PACMan: Precision Apple Cropload MANagement:

A USDA-NIFA Specialty Crop Research Initiative (SCRI) Project

Project Director: Terence Robinson, Cornell University

Presented by: Tory Schmidt, WA Tree Fruit Research Commission

Precision Apple Cropload MANagement

USDA National Institute of Food and Agriculture
U.S. DEPARTMENT OF AGRICULTURE

WASHINGTON TREE FRUIT RESEARCH COMMISSION

INSTITUTIONS INVOLVED IN THE PROJECT

Cornell University	Washington State University	Michigan State University
Penn State University	Virginia Tech	North Carolina State University
University of Mass	Washington Tree Fruit Research Commission	Multiple private technology companies

SCIENTISTS INVOLVED IN THE PROJECT

Title: Precision Crop Load Management For Apples		
PD: Terence Robinson	**Institution:** Cornell University, Cornell AgriTech	Physiologist
CO-PD: Lailiang Cheng	**Institution:** Cornell University	Physiologist
PI: Miguel Gomez	**Institution:** Cornell University	Economist
PI: Stefano Musacchi	**Institution:** Washington State University	Physiologist
PI: Todd Einhorn	**Institution:** Michigan State University	Physiologist
PI: Chris Layer	**Institution:** MOOG Inc.	Private manager
PI: Long He	**Institution:** Pennsylvania State University	Engineer
PI: Jon Clements	**Institution:** University of Massachusetts	Extensionist
CO-PI: Greg Peck	**Institution:** Cornell University	Physiologist
CO-PI: Yu Jiang	**Institution:** Cornell University	Engineer
CO-PI: Paul Heinemann	**Institution:** Pennsylvania State University	Engineer
CO-PI: Dana Choi	**Institution:** Pennsylvania State University	Engineer
CO-PI: Tom Kon	**Institution:** North Carolina State University	Physiologist
CO-PI: Sherif Sherif	**Institution:** Virginia Tech University	Physiologist
CO-PI: Karen Lewis	**Institution:** Washington State University	Extensionist
CO-PI: Mario Miranda	**Institution:** Cornell University	Extensionist
CO-PI: Craig Kahlke	**Institution:** Cornell University	Extensionist
CO-PI: Philip Schwallier	**Institution:** Michigan State University	Extensionist
CO-PI: Tory Schmidt	**Institution:** Washington Tree Fruit Res. Com.	Extensionist
Anna Wallis	**Institution:** Michigan State University	Extensionist

Advisory Committee

WA State	Suzanne Bishop	Allan Bros
	Darrin Belton	WA Fruit and Produce
	Garrett Grubs	Chelan Fruit
	Kevin Larson	Roche Fruit
New York	Paul Wafler	Wafler Farms
	James Zingler	Zingler Farms
	JD Fowler	Fowler Farms
	Joal Crist	Crist Orchards
	Christopher Whipple	DeMarree Fruit Farm
	Bobby Brown	Dale Fruit Farm
Michigan	Beth Whittenbach	Whittenbach Orchards
	Chris Kropf	Hart Fruit Farm
	Jamie Kober	Riveridge Packing
Pennsylvania	Bruce Hollabaugh	Hollabaugh Orchards
	Ben Keim	Keim Orchards
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Connecticut	Greg Parzych	Rogers Orchards
Oregon	Poliana Francescatto	Valent Biosciences
Ontario	Tom Ferri	Ferri Orchards

Precision Crop Load Management

Precision crop load management is a management philosophy that seeks to manage the number of apples on each tree in a precise number to obtain the best possible economic outcome.

CROP LOAD

Crop load management is one of the most economically critical management practices of growing apples.

Apple trees often produce many more flowers than needed for a commercial crop.

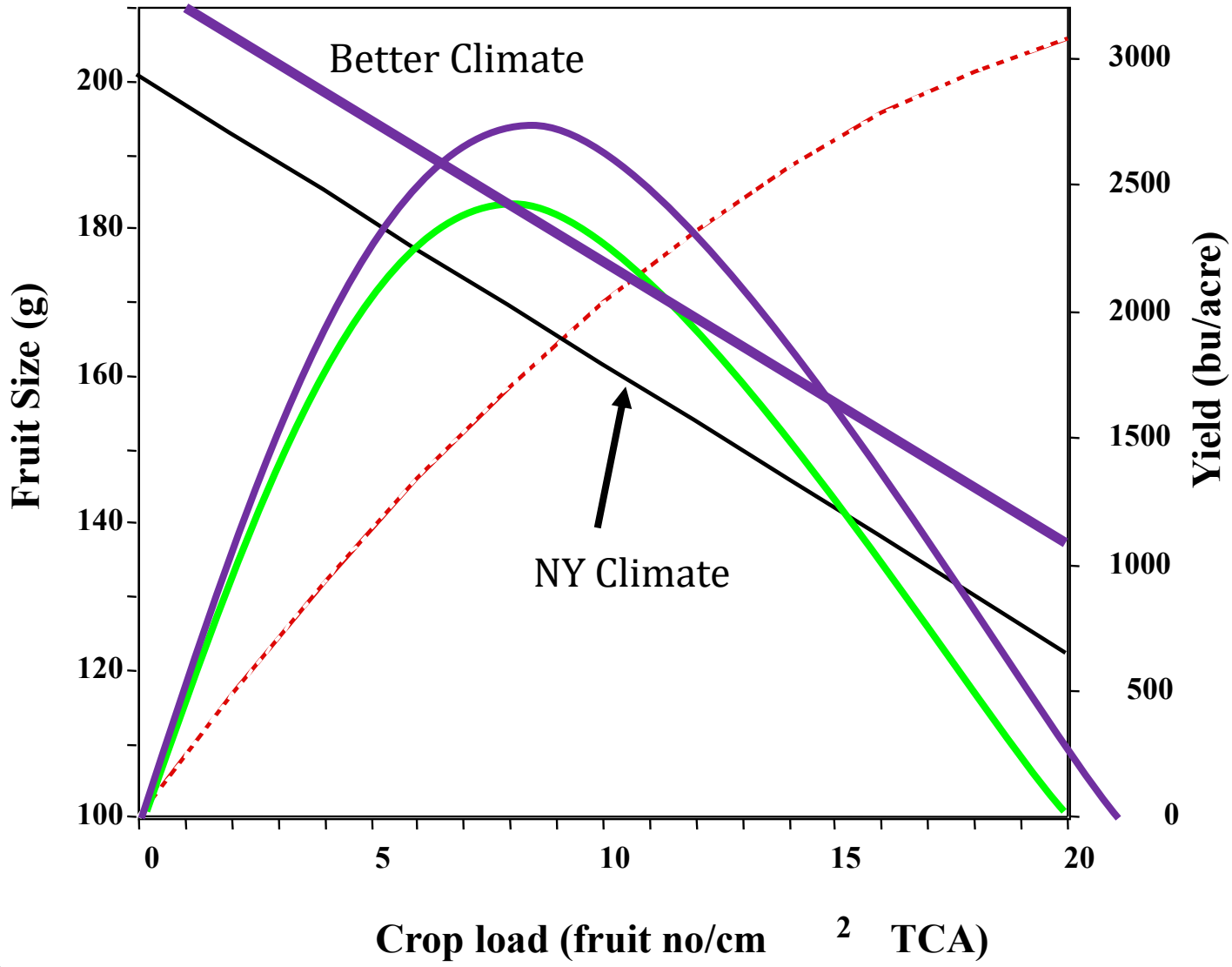
Only 3-10% of the initial population of flowers should be carried to harvest to optimize crop value and promote annual bearing.

Although some fruitlets abscise naturally, without active crop thinning, too many fruits remain, resulting in small fruit size and poor return flowering.

Small fruit size at harvest sharply reduces crop value.

Over-thinning also has serious economic consequences resulting in reduced yield and lower total crop value.

A Physiological Problem: The Optimum Crop Load and thus Optimum Fruit Number Varies with Climate



Credit to Terence Robinson

Physiological aspects 1

Define the optimum fruit number per tree based on physiological studies in several climates

Team: Terence Robinson, Tom Kon, Todd Einhorn and Stefano Musacchi

- Compare bud load and crop load in 4 climates (NY, MI, NC and WA) for 4 years with Gala and Honeycrisp
- Evaluate the optimum bud load and optimum crop load from an economic perspective to develop target bud and crop loads for each region.
- Develop targets for other varieties (NY1, WA38, Fuji, Maia)

Credit to Terence Robinson

WSU-Wenatchee: Musacchi group

Tree physiology in "Precision Crop Load Management for Apples"

WASHINGTON STATE UNIVERSITY

WSU TFREC Wenatchee • Washington

Timeline by phenology stage

SCRI

- **OBJ 1A1-Effect of Pruning Severity of Gala on Yield, Fruit Size and Crop Value in 4 climates** (Robinson, Musacchi, Einhorn and Kon)
- **OBJ 1A2-Effect of Crop Load of Gala and Honeycrisp on Yield, Fruit Size and Crop Value in 4 climates** (Robinson, Musacchi, Einhorn and Kon)
- **OBJ 1B-Imaging for bud quality and removal by pruning or thinning** (Einhorn, Robinson, Musacchi, and Kon)
- **OBJ 1C-Imaging, mapping and predicting early fruitlet drop to precisely manage thinning** (Einhorn, Robinson, Musacchi, and Kon)
- **OBJ 1F-Understand the fruit set mechanism in 'WA38'** (Serra-Musacchi)
- **OBJ 1G- Thinning with bee exclusion system for Fuji and WA38** (Musacchi-Serra)

Dormant buds → **Green tip** → **Tight green cluster** → **Full bloom (K+Lats open)** → **Start petal fall** → **End petal fall** → **10 mm fruitlets**

Trees selection (60 uniform trees/cv) Narrowed down later to 40 total

Pruning:

At green tip, reduce the total number of spur floral buds per tree to **50, 100, 150, 200, 250, 300, 350 or 400** with a target of 8 trees at each level. (The pruning must be done at green tip when floral spur buds can be easily distinguished from vegetative buds. Do not count lateral buds on 1-year wood) .
Pruning will be done by first eliminating 1-2 branches larger than ¾" diameter (2cm), then reducing the number of flower buds by spur pruning (extinction) by removing only the growing point from the spur.

