FINAL PROJECT REPORT

WTFRC Project Number: AP-16-108A

Project Title: Validation of the Red Delicious Pollen Tube Growth Model

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Tory Schmidt, Washington Tree Fruit Research Commission, Wenatchee, WA

Other funding sources: None

Total Project Funding: $33,280

Budget History:

WTFRC Collaborative expenses:

Item	2016	2017
Salaries	2000	2000
Benefits	600	600
Wages	1000	1000
Benefits	250	250
Shipping	50	50
Supplies	50	50
Travel	250	250
Total	**$4,200**	**$4,200**

Budget:
Organization Name: Virginia Polytechnic Institute and State University (Virginia Tech)
Contract Administrator: Eric James Dinwiddie, Pre-Award Administrator
Telephone: 540-231-9368 Email address: EricJD@VT.edu

Item	2016	2017
Salaries*	8000	8000
Benefits	4080	4080
Supplies	360	360
Total	**$12,440**	**$12,440**

***Note: Salary for Research Specialist Leon Combs.**

OBJECTIVES

1. **Validation Testing of Red Delicious Pollen Tube Growth Model in Washington Orchards. (Virginia Tech & WTFRC)**
   Pollen tube growth model validation includes criteria from three tests in 2016 and 2017:

   Test 1: Commercial use of the pollen tube growth models. In this test, grower-participants use the models made available to them through the AgWeatherNet website. These growers (beta-testers) trained in the use of the models then monitor the blocks start times and bloom thinning application timings. At the end of harvest, the beta-test participants rate their actual crop relative to their ideal expected yield. Comparing the desired yield with the actual harvested yield would demonstrate whether the beta-test participants understand the principles of the model and if it is working to their satisfaction. This harvest data will be cross-referenced with application timings as done with other models in previous years.

   Test 2: Validation test 2 includes flower samples collected in Washington orchards after thinning chemicals were applied, by comparing model-predicted pollen tube growth versus actual growth in flowers. Flower samples from beta-test blocks will be evaluated microscopically to determine if fertilization occurred on the segment of the flower population that was intended to be the harvested crop. Bloom thinning applications can then be re-applied to reduce unwanted additional cropping.

   Test 3: Harvest data from selected Washington orchard blocks that will be bloom thinned using the pollen tube growth model in the 2016-17 growing seasons for validating the Red Delicious model, will come from selected contributing beta-testers who had access to the Red Delicious beta test model for the 2016-17 growing season.

Objective 2:

WTFRC:

WTFRC staff will work with commercial growers to select several orchard blocks for these tests. In each block, they will randomly flag four trees (border and unhealthy trees will be avoided). On the flagged trees, they will tag or flag six flower clusters (with the king bloom open) that represent part of target crop load. In other words, these are typical of the flowers that should become fertilized before the first chemical thinning application. Forty-eight hours after first bloom thinning spray, whole flagged clusters will be removed from the tree. Petals will then be removed, and the king bloom marked with a permanent marker to distinguish it from the lateral blooms. The whole cluster will then be placed into a plastic bottle containing a 5% sodium sulfite (5 g/100 ml distilled water) solution. After all samples are collected, the samples will be shipped to Virginia Tech AHS-AREC for histological evaluation.

Virginia Tech

Upon receipt at the Virginia Tech facility, samples will be refrigerated at 38°F until processing. The flowers will be prepared and examined as described for Objective 1. Collected data will be the same as described for Objective 1.

SIGNIFICANT FINDINGS

- More than 100 Washington State Red Delicious beta-test blocks were bloom-thinned using the pollen tube growth model as a tool in 2016-17. From about 30 of those sites we received spray timing, yield data, and/or evaluated flower samples for evidence of fertilization.

