Precision Chemical Thinning

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For the past 50 years chemical thinning has been the primary method growers have used to achieve the proper crop load and consistent annual cropping but despite over 50 years of experience with chemical thinning, it remains an unpredictable part of apple production with large variations from year to year and within years due to weather.

The interactions of environment with thinning have been observed for many years. Beginning in 2000, we began to study this variability by conducted annual spray timing trials in NY State, which showed extreme variation in timing of response and thinning efficacy between years over the 3 week period after bloom when chemical thinners are applied (Fig. 1) (Robinson and Lakso, 2004; Lakso et al. 2006).

There are two major sources of this variability: spray chemical uptake and environmental effects on tree physiology. Variability in spray uptake includes the chemical thinner concentration, the environment at the time of application (temperature and humidity), application method and coverage, drying conditions, and leaf epicuticular wax. However, generally temperature and humidity largely compensate for one another in affecting drying time and uptake.

A second and more important source of variation is the sensitivity of the tree itself, which is related to the level of bloom, how many fruits are present at the time of application, leaf area, temperatures, sunlight, and tree vigor. Many of these factors are directly related to the balance of carbohydrate supply from tree photosynthesis in relation to the demand for carbohydrates from all of the competing organs of the tree (crop, shoots, roots, and woody structure).

Carbohydrates and Fruit Growth

Considerable research has examined the role of carbohydrates as a pivotal to the fate of young developing apple fruit. Carbohydrates are stored as reserves in the dormant tree but these reserves are depleted by bloom as tree use these to produce energy for pre-bloom growth and respiration.

After fertilization young fruit require currently produced carbohydrates for continuous development and the extent of this demand appears to be associated with the stage of fruit development and level of light. Immediately after petal fall, demand for carbohydrates by developing fruit is only moderate during the initial lag phase of an expolinear growth pattern. However, when fruit reach 8-10 mm in diameter (about 1-2 weeks after petal fall), rapid fruit growth results in an ever-increasingly large carbohydrate demand which may not be met by current photosynthesis.

At that time in spring considerable variation in temperature and light gives large variations in carbohydrate balance. Temperature, number of shoots, and number of fruit are important factors that control the demand for carbohydrates. With cool sunny days with a light initial crop, the balance of supply and demand carbohydrates is positive due to the high photosynthesis while the cool temperatures limit demand for carbohydrates by shoots and fruits. On the other hand, hot cloudy days with a heavy initial crop load have a negative balance of carbohydrates due to a reduced supply but the high temperatures drives up demand by stimulating growth rates of shoots and fruits.

Chemical thinners are reputed to work by providing a transient stress on the tree during the rapid growth stage of shoots and fruits and when fruits are most susceptible to a carbohydrate deficit. Chemical thinners appear to have the capability to create a carbohydrate stress by reducing photosynthesis, increasing respiration or impeding carbohydrate movement to the fruit. Many have observed that the greatest fruit abscission caused by thinners is associated with periods of 3-5 days of reduced carbohydrate availability immediately following thinner application. These weather conditions are generally a combination of warm temperatures and low light. Unfortunately, these are empirical observations that have not been quantified to aid in prediction of thinner response or used to make thinner recommendations.

Apple Tree Carbohydrate Balance Model

Alan Lakso at Cornell University has developed a simplified mathematical model that mechanistically estimates apple tree photosynthesis, respiration and growth of fruits, leaves, roots and woody structure. The model uses daily maximum and minimum temperatures and sunlight to calculate the production of carbohydrates each day and allocates the available carbohydrates to the organs of the tree. From these data the model calculates the daily balance of carbohydrates for a virtual tree based on an Empire/M.9 tree grown in Geneva, NY (Fig. 2).

Although 50 years of experience with chemical thinning has taught us that what to expect with extreme weather conditions, the model is especially valuable in estimating carbohydrate balance in less obvious conditions such as cool and cloudy compared to hot and sunny and gives a quantitative value under all conditions.

