# Managing Cropload with the Pollen Tube Growth Model in an Organic Apple Orchard

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## Summary

With funding from a USDA-SARE Farmer Rancher grant, we used the Pollen Tube Growth Model (PTGM) to time bloom thinning sprays of Regalia and oil in ten blocks of our organic apple orchard. The PTGM was logistically difficult to implement in our small diverse orchard because the model requires time to administer separately for each variety, dictates sprays at different times for each variety and block, and because the model does not specifically incorporate the unusual niche apple varieties which we grow. In general, we saw no evidence that the thinning sprays of Regalia and oil affected cropload or return bloom.

## Background and Objectives

### *Cropload Management in Apples*

By nature, apple trees often bear heavy crops of fruit, resulting in small, poor quality fruit and reduced bloom in the following year. In commercial orchards, therefore, it is important to "thin" flowers or small fruitlets and reduce the cropload. Non-organic growers often spray chemical thinning agents to manage cropload. Without access to synthetic chemical thinning agents, organic apple growers often thin by hand, which is labor-intensive and ineffective.

Alternatives to hand-thinning in organic apple orchards include fruitlet thinning sprays such as Protone, which can be sprayed when fruitlets are approximately 10 mm in diameter, and bloom thinning sprays which can be sprayed during bloom to kill flowers and reduce fruitset. Several bloom thinning spray materials are available to organic growers:

1. Liquid lime sulfur (LLS) is a common bloom thinning agent, sometimes used together with fish oil or another type of spray oil. A downside of liquid lime sulfur is its high toxicity to handlers and applicators - in concentrated form the product is highly caustic and corrosive and can cause irreversible eye damage and skin burns. LLS pesticides are marked with the Danger signal word which denotes highly toxic products. We have not used LLS in our orchard.

2. Potassium bicarbonate has been shown to be an effective bloom thinner in European trials in Poland and Switzerland. Although this practice has not been widely used in the U.S. to my knowledge, there is some discussion of it on the Holistic Orchard Network. We have used potassium bicarbonate in our orchard in past years and it has appeared moderately effective. Typically we have used 2-3 applications of potassium bicarbonate applied at 15 lbs/100 gallons water per acre.

3. Regalia (a plant based OMRI-listed plant disease resistance inducer) has been shown to be an effective bloom thinner when mixed with spray oil in several studies from Virginia. However, after those studies were conducted the manufacturer modified the formulation of Regalia, and the manufacturer believes that the newer formulation is not an effective bloom thinner. We and other growers have observed that the current Regalia formulation when applied together with spray oil causes obvious visible petal burn and accelerates petal drop and seems to provide some amount of fruit thinning as well. Dan Kelly, an organic apple grower at Blue Heron Orchard in Missouri reported excellent thinning when he sprayed Regalia (presumably new formulation) with oil according to the PTGM.

4. Various sprays oils have been shown effective for bloom thinning in Slovenia and China. To my knowledge, spray oils are not often used alone for thinning in the U.S., although they are often mixed with other thinners such as LLS or Regalia.

### *Pollen Tube Growth Model*

The Pollen Tube Growth Model (PTGM) uses weather data to time bloom thinning sprays. A detailed description of the PTGM was published in the New York Fruit Quarterly in 2018. Here is a brief overview:

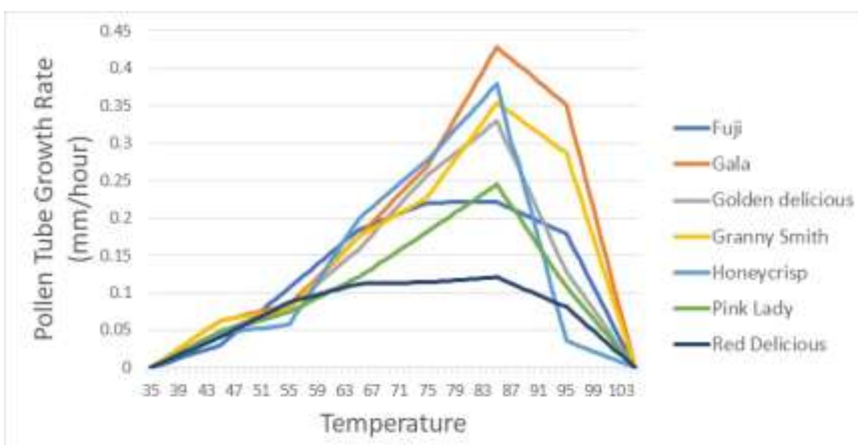
Apple fruits develop from flowers; a bee deposits pollen on the stigma of a flower, and pollen grains germinate into pollen tubes which grow into the style of the flower until they fertilize an ovule (a seed precursor) at the bottom of the style. Only flowers with fertilized ovules form fruit. Most bloomtime thinning sprays presumably work because they prevent ovule fertilization by killing floral organs before fertilization occurs.

The premise of the PTGM is that it is key to begin bloom thinning sprays when the ideal number of flowers have already been fertilized and additional fertilization is not desired, and then continue regular sprays until bloom has ended. If the first thinning spray is made too early, cropload will be low; if it is made too late, cropload will be high. The pollen tube growth model uses weather data and farmer observations of bloom timing to predict when thinning sprays should be made. The model is based on detailed experimental measurements of how fast pollen tubes grow at various temperatures. These growth rates vary by variety, and the model has been calibrated for use with seven common commercial varieties: Fuji, Gala, Golden Delicious, Granny Smith, Honeycrisp, Red Delicious, and Pink Lady.