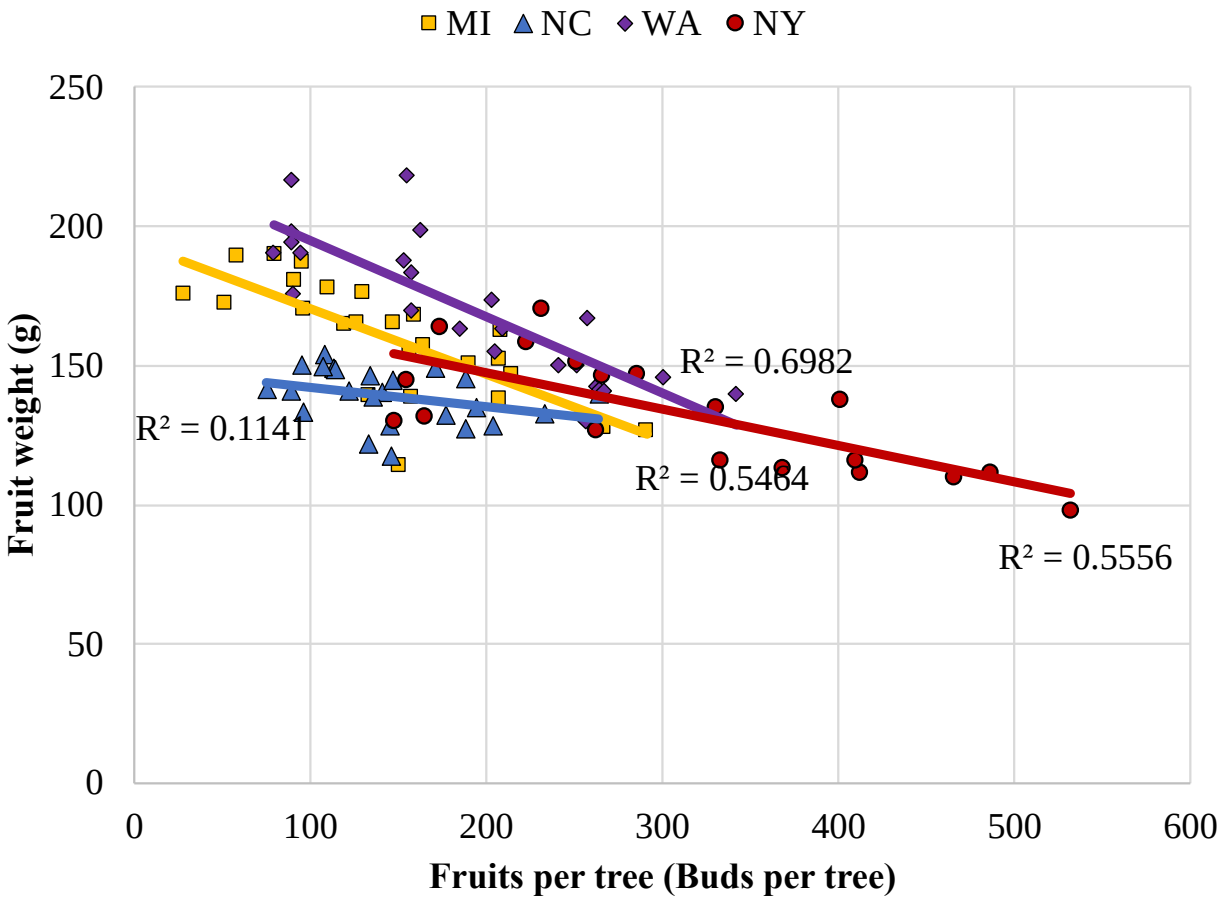
Thinning at Full Bloom

Hand thinning at full bloom to 2 flower per cluster then thin to single fruitlet (largest) at 10mm fruit size

Chemically thin at bloom with lime sulfur and fish oil guided by the pollen tube growth model, at Petal Fall with NAA+Sevin and 12mm with Maxcel+Sevin if needed. The number of thinning sprays determined locally.

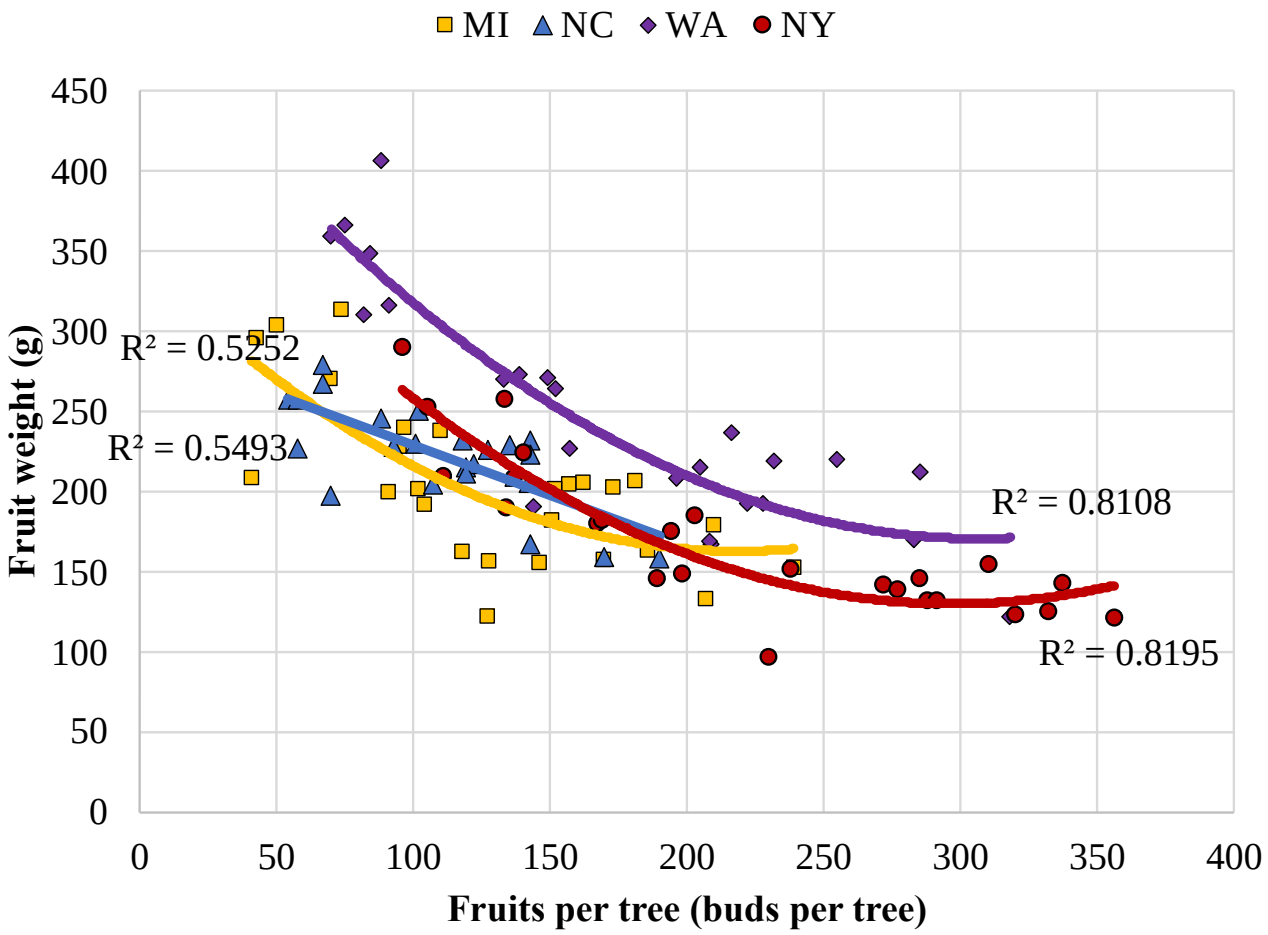
Results- Pruning Severity –Gala - 2022

- With Gala, the WA climate in 2022 gave the largest fruit size at low crop load but similar size as NY at high crop loads.
- The NY and MI climates had intermediate fruit size at any crop load.
- The NC climate had smaller fruit size at any crop load.