The value of the model in predicting chemical thinner efficacy has been studied since 2000 in both field and greenhouse thinning studies at Cornell University since 2000. In each year we identified periods during the 2-3 week thinning window where the model estimated either a carbohydrate surplus or a deficit and compared them to our observed thinning responses from the spray timing studies mentioned earlier (Fig. 1). For example, in 2004 a very warm, cloudy period occurred shortly after bloom resulted in a net carbohydrate deficit during the first 10-14 days after petal fall followed by a sunny cool period of particularly good carbohydrate balance (Fig. 3). The poor carbohydrate balance period correlated well with the strongest thinning response while the least thinning response later during the good carbohydrate balance. In 2006, however, the carbohydrate balance was good initially after bloom corresponding to light-moderate thinning. The hot period beginning at about 21 days after bloom led to a poor carbohydrate balance that correlated with the strongest thinning effect. Other years showed similar correlations that explained many of the year-to-year variations shown earlier (Fig. 2). We have used the estimated supply-demand balance of the tree to predict or explain thinning response as follows: carbohydrate surplus will support fruit growth giving less thinning while carbohydrate deficits will limit fruit growth giving more thinning

In 2008 we conducted a greenhouse study using potted apple trees where we imposed one of 3 temperature regimes (15/7.5°C; 22/15°C; 29/22.5°C with 30-35% of outside light) for a 5-day period immediately after thinner application of Napthaleneacetic acid (NAA)+Carbaryl or Benzyladenine(BA)+Carbaryl). The combined effects of the reduced light and temperature of the glasshouse were calculated as carbohydrate balance using the model. The 5-day average carbohydrate balance affected by temperatures and light was well correlated with fruit set in a strongly positive manner (Fig. 4). At all levels of deficit there was a strong added thinner effect with little difference between NAA+Carbaryl or BA+Carbaryl. Only when the carbohydrate balance showed no deficit did the chemicals thin moderately.

We have used these results to develop simple decision rules based on carbohydrate balance for the day of thinning and the next 3 days (Table 1).

In 2013 the carbon balance model was set up on a web server at Cornell University and linked to weather stations in NY, MA, VT, NJ and eastern PA for historical data and to improved weather forecasts for prediction. The server allows apple grower or consultants to run the model and receive suggestions in real time of carbohydrate balance and expected thinning efficacy. The carbohydrate model has potential to predict thinner responses prior to the application of thinners thus allowing growers to adjust thinner treatment and timing to achieve an optimal amount of thinning. However, it imprecisely assesses the real effect of the chemical thinner after application. A more precise assessment tool after application would be of value to growers in deciding whether to apply a second application of chemical thinner.

Apple Fruit Growth Rate Model

A method of early assessment of thinning efficacy after chemical application based on fruit growth rate has been developed by Duane Greene, and others (Greene et al., 2005). The model is based on the observation that fruitlets which have slowed growth rates (less than 50% of the fastest growth rates) are usually destined to abscise (Lakso et al., 2001b). The model requires the measurement of the diameter of fruitlets on 100 spurs (300-400 fruitlets) at 3 and 7 days after application of the chemical thinner to clearly differentiate abscising versus retained fruit. The growth rate of the fastest-growing fruitlets is used as reference to determine the percentage growth of fruitlets and what percent will abscise.

Early estimates of thinning efficacy after application allow timely decisions about the need for a second chemical application if needed.

In 2008 the fruit growth model was evaluated at NC and NY with several varieties. Thinning response to the thinner and final fruit set in NC was accurately predicted. In NY, initial fruit abscission response to the thinner was accurately predicted although a later cloudy period caused additional drop. As with the carbohydrate model this model needs additional validation in other climates, especially in arid climates like Idaho.

Precision Chemical Thinning

In the last 3 years we have begun working on an improved method of conducting chemical thinning that utilizes both the carbohydrate model and the fruit growth model. We have named the method "Precision Chemical Thinning". This method uses the carbon balance model as a predictive tool for predicting response prior to application and the fruit growth rate model for early assessment of thinning response immediately following application.