Although apple bloom occurs quickly in a relatively short period of time, flowers do not all open at that same time. To use the model, the grower must determine (by educated guess) when enough flowers are open on the trees to produce the desired crop in a particular orchard block. For example, if the grower wants 100 fruits per tree, the grower would estimate when 100 flowers per tree are open. The goal is then to time sprays to allow ovule fertilization in those 100 flowers, but not to allow fertilization in any flowers which open after those 100 flowers. The grower sets the start time for the PTGM on NEWA when the desired number of flowers per tree are open. In addition, the grower measures average style length in the orchard block of interest and enters that information into the NEWA model. From thereon, the model estimates, based on temperature and apple variety, the distance that pollen tubes have grown into the flower styles. The model displays the tube growth as a percent of the average style length. For example if the average style length in a block is 10 mm, 20% pollen tube growth means that pollen tubes have grown 2 mm into the styles. The goal is to make the first thinning spray at 100% pollen tube growth measured from the start time of the model. At this stage, the early-opening flowers from which fruit set is desired should be fertilized, but the thinning spray should prevent flowers which opened subsequently from being fertilized and setting fruit. A second spray should made before 100% pollen tube growth since the time of the first spray. Additional sprays should be made if needed according to the same principle until the end of bloom.

The PTGM has not gained widespread use in the eastern U.S. Non-organic apple growers already thin successfully by spraying synthetic growth regulators in the weeks after bloom and many have not been motivated to try bloom thinning based on the PTGM. Organic growers generally lack effective post-bloom thinning sprays and often hand-thin fruitlets, but hand thinning must be completed in a brief window of time to provide significant benefits and it is extraordinarily labor-intensive. Some organic growers have used bloom thinning sprays with inconsistent results, but the PTGM has not been widely used to time these sprays, although many commercial apple growers are comfortable using similar computer models which predict insect pest and disease development based on weather data.

Several weaknesses to the PTGM are apparent. First, the model was developed for seven specific varieties. Some of these, such as Granny Smith or Pink Lady, are very rare in organic apple orchards of the North Central region, whereas common organic varieties such as Liberty are not included in the model. Varieties do differ significantly in pollen tube growth rates (see graph to right), and so it is difficult to apply the PTGM to varieties other than the seven varieties specifically included in the model.




Second, the model assumes that flowers are pollinated immediately upon opening and that bloom thinning sprays will contact and kill all open flowers. Both of these assumptions are probably untrue in most real-world situations.

In addition, growers with many apple varieties are concerned about the time required to measure style lengths, run the model, and make separate thinning sprays for different varieties.

*Objectives*

For our study in 2022-2023, we opted to use Regalia and oil as a bloom thinner because of the previous successful reports for this combination. None of the varieties in our orchard is specifically included in the PTGM. Therefore we decided to use the model for Golden Delicious, a variety with relatively average pollen tube growth rates compared to the other varieties in the model. We also tried different timings of the initial thinning spray because delaying the initial spray later than what is recommended by the PTGM will address growers' concerns about slow pollination and and also concerns that the actual varieties in this study may have slower pollen tube growth rates than Golden Delicious.

The goals of our project were (i) to measure the effectiveness of Regalia and the PTGM for crop thinning in varieties not explicitly included in the PTGM and using three variations on initial spray timing and (ii) to measure the time required to implement the model.

## Methods

*Weather Station*

In spring 2022, we installed a Rainwise AgroMET Weather Station in our orchard. The weather station collects hourly data on temperature (as well as other weather data). Our weather station, as well as the weather stations from many other orchards, are connected to the NEWA network (https://newa.cornell.edu/). The NEWA system uses this orchard-specific weather data to run the pollen tube growth model (PTGM) and other models related to cropload management and insect and disease control. The NEWA website has a tutorial video on how to use the pollen tube growth model.

*Experimental Design*

We conducted this research in our certified organic apple orchard. The overall apple orchard was 2.5 acres in size in 2022. All trees are on dwarfing roostocks (mostly G.41, G.11, and G.16), and spaced 6' apart in the row. Between row spacing varies from 10.5' to 12', for a density of 605-690 trees per acre. We use hardwood bark mulch to maintain a weed-free strip 5-6' wide in the tree row. Trees are individually staked using Best Angle 10' metal stakes and irrigated with drip irrigation. Our target yield varies by variety but is generally 30-60 lbs per tree (approximately 500-1000 bushels per acre). Since 2017, actual annual yields per bearing acre have ranged from 525-925 bushels/acre.

In spring 2022 we selected ten blocks of trees to include in the experiment, each consisting of 35-50 similar-aged trees of a single variety. The blocks included seven varieties: Liberty, Goldrush, Winecrisp, Williams Pride, Pristine, Priscilla, and Sansa, all disease-resistant varieties common in organic orchards. We included multiple varieties because varieties differ in optimal cropload and response to thinning treatments. Blocks had been planted between 2012 and 2019. Young and mature trees can differ in their optimal cropload and response to thinning treatments.

Table. Blocks Used in Experiment

| Block Number | Variety | Year Planted |
|---|---|---|
| 1 | Priscilla | 2015 |
| 2 | Sansa | 2012-13 |
| 3 | Winecrisp | 2013 |
| 4 | Winecrisp | 2018 |
| 5 | Goldrush | 2018 |
| 6 | Liberty | 2018 |
| 7 | Winecrisp | 2019 |
| 8 | Pristine | 2019 |
| 9 | Liberty | 2019 |
| 10 | Williams Pride | 2019 |

Within each block, we selected 16 trees for the experiment, avoiding trees which obviously differed greatly from the others in bloom density in spring 2022. We divided the sixteen trees into four plots, which were randomly assigned to one of four treatments. One treatment was a control treatment, with no early bloom thinning sprays applied (by "early bloom" we mean sprays during spur bloom - see the results section for a discussion of late bloom on 1-year old wood). In the other three treatments, we applied early bloom thinning sprays with a tractor-mounted Pakblast 50 airblast sprayer with Regalia and JMS Organic Stylet Oil (both at 1% volume:volume concentration) according to the Pollen Tube Growth Model for the variety Golden Delicious. Spray volume was 100 gallons per acre, which is a relatively high volume spray in our setting, and which we expect to provide excellent spray coverage, especially during bloom when the canopy is still small. This Regalia concentration has worked well in published research results. The three spray treatments differed in the timing of the initial thinning spray: in one treatment we aimed to apply the initial spray at the 100% pollen tube growth stage, as recommended by the PTGM, in the second treatment at the 125% stage, and in the third treatment at the 150% stage. The rationale for sprays at 125% and 150% was to try more "conservative" thinning sprays and to allow for more flower fertilization if, for example, a variety had slower pollen tube growth rates than Golden Delicious or if insect pollination of flowers was slow.

