Some Uses of Plant Growth Regulators in Modern Apple Production Systems

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Summary

Plant growth regulators are used in all aspects of modern apple production systems from the use of branching agents in the nursery to postharvest application of the ethylene action inhibitor 1-MCP to enhance fruit quality after storage. Their effective use is dependent on a thorough knowledge not only of their mode of action, but also of the plant processes that they influence. This report describes how plant growth regulators can be used most effectively in modern apple production systems in four key areas: (i) crop load management, (ii) control of russet, (iii) promotion of flower bud formation in the “on” year of a biennial bearing cycle, and (iv) control of pre harvest fruit drop. The legal use of plant growth regulators will be governed by local, state and federal laws. Some of the plant growth regulators mentioned in this article may not be legally used in your state. Always check to make sure that the chemical products you apply to your crop are legally registered for that use. It is also important to check the label to make sure that the amount of active ingredient does not exceed the legal limit for your state.
How Carbohydrates and Chemical Thinners Interact to Thin Apples

Shading studies in a variety of fruiting plants have demonstrated the importance of an adequate supply of carbohydrates to developing flowers and fruit during the fruit set process. Shade treatments imposed during or soon after bloom have been shown to reduce fruit set in apples, peaches and grapes. Shade treatments are presumed to create a transient reduction in the supply of carbohydrates to developing fruit during a period when the fruit are sensitive to such a stress. Shading studies have helped to explain why even relatively short periods of cloudy weather can greatly increase the activity of chemical thinners in apple.

In apple, shoot growth has priority over fruit growth for carbohydrate partitioning when light levels during the first 40 d after bloom are limiting. A carbon balance modeling approach was used to identify a high probability of fruit production being limited by the development of a carbohydrate deficit in the tree during the 2-3 week period following bloom. A carbon balance modeling approach has been used help predict and explain chemical thinning responses.

Cloudy weather is not the only environmental condition that will reduce the amount of carbohydrates available to developing fruit in an apple tree. In 2010 there were widespread reports of over-thinning across the southeastern US. In many cases this was severe over-thinning; in some areas all cultivars dropped all their fruit while in others the aggressive thinning responses and heavy fruit drop were specific to only one or two cultivars. In Henderson County, NC, many ‘Red Delicious’ and ‘Gala’ trees were significantly over-thinned. In research plots at the MHCREC, Mills River, we observed that ‘Spur Red Delicious’ trees that had been sprayed with a post bloom thinner on 30 April when fruit were 10 mm in diameter were practically de-fruited regardless of the combination of thinning chemicals used, whereas unthinned control trees in the same trial set heavy crops of fruit (Fig. 1). Trees that were thinned with a petal fall Sevin XLR application on 21 April in the same study thinned down to an acceptable commercial crop load. It was also interesting to note that we did not see any additional thinning if the trees were shaded for one week following the petal fall Sevin XLR spray compared to Sevin XLR alone, providing evidence to support the view that fruit are relatively insensitive to a carbohydrate deficit immediately following bloom.
How could a conventional thinning spray of 6-BA + carbaryl applied when the fruit were 10 mm in diameter end up practically defruiting ‘Spur Red Delicious’, especially after initial fruit set had been high and the fruit appeared to be growing strongly? As was the case in our thinning study, the reports of severe over-thinning across the southeast were associated with trees that were chemical thinned around 30 April. Temperature and light records during this period indicated that while the daily maximum temperatures were generally adequate, the daily sunlight levels were low, and the night time minimum temperatures were unusually high (66°F) on 2 May and 3 May. These light and temperature data were used to run the ‘Malusim’ carbon balance model after the fact. Output from the model indicated there had been a severe carbohydrate deficit in the tree on 2 May and 3 May, immediately following thinner application (Fig. 2). Chemical thinners that were applied either before or after this period were certainly effective, but did not result in over-thinning.

The carbon balance model provided a reasonable explanation for why chemical thinning sprays that were applied around May 30 resulted in severe over-thinning in many orchards in the southeast in 2010. While it’s academically interesting to look back and review why this over-thinning occurred, the explanation provides little comfort to the many growers who had light crops as a consequence. It would be more useful to run the carbon balance model using short term light and temperature forecasts as a tool to predict thinning responses. Over the past several seasons the model has been used in exactly this way to provide growers with a prediction of chemical thinner efficacy in various regions including New York, Michigan, and North Carolina. Of course, the accuracy of a prediction system that relies upon light and temperature forecasts will depend on the accuracy of those forecasts.

