FINAL PROJECT REPORT

Project Title: Mechanized thinning for labor efficient tree fruit cropload management

PI: James Schupp
Organization: Penn State Univ.
Telephone: (717)677-6116
Email: jrs42@psu.edu
Address: 222 Farmhouse Road
Address 2: Fruit R and E Center
City: Biglerville
State/Zip: PA 17307

Co-PI(2): Karen Lewis
Organization: WA State Univ
Telephone: (509)754-2011
Email: kmlewis@wsu.edu
Address: POB 37
Address 2: Courthouse
City: Ephrata
State/Zip: WA 98823

Co-PI(3): Tara A. Baugher
Organization: Penn State University
Telephone: (717) 334-6271
Email: Tab36@psu.edu
Address: 670 Old Harrisburg Rd
Address 2: Suite 204
City/State/Zip: Gettysburg, PA 17325

Co-PI (4): James Remcheck
Organization: Penn State University
Telephone: 717.334.6271
Email: jar@psu.edu
Address: 670 Old Harrisburg Rd
Address 2: Suite 204
City/State/Zip: Gettysburg, PA 17325

Cooperators: Tory Schmidt and WTFRC internal program, Katie Ellis, Penn State University; Steve Miller, USDA-ARS; Washington and Pennsylvania Fruit Growers; Craig Hornblow, New Zealand First, Michael Blanke, Matt Peters

Other funding sources

Agency Name: USDA CSREES / SCRI – Innovative Technologies for Thinning of Fruit
PA Peach and Nectarine Board
Amount awarded: $1M plus $1M non federal match

Total Project Funding: **Year 1**: 25,172 **Year 2**: 26,304 **Year 3**: 27,594

Budget History: Penn State University

Item	2008	2009	2010
Salaries	6,387	6,611	6,842
Benefits	1,648	1,706	1,765
Wages	3,840	3,840	3,840
Benefits	315	315	315
Equipment	0	0	0
Supplies	1,000	1,000	1,000
Travel	0	0	0
Total	13,190	12,971	13,262

Budget History: Washington State University

Item	2008	2009	2010

Salaries	0	0	0
Benefits	0	0	0
Wages	1,700	0	0
Benefits	282	0	0
Equipment	0	0	0
Supplies	500	2,000	1,500
Travel	1,500	2,832	3,500
Total	3,982	4,832	5,000

Objectives:

1. Evaluate the effect of timing on efficacy of mechanical blossom thinning, relative to peach, apricot, nectarine or apple bloom stages (2008-2009).
2. Evaluate several labor-efficient thinning methods in various combinations. (2008-2010).
3. Evaluate hydraulic controls for positioning the string thinner spindle (2010)
4. Evaluate string pattern as a method of increasing thinner efficacy (2010).
5. Evaluate the University of Bonn Bonner string thinner in apples and cherries (2009-2010)
6. Establish operational parameters for Darwin and Bonner string thinners (2010)

Significant Findings, Objective 1: Completed

- The Darwin string thinner was an effective mechanical thinner every year of the study, consistently reduced follow-up hand thinning and increased fruit size in PA studies. In WA soft fruit organic block trials the Darwin effectively thinned bloom and significantly reduced follow up hand thinning each year across species. When compared to hand bloom thinned, we maintained or slightly increased final fruit size.
- There is a wide window of time during which the string thinner is effective for blossom thinning stone fruit. Blossom thinning with the string thinner was more effective between 20% bloom and petal fall than at earlier bud stages in 2008, while in 2009 thinning with the string thinner was more effective at petal fall than at earlier bud stages. WA studies were limited to nectarine and apricot and in both – across 3 years, the effective window for thinning is pink through petal fall, with greatest thinning at 60% - petal fall. Thinning efficacy can be manipulated with spindle speed and tractor ground speed.
- The Darwin string thinner is effective at removing apple cluster and / or bloom. Cluster thinning can be accomplished at and prior to partial-full separation. Bloom thinning can be accomplished at any time post full separation and right before full bloom (open king, a few open sides and a few balloon sides). Full bloom and petal fall applications may result in fruit damage.

