Editorial

Editorial: Telling our Story

The continuing education of a fruit grower never ceases to amaze me. As a young man growing up on a diversified grain, fruit and vegetable farm in Albion, NY, I had a romanticized idea of farming. It was FARMING. It was the cultivation of the land, the care of and attentiveness to the crops. Working on equipment, working with a team to get things done when the sun was shining. It was the gratification after spending years of hard work and tradition to harvest a quality crop, providing for the family and for the community. My, how the times have changed.

I still like to think of myself as a young man, but time flies when you're having fun. Over the years, the focus of my learning has changed from the day-to-day tasks of farming to the management of running a farm business. I believe I share in a lot of the challenges of fellow farmers in my generation. Gone are the stress-free days of listening to the local radio station playlist from 1986 on a daily repeat while driving back and forth in a tractor. Now days are spent attending to the matters that keep those tractor wheels turning.

My father recently retired and is able to spend his time now enjoying hobbies and making memories with grandkids. I remember a conversation with him not too long ago when he expressed to me, "If I had to contend with all the challenges that now exist to grow fruit, I'm not sure I would have been a fruit grower all those years".

I hear that quote in my head on almost a daily basis and can't help but think of the challenges my kids will have in front of them someday, should they choose to become fruit growers. It seems these days, my time is mostly spent preparing, anticipating and worrying about the next great challenge that will be set in front of not just my operation, but the New York State fruit industry as a whole. Largely, these challenges are things that seem out of my control. As farmers, we're somewhat used to the challenges of the weather here in New York. That alone has become increasingly unpredictable and extreme recently. But we also face the challenges of labor laws, government regulations, GAP audits, changing markets, and COVID, to name a few. And that is where the continuing education a fruit grower comes in.

Some of those things, we as growers, can impact, or at least we potentially could. I didn't realize as a young man, blowing the speakers out of a tractor to the tune of AC/DC's *Shook Me All Night Long* for the 4th time in a day, the impact and importance of being involved with organizations that help us have a voice. That changed the day I had the fortunate opportunity to shadow the late Paul Baker on a trip to Washington DC to meet with legislators. One of the most important things he taught me that day was "If you are not speaking with the people that have a direct impact on your business, someone else is." It blew my mind to realize that not everyone is on the side of the farmer or understands the challenges that farmers face to produce the very food they consume on a daily basis.

My education now focuses on understanding the challenges that I can help to control or mitigate. I focus my efforts on gaining knowledge of the challenges at hand, having honest conversations with the people pushing those challenges, and helping them to understand the impact that they will have. The importance of hearing these things directly from the farmer, cannot be overstated. That day in Washington, Paul taught me another lesson. I was intimidated to be there, what could I, a simple farmer from Albion who dragged out his one and only suit from the closet (previously reserved solely for weddings and the occasional visit to church), have to offer when it came to proposed legislation? Paul simply said, "Just tell them your story and how this will directly affect YOU." It was really that simple.

Folks in Albany and Washington don't get to hear how their actions will affect the people and our businesses without us telling them. But I can assure you, someone IS telling them how it will affect us. I realized that day, that I was much better qualified to tell my story, than to have someone tell it for me.

A few years back, I had the opportunity to plan an agriculture day for the county leadership program in my area. It surprised me greatly throughout the day, how little understanding there was of how food is actually produced and all that goes into it. It was a great day to be able to have different industry professionals come and explain to the group the different facets of farming. The group had wonderful questions and walked away with a much greater awareness of what the daily life of a farmer really entails. The unique challenge presented by running an agricultural business was not lost on them and they were truly grateful for the time, patience and honesty of the presenters. A lot of great conversation and being able to directly ask their questions to the people right here in their local community really drove home that these problems, and adversities were not something far off and disconnected from the group's own daily lives and access to quality, healthy food. It was another great example of how far separated people have become in understanding what it takes to feed them, and it was a realization for me that education works both ways. The chance to have open discussions about what their questions and concerns were, really opened my eyes to how much we can improve communication to the general public and to the leaders in our local communities.

And that is the message I would convey to the fruit industry of New York. Not only is it important for you and your business to be involved and supporting the organizations that represent you to the people that craft legislation, but it is essential even in your own local community and government. It will make a difference and is more successful than lying in bed at night, fretting about what challenge may come next or how it will impact you and your employees' livelihood. The New York Horticulture Society is devoted to telling our story as New York fruit growers. The same is true of the New York Farm Bureau, New York Apple Association and a host of others. I urge you to become involved, whether by reaching out to current board members and expressing interest of joining in on legislative visits, volunteering for future board openings or serving on committees.

Bret Kast
Kast Farms Inc.
President of the NY State Horticultural Society

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New York State Horticultural Society

President Brett Kast, Kast Farms, Inc.
2911 Densmore Rd., Albion, NY 14411
P: (585) 589-9557
C: (585) 507-0400
E: Brett.Kast@gmail.com

Vice President Elizabeth Malchoff
6064 Birchwood Lane, Sodus, NY 14551
P: (315) 812-1871
C: (315) 879-0516
E: emadison1234@gmail.com

Treasurer/Sec. Ted Furber, Cherry Lawn Farms
8130 Glover Road, Sodus, NY 14551
P: (315) 483-8529
C: (315) 573-4046
E: atfurber@yahoo.com

Interim Executive Director Jim Bittner, Bittner Singer Orchards
6620 Appleton, NY 14008
C: (716) 417-3173
E: jim@bittnersingerorchards.com

OfficeAdmin Karen Wilson, NYSHS
635 W. North St., Geneva, NY 14456
P: (315) 521-0852
E: wilsonk36@hotmail.com

Cornell Director Dr. Terence Robinson, NYSAES
Hedrick Hall, Room 125
Geneva, NY 14456
P: (315) 787-2227
C: (315) 521-0435
E: tlr1@cornell.edu

Director Randy Hart, Hart Apple Farms, LLC
2301 Rt. 22, Peru, NY 12972
C: (518) 524-5366
E: randy.hart1@gmail.com

Director Joel Crist, Crist Bros. Orchards
65 Crist Lane, Walden, NY 12586
P: (845) 778-7424
C: (845) 629-0761
E: joel@cristapples.com

Director Richard Breslawski,
Charles Breslawski Farm
501 Priem Rd., Hamlin, NY 14464
C: (585) 831-0643
E: richih1256@hotmail.com

Director Eric Brown, Orchard Dale Fruit Co.
1287 Oak Orchard River Rd.
Waterport, NY 14571
P: (585) 682-5569
C: (585) 764-0004
E: egb@orcharddale.com

Director Jenna Mulbury, Northern Orchard
537 Union Rd., Peru, NY 12972
P: (518) 643-9718
C: (518) 645-6500
E: jenna@northernorchard.com

Director Jacob Wafler, Wafler Nursery
C: (585) 749-9274
E: jwafler@waflernursery.com

Director Chris Whipple
C: (585) 260-0351
E: cwhipple@wnyapples.com

Director OPEN

Cover Photo: Tall Spindle Honeycrisp on G.969 rootstock have grown to the top wire by the end of the third year and yielded 400 bu/acre with no bitter pit.

New York State Agriculture and Markets
Apple Research & Development Program

Interim Chairman Ted Furber, Cherry Lawn Farms
8099 Glover Rd., Sodus, NY 14551
C: 315-573-4046
P: 315-483-9221
E: atfurber@yahoo.com

Grower Rep -Western Kevin Bittner, Singer Farms
8776 Coleman Rd., Barker, NY 14012
P: 716-795-3030
W: 716-778-7330
E: Kevin@bittnersingerorchards.com

Grower Rep -Western Robert Brown, Orchard Dale Fruit Co.
1287 Oak Orchard River Rd.
Waterport, NY 14571
P: (585) 721-7723
E: rrb3@orcharddale.com

Grower Rep -Eastern Peter Ten Eyck, Indian Ladder Farms
342 Altamont-Voorheesville Road
Altamont, NY 12009
C: 518-698-6258
P: 518-765-2956
E: Peter@indianladderfarms.com

Grower Rep -Eastern Joy Crist, Crist Brothers Orchard Inc.
5 Crist Ln, Walden, NY 12586
W: 845-778-7424
E: joy@cristapples.com

Grower Rep -Eastern Charles Hurd , Hurds Family Farm
90 Hurds Rd., Clintondale, NY 12515
W: 845-389-6609
E: information@hurdsfamilyfarm.com

Processor Rep -Western Jonathan Oakes
Leonard Oakes Estate Winery
10609 Ridge Rd., Medina, NY 14103
P: 585-318-4418
E: jonathanGOakes@hotmail.com

Handler Rep Chip Bailey, KC Bailey Orchards
3765 Shepherd Rd.
Williamson, NY 14589-9408
C: 315-587-5030
E: kcbnyusa@rochester.rr.com

Department Representative William Shattuck, NYS Dept. of Ag & Markets
10B Airline Drive, Albany, NY 12235
P: 518-485-7306
E: william.shattuck@agriculture.ny.gov

New York State Berry Growers Association

Chair Liz Madison, Empire Drip Supply
6064 Birchwood Lane,
Sodus, NY 14551
P: 315-879-0516
emadison1234@gmail.com

Treasurer Chuck Mead, Mead Orchards LLC
15 Scism Rd., Tivoli, NY 12583
P: 845-756-5641
C: 845-389-0731
chuck@meadorchards.com

Executive Director Jim Bittner, Bittner Singer Orchards
6620 Appleton, NY 14008
C: (716) 417-3173
E: jim@bittnersingerorchards.com

Directors Bruce Carson, Carson's Farm
2328 Reed Rd., Bergen, NY 14416
P: 585-507-2691
pasawaypapa@gmail.com

Dave Duda
Duda's Blues Family Farm and Winery
9582 N. Sisson Rd., Machias, NY 14101
P: 716-353-4303
dd4bbwine@gmail.com

Tony Emmi, Emmi Farms
1572 S. Ivy Trail, Baldwinsville, NY 13027
P: 315-374-3577
emmifarms@aol.com

Amy MacHamer, Hurd Orchards
17260 Ridge Rd., Holley, NY 14470
P: 585-638-8838
amy.machamer@gmail.com

Nolan Reeves
1100 Reeves Road, Baldwinsville
NY, 13027
P: 315-289-5743
E: nreeves88@gmail.com

Andy Underhill, Underhill Farm
4868 Batavia Alba Townline Rd.
Batavia, NY 14020
P: 585--813-4488
underhillandrewd@gmail.com

Jake Samascott, Samascott Orchards, LLC
5 Sunset Ave., Kinderhook, NY 12106
518-330-5649
jake@samascott.com

Michigan Apples Board Members

Chair Mike Dietrich
Conklin, Michigan

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Chris Alpers
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Executive Director Diane Smith, Michigan Apple Committee
13750 S. Sedona Pkwy, Suite 3
Laning, MI. 48906
O: 800.456.2753
M: 517.282.2044

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Editor Terence Robinson
Dept. of Horticulture
New York State Agricultural Experiment Station
Geneva, New York 14456-0462
P: 315-787-2227
tlr1@cornell.edu

Subscriptions, Advertising and Production Karen Wilson
NYSHS
635 W. North St., Geneva, NY 14456
P: 315-521-0852
wilsonk36@hotmail.com

Design Chris Cooley
Cooley Creative LLC
Rochester, NY
P: 315-263-5187
chris@cooleycreativellc.com

Characterizing Cold Hardiness Dynamics in Apple Rootstocks

Jason P Londo, Luis Gonzalez, and Terence L. Robinson

Horticulture Section: School of Integrative Plant Science, Cornell AgriTech Campus, Cornell University, Geneva, NY 14456 USA

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Apples use temperature cues during winter to adjust their cold hardiness and avoid freeze damage and as climate changes, these cues become less reliable. Freeze damage weakens the tree and can result in tree collapse when other stresses occur, such as from drought or pests. We are using electrolyte leakage, a measurement of cellular damage, to characterize the season long cold hardiness profile for rootstock genotypes in order to identify climate resilient germplasm for New York growers.

Apples, like all temperate woody fruit crops, survive the freezing temperatures of winter by entering dormancy and acquiring cold hardiness. Using decreasing temperature and photoperiod changes as cues in the fall, apples begin the process of dormancy by reducing metabolism and undergoing controlled dehydration to reduce the volume of free and freezable water in the plant tissues (Palonen and Buszard 1997). Once dormant, apples are typically considered quite hardy, able to survive very cold midwinter temperatures (< -25°C). The seasonal pattern of cold hardiness is described as a U-shaped curve, with three separate phases. Acclimation, or the gaining of cold hardiness, is the process in late fall and early winter where trees gain greater and greater ability to resist freezing damage. Midwinter (December-February) typically represents the deepest cold hardiness. The final phase is deacclimation, or the loss of cold hardiness. During this phase, trees become much more responsive to warming conditions and lose cold hardiness rapidly. Changes in climate stability, namely increased fall freezes and late winter false spring events have demonstrated weak points in apple winter physiology which results in repeated evidence of cold damage and tree collapse.

Cold hardiness in apple has been studied over the last 100 years, initially simply measured as survivability under field conditions. This method is useful for contrasting cultivars but requires consistently stressful winter conditions and is often only representative of regional responses. In recent years much of the effort to assess cold hardiness has moved to using detached stem assays in the lab. With these methods, stems or twigs are placed into programmable freezers and slowly frozen. Samples are extracted from the freezer at specific temperature steps and assessed for damage. The most common methods include oxidative browning and electrolyte leakage (EL) assays. For oxidative browning, stem segments are visually rated on a phenotypic scale and this scale of damage is the plotted as a dose response curve against temperature (Moran et al 2011, 2018, 2021). Similarly, EL evaluates the relative level of cellular leakage that occurs during freezing. By measuring the difference in conductivity of control and freeze treatments, an estimate of freeze damage can be determined (Kovaleski and Grossman, 2021). These two metrics often correlate well with each other, and with tree survivability under field conditions.

This report details the results of the first year of our ongoing study to examine the season-long dynamics of cold hardiness in apple rootstocks and scions. The objective of this research is to determine the acclimation, midwinter, and deacclimation profiles for important rootstock genotypes. This data will enable growers to select more adapted rootstocks for future orchards with a specific eye toward rootstocks that are less at risk from the different types of freeze conditions that can occur across New York's apple production regions.

Materials and Methods

Cold hardiness assessments were conducted monthly, starting in November 2021, and concluding in March 2022. Twenty-one rootstock genotypes (G.11, G.202, G.210, G.213, G.214, G.222, G.257, G.41, G.814, G.87, G.890, G.935, G.890, CG.2034, CG.3067, CG.4004, CG.6589, CG.8189, B.9, M.9, and Ottawa 3) and four scion genotypes (Empire, Gala, Honey Crisp, Snapdragon) were characterized. At each collection timepoint, 6-10 cuttings of 1 year-old stems were collected from each genotype, totaling ~152cm (60in) of dormant wood tissue. Cuttings were processed at the lab into 2.2cm (1 inch) segments, randomized and then dispersed into plastic falcon tubes for either electrolyte leakage or oxidative browning experiments. For electrolyte leakage, stem segments

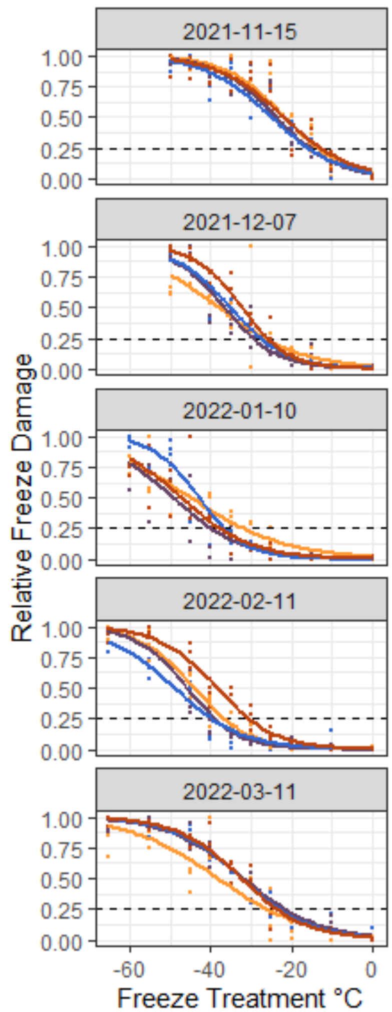

Figure 1. Electrolyte leakage damage curves for four genotypes in this study from November-March. Dashed line indicates the LT25 value and demonstrates the shifting cold hardiness across winter, and between genotypes.

were placed in 1 ml of dH_20 and sorted into 3 replicate 15ml falcon tubes for each freeze temperature. For oxidative leakage, 3 replicate stem segments were placed within a single 50ml falcon tube with a moistened square of paper napkin, to help maintain humidity without saturating the cuttings. Nine freeze temperature treatments and a control 4°C treatment was evaluated at each monthly time point. Using a large programmable freezer (Tenney TC30) temperature treatment followed a 5°C step difference from -10°C to -60°C, depending on each collection month. Tubes were taken from room temperature to -5°C for 2 hours to allow extracellular water and moistened paper to freeze. Then temperatures were reduced at -5°C/hour, pausing at each treatment temperature for 1 hour. At the end of each treatment hold, the freezer was briskly opened, tubes extracted, and then closed again to allow subsequent freeze temperature treatments to occur. After freeze exposure, tubes were allowed to thaw to room temperature. Nine mls of dH_20 was added to electrolyte leakage tubes, followed by overnight shaking to help release cellular electrolytes. The following day, conductivity was measured from all tubes using a handheld conductivity meter (Vernier, CON-BTA). Samples were then refrozen in a -70°C freezer to produce maximal freeze damage. After 8 hours of maximal freeze, samples were thawed at room temperature, mixed overnight, and remeasured for final conductivity. Tubes and samples to be used for oxidative browning studies were left at room temperature for 1 week. One mid-stem cross section was imaged for each of the three replicate segments for each temperature treatment.

