Washington Tree Fruit Research Commission Spring Technology Research Review
May 10, 2012
WA Cattlemen's, Ellensburg

Page No.	Time	PI	Project Title
	9:00	McFerson	**Introduction**
			Final Reports
1	9:05	Lewis	DBR harvest assist system evaluation
5	9:15	Gallardo	Cost estimation of tree fruit production
	9:25		**Continuing Reports**
18	9:30	Ashmore	Technology roadmap support: ***Written report only***
22	9:40	Gallardo	Cost estimation of producing Red Delicious Apples in WA
27	9:50	Jones	Evaluation of environmental data used for IPM models
34	10:00	Eastwell	Evaluating a universal plant virus microarray for virus detection
42	10:10	Zhang	Intelligent bin-dog system for tree fruit production
48	10:20	Karkee	3D machine vision for improved apple crop load estimation
54	10:30	Unruh	Protein-based foam for applying lacewings eggs to fruit trees by ATV
59	10:55	Hoogenboom	Development of apple bloom phenology and fruit growth models*
67	11:05	Hoogenboom	Effect of early spring temperature on apple and sweet cherry blooms

FINAL PROJECT REPORT
WTFRC Project Number: TR-11-102

Project Title: DBR harvest assist equipment evaluation under Washington conditions

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Cooperators: Penn State, WA Orchard Companies, CPAAS and WTFRC internal staff

Other funding sources

Agency Name: USDA Specialty Crop Research Initiative
Amt. requested/awarded: $6.1M (plus $6.1M non federal match) $94,000 was allocated to this specific project
Notes: Karen Lewis is a Co PI and the principles of DBR Conveyor Concepts are Co- investigators on the project Comprehensive Automation for Specialty Crops (CASC).

Total Project Funding: $60,000

Budget History:

Item	**2011/2012**
Equipment	60,000
Total	60,000

OBJECTIVES

The primary goal of this project is to finalize design and fabricate a harvest-augmentation system and to test the system under Washington State conditions.

We proposed to develop a harvest-augmentation system for the apple industry that handles the fruit from the time it is picked from the tree until it is placed in the bin.

Testing objectives are clustered into 2 major areas: 1) equipment performance and 2) human performance.

Specific objectives for the one-year project are as follows:

1) Design and build a harvest-augmentation system to Washington State specifications
2) Determine durability of equipment under WA conditions
3) Actively solicit grower and worker input on equipment design and function
4) Determine worker productivity and harvest efficiency in large scale harvest assist trials
5) Determine fruit damage by measuring degree and amount of bruising and identify where bruising occurs along the system
6) Identify ergonomic issues and develop strategy to address those that require equipment or use modifications
7) Determine worker fatigue in large scale harvest assist trials
8) Determine economic impact of harvest-augmentation under WA conditions when compared to equal tasks completed on ladders

SIGNIFICANT FINDINGS

- On arrival, bruising levels in Granny Smith, Ambrosia, Gala and Braeburn exceeded industry tolerances
- With a major redesign of decelerator mechanism, bruising decreased in Granny Smith , Gala and Fuji
- With current decelerator mechanism design and moderate changes to bin filler, Fuji bruising is within industry tolerance
- With above changes, the system can receive fruit at 4 apples per second / tube X 4 tubes for a total of 16 fruit per second. At arrival, the speed was 1 apple per second
- A small but randomized time trial resulted in a 20% efficiency increase when the DBR harvest was compared to a ladder and bag harvest
- Apples must be put in tubes one at a time
- Transport system, bin filler and people are best optimized in uniform tree structure and cropload
- The system is simple – easy to operate, debug and correct
- The tractor towing the system should have a "creep gear" kit installed to allow for smooth low speed, driverless operation
- Workers in general like working from the platform and like picking into tubes
- With the new decelerator mechanism design, repeated IRD tests indicate that the majority of apple to apple bruising is now occurring during the delivery to the elephant ear in the bin. and placement in the bin
- Need to have two work levels on the platform
- Minor design changes around position of platform levers, position / location of tube inlets, tractor noise and exhaust, and a few remaining metal pinch points need to be addressed

RESULTS AND DISCUSSION

The harvest assist system did not perform as anticipated upon arrival in terms of bruise levels and ability to handle fruit treated with eclipse. In addition, we put the machine into a 13 ft middle vertical axe gala block and quickly determined that 13 foot centers in a cone shape architecture is not a good fit. Most of the efforts over the 5 weeks were focused on bruise reduction and machine design and function.

