

# Retain Combined with NAA Controls Pre-harvest Drop of McIntosh Apples Better Than Either Chemical Alone

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McIntosh is the most important apple cultivar in the Northeastern USA. It is a high ethylene producing variety which has excessive pre-harvest drop. Amineoethoxyvinylglycine (Retain) which blocks ethylene synthesis limits pre-harvest drop and has become an essential tool in managing harvest of McIntosh in the Northeastern USA (Greene and Schupp, 2004; Robinson et al., 2006). In addition to reducing pre-harvest fruit drop, Retain also delays fruit color development which is

**“In some years Retain imperfectly controls pre-harvest drop of McIntosh. These years are warm with daytime temperatures over 95°F in August. Our research has shown that the addition of 20ppm NAA to the Retain sprays at 2 weeks before normal harvest improved pre-harvest drop control compared to Retain alone. When a half rate of Retain (167 g/acre) was combined with 20ppm NAA, the drop control was very similar to the full rate of Retain applied at 3 weeks before normal harvest but drop control did not last as long as the full rate of Retain+NAA.”**

a negative side effect for many growers (Robinson et al., 2006). Thus, many fruit growers apply less than the labeled rate or apply the spray close to the normal harvest date to minimize the negative impact on fruit color but often this results in less than satisfactory pre-harvest drop control.

## Variability Between Years in Efficacy of Pre-harvest Drop Control of Retain

In the 15 years that Retain has been used commercially in the USA, we have observed that in some years Retain imperfectly controls pre-harvest drop of McIntosh. These are often warm years with daytime temperatures over 95°F in August where the trees are stressed and begin to produce ethylene and form an abscission layer in early and mid-August. In these years it appears that Retain can reduce the amount of ethylene produced, if applied early enough and with a full dose, but it appears not to be able to completely stop the abscission zone in hot years.

Retain has shown variability in efficacy since our earliest trials in New York State in 1994 and 1995. In 1994, a rate study of Retain (ABG-3168) showed excellent pre-harvest drop control compared to the untreated control or the NAA standard treatment with McIntosh at Geneva (Figure 1). The highest rate gave better drop control than lower rates. However, in 1995 in the same orchard at Geneva, there was no significant drop control except at one date and there was no effect of rate of Retain (Figure 1). Since 1995, we have observed that in hot years, substantial pre-harvest drop is experienced even when a full rate of Retain is applied 4 weeks before normal harvest. Comparisons of average August temperatures at Geneva, NY show that over the period of 1994-2006 there have been 8 years when the average Aug. temperature has exceeded 80°F (Figure 2). These years are often associated with periods of >10 days when daytime temperatures are over 95°F. During one of these hot years (2006), we found that Retain

suppressed ethylene production but did not adequately control fruit drop (Figure 3).

Recently, Dr. Rongcai Yuan from Virginia Tech's research station in Winchester discovered that the combination of Retain and naphthaleneacetic acid (NAA) controlled pre-harvest drop of Delicious, Golden Supreme and Gold-