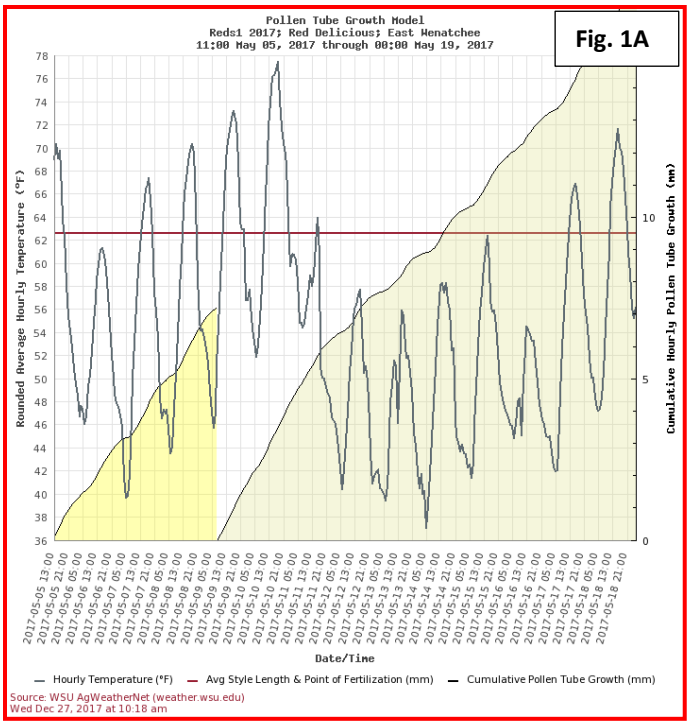
- Microscopic evaluation of sampled flowers in the laboratory to determine the percentage of flowers that had been fertilized showed predictive effectiveness of Red Delicious model in the field.
- Reported harvest data showed that the pollen tube growth model is helping growers to achieve their targeted crop loads.
- Style length data acquired from 2016-17 tests showed the importance of properly measured field style length when compared with style measurements in laboratory.
- There was some unexplained discrepancy in the style-length measurements taken in some test blocks compared to those measured in the samples submitted to the laboratory. Flowers with shorter styles would have been fertilized more quickly, resulting in higher than desired yield.
- Data showing pollen tube growth in styles confirms that proper timing of second and sometimes third follow-up applications is critical in reducing crop load.
- Of any cultivar we have tested, pollen tube growth is the slowest in Red Delicious styles, but with some appropriate cautions, this model will be released to the industry for 2018.

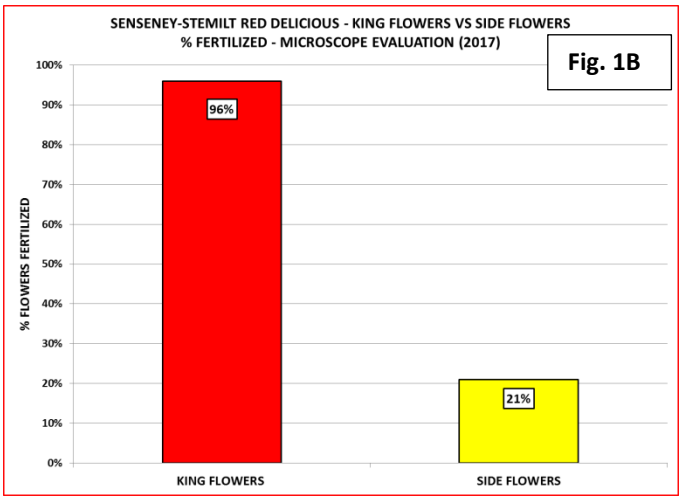
RESULTS & DISCUSSION

As stated in previous reports on models presently being used by growers (Table 1), tracking actual bloom thinning application timing and harvest totals versus desired cropping is needed to verify the models' effectiveness. These growers (beta-testers) are trained in the use of the models and monitor the blocks start times and bloom thinning application timings (Fig. 1A, 2A, 3A) as predicted by the AgWeatherNet website from inputs by model users. As in 2016, evaluation of the model in 2017 included sampling flowers from the field (Figs. 1B, 2B, 3B) to determine the percentage of flowers that have been fertilized, which further validates model predictions. Comparing desired crop load with actual harvest data (Fig. 1C, 2C, 3C) demonstrates either understanding of beta-testers in model implementation or the need for further training in initiation of the modeling program at the proper time. Results from field evaluations of desired bins/acre vs actual bins/acre harvested shows if the model helps beta-testers/growers achieve their targeted crop. Comparing average style length determined in the field and in the laboratory (Fig. 1D, 2D, 3D) is an integral part of evaluating and refining the model to actual field conditions as well.

Table 1. Chronology of beta-testing and release of the pollen tube growth models.

Pollen Model	Began field beta-testing using Excel spreadsheet models (Year)	Began field beta-testing using AgWeatherNet website models (Year)	Released for public use (Year)
Gala	2007	2012	2014
Golden Delicious	2007	2012	2014
Fuji	2009	2012	2014
Pink Lady	2011	2012	2014
Honeycrisp	2013	2013	2017
Granny Smith	2014	2014	2017
Red Delicious	**2014**	**2015**	**2018**





