Precision Crop Load Management

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The economic impacts of achieving the proper crop load each year are large (often $5,000-$10,000 per acre) and justify a more intense effort to manage crop load to achieve the optimum fruit number each year. Precision Thinning is a new strategy that begins with defining the optimum fruit number/tree (target fruit number) then applying sequential chemical thinning sprays (with rates and timing guided by the carbohydrate balance model to predict thinning efficacy and the fruit growth rate model to assess thinning efficacy in time to allow re-treatment when needed) with the goal of reducing fruit number per tree to close to the target fruit number to optimize crop value and reduce hand thinning costs.

Crop load management is the single most important yet difficult management strategy that determines the annual profitability of apple orchards. The number of fruit that remain on a tree directly affects yield, fruit size and the quality of fruit that are harvested, which largely determine crop value. If thinning is inadequate and too many fruits remain on the tree, fruit size will be small, fruit quality will be poor and flower bud initiation for the following year's crop may be either reduced or eliminated. Consequently, poor or inadequate thinning will reduce profitability in the current year and result in inadequate return bloom in the following year. Over thinning also carries economic perils since yield and crop value the year of application will be reduced and fruit size will be excessively large with reduced fruit quality due to reduced flesh firmness, reduced color and a much-reduced postharvest life. Thus, management of crop load is a balancing act between reducing crop load (yield) sufficiently to achieve optimum fruit size and adequate return bloom without reducing yield excessively (Fig. 1).

Economic Impacts of Crop Load

Calculations of crop value at various crop load levels using fruit size and yield as the main variables has shown in a number of experiments to that the relationship of crop value to crop load is curvilinear (Fig. 1). At very high crop loads (unthinned Gala trees) fruit size is often very small but yield is very high. Crop value in this situation is almost zero since the value of the fruit is often exceeded by the packing and storage costs. When crop load is reduced to more moderate levels through thinning, then crop value rises dramatically even though yield is lower due to larger fruit size, which has greater value. At some point crop value peaks and then with further reductions in crop load crop value declines due to lower and lower yield. Although fruit size continues to increase it does not compensate for the loss in yield. It is striking how narrow the crop value peak is in many situations. Identifying and then achieving this optimum crop value is often very difficult for apple growers. It is difficult for fruit growers to know the economic impact of not achieving the optimum crop load without having various levels of thinning each year to construct the curves shown in Fig. 1. The difference between the optimum crop load and under thinning or over thinning can sometimes be a difference of thousands of dollars per acre. Thus growers often fail to capture the full crop value possible without knowing how much "money they left on the table". More precisely managing crop load will help growers achieve the optimum crop load and maximize crop value.

Management Approaches to Precisely Managing Crop Load

There are 3 management practices that have a large effect on crop load: 1) pruning, 2) chemical thinning and 3) hand thinning. In recent years growers have relied primarily on chemical thinning to adjust crop load with a lesser reliance on hand thinning to reduce labor requirements. In other countries hand thinning is still the primary means of adjusting crop load. A few progressive growers have also begun to view pruning as a means to adjust crop load.

Precision crop load management utilizes all three management approaches to adjust crop load. It begins with precision pruning to leave on the tree a preset bud load, followed by precision chemical thinning to reduce initial flower number per tree to as close as possible to a preset fruit number per tree and ends with precision hand thinning to leave a precise number of fruits per tree.

Chemical Thinning

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 (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 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 flower fertilization young fruits 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 (Lakso et al., 2006, 2007). 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.

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 (Lakso et al., 20078; Robinson and Lakso, 2011). 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. 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) (Yoon et al., 2010). 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. At all levels of deficit there was a strong added thinner effect with little difference between NAA+Carbaryl and 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).

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., 2013). 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. The model requires the measurement of the diameter of fruitlets on 75 spurs (375 fruitlets) at 3 and 8 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.

Precision Chemical Thinning

In the last 3 years we have developed 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 (target 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

<u>Calculation of Desired Fruit Number (Gala Tall Spindle Example)</u>

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. Calculate 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 the thinning task in mind a precision thinning program is conducted by applying sequential 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.