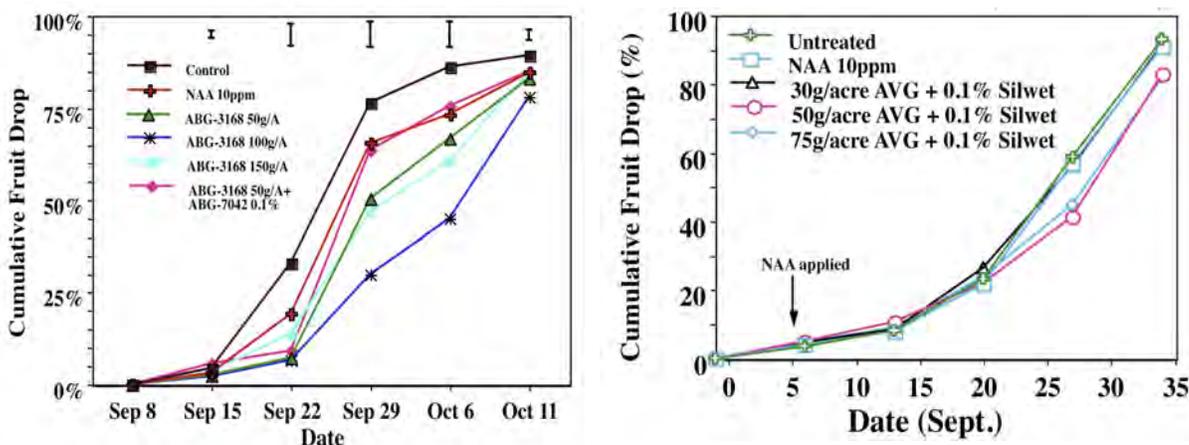


Figure 1. Effect of rate of AVG (Retain) on pre-harvest drop of McIntosh/M.9/MM.111 apple trees at Geneva, NY in 1994 (left) and 1995 (right).

en Delicious better than either chemical alone (Yuan and Carbaugh, 2007); Yuan and Li, 2008). The objective of this study was to investigate whether the effectiveness of Retain to control pre-harvest fruit drop of the high ethylene producing cultivar McIntosh could be improved by the addition of NAA to the spray mixture.

## Materials and Methods

Three field studies to control pre-harvest fruit drop of McIntosh were conducted at Geneva (Western New York State), Chazy (Northern New York State) and Hudson (Eastern New York State) in 2008. In each region, a single orchard block of mature 'McIntosh' trees trained as a central leader was used. Trees at Geneva and Hudson were on M.9 rootstock while at Chazy they were on M.26 rootstock. At 3, 2 and 1 week before normal harvest (Aug 22, Aug. 29 and Sept. 7 at Geneva; Aug. 25, Sept. 2 and Sept. 8 at Chazy; and Aug. 15, Aug.22 and Aug.29 at Hudson), Retain (333g/acre) was sprayed on the trees with an airblast sprayer using 100 gal water/acre. At 2 weeks and 1 week before harvest, Retain (333g/acre) plus NAA (20ppm Fruitone N) was applied. Also at 2 weeks before normal harvest, a half rate of Retain (167g/acre) plus 20ppm NAA was applied. Tree row volume at each location was 200 gal/acre. Each experimental plot consisted of 4 adjacent trees. The outer 2 trees served as guard trees and the middle 2 served as data trees with one used to collect drop data and the other used to collect fruit samples for fruit quality analysis (quality data not presented). At weekly intervals beginning on Sept. 8 at Geneva, Sept. 16 at Chazy and Sept. 4 at Hudson, the number of dropped fruits was counted and fruit samples were collected and evaluated for fruit maturity. Preharvest drop from each tree replicate was measured by counting and removing dropped fruit each week. At the last harvest date (Sept. 30 for Geneva, Oct. 7 for Chazy and Oct. 29 for Hudson, fruit remaining on the trees were counted and cumulative drop was calculated for each harvest date.

## Results

In 2008, temperatures in August and September were close to normal. As a consequence, fruit drop was moderate at Geneva and Hudson and low at Chazy until late in the harvest season.

At Geneva, pre-harvest fruit drop from untreated control trees exceeded 20% by Sept. 21 and by the end of Sept. had reached 60% drop (Figure 4). NAA applied on Sept. 7 did not reduce drop at any date and by the end of September had numerically higher drop than the untreated trees. The full rate of Retain (333g/acre) reduced fruit drop if applied Aug. 22 (3 weeks before harvest) or Aug. 29 (2 weeks before harvest), but not when applied on Sept. 7 (1 week before harvest). When applied late (1 week before harvest), Retain had no effect on drop until 2 weeks later (Sept. 21 when it had an intermediate effect). The addition of 20ppm NAA to the Retain sprays on either Aug. 29 or Sept. 7 improved the preharvest drop control. The combination spray on Aug. 29 had the lowest drop of any Retain treatment. However, if Retain+NAA was applied 1 week later on Sept. 7 (1 week before harvest) then its efficacy was reduced but was similar to Retain alone applied 3 or 2 weeks before harvest. When a half rate of Retain (167g/acre) was used combined with 20ppm NAA the efficacy in reducing drop was very similar to the full rate of Retain. As a comparison, 120 g/acre of Harvista (1-MCP) applied on Sept. 7 provided similar drop control as the best Retain+NAA

