**FINAL PROJECT REPORT**
**WTFRC Project Number:** AH-04-419

**Project Title:** Monitoring apple fruit growth for predicting chemical thinning response


**PI:** Duane W. Greene
**Organization:** University of Massachusetts
**Telephone/email:** 413-545-5219 dgreene@pssci.umass.edu
**Address:** Dept. Plant, Soil & Insect Sciences
**Address 2:** Bowditch Hall
**City:** Amherst
**State/Province/Zip** MA 01003

**Co-PI (2):** Alan N. Lasko
**Organization:** NYSAES Cornell Univ.
**Telephone/email:** 315-787-2399 anl2@cornell.edu
**Address:** Dept. Horticultural Science
**Address 2:** Hedrick Hall
**City:** Geneva
**State/Province/Zip:** NY 14456

**Co-PI(3):** Terence L. Robinson
**Organization:** NYSAES Cornell Univ.
**Telephone/email:** 315-787-2227/tlr1@cornell.edu
**Address:** Dept. Horticultural Science
**Address 2:** Hedrick Hall
**City:** Geneva
**State/Province/Zip** NY 14456

**Cooperators:** Philip Schwallier; Michigan State University; Clarksville Horticulture Expt. Station; 9302 Portland Rd.; Clarksville, MI 48815


**Budget History:**

| **Item** | **Year 1:** 2004 | **Year 2:** 2005 | **Year 3:** 2006 |
|---|---|---|---|
| **Salaries** | | | |
| **Benefits** | | | |
| **Wages** | $13,100.00 | $6,700.00 | $15,000.00 |
| **Benefits** | $4,978.00 | $2,345.00 | $5,719.00 |
| **Equipment** | | | |
| **Supplies** | $1,322.00 | $355.00 | $1,600.00 |
| **Travel** | | | |
| **Crop Loss** | $600.00 | $600.00 | $600.00 |
| **Spreadsheet** | | | $400.00 |
| | | | |
| **Miscellaneous** | | | |
| **Total** | $20,000.00 | $10,000.00 | $23,319.00 |

**Objectives**:
1. Follow fruit growth after thinner application to confirm that fruit growth is an appropriate and timely indicator of final indicator of final fruit set. Many things may ultimately determine whether a fruit persists or abscises, but the ultimate indicator appears to be fruit growth. The goal is to be able to determine a thinner response within 7 or 8 days of application, allowing for additional thinner follow up if deemed necessary while fruit are still susceptible to normally used thinners.
2. Develop a fruit growth model and procedure that can be used by growers to predict fruit set and thinner response.
3. Develop a procedure for selecting fruiting spurs that will assure that spurs selected and measured represent the response that is occurring on the whole tree.
4. Incorporate a heating degree component in the predictions system and confirm its usefulness in predicting thinning. Although following fruit growth has been a reliable predictor of thinner response, in some cool years it has required up to 12 days to make a judgment about thinner effectiveness. The hope is to establish a heating degree unit threshold that must be accumulated before an assessment of thinner response can be made.
5. Assemble an easy to follow and clear set of instructions that will outline spur selection, fruit numbering and measurement and data collection that will streamline the setting up and carrying out the procedure necessary for accurate thinner response prediction. The goal is to have the instructions and procedures sufficiently straight forward so that hourly laborers may carry out this activity.
6. Construct an Excel-based spreadsheet template that will simplify data input and automate the majority of required calculations. The hope is to ultimately have a system in place where data can be entered directly into the data base in the field and then download this into a computer to receive an near instantaneous result.
Utilize the Phytech® fruit growth sensor to accurately and continuously monitor and record growth information following thinner application. This activity will allow determination of the most precise information and earliest possible time that responses to a thinner can be detected.
7. Determine if the variability in tree response to the same thinner treatment applied at different times can be explained, then predicted, by accounting for tree sensitivity with a carbohydrate supply/demand estimate.