<u>In practice precision thinning begins with</u>:

1. A <u>bloom thinning spray</u> at 60-80% full bloom.
2. The first spray is followed by a <u>petal fall spray</u> 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, <u>a third spray</u> 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 <u>fourth spray</u> 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, MA, VT and NJ States in 2013

The precision thinning program was implemented in 2013 with growers, consultants and extension field staff in NY, MA, VT, and NJ. In 2013 we placed the apple carbohydrate thinning model on a web server at Cornell University, which is available over the Internet at the NEWA site (http://www.newa.cornell.edu). It is linked to on-farm weather stations in NY, MA, VT, NJ and eastern PA from which the model uses temperature and sunlight data beginning each year with the date of bud-break in the spring to daily calculate tree carbohydrate balance. The web version of the carbohydrate model also uses weather forecasts for prediction of carbohydrate balance 7 days into the future. The web site allows apple growers or consultants to run the model and receive predictions in real time of carbohydrate balance and suggested chemical thinner doses.

The fruit growth rate model is used to rapidly assess the effect of each chemical thinning spray. It requires growers to tag 15 representative spurs of 5 representative trees and then measure their diameter 3 and 8 days after each chemical thinning sprays. From these measurements fruit growth rate of each measured fruits is determined and those that are growing slow are predicted to fall off. From these data a percentage of the total fruitlets on the tree is calculated to fall off from that thinning spray. The fruit growth measurements require 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 $5,000-10,000 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.

For many fruit growers, it may be impractical to use the fruit growth rate model on all varieties since more than 20 varieties are grown in NY State. We suggest growers make the fruit diameter measurements on 3 varieties (2 hard to thin varieties and an easy to thin variety) to guide the decisions for other varieties. We suggest growers measure fruit diameters with Gala, McIntosh and Honeycrisp in the Northeast.

In 2013 more than 20 cooperating growers, consultants and extension staff implemented the precision thinning program on Gala and Honeycrisp in NY, MA, VT and NJ. The results of fruit diameter measurements made after petal fall thinning sprays around May 19th or 20th show that the sprays provided significant thinning on Gala and Honeycrisp but that additional thinning was still needed. In general fruit set was reduced by about 70% from the bloom and petal fall sprays (Table 2), however the target is to reduce fruit set by 90%. Thus substantial thinning on Gala and Honeycrisp remained to be done. This suggested another spray in these block at the 10-12mm fruit size stage. From this assessment we gave specific recommendations to each grower for another spray. A similar process was repeated after the 10-12mm spray to determine if another final spray was needed at 18-20mm fruit size stage.

Conclusions

The new precision thinning program for managing apple crop load allows growers to first determine a target fruit number and the initial fruit number per tree and then apply sequential thinning sprays beginning at bloom to reduce fruit number per tree in a step wise manner down to the target fruit number. The program utilizes the Cornell Apple Carbohydrate Thinning model and the Fruit Growth Rate model to provide real time information to growers of the progress in this step wise thinning process. The program gives growers confidence to thin when appropriate and sound information about when not to thin. The economic implications of optimum crop load and optimum fruit size are large and justify this more intensive management approach required by the Precision Thinning program.

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.

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

4-day Av. Carb. Balance	Thinning Recommendation
+20g/day to +80g/day	Increase Chemical Thinning Rate by 30%
+20g/day to 0g/day	Increase Chemical Thinning Rate by 15%
0g/day to -20g/day	Apply Standard Chemical Thinning Rate
-20g/day to -40g/day	Decrease Chemical Thinning Rate by 15%
-40g/day to -60 g/day	Decrease Chemical Thinning Rate by 30%
-60g/day to -80 g/day	Decrease Chemical Thinning Rate by 50%
< than -80g/day	Do not thin (many fruits will fall off naturally)

Table 2. Chemical thinning recommendations for 8 field studies using the fruit growth rate model to assess chemical thinner efficacy after the petal fall spray during May 2013 in NY State.