Cold hardiness was assessed as relative tissue damage as measured by changes in conductivity in the dH_20. Conductivity measurements were compared between genotypes using a logistic function to describe the impact of freeze damage on total electrolytes leaked into the dH_20 solution. EL measures from the 4°C control tubes were used to standardize each genotype's representative zero damage level, while measures taken from the -70°C second freeze was used to determine each genotype's maximal potential freeze damage. EL measures from the treatment temperatures were thus normalized to percent of maximal damage on a 0-100% scale. Logistic curves were determined using the drm function (drc library, R programming) and relative lethal temperature values were computed. The freeze treatments that resulted in 25% (LT25), 50% (LT50), and 75% (LT75) levels of freeze damage were used to contrast different genotypes throughout winter (Figure 2). Lethal temperature values were then compared with visual ratings of oxidative damage to try and assess the critical temperatures responsible for cellular damage.

Results and Discussion

Cold hardiness was evaluated at all five monthly timepoints for all genotypes except G.11, M.9, Honey Crisp, and Snapdragon, which were evaluated for December-March. All genotypes exhibited the expected U-shaped curve of cold hardiness throughout winter, with gentle decrease in cold hardiness during early winter, maximal hardiness in mid-winter, and rapid deacclimation in late winter. (Figure 2). Relative cold hardiness across the season changed for the different genotypes, with clear evidence of some genotypes exhibiting better early season cold hardiness while others had more resistant cold hardiness in late winter (Table 1). While LT50 values are commonly used to compare cold hardiness, for apple the freeze temperature values recorded are likely an overestimate of biologically relevant cold hardiness. We prefer to be more conservative in our evaluation and use the LT25 value as a point of comparison instead.

In November, LT25 values ranged from the least cold hardy rootstock CG.4004, at -10.2°C, to the most cold hardy G.257, at -21.5°C. LT25 values ranged from -20°C to -40.2°C (B.9 vs. G.87) in December, from -27.9°C to -42.7°C (G.935 vs. G.969) in January, from -30.8°C to -42.6°C (Gala vs. G.213) in February, and from -19.7°C to -32°C (CG.2034 vs. Empire) in March (Table 1). Cold hardiness was dynamic throughout the winter. In general, during early winter, G.257, G.87, G.213, and G.890 had the greatest cold hardiness while B.9, CG.8189, CG.6589, and CG.4004 were the least cold hardy (Table 1).

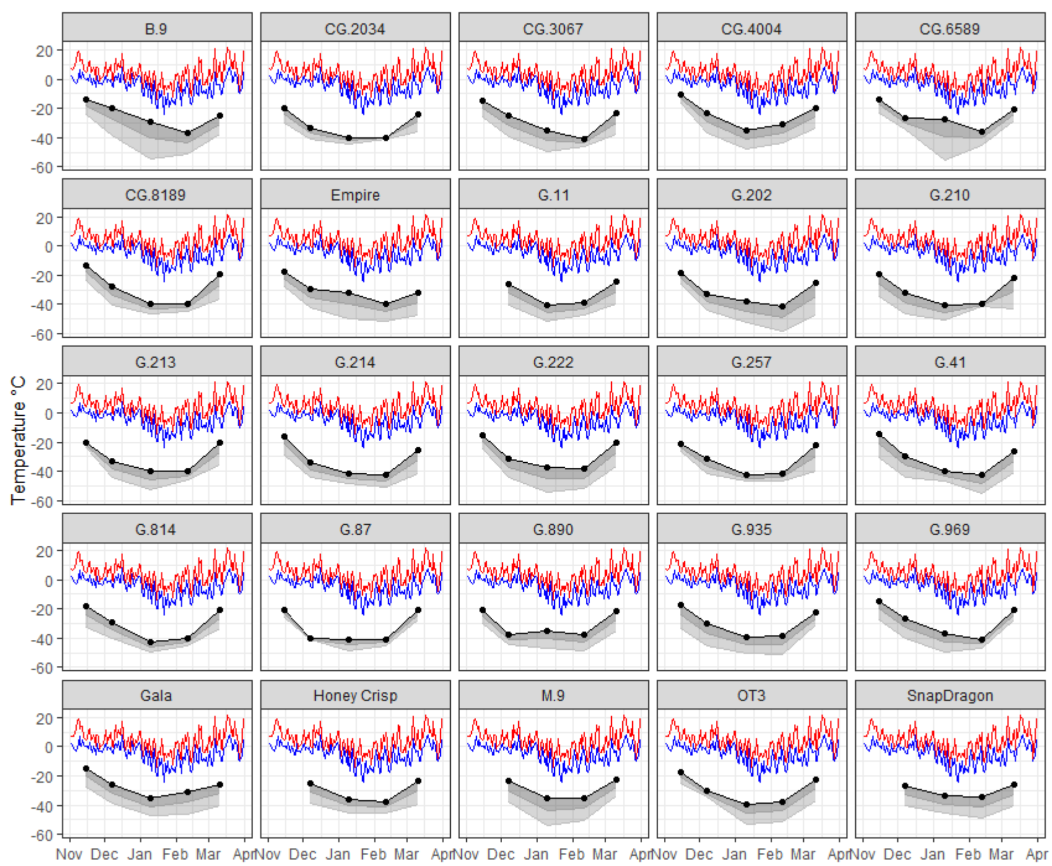

Figure 2. Electrolyte leakage damage curves for all genotypes in this study. Red and blue lines denote field daily max and min temperatures °C. Black line and points indicate the change LT25 value for each genotype. Gray ribbons denote the values for the LT50 and LT75 levels of damage.

Acclimation: The greatest gains in cold hardiness occurred during the acclimation phase between November-December, and December-January. Interestingly, there were roughly two groups of genotypes that had different cold acclimation profiles. One group demonstrated moderate gains between each of the early winter months, demonstrating a slow acclimation response. Examples of this phenotype are G.969, CG.6589, and CG.3067, and G.222 which gained roughly equal amounts of cold hardiness in each monthly transition. In contrast, G.87, G.890, G.214, and G.935 gained nearly all their maximum cold hardiness in the first monthly transition from November to December. The result demonstrates that this later group of genotypes are well adapted to a rapid gain of maximal cold hardiness in early winter and may represent ideal germplasm for regions with a rapid decrease in fall temperatures (Table 1).

Midwinter: The coldest portion of the winter in New York typically occurs between the middle of January and the middle of February. Results of this first year of study demonstrated impressive cold hardiness in all tested genotypes but in general, the rootstocks were more cold hardy than the few scions tested. In particular, G.969, G.222, G.213, were the most cold hardy, with G.890, G.41, and G.257 also being quite hardy. The least cold hardy rootstocks included M.9, B.9, and G.935, as well as the four scions (Table 1).

Deacclimation: Our dataset only allowed for a single monthly timepoint to be examined for deacclimation. Comparing field cold hardiness in March versus February gives us a comprehensive view of how fast the genotypes lost cold hardiness as spring temperatures rose. Here a very interesting pattern was observed. Deacclimation rate differences resulted in a swapping of cold hardiness phenotypes between rootstocks and scions. During the deacclimation phase, previously very cold hardy genotypes such as G.210, G.214, and G.969 rapidly lost cold hardiness whereas Gala, Empire, and Snapdragon showed impressive deacclimation resistance (Table 1). This result demonstrates the potential for some potentially problematic interactions between different rootstock-scion pairs. If the rootstock tissues are losing cold hardiness faster and earlier than scion genotypes in the spring, they would be more susceptible to rapid changes in temperature. Additionally, the potential for desynchronization between the vasculature tissues could lead to poor growth responses in the scion. Not all rootstocks were rapid deacclimators. Among the most resistant were B.9, M.9, G.890, and G.814. Of these four, only G.890 demonstrated good midwinter hardiness and rapid acclimation phenotypes. Taken together, G.890 appears to have performed well in this first year of the study. The responses of these genotypes are currently being tested in the second year of the study to determine if these patterns are resilient to annual variation.

Conclusions

Cold hardiness and the changes that occur during winter are dynamic aspects of apple tree physiology. This preliminary report identifies several key findings as it relates to apple rootstock cold hardiness. Clear differences between rapid acclimating and moderate acclimating rootstocks were observed, suggesting that some genotypes are better equipped for climates where rapid fall freezes at the end of the growing season are common (e.g., G.214, G.87, G. 890). Most rootstocks reached a comparable midwinter cold hardiness except for B.9, G.935, and G.814 which were least hardy overall, as well as the scion cultivars tested. These genotypes still achieved deep enough cold hardiness that they likely wouldn't suffer from midwinter freezes. However, given their relatively shallow cold hardiness curve, these genotypes may be at higher risk of midwinter false springs and rapid freezes. Finally, an interesting divergence in deacclimation response was noted, with scion genotypes being much less responsive to warming spring temperatures than rootstock genotypes. Several of the rootstock genotypes with preferred rapid acclimation patterns, also had rapid deacclimation response. These patterns require further years of study to validate the patterns seen here, but the data suggests that there is the need to include cold hardiness, acclimation, and deacclimation responses in rootstock choice metrics when planting future orchards.

Table 1. Cold hardiness differences across the winter between genotypes. LT25 (°C) values show temperature at which 25% of total damage is expected to occur (Left Panel). Change in cold hardiness (Right Panel) shows the gain (-) or loss (+) of cold hardiness throughout winter. Percent deac column indicates the percent of maximal midwinter cold hardiness (February) lost due to spring deacclimation in March and illustrates differences between fast deacclimating and slow deacclimating genotypes.

	Cold Hardiness LT25					Change in cold hardiness				
	Nov	Dec	Jan	Feb	Mar	ΔDec	ΔJan	ΔFeb	ΔMar	% deac
B.9	-14.0	-20.0	-29.6	-36.6	-24.8	-6.0	-9.6	-7.0	11.8	32.3
G.11	-	-25.8	-40.3	-39.2	-24.1	-	-14.5	1.0	15.1	38.5
G.202	-18.6	-32.6	-40.4	-39.8	-22.2	-14.0	-7.8	0.5	17.6	44.3
G.210	-19.2	-31.6	-40.1	-40.2	-20.3	-12.4	-8.5	0.0	19.8	49.3
G.213	-20.5	-33.2	-41.6	-42.6	-25.3	-12.7	-8.4	-1.0	17.4	40.8
G.214	-16.0	-34.3	-37.6	-38.6	-20.1	-18.3	-3.3	-1.0	18.5	48.0
G.222	-14.9	-31.2	-42.5	-41.4	-22.4	-16.3	-11.3	1.1	19.0	45.8
G.257	-21.5	-31.6	-35.1	-40.7	-23.6	-10.2	-3.5	-5.6	17.1	42.0
G.41	-14.6	-29.3	-38.3	-41.1	-24.9	-14.8	-8.9	-2.8	16.2	39.3
G.814	-18.1	-28.7	-35.4	-31.0	-19.7	-10.6	-6.7	4.4	11.2	36.3
G.87	-20.6	-40.2	-40.4	-40.1	-24.1	-19.6	-0.2	0.2	16.1	40.0
G.890	-20.4	-37.7	-39.8	-42.1	-26.3	-17.3	-2.1	-2.3	15.8	37.6
G.935	-17.7	-30.1	-27.9	-36.2	-20.9	-12.4	2.2	-8.3	15.3	42.2
G.969	-14.6	-26.9	-42.7	-40.3	-21.0	-12.3	-15.8	2.4	19.2	47.7
GC.2034	-19.7	-33.1	-39.9	-39.4	-19.7	-13.5	-6.7	0.5	19.7	50.0
GC.3067	-14.8	-25.2	-41.1	-40.8	-20.8	-10.3	-15.9	0.3	20.0	49.0
GC.4004	-10.2	-23.2	-34.8	-37.7	-21.8	-13.0	-11.6	-3.0	15.9	42.1
GC.6589	-13.5	-26.5	-39.6	-38.3	-22.7	-12.9	-13.1	1.3	15.7	40.9
GC.8189	-13.7	-27.9	-36.8	-40.7	-21.0	-14.2	-8.9	-3.9	19.8	48.5
M.9	-	-23.4	-35.0	-35.0	-22.5	-	-11.7	0.0	12.5	35.7
OT3	-17.5	-30.5	-39.4	-37.5	-22.3	-13.0	-8.9	1.9	15.2	40.5
Gala	-14.8	-26.2	-35.7	-30.8	-25.7	-11.4	-9.6	4.9	5.2	16.8
Empire	-18.0	-29.7	-31.8	-39.3	-32.2	-11.8	-2.1	-7.5	7.2	18.2
Honey Crisp	-	-25.0	-36.0	-37.8	-23.3	-	-11.0	-1.8	14.6	38.5
SnapDragon	-	-27.0	-33.8	-34.9	-25.8	-	-6.8	-1.1	9.1	26.2

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Jason Londo is a research and extension professor of fruit crop physiology at Cornell's AgriTech Campus in Geneva who leads Cornell's program in fruit crop adaption to climate change. **Luis Gonzalez** is a post-doctoral research associate who works with **Terence Robinson** who is a research and extension professor at Cornell's AgriTech campus in Geneva who leads Cornell's program in high-density orchard systems, rootstocks, irrigation, and plant growth regulators.

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]

[1]Michigan State University Extension, Grand Rapids, MI | [2]University of Massachusetts, Amherst, MA | [3]Cornell Cooperative Extension, Lake Ontario Fruit Program, Newark and Lockport, NY | [4]Washington State University Extension, Quincy, WA | [5]Dept. of Horticulture, North Carolina State University, Mills River, NC | [6]Horticulture Section, School of Integrative Plant Science, Cornell AgriTech, Geneva, NY

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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.

Table 1. Characteristics of commercial orchard blocks in Massachusetts, Michigan, and North Carolina for evaluation of fruit growth rate model prediction tools.

#	Block	Rootstock	System	Spacing	Target Crop
1	UMO 'Gala' (MA)	M.9	Tall Spindle	3x12'	60
2	UMO 'Fuji' (MA)	M.9	Tall Spindle	3x12'	80
3	UMO 'Honeycrisp' (MA)	G.11	Tall Spindle	3x12'	60
4	TFF 'Gala' (MA)	G.41	Tall Spindle	3x12'	100
5	TFF 'Honeycrisp' (MA)	G.41	Tall Spindle	3x12'	75
6	Vinton 'Honeycrisp' (MI)	Nic.29	Super Spindle	2x11'	150
7	Vinton 'Gala' (MI)	G.11	Super Spindle	2x11'	200
8	Thome 'Fuji' (MI)	B.9337	Vertical Axe	5x12'	90
9	Thome 'Gala' (MI)	Nic.29	Tall Spindle	4x12'	250
10	Cornell 'Honeycrisp' (NY)	M.9	Tall Spindle	3x11'	140
11	NCSU 'Gala' (NC)	M.9	Tall Spindle	3x13'	130

rate model" available at https://ag.umass.edu/fruit/fact-sheets/hrt-recipe-predicting-fruit-set-using-fruitlet-growth-rate-model. Five representative trees were selected per block, the number of flower clusters were counted on each tree (for potential fruit set), and then fourteen (MA) or fifteen (MI, NC, NY) flower clusters were tagged on each of the five trees for data collection. Fruitlets were measured using calipers beginning at approximately 6-7 mm fruitlet size and then at 4–7-day intervals; for Michigan, New York, and North Carolina, this corresponded with approximately 3 and 7 days after the first thinning application was made. Final fruit set was counted after June drop and/or at harvest.

In all four states (MA, MI, NY, NC), the Malusim app was evaluated using hand caliper measurements which were then entered into the Malusim app to generate predictions of fruit set. In MA, the Ferri app was also evaluated using the same trees and the same caliper measurements, entered into this app. In addition to the caliper measurements of fruitlets as described in the online protocol, the Farm Vision scanning technology was evaluated at all three states, using the company's directions and equipment: smart phone, stereo video camera, and enhanced GPS location identifier. The scans with the Farm Vision systems were carried out using the same trees where manual fruitlet measurements were being made. A final Farm Vision scan was also conducted in MA to determine the final fruit set in August. Because the objective was to evaluate and compare predicted fruit set using the fruitlet growth rate model, the chemical thinner applications are noted, but not further discussed. The specific details of each location are:

Massachusetts: The trials evaluating all three methods (Malusim, Ferri, and Farm Vision) were conducted at two orchards – the UMass Orchard in Belchertown and Tougas Family Farm in Northborough, using three varieties – 'Gala,' 'Fuji' (UMass Orchard only), and 'Honeycrisp.' At the UMass Orchard (UMO), five adjacent 'Gala' and 'Fuji' trees in two orchard blocks with uniform bloom were selected. In the 'Honeycrisp' block, five individual, non-adjacent trees were selected in another block. Measurements were taken when fruitlets were approx. 6-7 mm in size on 23-May and continuing subsequently on 26-May, 29-May, and lastly on 3-June, 2022. Although chemical thinners were applied at the UMass Orchard, the details are not available.