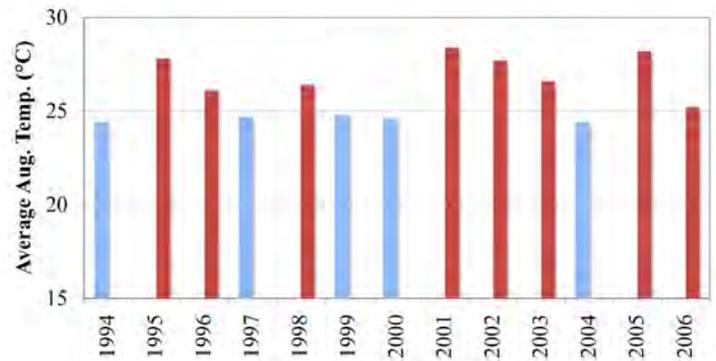


Figure 2. Average August temperatures at Geneva, NY from 1994-2006.

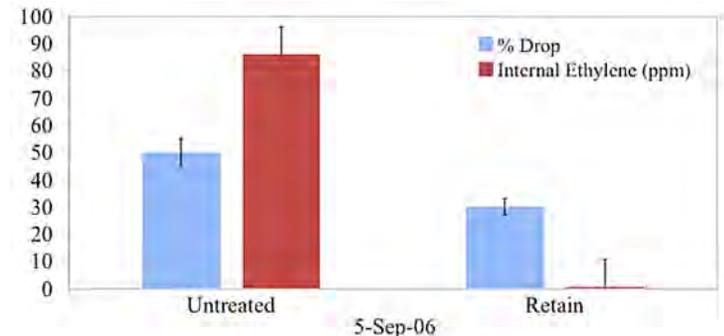


Figure 3. Effect of AVG (Retain) on fruit drop and internal ethylene concentration of McIntosh/M.7 apple trees at Marlboro, NY in 2006.

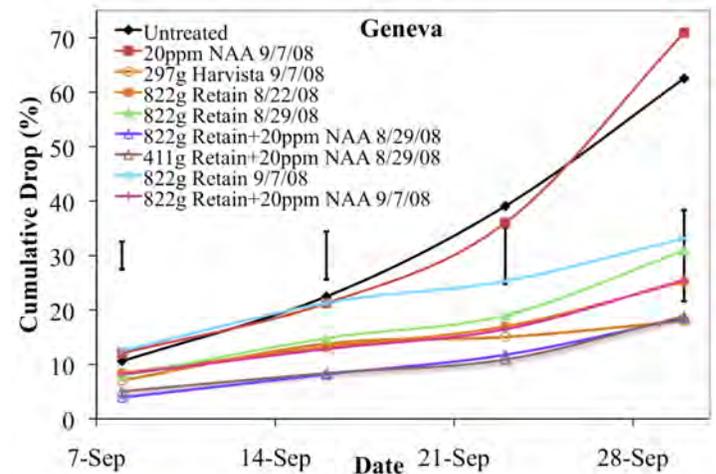
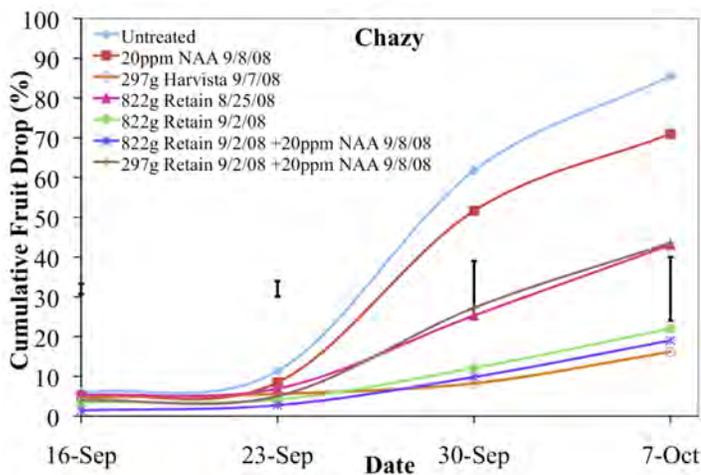