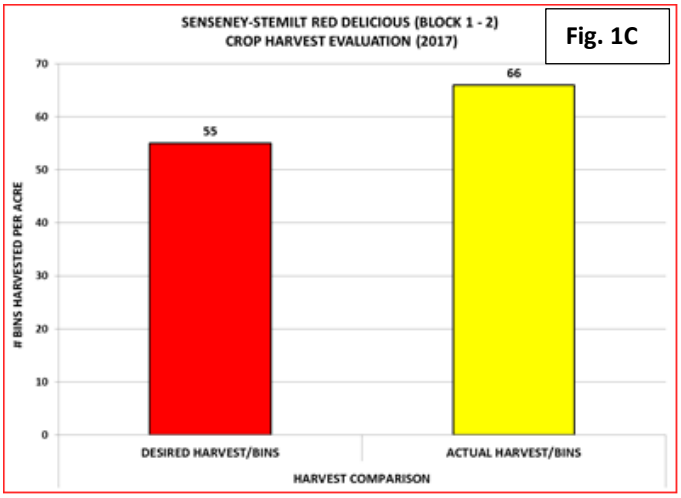


Figure 1. Beta-testing at Senseney-Stemilt Red Delicious (Block 1), East Wenatchee, WA.

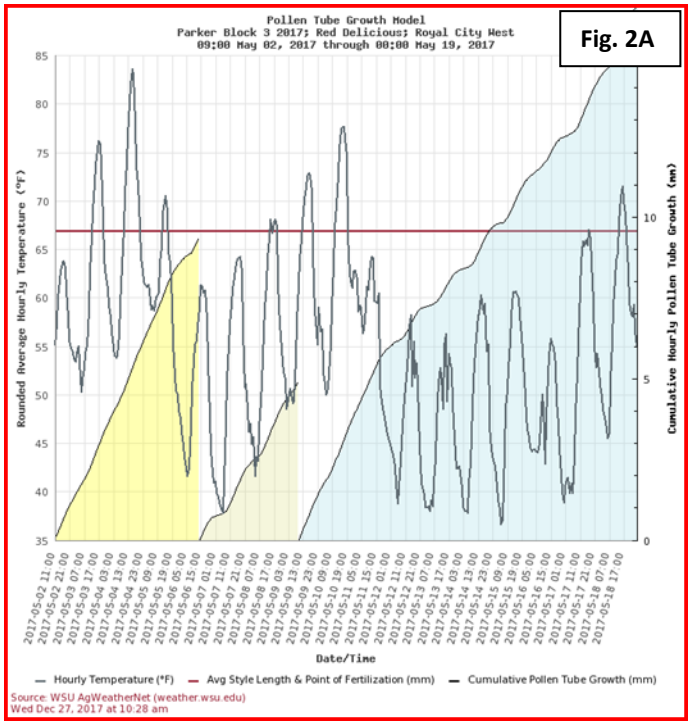
1-A: An image of the pollen tube growth model from WSU AgWeatherNet, showing progress of the pollen tube growth in this block, as related to temperatures and measured Red Delicious style length, and timing of a single bloom-thinning application.

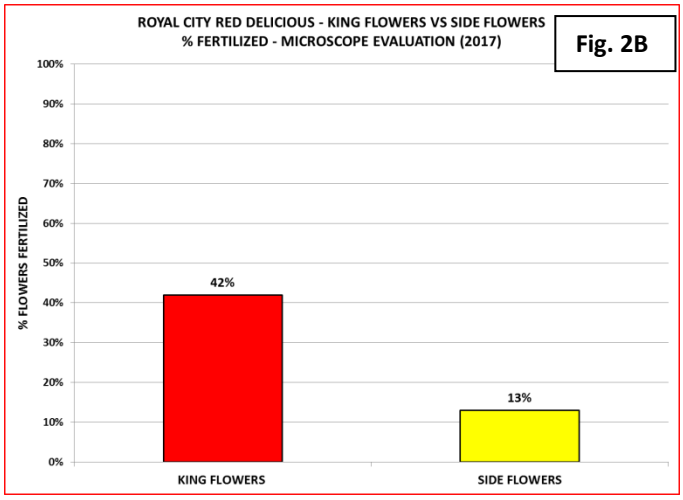
In this block, the first application was made early to compensate for a delay in starting the model until 75% king bloom open instead of the suggested 10-25% king bloom. The early application resulted in a high percent of king bloom fertilized and a relatively low percent of side bloom fertilized; however, the delay probably allowed too much set of king bloom, resulting in more bins per acre than was targeted. Also, not having a second application allowed all later bloom to set, further increasing the number of bins per block.

1-B: Laboratory assessment of percent fertilization of king bloom vs. side bloom of sampled flower clusters.

1-C: Comparison of targeted crop to actual harvested crop.

Ideally, comparison of targeted crop to actual harvested crop would demonstrate the model effectiveness in predicting thinning applications and the understanding of model concepts by end users.





