Using an Apple Tree Carbohydrate Model to Understand Thinning Responses to Weather and Chemical Thinners

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Many factors affect the response of apple trees to chemical thinners. One of the most difficult to understand is the variation in tree sensitivity related to previous yield history, bloom density, initial set, leaf area, leaf function, temperature, sunlight, tree vigor, etc. In this report, we attempt to understand the parts of variation induced by weather and carbohydrate supply and demand balances.

After years of study of post-bloom apple thinning with numerous field trials, we have not been able to fully understand and adequately control apple thinning. This is due to the extreme complexity of the entire system with dozens of interacting factors reported to affect chemical thinner response, which is so variable from year to year and orchard to orchard (Figure 1). There are probably two major aspects of chemical thinning that cause so much variability: (1) the spray application process that can vary with chemical thinner concentrations, temperature, humidity, application coverage, drying conditions, cuticle thickness and composition, etc.; and (2) variation in tree sensitivity related to previous yield history, bloom density, initial set, leaf area, leaf function, temperature, sunlight, tree vigor, etc. In this report, we attempt to understand the parts of variation induced by weather and carbohydrate supply:demand balances.

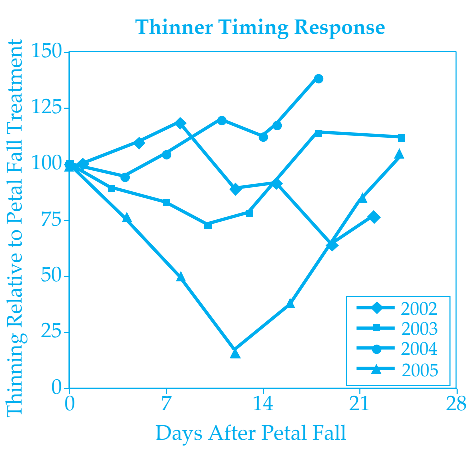

Figure 1. The pattern of chemical thinner response in four years to the same thinner and concentration (see text below) at different times after petal fall on Empire apples.

Drs. Edgerton and Williams (Williams 1979; Williams and Edgerton, 1981) many years ago summarized many of the tree status and weather factors related to observed variations in thinning response. Conditions that are associated with heavier set and more difficult thinning are: cool, sunny, light initial crop on a moderate number of spurs, healthy trees with good leaf area. Conditions that are associated with heavy drop and easier thinning are: hot, cloudy, heavy initial set on many weak spurs, stressed trees, inhibitors of photosynthesis, natural or imposed low light periods, and high night temperatures all cause or enhance fruit abscission (Williams, 1979; Williams and Edgerton, 1981; Greene 2002; Lakso unpublished data).

Many of these factors are directly related to the balance of carbohydrate supply from tree photosynthesis in relation to the demands for growth by all the competing organs of the tree (crop, shoots, roots, woody structure, etc.). The amount of sun, the temperature (optimum at about 80˚F), sunlight capture by leaves, and health of the leaves are the primary weather and tree factors controlling carbohydrate supply. Temperature, number of shoots, and number of fruit are important factors that control the demand for carbohydrates. So, cool sunny days with a light initial crop will be the best for the balance of supply to demand in giving good production of carbohydrates due to the sun while the cool temperatures limit excessive demand. On the other hand, hot cloudy days with a heavy initial set will be the worst as the low sunlight reduces supply but the high temperatures will drive up growth rates and thus the demand. It should be noted that cloudy periods may not necessarily be a problem if it is also cool, or very warm if also sunny, as both supply and demand are affected similarly and thus stay in balance. Of course, the amount of initial crop is important to the demand. In many cases, trees may have 10-15 times as many flowers as the desired final fruit numbers. At the time of thinning there may still be 3-10 times as many fruits as desired.

Modeling Tree Response to Chemical Thinners

From the many observations and studies of thinning, it appears that carbohydrate supply in relation to the demand of the fruit likely plays an important role, (but not the only factor), in apple tree response to chemical thinners. We suggest that the carbohydrate supply:demand balance is important to varying tree sensitivity to chemical thinning. Although many factors, described above, are involved in carbohydrate supply:demand balance, this is a process that is relatively well understood and has been modeled well in other crops. A model that can integrate weather and tree health factors may allow better understanding of why thinning is so variable and hopefully provide more precise prediction of thinner response under specific environmental and physiological conditions.

