The Physiology of Apple Pre-harvest Fruit Drop

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As apples ripen they begin to produce large amounts of the ripening hormone, ethylene. Ethylene stimulates fruit softening and the formation of an abscission zone in the stem. Ethylene stimulates the production of enzymes (cellulase and polyglacturonase) that break down the cell walls and the glue that holds cell walls together in the abscission zone of the stem, leaving the fruit connected to the tree by only the vascular strands, which are easily broken.

All apple varieties show some fruit drop as they progress through the ripening period but some varieties begin to drop large numbers of fruits early in the ripening period before they develop sufficient red color to meet market requirements. McIntosh is particularly prone to pre-harvest fruit drop. In some years losses can exceed 50% of the crop and frequently pre-harvest drop results in severe economic losses.

Orchard and Climatic Factors That Affect Pre-harvest Drop

The severity of pre-harvest drop is related to several orchard and climatic factors including tree mineral nutrition, summer pruning, insect or disease severity, water availability and growing season temperature.

1. Mineral Nutrition. Pre-harvest fruit drop is frequently more severe in orchards with low fertility soils, and in orchards with low magnesium (Mg), high potassium (K), and high boron (B). Most NY orchards require annual K fertilization and high leaf K concentration is associated with high yields and large fruit size, thus we recommend substantial amounts of K fertilization. To counter act the negative effect of high K on fruit drop we recommend that McIntosh orchards receive yearly maintenance sprays of Mg (Epsom Salts) at 1st and 3rd cover sprays to reduce pre-harvest drop.

2. Summer Pruning. Pre-harvest fruit drop is frequently more severe in orchards which are heavily summer pruned. This problem is likely associated with a limitation in carbohydrate supply when too many of the good leaves are cut off leaving older less functional leaves. If summer pruning reduces leaf-fruit ratio below 20: 1 then drop will be increased. We recommend moderate summer pruning where only a small fraction of the functional leaves are cut off.

3. Insects and Mites. Pre-harvest drop severity can be increased by heavy infestations of mites, tentiform leaf miners, and other insects or diseases that significantly reduce the photosynthate produced by the leaves. Severe mite and tentiform leafminer infestations have been shown to reduce photosynthetic capacity of leaves resulting in a limitation of carbohydrate supply to the fruits late in the season. IPM mite and insect control thresholds in the "Cornell Recommends" have been designed to not surpass the leaf damage that will result in increased pre-harvest drop. Thus, strict adherence to these thresholds will not normally result in any increased risk of drop. However, if substantial insect or mite damage is combined with summer

pruning or low Mg or drought stress the combine effects of each stress can increase the severity of pre-harvest drop.

4. Water Availability. Pre-harvest drop will be more severe in dry seasons than in seasons with adequate or more-than adequate rainfall. In dry years irrigation becomes an essential management tool to control pre-harvest drop.

5. Growing season temperatures. Growing season temperatures also influences pre-harvest drop of McIntosh apples. Hoffman showed that in hot growing seasons the period between bloom and fruit ripening is shorter than in cool growing seasons (Fig. 1). Thus in hot years McIntosh ripening and harvest are often pushed earlier in the season when temperatures are warmer. The higher the temperatures at the time fruits begin to ripen (begin to produce ethylene) the more severe and earlier is pre-harvest fruit drop. Walsh (1977) showed that the higher the daily temperatures when ethylene began to be produced the shorter was be the interval between the beginning of the ethylene rise and fruit drop (Table 1). Fruit internal ethylene can be estimated to begin when starch-iodine index is in the range of 3.5-4.5 range. Thus, the data in table 1 can be used to estimate the number of days until drop of sound McIntosh fruits will being once apples reach a starch index of 3.5. If forecasted weather for the next week was cool (i.e. 50°F) drop of sound fruit would not start for 13 days but if forecasted weather for the next week was hot (i.e. 70°F) then drop of sound apples would begin in 4 days.

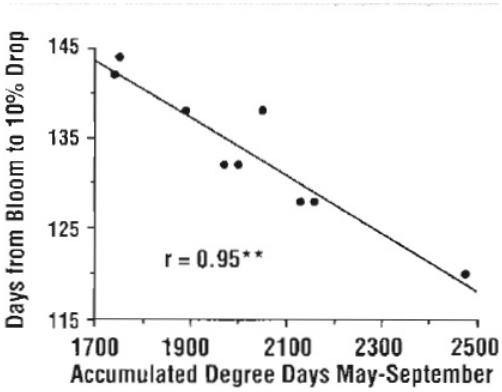

Fig. 1. Relationship between accumulated degree days (daily mean temperature minus 50°F) during the growing season and the number of days from full bloom to 10 percent drop of sound McIntosh apples. (From M.B. Hoffman, Cornell Univ.)