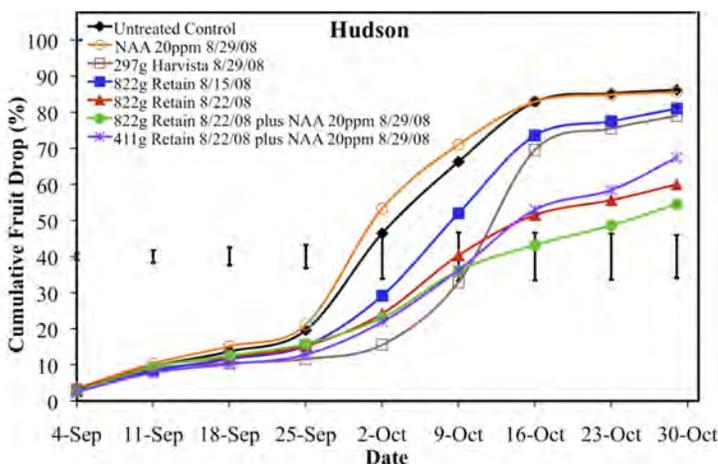
Figure 4. Effect of AVG (Retain) sprayed alone or in combination with NAA (Fruitone N) at various timings before harvest on pre-harvest fruit drop of mature McIntosh/M.9 trees at Geneva, New York in 2008. (Vertical bars are LSD's,  $P \leq 0.05$ ,  $n=5$ ).

treatment. However, Retain alone was less effective in controlling preharvest drop.

At Chazy, NY, pre-harvest fruit drop from untreated control trees remained low until Sept. 30 (Figure 5). Drop was only 10% on Sept. 23 but exceeded 60% by Sept. 30. NAA applied on Sep 7 did not statistically reduce drop at any date although there was a small numeric reduction in drop from NAA. Retain at the full rate (333g/acre) reduced fruit drop whether applied on Aug. 22, (3 weeks before harvest) or Sept. 2 (2 weeks before harvest) however, the efficacy was much better when applied 2 weeks before harvest than 3 weeks before harvest. The addition of 20ppm NAA to the Retain sprays on Sept. 2 did not statisti-



**Figure 5. Effect of AVG (Retain) sprayed alone or in combination with NAA (Fruitone N) at various timings before harvest on pre-harvest fruit drop of mature McIntosh/M.26 trees at Chazy, New York in 2008. (Vertical bars are LSD's,  $P \leq 0.05$ ,  $n=5$ ).**



**Figure 6. Effect of AVG (Retain) sprayed alone or in combination with NAA (Fruitone N) at various timings before harvest on pre-harvest fruit drop of mature McIntosh/M.26 trees at Hudson, New York in 2008. (Vertical bars are LSD's,  $P \leq 0.05$ ,  $n=5$ ).**

cally improve the performance of Retain but there was a small numeric improvement in drop control. When a reduced rate of Retain (167g/acre) was used with NAA, the efficacy in reducing drop was reduced compared to the full rate of Retain applied on the same day; however, the low rate of Retain plus NAA had similar efficacy to the full rate of Retain applied on Aug. 22. As a comparison, 120 g/acre of Harvista (1-MCP) applied on Sept. 7 provided similar drop control as the best Retain+NAA treatment. However, Retain alone applied Aug 25 was less effective in controlling preharvest drop.