Cultivar/Farm	**Initial number of clusters/fruitlets per tree (averaged from 5 trees)**	**Current number of clusters/fruitlets after bloom and/or petal fall spray(s) as May 28, 2013**	**Current set (% fruitlets/tree) after thinning spray(s)**	**Target fruit number per tree**	**Chemical thinning recommendation**
Gala Farm 1	146 initial clusters (or 729 initial fruitlets)	224 fruitlets	30.7%	111 fruit	Spray again
Honeycrisp Farm 1	210 clusters (or 1050 fruitlets)	414 fruitlets	39.4%	61 fruit	Spray again
Gala Farm 2	235 clusters (or 1175 fruitlets)	328 fruitlets	32.5%	135 fruit	Spray again
Gala Farm 3	488 clusters(or 2440 fruitlets)	748 fruitlets	30.6%	231 fruit	Spray again
Honeycrisp Farm 4	225 clusters (or 1125 fruitlets)	321 fruitlets	28.6%	65 fruits	Spray again
Gala Farm 4	470 clusters (or 2350 fruitlet)	578 fruitlets	24.6%	135 fruits	Spray again
Gala Farm 5	200 clusters (or 1000 fruitlets)	375	37.5	80	Spray again
Honeycrisp Farm 5	200 clusters (or 1000 fruitlets)	213	21.3	60	Spray again

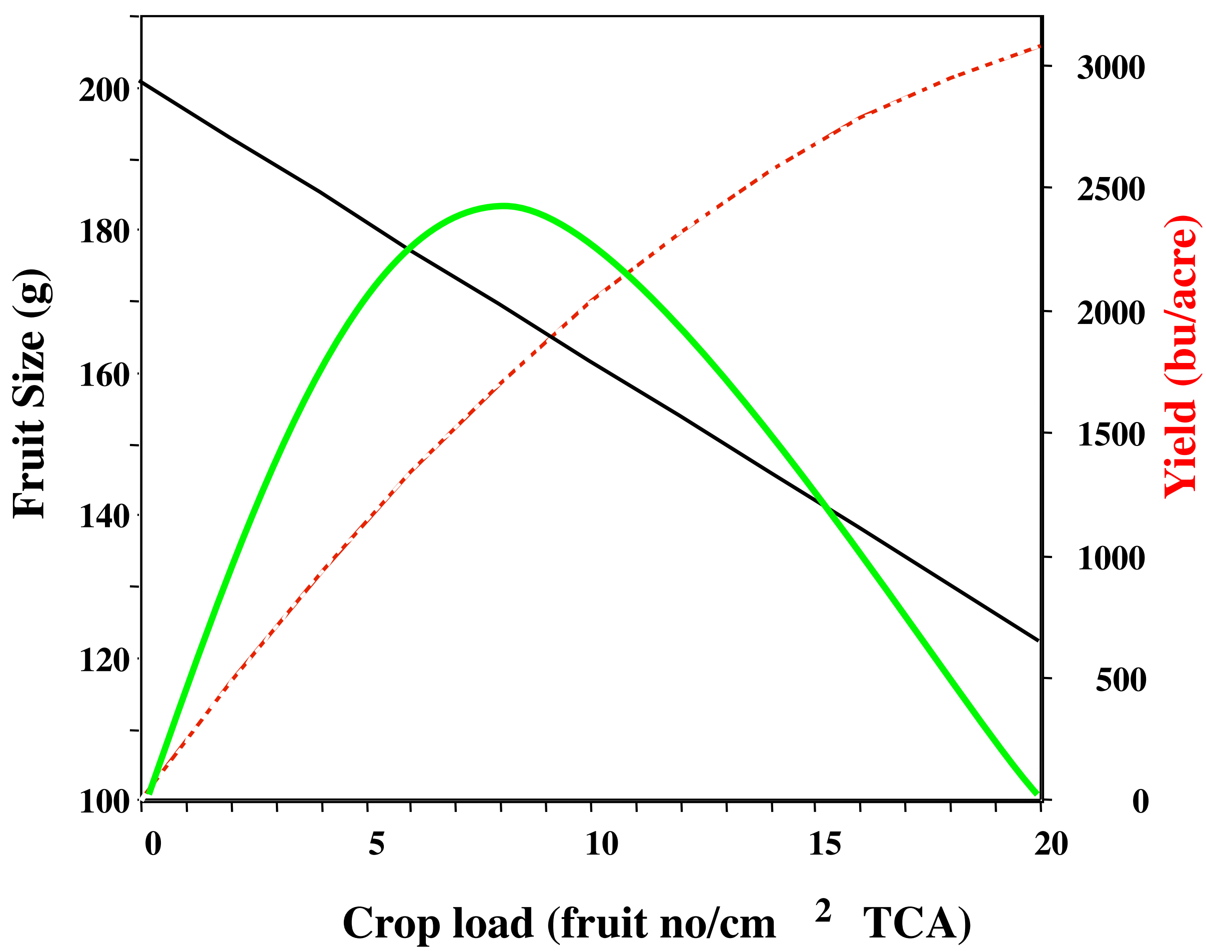

Fig. 1. Counter balancing responses of Gala fruit size and yield to crop load with the curvilinear response of crop value to crop load showing an optimum crop value at a crop load of ~8-9 fruits/cm^2 TCA.