The method begins with first calculating the final fruit number needed per tree (based on desired yield) and secondly assessing the number of flower clusters on the trees (after pruning) by counting 5 representative trees. Once the number of flower clusters/tree is known (each cluster with 5 flowers) and the final fruit number needed for the desired yield the percent of the initial flowers needed after thinning can be calculated. The optimum final fruit number per tree is different for each variety and depends on genetic fruit size of the variety (Gala is small genetically and Jonagold is large genetically) and the price in the market (large Gala's have a much higher price than small Gala's while Jonagold's that are too big have a lower market price) and the inherent bieniality of the variety (Honeycrisp are very biennial and must be managed at a lower crop load than Gala which is not biennial). An example of calculating the optimum fruit number per tree is given for Gala

Calculation of Desired Fruit Number (Tall Spindle Example)

1. Determine desired yield/acre (in this example I chose 1500 bu/acre) and desired fruit size (in this example I chose 100 count fruit size ~175-180g)
2. Calculate the desired number of fruits per acre (1500bu/acre X 100 fruits/bu=150,000 fruits/acre
3. Calcualte the desired number of fruits per tree ((150,000 fruits per acre / 1210 trees/acre = 124 fruits/tree
4. Count flowering spurs on 5 representative trees at pink. (In this example I counted flower clusters on 5 trees, which had an average of 200 flowering cluster/tree
5. Calculate the number of potential fruits per tree (200 flowering spurs X 5 flowers per spur = 1,000 potential fruits/tree)
6. Calculate percent of fruits needed after thinning which equals the thinning task (124 desired fruits per tree/1000 potential fruits per tree = 12.4%)

With the variety specific target of final fruit number per tree and thinning task in mind a precision thinning program is conducted by applying successive thinning sprays followed by rapid assessment of the results in time to apply a subsequent thinning spray and then an early re-assessment, followed by another spray if needed until the final target fruit number for each variety is achieved.

In practice precision thinning begins with:

1. A bloom thinning spray at 60-80% full bloom.
2. The first spray is followed by a petal fall spray applied 2-4 days after petal fall (about 1 week after the bloom spray) when fruits are 5-6mm in diameter. Before the petal fall spray the results of the carbohydrate model are used to guide the rate of chemical and the exact timing of the petal fall spray.
3. The first two sprays are followed by an assessment of the efficacy of those 2 sprays using the fruit growth rate model which indicates the percentage of thinning achieved with the first 2 sprays.
4. Then, if needed, a third spray is applied at 10-13mm fruit diameter (about 1 week after the petal fall spray). Before the petal fall spray the results of the carbohydrate model are used to guide the rate of chemical and the exact timing of the third spray.
5. The third spray is followed by an assessment of the effectiveness of all previous sprays using the fruit growth rate model, which indicates the percentage of thinning achieved with all 3 previous sprays.
6. Lastly, if still more thinning is needed, a fourth spray is applied at 16-20mm (about 1 week after the third spray) to achieve the target fruit number.

Figure 5 shows a decision making tree we envision being used by growers to achieve the optimum crop load.

Precision Thinning in NY State in 2013

The precision thinning program can be implemented in 2013 by growers in NY, MA, VT, NJ and eastern PA. The carbohydrate model has now been mounted on a web-server at Cornell University and is available over the Internet at the NEWA site. This will allow apple growers or crop consultants can use the carbohydrate model to predict chemical thinner efficacy before applications of thinners at bloom, petal fall, 10-13mm and at 16-20mm. The fruit growth rate model requires laborious and time consuming fruit tagging and fruit diameter measurements. This aspect will discourage some growers from using this valuable tool. However, the economic impact of optimum crop load adjustment can be work $5,000-8,000 per acre. Thus a labor intense assessment of fruit thinning is justified and is much less expensive than hand thinning or the losses incurred by over thinning.

A second problem is the many varieties grown by most growers in the eastern US. It may be impractical to apply the fruit growth rate model to all varieties. If a grower or consultant could make the fruit diameter measurements on 2 varieties (a hard to thin variety and an easy to thin variety) this data could then guide the decisions for other varieties. We suggest that growers and consultants use the fruit growth rate model on Gala and McIntosh in the Northeast.

Lastly, precision thinning will be more easily applied to the simple trees in high-density orchards such as the Tall Spindle or Super Spindle where counting of whole trees is easier than large trees.