Figure 2. Daily carbon balance of apple trees in 2010 in North Carolina according to the Malusim model. The model was kindly run by Dr. Terence Robinson using light and temperature data from Henderson County, NC.
Shade and Chemical Thinners Slow Down the Rate of Fruit Growth

One of the earliest responses of apple fruit to shading treatments is a reduction in the rate of fruit growth. Most chemical thinners will also result in a measurable reduction in the rate of fruit growth during the first week following their application. In fact, this slowing down of the fruit growth rate can be used to predict the chemical thinning response. This method assumes that any fruit which are growing at a rate less than 50 percent of the fastest growing fruit on the tree will drop. A post bloom thinning application of 6-BA and carbaryl to ‘Gala’ at the 10 mm stage increased the number of slow-growing fruits compared to fruit on unthinned trees (Fig. 3). These observations imply that chemical thinners can have a rapid negative effect on the level of nutrients or carbohydrates available for fruit growth. Recent studies have suggested that one of the primary effects of chemical thinners such as 6-BA or NAA is to create a nutrient or carbohydrate stress that is perceived in the cortex of the fruit. In the case of 6-BA, stimulation of shoot and lateral bud growth following application was hypothesized to result in increased competition between the fruit and the shoots for stored carbohydrates. This increased competition was perceived in the weaker fruitlets as a nutritional stress that slowed their growth even further. NAA, on the other hand, was found to suppress leaf photosynthesis within 10 minutes of application, and also to reduce the expression of genes involved in the transport of carbohydrates (sorbitol) from leaves to fruit.

So it would seem that environmental conditions such as low light levels and high night time temperatures, and at least some thinning chemicals, may have a common primary mode of action i.e. they rapidly create a carbohydrate deficit in the tree that is perceived in the fruit. The weakest/smallest fruit are more sensitive to this carbohydrate deficit and respond by exhibiting a more pronounced reduction in growth rate compared to stronger/larger fruit.

The Malusim carbon balance model may prove to be an excellent tool for achieving more predictable chemical thinning responses. By estimating the current daily carbon balance of an apple tree and predicting the carbon balance for 3-5 days ahead, the model provides an indication of the level of carbohydrates available for fruit growth. Chemical thinners such as 6-BA and NAA which are believed to act primarily through creation of a transient carbohydrate stress will reduce the daily carbon balance in the tree. If the reduction in carbon balance following application of a chemical thinner coincides with a period of natural carbon surplus in the tree then the effects of the thinner are expected to be nil or minimal. However, if the thinner application coincides with a period of mild or even moderate carbon deficit then the combined effects will result in adequate thinning. The problem of over-thinning will occur if thinners are
applied in conjunction with a period of severe carbon deficit, as we observed on many orchards across the southeast that were thinned around 30 April in 2010.

While chemical thinners may reduce the carbon balance within the tree, the extent and duration of their negative effects on whole-tree carbon balance are not well understood at this time. As has been mentioned by many workers in this field in the past, the effects of a chemical thinner are dependent on a myriad of factors including water rates and spray coverage, droplet size, drying times, the inclusion of wetting agents or surfactants in the spray tank, uptake and metabolism in the leaf, etc. Because the relative contributions of each of these factors to the effect that a thinning spray will have on whole-tree carbon balance will be different each time a thinner is applied, it is unlikely that the final thinning response will be predicted with a high degree of accuracy. Nevertheless, a carbon balance modeling approach to chemical thinning will provide growers with a good indication of the likelihood of over-thinning or under-thinning.
Russet, Gibberellins and a Convenient Truth About Apogee (Regalis)

Russet and scarf skin are surface defects of apple fruit that can reduce fresh market value. Fruit with an aggregate of more than 10 percent of the surface area covered with russet are excluded from both the US Extra Fancy and US Fancy grades, and fruit with an aggregate area of russet exceeding 25 percent of their surface are excluded from the US No. 1 grade. Major differences in russet susceptibility exist between varieties or even between sports or sub clones of a single variety. The cultivars ‘Golden Delicious’, ‘Gala’, and ‘Fuji’, collectively representing 32 percent of current US apple production, are generally considered to be russet susceptible.

What Causes Russet?