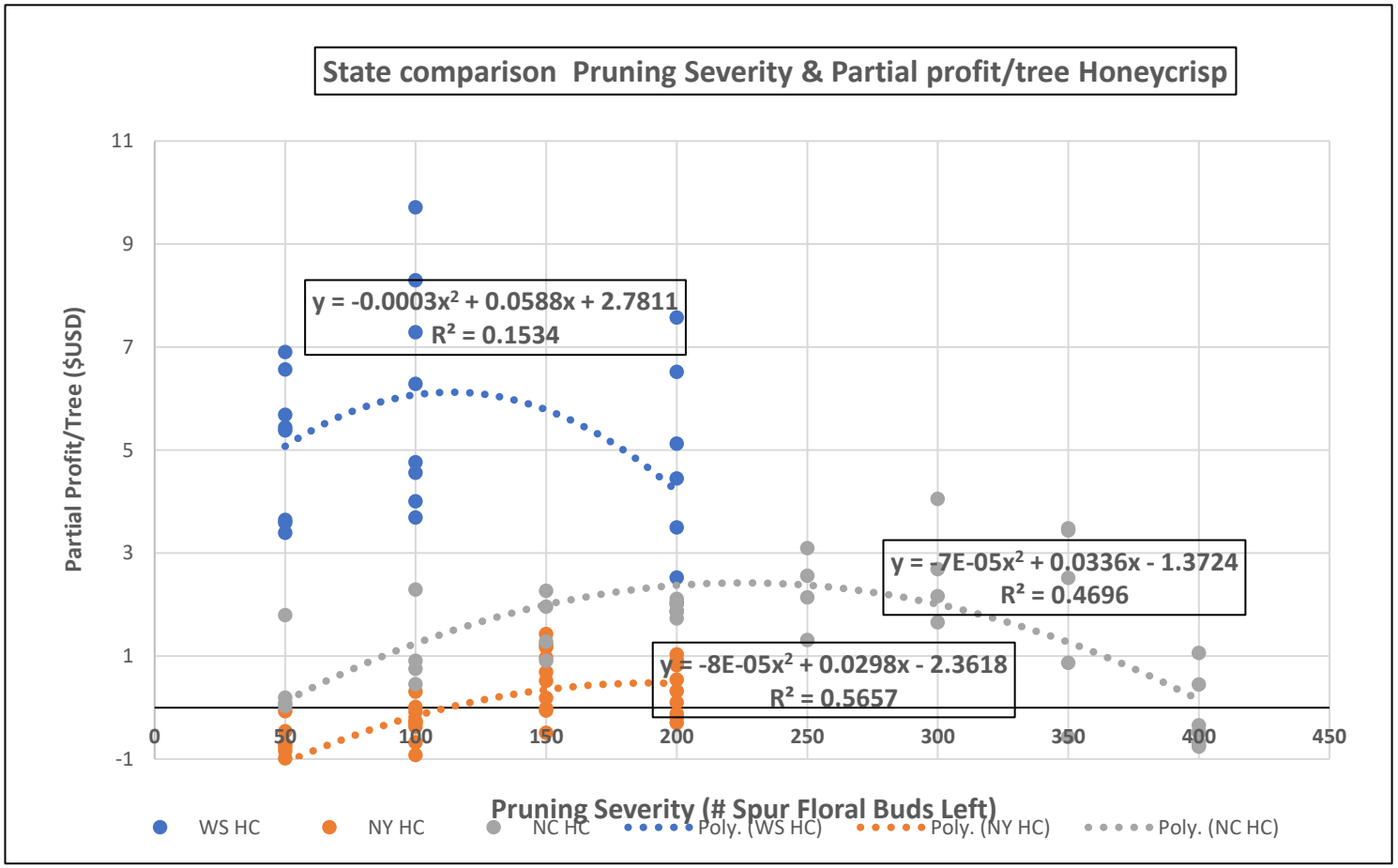
Results- Pruning Severity – Honeycrisp - 2022

- With Honeycrisp, the WA climate gave the largest fruit size at any crop load.
- The NY, MI and NC climates had smaller fruit size at any crop load.



Economic Results of Pruning Severity - 2021

How many flowering spurs to leave on Honeycrisp?



- For Honeycrisp leave 200 to 250 flowering spurs per tall spindle tree
- In 2022 flowering spur counts at Geneva showed 500 flowering spurs

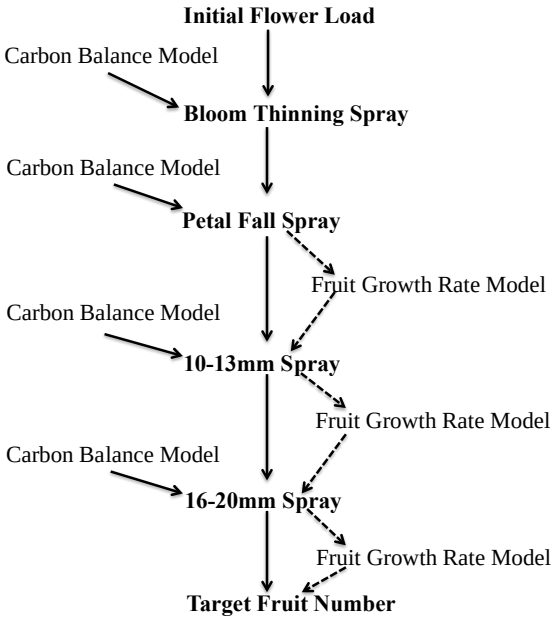
Physiological aspects 2

Improve the models that guide chemical thinning

Team: Terence Robinson, Lailiang Cheng, Greg Peck, Sherif Sherif, Tory Schmidt, Todd Einhorn and Stefano Musacchi

- Universal Pollen Tube Growth Model
- Refine Carbohydrate Model
- Extend Carbohydrate Model to Western States
- Improve Fruit Growth Rate Model
- Develop methods to use fruit growth rate without measuring fruit diameters

Pollen Tube Growth Model

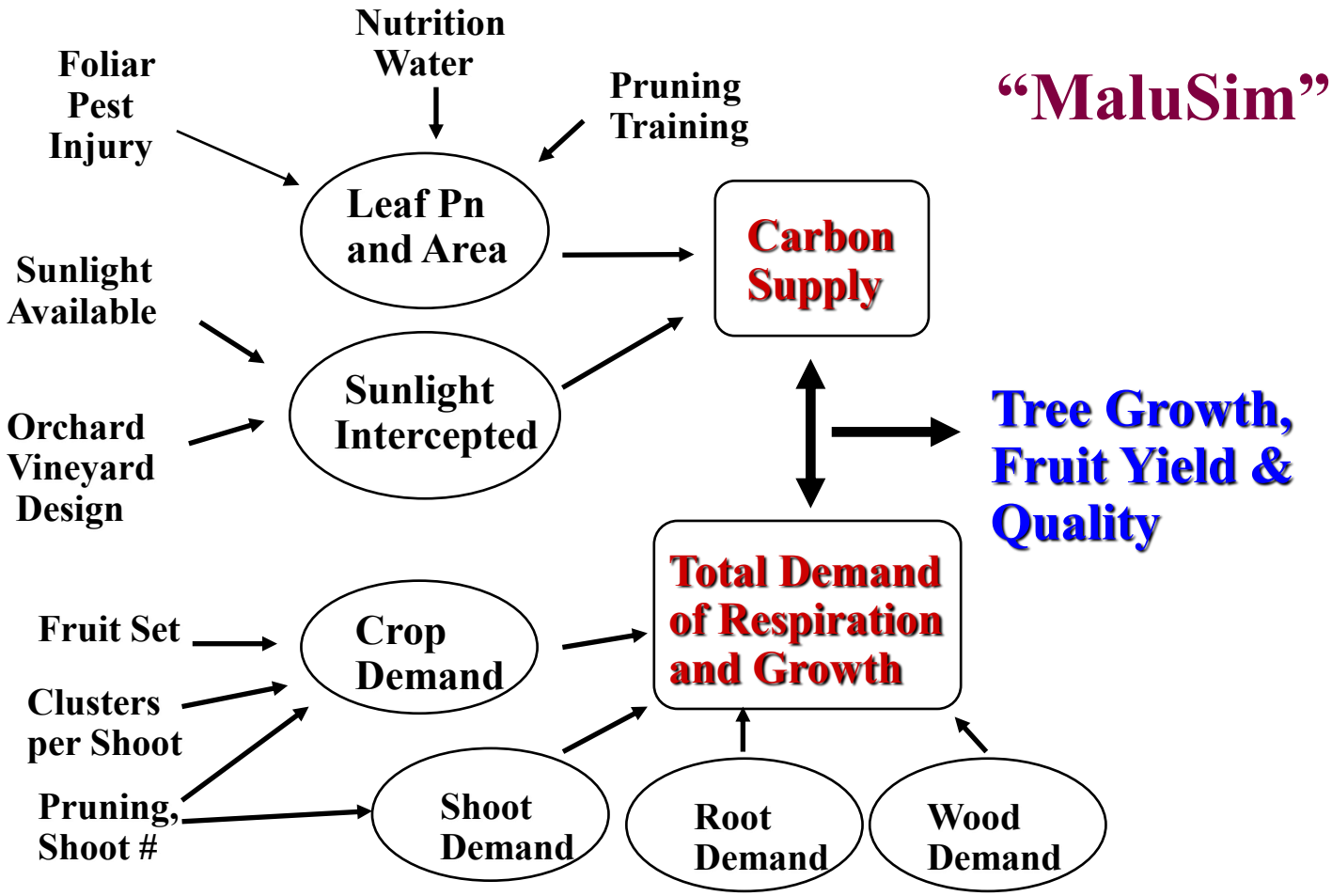


Credit to Terence Robinson

Fine-tune the MaluSim model for ‘Honeycrisp’



Lialiang Cheng, Terence Robinson, Alan Lakso
School of Integrative Plant Science, Cornell University



Cornell Carbohydrate Model:

- Both a Web-based version (newa.cornell.edu) and a mobile phone version (MaluSim.org) are available for USA growers.
- The model uses sunlight and temperature to estimate carbohydrate availability for fruit growth.
- We estimate thinning efficacy for any given spray using an average carbohydrate balance 2 days before and 4 days after the spray.
- The model also calculates degree days after bloom and adjusts predicted thinning efficacy according to the number of DD from full bloom for any given spray.
  - Apply PF spray at 110-130 DD after full bloom
  - Apply 12mm spray at 200-250 DD after full bloom
  - Apply 18mm spray at 300-350DD after full bloom

Fine-tune the MaluSim model for ‘Honeycrisp’

The original MaluSim model was developed on ‘Empire’ spindle trees

The model has been used extensively for predicting tree thinning responses based on tree carbon balance:

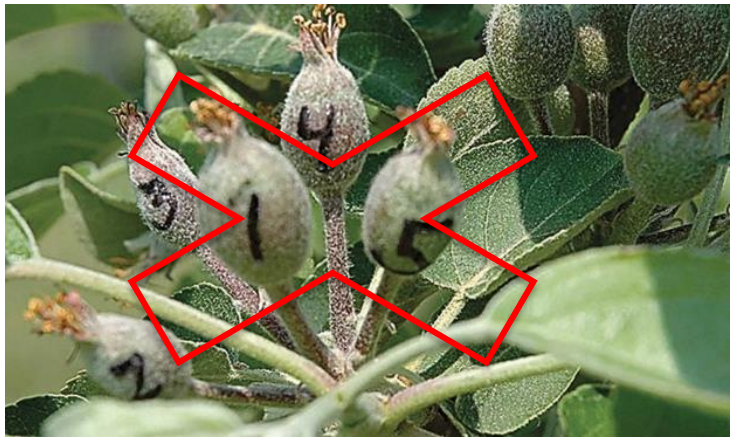
Carbon surplus supports fruit growth, resulting in less thinning
Carbon deficits limit fruit growth, leading to more thinning

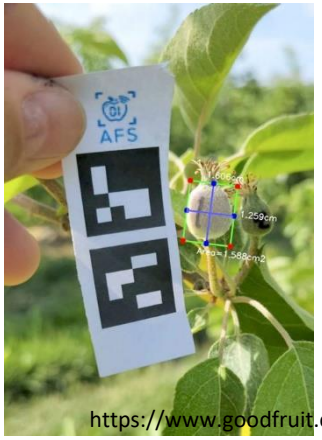
However, early season leaf area development needs more accuracy

We conducted whole tree destructive sampling on ‘Honeycrisp’ on B9, M9, G11 an G41 at budbreak, bloom, end of spur leaf growth, and end of shoot growth to collect data on total tree leaf area, photosynthesis and dry matter for testing and refining the MaluSim model to adapt the model to this weak growing variety.