At Hudson, NY, pre-harvest fruit drop from untreated control trees remained low until late Sept. (Figure 6). Drop was only 18% by Sept. 25 but exceeded 50% by Oct. 2. NAA applied on Aug. 29 did not significantly reduce drop at any date. Retain at the full rate (333g/acre) reduced fruit drop whether applied on Aug. 15, (3 weeks before harvest) or Aug. 22 (2 weeks before harvest); however, the drop control in late Sept. and Oct. was much better when applied 2 weeks before harvest than 3 weeks before harvest. The addition of 20ppm NAA to the Retain sprays on Aug. 29 did not statistically improve the performance of Retain, but there was a small numeric improvement in drop control. When

a reduced rate of Retain (167 g/acre) was used with NAA, the efficacy in reducing drop similar to the full rate of Retain applied on the same day and was better than the full rate of Retain applied on Aug. 15. As a comparison, a spray of 120 g/acre of Harvista (1-MCP) on Aug. 29 provided excellent drop control in the Hudson, NY study until early Oct when drop control was lost and it was significantly less effective than Retain alone (applied on Aug. 22) or Retain+NAA which had reasonable drop control until the end of Oct.

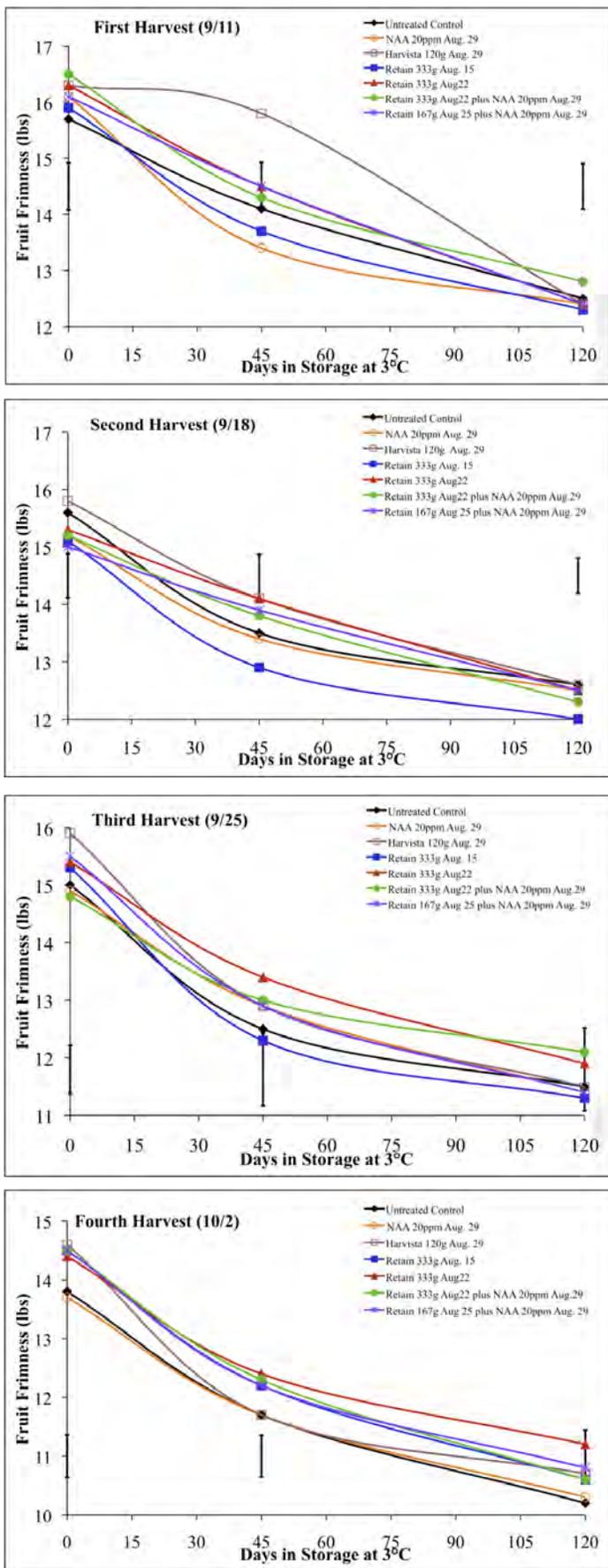
We also evaluated the impact of combining Retain and NAA in the spray on fruit quality at harvest and after cold storage. There was no deleterious effect of NAA in the spray mixture on McIntosh fruit firmness at harvest or after storage (Figure 7). Retain alone or Retain+NAA did not improve postharvest firmness of McIntosh apples; however, Harvista applied one week before normal harvest did prevent firmness loss for 45 days in regular storage if the apples were harvested at the first harvest date (Sept. 11). If harvest was delayed a week later then none of the chemical treatments improved post-harvest firmness.