How the Model Works

We have developed over the past 15 years a model of apple tree carbohydrate supply and demand the can integrate many of the environment and tree factors that are known to affect thinner response (Lakso et al., 2001). The model was developed to: (1) summarize all our measurements of seasonal growth and productivity, (2) determine if there are periods of likely carbon deficits or surpluses that may affect orchard performance, and (3) evaluate the effects of environmental changes and cultural practices.

A simplified model was developed that estimated shoot growth, whole tree photosynthesis, respiration of fruits, leaf area, roots and woody structure. The model distributes the available carbohydrates to the growing organs of the tree. If the carbohydrate supply is inadequate to support all the growth of the tree and crop, then competition occurs. We have found in related studies that during the thinning window, shoot growth will outcompete fruit for carbohydrates if there is not enough for both (Figure. 2).

In this report we focus on comparing the model estimates of early season pattern of carbohydrate supply to total demand for carbohydrates to look for periods of particularly good or poor supply:demand balance based on yearly weather patterns of several years. The yearly weather effects are shown by using a "standard" Empire spindle tree using the weather from individual years. These patterns of supply to demand were

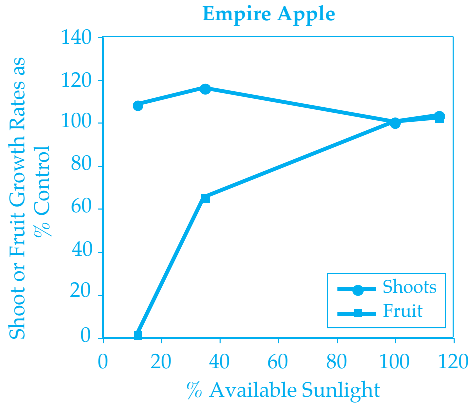

Figure 2. Competition between shoot growth and fruit growth in Empire apple trees at the time of thinning. Trees were shaded to different light levels as well as given extra light with reflectors in the alleyways for six days. Shoot growth was not affected by the reduction in carbohydrates caused by the shade, but fruit growth was severely reduced at lower light, defruiting the trees at the lowest light.

then compared to observed responses in a set of studies using the same chemical thinners applied at different times each year (see below).

Thinning Trial Procedures

Beginning in 2000, spray timing trials were conducted on mature vertical axis 'Royal Gala'/M.9 and 'Ace Delicous'/M.9 trees in the same orchard that were planted in 1995. Single application sprays of a tank mix of 7.5 ppm of naphthaleneacetic Acid (NAA) (formulation Fruitone N) plus a pint/100 gal of carbaryl (formulation Sevin XLR Plus) or 75 ppm of 6-benzlyadenine (BA) (formulation Maxcel) plus pint/100 gal of Carbaryl were applied at three or four day intervals beginning at petal fall until 21 days after petal fall (DAPF).

Normally about seven timings were achieved during the thinning period. Trees were sprayed with an airblast sprayer at 100 gallons/acre using a 2X concentration of chemicals. Calculated tree row volume was 200 gallons/acre. Upper and lower branches in each tree were selected and counted for flower cluster numbers and final fruit numbers to allow estimates of percentage fruit set. At harvest, all fruits/tree were counted and total yield weighed to allow expressions of crop level and crop load per cm^2 of trunk cross sectional area. For comparisons of overall thinning results to the model estimates, results from both cultivars and both thinners were combined since the general results from both cultivars and thinners were similar.

Model Estimation Procedures

The apple carbohydrate model was used to obtain carbon balance estimates with only the inputs of each year's daily maximum and minimum temperatures and total radiation beginning at budbreak. All other tree and physiological parameters were set based on a mature slender spindle tree at approximately 800 trees/acre. The estimated thinning season patterns shown are the total daily carbohydrate supply (daily canopy photosynthesis minus total daily respiration), total demand of all organs for carbohydrates (a difficult value to estimate precisely, but estimated consistently in all simulations), or the difference between supply and demand.