**Significant Findings:**

- We have confirmed that following fruit growth is an extremely accurate way to predict the fruit response to chemical thinner application and weather.
- The weather following thinner application, especially temperature, influences not only the extent of thinner response but also the time required to see a response. We now have a clear picture of the number of degree days required to see and observe a response.
- We have established a very simple and straight forward system so that workers can be trained in a minimum amount of time to collect and process the appropriate data.
- We have established a proactive chemical thinning approach where a decision at bloom is made about the crop load density that an orchardist hopes to achieve at the end of June drop and then allows that grower to monitor the progress toward that goal and allow for corrections if the goal is not predicted to be achieved.
- We have constructed an Excel-based spreadsheet that data can be downloaded into and where nearly all required calculation are done by the macros contained in the spreadsheet.
- Physiological and environmental data collected over the course of several years has allowed us to improve and refine the ability of the carbohydrate model to predict fruit abscission.

**Methods:**

Number of Spurs to Measure and Location of Spurs

Six 7-year-old Honeycrisp/M.9 were selected. Three lower scaffold limbs, three upper scaffold limbs and the central leaser were separately tagged and all blossom clusters counted at the pink sage of flower development. Six 4-year-old trees each of Desert Rose Fuji and Braeburn trained as super spindle trees were selected and the trees divided equally with tape into 4 sections: bottom, lower 25-50%, upper 50-75%, and the top of the tree. At bloom time every other blossoming spur on the Honeycrisp, Fuji and Braeburn were tagged. At the end of June drop all fruit on each limb or tree segment was counted and fruit set was taken on individual spurs. Fruit were identified as being located on a tagged or untagged spur.

Heating Degree Day Studies and Fruit Growth Studies

Heating degree days were calculated from temperatures taken in the orchard where the thinning studies were conducted from 2003 through 2006. Spurs were tagged and measurements taken on tagged and numbered fruit according to the method outlined in the Results. Thinners were then applied and fruit periodically measured. Based upon growth rate of measured fruit, the days after thinner application when a prediction with 90% accuracy could be made was noted.

**Results and Discussion**

The Basis for Predicting Thinner Effectiveness

The basis for the prediction is the slowing of growth of fruit that are destine to drop. This slowing of growth can be evident within 3 days when very warm conditions follow thinner application but may take as long as 8 days if the weather is cool. Fruit do not stop growth immediately but this reduction in growth can be detected before growth stops with careful measurements. Figure 1 illustrates the typical growth curve of a fruit that will persist to harvest and one that will abscise as the result of thinner application. A fruit is predicted to drop if the growth rate falls to 50% or less than the growth of the fastest growing fruit being measured. Although the relationship between fruit drop and fruit growth rate is a curve, based upon previous experience, we have selected 50% as our simplified cut-off level (Compact Fruit Tree 38(3)17-20, 2005).

Number of Spurs to Measure

Tagging, marking and measuring spurs is a time consuming process. Consequently, we wanted to determine the approximate number of spurs to measure to get a good prediction of response on the tree without incurring unnecessary work. The result in Table 1 show how close prediction of set on spurs was to the actual number of fruit on the tree. These are the average results from 5 trees. A 100% prediction is where the prediction and the actual number of fruit on the tree are exactly the same. A 90% or 110% represent a prediction that is either 10% too low or 10% too high, respectively. In our estimation a sampling error of +/- 10% is a reasonable compromise for precisions vs number of spurs measured. For the Honeycrisp 1 in 22 spurs measured gave a good representation whereas on Fuji 1 in 16 or 18 spurs seemed adequate. The Honeycrisp had 350 to 400 blossom cluster whereas the Fuji had 150 to 175. Based upon these data we feel that measuring 15 spurs on 6 different trees ( a total of 90 spurs) would give a representative prediction for the whole tree. These results also confirm our original protocol suggestion of using a total of 100 spurs on several trees.

We evaluated fruit set on various portions of the tree to use as a guide in determining the distribution of spurs on the tree. On both Honeycrisp and Fuji in both years fruit set was not the same on all portions of the tree, even though blossom cluster density was frequently similar (data not shown). In general, fruit set was higher on the upper portion of the trees and in some instances it was more than twice the amount. This confirms that the distribution of the tagged spurs to measure must

be in all portions of the tree and that they should be distributed in direct proportion to the blossom cluster density.