- Todd Einhorn, Ph.D.
- MSU
- East Lansing, MI
- Physiology Team
- Precision bud pruning, fruit set prediction models, characterizing the physiological responses of vegetative and flowering/fruiting processes to crop load





https://www.goodfruit.com/evolutions-in-imaging/

- Our goal was to develop an alternative model that generates similar fruit set predictions as the fruit growth rate model without the need for repeated fruit measures
- Our approach is based on the distribution of fruitlet weights from a harvested sample population
- This approach can inform automated fruitlet imaging technologies by eliminating the need for geo-referencing

Protocol

MICHIGAN STATE UNIVERSITY | Extension

First, Tag 150 random clusters in orchard; then, count all clusters on 3-5 trees

Count the number of flowers of 25 clusters

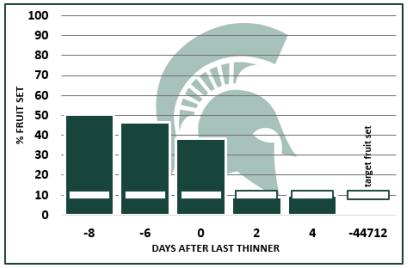
Apply thinner, ideally no later than ~6 mm diameter

(TJ Mullinax/Good Fruit Grower)

Collect 50 of the tagged clusters on 3, 6 and 9 d after thinner application

Defruit clusters

https://pacman.extension.org/category/uncategorized/

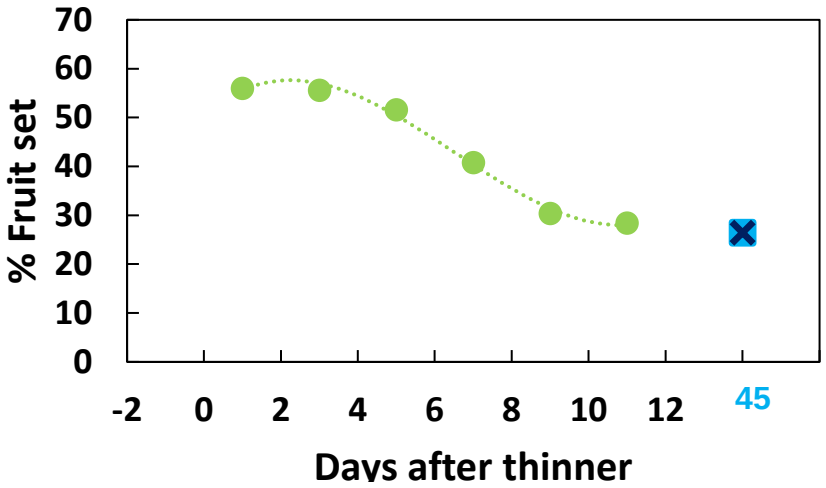


(TJ Mullinax/Good Fruit Grower)

Reapply thinner if prediction is higher than target

Predictions are automatically generated and graphed

Weigh fruit individually on scale connected to computer- data exports automatically to Excel



- The FSDM accurately estimates the final fruit set (recorded at 'June drop') by 8 days after thinner application (6 mm)
  - Too late? 6 mm dia.* 0.93 mm/d * 8 d = 13.4 mm dia. (still high sensitivity to chemical thinners)

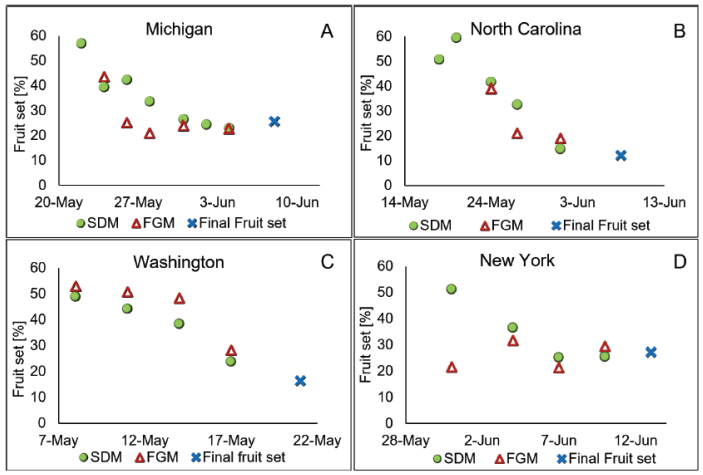


Figure 5. Fruit set predictions of the FGM (triangles) and SDM (circles) and final fruit set (x) for thinned Gala trees in 2021 for four different states across the US. Data for FGM and SDM were means of 5 replicates, n=20 spurs per replicate. Standard thinner was applied on 20-May 2021 (Michigan), 19-May 2021 (North Carolina), 6-May 2021 (Washington), and 25-May 2021 (New York). Final fruit set was taken at harvest at each of the four locations from a total of 200 spurs (5 replicates of 40 spurs per tree).

- The FSDM has generated similar predictions as the FGR model
- The FSDM requires substantially less time to implement the protocol

Dr. Tom Kon
Assistant Professor
Mountain Horticultural Crops Research and Extension Center
Mills River, NC
Physiology Group

Project activities

Participated in coordinated trials in NC, NY, MI, and WA:

1a. Determine the economic optimum crop load for apple regions

1b. Imaging for bud quality and removal by pruning or thinning

1c. Imaging, mapping and predicting early fruitlet drop to precisely manage thinning

- Led an effort to evaluate NIR/Vis spectroscopy to predict fruit abscission

Participated in coordinated trials in NC, NY, and WA:

1d. Develop a universal pollen tube growth model

Local and regional outreach of project findings (Objective 5)

NC STATE UNIVERSITY

CLEMSON UNIVERSITY

UNIVERSITY OF GEORGIA
1785

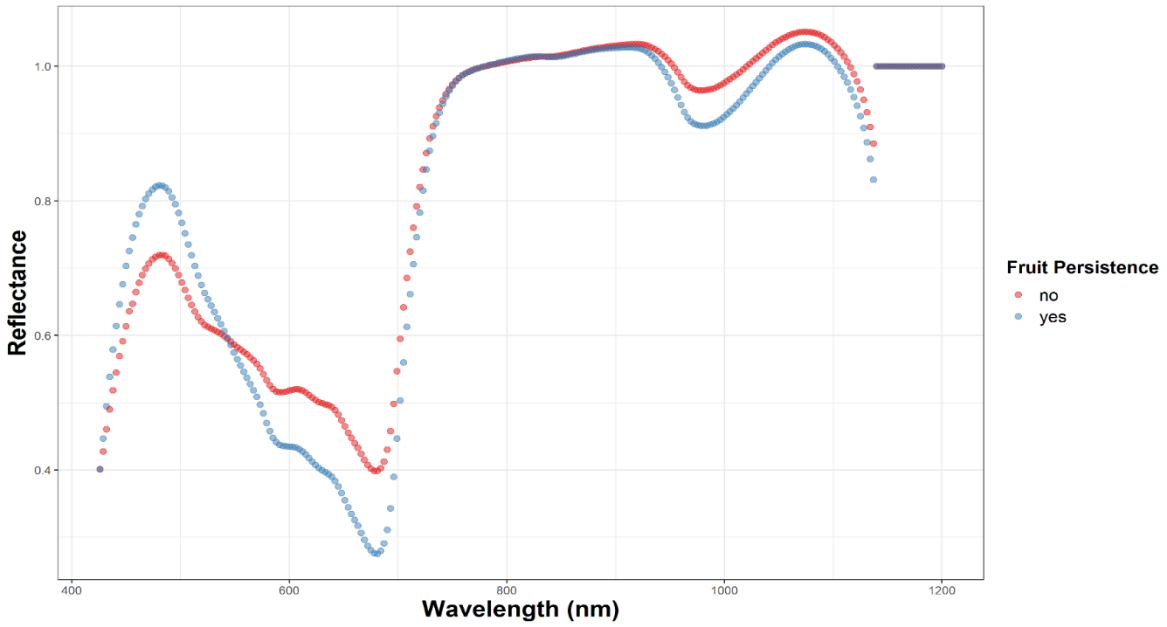
Is there an earlier/more accurate indicator of fruitlet abscission?

- Orlova et al., 2020
  - Vis/NIR spectroscopy → measures the reflectance of light
  - >80% accuracy in abscission prediction @ 6 days after thinner application
  - Suggested that **trichome density** led to differences in spectral reflectance

Key questions:

- Can an off-the-shelf portable Vis/NIR spectrometer be used to predict fruit abscission?
- Can machine learning models improve the accuracy of predictions?
- What are the key differences in abscising/persisting fruit that this instrument is detecting?