*A bumblebee quad in the orchard during bloom. Pallets above the quad provide shade and reduce the chance of overheating.*

### *Pollinators*

Our orchard is primarily surrounded by corn and soybean fields. Although we have established pollinator habitat on our 12 acre farm, native pollinator populations are modest. Therefore we have purchased bumblebee colonies to ensure adequate pollination. In both 2022 and 2023 we purchased two bumblebee quads from Koppert Biological Supply, and these bees foraged on two acres of bearing apples plus an additional 0.25 acres of gooseberries and 0.25 acres of currants. (Gooseberries in particular bloom simultaneously with apples and are very attractive to foraging bumblebees.)

*Data Collection*

We measured the following data:

| | |
|---|---|
| Time required | We recorded time required for each experimental treatment (time to manage the PTGM on the computer and to apply thinning sprays, and time to hand-thin). |
| Cropload | Before handthinning in June we measured cropload by recording desired number of fruit and viable fruitlets on five branches per experimental tree. At harvest, we measured yield (bushels of fruit) on each tree as a measure of final cropload. |
| Bloom intensity | At the beginning of bloom in each year, we scored 10 branches in each experimental plot for bloom intensity on the following scale: 0=No bloom, 0.5=<1 flower cluster per desired fruit, 1=approximately 1 flower cluster per desired fruit, 2=approximately two flower clusters per desired fruit, and 3=approximately three or more flower clusters per desired fruit. |
| Bloom development and weather | During bloom, we recorded daily high and low temperatures and daily approximate percentage of flower buds open in each variety. (We were prepared to collect data on extent of flower bud damage from freezing weather, but there was no freeze damage to flowers in 2022 or 2023.) |
| Yield | Weight of fruit per tree in each experimental plot. |

## Results and Discussion

*Bloom Weather*

In the 2022 bloom season, it was extremely challenging to time and apply bloom thinning sprays because of the unseasonably hot weather. Daytime highs were 90+ degrees during the first five days of bloom. Consequently, bloom development was extremely rapid. The first flower opened on 5/10, and essentially all petals had fallen off the trees nine days later, on 5/19, with 10 days total of bloom. (In 2021, by contrast, bloom lasted from 4/27 to 5/19, 23 days total.)

In 2023, bloom weather was much more mild, although not cold: daytime highs were typically in the 70's, with lows mostly in the 40's and 50's. The first flowers opened on 5/3, and petal fall was essentially complete on 5/19, with 16 days total of bloom.

There was no freeze damage to flowers in 2022 or 2023.

Table: Bloom weather in 2022

| Date | Maximum Temperature (degrees F) | Minimum Temperature (degrees F) | Daily Rainfall (Inches) |
|---|---|---|---|
| 5/10 | 93 | 66 | |
| 5/11 | 98 | 68 | |
| 5/12 | 98 | 69 | |
| 5/13 | 96 | 64 | 0.02 |
| 5/14 | 90 | 57 | 0.01 |
| 5/15 | 77 | 55 | |
| 5/16 | 80 | 52 | |
| 5/17 | 68 | 50 | 0.04 |
| 5/18 | 66 | 46 | 0.2 |
| 5/19 | 87 | 53 | |

Table: Bloom Weather in 2023

| Date | Maximum Temperature (degrees F) | Minimum Temperature (degrees F) | Daily Rainfall (Inches) |
|---|---|---|---|
| 5/3 | 64 | 34 | |
| 5/4 | 76 | 39 | |
| 5/5 | 76 | 51 | 0.7 |
| 5/6 | 71 | 54 | 0.1 |
| 5/7 | 85 | 57 | |
| 5/8 | 64 | 53 | 0.67 |
| 5/9 | 72 | 52 | |
| 5/10 | 80 | 51 | |
| 5/11 | 85 | 52 | |
| 5/12 | 73 | 59 | 0.04 |
| 5/13 | 74 | 58 | |
| 5/14 | 61 | 47 | 1.28 |
| 5/15 | 75 | 45 | |
| 5/16 | 80 | 52 | |
| 5/17 | 66 | 43 | |
| 5/18 | 77 | 41 | 0.03 |
| 5/19 | 63 | 48 | 0.26 |

*Bloom Intensity.*

In general, bloom was more abundant in 2022 than in 2023.

Table. Average bloom intensity per experimental block in each year. Bloom intensity was measured on 40 branches per experimental block, and scored on a scale of 0=No bloom, 0.5=<1 flower cluster per desired fruit, 1=approximately 1 flower cluster per desired fruit, 2=approximately two flower clusters per desired fruit, and 3=approximately three or more flower clusters per desired fruit.

| Block | Variety | Average Bloom Intensity 2022 | Average Bloom Intensity 2023 |
|---|---|---|---|
| 1 | Priscilla | 2.6 | 2.5 |
| 2 | Sansa | 2.7 | 0.7 |
| 3 | Winecrisp | 2.8 | 0.3 |
| 4 | Winecrisp | 1.1 | 1.9 |
| 5 | Goldrush | 3.0 | 1.0 |
| 6 | Liberty | 2.8 | 2.8 |
| 7 | Winecrisp | 2.7 | 1.7 |
| 8 | Pristine | 2.9 | 1.3 |
| 9 | Liberty | 2.7 | 1.3 |
| 10 | Williams Pride | 2.0 | 3.0 |

*Bloom Phenology and PTGM Parameters.*

Style length varied significantly between blocks, varieties, and years, which shows the importance of actually measuring style length separately for each variety or block.