Table 1. Effect of the number of spurs sampled on a tree to predict final set on the accuracy of the prediction. The percent given represents the amount above or below the actual number of fruit counted on the tree at the end of June drop.

| Spurs | Honeycrisp (%) | | Desert Rose Fuji (%) | |
|---|---|---|---|---|
| Sampled | 2005 | 2006 | 2005 | 2006 |
| All spurs | 100 | 100 | 100 | 100 |
| 1 of 2 | 111 | 106 | 100 | 94 |
| 1 of 4 | 107 | 101 | 107 | 94 |
| 1 of 6 | 102 | 100 | 97 | 88 |
| 1 of 8 | 109 | 107 | 95 | 100 |
| 1 of 10 | 112 | 88 | 101 | 84 |
| 1 of 12 | 94 | 108 | 130 | 103 |
| 1 of 14 | 119 | 95 | 85 | 96 |
| 1 of 16 | 121 | 121 | 91 | 83 |
| 1 of 18 | 91 | 100 | 93 | 117 |
| 1 of 20 | 103 | 86 | 134 | --- |
| 1 of 22 | 96 | 114 | --- | --- |
| 1 of 24 | 68 | 106 | 138 | --- |
| 1 of 30 | 131 | 83 | --- | --- |

Heating Degree Day Studies and Fruit Growth Studies

While doing the research to develop a protocol for predicting thinning we measured fruit at 2 to 3 day intervals after thinner application and based upon growth rate of fruit we could make a prediction at each of the times of measurement. The accuracy of or prediction was tested by comparing actual set at the end of June drop. If this method is to be a useful tool for orchardists a call must be made soon after thinner application, but without the benefit knowing the final set. We noted in most years that an accurate prediction could be made within about 6 to 7 days from thinner application but sometimes it took as long as 12 days. In nearly every situation where the time of prediction was unduly delayed, it was associated with cold weather following thinner application. We initiated this study to see if we could use a heating degree day model to tell us when sufficient heat unit had a heating degree units following thinner application in 13 experiments over 4 years. We also determined when we could make a prediction of final set that was accurate to within 10% of the final set. Two things should be noted from this table. First, it requires 6 to 7 days after application for a thinner to cause physiological events that result in fruit abscission. If trees are exposed to 130 to 140 heating degree units (base 50) following thinner application, a thinning prediction can be made in about 7 days. However, if cold weather follows thinner application it took much longer. Our conclusion from these data is that an accurate prediction can be made 7 days after application if trees are exposed to approximately 130 heating degree units. If cool weather follows application then you must wait not only the 7 days but also until the 130 heating degree unit has been accumulated. The data for 2006 should be explained. The Fuji, Braeburn and Gala trees were all sprayed with a petal fall spray of carbaryl. This was then followed at the 7 mm stage with MaxCel. The days after application are for MaxCel and not carbaryl. Following carbaryl application weather turned warm and over 70 heating degree units was accumulated before MaxCel application. Therefore, the prediction results represent the earlier application of carbaryl.

Table 2. Growing degree days (base 50) following application of thinners in 2003-2006. Thinning and prediction of thinner response could be accurately made in 2003 and 2005 at 5-8 days after application, whereas it required 10-12 days for a similarly accurate prediction in 2004. The * indicates the time at which a thinning prediction could be made with 90% + accuracy.

| Days | 2003 | | 2004 | | 2005 | | | 2006 |
|---|---|---|---|---|---|---|---|---|
| after | Delicious | Golden Delicious | Golden Delicious | Delicious | Braeburn | Delicious | Braeburn | Fuji |
| application | McIntosh | | | McIntosh | Fuji | | | Braeburn |
| | | | | | | | | Gala |
| 1 | 14.3 | 22.8 | 9.2 | 10.3 | 7.9 | 10.0 | 12.8 | 28.3 |
| 2 | 31.6 | 38.6 | 19.5 | 25.4 | 18.4 | 22.8 | 34.0 | 50.0 |
| 3 | 46.4 | 56.0 | 30.3 | 29.0 | 28.4 | 44.0 | 58.6 | 84.1 |
| 4 | 60.1 | 74.2 | 45.2 | 40.5 | 41.2 | 68.6 | 76.1 | 110.8** |
| 5 | 82.9 | 97.9 | 55.9 | 47.8 | 87.0 | 86.1 | 100.1 | 132.0* |
| 6 | 98.7 | 119.6 | 70.3 | 57.0 | 104.5 | 110.6 | 126.1 | 144.1 |
| 7 | 116.1* | 145.7* | 84.8 | 67.3 | 129.0* | 136.1* | 151.4* | 156.8 |
| 8 | 134.3 | 161.7 | 84.8 | 78.1 | 154.5** | 161.4 | 174.3 | 172.4 |
| 9 | 158.0* | 181.8 | 98.7 | 93.0 | 179.8 | 184.3 | 199.6 | 193.8 |
| 10 | 179.7 | 207.3 | 110.2 | 103.7 | 202.7 | 209.6 | 223.4 | 206.3 |
| 11 | 205.8 | 224.3 | 120.4 | 118.1** | 228.0 | 233.4 | 250.6 | 219.8 |
| 12 | 221.3 | 240.9 | 132.9* | 132.6 | 251.8 | 260.6 | 275.7 | 237.3 |