Reflectance Spectra – 3 Days After Thinner



'Honeycrisp' Vis/NIR Model Accuracy – 2021 + 2022

Days after Thinner	Overall Accuracy (%)	Predict Persisting (%)	Predict Abscising (%)
3	90	89	90
5/6	91	89	92
9	95	94	95

Key findings (published in HortScience)

- ~90% accuracy in prediction 3 days after thinner application
  - Using machine learning models
  - Consistent across a 2-year period on 'Honeycrisp'
- Multiple potential early indicators were identified:
  - fruit water content
  - total chlorophyll
  - trichome density?
- Cultivar, thinning timing, chemistry, and fruit size considerations?
  - Address this in 2023 coordinated trials with Cornell and MSU

Links to manuscripts on our work to date with this technology

Improving the Pollen Tube Growth Models for more Precise Flower Thinning

- Brent Arnoldussen (PostDoc) & Greg Peck (PI)
- Cornell University (Ithaca, NY Campus)
- Physiology Team
- Objective 1d. Develop a universal pollen tube growth model

Major Activities

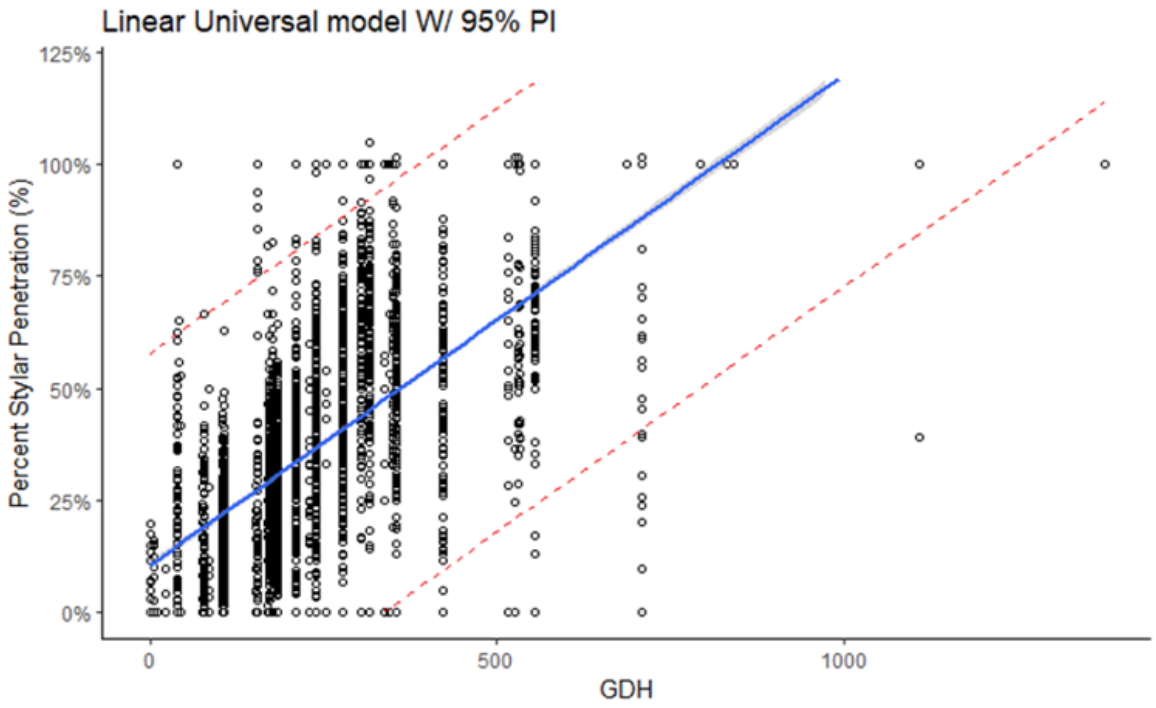
Utilize 10 years of pollen tube growth rate data to create "universal" models

Dr. Brent Arnoldussen hand-pollinating flowers

Ground truth new models in existing and new cultivars through nationwide trials

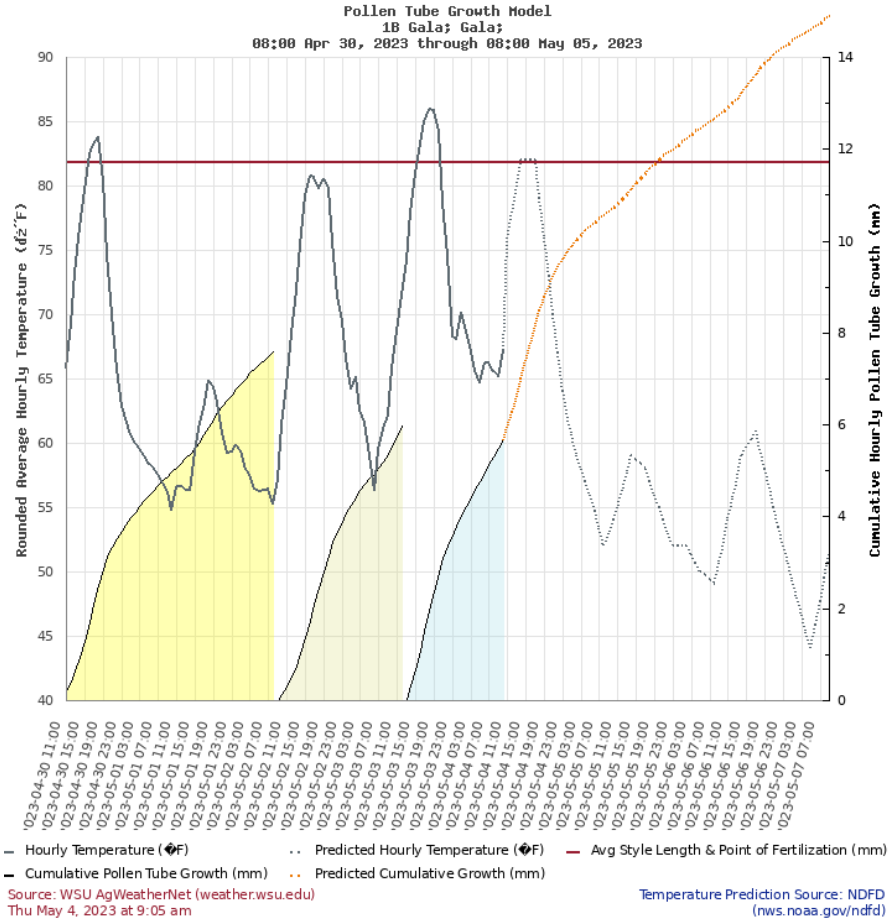
Make the most accurate and reliable models available through mesonet systems for national beta testing in commercial orchards

Key Findings



- Style length not correlated to pollen tube growth rate
- New models use Growing Degree Hours by Percent Stylar Penetration
- Several new models can accurately predict pollen tube growth regardless of cultivar
- New models do not require style length measurements
- New models provide ranges for when flower thinning chemicals can be applied

2023 WA pollen tube growth model testing



WASHINGTON TREE FRUIT RESEARCH COMMISSION

Sherif M. Sherif, PhD

Associate Professor, Tree Fruit Physiology & Molecular Biology, Virginia Tech

Alson H. Smith Jr. Agricultural Research and Extension Center, Winchester, VA

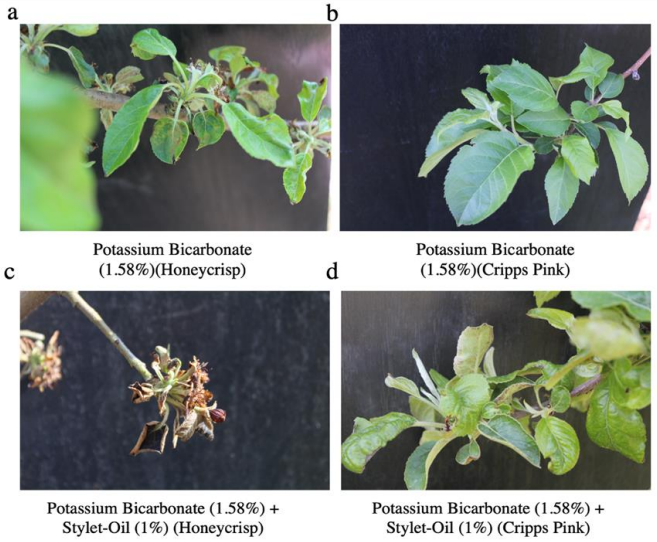
PACMan team(s) you’re serving on (Physiology-Bloom Thinning Materials and Models)