Table. Mean style length in experimental plots in both 2022 and 2023 (style length was measured on 25 flowers per block in both years).

| Block Number | Variety | Mean Style Length 2022 (mm) | Mean Style Length 2023 (mm) |
|---|---|---|---|
| 1 | Priscilla | 7.9 | 9.6 |
| 2 | Sansa | 9.88 | 12.36 |
| 3 | Winecrisp | 11.38 | 3.5 |
| 4 | Winecrisp | 10 | 10.36 |
| 5 | Goldrush | 8.56 | 9.22 |
| 6 | Liberty | 8.36 | 8.96 |
| 7 | Winecrisp | 10.46 | 10.58 |
| 8 | Pristine | 7.12 | 9.44 |
| 9 | Liberty | 8.14 | 9.54 |
| 10 | Williams Pride | 8.14 | 7.84 |

The following tables show start time for the PTGM (determined based on observation and experience) and bloom phenology by day in 2022 and 2023. Note the extremely rapid progression of bloom in 2022, when bloomtime temperatures were very hot: e.g., Liberty and Winecrisp trees developed from 1% spur bloom to 70% spur bloom in a single day.

Table: PTGM Start time and bloom phenology in 2022

| | | | | Estimated percent of flowers open in flower clusters from terminal buds or spurs | | | | |
|---|---|---|---|---|---|---|---|---|
| Block Number | Variety | Year Planted | Start Time For PTGM | 11-May | 12-May | 13-May | 14-May | 15-May |
| 1 | Priscilla | 2015 | 5/12/2022 16:00 | 0% | 5% | 40% | 99% | 100% |
| 2 | Sansa | 2012-13 | 5/13/2022 10:00 | 0% | 5% | 40% | 95% | 100% |
| 3 | Winecrisp | 2013 | 5/12/2022 10:00 | 0% | 1% | 70% | 95% | 100% |
| 4 | Winecrisp | 2018 | 5/13/2022 10:00 | 0% | 1% | 70% | 95% | 100% |
| 5 | Goldrush | 2018 | 5/13/2022 10:00 | 1% | 5% | 40% | 99% | 100% |
| 6 | Liberty | 2018 | 5/12/2022 10:00 | 1% | 70% | 95% | 99% | 100% |
| 7 | Winecrisp | 2019 | 5/13/2022 10:00 | 0% | 5% | 40% | 95% | 100% |
| 8 | Pristine | 2019 | 5/12/2022 10:00 | 1% | 20% | 95% | 99% | 100% |
| 9 | Liberty | 2019 | 5/12/2022 10:00 | 1% | 70% | 99% | 99% | 100% |
| 10 | Williams Pride | 2019 | 5/12/2022 10:00 | 5% | 40% | 70% | 99% | 100% |

Table: PTGM Start time and bloom phenology in 2023

| Block Number | Variety | Start Time For PTGM | 4-May | 5-May | 6-May | 7-May | 8-May | 9-May | 10-May | 11-May | 12-May |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Priscilla | 5/7/2023 10:00 | 0% | 0% | 1% | 5% | 20% | 40% | 70% | 95% | 100% |
| 2 | Sansa | 5/8/2023 17:00 | 0% | 0% | 0% | 1% | 5% | 50% | 70% | 95% | 100% |
| 3 | Winecrisp | 5/8/2023 12:00 | 0% | 0% | 0% | 5% | 20% | 50% | 90% | 95% | 100% |
| 4 | Winecrisp | 5/8/2023 6:00 | 0% | 0% | 0% | 5% | 20% | 70% | 90% | 95% | 100% |
| 5 | Goldrush | 5/8/2023 10:00 | 0% | 0% | 1% | 5% | 20% | 70% | 90% | 95% | 100% |
| 6 | Liberty | 5/6/2023 11:00 | 1% | 1% | 5% | 20% | 95% | 99% | 99% | 100% | 100% |
| 7 | Winecrisp | 5/8/2023 10:00 | 0% | 0% | 0% | 5% | 10% | 40% | 50% | 95% | 100% |
| 8 | Pristine | 5/6/2023 16:00 | 1% | 5% | 10% | 40% | 95% | 99% | 99% | 100% | 100% |
| 9 | Liberty | 5/6/2023 16:00 | 0% | 1% | 5% | 20% | 95% | 99% | 99% | 100% | 100% |
| 10 | Williams Pride | 5/6/2023 8:00 | 1% | 5% | 10% | 40% | 90% | 99% | 100% | 100% | 100% |

The following table shows the timing and weather conditions when thinning sprays of Regalia+Oil were applied. Most of these sprays were not applied to all experimental plots - the subsequent table shows which plots were included in each spray application. Note that the time required for spraying, measured in minutes per tree sprayed, was higher when fewer trees were sprayed. This is because of the "overhead" time required for filling the first tank and for rinsing out the tank, which are similar regardless of the number of trees sprayed.