Russet in ‘Golden Delicious’ is related to abnormal development of the cuticle which is a layer of fatty material covering the epidermal cells. Non-russeted portions of ‘Golden Delicious’ fruit were found to have either a thicker, more convoluted cuticle or a double layer of cuticle compared to russeted portions. Russet was first observed on ‘Golden Delicious’ apples 35-45 days after full bloom, coincident with a rapid increase in the width of epidermal cells. Epidermal cells of russeted fruit increased in width more rapidly than epidermal cells in non-russeted fruit. ‘Golden Delicious’ russet was caused by a weakness in cuticle formation that led to micro-cracks in the cuticle, these micro-cracks expanded further with fruit enlargement. Exposure of the hypodermal cells beneath micro-cracks to air results in formation of a cork cambium that is known as russet.

Russet may be caused by different stimuli including fungi or yeasts on the fruit surface, insect feeding, frost around the time of bloom, high humidity and precipitation, particularly during the period from 15-20 days after bloom, or various crop protection sprays. It is likely that these factors may interact with each other to alter the final russet severity. To illustrate the interaction between environmental conditions and a chemical spray, the data in Figure 2 shows the incidence of russet on ‘Gala’ apples in response to two different climatic regions of New Zealand and to multiple applications of lime sulfur as a bloom thinning spray. Lime sulfur sprays increased the incidence of russet two-fold in both regions. However, the overall incidence of russet was much lower in the region with a drier, more continental climate (Otago) compared to the region with a wetter, more humid climate (Hawke’s Bay). As a grower, you might be able

![Figure 1](image-url)

**Figure 1**

Russet (left) is initiated as micro-cracks in the epicuticular waxes that can develop in the first few weeks after bloom. Scarf skin (right) results from development of air spaces in the epidermal cell layer beneath the fruit cuticle.
to live with an increase in the incidence of fruit with russet from 3% to 8%, but what about an increase from 18% to 36%?

Figure 2

Effects of lime sulfur thinning sprays on russet of ‘Gala’ in two different climatic regions of New Zealand. Data are averages from five different orchards in each region.

What Causes Scarf Skin?

Scarf skin or “opalescence” is the term used to describe a milky appearance of the fruit surface. The disorder was first described in ‘Sweet Winesap’ and ‘Black Gilliflower’ in 1905, but is frequently observed in the more red strains of modern cultivars such as ‘Rome’ and ‘Gala’. The milky appearance is not a consequence of micro-cracks in the fruit cuticle as in the case of russet, but results from light being reflected from heavily pigmented hypodermal cells into intercellular air spaces that arise several cell layers below the fruit epidermis. russet and scarf skin are initiated in the first 40-50 days after bloom, during the period when relative fruit growth rates are at their greatest.

Gibberellins Reduce Russet and Scarf Skin

Multiple sprays of gibberellinA4 and A7 (GA\textsubscript{4+7}) can be applied at 7-10 day intervals during the first month after bloom to reduce the incidence and severity of both russet and scarf skin. Three or four applications of a proprietary mixture of 15-20 mg L\textsuperscript{-1} GA\textsubscript{4+7} beginning at PF are recommended to reduce russet severity on susceptible cultivars in the US. The estimated material cost of such a program ranges from US$300-$500 per hectare depending on product concentration, number of applications, and water rate. Many growers remain skeptical of the economic benefits arising from the use of GA\textsubscript{4+7} sprays to reduce russet because the increase in crop value following a GA\textsubscript{4+7} program may not be sufficient to offset the additional cost in some years or regions.

Prohexadione-Calcium Improves Russet Control by GA\textsubscript{4+7} Sprays

Prohexadione-calcium (BASF Apogee/Regalis), an inhibitor of gibberellins biosynthesis, is being used increasingly in apple production systems globally to reduce vegetative growth, improve fruit set by reducing June drop, and to reduce the incidence of fire blight and other diseases. Prohexadione-calcium is rapidly degraded in plants, having a biological half-life of 10-14 days. The initial application of prohexadione-calcium is made when two to five leaves are fully developed on each shoot, corresponding in most seasons to around the time of petal fall when shoots are 2-5 cm in length. Thus, timing of the first P-Ca spray coincides with the initial application of GA\textsubscript{4+7} in a russet control program. Prohexadione-calcium inhibits gibberellin biosynthesis during the period when GA\textsubscript{4+7} sprays are being applied for russet control. Since
GA4+7 sprays reduce russet, then application of a gibberellin inhibitor at this time might be expected to increase russet, and might also be expected to interfere with the efficacy of a GA4+7 program for russet control.