Significant Findings, Objective 2: Completed

- Combinations of the string thinner at bloom followed by green fruit thinning with a drum shaker were highly effective thinning combinations.
- Blossom combinations of the Peach drum shaker at bloom followed by green fruit thinning with the drum shaker were no more effective than a single green fruit treatment with the drum shaker.
- The 1.25 inch diameter nylon rods on the original USDA and grower-built drum shakers, while necessary to the original purpose of shaking citrus fruit, are too large for thinning peach blossoms or green peaches, and are prone to damaging the bark of the scaffold limbs.
- While it appeared that two drums might be somewhat more consistent for thinning than a single drum, a single drum was effective and resulted in less limb breakage.

- The earlier peach drum shaker prototype was most effective as a peach thinner when operated at 350 cpm. Subsequent studies showed peach fruit removal was about the same from 300 - 400cycles per minute, and there was no clear trend in damage incidence from increasing the cycles per minute.
- Qualitative studies with a smaller drum shaker that was designed by Dr. Don Peterson at AFRS for harvesting raspberries demonstrated that a smaller machine with smaller nylon rods can be very effective for thinning peaches and this design was used to develop a new drum shaker prototype designed especially for thinning peaches.
- The ability to tilt the drum of the single drum shaker peach thinner prototype so that the rods were perpendicular to the scaffolds was beneficial. Adapting the drum shaker so that it could be mounted in front instead of behind the driver also improved performance and operator ergonomics.

Significant Findings, Objective 3: Completed

- Operating the Darwin string thinner with new hydraulic controls in perpendicular V peach trees provided thinning equal to (in White Lady), or better (in Saturn) than that provided by standard positioning by tractor.

Significant Findings, Objective 4: Completed

- String pattern on the Darwin spindle does not appear to be an important parameter for thinning of stone fruit.

Significant Findings, Objective 5: Completed

- The Bonner string thinner is effective as a bloom thinner in both apples and cherries
- Severity of thinning can be manipulated by same operational variables as the Darwin
- The Bonner allows for greater cord to wood contact in 3D systems

Significant Findings, Objective 6: In process

Results and Discussion

<u>Objective 1. Bloom Stage/ Equipment</u>

Thinning of blossoms or fruitlets is a labor-intensive requirement in the production of peach, nectarine and apricot fruit of optimum size and quality. Prior research conducted by the authors on string blossom thinners for managing peach tree cropload demonstrated that this new technology reduces labor requirement and improves fruit size. Research supported by WTFRC was conducted in PA over two years on ‘Sugar Giant peach and ‘Arctic Sweet’ nectarine to evaluate string blossom thinner efficacy at variable stages of bloom development, ranging from pink to petal fall. WTFRC soft fruit trials in WA include ‘Grand Bright’ and ‘WA Pride’ nectarine and ‘Robada’ and ‘GoldBar’ apricot and ‘Gala’, ‘Golden Delicious’, ‘Granny Smith’ ‘Honeycrisp’ and ‘Fuji’ apple trials.

Drum shaker technology was also developed and evaluated to reduce the cost and time required for hand thinning peach. This study evaluated spiked drum shakers for thinning at bloom or at the green fruit (pit hardening) stage. Five trials were conducted over two years in grower orchards with trees trained to a perpendicular V system to compare various drum shaker prototypes, alone, and in combination with the Darwin string thinner, and to determine optimal speed of drum oscillation.