Table: Thinning Spray Applications

| Year | Spray | Date | Time Start | Temperature (degrees F) | Percent Relative Humidity | Windspeed (mph) | Total Trees Sprayed[1] | Minutes per Tree[2] |
|---|---|---|---|---|---|---|---|---|
| 2022 | 1 | 5/12/2022 | 7:45 PM | 78 | 38 | 4.5 | 236 | 0.25 |
| | 2 | 5/13/2022 | 7:55 AM | 75 | 72 | 3.1 | 329 | 0.24 |
| | 3 | 5/14/2022 | 9:00 AM | 68 | 59 | 1.8 | 200 | 0.30 |
| | 4 | 5/14/2022 | 10:10 AM | 76 | 49 | 3.9 | 606 | 0.16 |
| | 5 | 5/15/2022 | 8:10 AM | 64 | 53 | 4.2 | 859 | 0.16 |
| | 6 | 5/16/2022 | 5:35 AM | 54 | 58 | 2.5 | 1016 | 0.11 |
| 2023 | 1 | 5/9/2023 | 8:40 AM | 75 | 90% | 0.4 | 727.5 | 0.16 |
| | 2 | 5/10/2023 | 8:20 AM | 68 | 84% | 2.8 | 988.5 | 0.14 |
| | 3 | 5/11/2023 | 6:40 AM | 76 | 80% | 1.8 | 775.5 | 0.23 |
| | 4 | 5/13/2023 | 10:00 AM | 64 | 67% | 6.5 | 510.5 | 0.18 |

[1]Including trees not in experimental plots
[2]Time for spraying includes time for filling and rinsing the spray tank.

The following tables show the pollen tube growth on each thinning spray date. Note that in some cases it was not possible to make the thinning spray at the intended stage of pollen tub development because of weather and logistic constraints.

Table: Pollen tube growth calculated by the PTGM since the start time of the model (using the model for Golden Delicious) on the date of each thinning spray in 2022, with pollen tube growth expressed as a percentage of mean style length in that plot. "No spray" indicates that no spray was made on the date in question.

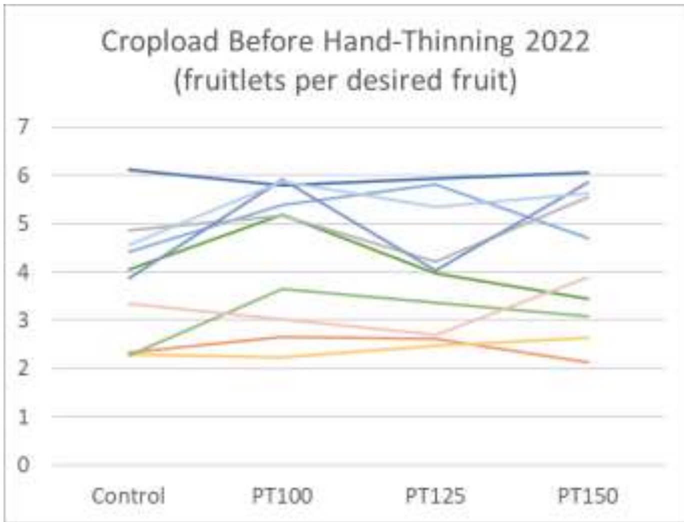
| Block | Treatment | 5/12 20:00 | 5/13 8:00 | 5/14 9:00 | 5/14 11:00 | 5/15 9:00 | 5/16 6:00 |
|---|---|---|---|---|---|---|---|
| Priscilla (2015) | Control | No spray | No spray | No spray | No spray | 183% | 224% |
| Priscilla (2015) | PT100 | No spray | No spray | 116% | No spray | 183% | 224% |
| Priscilla (2015) | PT125 | No spray | No spray | 116% | No spray | 183% | 224% |
| Priscilla (2015) | PT150 | No spray | No spray | No spray | 123% | 183% | 224% |
| Sansa (2012-13) | Control | No spray | No spray | No spray | No spray | 102% | 135% |
| Sansa (2012-13) | PT100 | No spray | No spray | 49% | No spray | 102% | 135% |
| Sansa (2012-13) | PT125 | No spray | No spray | 49% | No spray | 102% | 135% |
| Sansa (2012-13) | PT150 | No spray | No spray | No spray | 54% | 102% | 135% |
| Winecrisp (2013) | Control | No spray | No spray | No spray | No spray | 137% | 165% |
| Winecrisp (2013) | PT100 | 18% | No spray | No spray | 95% | 137% | 165% |
| Winecrisp (2013) | PT125 | No spray | 43% | No spray | 95% | 137% | 165% |
| Winecrisp (2013) | PT150 | No spray | No spray | 91% | No spray | 137% | 165% |
| Winecrisp (2018) | Control | No spray | No spray | No spray | No spray | 101% | 133% |
| Winecrisp (2018) | PT100 | No spray | No spray | 48% | No spray | 101% | 133% |
| Winecrisp (2018) | PT125 | No spray | No spray | 48% | No spray | 101% | 133% |
| Winecrisp (2018) | PT150 | No spray | No spray | No spray | 54% | 101% | 133% |
| Goldrush (2018) | Control | No spray | No spray | No spray | No spray | 118% | 156% |
| Goldrush (2018) | PT100 | No spray | No spray | 56% | No spray | 118% | 156% |
| Goldrush (2018) | PT125 | No spray | No spray | 56% | No spray | 118% | 156% |
| Goldrush (2018) | PT150 | No spray | No spray | No spray | 63% | 118% | 156% |
| Liberty (2018) | Control | No spray | No spray | No spray | No spray | 186% | 225% |
| Liberty (2018) | PT100 | 24% | No spray | No spray | 130% | 186% | 225% |
| Liberty (2018) | PT125 | No spray | 58% | No spray | 130% | 186% | 225% |
| Liberty (2018) | PT150 | No spray | No spray | 123% | No spray | 186% | 225% |
| Winecrisp (2019) | Control | No spray | No spray | No spray | No spray | 97% | 128% |
| Winecrisp (2019) | PT100 | No spray | No spray | 46% | No spray | 97% | 128% |
| Winecrisp (2019) | PT125 | No spray | No spray | 46% | No spray | 97% | 128% |
| Winecrisp (2019) | PT150 | No spray | No spray | No spray | 51% | 97% | 128% |
| Pristine (2019) | Control | No spray | No spray | No spray | No spray | 219% | 264% |
| Pristine (2019) | PT100 | 28% | No spray | No spray | 152% | 219% | 264% |
| Pristine (2019) | PT125 | No spray | 68% | No spray | 152% | 219% | 264% |
| Pristine (2019) | PT150 | No spray | No spray | 145% | No spray | 219% | 264% |
| Liberty (2019) | Control | No spray | No spray | No spray | No spray | 191% | 231% |
| Liberty (2019) | PT100 | 25% | No spray | No spray | 133% | 191% | 231% |
| Liberty (2019) | PT125 | No spray | 60% | No spray | 133% | 191% | 231% |
| Liberty (2019) | PT150 | No spray | No spray | 127% | No spray | 191% | 231% |
| Williams Pride (2019) | Control | No spray | No spray | No spray | No spray | 191% | 231% |
| Williams Pride (2019) | PT100 | 25% | No spray | No spray | 133% | 191% | 231% |
| Williams Pride (2019) | PT125 | No spray | 60% | No spray | 133% | 191% | 231% |
| Williams Pride (2019) | PT150 | No spray | No spray | 127% | No spray | 191% | 231% |