At Tougas Family Farm (TFF) we evaluated 'Gala' and 'Honeycrisp.' Fruitlet measurement dates were 21-May, 25-May, and 27-May, 2022. Chemical thinner applications were made to the 'Gala' at bloom on 12-May of Promalin + AmidThin, and 20-May of 6-BA. Chemical thinner applications made to the 'Honeycrisp' included NAA (10 ppm) at bloom on 12-May, NAA (10 ppm) + carbaryl (1 pt) on 18-May, and NAA (5 ppm) on 27-May.

Michigan: The Malusim app and Farm Vision technology were evaluated in four mature, bearing, high-density, commercial orchard blocks in Sparta, MI. These included a 'Buckeye Gala'/G.11 and 'Honeycrisp'/Nic.29 planting at Schwallier's Country Basket (Vinton) and a 'Aztec Fuji'/M.9337 and 'Gale Gala'/Nic.29 planting at Bernard Thome Orchards (Thome). At the Vinton orchard, thinning applications were made on May 23 to 'Gala' of 6-BA (150 ppm) + carbaryl (1 pt), and to 'Honeycrisp' of NAA (10 ppm). At the Thome orchard, a thinning application was made on May 28. Fruitlet caliper measurements and scans were made on 23-May, 27-May, and 31-May at Vinton, and 28-May, 30-May, and 3-June at Thome. A final fruitlet count was made after June drop on 27-June.

New York: In New York, the Malusim app and Farm Vision technology were evaluated in a mature 'Honeycrisp'/M.9 block at the Cornell AgriTech Campus in Geneva. A thinning application was made on 21-May at approximately 9.5 mm fruitlet diameter, of 6-BA (150 ppm) + carbaryl (1 pt). Caliper measurements and scans were conducted on 21-May, 23-May, 27-May, and 31-May. Final fruit counts were conducted at harvest on 20-Sept.

North Carolina: In North Carolina, the Malusim app and Farm Vision technology were evaluated in a mature tall spindle 'Ultima Gala'/M.9 planting at the Mountain Horticultural Crops Research and Extension Center, Mills River NC. Flower cluster counts were recorded at bloom. Thinning application of 6-BA (75 ppm) + carbaryl (1 pt) was made on 2-May, and subsequent caliper measurements and scans were made on 5-May, 9-May, 11-May, 15-May, and 18-May. Final fruit count was recorded after June drop.

Results and Discussion

Results from individual trials are presented in Table 2 and Figure 2 (A-J), and a summary of percent accuracy for all of the trials are presented in Table 3 and Figure 3. Scans and caliper measurements were taken on four or five dates in all trials. In all cases, predicted fruit set is based on the change in fruitlet size between two subsequent measurements. Therefore, no prediction is made or presented on the first measurement date. In addition, these model and algorithms are optimized for predicting fruit set after taking measurements 3 and 7 days after a thinning application. Therefore, the first predicted fruit set estimate were made after the 7-day or second date for measurements and or scanning following a thinning treatment

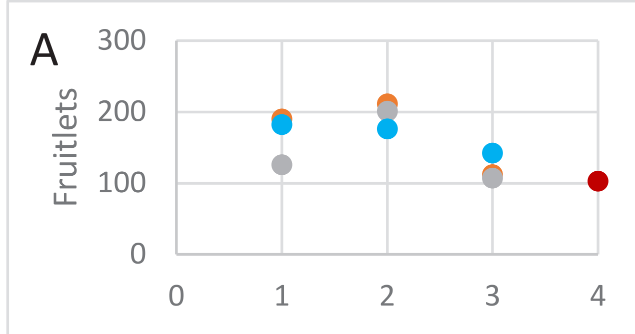
In general, both the Malusim and the Ferri apps, predicted fruit set reasonably well in comparison to the actual fruit set, but not exactly equal. Compared to final fruit set counted by hand after June drop or near harvest, Malusim predictions (made approx. 7 days after thinning application or 6-7 mm fruitlet size) ranged from 43-352% of actual fruit set with median 137%, and Ferri predictions ranged from 107-258% with median 161%. Both apps were most frequently within 20-30% accuracy.

Some discrepancy is to be expected, as the exact implementation of the fruit growth model in each app may be slightly different. In addition, both apps use some form of error correction, where measurements are discarded if deemed to be out of "range." For example, in Malusim when the growth rate is more than 1.5 mm per day or is an outlier (more than 2 standard deviations of all growth rates) it is discarded. Also, some human error is expected. It is recommended to have the same person measure fruitlets on each measurement date. Some of the error in MA measurements may be attributed to different people doing the measurements on different dates (for example when

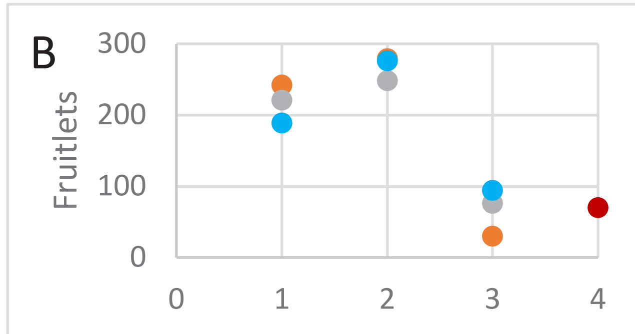
Table 2 (A-J). Actual and predicted fruit set (per tree) using Malusim, Ferri, or Farm Vision technologies for orchard blocks in MA, MI, NY, and NC in 2022.

A. UMO Gala (MA)					
		1	2	3	4
Actual Count					103
Malusim	predicted[z] %	190	211	112	
	of actual[y]	(184%)	(205%)	(109%)	
Ferri	predicted %	126	201	107	
	of actual	122%	195%	104%	
Farm Vision	predicted %	182	176	142	
	of actual	177%	171%	138%	

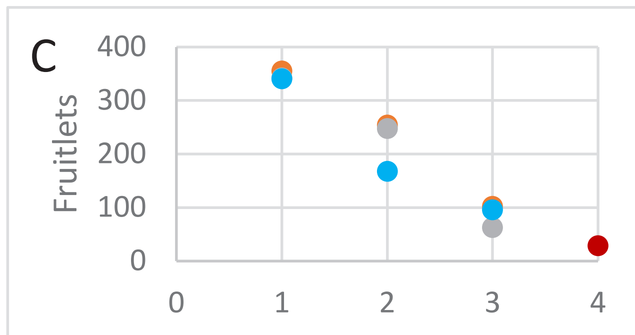
[z]predicted fruit set per tree | [y]percent accuracy = predicted fruit set / actual fruit set



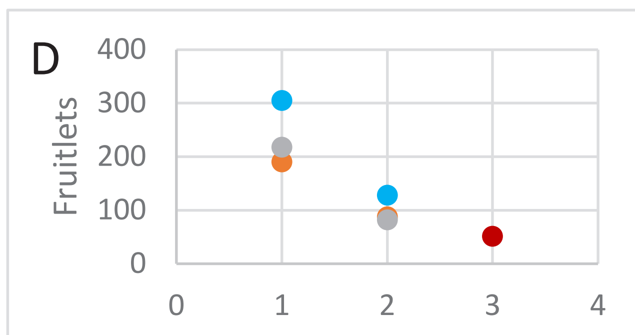
B. UMO Fuji (MA)					
		1	2	3	4
Actual Count					70
Malusim	predicted	242	279	30	
	% of actual	346%	399%	43%	
Ferri	predicted	221	248	76	
	% of actual	316%	354%	109%	
Farm Vision	predicted	189	276	94	
	% of actual	270%	394%	134%	



C. UMO Honeycrisp (MA)					
		1	2	3	4
Actual Count					29
Malusim	predicted	355	254	102	
	% of actual	1224%	876%	352%	
Ferri	predicted	342	248	63	
	% of actual	1179%	855%	217%	
Farm Vision	predicted	341	168	96	
	% of actual	1176%	579%	331%	



D. TFF Gala (MA)				
		1	2	3
Actual Count				51
Malusim	predicted	190	88	
	% of actual	373%	173%	
Ferri	predicted	218	82	
	% of actual	427%	161%	
Farm Vision	predicted	305	128	
	% of actual	598%	251%	



E. Vinton Honeycrisp (MI)					
		20-May	27-May	31-May	27-Jun
Actual Count		822			148
Malusim	predicted		206	80	
	% of actual		139%	54%	
Farm Vision	predicted		276	128	
	% of actual		186%	86%	

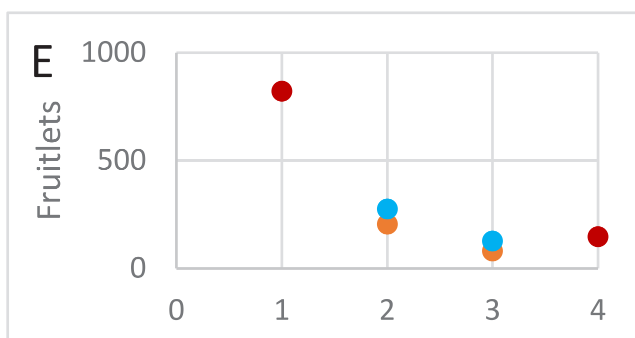
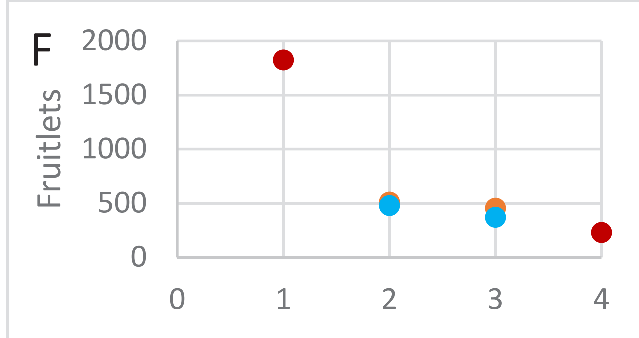
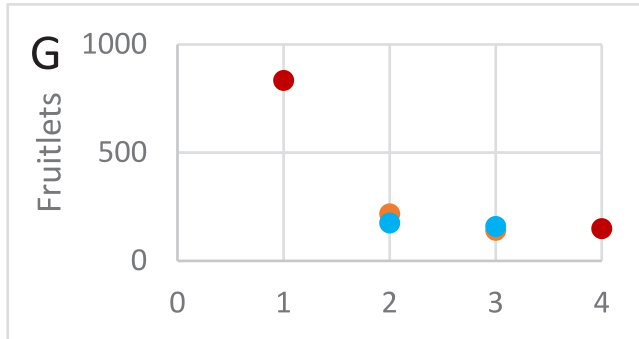


Figure 2 (A-J). Actual and predicted fruit set (per tree) using Malusim, Ferri, or Farm Vision technologies for orchard blocks in MA, MI, NY, and NC in 2022.

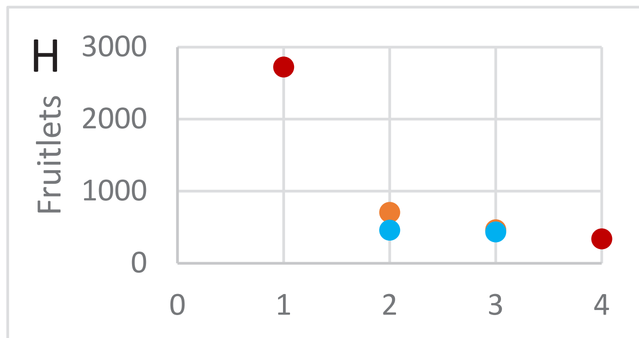
F. Vinton Gala (MI)					
		20-May	27-May	31-May	27-Jun
Actual Count		1824			229
Malusim	predicted		511	456	
	% of actual		223%	199%	
Farm Vision	predicted		479	372	
	% of actual		209%	162%	



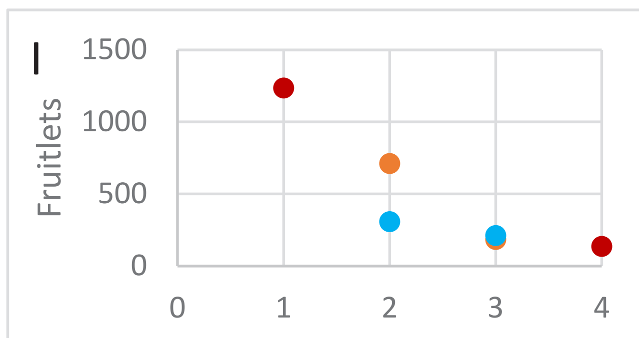
G. Thome Fuji (MI)					
		20-May	30-May	3-Jun	27-Jun
Actual Count		833			150
Malusim	predicted		217	142	
	% of actual		145%	95%	
Farm Vision	predicted		175	159	
	% of actual		117%	106%	



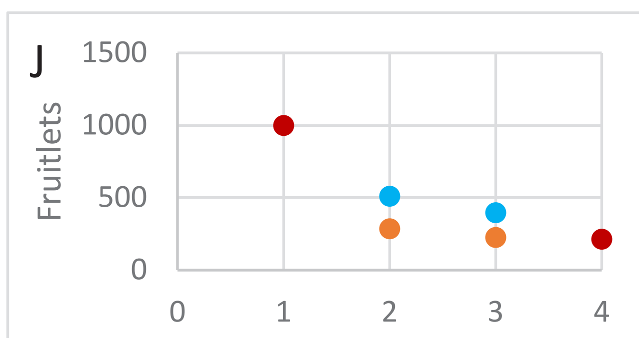
G. Thome Fuji (MI)					
		20-May	30-May	3-Jun	27-Jun
Actual Count		2722			337
Malusim	predicted		708	463	
	% of actual		210%	137%	
Farm Vision	predicted		460	435	
	% of actual		136%	129%	



I. Cornell AgriTech Honeycrisp (NY)					
		21-May	23-May	27-May	27-Oct
Actual Count		1235			135
Malusim	predicted		712	186	
	% of actual		527%	138%	
Farm Vision	predicted		308	212	
	% of actual		228%	157%	



J. NCSU Gala (NC)					
			9-May	11-May	
Actual Count		998			213
Malusim	predicted		287	226	
	% of actual		135%	106%	
Farm Vision	predicted		510	396	
	% of actual		239%	186%	



the predicted fruit set actually increased (UMO 'Gala' and 'Fuji'). In conclusion, the two apps were comparable in their results, they gave similar predictions of fruit set, and were fairly accurate in relation to the actual fruit set.

With the Farm Vision technology there was also variability in prediction of final fruit set compared to other models, and in accuracy compared to actual fruit set. Compared to the final fruit set counted after June drop or near harvest, the final prediction of fruit set by Farm Vision ranged from 86-331% of final fruit set with median 152%. Like the Malusim and Ferri apps, most frequently predictions were within 20-30% of actual fruit set.

A few blocks appear to have been outliers, with gross over or under predictions compared to actual fruit set. In the UMO 'Fuji' block, Malusim greatly under predicted fruit set (43% of actual), but Ferri and Farm Vision methods did not (109% and 134% respectively). In the Vinton 'Honeycrisp' block, Malusim under predicted fruit set (54%) but Farm Vision only slightly under predicted (86%). This was most likely due to the placement of flagged clusters in these trees. A large portion of the clusters were in the lower part of the canopy, which experienced some over thinning compared to the tops of the trees. This is an excellent illustration of the importance of flagging clusters throughout the canopy in order to reflect thinning and fruit set of the entire tree. In the UMO 'Honeycrisp' block, all three methods significantly over predicted fruit set (Malusim 352%, Ferri 217%, Farm Vision 331%). This indicates that more thinning occurred after the measurements and scans were complete and predictions made. Additional thinners may have been applied to this block, or other environmental conditions may have imposed additional stress that resulted in further fruitlet abscission (i.e., carbohydrate deficits induced by low sunlight and excessive heat).

When comparing the Farm Vision to the Malusim and Ferri apps, all three showed similar trends in fruit set predictions, but Malusim and Ferri were much more similar than Farm Vision. This is mostly as expected. We might consider it a bit like comparing "apples to oranges". The Malusim and Ferri apps use a similar method of data collection, measuring by hand with calipers a known number of fruitlets, with slightly different models for making fruit set predictions. On the other hand, Farm Vision introduces a different technology for "seeing" and measuring fruitlets (cameras and computer vision) and algorithms for determining the actual number of fruitlets present based on occlusion models calibrated to a given planting. In addition, Malusim and Ferri make predictions on fruit set on a per tree basis, whereas at the time of this work, Farm Vision was estimating set on a linear basis (i.e., predicted fruit set per meter). In the future Farm Vision will be changing its models to operate on a per tree basis, and they will continue to ground truth results. In general, less data used in the Malusim and Ferri apps than in the Farm Vision method could have led to some of this variation.

Table 3. Accuracy of fruit set predictions by Malusim, Ferri , or Farm Vision scanning technology compared to actual fruit set. Reported as percent (%).