Table 1. Decision rules for using the output of the carbohydrate model to adjust chemical thinning rate

4-day Av. Carb. Balance	Thinning Recommendation
+20g/day to 0g/day	Increase Chemical Thinning Rate by 30%
0g/day to -20g/day	Apply Standard Chemical Thinning Rate
-20g/day to -40g/day	Decrease Chemical Thinning Rate by 10%
-40g/day to -60 g/day	Decrease Chemical Thinning Rate by 20%
-60g/day to -80 g/day	Decrease Chemical Thinning Rate by 30%
< than -80g/day	Do not thin (many fruits will fall off naturally)

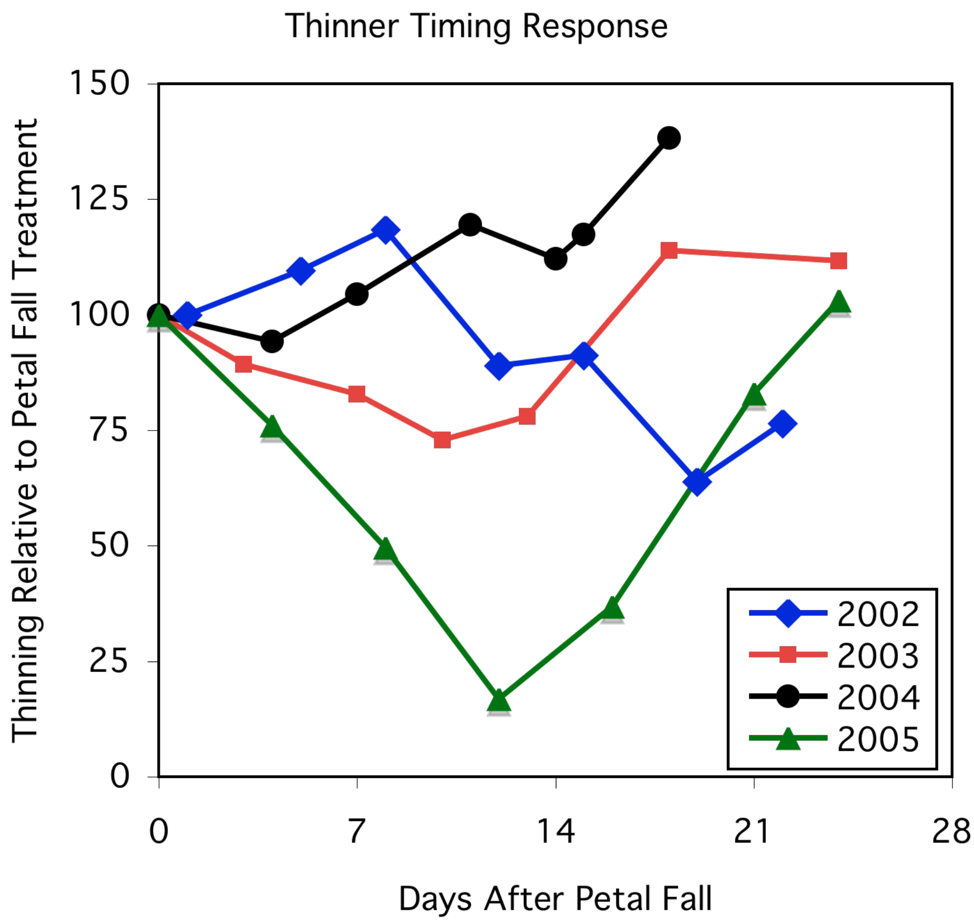

Fig. 1 Variability in chemical thinner response in 4 years at Geneva, NY

Critical periods of carbohydrate deficits

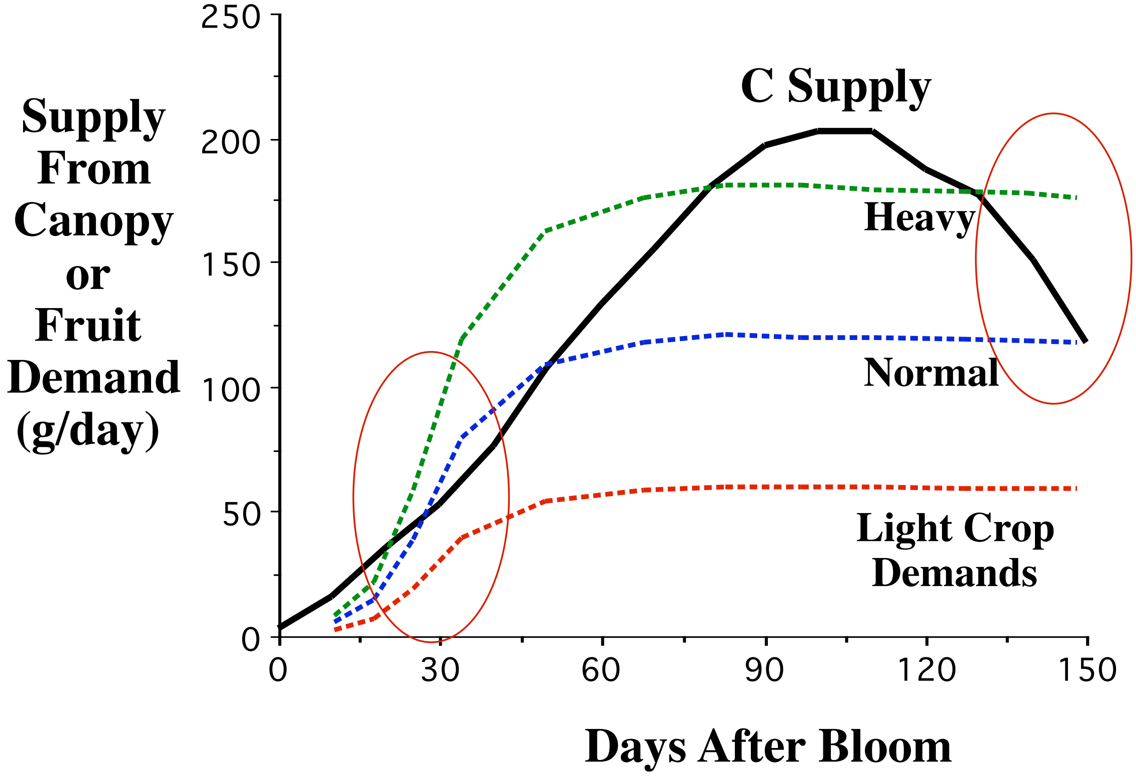

Fig. 2. General seasonal pattern of carbon availability to support crop growth and demands of light normal and heavy crops on reference trees.