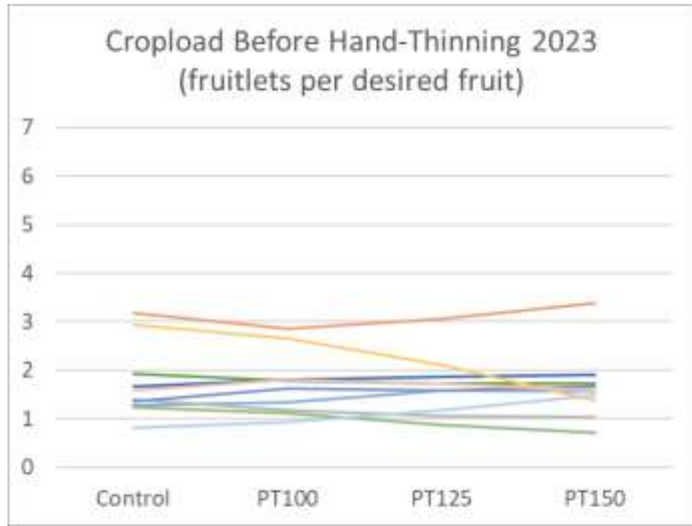
Table: Pollen tube growth calculated by the PTGM since the start time of the model (using the model for Golden Delicious) on the date of each thinning spray in 2023, with pollen tube growth expressed as a percentage of mean style length in that plot. "No spray" indicates that no spray was made on the date in question.

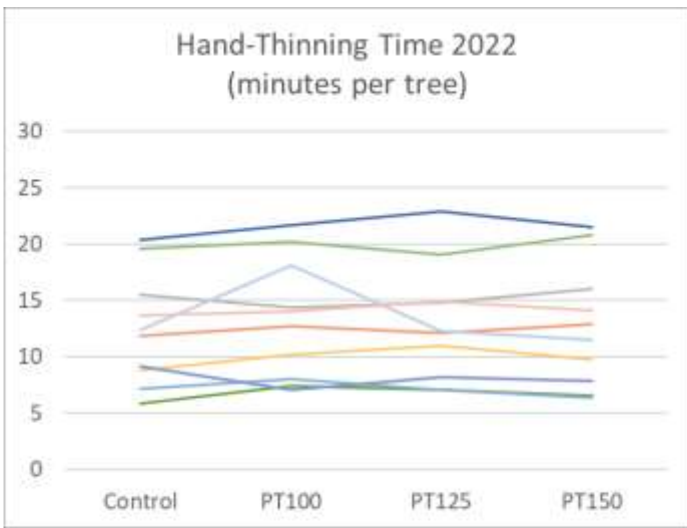
| Block | Treatment | 5/9 9:00 | 5/10 9:00 | 5/11 8:00 | 5/13 11:00 |
|---|---|---|---|---|---|
| Priscilla (2015) | Control | No spray | No spray | No spray | No spray |
| Priscilla (2015) | PT100 | No spray | 100% | 141% | 238% |
| Priscilla (2015) | PT125 | No spray | No spray | 141% | 238% |
| Priscilla (2015) | PT150 | No spray | No spray | 141% | 238% |
| Sansa (2012-13) | Control | No spray | No spray | No spray | No spray |
| Sansa (2012-13) | PT100 | No spray | No spray | No spray | 144% |
| Sansa (2012-13) | PT125 | No spray | No spray | No spray | 144% |
| Sansa (2012-13) | PT150 | No spray | No spray | No spray | 144% |
| Winecrisp (2013) | Control | No spray | No spray | No spray | No spray |
| Winecrisp (2013) | PT100 | No spray | 145% | 258% | 525% |
| Winecrisp (2013) | PT125 | No spray | 145% | 258% | 525% |
| Winecrisp (2013) | PT150 | No spray | 145% | 258% | 525% |
| Winecrisp (2018) | Control | No spray | No spray | No spray | No spray |
| Winecrisp (2018) | PT100 | No spray | No spray | 92% | 183% |
| Winecrisp (2018) | PT125 | No spray | No spray | No spray | 183% |
| Winecrisp (2018) | PT150 | No spray | No spray | No spray | 183% |
| Goldrush (2018) | Control | No spray | No spray | No spray | No spray |
| Goldrush (2018) | PT100 | No spray | No spray | 100% | 201% |
| Goldrush (2018) | PT125 | No spray | No spray | 100% | 201% |
| Goldrush (2018) | PT150 | No spray | No spray | No spray | 201% |
| Liberty (2018) | Control | No spray | No spray | No spray | No spray |
| Liberty (2018) | PT100 | 111% | No spray | 191% | 296% |
| Liberty (2018) | PT125 | No spray | 147% | 191% | 296% |
| Liberty (2018) | PT150 | No spray | 147% | 191% | 296% |
| Winecrisp (2019) | Control | No spray | No spray | No spray | No spray |
| Winecrisp (2019) | PT100 | No spray | No spray | 87% | 175% |
| Winecrisp (2019) | PT125 | No spray | No spray | No spray | 175% |
| Winecrisp (2019) | PT150 | No spray | No spray | No spray | 175% |
| Pristine (2019) | Control | No spray | No spray | No spray | No spray |
| Pristine (2019) | PT100 | 98% | No spray | 174% | 273% |
| Pristine (2019) | PT125 | No spray | 132% | 174% | 273% |
| Pristine (2019) | PT150 | No spray | 132% | 174% | 273% |
| Liberty (2019) | Control | No spray | No spray | No spray | No spray |
| Liberty (2019) | PT100 | 97% | No spray | 172% | 270% |
| Liberty (2019) | PT125 | No spray | 130% | 172% | 270% |
| Liberty (2019) | PT150 | No spray | 130% | 172% | 270% |
| Williams Pride (2019) | Control | No spray | No spray | No spray | No spray |
| Williams Pride (2019) | PT100 | 131% | No spray | 222% | 341% |
| Williams Pride (2019) | PT125 | 131% | No spray | 222% | 341% |
| Williams Pride (2019) | PT150 | 131% | No spray | 222% | 341% |