Surprisingly, prohexadione-calcium was in fact found to reduce russet of ‘Golden Delicious’; two applications of 188 mg.L\(^{-1}\) prohexadione-calcium reducing russet as effectively as four applications of GA4+7. In our own studies we found that a single application of 150 mg.L\(^{-1}\) prohexadione-calcium at petal fall reduced the severity of both russet and scarf skin (Table 1). We found that a single application of prohexadione-calcium at petal fall was less effective at reducing russet and scarfskin compared to a standard program of three or four GA4+7 sprays. However, we also found that the efficacy of GA4+7 sprays for russet and scarf skin control tended to be greater when prohexadione-calcium was tank-mixed with the first GA4+7 spray in a control program.

Table 1

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Russet Experiments Exp. 1</th>
<th>Russet Experiments Exp. 2</th>
<th>Scarf Skin Experiments Exp. 1</th>
<th>Scarf Skin Experiments Exp. 2</th>
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<tbody>
<tr>
<td>Control</td>
<td>88a</td>
<td>16a</td>
<td>22a</td>
<td>71a</td>
</tr>
<tr>
<td>P-Ca</td>
<td>92b</td>
<td>33b</td>
<td>22a</td>
<td>81bc</td>
</tr>
<tr>
<td>GA4+7</td>
<td>99c</td>
<td>65c</td>
<td>33b</td>
<td>80ab</td>
</tr>
<tr>
<td>P-Ca + GA4+7</td>
<td>98c</td>
<td>76d</td>
<td>39c</td>
<td>87c</td>
</tr>
</tbody>
</table>

Individual and combined effects of prohexadione-calcium (P-Ca) and GA4+7 on russet and scarf skin. Prohexadione-calcium was applied once only in each experiment at a concentration approx. 150 mg.L\(^{-1}\), in combination with the first GA4+7 application in a standard program of three or four sprays. Russet data are the percent of ‘Golden Delicious’ fruit with <20\% of the fruit surface russeted. Scarf skin data are the percent of ‘Buckeye Gala’ (Exp. 1) and ‘Rome’ (Exp. 2) fruit with <10\% of the fruit surface covered. Means within each column followed by different letters are significantly different (P<0.05).

Russet and scarf skin arise from aberrant development of the fruit cuticle and hypodermis, respectively, during the early part of the season when the relative growth rates of the fruit are greatest. The chemical cost of a russet control program with proprietary mixtures of GA4+7 can be high, but can be recovered with increases in fruit pack-outs of approximately three to five percent on a typical orchard. Increases of this magnitude may not be realized in regions with a low natural incidence of fruit russet, but are frequently observed in regions with a higher russet risk. The gibberellin biosynthesis inhibitor prohexadione-calcium (BASF Apogee/Regalis) does not interfere with a standard russet control program of multiple GA4+7 sprays. Paradoxically, prohexadione-calcium can in fact directly reduce the severity of both russet and scarf skin, and may increase the efficacy of standard GA4+7 programs for control of these disorders.
Managing Alternate Year Bearing in Apples

Many apple cultivars including ‘Braeburn’, ‘Cameo’, ‘Fuji’, ‘Golden Delicious’, ‘Honeycrisp’, ‘Pacific Rose’ and ‘York Imperial’ are prone to develop a biennial bearing habit; a repeating cycle of heavy and light blooming/cropping years. Biennial bearing will negatively influence orchard profitability due to effects on fruit size, fruit quality and orchard productivity. Cumulative yields of apple cultivars that exhibit a biennial bearing habit are typically less than those of cultivars that bear regularly. Fruit from light-cropping trees can develop a higher incidence of the calcium-related storage disorder bitter pit.

Biennial bearing is the consequence of an imbalance between the proportion of vegetative (resting) and fruiting spurs. In the off-crop year of the cycle most (or all) developing buds on the tree produce mixed buds with both leaf and flower primordia for the following year whereas in the on-crop year most (or all) of the buds produce vegetative buds with leaf primordia only. Spurs that carry one or more fruit are less likely to produce a flower in the following year; this is a trait that all apple cultivars exhibit to a greater or lesser extent. Fruiting spurs on cultivars that crop relatively regularly such as ‘Gala’ are more likely to produce a flower bud compared to cultivars that are susceptible to develop a biennial bearing habit.