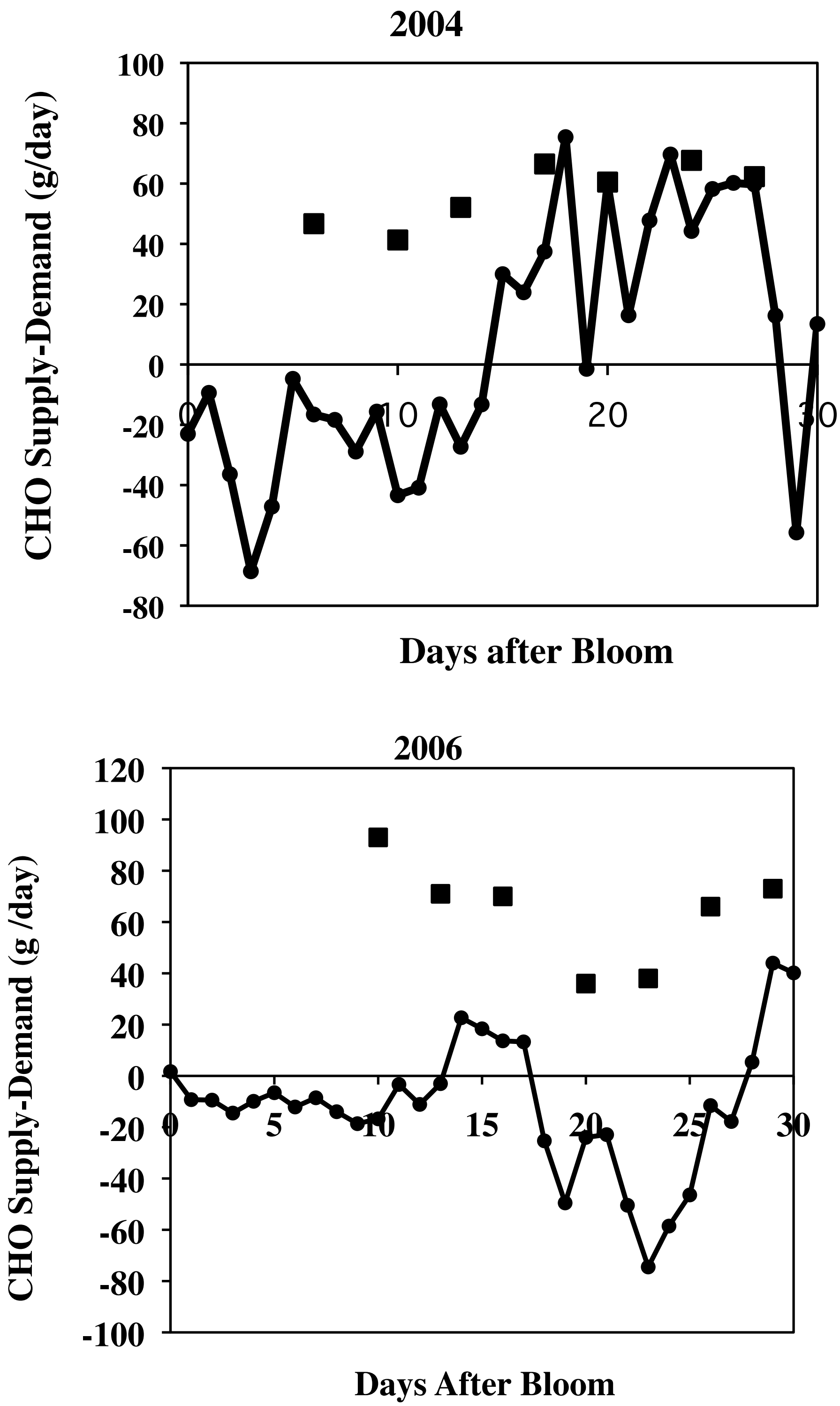

Fig . 3. Predicted daily carbohydrate balance (line) at Geneva, NY in 2004 and 2006 and results of timing trials of thinning as % of the crop load on unthinned trees (square data points).