Block	Malusim	Farm Vision	Ferri
UMO 'Gala'	109%	138%	104%
UMO 'Fuji'	43%	134%	109%
UMO 'Honeycrisp'	352%	331%	217%
TFF 'Gala'	173%	251%	161%
TFF 'Honeycrisp'	183%	.	258%
Vinton 'Honeycrisp'	54%	86%	.
Vinton 'Gala'	199%	162%	.
Thome 'Fuji'	95%	106%	.
Thome 'Gala'	137%	129%	.
Cornell 'Honeycrisp'	138%	157%	.
NCSU 'Gala'	106%	186%	.
Average	144%	168%	170%
Max	352%	331%	258%
Min	43%	86%	104%
Median	137%	148%	161%

There were a few concerns with the Farm Vision hardware during our work. These were primarily related to the QR code signs needed to geo-locate the trees, which were easily obscured. Also, RTK GPS connectivity was a challenge in some locations. In 2023, Farm Vision (Pometa) is eliminating and/or changing several aspects of their hardware and data presentations. For example, QR code signs are being reimagined and the app can now be used without an external RTK GPS device, eliminating connectivity issues. These are examples of how Farm Vision, and other technologies, are rapidly responding to user experiences and improving their output going forward. In general, we found Farm Vision support very easy to work with and responsive to our concerns.

Farm Vision offers some advantages to the Malusim and Ferri apps. The time for data collection is drastically reduced. Data collection for either Malusim or Ferri from a single block typically took us the greater part of an hour, and it is difficult to accomplish alone. Farm Vision took less than five minutes per block to complete the scans, once the hardware was set up and GPS was connected, plus walking time between trees. In addition, Farm Vision uses a much larger sample size of fruitlets to make predictions (all visible fruitlets), whereas the Malusim and Ferri apps are limited by a small sample size. In these apps, only 70-75 clusters were measured (14 or 15 clusters on each of 5 trees). If these clusters were an inaccurate representation of the total tree or block, they would have provided poor fruit set predictions. Based on our personal experiences, even one aberrant tree or flower cluster(s) can seriously skew the results.

Overall, all methods tended to over-predict fruit set. This means they are conservative by nature, and the risk of over-thinning is minimal. All three followed similar trends in nearly all situations and provide similar predictions of fruit set and corresponding recom-

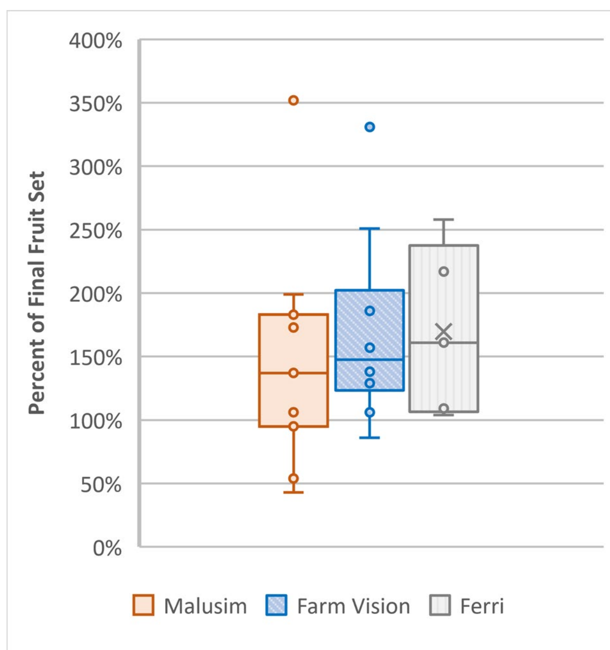


Figure 3. Accuracy of fruit set predictions by Malusim, Ferri, or Farm Vision, compared to actual fruit set.

Table 4. Actual yields and yield estimations with a cell phone camera at two mature WNY orchard sites in the fall of 2022.

Site	Number of rows and scanned acreage	Yield (bins)		
		Actual Yield	Predicted (cell phone camera)	
			With Occlusion Model	Without Occlusion model
'Fuji'/B.9 (2x11ft)	12 rows (2.87acres)	127	154 (Overpredicted by 21%)	114.5 (Under-predicted by 10%)
'Evercrisp'/ B.9(3x12ft)	8 rows (1.5acres)	83	80.1 (Slightly under-predicted by 3%)	NA

mendations for thinning.

Yield Estimation Studies with Farm Vision in New York

As a follow up to our work in the spring to estimate fruit set, in the fall of 2022, we conducted two yield estimation studies with Farm Vision in the Lake Ontario Fruit region of New York. Orchard scans were conducted at two locations. The first was a commercial five-year old 'Fuji'/B.9 planting at 2x11 ft (Fish Creek Orchards, Orleans County, NY) on September 14, 2022. A second trial was conducted at a commercial six-year-old 'Evercrisp'/B.9 planting at 3x12 ft (Cherry Lawn Farm, Wayne County, NY) on October 13, 2022.

Calibrations for occlusion were conducted prior to full scanning of rows for yield estimation. At each of the two sites, five 3-tree plots which were randomly distributed in the orchard were used for calibration of occlusion. Calibration plots had uniform crop load, tree height, canopy width, and trunk diameter. Fruit counts/tree were conducted for each of the calibration plots before the scanning of full rows. Setting up of calibration plots and ground-truth work took one hour for two people at each of the orchard sites.

Full row scans were conducted with two people. One person drove an ATV at approximately 10 miles/hour and a cell phone operator scanned full rows (both sides) that contained the five calibration plots. Entire tree canopies and trunks were scanned by the cell phone operator. Scanning with the cell phone camera took less than 10-12 mins with one ATV and two people at each of the orchard sites.

At Fish Creek Orchards we scanned 12 rows or 2.87 acres. The Farm Vision technology estimated 2,926 bushels or 154 bins (19 bushels/bin) from the 12 rows (Table 4). The actual yield from the 12 rows was 2,413 bushels or 127 bins recorded on October 12, 2022. At Cherry Lawn Farms we scanned 8 rows or 1.5 acres. The Farm Vision technology estimated 1,602 bushels or 80.1 bins (20 bushels/bin) from the 8 rows (Table 4). The actual yield from the 8 rows was 1,658 bushels or 82.9 bins recorded on October 26, 2022. The Farm Vision yield estimates overpredicted the yield of 'Fuji' by 21% and slightly underpredicted the yield of 'Evercrisp' by 3%. The large overestimation of 'Fuji' fruit seemed to be associated with the occlusion model when scanning both sides of the Fuji trees were scanned. The Super Spindle Fuji orchard had a very narrow 2-dimensional canopy with almost all fruit visible to the camera from one side. In this case, the Farm Vision technology had some double-counting of fruit, even though the system attempts to compensate. When the scanning results for Fuji were re-run by Farm Vision and the occlusion model was turned off for the analysis, the new Fuji yield estimate was 114.5 bins and only 10% lower than the actual Fuji yield at harvest. This result showed that the Farm Vision technology can be used to scan very thin, 2-D fruitful canopies, from a single side of a row, without the use of an occlusion model. This took less time than other yield estimation models.

Conclusions

Many tools utilizing computer vision, AI, and ML are rapidly becoming available to assist with PACMAN, specifically to improve and expedite the process of fruitlet measuring to predict fruit set according to the fruit growth rate model, as well as to make harvest predictions. The tools tested here, including the Malusim app, Ferri app, and Farm Vision (Pometa) scanning, varied in accuracy in our 2022 trials. This and other tools are continuing to be updated and improved, both in terms of accuracy of predictions and user friendliness. We are optimistic about the accuracy and efficiency with which computer vision tools will accomplish this task in the future. As with all models or tools, they are not perfect, they are an excellent "decision aid." As always, grower experience should be a factor in making chemical thinning decisions, don't rely on the models alone.

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Anna Wallis was formerly an extension specialist with Michigan State University who led this project. **Jon Clements** is an extension educator with University of Massachusetts, **Mario Miranda Sazo, and Craig Kahlke** are extension educators that specialize in orchard management, and fruit quality management who work with the Cornell Lake Ontario Fruit Program, **Karen Lewis** is an extension educator with Washington State University, **Tom Kon** is an Assistant Professor of horticulture at North Carolina State University, **Luis Gonzalez** is a post-doctoral research associate who works with Dr. Robinson, **Yu Jiang** is a research and extension professor at Cornell's AgriTech campus in Geneva who leads Cornell's program in digital technology for horticultural crops, and **Terence Robinson** is a research and extension professor at Cornell's AgriTech campus in Geneva who leads Cornell's program in precision crop load management, high-density orchard systems, rootstocks, irrigation, and plant growth regulators.


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Life After Lorsban

Julianna K. Wilson

Department of Entomology, Michigan State University, East Lansing, MI

Keywords: chlorpyrifos, borers, San Jose scale, aphids

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As we move forward without chlorpyrifos, this article proposes alternative approaches to managing borers and soft-bodied insect pests in orchards.

In February 2022, the U.S. Environmental Protection Agency (EPA) revoked the label registration on bearing fruit trees for chlorpyrifos, which many tree fruit growers purchased under the trade name Lorsban (also known as Govern, Warhawk). This was the result of a process under which the EPA is obligated by law to reevaluate registered pesticides every 15 years to make sure that the current use of these products matches our current understanding of the science, including worker and food safety and environmental impacts. Unfortunately for growers who were used to depending on this material, it was determined that the risks outweighed the benefits.

There were two main uses for this product in orchards: as a trunk spray against borers, and when combined with a dormant oil, to manage early season populations of soft-bodied insects such as scale and aphids. These are all insects that mainly cause damage to the trees themselves as opposed to direct fruit damage – and putting an economic value on their management is difficult. That said, these pests are known to impact tree health and longevity, particularly under high population pressure.

As we move forward without chlorpyrifos, the purpose of this article is to discuss alternative approaches to managing borers and soft-bodied insect pests. Since the biggest challenge in managing these pests relates to the fact that for most of their lifecycle they are hidden or well protected, timing becomes the crucial key to success. I will also review existing resources and gaps in our knowledge with respect to managing these pests sustainably.

Borers

Wood-boring insects that attack living trees are generally either moths or beetles. Some borers are attracted to trees sending out stress signals (*e.g.,* ambrosia beetles like the black stem borer). Other borers are attracted to pre-existing wounds, cankers, burr knots at the base of trees, or rough bark (*e.g.,* Sesiid moths like dogwood borer; American plum borer). The process of boring into trunks or limbs can girdle them or allow pathogens to enter wounds, which can interfere with sap flow. One trunk spray of chlorpyrifos timed with when adults of a particular species were likely to be active was used to keep these pests at bay.

Some researchers suspect the cause of recent (within the last 10 or so years) increased incidence of borer damage in orchards may be due to an increase in tree stress. This tree stress is hypothesized to be caused by a changing climate, including increased incidence of winter injury and alternating periods of drought and heavy rains. It may also be due in part to increases in acreage devoted to high density orchards, systems in which significantly more trees are planted per acre and pushed to produce fruit as soon as possible after planting. Technologies are being developed to improve and automate irrigation systems and nutrient management, and frost fans are being used to break up inversion layers when trees are at their most vulnerable to injury in the spring. However, these technologies are not able to prevent damage due to temperature extremes in the fall when trees enter dormancy, and can't control times of the year when we receive an over-abundance of water. All of this is just to say that our troubles with borers are not going away any time soon.

Most of the insecticide efficacy work on tree fruit borers comparing alternatives to chlorpyrifos is from 20-30 years ago. This is partly because chlorpyrifos worked so well and few new materials have come to market, but also because borers are a really challenging pest to study and keep in lab-reared colonies. With the insecticides that remain labeled for use against borers in orchards, we know that they are very likely to require two or more applications because their residues are less persistent and as such should be applied with a compatible spreader-sticker to maximize longevity. Products that are less persistent also require more precise timing to target susceptible life stages.

For many of the key tree fruit borers (*e.g.,* dogwood borer, peachtree borers, American plum borer), the pheromones emitted by females to attract mates are known and manufactured in commercial lures and can be used to monitor male flight. For ambrosia beetles like the black stem borer, ethanol traps can be used to monitor when females are searching for new trees to infest. Knowing when these species are actively searching for mates or new trees to infest is critical for targeted insecticide sprays. If no traps are set for these pests, or if traps are set and no one is trained to identify these pests, this is a missed opportunity to improve timing and therefore efficacy.

For some moth species of borers, pheromone dispensers are commercially available to distribute in orchards to prevent males from finding females, thereby reducing egg laying, and in theory, reducing the need to apply insecticides targeting these pests. For growers with trees on rootstocks known to produce

Figure1

burr knots or that are susceptible to cracking, this is an important alternative to consider. For growers with orchard blocks where these kinds of borers have been a problem, it may take 2-3 years to knock populations back down with this technique. There are nuances to using these dispensers that may be different from what growers familiar with mating disruption against codling moth or Oriental fruit moth are used to. Check the product label for recommended dispenser density per acre and placement of the dispensers in the canopy for maximum efficacy (*e.g.,* depending on the product, dispensers may need to be placed lower in the canopy than codling moth dispensers).

Some growers have tried with some success applying materials that act as a feeding deterrent (*e.g.,* kaolin clay). There is also active research into the use of entomopathogenic nematodes (EPNs) against Sesiid moth borers and on the use of systemic fungicides against ambrosia beetles and their fungal colonies. However, these approaches require further research or are still a way off in terms of their practical use. For borers, there is a wide-open area of research focus needed to optimize our management of these pests in orchard systems.

Soft-bodied Insect Pests

San Jose scale become active with sap flow in early spring. Combined with dormant oil, an application of chlorpyrifos was traditionally made in early spring to coincide with the onset of sap flow. This two-punch approach with the oil suffocating the insects in combination with a nerve toxin was used rather successfully to suppress populations of this pest, although the use of chlorpyrifos in this case, likely suppressed natural enemies as well.

San Jose scale is a tiny cryptic pest, perfectly camouflaged and protected for most of the season under waxy scales that look a lot like the normal features of bark. Except for the crawler stage, females are sedentary under these waxy covers and call to winged males with a pheromone signal. Juvenile males and females develop and overwinter under waxy caps. Dormant oils on their own can still do a lot to suppress sedentary stages of San Jose scale, but caution is warranted if a frost is expected 2 days before or after application, or when combined with materials in tank mixes that are known to cause crop injury.

During their flight periods, males captured on baited traps appear as really tiny yellow specks. Because their flight period tends to coincide with the first flight of male codling moth in apple orchards, some growers use the codling moth biofix to begin a growing degree day (GDD) accumulation model for timing management of the crawler stage of San Jose scale. A well-timed application of an insect growth regulator (IGR) can be very effective in reducing San Jose scale populations and seems to have a strong carry-over effect into at least the next season. It is also exciting to note that it is easy to disrupt San Jose scale mating with pheromone dispensers, but as of this writing we are waiting on registration of commercially available products.

Aphids can seem to appear out of nowhere because of how rapidly they reproduce under the right conditions. There are at least five species of aphids that use apples for part or all of their lifecycles. These include three species of green apple aphids (*i.e.,* apple grain aphid, apple aphid, and spirea aphid), the rosy apple aphid, and the woolly apple aphid. The earliest to appear in spring is the apple grain aphid, but this is not an economically important species and no treatment is recommended.

About a week to ten days later, however, the rosy apple aphid hatches over a period of about 2 weeks, seeking apple buds as they open, causing leaves to curl and fruit to deform as they suck sap. Curled leaves are the most telling sign of rosy apple aphid presence in spring. The fact that they spend part of their lifecycle on narrow-leaved plantain should motivate growers to try to eliminate it from the orchard floor – especially near susceptible cultivars like Golden Delicious and its relatives. A threshold was developed for rosy apple aphid when fast-acting materials like chlorpyrifos were widely used. The recommendation was to examine 100 fruit clusters in the center of susceptible blocks from tight cluster through petal-fall and then apply a spray if an average of one colony or more per tree was found. Research is needed to know whether this threshold is applicable with the use of slower-acting insecticides like modern IGRs.

The other two green apple aphid species, the apple aphid and the spirea aphid, start being active in early spring but are more likely to be found starting in June and are most abundant in June and July on vigorous new growth such as water sprouts. The threshold for triggering management of these species was based on examining 10 growing shoots on each of five trees in a block; if an average of more than four leaves on these shoots were infested with green aphids then an insecticide application was recommended. Again, this threshold was developed at a time when growers had access to fast-acting contact sprays and needs to be reevaluated with slower acting materials. It is important to note that with these species and with the rosy apple aphid, once leaves become curled from heavy infestation, they are more difficult to manage and may require the use of a systemic insecticide.

Colonies of woolly apple aphids may be found either above or below ground on roots. Serious damage to apples by this aphid is mainly from their root feeding, but there are some rootstocks, particularly those in the Malling series, that are not resistant to them. Above ground colonies cause consternation during harvest producing a red, sticky mess when they are inadvertently crushed by workers harvesting apples. The recommendation is to look for white cottony masses covering colonies of woolly apple aphids starting at petal fall on twigs, water sprouts, and callus tissue, but there is no threshold for triggering action other than "if numbers warrant treatment".

In orchards with a healthy community of natural enemies (*e.g.,* parasitoid wasps, lacewing larvae, and lady beetle adults and larvae), aphids tend to stay below threshold levels of concern. In these orchards it will be common to find mummified aphids, which are aphids that have been attacked and killed by parasitoid wasps. However, a cool, wet spring favors aphid development because these conditions are unfavorable to aphid parasites and predators. In addition, repeated use of pyrethroid insecticides, which are very toxic to parasitoid wasps, will knock out this natural source of pest suppression.