*Effects of Thinning Sprays*

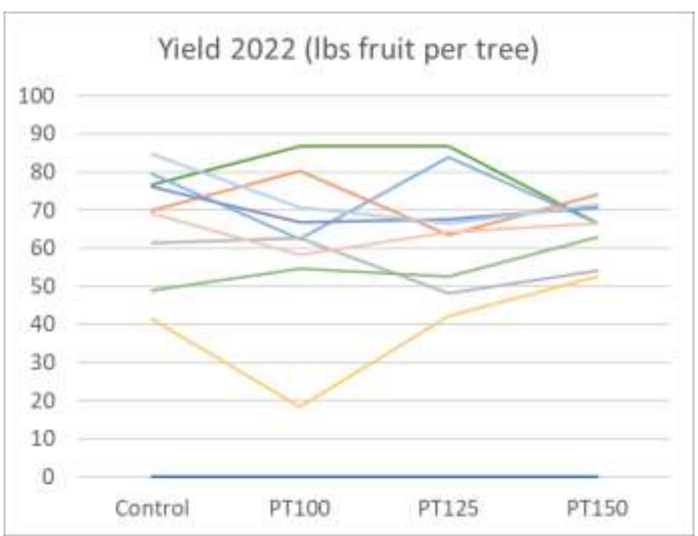
In general, there was no consistent effect of thinning sprays on any of the response variables which we measured. The following graphs show the effects of treatment on various response variables:

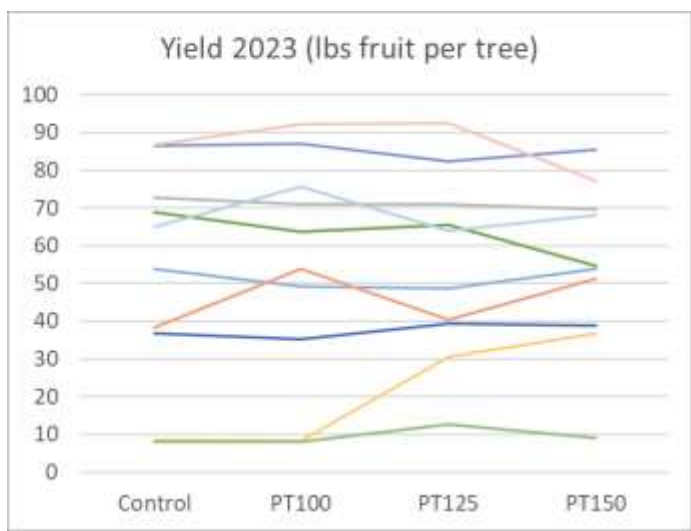


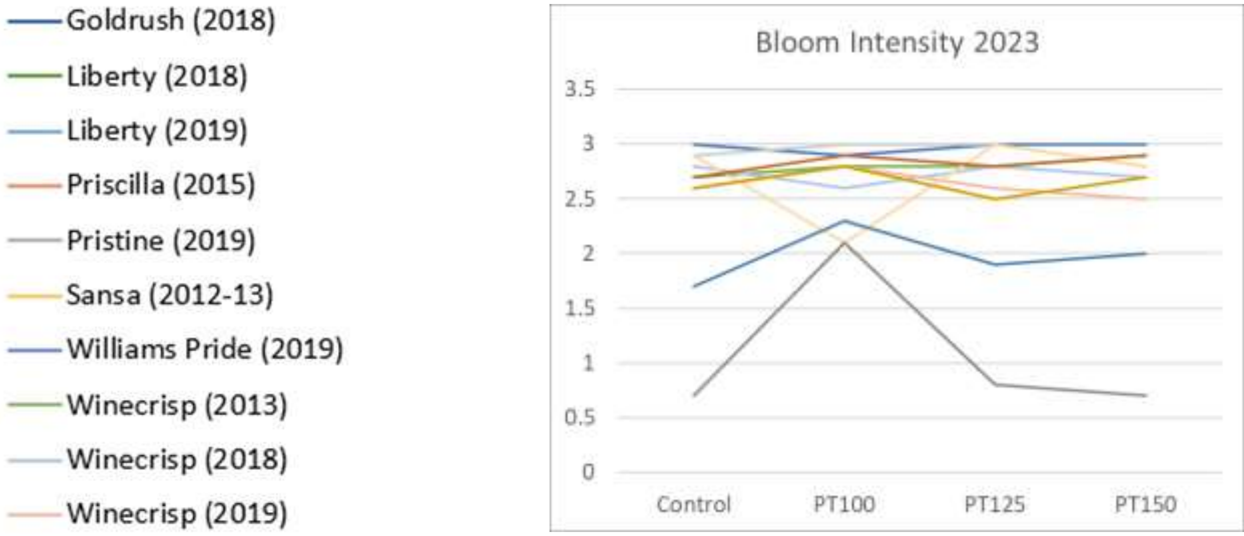










*Time Requirements*

The time required for measuring and recording style length from 25 flowers from one block averaged 9 minutes 40 seconds. During the 5 days of bloom in 2022 when we made thinning sprays, we spent an average 36 minutes per day doing office work related to managing the PTGM on the computer and timing sprays for the 10 blocks in this study. In 2023, the time spent on these tasks averaged 44 minutes per day. Therefore the *total time per block required each year* to measure styles and do office work related to the PTGM was about 30 minutes.

*Conclusions and Observations*

1. Throughout our orchard (not only in the experimental plots), 2022 was a very difficult year for thinning. Bloom was extremely heavy. Many of our trees outside the experimental plots overcropped despite thinning sprays which have been fairly effective in other years. In 2023, bloom and fruitset were generally more moderate throughout our orchard.

2. It was extremely difficult to precisely time thinning spray applications according to the pollen tube growth model. The hot weather during 2022 bloom represented a worst case scenario in this regard. Pollen tubes grow very rapidly in high temperatures and therefore the ideal spray window identified in the pollen tube growth model can pass very quickly. From a practical standpoint it can be very difficult to spray during such a brief window because of weather (rain or high wind) which prevents spraying and/or because of time management: in a diverse orchard of 20+ varieties, an orchardist would need to be spraying almost constantly, day and night to time sprays perfectly for each variety. The charts above show that in many cases we ended up applying sprays at times not dictated by the PTGM, simply because we projected that weather or logistics would prevent us from making a perfectly timed spray.

3. The work required to implement the PTGM is not difficult, but it does require time and record-keeping. And the model must be implemented separately for each variety in an orchard. In our study, the total time for measuring style lengths and doing computer/planning work related to the model was 30 minutes per variety. In an orchard of 20-40 varieties, this means that 10-20 hours of work would be required during bloom, *not counting* the time to actually apply thinning sprays. The time required for thinning sprays will vary substantially depending on the sprayer used, orchard layout, etc., but in an orchard with multiple varieties that differ in bloom time, style lengths, and bloom intensity, the PTGM will inevitably dictate multiple partial-orchard sprays spaced close together in time, especially in years where warm weather during bloom causes rapid pollen tube growth.

4. In our study there were no clear effects of any treatment on cropload, yield, hand-thinning time, or return bloom. The fact that the thinning sprays "did not work" anywhere in our experiment suggests strongly that Regalia+Oil is simply not a good bloom thinner (perhaps because of the manufacturer's change to the formulation) or that this mix is only weakly toxic to flower organs and would need to be applied before or shortly after pollination to be effective, before the 100% stage on the PTGM.

5.  Abundant bloom on one-year old wood causes problems for cropload management. In 2022, it was evident, although we did not specifically collect data to quantify this trend, that much of the excess fruitset in experimental plots occurred in bloom from flower clusters which developed from lateral buds on 1-year old wood.  In contrast, we qualitatively observed in 2022 that fruitset from spur bloom was modest and there may have been some trend for the control treatments to set more fruit on spur bloom than the other three treatments, particularly the PT100 and PT125 treatments.  In 2023, there was generally less bloom on one-year old wood, although it was still abundant on particular varieties or individual trees.

Lateral buds on 1-year old wood often produce extremely dense clusters of flowers in close proximity to each other.  These flowers generally open later than flowers produced on spurs.  See the pictures below, which were taken of the same tree on the same day.  In 2022, we sprayed all experimental plots with both potassium bicarbonate on May 15th and 16th to reduce fruitset from the late bloom on 1-year old wood, but there was still substantial fruitset.  We have found this to be the case in other years as well.

*Spur bloom on Liberty May 15, 2022.  Note that most flowers have already dropped their petals.*

*Bloom from lateral buds on 1 year old wood on Liberty, May 15, 2022.  Note the dense aggregation of flowers and that these flower clusters are at peak bloom and that few petals have dropped.*

There are several possible reasons why we have struggled to control fruitset on 1-year old wood with bloom thinning sprays. I estimate that a single 1-year old branch with dense bloom from lateral buds can bear 50-100 flowers in 12-18" of branch length.  In such a case even if only 5% of the flowers set fruit, there will be substantial overcropping.  Moreover, in such a dense array of flowers, stigmas and styles may often be shielded from thinning sprays by the petals of adjacent flowers.  In our experience, when heavy bloom on 1-year old is expected it may be best to aggressively prune off 1-year shoots during dormant pruning to reduce the need for thinning.  The extent of lateral bloom on 1-year old wood varies. Some varieties, such as Priscilla and Enterprise rarely produce substantial 1-year old bloom in our orchard, while others such as Williams Pride, Liberty, and Pristine, can produce immense numbers of flowers on 1-year old wood. These flowers are also particularly abundant in the year following years with relatively low yield.

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