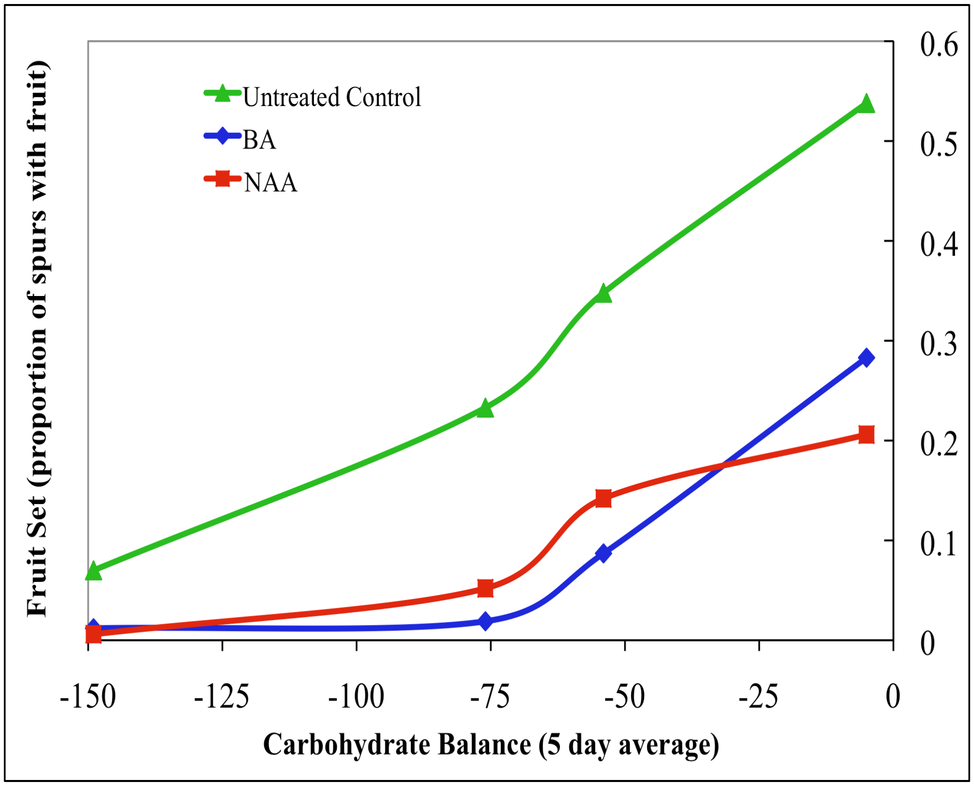

Fig. 4. Fruit set of trees with varying light and temperature, with and without chemical thinners, as a function of 5-day post-application carbohydrate balance.