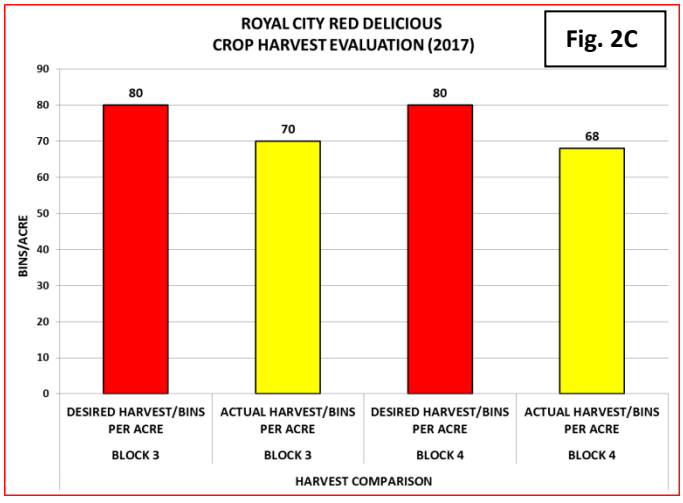


Figure 2. Beta-testing at Royal City West Red Delicious (Parker Blocks 3 & 4), Royal City, WA.

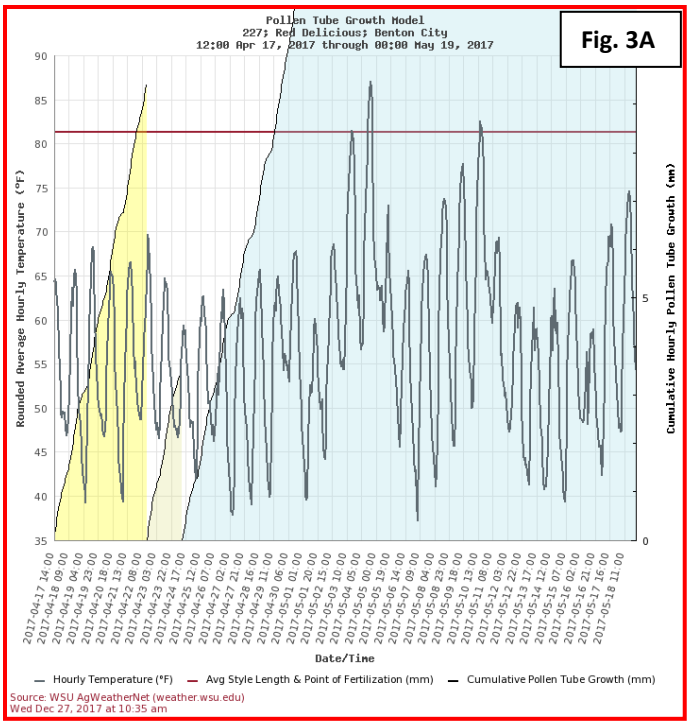
2-A: An image of the pollen tube growth model from WSU AgWeatherNet, showing progress of the pollen tube growth, as related to temperatures and measured Red Delicious style length, and timing of two bloom-thinning applications.

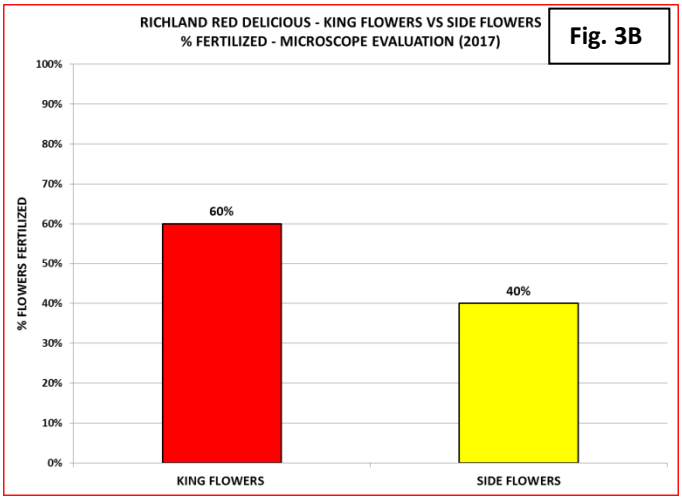
In these blocks, the first application was closely timed by the model, resulting in a good comparison of king bloom vs. side bloom fertilized. The well-timed follow-up application reduced further fruit set, resulting in fewer bins than the targeted yield in both blocks

2-B: Laboratory assessment of percent fertilization of king bloom vs. side bloom of sampled flower clusters.

2-C: Comparison of targeted crop to actual harvested crop.

Here, comparison of targeted crop to actual harvested crop suggests that there may have been more thinning than desired. Whether this is true, and its economic significance would need to be confirmed by looking at fruit sizes in the packout and checking return bloom in 2018.