What is it about the fruit that prevents flower bud formation? Research conducted at the New York State Agricultural Experiment Station in Geneva between 1964 and 1966 clearly demonstrated a negative relationship between the total number of developing seeds on a spur (not the number of fruit per spur!) and the probability of that spur producing a flower in the following year. Using the naturally seedless cultivar ‘Spencer Seedless’ they found that 95 percent of spurs that produced fruit but no seeds flowered in the subsequent year whereas if between one and five seeds were allowed to develop on a spur then only 13 percent of the spurs produced a flower cluster in the subsequent year. Since an apple fruit will typically have at least five seeds, the presence of a single fruit on a spur is probably enough to inhibit flower bud formation in spurs of strongly biennial cultivars. Removal of seeded fruits just three weeks after pollination did not overcome the inhibitory effect of seed formation on flowering. In the more than forty years since this research was published it has generally become accepted that gibberellins derived from the seeds during the early part of the season are one of the major factors responsible for inhibition of flower bud formation in adjacent buds (Figure 1).

A successful chemical thinning program will reduce the number of fruit (and seeds) per tree or per spur, and may also completely de-fruit some spurs, resulting in adequate return bloom. The increased consistency of U.S. apple production after 1949 was attributed to the widespread commercial adoption of chemical thinning technology from that year (3). However, cultivars that exhibit a strong natural tendency for biennial bearing may not produce
sufficient bloom to guarantee a return crop, even after a successful post-bloom chemical thinning program. The lack of a return bloom response in such cases may be due, at least in part, to the delayed timing of fruit drop in relation to the inhibitory signal emanating from the seeds. Presumably, the fruit drop following a post-bloom thinner application occurs after the signal to inhibit flowering is sent from the developing seeds, which occurred within the first month after bloom in ‘Spencer Seedless’. Once a biennial bearing cycle has been triggered, the challenge is to apply crop load management and related technologies that will return trees to a more consistent cropping pattern. Restoring a balance between the number of flowering and resting spurs is the first step towards achieving this goal.

The Flower Bud Formation Process in Apple

A primordium is the term used to describe the earliest stage of organ development. Dormant vegetative apple buds contain leaf primordia only, whereas dormant reproductive buds contain a mixture of both leaf and flower primordia. A developing bud will have already formed six to seven primordia at bloom which continue developing throughout the summer to form the scales that provide a protective layer around the bud. New primordia continue to be formed at the apical meristem of the bud throughout the summer in an ordered sequence. The first few of these new primordia develop into an intermediate form between bud scales and true leaves referred to as transition leaves. Subsequent primordia produced at the apical meristem develop into true leaves. Eventually the apical meristem will (hopefully) become committed to floral development.

A change in the shape of the apical meristem from a flattened to a domed appearance (Figure 2) is the first easily observable indication of floral commitment within developing apple buds. Four to six lateral floral primordia are initiated on the flanks of the floral meristem before a terminal floral meristem, referred to as the “king” flower, is initiated. Although it is the last of the floral meristems to be initiated, the “king” flower develops more rapidly and assumes dominance over the lateral flowers. Flower morphogenesis proceeds rapidly once buds become committed to floral development (meristem doming). By the time of leaf fall, the king flower has developed sepals, stamen and carpels.

Figure 2
The first easily observable indication of the transition from vegetative to floral development in apple buds occurs when the apical meristem changes from a flattened (left) to a domed (center) appearance. Doming typically occurs during the period from 80 to 120 days after bloom depending on a number of factors including year, cultivar, crop load. Dormant floral buds contain more completely developed flowers, with differentiated sepals, stamen and carpels (right). Micrographs courtesy of Toshi Foster (HortResearch, NZ).
The timing and rate of development of the different organs within a floral apple bud can vary depending on the year and cultivar. Dorming occurred between ten and fourteen weeks after bloom in ‘Royal Gala’ buds in New Zealand depending on the year. Cultivars may also exhibit different patterns of flower bud development over time. Cultivar-specific differences in the pattern of development within differentiating floral buds do not appear to be related to their bloom or harvest dates, or to their propensity to develop a biennial bearing habit.