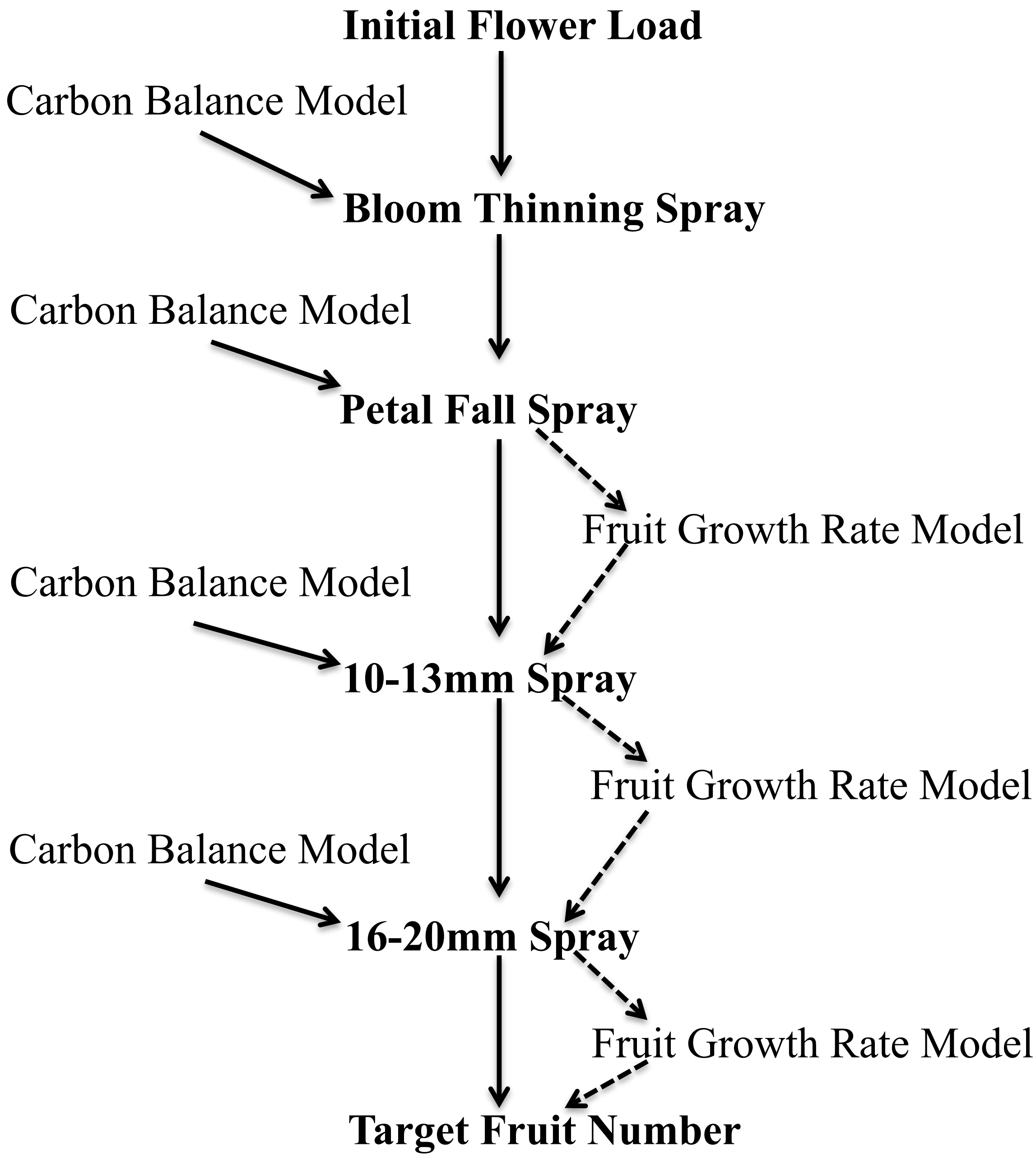

Fig. 5. Flow chart of precision thinning program to achieve a target crop load