Numerous alternatives to chlorpyrifos are registered for use against aphids, including other products that act on nerves or muscles, products that interfere with respiration, and products that interfere insect growth. Insecticides that act on nerve or muscle targets or interfere with respiration are generally fast to moderately fast acting. Insecticides that interfere with growth, otherwise known as insect growth regulators or IGRs, are generally slow to moderately slow acting and need to be applied when the target life stage is present. Whether the insecticide is a contact spray or a systemic transported within the plant being protected, will also impact how quickly or slowly a material will work against a target pest. Good coverage through proper sprayer calibration, not skipping rows when spraying, and avoiding materials known to be very toxic to natural enemies are the keys to success for managing aphids. Thresholds may need to be adjusted to accommodate for the use of slower-acting insecticides.

Conclusion

Although it can feel discouraging when a reliable tool is no longer available, there are alternative materials and approaches to managing borers and soft-bodied insect pests in spring without chlorpyrifos. Here is a quick recap of those alternative materials and approaches.

- Use available monitoring tools (*e.g.,* traps, lures/baits, systematic scouting techniques) and growing degree day based models for better precision. Thresholds may need to be adjusted when switching to insecticides that are slower acting like IGRs.
- For moth borers, consider using pheromone mating disruption (MD), especially in blocks with trees on rootstocks known to produce burr knots or that are susceptible to cracking. In high pressure blocks, a combination of trunk sprays and MD may be necessary for the first couple years.
- When applying trunk sprays, be sure to use a compatible spreader-sticker to maximize longevity; multiple applications may be required.
- For foliar applications, calibrate sprayers to maximize coverage and don't skip rows; choose systemic insecticides when target life stages are well-protected by waxy coverings or curled leaves.
- A dormant oil application is still an effective approach for suppressing San Jose scale in early spring but requires caution immediately after or right before cold weather. A properly timed IGR can knock back San Jose scale in problem blocks.
- Cool, wet spring weather favors aphid development because these conditions are unfavorable to aphid parasites and predators. Also, beware of repeated use of pyrethroid insecticides – these will knock out beneficial insects, allowing aphid populations to explode.
- For orchards with a history of rosy apple aphid infestation, consider eliminating narrow-leaved plantain from orchard floors especially near susceptible cultivars like Golden Delicious.

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Julianna Wilson is an Assistant Professor and Extension Specialist who directs the Tree Fruit Entomology Lab at Michigan State University.

Grower Impressions of Low Tunnel Utility for June-Bearing Strawberry Production

Elisabeth Hodgdon[1], Laura McDermott[1], Rebecca Sideman[2] and Kaitlyn Orde[2]

[1]Cornell Cooperative Extension Eastern NY Commercial Horticulture Program | [2]University of New Hampshire Cooperative Extension

Keywords: Strawberries, botrytis fruit rot, fruit quality, low tunnel, frost, early harvest

Low tunnels offer an economical way for strawberry growers to use protected culture, resulting in higher quality fruit, potential early ripening, and reduced need for fungicides but they may not be appropriate for all operations in the northeastern U.S. Our on-farm studies showed that low tunnels may also increase yield and quality in June-bearing strawberries during wet seasons.

Strawberry growers know that the first berries to market in the spring can be sold for premium prices, drawing in customers to retail operations. With more and more high tunnels being constructed on farms every year, growers are interested in diversifying their crop production in tunnels and including strawberries in addition to tomatoes and other crops. We see a wide variety of strawberry production systems under cover around the Northeast, ranging from sophisticated greenhouses with hydroponic production to high tunnels and smaller caterpillar tunnels. These structures help extend the season for June-bearing (JB) strawberries, hastening maturity in May. They also protect plants from rain and extreme weather events, reducing disease pressure and direct damage to fruit from precipitation. Although larger tunnel structures are a more common sight on New York farms due to federal funding initiatives, we seldom see plastic-covered low tunnels—waist-high structures—on farms. Low tunnels offer some of the same benefits as larger tunnels, but at a lower cost: approximately $20,000 as a high end estimate for materials to construct one acre of low tunnels.

Plastic tunnel structures offer a variety of benefits for improving crop yield and quality. When grown in low tunnels, day-neutral (DN) strawberries benefit from an extended harvest season and greater yields. Researchers in Maryland reported greater overall yields of strawberries grown in low tunnels compared to open field production (Lewers et al 2017). In a New Hampshire study, strawberry yields were markedly higher during the shoulder seasons under low tunnels, which offers a benefit to producers in the fall when local strawberries are typically less available (Orde and Sideman 2019).

Additionally, tunnels can increase the share of marketable yield and reduce disease occurrence (Conner and Demchak 2018; Demchak 2009; Lewers et al 2017; Orde and Sideman 2019). The plastic covering of tunnels creates a beneficial environment through increased daytime temperatures when sides are rolled down and protection from precipitation and wind. Keeping rain and hail off fruit decreases diseases pressure from *Botrytis* and other pathogens, resulting in a higher percentage of marketable yield. Few studies have been conducted on low tunnels in the Northeast, but Orde and Sideman (2019) measured higher marketable berry yield of DN strawberries grown in low tunnels during the shoulder seasons compared to traditional open field production.

Figure 1. Three low tunnels draped in bird netting at Farm A in April 2021.

Low tunnels are simple structures that do not require specialized expertise to install and maintain but do require additional materials and labor investment at the start and end of the season. They consist primarily of short hoops, clear plastic film covering, stakes, and bungee cords holding the covering in place. In comparison to larger, more sophisticated structures, they allow for more flexibility for movement from field to field according to crop rotation. Annual strawberry systems with low tunnels are a logistical good fit in vegetable crop rotation schemes. While low tunnels are simple to use, materials can be costly and labor is required to set up and take down the tunnels at the beginning and end of the season (Conner and Demchack 2018). Additionally, tunnels covering rows of strawberries render in-season pesticide application and weed control difficult for some equipment because rows are not easily accessible by tractor-drawn equipment traveling close to the ground. The cost-benefit analyses of low tunnels for individual farms are therefore dependent upon the price received for strawberries and labor availability in-season.

While research has been done on DN strawberries in low tunnels, little is known about whether low tunnels are worthwhile for JB production. Here, we present results from a series of on-farm demonstrations of low tunnels installed over JB strawberries. Results from our demonstrations emphasize grower perspectives on logistic and economic feasibility of low tunnels. We also report data comparing marketable and unmarketable strawberry yield under low tunnels versus open field from two of our farm sites.

Figure 2. Inner tunnel environment at Farm A, with plastic cover draped in bird netting over plasticulture strawberries.

Materials and Methods

In 2021 and 2022, we installed low tunnels over JB strawberries at two commercial farms in eastern New York (Farms A and B) and one farm in central New Hampshire (Farm C) to gather grower input on whether they impacted maturity, yield, and quality of JB strawberries. One of the farms was certified organic, while the other two were conventional. All farms participating in the low tunnel demonstrations were diversified fruit and vegetable farms that included retail sales of their products. At each site, the grower compared quantity and quality of berries grown under three 30' long low tunnels versus those grown in the open field in adjacent rows. Our low tunnel materials were sourced from Dubois Agrinovation (St-Rémi, QC; Table 1) and were installed by extension staff.

At two of the farms (Farms B and C), marketable and unmarketable strawberry yield was measured during two harvests in 2021. Fruit damaged by pests, disease, or precipitation, and fruit that were undersized were deemed unmarketable. Extension staff collected harvest data at Farm B, while the grower host collected data at Farm C. At Farm B, data from each of the three tunnel and open field replicate beds were analyzed using t-tests performed in JMP statistical software. At Farm C, berries were harvested from only one open field replicate, and no statistical analyses were conducted. No quantitative yield data was collected at Farm A or in 2022 at any of the participating farms. At the end of the strawberry season each year, we recorded our observations and those of the grower hosts. Here, we discuss our findings from the past two qualitative seasons and grower conclusions as to whether low tunnel systems were feasible for JB strawberries on their farms.

Results

Farm A is a diversified certified organic small fruit and vegetable farm that sells strawberries through farmers markets and community-supported agriculture (CSA) in eastern New York. The growers manage their small-scale production intensively, utilizing multiple high tunnels and row covers for season extension. Grower A was intrigued by the use of low tunnels for earlier harvests of berries to bring to spring markets.

We installed low tunnels over three sections of their rows of 'Chandler' plasticulture strawberries in late April in 2021 and 2022 at first bloom. No drip irrigation was installed in the field, and straw was used between rows for weed management. Due to deer and bird pressure, Farm A used wide-mesh bird netting as a deterrent (Figs. 1 & 2). We draped the bird netting over the tunnels to accommodate the low tunnel system. Unfortunately, due to a freeze later in May 2021 (several hours of temperatures in the 20's F), Farm A lost most of the primary strawberry blossoms. Due to the warming effect of the tunnels, the plants and flowers within the structures were slightly more mature than those in the open field, and therefore tunnel plants may have lost a higher number of primary blossoms than the uncovered plants.

The quality of fruit in low tunnels was good and we observed a reduction in loss from disease compared with open field berries. Remaining low tunnel fruit in 2021 after the early freeze also ripened earlier by a few days which was encouraging for the growers. In 2022 the fruit under the low tunnels were slightly larger and again ripened earlier than the open field strawberries. The growers did report that they found that the low tunnel plants finished quicker than did the field grown berries, resulting in an earlier finish to the season by about 4 days, but this would be expected if harvests began earlier.

Lessons learned at Farm A:

- Low tunnel structures do not provide protection from low nighttime temperatures. Additional frost protection (e.g., row cover or micro-irrigation) is still needed to protect flowers from late frosts and freezes. This observation aligns with research conducted at the University of New Hampshire in recent years (Orde and Sideman 2019).
- Bird netting plus the tunnel structures created an overly complex harvesting environment for employees at this farm. Netting had to be removed, and the sides of the tunnels needed to be raised at each harvest.
- Despite yield losses due to the freeze in 2021, Farm A observed improved fruit quality under the low tunnels.
- The seasonality of the fruit is impacted by the low tunnel environment, causing earlier ripening and possibly an earlier end to the season.

Conclusions: Low tunnels were not worth the management effort for Farm A, particularly while using bird netting. Grower A is still interested in protected culture of strawberries given the improved fruit quality but believes that caterpillar or high tunnels would be easier for them to manage.

Farm B is a conventional diversified fruit and vegetable operation in eastern New York offering strawberries at their retail store and for pick-your-own. Grower B was interested in using low tunnels to determine whether the structures would hasten berry harvest; earlier berries in May would draw customers to their farm store.

Figure 3. Low tunnels installed over matted row strawberries at Farm B in May 2021.

Table 1. Materials used for low tunnel demonstrations at commercial farms in New York and New Hampshire during 2021-2022 strawberry seasons

Material	Size	Notes
Galvanized steel "TunnelFlex" hoops	46" wide x 39.5" tall	Hoops include loops on each side for grounding stakes
Rubber-coated end hoop[1]	~46" wide x 30" tall	Thicker steel end hoop set at 45° angle to taper plastic to anchor stake
Galvanized steel extension posts	2' tall	To anchor ends of tunnel
Galvanized steel anchor stakes	18" tall	Grounding stakes for hoops
Clear perforated plastic film	39.5" wide	1.5 mil thickness with 12" strip of small holes for ventilation on each edge
Bungee cord	1 x ~8' long piece per hoop	Tied in a loop, to hold film tightly on hoops
Ratchet, paracord, and zip-ties	Variable	To tie plastic to anchor posts at ends of tunnel

[1]While shorter end hoops were used in our demonstrations, they are optional. The larger steel TunnelFlex hoops may be used in their place.

On Farm B, we installed the low tunnels over matted row 'Dickens' strawberries (Figs. 3 & 4) in 2021 and 2022. We were limited in where we could install the tunnels, because only one field had drip irrigation set up. The grower typically uses overhead irrigation for strawberries and preferred using tunnels only where drip irrigation was available. Shortly after setup in 2021, the farm's boom sprayer accidentally ripped the plastic because the boom could not clear the tunnels, and it was replaced. The plastic covering on the tunnels was rolled up during sunny days and closed during storms to prevent rain from contacting berries underneath. In addition to the farm workers' harvests, we harvested some of the berries for comparison between the tunnels and adjacent bare rows in 2021 (Table 2). In 2022, Farm B opened the low tunnels for pick-your-own customers and we did not harvest berries for data collection.

Lessons learned at Farm B:

- To reduce risk of crop loss, low tunnels are best used with drip irrigation. Not all growers, however, use drip irrigation.
- Strawberry yield early in the season was numerically higher under the tunnels, but this difference was not statistically significant during our early season harvest ($P > 0.05$)
- The strawberry season was very dry in Farm B's region in 2021, thus there was little disease pressure from *Botrytis* and anthracnose overall. Workers reported firmer, higher quality berries under the tunnels, nevertheless. We measured no significant differences in marketable and unmarketable fruit yield across treatments from our harvests.
- Harvesting under the tunnels was less efficient. While workers typically straddle rows to harvest, one can only harvest one side at a time under a tunnel.
- Pick-your-own customers did not provide negative feedback on their experiences picking strawberries under the low tunnels.
- Spraying with a boom sprayer can be challenging with low tunnels. Tunnel plastic could be rolled up to its highest point on the hoops during spraying, but it can be difficult to navigate the structures in the field, particularly when tunnels are placed over rows with narrow spacing.

Conclusions: Low tunnels would be useful for a small proportion of the farm's early strawberry varieties to achieve earlier harvests. They would be too challenging to implement on a larger scale. Grower B is interested in constructing more low tunnels for early varieties that could boost spring sales in addition to using their high tunnel for strawberry production in the future. No significant differences between strawberry yield under low tunnels versus open field were measured, however, 2021 and 2022 strawberry seasons were abnormally dry with low disease pressure.

Farm C is a conventional diversified fruit and vegetable farm located in central New Hampshire. Their strawberries are sold through their CSA program, farm store, and through pick-your-own. Grower C was particularly intrigued by the ability of the tunnels to reduce disease and improve marketable berry yield and was willing to keep the tunnel sides lowered while spraying for a true comparison of disease incidence between the tunnels and adjacent open ground plants.

At Farm C, low tunnels were set up in 2021 over 'AC Valley Sunset' berries grown in a traditional matted row system. The rows of berries were quite wide on this particular farm, and low tunnels were not wide enough to cover the outer edges of the rows of plants (Fig. 5). The strawberries were irrigated using drip tape, which was also used to apply fungicides and fertilizer. Farm C had a very robust spray program for the berries to manage pests and disease. The 2021 berry season was particularly wet, with rain events of up to 7" in June. Workers harvested berries from the tunnels, and grower C provided quantitative data from two strawberry harvests and observations and data on berry quality and disease incidence during the season.

Lessons learned at Farm C:

- Although the low tunnels did not eliminate disease, marketable berry yield was higher under the low tunnels versus open field during the rainy 2021 season (Table 2).
- A very minor amount of leaf spot, leaf scorch, and powdery mildew was observed on plants in the low tunnels, but not on other plants in the open field. Heat may have contributed to these symptoms. Overall, the numbers of *Botrytis*-infected berries in the low tunnels were not reduced, but overall incidence at Farm C was very high.
- Workers preferred harvesting berries under the tunnels because it was easier to find marketable fruit. Two workers harvested each row of low tunnel berries, one on each side of the bed. This is already standard practice on the farm because of their unusually wide beds.
- Applying pesticides using a boom sprayer was not a problem; Farm C's boom sprayer could be raised high enough to clear the tunnels.

Conclusions: Data collected at Farm C found the structures demonstrated increased marketable yield compared to the open field plants. Harvesters also preferred picking under the tunnels because of the higher proportion of marketable fruit (it was a wet

Figure 4. Sides rolled up to allow for air flow and temperature control at Farm B.

Table 2. Marketable and unmarketable strawberry yield at Farms B and C in 2021 under low tunnels and in open field plots

Demonstration site	Harvest date	Mean yield (lbs fruit/30 ft plot)			
		Marketable		Unmarketable	
		Low tunnel	Open field	Low tunnel	Open field
Farm B	11-Jun	2.00	1.69	0.78	0.20
	23-Jun	17.08	21.88	3.22	3.00
Farm C	2-Jul	11.00	6.001	11.5	10.5
	7-Jul	5.00	3.00	9.5	15

[1]Yield in open field treatment at Farm C measured in one 30 ft section only.

Figure 5. Low tunnels were unable to fully cover wide rows of plants at Farm C. A wider low tunnel system would be needed for this bed setup.

season with high *Botrytis* rates, however). The farm was willing to try them again and felt wider tunnel hoops would be beneficial given their unique ultra-wide matted row beds.

Discussion

Low tunnels offer an economical way for growers to use protected culture, resulting in higher quality fruit, potential early ripening, and reduced need for fungicides. Low tunnels are used in Europe and elsewhere across the globe with great success, but they may not be appropriate for all operations in the northeastern U.S. The major challenges observed in our demonstrations on individual farms centered around labor requirements. Low tunnels are a new object in the field and will impact all activities. They require a degree of active management, especially in the shoulder seasons and during precipitation events when plastic sides are lowered and raised. Workers may need to change their harvesting practices to be compatible with the structures, and farms using tractor-drawn boom sprayers need to ensure they have adequate clearance and awareness as they navigate them in the field with equipment. Other considerations include row width, frost protection (as they do not provide low temperature protection), and bird control.