Evaluation of blossom thinning spray timing strategies in apple

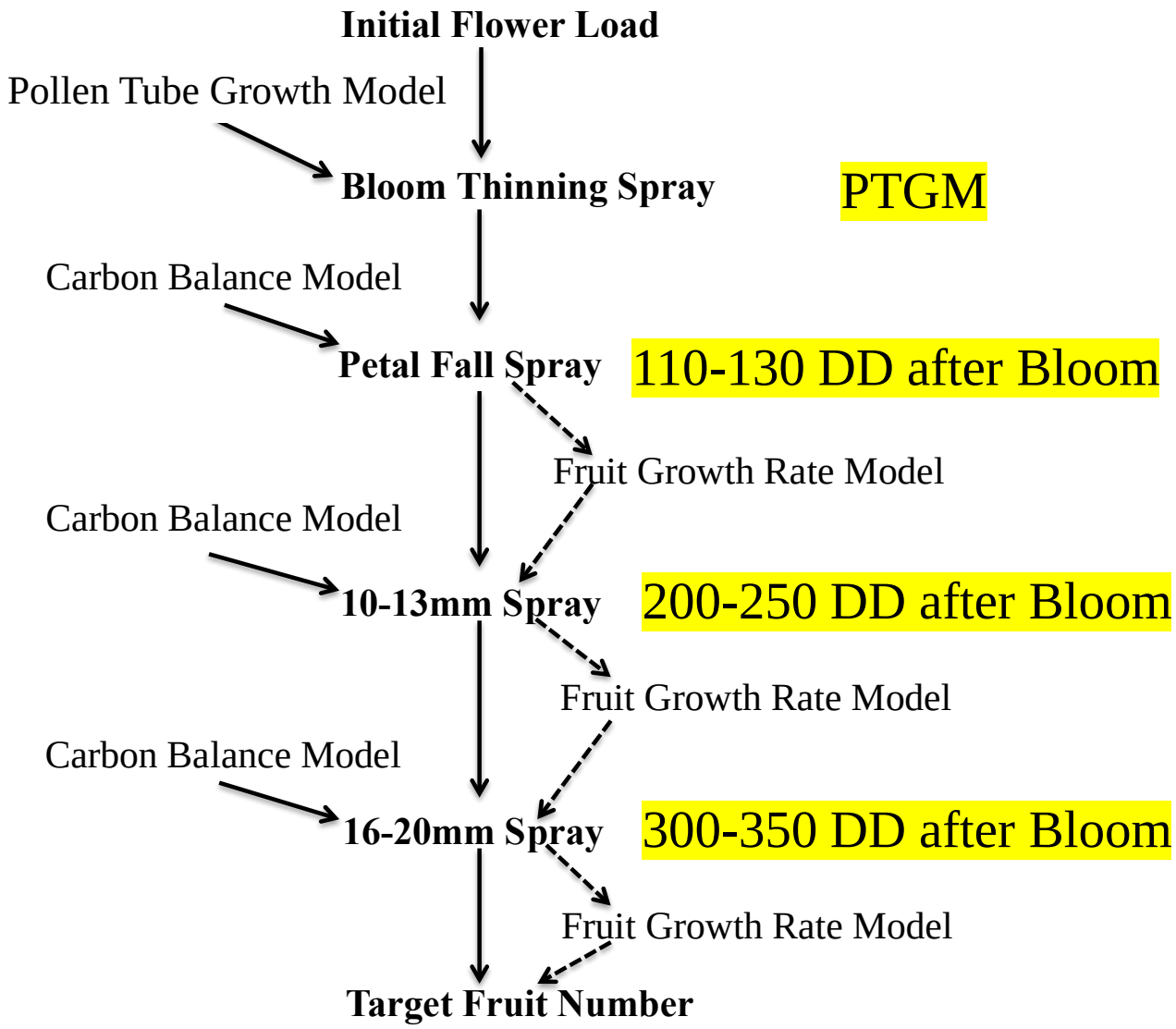
- **Research Focus**: Evaluating lime sulfur + stylet oil for apple blossom thinning in the Eastern USA (‘Gala’ apples),
- **Locations**: Winchester, Virginia, and Mills River, North Carolina.
- **Spray Timings Tested**:
  - Model-guided (PTGM).
  - Fixed intervals: First spray at 20% or 80% open bloom, second spray after 48 or 72 hours.
- **Findings**:
  - Effective Thinning: Early spraying (20% bloom + 48h) and PTGM method.
  - Ineffective: Delayed spraying (80% bloom) or extended interval (72h).
- **Safety**: No adverse effects on russet formation or leaf phytotoxicity.

Trials on Thinning Materials

- **ATS (1.5%) Treatments**:
  - With/Without Stylet-Oil (1%) effectively reduced fruit/crop density, leading to larger and heavier fruits.
- **Potassium Bicarbonate (1.5%) + Stylet-Oil (1%)**:
  - Noted damage to plant foliage and flowers.
- **LS Rates Impact**:
  - High rates (3% Lime Sulfur, 2% Stylet Oil) led to severe russeting & lower fruit packout.
  - Low rates (1% Lime Sulfur, 1% Stylet Oil) showed no significant thinning effect.
- **Optimal LS Rates**:
  - Using 1.5-2% Lime Sulfur with 2% Oil achieved effective thinning with minimal russeting.



Steps in Precision Chemical Thinning



Engineering design and robotic machine

Automate fruit, bud and flower counting using computer vision.

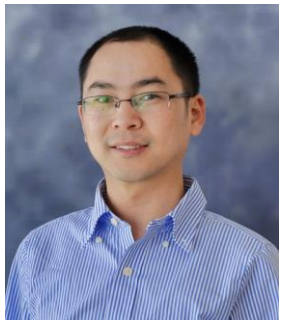
Team: Chris Layer (MOOG), Paul Heineman, Long He, Dana Choi and Yu Jiang

- **Autonomous or driven vehicle with computer vision to geo-reference each tree in the orchard and then count/measure**
- trunk area
- dormant flower buds
- floral buds at green tip to pink
- flowers at bloom
- fruitlets at 10-20mm size
- fruits at 25-35mm size
- fruits pre-harvest.

- **Convey to human workers actionable information** to assist in crop load management during dormant pruning and hand thinning.
- **Fully autonomous crop load management vehicles that can count crop load, calculate optimum crop load and then adjust crop load.**

Credit to Terence Robinson

Long He[1] and Paul Heinemann[2]
The Pennsylvania State University



[1]Fruit Research and Extension Center, Biglerville, PA
[2]University Park, PA

Engineering Team

Project objectives addressed:

Objective 2: Develop computer vision systems to count dormant buds, newly expanding buds in the spring, flowers and fruitlets to guide human workers in crop load management activities.

Objective 3: Conduct engineering design and development of robotic machines to conduct bud, flower or fruitlet thinning autonomously.

Major Activities and Trials:

- ❑ Deep learning-based models for flower bud detection in tree canopy
- ❑ Mechanical end-effector development and field test for excessive bud removal on branches
- ❑ Extension event on precision crop load management for apples

Flower Bud Detection

Silver tip Green tip Tight cluster

Bud Stages	Average Precision with different Models (%)		
	YOLOv4	YOLOv5	YOLOv7
Silver Tip	94.0	75.0	70.3
Green Tip	93.7	72.1	63.3
Tight Cluster	98.1	95.6	94.4

Flower Bud Removal (Fuji)

Bud Stages	Removal efficiency (%)	
	Scissors	Brush
Silver Tip	94.7	72.5
Green Tip	92.6	93.0
Tight Cluster	94.6	92.1

Note: this is only for end-effector test, no integration with machine vision system and robotic arm.

Extension Event – Precision Crop Load Management

PRECISION AGRICULTURE TECHNOLOGY FIELD DAY

TUESDAY, 6 JUNE 2023 ••• 10:00 A.M. – 3:00 P.M

Penn State Fruit Research and Extension Center (FREC)
290 University Drive • Biglerville • PA • 17307

You are invited to a Penn State Ag Engineering field day where the latest innovations in drone spraying technologies and early apple yield prediction systems will be in use and on display. Also featuring at this event: an inside look at the latest research being conducted in the Penn State Ag Robotics & Sensing Lab. The field day will be held in the orchards at FREC, with opportunities to interact with the experts.

9:45 a.m.	– 10:00 a.m.	**Welcome & Meet and Greet** FREC Auditorium (Parking available in the lower level lot or adjacent lawn)
10:00 a.m.	– 11:00 a.m.	**Orchard Drone Sprayer Demonstration with Accurate Ag Spraying, LLC** Drone sprayer overview: capacity, technology, and configuration Sprayer in flight & coverage observations
11:00 a.m.	– 12:00 p.m.	**Vivid-X Vision System for Early Apple Yield Prediction with Vivid Machines, Inc.** Vivid-X system technologies and operation Data display and analytical report interpretation
12:00 p.m.	– 1:00 p.m.	**Lunch**
1:00 p.m.	– 3:00 p.m.	**Research Project Live Demonstrations** An introduction of robotic crop load management (Long He) Precision blossom thinning demonstration (Xinyong Mu) Robotic green fruit thinning demonstration (Mogen Hussain)

The demonstrations are free and open to the public. A boxed lunch may be purchased for a modest $15 fee, which covers the cost of the meal and incidentals like coffee. Lunch selections include chips, drinks, a cookie, and one of the following sandwich options:

- ham & provolone
- turkey & provolone
- tuna fish
- roast beef & provolone
- original Italian
- veggie

To register for this event, contact **Kristy Loper at (717) 677-6116 or kkl5535@psu.edu.** If purchasing a boxed lunch, your sandwich selection must be made by **4:00 p.m. on Thursday, June 1st.** Payment for the lunch may be made via cash or check and will be collected at the door.

For additional inquiries about this meeting, contact Dr. Daniel Weber (daniel.weber@psu.edu) or Dr. Long He (luh378@psu.edu).

Precision Apple Cropload MANagement
USDA-NIFA-SCRI SMYP 2020-51181-32197

This publication is available in alternative media on request.

The Pennsylvania State University encourages qualified persons with disabilities to participate in its programs and activities. If you anticipate needing any type of accommodations or have questions about the physical access provided, please contact Penn State Extension, (717) 677-8116, in advance of your participation or visit

Note: this extension event was supported by the NIFA-SCRI project - Precision Crop Load Management for Apples.

Economic and sociological impacts

Evaluate the economics of precision crop load management and of automating crop load management

Team: Miguel Gomez, Rod Farrow and Terence Robinson, MOOG business group

- Evaluate the economics of precision crop load management in comparison to traditional thinning strategy
- Evaluate various business models for implementing the automation technology

Credit to Terence Robinson

Miguel Gomez & Mauricio Guerra Funes
Cornell University
Ithaca, NY

Workstream: Economics (Objective 4)

Objective: Evaluation of the economic and sociologic impact of adopting precision crop load management for sustainable apple production

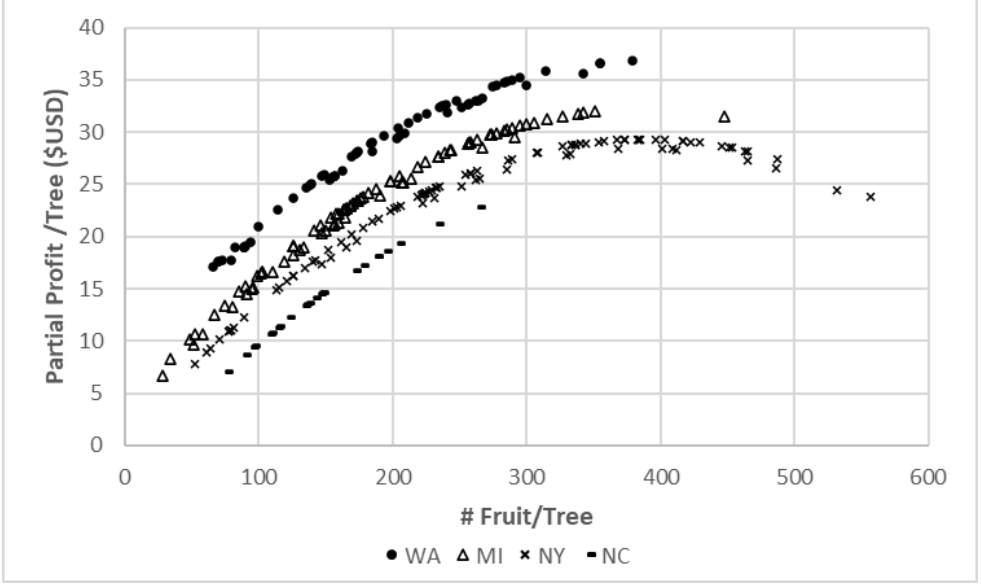
Major Activities:

1. **Develop a profit function based on experimental data that predicts profit as a function of fruit load.**
2. **Develop a phone-based Survey + Choice Experiment to address Grower Technology Adoption Insights**

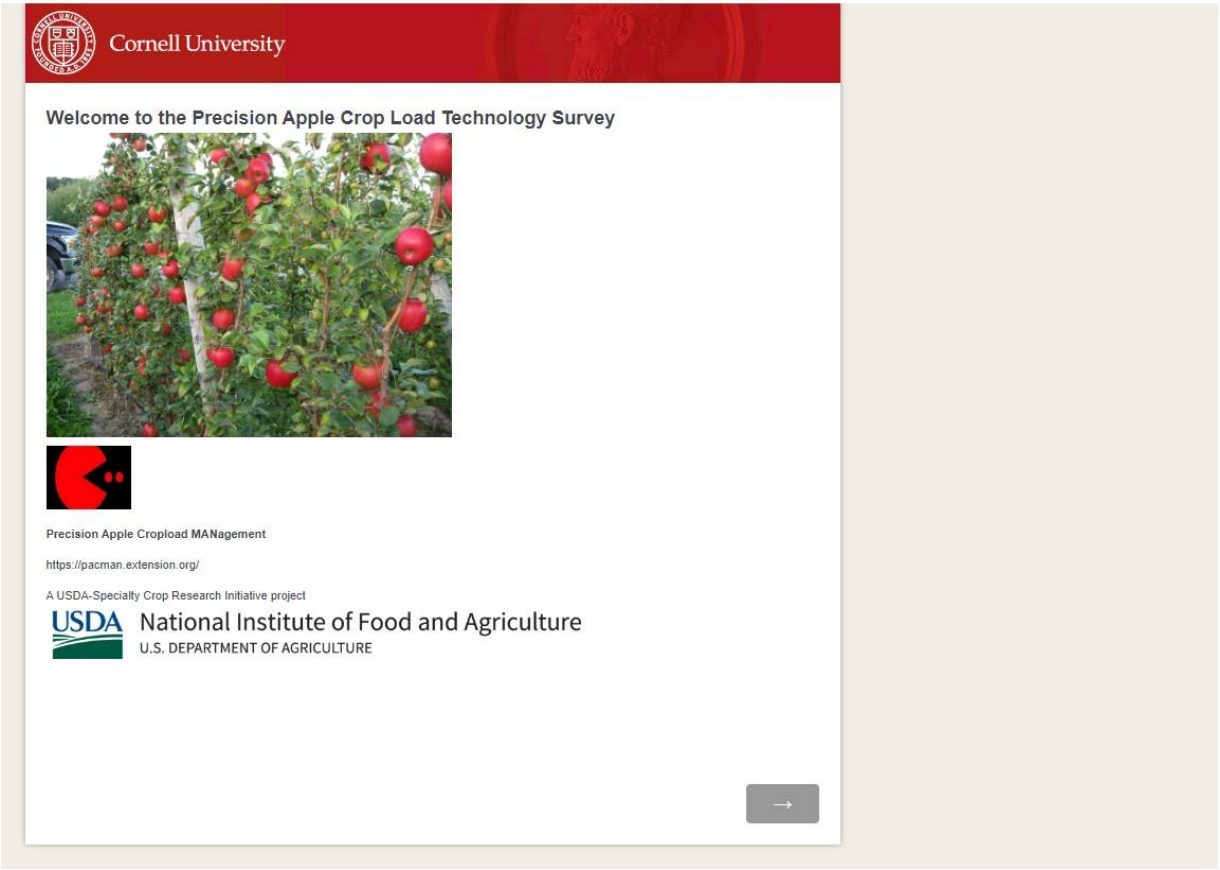
Key Findings

- As expected, we do see differences among states, Washington operates at a higher profit range
- The relationship between cropload and profit is curvilinear and concave, indicating a maximum profit range exists. Based on 2 years of harvest data, that point is 387 fruit per tree (Gala).
- Implication: per every unit of fruit we increase per tree we can expect to see an increase in profit of $0.148, up to a maximum of 387 fruit per tree. We can also expect a profit decrease rate of $-0.148 if we keep increasing fruit per tree beyond 387 units.

State comparison for the relationship between Fruit/tree and partial profit



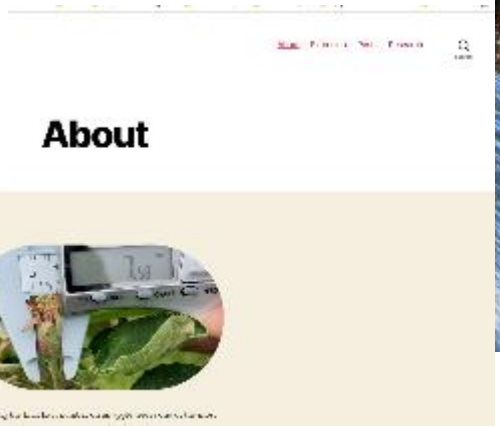
Choice Experiment & Survey in execution at 2023 NW Hort Expo



Outreach efforts to increase the adoption of precision crop load management

1. Extension Team: Jon Clements, Karen Lewis, Tory Schmidt, Mario Miranda Sazo, Craig Kahlke, Phil Schwallier and Anna Wallis
2. Stakeholder advisory committee of growers and researchers.
3. New website: https://pacman.extension.org/
4. Field demonstrations

Precision Apple Cropload MANagement



PACMAN Extension Team

Jon Clements – UMass Amherst

Karen Lewis (Washington State University) and Tory Schmidt (WTFRC – not pictured)

Mario Miranda, Craig Kahlke, Michael Basedow
and Yu Jiang (not pictured) – Cornell University

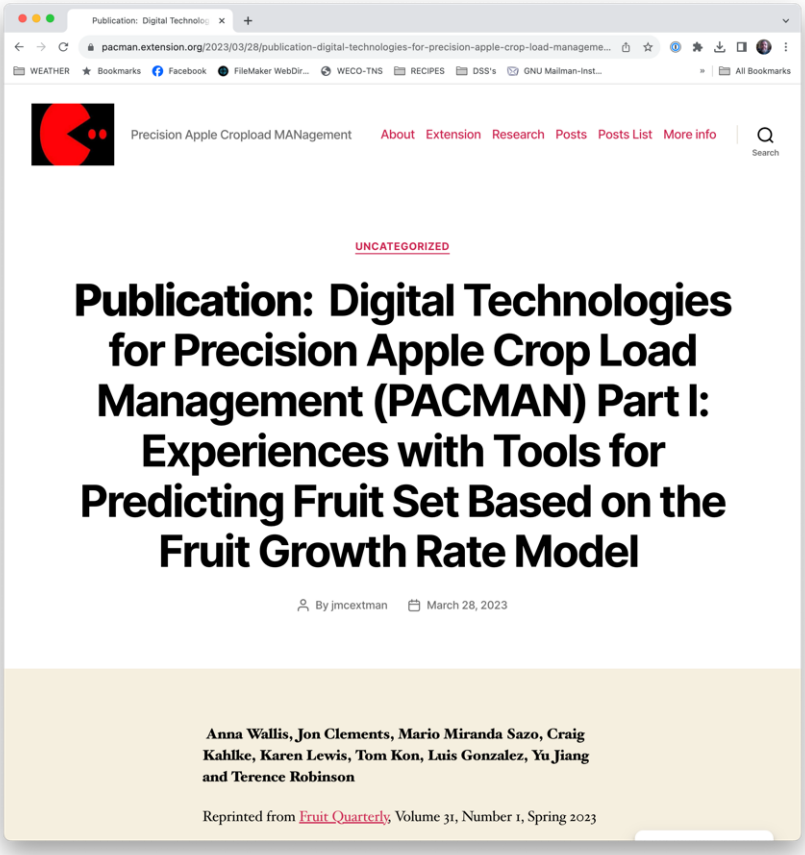
Long He and Daniel Weber – Pennsylvania State University

Anna Wallis and Phil Schwallier – Michigan State University (not pictured)

PACMAN Extension Team - Objectives

- Conduct in-field demonstrations, organize winter grower meetings, and summer field tours/field days
- Develop and disseminate information via Extension publications, trade journals and web-based resources
- Conduct collaborative on-farm trials with leading growers and crop consultants to demonstrate the economic impact of precisely managing crop load and to expedite industry adoption

pacman.extension.org - Posts



Digital Technologies for Precision Apple Crop Load Management (PACMAN) Part I: Experiences with Tools for Predicting Fruit Set Based on the Fruit Growth Rate Model

Anna Wallis[1], Jon Clements[2], Mario Miranda Sazo[3], Craig Kahlke[3], Karen Lewis[4], Tom Kon[5], Luis Gonzalez[6], Yu Jiang[6] and Terence Robinson[6]

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Keywords: apple, fruit size, chemical thinning, fruit growth rate model, computer vision

This research was supported by the New York Apple Research and Development Program and the Michigan Apple Committee

We are working with several companies to evaluate methods to streamline the use of the fruit growth rate model to manage crop load more precisely. In this article we report on our evaluations of a smart phone camera system of measuring fruit size distribution to determine fruit set after a thinning spray that was developed by Pometa company. We also evaluated their method of yield estimation.