We evaluated the basic method to predict thinning in 2006 in both New York and Massachusetts and we found it to be very accurate in predicting the final set within 7 days. Following application at both locations a warm period occurred which resulted in the exquisite accumulation of over 130 heating degree units within the 7 day period.

The Carbon Balance Model

Over the period of this grant we have used the information collected to refine the model to predict and explain thinner response under differing environmental conditions. The use of a mathematical carbohydrate supply-demand balance model to integrate the weather effects was found again to help explain a pattern of relative thinner response to a timing trial with the same NAA/Sevin treatment. When the carbohydrate balance was good, there was mild thinning. However, a very warm period occurred at the 10-14 mm stage, leading to a poor carbohydrate balance and much stronger thinning response at that time. This again shows that using such a model to integrate weather effects can help explain and better predict (within the limits of weather predictions) the thinning response related to weather

The Generalized Procedure for Predicting Thinner Response

Select and tag spurs

On 5 to 8 representative trees select 10 to 15 spurs for a total of about 100 flowering spurs. The distribution of these spurs should be in proportion to the flower distribution on the tree. If you feel that set on your trees is uniform throughout, placement of spurs may be made for convenience and ease of measurement.

Time to select spur and mark fruit

Spurs should not be selected until average fruit size has reached at least 6 mm. At this time fruit are sizing rapidly and this is the time when there is the start of intense competition among fruit and growing fruits for available carbohydrates. Each fruit in each cluster should be marked with a pen with indelible ink (eg Sharpie) to identify each fruit. The method that works well is the simple numbering system 1, 2, etc. in each cluster.

Measuring the fruit

There are two key things that must not be deviated from during the measuring and data collection process. First, fruit must be measured at the same location each time. Fruit are frequently asymmetrical and measuring the fruit at a different location can cause variability that is greater than the fruit growth over an individual measurement period. Secondly, the growth of individual fruit must be identified so that their growth rate can be calculated individually.

Determine bloom density and target fruit set

We suggest that before you put on any thinner you establish a target crop load that you would like to see at the end of June drop. This can be done by counting all blossom clusters on 2 limbs per tree on 5 to 6 trees or all blossom clusters on smaller trees at the pink stage of flower development. You then determine ideally how many fruit you would like to set and persist to harvest. For example, if you have 200 blossom clusters and you would like to see 100 fruit in total from these spurs then your goal is to have a final set of 50% or 1 fruit for each 2 flowering spur. The spurs that you have selected are representative of the spurs on the whole tree. If you have tagged 100 spurs and after measuring all fruit you have 430 developing fruit. On those spurs you would like to see 50 fruit, or an average of 1 fruit per 2 spurs. Therefore, you would like to see 50/430 x 100 = 11.9% of those developing fruit to persist to give you the ideal crop load.

Identifying fruit that will persist to harvest

To determine if fruit growth is slowing you must identify fruit that will persist. Initially it may appear that identification of the fruit that will persist to harvest may be an impossible task. In actuality, identification of these has proven to be relatively easy and reliable. The largest and fastest growing fruit are the most able to compete with smaller and slower growing fruit. Usually 99% of the fastest growing fruit will persist. To arrive at the growth rate of fruit to persist to harvest at each measurement period we take an average of the 20 fastest growing fruit. The Excel spreadsheet automatically identifies these rapidly growing fruit and makes the calculation.

