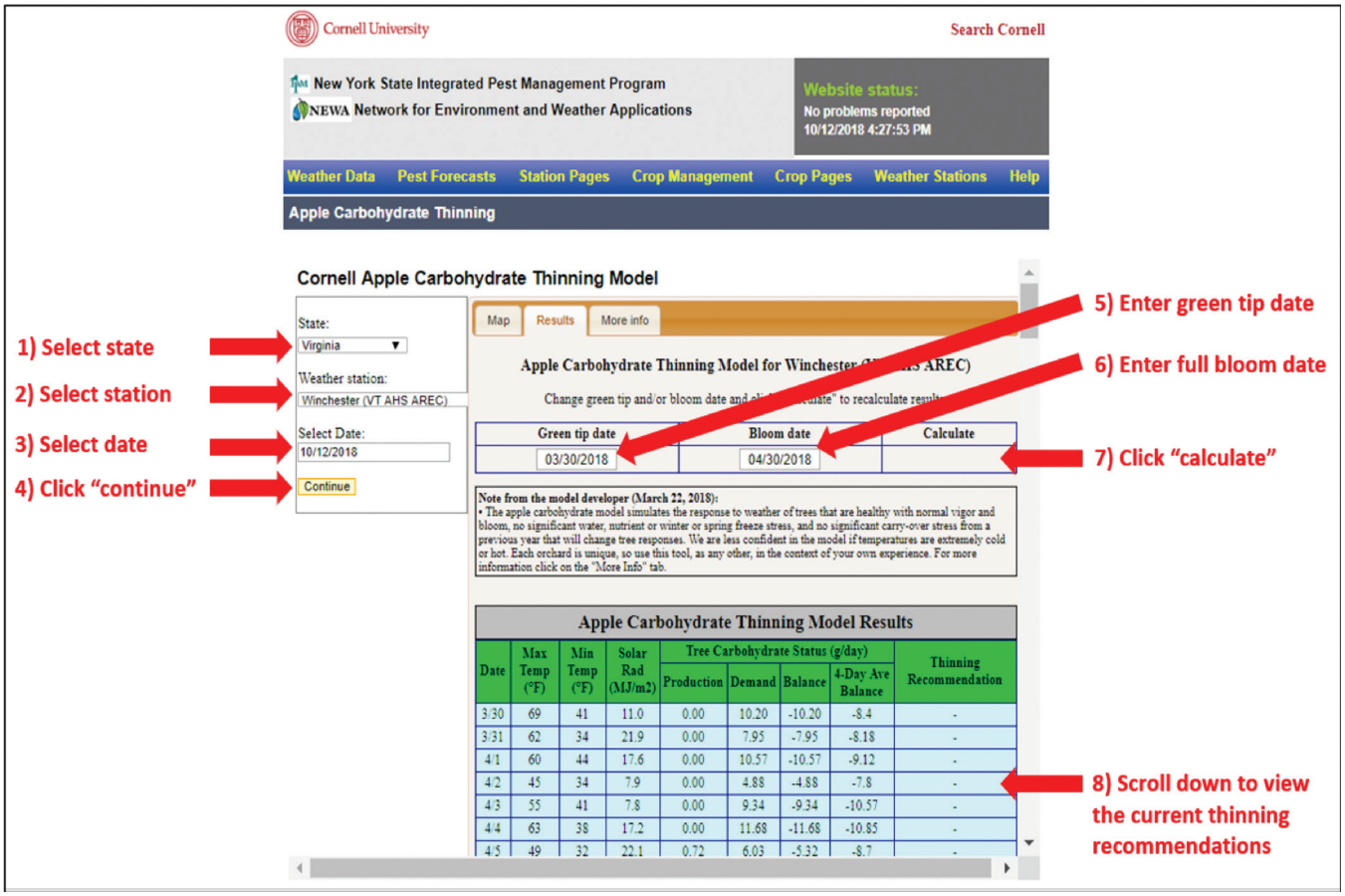

Figure 1: Steps for the using the carbohydrate thinning model.

process for using the model. Although the model can be a very useful resource to growers, it is important to remember that the model approximates tree sensitivity to chemical thinners (Lakso, Robinson, and Greene, 2007). Consequently, common sense and good judgment should be used when viewing the model's recommendations.

Conclusion

Chemical fruit thinning is currently the major means of crop load management by Virginia apple growers and other apple growers across the East Coast. The practice of chemical fruit thinning is highly relied upon by producers to increase fruit size, enhance fruit color, increase return bloom, and prevent biennial bearing. Many factors can affect chemical fruit thinning, such as temperature, light, variety, tree vigor, etc. Consequently, growers must account for these many factors when making thinning spray applications. Additionally, growers will need to carefully evaluate application timing, chemical thinner selection, and rates in order to make an effective thinning spray that will obtain the best possible thinning response. Furthermore, tools such as the carbohydrate thinning model are now available to assist growers in making thinning spray decisions. Although there is much progress and many new developments in the practice of chemical fruit thinning, it remains an acquired skill, closely resembling an art, which is developed from acquired field experience, knowledge, and wisdom.

References

Byers, R. E. 2002. "Influence of Temperature and Darkness on Apple Fruit Abscission and Chemical Thinning." *Journal of Tree Fruit Production* 3(1):41-53.

Clements, J. M., and W. R. Autio. 2011. "Looking into the Crystal Ball – Apple Fruit Thinning Without Carbaryl." University of Massachusetts

Center for Agriculture, *Fruit Notes* 76(2):5-8. http://umassfruitnotes.com/v76n2/a2.pdf.

Peter, K.A., publication coordinator, 2018. *Penn State Tree Fruit Production Guide*. Pennsylvania State University.

Cornell University.n.d."Cornell Apple Carbohydrate Thinning Model." Accessed November 28, 2018. http://newa.cornell.edu/index.php?page=apple-thin.

Forshey, C. G. 1986. "Chemical Fruit Thinning of Apples." Cornell University, *New York's Food and Life Sciences Bulletin*. 116:1-7. https://ecommons.cornell.edu/bitstream/handle/1813/5147/FLS-116.pdf?sequence=1&isAllowed=y.

Greene, D. W., and A. N. Lakso. 2013. "Prediction of Initial Set and the Thinning Response to Postbloom Chemical Thinners on Apples." *International Journal of Fruit Science*, 13(4):430-440.

Kolaric, J. 2010. "Abscission of Young Apple Fruits (Malus domestica Borkh.): A Review." *Agricultura*, 7:31-36.

Lakso, A. N., T. L. Robinson, and D. W. Greene. 2007. "Using an Apple Tree Carbohydrate Model to Understand Thinning Responses to Weather and Chemical Thinners." *New York Fruit Quarterly*, 15(3):17-20. http://nyshs.org/wp-content/uploads/2016/10/Using-an-Apple-Tree-Carbohydrate-Model-to-Understand-Thinning-Responses-to-Weather-and-Chemical-Thinners.pdf.

Pfeiffer, D. G., publication coordinator. 2019. *Spray Bulletin for Commercial Tree Fruit Growers*. Virginia Cooperative Extension, West Virginia University, and University of Maryland Extension. Publication 456-419.

Wismer, P. T., J. T. A. Proctor, and D. C. Elfving. 1995. "Benzyladenine Affects Cell Division and Cell Size During Apple Fruit Thinning." *Journal of the American Society for Horticultural Science*, 120(5):802-807. https://journals.ashs.org/jashs/view/journals/jashs/120/5/article-p802.xml.