We tested two mechanical blossom thinners (Darwin, PT-250), and several spiked-drum shaker prototypes for thinning tree fruit at the Penn State Fruit Research and Extension Center, and at several

commercial peach orchards in Pennsylvania. Unless otherwise stated, all vertical string thinner and drum shaker treatments were applied at 2 mph. Thinning with the Darwin vertical string thinner was conducted on peach and nectarine trees trained to perpendicular V at pink, 20% full bloom, 80% full bloom, or petal fall, and thinning with the spiked-drum shaker was conducted at 80% bloom or 35 days after full bloom. The double drum shaker, developed at USDA-ARS for harvesting citrus was evaluated for both blossom thinning and green fruit thinning of peach, while a single drum prototype built by a New York fruit grower (based on the ARS citrus harvester) was tested only as a green fruit thinner. In WA we tested the Darwin 300 and the Uni Bonn string thinners in commercial and research station orchards. Ground speed in all Washington trials was set at 3mph. Nectarine blocks were trained to perpendicular V, apricot to angled planer system and apples to vertical and angled planer, tall spindle and other variations of modern 2D systems.

The experimental design in all trials was randomized block with multiple tree replicates. Blossom removal and reductions in fruit set were evaluated from detailed flower and fruit counts of whole scaffolds, divided into upper and lower canopy sectors. Following physiological drop all trees were hand thinned to a uniform crop load. Hand thinning time per plot was recorded to determine potential reductions in labor inputs. At harvest, yield per tree was assessed, and a sample of fruit evaluated for mean fruit diameter, fruit size distribution, and fruit quality characteristics. Economic cost/benefit analyses were performed to evaluate the impact of each thinning regime on fruit returns, utilizing partial budget analyses.

Blossom removal at the pink stage of bloom development was lower than at other stages in 2008; however, a 150 rpm versus 120 rpm spindle rotation speed resulted in blossom removal similar to the 80% full bloom (FB) treatment in 2009. Blossom removal at the petal fall stage was similar to the open bloom stage with the exception of the 2009 'Sugar Giant' trial, where blossom removal was higher. Flower density following thinning and fruit set of the bloom stage compared to hand thinned control treatments followed a similar trend, with the exception that there were fewer differences in 2009 and in lower canopy regions. Follow-up hand thinning time was reduced by all treatment and year combinations except the 'Arctic Sweet' at pink in 2008 and 2009 and at petal fall in 2009. The best treatments reduced follow-up hand thinning time compared to green fruit thinning alone by 51%, 41%, 42%, and 22% for 'Sugar Giant' and 'Arctic Sweet' in years 1 and 2, respectively. In 2008, the percentage of fruit in the 2.8" or greater size category was increased by all bloom stage treatments in both cultivars. The 2009 size distribution of 'Arctic Sweet' fruit was unaffected, but the percentage of 'Sugar Giant' fruit in higher market value size categories was increased in the 80% FB and higher rpm pink treatments. The savings in hand thinning time and/or increases in fruit size in both years associated with the bloom stage treatments increased the value of the peach and nectarine crops beyond that of hand thinning alone, and resulted in a net positive economic impact of $49 to 548/ac.

In WA, soft fruit trials were limited to organic blocks where the crop load management program was two fold: bloom and post bloom thinning by hand and green fruit thinning by hand. This differs from other states and trials where the only thinning treatment is at green fruit timing. Nectarine blocks trained to Perpendicular V responded well to mechanical thinning in terms of bloom removal and reduced follow up green fruit thinning where there was cord to wood contact. In some blocks, the trees had heavy secondary scaffold wood that prevented sufficient contact. Nectarine trials final fruit size and weight was greater in Darwin thinned treatments over hand blossom thinned treatments in 'Grand Bright' 2 of the 3 years. The increase was not statistically significant. A higher percentage of 'Grand Bright' fruit met first pick size and color standards on tree mechanically thinned when compared to trees that were not blossom thinned but were green fruit thinned. In year one, total yield was reduced due to over thinning in 'Grand Bright', 'Washington Pride' and 'Honey Kist' at rpm's greater than 240. Bloom thinning costs were reduced by $350-500/ac in one organic block 2 years in a row.