It should be noted that the model is not intended to, nor is it capable of, providing exact predictions of tree sensitivity to chemical thinners. It is designed to help integrate many parameters realistically to show patterns of tree behavior that may be helpful for our understanding. For this study, we have limited the demand for carbohydrates for fruit development to a realistic level of 300 fruits/tree (a heavy, but not uncommon crop level for the "standard" tree). This was done since modeling of the complex process of fruit drop from an initial crop of about 2000 initial fruitlets is currently not good enough yet.

Comparison of Thinning Results to Model Estimates

The general pattern of estimated carbohydrate supply versus total tree demand shows that before bloom, the current season carbohydrate supply is insufficient to support growth demands, but carbohydrate reserves from the roots and wood fulfill that need. After bloom, however, it appears that reserves play a minor role, so modeling of current supplies and demands can be useful during post-bloom thinning.

Overall, the supply curve increases as the canopy grows and captures increasing amounts of sunlight energy. The demand curve also increases as the different organs of the tree develop. Using long-term average weather data for Geneva, NY, the early season pattern of supply to demand indicates that the tree carbohydrate supply is generally in balance with observed demands for the growth of the tree growth and a crop of 300 fruit (Figure. 3). By about 3 weeks

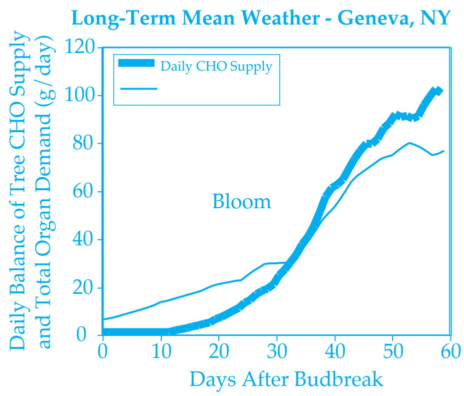

Figure 3. General model estimates of early-season pattern of carbohydrate supply and demand of apple trees with long-term Geneva, NY weather. Demand curve represents all organs, but 300 fruits.

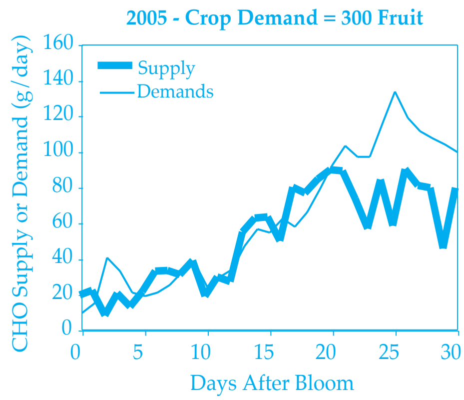

Figure 4. Models estimates of supply and demands (fruit demand limited to 300 fruits) using Geneva, NY weather in 2005. Note the period after 21days when demands greatly exceed supply.

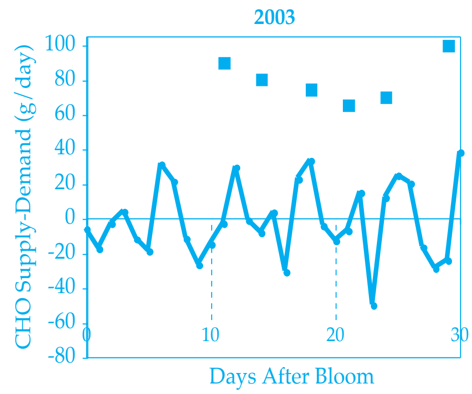

Figure 5. Simulated supply minus demands (fruit demand limited to 300 fruits) using Geneva, NY weather from 2003. Square data points are results of timing trials of thinning as % of control crop load.

after bloom the demands level off relative to the supply as cell division in the fruit declines and an increasing fraction of shoots terminate growth.

To provide realistic demand curves, fruit numbers were limited to 300 fruit/tree. When actual weather data from several years was used for the simulations, periods of particularly positive or negative supply:demand balance were seen in several cases but not all. Other studies here and elsewhere have shown that it requires two to three days of poor weather (clouds or heat) to cause a significant effect on the trees. They seem to have the ability to not respond much to single day weather conditions but do respond to two, three or more days of good or bad weather. So we look for periods of at least two to three days or more of particularly good or bad carbohydrate balance as key periods. An example is shown in Figure 4 where about three weeks after bloom it was hot and cloudy, giving poor carbohydrate balance.