## Discussion

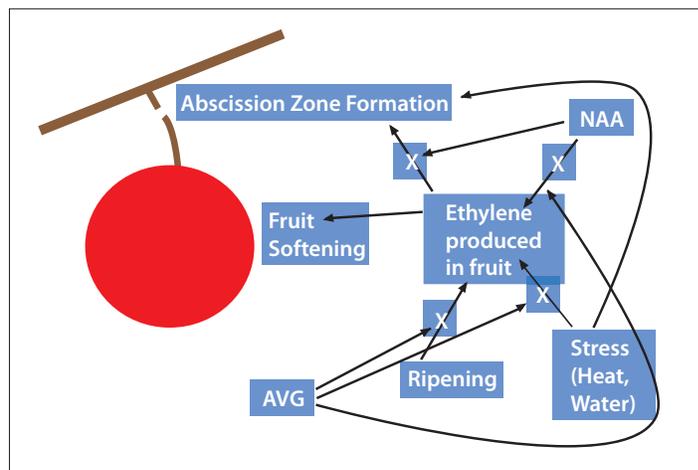
The use of Retain to reduce preharvest drop of 'McIntosh' apples and to delay harvest is a well established practice in the North-eastern USA. The results of these experiments again demonstrate that Retain delays fruit drop and is effective in delaying harvest of McIntosh when applied at the right timing, at a full rate and temperatures in August are not too hot.

The results of our study suggest that early applications of Retain (3 weeks before normal harvest) give good drop control for 2-3 weeks after normal harvest but by 4 weeks after the normal harvest date, drop control diminishes. Applications of Retain at 2 weeks before normal harvest appear to give similar early drop control but give longer drop control after the normal harvest date. Based on this data the optimum time of Retain application will depend on the length of time that the fruit grower needs to prevent fruit drop. In Western and Eastern New York (WNY and ENY), most fruit growers have many varieties and McIntosh is one of the first. Thus, growers need to achieve 1-2 weeks of drop control and then complete McIntosh harvest by mid Sept. in the Hudson Valley and by Sept. 25 in WNY and then move onto other varieties. However, in Northern New York (NNY) fruit growers have 70-80% of their orchard area planted to McIntosh and this requires very long drop control periods to allow the harvest of all of their acreage before significant drop occurs. It appears that in NNY if Retain is applied too early, its effects wear off by late September when massive drop begins. In NNY, the optimum timing for application of Retain appears to be 2 weeks before normal harvest (this is usually late August). In WNY and ENY, the optimum application timing appears to be 3 weeks before normal harvest. This is mid Aug. in ENY and around Aug. 21 in WNY. The traditional timing of Retain application has been 4 weeks before normal harvest. Most growers interpret this as early to mid August. It appears that this timing should be delayed to later in August. The data from this study show that by late Sept. the drop control effects of Retain applied in mid August had disappeared. The benefits of delaying Retain application are also suggested by others (Greene and Schupp, 2004; Robinson et al., 2006).

Our study also indicates that the addition of NAA to sprays of Retain appears to improve the efficacy of Retain in controlling preharvest drop of McIntosh. This is similar to the results of Yuan



**Figure 7. Effect of pre-harvest sprays of Retain with and with NAA on fruit firmness of McIntosh/M.9 apples at each of 4 harvest dates in September and October and after 45 or 120 days of regular cold storage at 3°C at Hudson NY. (Vertical bars are LSD's, P<0.05, n=5).**



**Figure 8. Proposed Model of Abscission (based on gene regulation data from Rongcai Yuan, 2008).**

(2007, 2008) with Delicious, Golden Supreme and Golden Delicious. In our study, the combination of Retain and NAA gave as good of drop control as the sprayable MCP (Harvista). The best timing of application of Retain and NAA is about 2 weeks before normal harvest. In our studies there was no deleterious effect of NAA in the spray mixture on McIntosh fruit firmness at harvest or after storage.