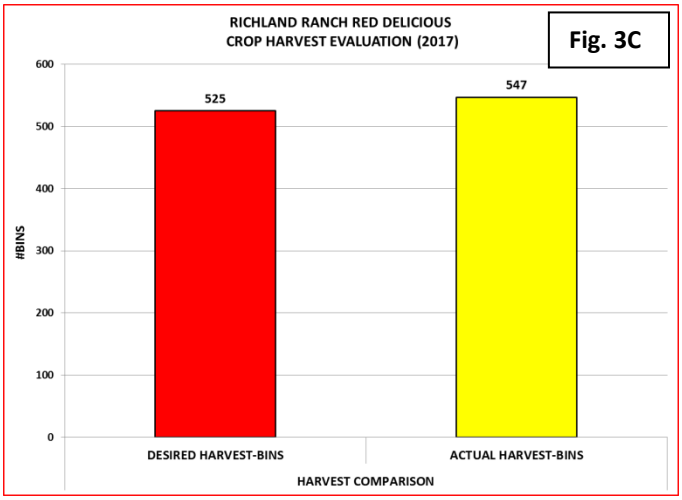


Figure 3. Beta-testing at 227, Red Delicious, Benton City, WA.

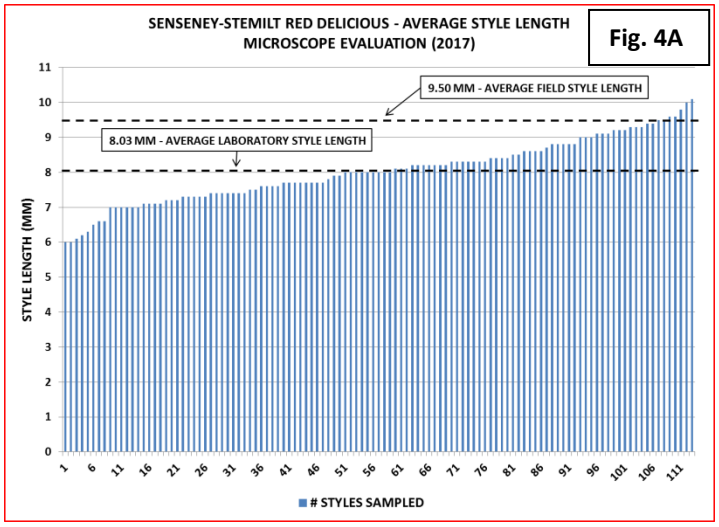
3-A: An image of the pollen tube growth model from WSU AgWeatherNet, showing progress of the pollen tube growth, as related to temperatures and measured Red Delicious style length, and timing of two bloom-thinning applications.

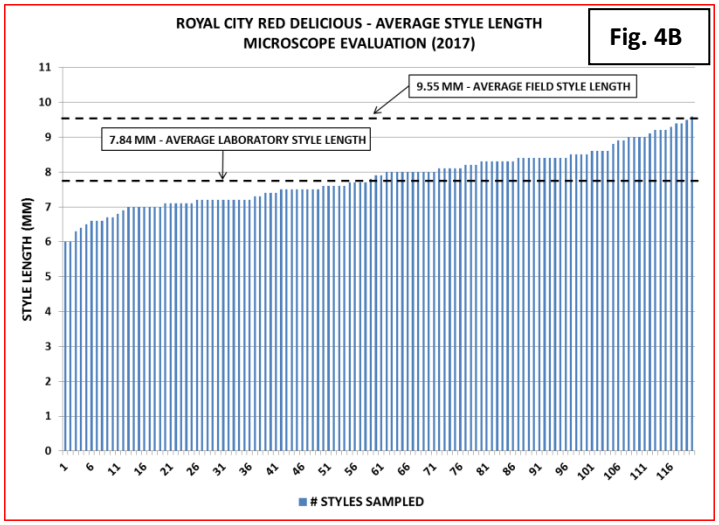
In this block, the first application was well-timed to allow adequate fruit set, the follow-up application two days later resulted in a reduced percentage of side bloom setting fruit, and yield was relatively close to the targeted amount.