Differing precipitation patterns across the regions allowed us to observe effects of low tunnels in both unusually wet and dry seasons. Most notably, dry conditions at Farm B resulted in little difference between treatments, while abnormally wet weather at Farm C resulted in a measurable increase in fruit yield and quality when comparing harvests from low tunnels to open field. In a changing climate, the Northeast will continue to experience increased incidence of extreme weather events. Low tunnels may be an important tool in mitigating effects of heavy rain, hail, and wind brought by spring and early summer storms, as long as tunnel structures are wide enough to cover rows of plants. While low tunnels have previously been shown to have benefits for DN varieties, these on-farm studies showed that low tunnels may also increase yield and quality in June-bearing strawberries during wet seasons.

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Elisabeth Hodgdon is a regional vegetable extension specialist with Cornell Cooperative Extension located in Plattsburgh NY. **Laura McDermott** is a regional berry extension specialist with Cornell Cooperative Extension located in Hudson Falls, NY, **Rebecca Sideman** is a professor of sustainable agriculture at the University of New Hampshire and **Kaitlyn Orde** is a former research assistant and graduate student with Dr. Sideman.

An Economic Evaluation of Alternative Methods to Manage Fire Blight in Apple Production

Bradley J. Rickard[1], Srđan G. Aćimović[2], Gennaro Fazio[3] and Casey Silver[4]

[1]Dyson School of Applied Economics and Management, Cornell University, Ithaca NY | [2]Alson H. Smith Jr. Agricultural Research and Extension Center Virginia Polytechnic Institute and State University, Winchester, VA | [3]USDA-ARS Plant Genetics Resources Unit, Geneva, NY | [4]McKinsey & Company, Cambridge, MA

Keywords: fire blight, Geneva® rootstocks, tree insurance, pre- and post-infection spray programs

Our research examined the economic implications of managing fire blight in apple production by using susceptible rootstocks or resistant rootstocks with and without protective sprays. Our results indicate that use Geneva® rootstocks across all incidence levels of fire blight considered gave superior economic outcomes compared to susceptible rootstocks or tree insurance for fire blight.

Fire blight outbreaks have become more common and more severe in apple orchards in New York in recent years (Milkovich, 2022; Robbins 2019). The pathogen has created significant economic distress for apple producers in 2012 in the Hudson Valley, in 2016 in the Champlain Lake Valley and Western New York (Aćimović et al., 2019; Aćimović et al., 2021), and then again in 2020 in Western New York. Damage estimates to producers from the 2016 epidemic exceed $16 million in Champlain Lake Valley. These sudden fire blight outbreaks can cause over 50% apple tree losses in young, recently planted orchards (Breth 2008). The most severe symptom behind tree death is the girdling effect of a fire blight canker on susceptible rootstock (Fig. 1). Scientists and growers are considering a range of strategies to manage the pathogen, and the purpose of this research was to outline the economic implications of adopting a few alternative strategies.

We evaluated five scenarios to manage fire blight where each scenario is based on the adoption of a different strategy. Scenarios model the outcomes of using individual tools (e.g., Geneva® rootstocks (G) alone) and combinations of tools (e.g., Geneva® rootstocks plus post-infection spray programs). The first scenario is a baseline scenario that does not employ a management strategy for fire blight (specifically, the baseline case assumes the use of Malling rootstocks (M) without the use of tree insurance or the use of pre- or post-infection spray applications). The Malling rootstocks M.26 and M.9 and its subclones (Nic29, T337, Pajam 2) are very susceptible to fire blight, M.7, and the Budagovskij series B.9 and B.118 are tolerant or moderately resistant to fire blight. The Geneva® rootstocks G.11, G.41, G.202, G.214 , G. 890, G.935, G.969 and others are fire blight resistant (Wertheim, 1998; Aldwinckle et al., 2001, 2004; WSU, 2022).

The other four scenarios that we modeled included the adoption of 1) Geneva® rootstocks, 2) pre- and post-infection spray programs coupled with Malling rootstocks, 3) pre- and post-infection spray programs coupled with Geneva® rootstocks, and 4) the use of tree insurance products offered by the USDA - Risk Management Agency (RMA) coupled with the Malling rootstocks. We do not consider scenarios that adopt Geneva rootstocks with tree insurance as this combination is unlikely to be adopted by a commercial orchard owner. Our analysis also considers the adoption of these scenarios across a range of fire blight incidence levels (ranging from 0% incidence to 40% incidence). Incidence refers to the intensity rate of infection on the tree crown; the incidence rate describes the estimated share of infected flowers/shoots in the tree canopy on average. The exact nature of the link between the incidence rate and the percent of overall rootstock infection is unknown.

A Description of Fire Blight Management Tools

The baseline scenario was based on the use of Malling rootstocks and absent any pre- or post-infection spray programs and tree insurance. The Malling rootstocks are susceptible to fire blight and exposure to fire blight necessitates tree removal and replacement. There are no surcharges associated with planting the Malling rootstock (tree plus rootstock costs=$8/each) and trees must be replaced (also at $8 per tree and rootstock, and with the assumption that replanted trees will restart the standard production progression that reaches full production in the sixth year after planting). This replant also requires soil preparation, a cost that is scaled to the level of damage. A scenario with greater than 30% incidence of fire blight (i.e., average intensity rate of infection in the tree canopy) is assumed to require a full replant and will also require the costs associated with orchard soil preparation.

The Geneva® rootstocks, developed by a partnership between Cornell University and the United States Department of Agriculture-Agricultural Research Service, were created to increase resistance to disease (particularly fire blight) for fruit trees (Fazio, et al., 2013). Geneva® apple rootstocks were developed to overcome the limitations present in commercial dwarfing and precocious rootstocks which are sensitive to fire blight (M.9 clones, M.26, O.3, etc.) resulting in the death of the whole tree once infected. Genetic resistance to *E. amylovora* was observed in wild apple species, and this natural resistance was utilized by conventional breeding to develop apple rootstocks genetically resistant to fire blight (G.65, G.11, G.16, G.30, G.202, G.41, G.935, G.213, G.214, G.969, G.890, G.222 and G.210). The use of fire blight resistant rootstocks has been shown to decrease the severity of the disease in susceptible scions (Jensen et al., 2012; Jensen et al., 2011) possibly by changing the expression of genes during the infection (Baldo et al., 2010; Norelli et al., 2009; Norelli et al., 2008). We assume that G rootstocks cost 25% more than comparable M rootstocks (a supplemental $2), which is included as a one-time cost that is paid when the trees are planted (in Year 1). The most notable assumption built into this model is that these rootstocks protect trees from requiring a full replant when exposed to fire blight; trees planted on G rootstocks can simply be pruned back (resulting in a 1-year slowdown in productivity).

Fire blight spray programs have been developed to protect apple trees against climatic conditions associated with the blossom blight infections. The programs typically include a combination of streptomycin and prohexadione calcium spray applications (among others) after specific weather triggers (Aćimović, Higgins, and Meredith, 2019). In this model there are no annual costs associated with this treatment—the only costs are in years where fire blight prediction models recommend application [Maryblyt7.1.1 (Steiner 1990; Turechek and Biggs 2015), CougarBlight (Smith and Pusey 2011), and RIMpro-Erwinia (Philion and Trapman 2011)]. There is a one-time cost for materials and labor in years when the spray program is required. We used prices of protective spray materials available to authors in 2020 and 2021; results could be impacted with changes in material costs related to preferential customer pricing by distributors and market inflation. In our model we considered the impact for an inexperienced grower using the spray program; in this worst-case scenario that employs a non-optimal and untimely spray application results in a 50% reduction in blight severity (e.g., for a 40% blight incidence we would observe only a 20% actual fire blight impact). A more skilled grower with greater familiarity with the fire blight prediction models could achieve reductions in blight by up to 90%. This spray program can be used with either M or G rootstocks, and the rootstocks were assumed to maintain their original properties (so G rootstocks would require pruning but not require a replant, but M rootstocks would require a replant).

Our scenarios that consider the adoption of tree insurance are based on a new risk management product provided through the USDA-RMA and was developed in partnership with AgriLogic Consulting (USDA, Federal Crop Insurance Corporation. 2021). Tree insurance is designed to protect apple farmers from making big up-front investments in their orchards and is modeled, in part, after a similar product that is available to U.S. pecan producers. (USDA-RMA 2020). Tree insurance is different from traditional crop insurance in that it aims to place value on the trees themselves (particularly as plantings become denser and more vulnerable to communicable infections). Within this model there are annual costs associated with tree insurance and premiums are tied to tree age (Stages I, II, & III) and are paid every year. The current rates for tree insurance for the Honeycrisp cultivar are $1,513 (Stage I), $1,299 (Stage II), and $1,699 (Stage III). Our model assumed that the Occurrence Loss Option (OLO) and the Fire Blight Endorsement (FBE) had both been purchased by the orchard owner, the latter of which is mandatory in the Northeast Region of the U.S. With these endorsements an indemnity would be paid any time the damage *exceeds* 10%. Indemnity payments were calculated based on a model provided by New York State crop insurance agents.

Materials and Methods

Our analysis identified the costs and benefits for an orchard owner producing one acre of Honeycrisp over a 15-year period. The costs and benefits were incorporated into a net present value (NPV) model to calculate the net economic benefits associated with the adoption of the various fire blight management strategies over the life of the orchard. This is a widely used tool by agricultural economists to compare the economic outcomes for the adoption of technologies across a range of time horizons. The economic analysis was based on a set of representative costs, yields, and prices that are reflective of those in the industry in New York State. The values we used in our analysis may not always align with those for all growers in all regions. However, the purpose of our analysis was to shed new light on the relative merit of the different strategies to manage fire blight, and our results using representative data are able to provide useful information for orchard owners to address business decisions concerning strategies to manage fire blight.

The NPV framework requires estimates for establishment costs (in the first year), on-going costs that occur each year of production, per acre yields, and prices. Table 1 outlines the main categories of costs that are required to establish an orchard in New York State. Many of these cost items included expenses for materials plus expenses for labor to conduct the work. The top establishment expenses are for land, trees (plus rootstocks), trellising materials, and irrigation equipment. The establishment costs shown in Table 1 are similar in magnitude to those in a recent report outlining establishment costs for Honeycrisp production in Washington State (Gallardo and Galinato 2020). We made several assumptions in our economic

Table 1. Establishment costs for 1 acre of Honeycrisp (on Geneva® rootstocks)

Item	Material/Unit	Quantity	Labor Hours	Labor Rate	Total Cost
Land	$6,000.00	1			$6,000.00
Property Taxes	$150.00	1			$150.00
H2A Housing	$1,000.00	1			$1,000.00
Equipment Depreciation	$250.00	1			$250.00
Soil preparation	$1,242.00	1	1.5	19.99	$1,271.99
Trees	$8.00	1320	1320	0.30	$10,956.00
G Rootstock surcharge	$2.00	1320			$2,640.00
Trellising	$5,000.00	1			$5,000.00
Irrigation Install	$3,200.00	1	53	18.74	$4,193.22
Irrigation Operation	$180.00	1	10	19.99	$379.90
Pruning and Training	$0.00		29	$18.74	$543.46
Hand Thinning			15	18.74	$281.10
Fuel	$3.30	45			$148.50
H2A Transportation	$200.00	1			$200.00
Management	$700.00	1			$700.00
Herbicide	$73.00	1	0.75	19.99	$87.99
Insecticide	$0.00	0	0	19.99	$0.00
Other Fungicide	$300.00	1	2.5	19.99	$349.98
Rodenticide	$29.60	1	0.5	19.99	$39.60
Total					**$34,191.73**

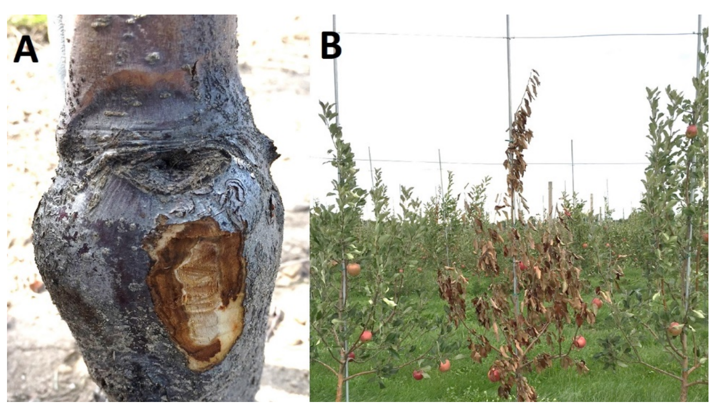

Figure 1. Figure 1. (A) Fire blight canker on apple rootstock with an exposed canker margin. (B) Dead apple tree from rootstock girdling by a fire blight canker (Photo by Wallis A. E. 2016, Cornell Cooperative Extension; re-printed by permission from Aćimović et al. 2023).

analysis, and we outline some of the important assumptions below.

The adverse labor rate in New York State was $14.99 in 2022; given 25% benefits we assumed the hourly wage rate is $18.74. For some technical activities (e.g., spraying and irrigation labor) we included a $1/hour supplement and set the hourly wage at $19.99 per hour for these activities. We assumed that land used for apple orchards is valued at $6,000 per acre and that property taxes are assessed at 2.5% per acre per year. In all our scenarios we assumed that the trees were planted in a tall spindle orchard system, and that the trellising cost were $5,000 per acre including labor.

On the revenue side, we assumed that a bin of apples weighs 800 pounds, and we used an average price per bin of $543.71 based on 2018-2020 prices for Honeycrisp apples sold in New York State. We assumed that apples are sold through a wholesaler and that growers are not responsible for additional marketing costs. In the scenarios that modeled a fire blight incident, we assumed this happened in the fourth year of production. For the scenarios that included Geneva® rootstocks, we assumed that fire blight can be managed via pruning and that yields are delayed by one year. Labor costs for tree pruning (and tree removal in scenarios that include tree removal) were assumed to be twice the original amount that it costs to plant tree. The spray programs were assumed to save 50% of the affected trees. In the scenarios that employed tree insurance, we assumed it is purchased at a 75% coverage level with both the Fire Blight Endorsement and the Occurrence Loss Option (and no Comprehensive Tree Value Insurance).

Table 2. Costs and Revenues in Year 4 (with Geneva® rootstocks and 10% fire blight incidence)

Item	Material/Unit	Quantity	Labor Hours	Labor Rate	Total Cost
Property Taxes	$150.00	1			$150.00
Equipment Depreciation	$250.00	1			$250.00
Trellising	$0.00	0		$19.99	$0.00
Irrigation Operation	$180.00	1	10	$18.74	$367.40
Pruning and Training	$0.00	0	25	$18.74	$468.50
Hand thinning	$0.00	0	35	$19.99	$699.65
Chemical thinning	$250.00	1	5	$18.74	$343.70
Growth regulator	$330.00	1	1	$0.00	$330.00
Fuel	$3.30	45	0	$0.00	$148.50
H2A Transportation	$200.00	1	0	$0.00	$200.00
Management	$700.00	1	0	$0.00	$700.00
Beehive	$50.00	1.2	0	$19.99	$60.00
Herbicide	$200.00	1	2.5	$19.99	$249.98
Insecticide	680	1	7.5	$19.99	$829.93
Fungicide	$300.00	1	10	$19.99	$499.90
Rodenticide	$30.00	1	1		$30.00
Ethylene inhibitor	$500.00	1			$500.00
Crop Insurance	$2,000.00	1		$18.74	$2,000.00
Harvesting			105.84	$18.74	$1,983.44
Packing			162	$18.74	$3,035.88
Potential costs to manage fire blight[a]					
Blight Pruning			132	$0.60	$79.20
Fire blight spray	278.25	0	0	$19.99	$0.00
Tree Removal			132	$0.60	$0.00
Tree Insurance	$0.00	1			$0.00
Total Costs					**$12,926.07**
Apple Sales	**$543.71**	**37.8**			**$20,552.28**
Net Annual Return					**$7,626.21**

[a] The potential costs depend on the scenario being considered. In this example, the Geneva rootstocks were used and therefore the added costs to manage the fire blight incident related only to the tree pruning activities.

Table 2 outlines the annual costs and revenues in Year 4 which is the year when we assumed fire blight occurred and by modeling that year, we could illustrate the impact of the management strategies we considered. Full production is modeled to begin in the sixth year of production at which point many of the cost items increase (relative to those shown in Table 4), crop insurance costs become $3,500 per acre, total costs are approximately $19,300, and yields reach their maximum of 70 bins per acre. The bottom section of Table 2, labeled “Potential costs to manage fire blight” lists four cost items that could be activated depending on the scenario. Table 2 represents the scenario with a 10% incidence of fire blight and the use of G rootstocks. In this scenario the strategy is to prune the infected trees for a cost of $79.20 per acre and yields are delayed by one year for the infected trees.