**Manipulating Flower Bud Formation with Growth Regulators**

Establishing a more equal balance between floral and vegetative buds is the first step towards restoring trees from a biennial bearing cycle to more consistent cropping. Growth regulators that are capable of partially (but not completely) inhibiting flower bud formation in the off-crop year, or promoting flower bud formation in the on-crop year, may be used to achieve this goal. Various gibberellins including GA$_3$ and GA$_7$ have been shown to inhibit flower bud formation in apple. Application of GA$_3$ or GA$_7$ to ‘Braeburn’ in the off-crop year of a biennial bearing cycle resulted in a more equal balance between vegetative and floral spurs in each of the two years following treatment. However, this strategy has not been adopted in commercial practice for various reasons including the high chemical cost at the rates required for efficacy, and the unpredictable nature of the response. Greater than expected inhibition of flower bud formation following gibberellin treatment(s) can potentially result in two successive off-crop years in a row, a response that most growers would find unacceptable.

Ethrel or NAA promote flower bud formation in apple, and there are web-based recommendations that describe how either of these materials can be used to promote return bloom. A series of eleven experiments conducted on commercial orchards in the southeast between 1998 and 2006 found that NAA or Ethrel treatments significantly increased return bloom in almost two thirds of the experiments. Summer NAA programs (typically four applications of 5 ppm NAA as a dilute spray at two-week intervals beginning in mid-June) increased return bloom more consistently than fewer applications. Weekly pre harvest applications of 5 ppm NAA during the final month before harvest have been found to increase return bloom in all experiments where a summer NAA program was also effective (Figure 3). A single application of Ethrel (240 g a.i. per L product) as a dilute spray between five and seven weeks after bloom at rates ranging from 24-96 ounces per acre also increased return bloom without affecting fruit set or firmness at harvest. Combinations of NAA and Ethrel in a series of four early summer sprays did not consistently
increase return bloom compared to either material alone. **Enhancement of return bloom with Ethrel or NAA will not necessarily result in a heavy or “snowball” bloom in the year after treatment, but the level of bloom may be increased above that required to achieve a commercial crop load.**

NAA and Ethrel treatments for increasing return bloom will be less effective if trees are not chemically thinned or have a heavy initial crop load. Even the level of bloom in the on-year of a biennial bearing cycle will have a pronounced negative effect on return bloom (Figure 4). Ethrel sprays can partially overcome, but not eliminate, the effects of a heavy bloom in the on-crop year.

**Integrating Growth Regulators into a Program for Consistent Cropping**

NAA and Ethrel treatments are not a “silver bullet” for overcoming biennial bearing. They will not result in a snowball bloom in the year after treatment and their efficacy will be minimal if there has been little or no response to a chemical thinning program and initial crop load is high in the year of treatment. In conjunction with a successful chemical thinning program, they will often increase the proportion of spurs that bloom in the year after treatment and increase the likelihood of achieving a commercial crop load. Four applications of 5 ppm NAA as a dilute spray at two-week intervals beginning in mid-June are effective; these can be included with the cover sprays during this period. A preharvest NAA program of four applications of 5 ppm NAA at weekly intervals leading up to harvest may also be effective and may have the added benefit of providing some preharvest drop control, but will require additional trips through the orchard with the sprayer at a time of year when this may not be convenient. One or two applications of Ethrel at two to three weeks apart beginning in mid-June will also increase return bloom. Effective rates of Ethrel will vary between 16 and 96 fluid oz/acre (of a 240 g a.i. per L product), depending on cultivar, initial crop load and the number of sprays applied. Under commercial conditions Ethrel may be a less practical option because the rate of Ethrel is cultivar-dependent, and there may be increased risk of preharvest drop for some early season cultivars. In addition, rates of Ethrel above 48 oz/acre may trigger fruit drop if the trees are under stress or temperatures during or following application are very high. NAA or Ethrel treatments in the on-crop year must follow an effective, aggressive chemical thinning program in order to increase return bloom of apple cultivars that are exhibiting a severe biennial bearing habit.
Comparison of Summer NAA and Ethrel programs for return bloom in apple.

<table>
<thead>
<tr>
<th></th>
<th>Summer NAA</th>
<th>Ethrel(^z)</th>
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<tbody>
<tr>
<td><strong>Timing:</strong></td>
<td>Start program in late June(^y).</td>
<td>Make one application 5-6 weeks after bloom when the thinning window is over.</td>
</tr>
<tr>
<td><strong>Frequency:</strong></td>
<td>Four bi-weekly applications.</td>
<td>Usually only one application is needed.</td>
</tr>
<tr>
<td><strong>Rate:</strong></td>
<td>5 ppm NAA (Fruitone L) for all varieties.</td>
<td>Rate is variety dependent.</td>
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<tr>
<td></td>
<td></td>
<td>16-24 oz(^x)/acre: Gala, Rome, Red Delicious</td>
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<tr>
<td></td>
<td></td>
<td>24-48 oz/acre: Golden Delicious</td>
</tr>
<tr>
<td></td>
<td></td>
<td>48-72 oz/acre: Fuji, Cameo</td>
</tr>
<tr>
<td><strong>Notes:</strong></td>
<td>Can be included with cover sprays.</td>
<td>Not recommended on early season varieties prone to pre harvest drop eg. Honeycrisp.</td>
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</table>