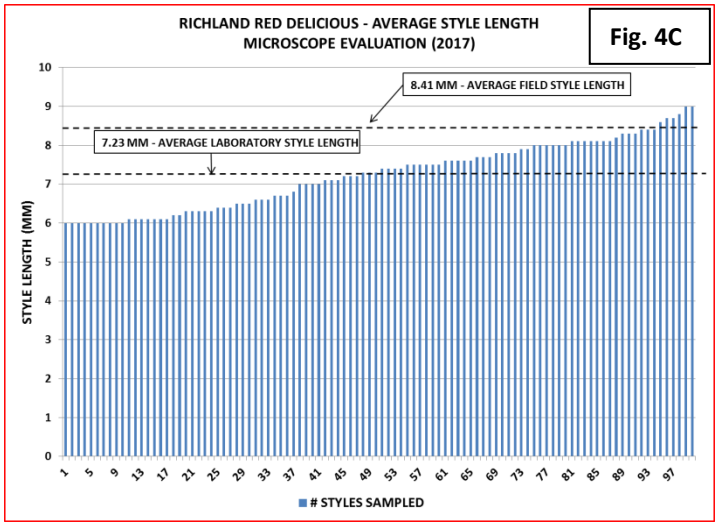
3-B: Laboratory assessment of percent fertilization of king bloom vs. side bloom of sampled flower clusters.

3-C: Comparison of targeted crop to actual harvested crop.

Again, comparison of targeted crop to actual harvested crop offers a good assessment of the effectiveness of the model in predicting thinning applications and understanding of model concept by users.







Figures 4A-C show the lengths of styles measured in sampled in the beta-test blocks. The average field style length lines are of the measurements that were recorded on site; the average laboratory style length lines were recorded from 100 or more styles on sampled flowers that were sent to our laboratory from the test sites. It is surprising that the measurements taken in the orchard average consistently longer than those in the lab, by 1.2-1.7 mm. We do not have an explanation for this, but it could have made a significant difference in the amount of thinning. Thinning applications were applied at each location based on measurements in the orchard. But, if the styles were indeed shorter than those indicated in Figures 1A, 2A and 3A, more thinning would have resulted because fewer flowers would have been fertilized by the time of the first application, and this would reduce the number of bins per block.

As was stated in our proposal, an in-orchard study at Winchester, VA in 2007 showed that there might be as much as a three-fold difference in Snowdrift pollen tube growth rates among cultivars, with 'Red Delicious' standing out as having the slowest pollen tube growth of seven cultivar models available to the public for use as a bloom thinning tool. This delayed pollen tube growth in Red Delicious could lead to serious over-thinning if one ignored this difference and based the timing of Red Delicious bloom-thinning applications on the models for other cultivars available through AgWeatherNet rather than on a fully validated Red Delicious model. In all models, the user will need to implement the models according to thinning factors, whether thinning for conventional crops or organic production. The options for thinning are more restricted in organic crops so those growers need to test the Red Delicious model rigorously in their own orchard conditions. As shown below in Figure 5, crop load results for 2016 at beta-test sites in Washington showed that the model helped in crop load management in all but one test site.