Control of Pre-harvest Drop with PGR's

Control of pre-harvest drop has relied upon plant growth regulators (PGR's) for almost 50 years. Over a half a century ago, it was found that naphthaleneacetic acid (NAA) could retard pre-harvest drop (Batjer and Thompson, 1948). While NAA was effective, its limitations included: proper timing of application was essential, ripening may be advanced if harvest was delayed, and the storage potential and shelf life of treated fruit was frequently reduced (Smock and Gross, 1947).

Table 1. Relationship between mean daily temperatures and elapsed days between start of the ethylene rise and abscission of McIntosh apples.

Mean daily temp.(°F)	Days from start of ethylene rise to abscission
40	25
45	18
50	13
55	9
60	7
65	5
70	4

Source: Christopher S. Walsh, 1977.

Daminozide (Alar) was discovered in the 1960's and it provided excellent pre-harvest drop control and also increased flesh firmness (Southwick and Lord, 1969). Since it delayed ripening it provided a means for growers to retard ripening of a portion of their crop to allow a more orderly and timely harvest of extensively planted cultivars. The

registration of daminozide for use on apples was withdrawn in 1989 leaving orchardists with NAA as the only pre-harvest drop control option.

Aminoethoxyvinylglycine (AVG) which was discovered in the early 1970's is a naturally occurring compound which blocks ethylene synthesis and limits pre-harvest drop. The commercial formulation of AVG, Retain, and has become an essential tool in managing harvest of McIntosh in the Northeastern USA (Robinson et al., 2006). In addition to inhibiting ethylene biosynthesis it delays ripening (Bramlage et al., 1980) and also delays fruit color development which is a negative side effect for many growers (Robinson et al., 2006). However, in some years Retain imperfectly controls pre-harvest drop of McIntosh. These years are warm with daytime temperatures over 95°F in August. During one of these hot years (2006), we found that Retain suppressed ethylene production but did not adequately control fruit drop.

Recently, Dr. Rongcai Yuan from Virginia Tech's research station in Winchester discovered that the combination of Retain and napthaleneacetic acid (NAA) controlled pre-harvest drop of Delicious, Golden Supreme and Golden Delicious better than either chemical alone (Yuan and Carbaugh, 2007); Yuan and Li, 2008). 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 2). 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 (MdPG2 and MdEG1) but as a negative side effect it stimulates ethylene production in the flesh which advances ripening including color formation and fruit softening caused by polyglacturonase controlled by MdPG1 gene). In contrast, Retain acts by controlling ethylene biosynthesis and thus the genes associated with fruit abscission (MdPG2) and fruit softening (MdPG1) but in hot years pre-harvest drop of McIntosh is not adequately controlled indicating that abscission zone genes (MdPG2 and MdEG1) are not totally under the control of ethylene and that Retain does not control these genes adequately under stress conditions. When NAA and Retain are applied together there is a synergistic effect of NAA controlling the genes associated with abscission (MdPG2 and MdEG1) better than Retain while Retain blocks the production of ethylene caused by NAA and controls the fruit softening genes (MdPG1) in the fruit flesh. Thus, excellent control of abscission genes is achieved through the combined effects of both chemicals, but the negative effects of NAA on ethylene production and fruit softening are counteracted by Retain's control of ethylene synthesis.

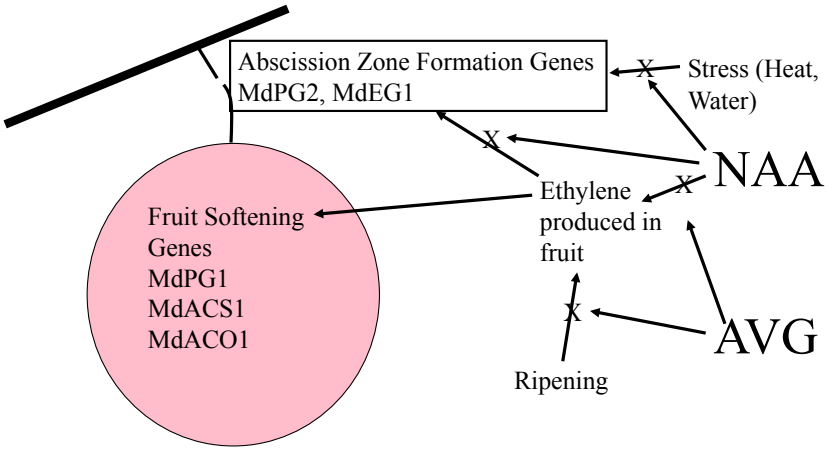

Fig. 2. Proposed Model of Abscission (based on data from Rongcai Yuan, 2008)