In apricots we have shown with repetition that when compared to hand blossom thinning with rakes or green fruit thinning alone the Darwin thinner is equally effective in removing bloom and reducing fruit set and that final fruit size is either the same or larger in Darwin thinned trees. Mechanized thinning apricots with the Darwin thinner set between 200 and 240 rpm has no negative impact on final fruit size or yield when compared to hand blossom thinning with a cost savings of between $120-300 / acre. We were able to dial in the grower determined bloom removal and follow up green fruit thinning was reduced by 44%, 48% and 60% across three trials. The positive results in both 'Goldbar' and 'Robada' trials can be partially attributed to the orchard systems (angled/ planer), uniformity of trees, orchard floor conditions and bloom stage timing.

Overall, the Darwin has a place in the crop load management toolbox. In all trials, across all varieties and seasons, we removed from 35 to 80% of the bloom when application was made at open king, balloon side stage. We over thinned roughly 50% of the trials (compounded with frost?). Fruit size was increased in those trials that were not over thinned and required follow up green fruit thinning. Size increase was never significant when compared to trees chemically thinned at bloom or post bloom. We anticipated that we would be able to sort out response differences between varieties but we could not. Stem length could make a difference but stem length varies from year to year with the short, medium and long stem classes. There are many operational and biological variables to work around. To get clusters down to singles and doubles you must have longer cord to wood contact. King bloom survival rates were collected in 'Honeycrisp', 'Golden Delicious', 'Granny Smith' and 'Fuji' in 2010. The range was 60 to 84% with 'Honeycrisp' at the high end. Although only significant in the Granny Smith trial, in all trials, percent king bloom survival decreased with increased spindle rpm speeds. In all apple trials, the higher the rpm the greater the thinning, the greater incidence of full cluster removal and the greater percentage of doubles, triples and quads left intact. The *high speed* Fuji and Honeycrisp treatments left the greatest number of flower clusters intact. Regardless of rpm speed, the Golden Delicious and Granny Smith low speed trials had almost no doubles, triples or quads left intact. Increasing spindle speed resulted in reduced leaf area per spur (leaves removed or shredded), reduced fruit set, and increased full cluster removal and secondary bloom.

Bloom thinning with the Darwin in UFO cherries yielded mixed results. Across the trials and demonstrations we more often over-thinned than under-thinned. The amount of blank wood in the Darwin treated trees was considered unacceptable. Dormant thinning with the Darwin removed 20-27% of flower buds (not clusters). 2010 cherry results warrant further research in sweet cherries and in specific cherry systems.

Objective 2, Drum Shaker Oscillation Speed:

An experiment was conducted in 2010 to determine if altering the oscillating drum speed between 300 and 400 cycles per minute of the USDA Drum Shaker affected green peach fruit thinning efficacy or incidence of peach limb damage. These treatments were compared to a hand thinned control in young PF 17 peach and Fantasia nectarine trees trained to the perpendicular V system which were grown at the Penn State Fruit Research and Extension Center. The forward speed of the drum shaker vehicle was 4.0 km per hour (2.5 mph), and treatments were applied at 35 days after full bloom.

A Darwin string thinner at 60% to 80% full bloom (FB) reduced crop load (fruit/cm^2 limb cross-sectional area) on scaffold limbs by 21% to 50%, compared to a hand-thinned control. At the 60% FB stage, a USDA designed double spiked drum shaker reduced crop load by 27% and in another trial a USDA prototype single drum shaker reduced crop load by 9%. Across all trials the spiked drum shakers (single or double units) removed an average of 37% of the green fruit. All mechanical