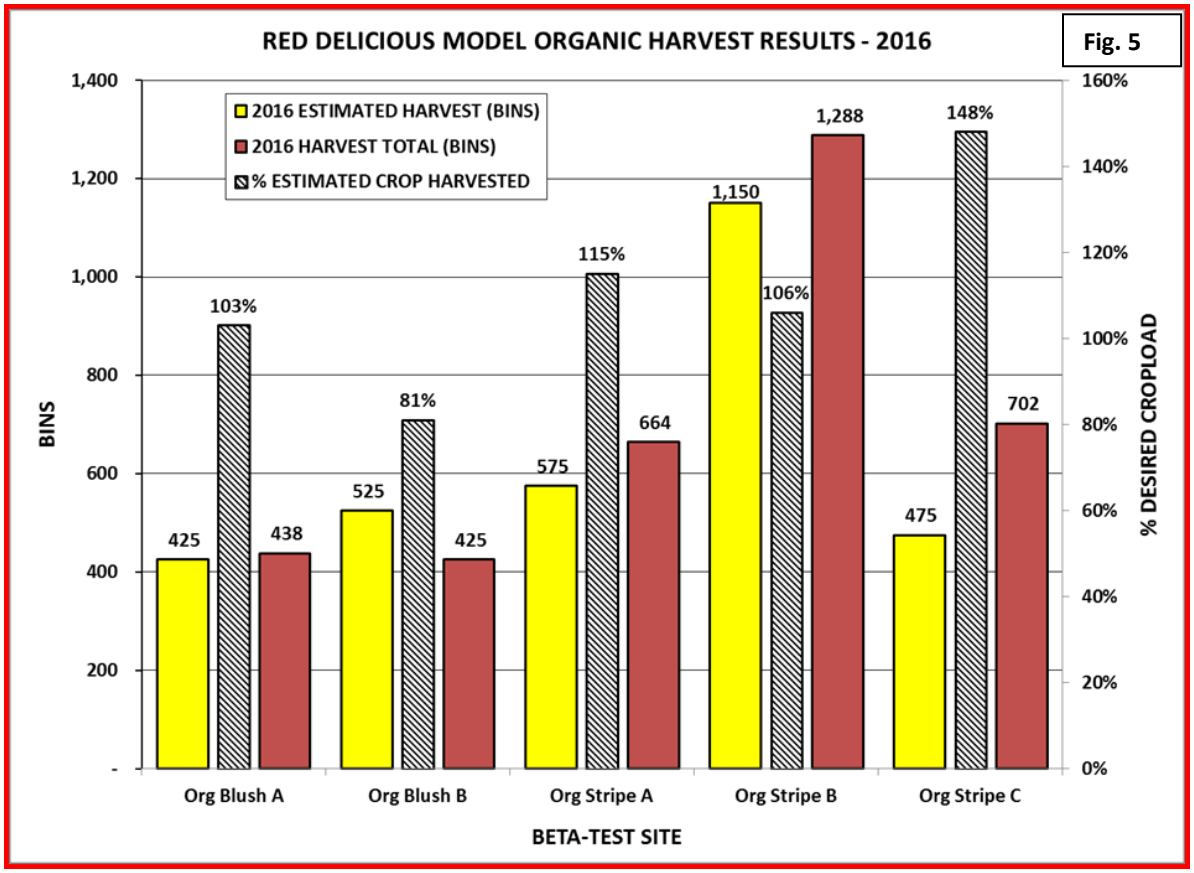


Figure 5: Targeted yields versus actual yields in five organic Red Delicious orchard blocks, 2016.

Our final report: We see this as more than just the final report for the current Red Delicious project. Release of the Red Delicious model completes our assigned series of related projects with WTFRC. The Red Delicious model will join Gala, Golden Delicious, Fuji, Cripps Pink, Granny Smith and Honeycrisp for public use on AgWeatherNet. In apple production, properly timed bloom-thinning gives the grower the optimum advantage for producing the best quality fruit. Understanding the progression of pollen tube growth after pollination is critical in applying bloom thinners at the proper time. In addition to optimal sizing benefits, crop loads not sufficiently thinned could result in trees being thrown into biennial bearing with little or no crop in the 'off' year. Previously, the application timing for this spray was often subjective, usually based upon the percent of full bloom open (e.g., applications at 20 and 80% full bloom). While this approach became a standard practice in

some growing regions, more precise application timing can be achieved through modeling the fertilization of the desired percent of king bloom needed to achieve a full crop at the desired fruit size.

From the earliest efforts in these projects, we had pursued this as a work in progress, but our main goal was to provide a better basis of fine-tuning the timing of bloom thinning applications, from the old "20 and 80% bloom" timing to a more refined method that would pinpoint narrow timing windows. Also, we recognized that, ideally, the method could and should be predictive, based on the local weather forecast, so that growers could set priorities and optimize timing for multiple blocks. The early, surprising, result with Red Delicious in 2007 forewarned us that each model must be cultivar-specific, not "one size fits all".

Looking back, and forward: Over several project cycles since 2004 we have addressed the challenges of technical aspects of how to most efficiently conduct this research. With feedback from Commission members and beta-testers, we have continually considered priorities among cultivars and temperature ranges to be tested. We settled on Snowdrift as the model pollinizer, although we recognize that there are differences in growth rates due to different pollen sources. There have been several spin-offs technically and academically, with kindled interest in development of different products and methods for bloom thinning, and at least three graduate student projects have expanded our understanding of bloom-thinning related issues. We know that some of the techniques developed in this research are also applicable to related problems with cherries, pears and peaches.

There remains work to be done in the area of crop load management at bloom: There will always be new cultivars with different thinning needs. We know that specific pollinizers can affect the speed and rate of fertilization, apart from the common compatibility aspects. We know that style length is an important factor that must be recognized in rate of fertilization, and we also know that "average" style length can vary considerably in a cultivar, from block to block, and from year to year, but we really don't know what factors cause this variation. Finally, there is more to be known about how different thinning materials act, and what can be done to maximize their thinning effectiveness while minimizing their injury to foliage and fruit. There are also benefits to be gained, especially in organic production, by better integrating the disease management capabilities of thinning products.

On a more personal note in this final report, we must recognize the diligent effort that Leon Combs, Research Specialist, Virginia Tech, has provided to all aspects these projects since 2004. Much of the success of these projects in the development and implementation of pollen tube growth models for crop load management in apples is due to his innovative and diligent research and development efforts. Leon has announced his retirement as of January 1, 2018.

Above, Leon Combs (standing) and Tory Schmidt (left) conduct one of the in-depth training sessions for beta-testers using the first AgWeatherNet website models in 2014.