\(^z\) The Ethrel formulation described here contains 240 g a.i. per L. If a 480 g a.i. per L product is used then the amount used per acre will need to be halved.

\(^y\) In the Northern Hemisphere. This is approx. 8 weeks after bloom.

\(^x\) 1 fluid ounce is equivalent to 29.57 ml.
Effective Use of Stop-Drop Chemicals in Apples

The need to minimize pre harvest fruit drop and to slow the rate of fruit ripening are different scenarios where plant growth regulators, when correctly applied, can make you money. Apples develop an abscission zone at the base of the fruit stem as part of the normal ripening process. However, many important cultivars including ‘Golden Delicious’, ‘Red Delicious’, ‘Honeycrisp’, ‘Suncrisp’, and ‘Rome’ may develop this abscission zone and drop from the tree before the fruit develop commercially acceptable red color, maturity, or size. Stop-drop sprays delay the formation of this abscission zone, thereby minimizing losses due to pre harvest fruit drop. Alternatively, stop-drop sprays may be used to delay harvest in response to a labor shortage or bad weather, or to let the fruit hang in order to attain more commercially desirable size or color. In addition to inhibiting abscission zone formation, stop-drop sprays may interfere with ripening related processes including ethylene formation, accumulation of anthocyanins, and fruit softening.

A study of fruit drop in the same ‘Scarletspur Delicious’ orchard over a ten year period (1) revealed that natural fruit drop varied from zero to 17 percent of the total crop at the start of the normal harvest window. However, if harvest was delayed by just one week then natural fruit drop increase to between 2% and 33% depending on the year. The plant growth regulators ReTain (AVG) and Fruitone L (NAA) can be used to minimize losses in harvested yield due to preharvest fruit drop. ReTain and NAA have different modes of action in their control of fruit drop and fruit ripening and it is important to understand these differences in order to get the maximum benefits from their use.

**ReTain or NAA?**

NAA delays fruit drop by inhibiting the enzymes responsible for breaking down the walls of the cells in the abscission zone of the fruit stem. NAA specifically inhibits expression of the genes controlling levels of polygalacturonase and endo-glucanase enzymes (MdPG2, MdEG1) in these tissues. However, stop-drop sprays of NAA can also sometimes have a negative effect on ethylene formation and fruit softening if applied at high rates (20 ppm or higher) or under high temperatures (>90°F). Under such conditions NAA may increase ethylene levels in the fruit as a consequence of stimulating the expression of two of the key genes controlling ethylene biosynthesis (MdACS1 and MdACO1). The stimulation of ethylene by NAA can trigger the normal ripening processes, including fruit softening. Thus, NAA reduces fruit drop due to its inhibitory effects on cell wall degrading enzymes in the fruit abscission zone, but at the same time it may hasten fruit softening. Since fruit from trees that have been sprayed with NAA for drop control may soften more quickly in some years, the use of NAA as a drop control treatment should be limited to fruit that are destined for short-term storage or firmness should be closely monitored during storage.

A standard NAA program for control of fruit drop consists of a single application at 10-20 ppm, applied at the onset of drop. Applications after the onset of fruit drop are generally less effective, but can be used as a rescue treatment since the effects are normally seen within 3-4 days after spraying. A single application of NAA will control fruit drop for approximately five to seven days. Subsequent applications may be made at weekly intervals to extend the period of
drop control. Dr. Dick Unrath showed that the most effective and longest lasting drop control program with NAA was obtained by preloading the tree with small (5 ppm) doses starting four weeks before the anticipated harvest date. If harvest is delayed beyond the normal harvest date then as many as six applications of NAA at 5 ppm each can be made at weekly intervals. Since NAA is applied at lower rates in a preload program the risk of fruit softening is reduced.