devices reduced the time required for follow-up hand thinning. Follow-up hand thinning costs (US$/acre) were reduced an average of 27% by mechanical thinning devices over hand-thinned control trees. Fruit size was increased over hand-thinned controls by mechanical thinning in most, but not all trials. A combined treatment of the Darwin string thinner at bloom followed by a drum shaker (single or double unit) at the green fruit stage produced the greatest net economic impact in a number of the trials. Peach fruit removal was about the same regardless of the cycles per minute at which the USDA Drum Shaker was operated. Peach and nectarine tree damage from the USDA Drum Shaker was minor in 2010, and there was no clear trend in damage incidence from increasing the cycles per minute. These results differ from earlier work, possibly in part because the trees used for this year's study were younger 4th leaf trees, and had been trained and pruned to more closely adhere to the perpendicular V training system than trees used in earlier trials. Thus the diameters of the scaffolds were smaller than those of trees in earlier trials, and less rigid. Also, there was little or no secondary limb structure in which the nylon rods could become entangled. The drum shaker thins by shaking the scaffolds, thus the size and branch hierarchy of the tree canopy will be an important cofactor in thinning and tree damage resulting from this treatment. Despite over thinning in some trials, the mechanical thinning devices described provide a potential alternative to hand thinning alone in peach production.

Objective 3, Automated Positioning:

Sensors were added to the string thinner to test the feasibility of automatic positioning of the spindle in perpendicular V peach orchards, which would reduce driver fatigue and potentially increase the speed of thinning. Penn State Ag Engineering MS candidate Reuben Dise investigated sonar and laser sensors for this purpose, in cooperation with a graduate student and scientists from Carnegie Mellon University.

Reuben Dise also installed and tested hydraulic controls for positioning the spindle. Initial tests were made to compare positioning of the spindle by manipulating the new controls with a joystick versus the standard tractor positioning method. These spindle-positioning controls were compared in young Saturn and White Lady peach trees trained to the perpendicular V system.

Baseline data was obtained with sonar and with laser sensors for adapting the Darwin thinner to autonomous operation. This data is currently being analyzed to determine if the automated system will be able to accurately sense the trees and position itself and will match the performance of the manually operated machine. Work will continue on this objective in 2011.

Operating the Darwin thinner with the new hydraulic controls and joystick in perpendicular V peach trees provided thinning equal to (in White Lady), or better (in Saturn) than that provided by standard positioning by tractor. Rotation of the Darwin spindle requires a continuous flow of oil from the hydraulic system, which reduces flow to other hydraulic control systems. Thus in order to operate the additional hydraulics required by the joystick control method, it appears that a separate hydraulic system will have to be employed, similar to findings in SC.

Objective 4, String Pattern:

Darwin thinner spindle string pattern was evaluated to compare the "standard" 2 string column arrangement to 3- and 6-column helix patterns, all utilizing 90 total strings. Trials were conducted in both perpendicular V- and open center vase- trained peach trees. A helix string arrangement around the clockwise-spinning spindle that sequentially brought the next distal string into contact with the tree canopy, labeled "helix up", was compared to a string arrangement that brought each succeeding proximal string into contact, which we labeled "helix down".

All string patterns we tested on the Darwin thinner provided similar amounts of flower removal and fruit set in peach in two of three trials. In one trial the treatment "helix up" removed significantly more flowers than the other string patterns, but slow motion photography confirmed visual observation that flowering shoots were being contacted by strings repeatedly with all the string patterns, making it unlikely that string pattern would influence thinning or the pattern of flower distribution. Frequency distribution graphs revealed that all string patterns were equally effective in reducing the numbers of flowers and setting fruits per shoot. In one trial, string pattern did not impact blossom removal or fruit set in the spring, but final fruit size was larger and weighed more in trees thinned with the WA Helix pattern when compared to the standard pattern. This trial was not repeated. String pattern on the Darwin spindle does not appear to be an important parameter for thinning of stone fruit.

Objective 5, Bonner String Thinner:

The Bonner string thinner was tested in one replicated Granny Smith trial. The Bonner at 3 different speeds was effective in reducing bloom by breaking down clusters to singles or removing clusters completely. In this study, the Bonner out performed the Darwin in whole tree percent bloom removal and in breaking up clusters to the desired single / double crop load. The thinner was easily manipulated to make sufficient cord to wood contact in a woody tall spindle system. The Bonner was selected over the Darwin to thin non-treatment blocks at Sunrise.