Table 3 is included to showcase the effect of the fire blight management strategies (and the associated scenarios) on yields, and hence revenues. The first column in Table 3 shows the yields that are modeled in the absence of fire blight; in this case a maximum yield of 70 bins per acre is reached in Year 6. The other columns highlight the effects of either a 10% or 40% fire blight incidence, and the associated management strategy, on yields. The use of the M rootstock with replanting (column 2) or with the spray program (column 5) in Year 4 delay reaching maximum yields by 4 years

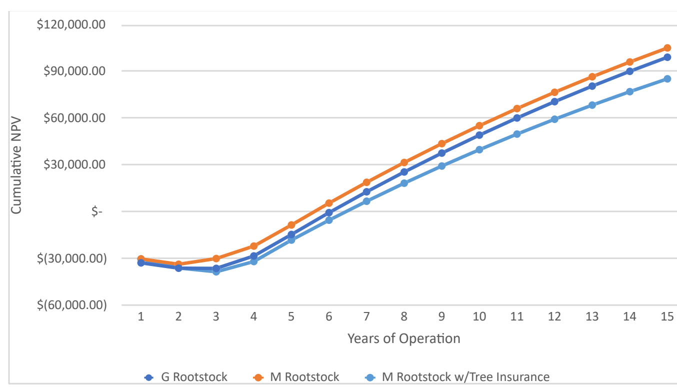

Figure 2. NPV results assuming no fire blight incidence

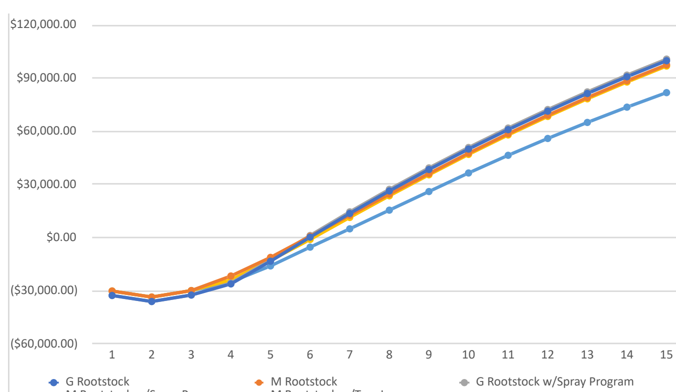

Figure 3. NPV results assuming 10% fire blight incidence in Year 4

(until Year 10). Other strategies with the G rootstocks (with or without the spray program) allow the maximum yield to be delayed by only one year. The final four columns in Table 3 show that as the incidence of fire blight increases, the yields are slower to rebound back to their maximum, and this is most notable for the scenarios with M rootstocks.

Results

The NPV results are presented in a series of figures as a way to parsimoniously show their cumulative values over time. The figures also allow for an illustrative comparison of the net economic returns across the five scenarios. Each figure shows the cumulative NPVs for the relevant scenarios, and the progression of the figures highlights how the NPVs are affected with greater rates of incidence of fire blight in Year 4.

Figure 2 shows the NPVs with three management scenarios for the case with no fire blight incidence in Year 4. Here we do not model scenarios involving the spray programs as these are only triggered with the fire blight prediction models recommending application. In this case we see that the NPV is greatest for the scenario that uses the M rootstock; this makes economic sense as the G rootstocks cost more than the M rootstocks and without fire blight incident(s) the yields are unaffected in Year 4 and thereafter. The result in this case with the M rootstocks also represents the maximum NPV of $105,204.73. The strategy with the lowest NPV (in Figure 2) was the scenario with M rootstocks and the tree insurance (given that there are non-trivial costs to purchase the tree insurance each year).

Figures 3, 4, and 5 consider all five management strategies under various levels of fire blight incidence in Year 4. Figure 3 shows the results for 10% fire blight incidence in Year 4, and in this case, we see that the highest NPV was achieved in the scenarios that implement the pre- and post-infection spray program; the NPV for the case with G rootstocks and the spray program slightly outperforms that with M rootstocks and the spray program, however, the differences were not significant. The NPV for the scenario with M rootstock and tree insurance continued to result in the lowest NPV. In Figure 4 we find qualitatively similar results as those in Figure 3, yet in this case with 25% fire blight incidence in Year 4, the NPVs for the strategies that include G rootstocks (with or without the spray programs) and the strategy with M rootstocks and the spray program are noticeably higher compared to the management strategy with only M rootstocks. With 25% fire blight incidence in Year 4, the strategy that employs tree insurance (with the M rootstocks) yields the lowest NPV again.

In Figure 5 we show the NPV results for the case with a significant fire blight incident in Year 4 (40% incidence). Now we see greater differences in the calculated NPVs across the five strategies. A NPV of approximately $100,000 is found for the scenario employing G rootstocks and the spray program; this is in line with the maximum NPV achieved with various strategies when the fire blight incidence was 0%, 10%, and 25%. However, with the 40% incidence level, the other strategies (G rootstocks alone and M rootstocks with the spray program) begin to generate less NPV compared to the strategy employing the G rootstocks and

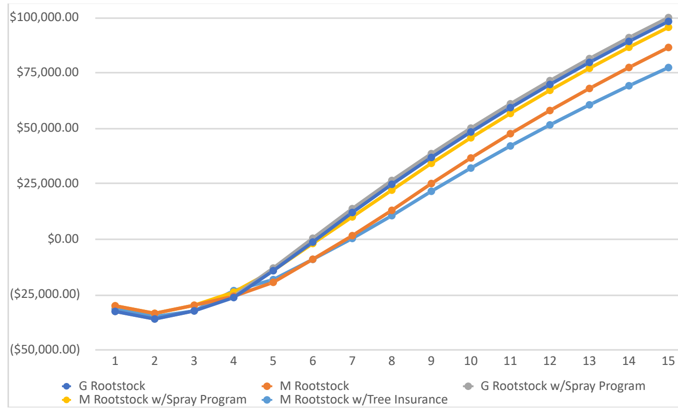

Figure 4. NPV results assuming 25% fire blight incidence in Year 4

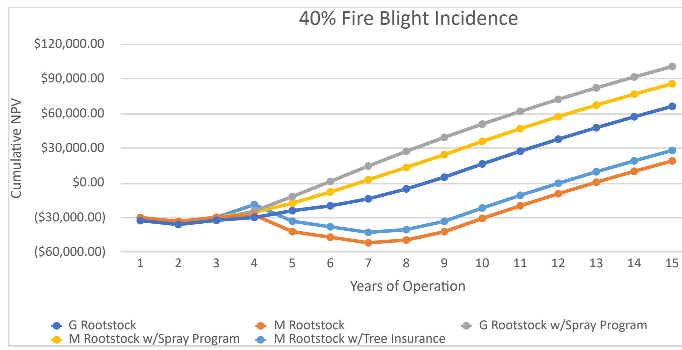

Figure 5. NPV results assuming 40% fire blight incidence in Year 4

Table 3. Assumptions on the effect of fire blight on yields (10% and 40% fire blight incidence scenarios shown)

Year	M rootstock, no fire blight	M rootstock with 10% fire blight, spot replant	Geneva rootstock with 10% fire blight, spot pruning	Geneva rootstock with 10% fire blight, spray program	M rootstock with 10% fire blight, spray program	Geneva rootstock with 40% fire blight, spot pruning	M rootstock with 40% fire blight, full replant	Geneva rootstock with 40% fire blight, spray program	M rootstock with 40% fire blight, spray program and replant
Bins per acre									
1	0	0	0.0	0.0	0.0	0	0	0	0
2	0	0	0.0	0.0	0.0	0	0	0	0
3	23	23	23.0	23.1	23.1	23	23	23	23
4	42	37.8	37.8	39.9	37.8	25.2	25.2	38.22	33.6
5	56	50.4	54.6	55.3	50.4	33.6	0	53.2	44.8
6	70	63	68.6	69.3	63.0	42	0	67.2	56
7	70	65.31	70.0	70.0	67.7	51.24	23	70	60.62
8	70	67.2	70.0	70.0	68.6	58.8	42	70	64.4
9	70	68.6	70.0	70.0	69.3	64.4	56	70	67.2
10	70	70	70.0	70.0	70.0	70	70	70	70
11	70	70	70.0	70.0	70.0	70	70	70	70
12	70	70	70.0	70.0	70.0	70	70	70	70
13	70	70	70.0	70.0	70.0	70	70	70	70
14	70	70	70.0	70.0	70.0	70	70	70	70
15	70	70	70.0	70.0	70.0	70	70	70	70

the spray programs. Finally, the NPV drops considerably for the strategies that use only M rootstocks and M rootstocks with tree insurance when there is a 40% incidence of fire blight. Interestingly, in this case we see that the strategy using tree insurance no longer generated the lowest NPV.

Discussion

Fire blight is a significant issue facing apple growers in the Northeast. Our research examines the economic implications associated with different strategies to manage and/or control the pathogen. The analysis also considers the efficacy of the strategies across different levels of incidence of fire blight (i.e., average intensity rate of infection in the tree canopy). Results show that even with low levels of fire blight incidence, there are clear economic benefits from adopting G rootstocks relative to M rootstocks. For the case with 10% fire blight incidence, the adoption of G rootstocks leads to a NPV of $99.830.85 compared to $97,530.85 with M rootstocks; this is equivalent to an additional $2300 per acre over the 15-year period. Furthermore, coupling the spray program with the G rootstocks increases the NPV to $100,738.48 (an increase of $3207.63 per acre compared to the M rootstocks) with 10% fire blight incidence. Additional results that model the effects with 25% and 40% incidence of fire blight showcase even stronger evidence on the economic case to adopt G rootstocks (coupled with the spray applications based on the fire blight prediction models).

M rootstocks are still widely planted in the United States and elsewhere and we expect this trend is likely to continue until we experience a greater number of fire blight epidemics in the future. In the last 20 years there has been a strong dependence of apple industry on M.9 rootstock in high density apple orchards (Russo et al. 2007). M.9 rootstock is widely available because in nursery stool beds, M.9 rootstock “mother plants” are more productive in growing rootstock liners when compared to G rootstock mother plants. However, M.9 is extremely susceptible to fire blight and in years with devastating fire blight epidemics, more than 50% to 60% apple tree mortality is often recorded in orchards on M.9 rootstock (Breth 2008; Ferree et al. 2002; Norelli et al. 2003a; Robinson et al. 2007). Therefore, the fire blight resistant G rootstocks are a key integral part of growers’ long-term economic insurance against violent fire blight epidemics protecting trees and trellis systems.

Tree insurance products made available by the USDA-RMA show some promise in certain situations (high incidence of fire blight and relative to M rootstocks). However, our results indicate that tree insurance is economically inferior to the adoption of G rootstocks across all incidence levels of fire blight considered. This finding is driven largely by the non-trivial annual cost of premiums required to adopt tree insurance in apple production.

The economic results presented here are for a representative acre producing Honeycrisp apples in New York State. Extensions to our work should consider the effects of fire blight management strategies for other cultivars, in other regions, and across a range of tree density/orchard designs. Lastly, although the focus of this research is to examine the economic implications of managing fire blight in apple production, our modeling framework could be augmented to consider the economic consequences of pathogens that impact production of other perennial fruit crops, and strategies that could be employed to manage such pathogens.

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Bradley Rickard is a professor of food and agricultural economics at Cornell University. **Srđan Aćimović** is an Assistant Professor of Tree Fruit and Specialty Crop Pathology at the Alson H. Smith Jr. Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University. **Gennaro Fazio** is a research scientist who leads the Cornell/USDA apple rootstock breeding program at Geneva, NY. **Casey Silver** completed her MS in the Dyson School of Applied Economics and Management at Cornell University and now works as an Insights Analyst with McKinsey & Company in Cambridge, MA.

New Releases from the Geneva® Apple Rootstock Breeding Program

Gennaro Fazio[1] and Terence Robinson[2]

[1]Plant Genetics Resources Unit, USDA/ARS, Geneva, NY 14456 | [2]School of Integrative Plant Science, Horticulture Section, Cornell University AgriTech Campus, Geneva, NY 14456

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In this article we announce the release of three semi-dwarfing, disease resistant and highly productive apple rootstocks. G.257, G.484 and G.66

Since its inception the Geneva apple rootstock breeding program has had the objective of breeding rootstocks with disease resistance (Aldwinckle et al. 1974, Aldwinckle et al. 1976; Cummins and Aldwinckle 1974). This emphasis has resulted in the release of several apple rootstock varieties (G.11, G.16, G.41, G.935, G.214, G.213, G.210, G.969, G.890) which are resistant to several rootstock diseases such as fire blight, apple replant disease complex, crown and root rot caused by *P. cactorum* (Fazio et al. 2022), and insects such as woolly apple aphid. While disease and insect resistance has been the main goal of the breeding program, whole orchard productivity, a trait influenced by dwarfing, early bearing and the propensity of the rootstock to impact partitioning of photosynthate away from excessive vegetative growth and into fruit production have been essential parameter used to select all new apple rootstocks.

More recently, the program has been focusing on additional traits that modulate fruit quality, including the ability of apple rootstocks to increase the average fruit size of grafted cultivars, or modify its nutrient profile including the ratio like potassium/calcium which can lead to more or less bitter pit in apples depending on what nutrients rootstocks promote in a particular environment (Fazio et al. 2018a; Fazio et al. 2018b). Among the rootstocks we have released we have discovered two contrasting apple rootstocks in G.41 and G.214 in terms of absorption of potassium and nitrogen (high in G.41 and low in G.214) which leads to very different outcomes with regards to fruit quality of 'Honeycrisp'. This has resulted in very different fertilization management for each rootstock in order to produce the best outcome. In the same realm of tree nutrition, G.935 is exceptional at mining boron from the soil and sending it to scion – a trait which might contribute to yield efficiencies that are 110-135% of M.9 which is known to be very poor at up taking boron. This positive outcome is great for apple growers that remember this fact and apply less boron on G.935 trees to avoid phytotoxicity. Similarly, more apple growers are converting their operations from conventional management to organic management which requires apple rootstocks that are better able to mine nutrients from the soil like nitrogen, potassium, and phosphorous in a very different soil environment than conventionally managed orchards.

Another trait that might be important to apple growers in the Southern tier of U.S. apple orchards where chilling hours are often less than ideal is the ability of G.213 and other similar rootstocks to decrease the chilling requirement of grafted scions. This can result in more uniform bud break in the spring than currently seen with traditional rootstocks.

Another trait (or problem) that we have seen in the Geneva breeding program is one of brittle graft unions with some scion/rootstock combinations where Cripps Pink/G.41 is very brittle and Cripps Pink/G.214 is very strong. In addition, several novel scion varieties like NY-1 (SnapDragon) have weak growing habits and need stronger rootstocks to support productivity and canopy development. Some apple orchards are also leveraging increased the increase vigor of semi-dwarfing Geneva rootstocks which induce early bearing to establish multi-leader training systems with planar canopies.

As we learn more about each of the Geneva® rootstocks, it is clear that each has many positive traits but also has negative traits. In addition, each orchard is unique in its soil and climate characteristics. This combined with different scion cultivar characteristics and vigor means that no one rootstock is the best choice in all situations. This leads us to continue to look for new rootstocks which are better in certain niche situations than all other rootstocks. All these considerations, in addition to new nursery and field performance results have led the Geneva® apple rootstock breeding program jointly conducted by U.S. Department of Agriculture – Agricultural Research Service, and Cornell University to release three new rootstocks this year: Geneva® 257 (G.257), Geneva® (G.484), and Geneva® (G.66).

Apple Rootstock Geneva® 257 (G.257)

This new semi-dwarfing apple rootstock named Geneva®257 (G.257) has been in testing in the breeding program since the late 1970's and has appeared in national tests as CG.5257 (Figure 1). Apple rootstock G.257 was selected as a young seedling by surviving challenges with organisms that cause phytophthora crown

Figure 1. NY1 (SnapDragon) on G.257 in a field trial in the Hudson Valley, NY State.

rot in apple rootstocks and inoculation with fire blight (*Erwinia amylovora*) demonstrating tolerance or resistance to the pathogens that were used for these tests (Fazio et al. 2015b). This selection was followed by a decades long process that included multiple trial plantings in New York state as a finished tree grafted with different scions including Empire, Gala, Fuji, Golden Delicious, Honeycrisp, NY-1 and Mutsu.

The performance of G.257 in these trials showed it is a semi-dwarf (40-50% of seedling rootstock) whose productivity, yield efficiency and disease resistance are in the superior category among the rootstocks tested (Reig et al. 2018). This rootstock was particularly successful in displaying high productivity and fruit size of NY-1 scions (Table 1).

In the rootstock layer bed nursery, G.257 displays mostly straight shanks with low-medium spine production. The layer bed of G.257 is at least as productive as an M.26 layer bed. G.257 was also evaluated for liner production in a rootstock nursery for more than 10 years in Geneva, NY and displayed acceptable rooting properties which can be improved by the application of prohexadione calcium after the first mounding. G.257 was subjected to bench grafting and budding tests with different scion varieties to evaluate success rate and healing of buds in several finished tree nurseries showing good healing and production of finished trees.

G.257 rootstock was also tested independently on apple grower farms located in multiple testing environments and in several U.S. states which revealed the ability of this rootstock to produce larger fruit and achieve high productivity (Auvil et al. 2011; Fazio and Robinson 2021; Robinson et al. 2011a).

Testing of G.257 with extreme cold treatments in fall and spring seasons in Maine indicated normal acclimation and good tolerance to cold in the fall but a potential sensitivity of cambial tissues in the springtime (Moran et al. 2018; Moran et al. 2021).

Testing of nutrient and micronutrient content of leaves and fruit at multiple sites and with multiple grafted scions revealed superior absorption and translocation of boron, potassium and nitrogen (depending on soil type and scion) and medium levels of calcium (Fazio et al. 2015a; Reig et al. 2018).