The primary mode of action of Retain is to inhibit ethylene production. The rapid increase in ethylene formation that occurs as the fruit ripens provides the trigger for many of the processes occurring during the ripening process, including stem loosening, accumulation of the red anthocyanin pigments in the skin, conversion of starch in the fruit to sugars, and fruit softening. By inhibiting ethylene production, Retain also inhibits these other ripening-related processes. Retain typically provides better drop control than NAA, and has the added benefit of delaying fruit maturity. However, it may take 7-10 days following an application of Retain before development of the fruit abscission zone is inhibited. Although it can be applied as late as one week before anticipated harvest, Retain is typically applied four weeks prior to the anticipated harvest date. Retain cannot be used as a rescue treatment. As described above, Retain can inhibit the development of red color, a negative effect that may limit its use on weaker-coloring strains of varieties such as ‘Gala’, particularly in warmer climates.

Using Retain in Hot Years

Growers and researchers in the Hudson Valley region of New York State have observed that Retain tends to be less effective in hot years, and that applications made closer to harvest are more effective in hot years. These observations are in agreement with data collected in the southeast over the past four summers (compare cumulative fruit drop curves of spur Red Delicious in Figure 1 and Figure 2). 2008 and 2009 were cooler summers (578 degree and 333 days above 65°F in July and August, respectively) with significant drop of spur Red Delicious during the normal harvest window and stop-drop sprays were generally very effective (Figure 1). On the other hand, the summers in 2010 and 2011 were much warmer (approx. 700 degree days above 65°F in July and August each year) with considerably less natural fruit drop, and application of Retain at the normal timing (28 days prior to harvest) was mostly ineffective (Figure 2). Note however that when a full rate of Retain was applied later in 2010 (two weeks prior to the anticipated harvest date) it was effective, compared with application at the normal timing.
Tank Mixing ReTain with NAA

Recent research has demonstrated that a tank-mix of ReTain and NAA can provide better control of fruit drop compared to either material alone (3). We have compared the performance of tank mixes of ReTain and NAA with standard ReTain or NAA programs for the control of fruit drop on ‘Red Delicious’ in North Carolina over the past four seasons (see data in Figures 1 and 2). The tank-mix of ReTain and NAA was applied two weeks before the anticipated harvest date each year, either with a full rate (125 ppm), and sometimes with a half rate (62.5 ppm) of ReTain. The tank-mix combination of ReTain and NAA is normally applied closer to harvest, typically two weeks prior to the anticipated harvest date. Presumably the NAA in the tank mixture provides immediate drop control until the inhibitory effects of ReTain on abscission zone formation are expressed. The ReTain also presumably suppresses any stimulation of ethylene formation by NAA so that the risk of NAA-induced softening is eliminated when NAA is applied in a tank mix combination with ReTain. It has also been reported that the rate of ReTain can be reduced by up to half when applied in a tank-mix combination with NAA without any loss of drop control compared to a ReTain application at the standard rate and time. In our research with spur Red Delicious, we have found that the best control of fruit drop and fruit softening on the tree is achieved with a full rate of ReTain applied as a tank mixture with 10 or 20 ppm NAA two weeks before the normal harvest date.

The current label for ReTain specifies it must be applied with an adjuvant; either Break-Thru®, RNA Si 100, Silwet L-77®, or Sylgard® 309 organosilicone surfactant. One of the concerns we initially had with tank-mixing ReTain and NAA was the potential for the adjuvant to increase the risk of fruit softening that is occasionally observed with NAA. We have found that addition of an adjuvant to the tank-mix of ReTain and NAA has not resulted in any softening when full rates of ReTain were used in the combination.

Conclusions

ReTain and NAA have different modes of action in controlling pre harvest fruit drop of apples. NAA inhibits formation of the fruit abscission zone and it either has no effect or may even enhance fruit softening in some years. ReTain inhibits ethylene biosynthesis, so in addition to delaying fruit drop it may also inhibit many of the other ethylene mediated processes occurring during fruit ripening including fruit softening, red color development, and the conversion of starch to sugar. Applying a tank-mix of ReTain and NAA two weeks before the anticipated harvest date provide equivalent or even improved control of fruit drop and fruit softening.
softening compared to either material alone. Rates of ReTain could be reduced by up to half without a significant loss of drop control. In our evaluations over the past four years in the southeast we have found that the best control of fruit drop and fruit softening on the tree is achieved with a full rate of ReTain applied as a tank mixture with 10 or 20 ppm NAA two weeks before the normal harvest date.

Literature cited