When to measure fruit and when you can make a reliable prediction

During the development of this procedure for predicting thinner response we measured fruit initially and again at 2 to 3 day intervals. This was necessary for development of the model. When put into practice in a grower orchard fewer measurements probably will not be necessary. The initial measurement may not be required. Once applied it requires 3 to 4 days for a thinner to slow growth. At least one measurement will be necessary at this time. Normally, it requires about 7 days for growth reduction to be manifest, but temperature has a strong modifying effect (Table 2). Therefore, we suggest that you monitor the accumulation of heating degree units and make no final measurement or determination until at least 130 to 140 heating degree units (base 50) have accumulated. We also suggest initially that at least 3 measurements should be made between 3 and 8 days after application.

Predicting which fruit will persist or drop

A fruit is predicted to drop if the growth rate of a fruit is less than 50% of the growth rate of the average of the 20 fastest growing fruit. Conversely, a fruit is predicted to set if the growth rate of that fruit is 50% or greater of the 20 fastest growing fruit.

Taking and recording data

Attached is a portion of a fruit size data base that we used in one of our experiments (Table 3). The Excel spreadsheet is set up to accept data in this format. In this experiment we used 5 trees with 20 spurs per tree tagged. Each spur had an initial set of 2 to 5 fruit. We suggest that you use a format similar to this when organizing and collecting fruit growth data.

Table 3. Excel data template showing fruit size measurements in mm fruit diameter that may be useful in organizing and entering fruit growth data.

| Tree | Spur | Fruit | 28May | 31May | 2 June | 5June | 7Jun |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 8.0 | 10.9 | 12.1 | 13.9 | 15.0 |
| 1 | 1 | 2 | 7.3 | 10.2 | 11.1 | 12.0 | 13.6 |
| 1 | 1 | 3 | 7.7 | 8.1 | 8.0 | 8.0 | 8.0 |
| 1 | 2 | 1 | 7.7 | 10.4 | 11.7 | 12.9 | 14.2 |
| 1 | 2 | 2 | 6.7 | 9.0 | 9.7 | 11.3 | 11.5 |
| 1 | 2 | 3 | 6.8 | 7.0 | 7.0 | 6.9 | 6.8 |
| 1 | 3 | 1 | 6.9 | 9.4 | 10.8 | 12.2 | 13.3 |
| 1 | 3 | 2 | 7.1 | 9.5 | 10.9 | 12.3 | 13.2 |
| 1 | 3 | 3 | 6.2 | 7.0 | 7.2 | 7.1 | 7.0 |
| 1 | 3 | 4 | 6.4 | 9.9 | 10.0 | 10.7 | 10.8 |

Predicting thinning where multiple thinners are used.

Increasingly growers are using a multiple thinner approach to achieve appropriate crop loads. Frequently a bloom or petal fall spray is used. The system outlined is valid in predicting final set. No adjustments need to be made. There is a danger however, of taking measurements too early before fruit reach 6 to 7 mm. If one starts the timer too early, before the period of rapid growth begins and fruit competition is not great, it is like to take several days longer to note reductions in fruit growth and make a prediction.

Is an untreated control necessary?

Initially we included in our experimental protocol an untreated control. The primary purpose was to use fruit on these trees to establish the growth rate of the fastest growing trees. However, we felt that under most conditions growers are unlikely to leaves trees unthinned and measuring fruit on more trees was time consuming. We have made successful predictions on thinned trees in the past couple of years. The only danger of not using an untreated control is if the thinner(s) are so aggressive that no fruit set, and this is an unlikely occurrence.

The Excel spreadsheet with automatic calculations

Macros have been written in the Excel spreadsheet to make all of the calculations automatically. The spreadsheet consists of 6 sheets: Input, Staging, Setup, Summary, Diameter and Growth Rate, and a Count sheet. The Input sheet is where the data is downloaded. The Staging sheet is where the data is reorganized for calculations. The Setup sheet shows tables of the sampling date and the target fruit number and percent set. The Summary sheet is most informative in that it shows on each sampling date the fruit diameter of the fastest growing fruit the number of fruit that grow greater and less that the 20 fastest growing fruit, a predicted % set and a predicted % drop. Finally there is a Diameter sheet and a Count sheet.

# FIGURE 1. FRUIT GROWTH