We compared the relative balance of supply to demand by subtracting the demand from supply. The next figure will show an excess of carbohydrates above zero and a deficit below zero. Estimates using weather data from 2003 (Figure 5) showed that both supply and demand varied with temperatures and light, but they tended to vary similarly so their appeared to be no periods of more than one day of especially good or poor supply:demand balance. So we did not expect any variation in thinning response to be caused by the carbohydrate supply vs demand in 2003. There was a trend in the thinning response (square symbols in Figures), but it does not relate to the carbohydrate supply-to-demand. However, in 2004 a very warm and very cloudy period for the first 14 days after bloom caused an extended poor supply:demand balance followed by a period of particularly good balance (Figure. 6). Similarly, the thinning response was strongest during the earliest thinning times, a very different pattern from 2003.

In 2005, the opposite pattern occurred with a good balance initially, then at about 18 days after bloom, an extremely warm period (very high demand) with some cloudiness (limited supply) caused a very poor carbohydrate supply:demand balance (Figure 7). Again this poor period of supply and demand corresponded with the strongest thinning effect. It also appears that the strongest thinning occurred when the thinner is applied just before the temperatures became hot, not necessarily during or after the heat. Finally, in 2006, the carbohydrate supply demand balance pattern was similar to 2005 with a hot period leading to poor carbohydrate balance that also correlated with the strongest thinning effect (Figure. 8).

In summary, although many factors in apple thinning may be critical, it appears that particularly good or poor post-bloom carbohydrate supply and demand as estimated by our model are important to the response to postbloom chemical thinners. This is very useful in

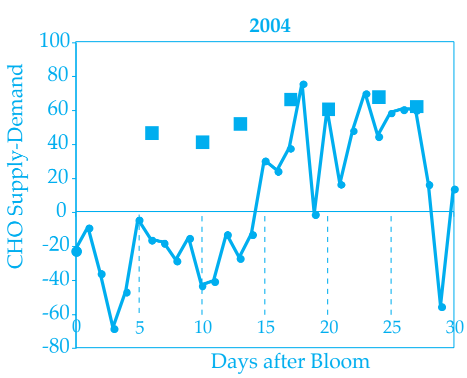

Figure 6. Simulated supply minus demands (fruit demand limited to 300 fruits) using Geneva, NY weather from 2004. Square data points are results of timing trials of thinning as % of control crop load.

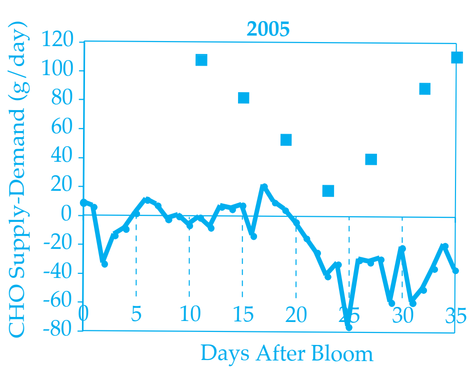

Figure 7. Simulated supply minus demands (fruit demand limited to 300 fruits) using Geneva, NY weather from 2005. Square data points are results of timing trials of thinning as % of control crop load.

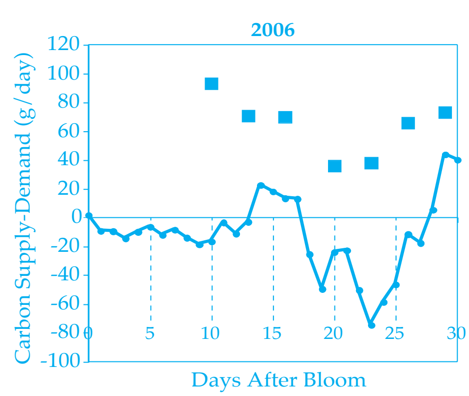

Figure 8. Simulated supply minus demands (fruit demand limited to 300 fruits) using Geneva, NY weather from 2006. Square data points are results of timing trials of thinning as % of control crop load.

better understanding why thinning is so variable. With accurate weather forecasts, the model may also be useful to provide real-time predictions of weather-related variations in response to thinners.

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