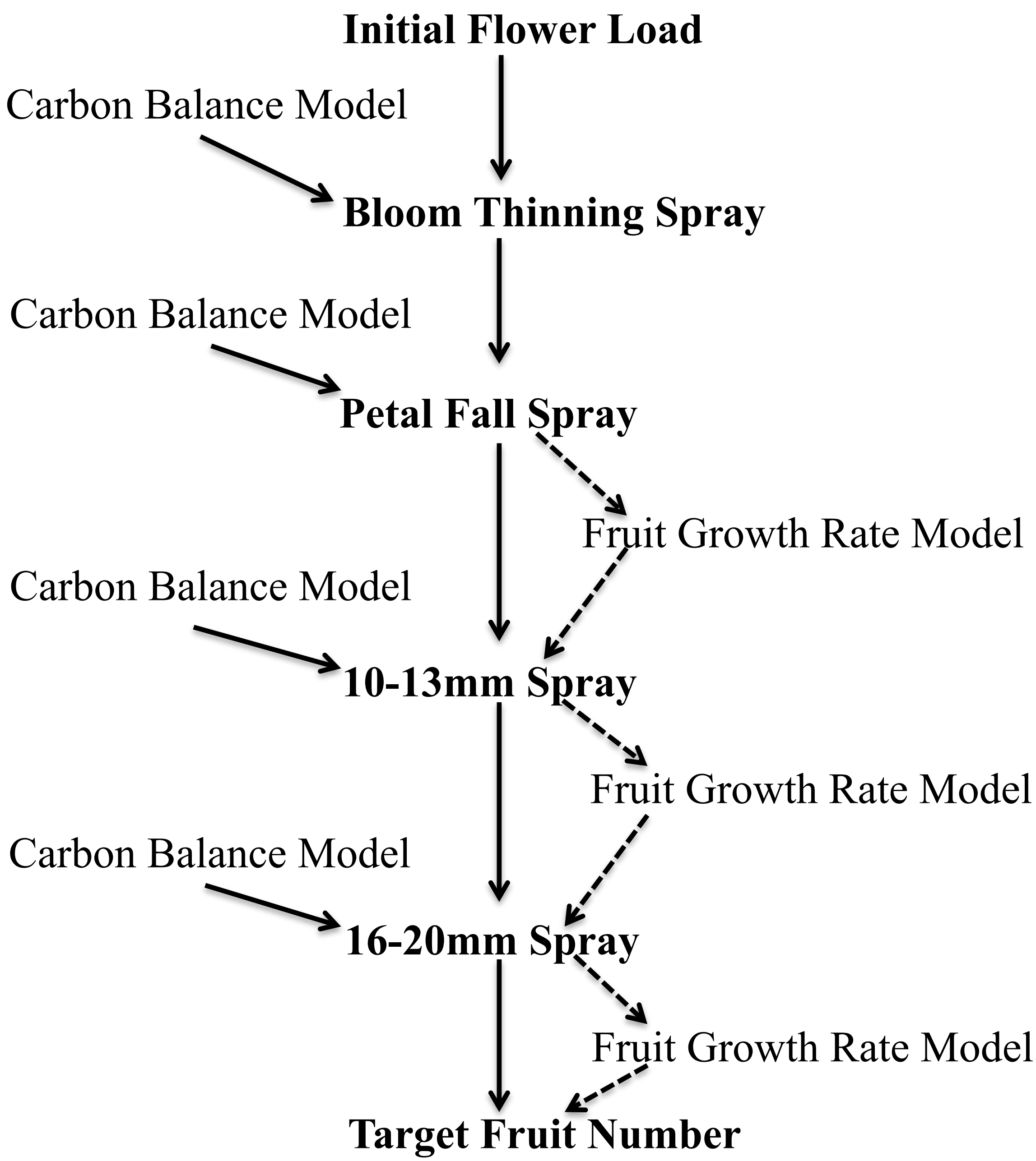

Fig. 2. Flow chart of precision thinning program to achieve a target crop load