Decades of work have demonstrated that PACMAN (Precision Apple Crop load MANagement) is an extremely effective method for successfully managing crop load. Effective crop load management has a direct effect on yield, quality, size, and return bloom, and ultimately an orchard's profitability. The process involves three management practices: 1) pruning, 2) chemical thinning, and 3) hand thinning, which have been described in detail in previous articles (Robinson et al., 2014a,b). We are continuing to refine recommendations for PACMAN, on a regional basis, as part of a 4-year national project, funded by the USDA-NIFA SCRI. This article is a follow-up to our previous article summarizing earlier work on this project (Robinson et al., 2022).

A key element of precision crop load management is the fruit growth rate model (Greene et al., 2013). Despite the successes of many research and pilot projects, commercial adoption of the model has been slow. The model requires tedious hand counting and measuring of fruitlets during the thinning window, which some growers view as time prohibitive. Even after successfully using the approach and seeing the payoff, many farmers report that they simply do not have the time during this busy period of the season.

As part of the PACMAN SCRI project, we are working to alleviate this challenge by developing robotic and digital technologies that offer practical implementation of PACMAN. In addition, in the past few years, a multitude of companies have emerged from the private sector with tools to accomplish these tasks. In 2021 and 2022, our team began identifying, advising, and evaluating these companies and their technologies on commercial and research orchards. Efforts to date have included field days, demonstrations, and data collection to verify information provided by these technologies. This will be an ongoing process, as the landscape of digital and robotic technologies is changing rapidly.

In 2022, we conducted trials to evaluate the accuracy of several technologies for predicting fruit set following a chemical thinning spray. The objective was to evaluate and compare three methods of predicting fruit set – Malusim app (Malusim), Ferri Fruit Growth Model app (Ferri), and Farm Vision scans (Farm Vision) – all of which are based on the fruitlet growth rate model. Farm Vision was a company founded by Patrick Plonski, University of Minnesota graduate, offering a technology for counting and measuring fruitlets to make fruit set and harvest estimations. In January 2023, Farm Vision was purchased by Meter Group and renamed Pometa. Pometa is referred to here as Farm Vision, reflecting the name at the time the work was conducted.

The trials presented here represent a ground truthing effort of one of the new AI technologies, as compared to the previously validated hand measurement methods of fruit set predictions. The results and experiences from the 2022 season will be used to guide further evaluations of more technologies in the future.

For the latest updates, please visit the PACMAN website: pacman.extension.org

Methods

Trials were carried out in 11 orchard blocks in Massachusetts, Michigan, New York, and North Carolina (Table 1). In each location, fruit set following a chemical thinning spray was evaluated according to the protocol of predicting fruit set using the fruitlet growth

Figure 1. Scanning of an orchard using Farm Vision equipment, including cellphone, RTK GPS, and battery pack, affixed to stabilizing device (3 ft pole). This equipment will no longer be used in 2023. Harvest scans were conducted with two people using an ATV. One person drove the ATV and a cell phone operator scanned full rows (both sides) as shown in the cell phone screen. *Photo:* Mario Miranda Sazo.

Digital Technologies for Precision Crop Load Management

Automation of geo-referenced fruit, bud and flower counting using computer vision:

- trunk diameter
- dormant flower buds
- floral buds at green tip to pink
- flowers at bloom
- fruitlets at 10-20mm size
- fruits at 25-35mm size
- fruits pre-harvest

Rovers with cameras, drones, or hand-held phones used to count buds and fruitlets to produce heat maps to guide thinning

- MOOG
- Green Atlas
- Vivid Machines
- Outfield
- Aurea/Munckhof

- Farm Vision/Pometa
- Fruit Scout
- Orchard Robotics
- Agerpix

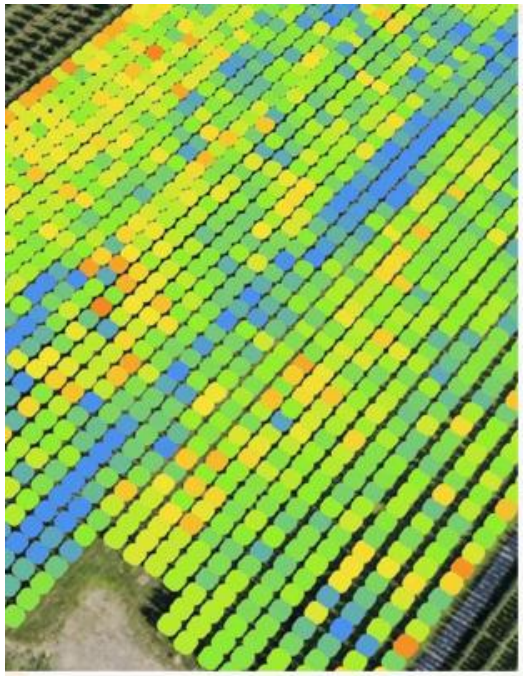
Using Cell phone camera to count and measure fruitlet diameter

Fruit Scout – uses individual fruit pictures to measure fruit growth rate and estimate fruit set after a thinning spray

Pometa/Farm Vision – uses a cell phone video of several trees to identify and measure fruitlet diameter and fruit set after a thinning spray

Orchard Robotics Inc.

Detect and Size Fruit



Analyze & View Data

PACMan physiology field plots - Orondo, WA

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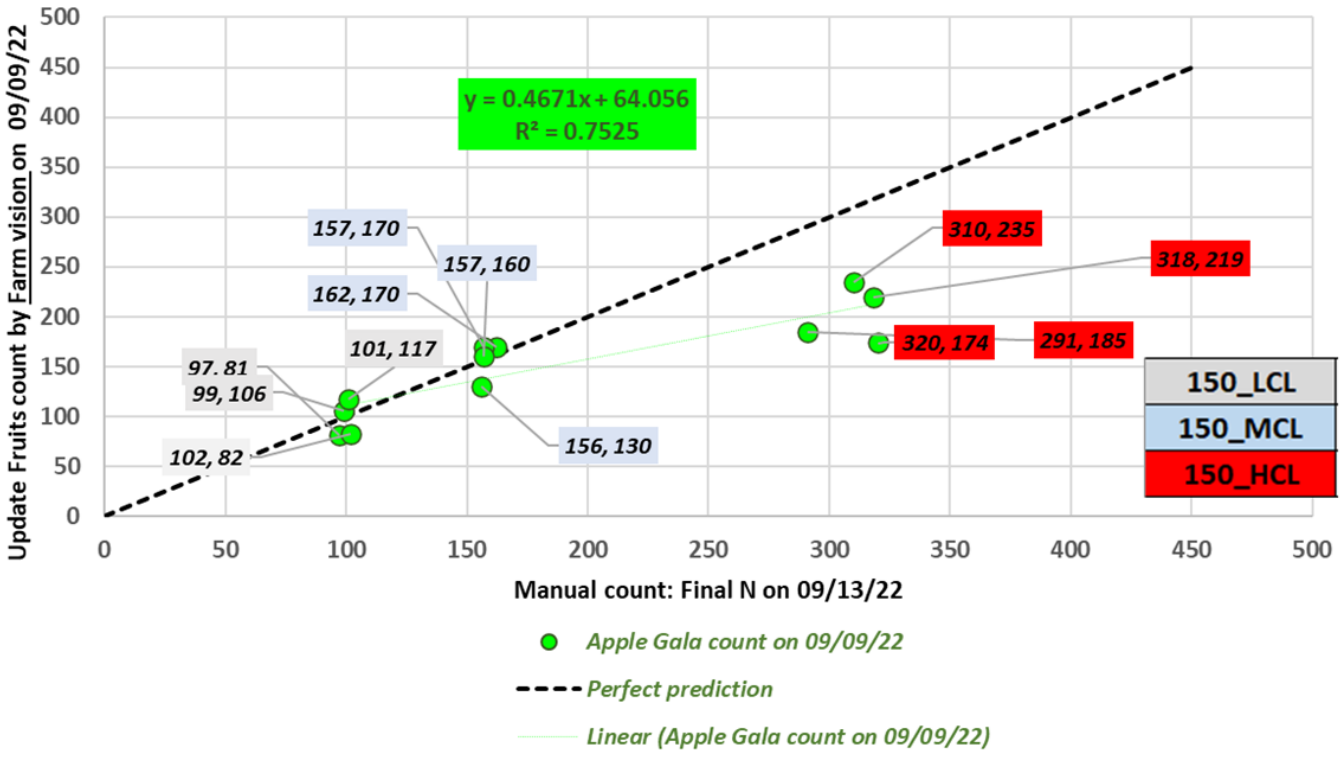
Vision systems evaluated

2022: Farm Vision

2023: Pometa, Green Atlas

2022 fruit scans: Farm Vision vs. hand counts



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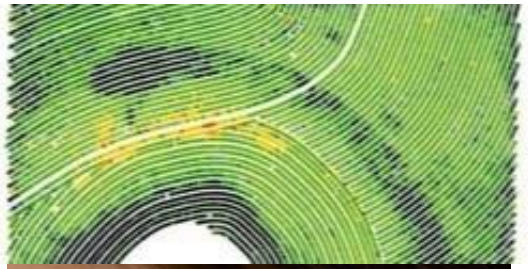
How to transform information from automated counting into actionable information

1. Maps of variability provided to orchard owner/manager can help managers address crop load and variability across orchard.

2. Conveying actionable information to human workers would allow tree specific crop load management during dormant pruning and hand thinning.

3. Smart sprayers linked with geo-referenced information about flower bud, flower cluster, or fruitlet data would allow variable rate spraying.

4. Individual tree information on crop load and yield will allow more precise management of fertilization with variable rate fertilizer machines.



Is precision crop load management worth the effort

- There will be a cost in time, money and effort.
- However, the returns for the extra effort can be very large.

With Gala – mostly small apples return $10,000 per acre
– optimum crop load return $15,000 per acre
With Honeycrisp – mostly small apples returns $20,000 per acre
– optimum crop load return $35,000 per ha

THANKS!!

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www.treefruitresearch.com
www.treefruit.wsu.edu
www.pacman.extension.org

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