Objective 5, Best Use Parameters:

The multi state SCRI project "Innovative Technologies for Thinning Fruit" has and will continue to yield information to guide the end user in the operation and optimization of the Darwin string thinner. It is clear that this tool will require adjustments from block to block, season to season. Our studies have narrowed down the operational ranges for peach, nectarine, apricot, apple and sweet cherry under our conditions. We have validated relationships between spindle speed, ground speed, and number of cords and placement of cords.

Executive Summary

The work documented in this report is part of a larger multi-state SCRI project titled *Innovative Technologies for Thinning Fruit* (www.abe.psu.edu/scri). This project and associated funding positioned the investigators to successfully secure funding through the SCRI program. The SCRI project continues through October 2012.

The Darwin and P250 string thinners have been tested in replicated trials in PA and WA peach, nectarine and apricot orchards for 3 seasons. Where there is cord to wood contact, both thinners effectively reduce bloom and follow up green fruit thinning times when applied between pink and petal fall bloom stages. In all cases, the costs incurred to mechanically thin was less than the cost to bloom thin by hand or green fruit thin on trees that had not been blossom thinned. It is estimated that the cost to thin with the Darwin is $45-55 / acre including the cost of equipment. When compared to green fruit thinned trees, final fruit size was more often significantly larger in Darwin bloom thinned trees. When compared to hand blossom thinned trees, final fruit size was most often equal or only slightly larger in Darwin thinned trees. Distribution to larger premium sizes and/or to "first pick" criteria was recorded in the majority of trials.

String pattern does not appear to be an important factor for bloom thinning of soft fruit. Number of cords, number of spines, spindle rpm, and ground speed are important operational factors.

Across all trials the spiked drum shakers (single or double units) removed an average of 37% of the green fruit. Drum shaker alone or drum shaker with the Darwin reduced the time required for follow-up hand thinning. Follow-up hand thinning costs were reduced an average of 27% by mechanical thinning devices over hand-thinned control trees. Fruit size was increased over hand-thinned controls by mechanical thinning in most, but not all trials. A combined treatment of the Darwin string thinner at bloom followed by a drum shaker (single or double unit) at the green fruit stage produced the greatest net economic impact in a number of the trials.

The hydraulic control for spindle placement showed promise in 2010 trials. Operating the Darwin thinner with the hydraulic controls and joystick in perpendicular V peach trees provided thinning equal to (in White Lady), or better (in Saturn) than that provided by standard positioning by tractor. Work on the hydraulic control will continue in 2011.

The Darwin and Bonner are effective at removing clusters and bloom in apples. Bloom stage for bloom thinning is from full separation to open king and mostly open sides. Earlier than this you risk cluster thinning, later than this you risk fruit damage. Increasing spindle speed resulted in reduced leaf area per spur (leaves removed or shredded), reduced fruit set, and increased full cluster removal and secondary bloom. King bloom survival in mechanical thinning trials was between 60-84%. Survival rate was most often associated with spindle speed.

Future apple work will include combination treatments of mechanical at bloom and PGR's postbloom. Return bloom will be measured in every trial and we will make severity assessments of in the reduction of spur leaves post thinning. Fireblight is a reasonable concern surrounding the use of mechanical thinners in apples. Research has shown that the bacterium is moved from tree to tree on the cords. When warranted, future trials will include a prophylactic application of antibiotics post thinning.

The Bonner and Darwin are effective at removing bloom in sweet cherry. The Darwin is effective at removing complete and partial buds at dormant timing. Concerns over bud damage in cherries this season and our history of over thinning blocks and stimulating blank wood has put mechanical dormant and bloom thinning in cherries on hold. We will restart the research and demonstration efforts in 2012.

This work and the work of colleagues in South Carolina and California will generate user guidelines to assist producers in using these technologies in stone and pome fruit. The work has been done in partnership with producers and most of the data collected and economic analysis has been from commercial orchards. Our work supports previous work that showed that when used correctly, this technology is an affordable tool for the crop load management in soft fruits.