ACKNOWLEDGEMENTS:
We thank the Washington Tree Fruit Research Commission for their ongoing support throughout the development of these models. We would particularly like to thank Tory Schmidt and support staff, whose help on the project has been essential to the project's success. We thank Sean Hill (WSU-AgWeatherNet) for rapidly providing and adjusting the AgWeatherNet interface for the models. We would like to thank the many beta-testers, growers, and others who have provided valuable feedback and guidance on many aspects of the pollen tube growth models over the years since 2004:
Jim McFerson and Tory Schmidt and support staff, Washington Tree Fruit Research Commission; Tom Butler, Dan Plath and Adam Zediker (Washington Fruit & Produce Co); Harold Ostenson (Stemilt Growers); Kevin Larson (Roche Fruit); Darin Case (Dovex Fruit Company); Harold Schell (Chelan Fruit Company); Mike Robinson (Double Diamond Fruit); Dan Flick (Wilbur-Ellis); Gary Snyder (C & O Nursery); Dena Ybarra (Columbia Basin Nursery). Sean Hill, (WSU-AgWeatherNet); Firman Pollen Co., AgriMACS; We also recognize the input of the CO-PIs in these projects, the late Dr. Rongcai Yuan (Virginia Tech), Dr. Greg Peck (Virginia Tech, now with Cornell University), and Drs. Gerrit Hoogenboom and Melba Salazar (WSU-AgWeatherNet), and Dr. Vince Jones (WSU-TFREC).

EXECUTIVE SUMMARY

The overall goal of this project was validation of the Red Delicious pollen tube growth model in Washington orchards. This involved two years of commercial use of the model by grower-participants (beta-testers) trained in the use of the model made available to them through the AgWeatherNet website. These beta-test participants monitored the blocks start times and bloom thinning application timings and at harvest they compared their actual crop relative to their ideal expected yield to demonstrate whether the beta-test participants understood the principles of the model and if it was working to their satisfaction.

To check predicted pollen tube growth versus actual growth in flowers, flower samples were collected by WTFRC staff in Washington orchards after thinning chemicals were applied, and these samples from beta-test blocks were evaluated microscopically in the laboratory at Virginia Tech to determine if fertilization had occurred on the segment of the flower population that was intended to be the harvested crop. The sampled flowers were to come from clusters, with the king bloom open, that represented part of target crop load. In other words, these were typical of the flowers that should have been fertilized before the first chemical thinning application.

Under this limited program, more than 100 Washington State Red Delicious beta-test blocks were bloom-thinned using the pollen tube growth model as a tool in 2016-17. From about 30 of those sites we received spray timing, yield data, and/or evaluated flower samples for evidence of fertilization. Microscopic evaluation of sampled flowers in the laboratory to determine the percentage of flowers that had been fertilized showed predictive effectiveness of Red Delicious model in the field. Reported harvest data showed that the pollen tube growth model is helping growers to achieve their targeted crop loads.

Style length data acquired from 2016-17 tests showed the importance of properly measured field style length when compared with style measurements in laboratory. There was some unexplained discrepancy in the style-length measurements taken in some test blocks compared to those measured in the samples submitted to the laboratory. Flowers with shorter styles would have been fertilized more quickly, resulting in higher than desired yield. Data showing pollen tube growth in styles confirms that proper timing of second and sometimes third follow-up applications is critical in reducing crop load.

Of all the cultivars we have tested, pollen tube growth remains the slowest in Red Delicious styles. Because of this unusual characteristic, we urge considerable early caution in grower use of the Red Delicious model, but with some appropriate cautions, this model will be released to the industry for use in 2018.

Release of the Red Delicious model completes our assigned series of related projects with WTFRC. The Red Delicious model will join Gala, Golden Delicious, Fuji, Cripps Pink, Granny Smith and Honeycrisp for public use on AgWeatherNet. In apple production, properly timed bloom-thinning gives the grower the optimum advantage for producing the best quality fruit. Understanding the progression of pollen tube growth after pollination is critical in applying bloom thinners at the proper time. In addition to optimal sizing benefits, crop loads not sufficiently thinned could result in trees being thrown into biennial bearing with little or no crop in the ‘off’ year. Previously, the application timing for this spray was often subjective, usually based upon the percent of full bloom open (e.g., applications at 20 and 80% full bloom). While this approach became a standard practice in some growing regions, more precise application timing can be achieved through modeling the fertilization of the desired percent of king bloom needed to achieve a full crop at the desired fruit size.

We thank the Washington Tree Fruit Research Commission for their ongoing support in the development of these models. We would particularly like to thank Tory Schmidt, whose help on the project has been essential to the project’s success. Lastly, we would like to thank the beta-testers, growers, and others who have provided critical feedback on all of the pollen tube growth models.