In preparation for release, clonal material of G.257 was tested for common latent apple viruses (ASPV, ASGV, ACLSV, ToRSV, etc.) and other viral or viroid particles using multiple rounds of High Throughput Sequencing (HTS) which showed negative results (Bettoni et al. 2022). G.257 when grafted with virus laden wood might display sensitivity and stunting depending on viral load and type, therefore it is highly recommended that only certified graft wood and bud wood be used in the nursery and orchard establishment stages.

Certified clonal material of G.257 was placed in a sterile micro-propagation regime which showed good properties of propagation, cycling and acclimation percentages. Media recipes and protocols for micropropagation of G.257 are available upon request.

A recently completed 10-year trial with G.257 using NY1 as the scion variety showed that G.257 produces a tall spindle tree that fills the space by the end of the 3rd years while trees on M.9 did not fill the space ever (Table 1). Production on G.257 was higher, fruit size was larger and biennial bearing was lower than with M.9. Estimates of the planting density required to equal the production of G.257 planted at 1157 trees/acre (3'X12') indicated that M.9 would need to be planted at almost double the density (2178 trees per acre 2'X11'). In the Geneva trial, G.257 was the best rootstock for NY1 and its release and commercialization will be a great benefit to growers of this variety.

Figure 2. Honeycrisp on G.484 in a farm trial in upstate NY.

Apple Rootstock Geneva® 484 (G.484)

Geneva®484 (G.484) apple rootstock is a semi-dwarfing rootstock that is being released because it induces early bearing on grafted scions, is highly productive, yield efficient and resistant to fire blight (*Erwinia amylovora*). When fully developed, this rootstock produces trees that are 35-45% the size of a standard apple seedling tree (Figure 2). G.484 has been tested in the breeding program in NY since the late 1980's and has entered national and international tests as selection CG.4004. The initial stages of selection for G.484 began with inoculation with fire blight (*Erwinia*

Table 1. Performance of G.257 rootstock compared to other named rootstocks with 'NY1' (Snapdragon) as the scion at Geneva, NY from 2013-2022.

Rootstock	Trunk Cross-Sectional Area (cm2)	Cum. Fruit Number per Tree	Cum. Yield (kg/tree)	Cum. Yield Efficiency (kg/cm2 TCA)	Average Fruit Size (g)	Fruit Size adjusted for Crop Load (g)	Average Crop Load (no/cm2 TCA)	Cum. Suckers (no.)	Biennial Bearing Index (0-1)	Projected Optimum Planting Density based on TCA (trees/acre)	Projected Cum. Yield at Optimum Density (bu/acre)
M.9T337	19.6	629	87	4.9	173	177	5.9	20	0.47	2,178	10,421
M.26	20.7	614	89	4.4	176	179	5.4	5	0.44	2,062	10,140
G.11	22.5	788	121	5.5	185	189	5.8	1	0.45	1,897	12,725
G.214	26.4	763	112	4.3	174	173	4.9	34	0.37	1,617	10,006
G.814	33.2	907	132	4.2	184	183	5.0	16	0.45	1,286	9,406
G.935	33.3	997	138	4.2	177	178	5.4	5	0.47	1,282	9,767
G.222	36.0	674	107	3.0	178	172	3.5	42	0.41	1,186	7,036
G.257	36.9	968	159	4.4	189	188	4.7	16	0.35	1,157	10,188
LSD $P \leq 0.05$	5.7	128	20	0.7	7	6	0.8	16	0.06		

*Rootstocks ranked by increasing trunk cross-sectional area.

amylovora) and a challenge with organisms that cause phytophthora crown rot in apple rootstocks where it displayed its inherited resistance to the pathogens used in the inoculation procedures. This initial selection was followed by decades long research which included multiple plantings in New York as a finished tree grafted with different scions including Gala, Fuji, Golden Delicious, and Mutsu where productivity, yield efficiency and disease resistance were examined and deemed to fall in the superior category among the rootstocks tested (Robinson et al. 2011b; Russo et al. 2007).

G.484 was also evaluated for liner production in a rootstock nursery for more than 10 years in Geneva, NY and displayed acceptable rooting properties, minor production of spines and straight upright liners. Layer beds of G.484 are at least as productive as M.9 layerbeds. G.484 was subjected to bench grafting and budding with different scion varieties to evaluate success rate and healing of buds in several finished tree nurseries showing no major issues with healing and production of finished trees.

Additional testing in the nation-wide rootstock testing network NC-140 confirmed the desirable horticultural performance of G.484 as one of the most yield efficient rootstocks in its size category (Autio et al. 2020a; Autio et al. 2020b) and revealed that in certain sites it may produce a limited number of root suckers. This rootstock was also tested independently on apple grower farms that featured organic and conventional management practices, revealing similar superior performance in both.

Testing of nutrient and micronutrient content of leaves and fruit at multiple sites and with multiple grafted scions revealed superior absorption and translocation of potassium and medium levels of calcium which makes this rootstock more suitable for scion varieties that are not sensitive to bitter pit caused by an unbalanced K/Ca ratio (Fazio et al. 2020), however, in orchards under organic management this rootstock seemed to have higher uptake of nitrogen and potassium which propelled the trees into a high level of productivity.

In preparation for release clonal material of G.484 was tested for common latent apple viruses (ASPV, ASGV, ACLSV, ToRSV, etc.) and other viral or viroid particles using multiple rounds of High Throughput Sequencing (HTS) which showed negative results. G.484 when grafted with virus laden wood might display sensitivity and stunting depending on viral load and type, therefore it is highly

Table 2. Performance of G.484 rootstock in comparison with other named rootstocks with 'Honeycrisp' as the scion at 8 locations in North America (BC, MA, MI, MN, NS, NY, OH, WI) from 2010-2017. (Extracted from Autio et al., 2020b).

Rootstock	Trunk Cross-sectional Area 2017 (cm2)	Survival 2010-17 (%)	Cum. Root Suckers 2010-17 (no/tree)	Cum. Yield/tree 2011-17 (kg)	Biennial Bearing Index (0-1)	Cum. Yield Efficiency 2011-17 (kg/cm2 TCA)	Average Fruit Size 2012-17 (g)	Projected Optimum Planting Density based on TCA (trees/acre)	Projected Cum. Yield at Optimum Planting Density 2011-17 (bu/acre)
B.9	10.2	99	9.8	44	0.55	4.37	204	3,224	7,838
G.11	13.6	89	5.1	69.9	0.56	5.08	208	2,418	9,339
M.9T337	15.1	95	11.4	62.6	0.56	4.3	209	2,178	7,533
B.10	15.6	95	2.4	69	0.54	4.57	208	2,108	8,037
M.9Pajam2	16.7	92	21.3	62.1	0.56	3.81	204	1,969	6,757
G.41	17.1	88	1.8	75.5	0.55	4.51	216	1,923	8,022
G.202	17.5	89	13.9	66.3	0.57	3.88	199	1,879	6,884
G.214	17.7	93	32	82	0.53	4.85	202	1,858	8,418
G.935	18.7	84	16.7	82.5	0.58	4.47	204	1,759	8,016
M.26EMLA	18.8	87	7.7	61.5	0.59	3.37	212	1,749	5,944
G.814	19.5	76	17.4	79.3	0.53	4.12	185	1,687	7,389
G.222	22.9	83	23.4	76.6	0.55	3.6	207	1,436	6,078
G.484	28.9	98	11.6	105.7	0.57	3.81	215	1,138	6,646
Estimated HSD	4.6	17	8.5	12.8	0.1	0.67	18	205	1,712

***Rootstocks ranked by increasing trunk cross-sectional area.**

Table 3. Performance of G.484 rootstocks in comparison with other named rootstocks with 'Aztec Fuji' as the scion at 6 locations in North America (ID, KY, NC, NY and UT) from 2010-2017. (Extracted from Autio et al., 2020a).

Rootstock	Trunk Cross-sectional Area 2017 (cm2)	Survival 2010-17 (%)	Cum. Root Suckers 2010-17 (no/tree)	Cum. Yield/tree 2011-17 (kg)	Biennial Bearing Index (0-1)	Cum. Yield Efficiency 2011-17 (kg/cm2 TCA)	Average Fruit Size 2012-17 (g)	Projected Optimum Planting Density based on TCA (trees/ha)	Projected Cum. Yield at Optimum Planting Density 2011-17 (MT/ha)
B.9	17.9	97	14	59	0.58	3.23	167	2,905	9,022
G.214	32.5	100	14.1	93	0.6	3.16	193	1,600	7,833
G.202	36.9	100	17.8	98	0.63	2.82	180	1,409	7,270
B.10	37.6	91	2.8	94	0.62	2.66	199	1,383	6,843
M.9T337	39.4	79	15.2	100	0.65	2.88	195	1,320	6,947
G.11	41.6	97	4.1	105	0.63	2.83	205	1,250	6,909
M.9Pajam2	46.4	81	29.6	108	0.62	2.48	196	1,121	6,371
G.935	47.1	94	11.2	143	0.59	3.35	198	1,104	8,311
G.814	47.8	95	20.1	111	0.61	2.61	187	1,088	6,356
G.41	48.3	100	3.4	123	0.62	2.49	211	1,077	6,971
G.484	59.9	100	13.4	149	0.65	2.63	214	868	6,809
G.222	60.6	100	19.5	124	0.64	2.14	201	858	5,601
M.26EMLA	72.6	84	1.9	113	0.66	1.68	210	716	4,260
Estimated HSD	13	20	15.7	23	0.12	0.65	17	2,905	9,022

***Rootstocks ranked by increasing trunk cross-sectional area.**

recommended that only certified graft wood and bud wood be used in the nursery and orchard establishment stages.

Certified clonal material of G.484 was placed in a sterile micro-propagation regime which showed good properties of propagation cycling and acclimation percentages. Media recipes and protocols for micro-propagation of G.484 are available upon request.

G.484 was included in two nationwide trials of rootstocks conducted from 2010-2017. One trial used Honeycrisp as the scion at 8 locations and the other trial used Fuji as the scion at 5 locations. With Honeycrisp, G.484 had good survival and produced a tree larger than M.26 and had the highest yield per tree among the stocks evaluated (Table 2). The optimum planting density for G.484 was estimated to be 1157 trees/acre (3'X12') while more dwarfing stocks such as M.9 would require 2178 trees/acre (2'X10') and B.9 would require 3224 trees/acre (1.3'X10'). With Fuji as the scion, G.484 was smaller than M.26 but produced the highest yield per tree among all the rootstocks evaluated in the trial (Table 3). The optimum planting density for G.484 with Fuji was estimated to be 868 trees/acre (3.9'X13') while M.9 would require 1320 trees/acre (3'X11') to produce the same yield.

G.484 appears to be a good choice on weak soils or under organic management due to its good uptake of N and K. Although the good uptake of K with this stock would make a poor choice with Honeycrisp, its good growth on weak soils or under organic management would make it an excellent choice with other weak cultivars since it will fill the allotted space rapidly and will produce high yields.

Apple Rootstock Geneva® 66 (G.66)

Geneva® 66 (G.66) is a semi-dwarfing (35-40% of seedling), red leafed, precocious and productive rootstock which is resistant to fire blight (Figure 3). G.66 has been in testing in the breeding program since the late 1970's and appeared in national and international trials as CG.6006. G.66 underwent greenhouse and field resistance testing for fire blight (*Erwinia amylovora*) and crown and root rot caused by *Phytophthora* species. The process of selection of G.66 included more than 30 years of field testing that featured multiple locations/environments and scion varieties which included Empire, Gala, Fuji, Golden Delicious, and Honeycrisp (Robinson

Figure 3. Torres Fuji on G.66 rootstock in a trial in Washington State.

Table 4. Performance of G.66 rootstock in comparison with other named rootstocks with 'Fuji' at Milton NY from 2005-2015. (Extracted from Reig et al., 2018).

Rootstock	Trunk Cross-sectional Area (cm2)	Tree Survival (%)	Cum. Fruit Number	Cum. Yield (kg/tree)	Cum. yield efficiency (kg/cm2 TCSA)	Average fruit size (g)	Cum. Crop Load (fruit/cm2 TCSA)	Cum. No. Root Suckers	Biennial Bearing Index (0-1)	Projected Optimum Planting Density (trees/acre)	Projected Cum. Yield at Optimum Planting Density (bu/acre)
M.9	36	80	1346	262	7.4	200	38	0.0	0.3	1,320	18,223
G.202	39	100	792	165	4.2	192	20	0.5	0.4	1,218	10,588
M.26	47	90	1239	241	5.5	201	28	0.0	0.4	1,005	12,727
G.214	56	100	1281	256	5.0	202	25	0.1	0.2	850	11,458
G.66	64	80	2369	446	7.1	195	38	1.0	0.3	743	17,441
G.935	66	100	1667	343	5.3	209	26	0.1	0.3	720	13,005
G.814	68	70	1158	219	3.3	187	18	1.0	0.4	701	8,090
G.484	72	100	1929	386	5.5	203	28	0.6	0.3	659	13,386
G.257	73	90	1447	296	4.2	209	21	0.1	0.3	654	10,166
G.222	74	100	1663	331	4.7	205	24	0.0	0.3	647	11,260
G.969	75	100	2379	431	6.0	186	33	0.6	0.3	632	14,328
G.210	89	100	1845	360	4.1	204	21	0.6	0.3	535	10,139
G.890	89	75	1971	400	4.6	214	23	2.0	0.4	533	11,221
MM.106	94	90	2317	460	5.0	204	26	0.4	0.3	506	12,239
M.7	100	100	1619	344	3.7	220	17	19.2	0.4	475	8,595
LSD P < 0.05	22	22	308	62	0.9	15	5	1.9	0.1		

***Rootstocks ranked by increasing trunk cross-sectional area.**

et al. 2011b; Russo et al. 2007). G.66 was consistently rated high in horticultural performance and productivity where in a trial with Fuji scion in the Hudson valley it displayed the highest cumulative production in its size category (Reig et al. 2017).

Graft unions with G.66 are generally strong. G.66 has displayed a good potassium to calcium balance in several experiment with scion varieties like Fuji and Honeycrisp, making it less prone to bitter pit induction than other rootstocks (Fazio et al. 2015a; Reig et al. 2018).

In the rootstock layer bed nursery, G.66 displays mostly straight shanks with low-medium spine production. The layer bed of G.66 is at least as productive as a M.26 layer bed. G.66 was also evaluated for liner production in a rootstock nursery for more than 10 years in Geneva, NY and displayed acceptable rooting properties which can be improved by the application of prohexadione calcium after the first mounding. G.66 was subjected to bench grafting and budding with different scion varieties to evaluate success rate and healing of buds in several finished tree nurseries showing good healing and production of finished trees.

Certified clonal material of G.66 was placed in a sterile micro-propagation regime which showed good properties of propagation, cycling and acclimation percentages. Media recipes and protocols for micro-propagation of G.66 are available upon request.

In preparation for release, clonal material of G.66 was tested for common latent apple viruses (ASPV, ASGV, ACLSV, ToRSV, etc.) and other viral or viroid particles using multiple rounds of High Throughput Sequencing (HTS) which showed negative results (Bettoni et al. 2022). G.66 when grafted with virus laden wood might display sensitivity and stunting depending on viral load and type, therefore it is highly recommended that only certified graft wood and bud wood be used in the nursery and orchard establishment stages.

G.66 was included in rootstock conducted in the Hudson Valley of NY from 2005-2015 with Fuji as the scion variety. G.66 had excellent survival and produced a tree larger than M.26 but smaller than M.7 and MM.106. It had the highest yield per tree among the stocks evaluated (Table 4). The optimum planting density for G.66 with Fuji was estimated to be 743 trees/acre (4.2'X12') while M.9 would require 1320 trees/acre (3'X11') to produce the same yield.

G.66 appears to be a good choice for weak cultivars like Honeycrisp because it has a good K/Ca ratio. It also would be a good stock for multi-leader trees since its vigor level will allow the trees to rapidly grow several leaders on each tree and thus fill the allotted space rapidly resulting in high yields.

Conclusions

The three newly released rootstocks from the Geneva rootstock program have performed well in local and national trials. Virus free budwood has been sent to licensed nurseries and commercial quantities of these rootstocks should be available in 1-2 years. They expand the list of released Geneva® rootstocks to 18 varieties and give apple growers new options for conventional and organic production. Each of the three new rootstocks has unique advantages in specific situations of climate, soil type, cultivar and management system. As they are planted more widely and in commercial quantities, their niche in the apple industry will become more clear.

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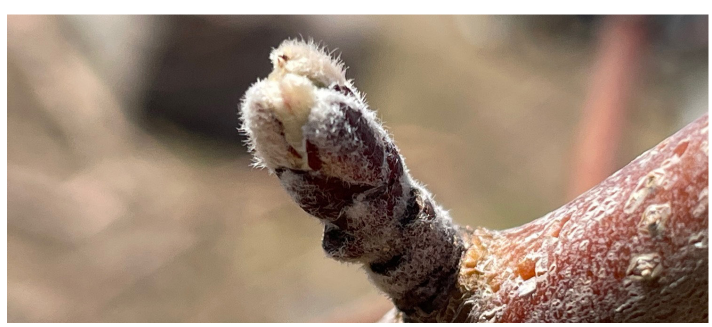
Gennaro Fazio is a research scientist with the USDA-ARS who leads the Geneva apple rootstock breeding program. **Terence Robinson** is a research and extension professor at Cornell University who is the co-leader of the Geneva apple rootstock breeding program.

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