We also evaluated a reduced rate of Retain combined with NAA. This combination gave excellent drop control but the effects were shorter lived than the full rate of Retain+NAA. For McIntosh growers who need 2 weeks of drop control, but want to avoid the negative effects of the full rate of Retain on fruit red color, the strategy of using a half rate of Retain combined with NAA appears to be a promising strategy. For growers who want maximum drop control into October, the full rate of Retain plus NAA is the best strategy.

The positive results of the combination of Retain and NAA was not expected since NAA has such a negative impact stimulating ethylene and advancing fruit maturity. However, an explanation of our data can be found in the recent work by Rongcai Yuan (Li and Yuan, 2008; Zhu et al., 2008) on gene regulation with Retain and NAA. Based on their work we propose the following hypothesis about the individual and combined effects of NAA and Retain in controlling pre-harvest drop of McIntosh apples (Fig 8). When NAA is used alone to control pre-harvest drop, Yuan (Li and Yuan, 2008; Zhu et al., 2008) has shown it controls the genes associated with abscission zone formation but as a negative side effect it stimulates ethylene production which advances ripening (including color formation and softening). With McIntosh, the high production of ethylene by this variety often overwhelms the stop drop effect of NAA on abscission genes and there is little apparent drop control. Our data in 3 locations in 2008 showed no drop control with NAA alone. In contrast, Retain acts by controlling ethylene biosynthesis but in hot years, pre-harvest drop of McIntosh is not adequately controlled indicating that abscission zone genes are not totally under the control of ethylene and that Retain does not control these genes adequately under stress conditions. A possible mechanism for the synergistic effect of NAA and Retain is that NAA controls the genes associated with abscission better than Retain while Retain blocks the production of ethylene caused by NAA. Thus, excellent control of abscission genes is achieved through the combined effects of both chemicals, but the negative

effects of NAA on ethylene production are counteracted by Retain's control of ethylene synthesis.

### Conclusions

The traditional use of NAA to control preharvest drop of McIntosh is often ineffective. This is likely due to the high ethylene production of this variety which stimulates ripening. Retain has proven to be a much better drop control material but the two limitations of Retain are that color development is delayed when a full rate is used and in hot years pre-harvest drop is inadequately controlled. This is likely caused by the incomplete control of abscission zone genes resulting in significant fruit drop. However, the combinations of Retain and NAA applied 2 weeks before normal harvest work synergistically and can control drop better than either chemical alone. Further a half rate of Retain (167 g/acre) combined with 10-20ppm NAA was very effective in preventing drop and was very similar to the full rate of Retain but the drop control did not last as long as a full rate. The best Retain+NAA treatment gave similar drop control as sprayable 1-methylcyclopropene (Harvista).

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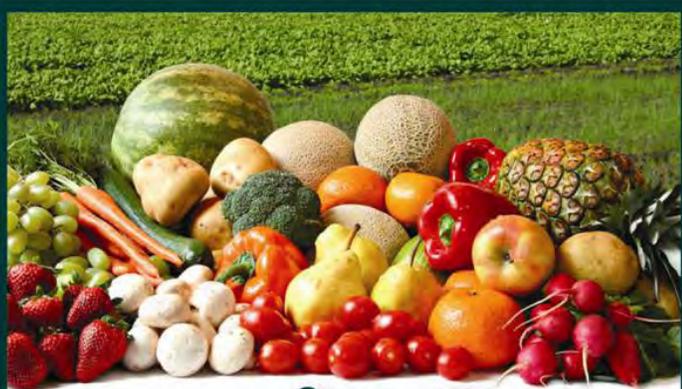
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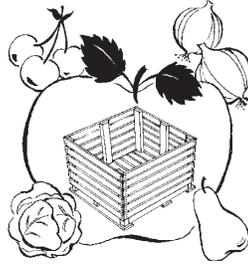
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