With the original decelerator design, bruising was recorded as high as 50% in under mature Granny Smith and 65% in Ambrosia. After redesign of decelerator mechanism and modifications to bin filler– bruising was recorded at levels of 25% in 'Gala', 30% in 'Granny Smith', 20% in 'Braeburn and 23% in 'Jazz'.

With a modification to the mechanism redesign– a small run of 'Fuji' resulted in 5.2% bruising with a minimum of 4.8% downgrade. Over mature 11-12# 'Gala' in two tests resulted in 14% and 11% bruising.

The redesign of the decelerator mechanism resulted in increased volume capacity and decreased apple to apple bruising. Modifications to bin filler have reduced – but not eliminated, apple to apple bruising in the bin.

The efficiency of the DBR system was evaluated in a single randomized time trial. We used the same crew, in the same block and timed bin filling using the DBR system and the ladder and bag system. Harvest using the DBR system resulted in a 20% increase in bin filling time.

Executive Summary

The funding from this project co-financed the design and fabrication of a 2011 DBR Conveyor Concepts harvest assist prototype. Additional funds of $94,000 were allocated through the SCRI CASC project. Total costs for design and fabrication were $154,000. Costs associated with delivery, setup and field validation were provided through the WSU CASC sub award. Because of crew demands and damaged fruit, substantial costs were incurred by project collaborators McDougall & Sons, Allred Farms and Allan Brothers. DBR traveled to Washington State 3 times during the 5 week harvest period. DBR principles have been innovative, proactive, responsive and successful with the redesigns and modifications.

The objective of this one year project was to design, fabricate and field test the DBR harvest assist system in Washington State. The system arrived September 19, allowing 5 weeks of in-field testing. The harvest assist system did not perform as anticipated upon arrival in terms of bruise levels, capacity and ability to handle fruit treated with eclipse. Most of the efforts over the 5 weeks were focused on bruise reduction and machine design and function. We tested the system in Granny Smith, Gala, Ambrosia, Jazz, Braeburn, and Fuji. We worked in several different orchard architectures and in blocks that required stem clipping and color picking. We worked with both internal and commercial crews and worked with 4 on the platform and 2 on the ground and 2 on the platform.

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Impact Recording Device (IRD) trials indicate that the majority of impacts occur in the transport tubes but that only .11% are above the threshold of a 10% chance that the impact will result in a bruise. The 3 major locations of high g-level impacts are: both ends of tubes, joints between tubes and decelerator, and where the tube inflects or bends.

The DBR system was shipped back to MI for modifications and upgrades. Modifications include but are not limited to, installation of lighting system for nighttime operations, auto steer kit for Kubota, upgraded electric eye, elephant ear redesign and repositioning of tube inlet for platform work. Self leveling for the bin filler will be installed.

In collaboration with the CA Canning Peach Association and UC Davis, the system will be evaluated in CA peaches and pears during the month of August. During this time, extensive ergonomic, engineering and efficiency studies will be conducted by UC Engineering and UC Extension. The system will be evaluated in WA state apples in September and October.

FINAL PROJECT REPORT

Project Title: Cost estimation and analysis of tree fruit production

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Cooperators: Ron Mittelhammer (Regents Professor, School of Economic Sciences), Tom Marsh (IMPACT Director, School of Economic Sciences), Jim McFerson (Washington Tree Fruit Research Commission)

Total Project Funding: $40,000

Budget History:

Item	**Year 1: 2010-2011**	**Year 2: 2011-2012***	**Total**
Salaries	$ 26,250	$ 0	$ 26,250
Benefits	$ 8,190	$ 0	$ 8,190
Wages			
Benefits			
Equipment			
Supplies	$ 500	$ 0	$ 500
Travel	$ 3,000	$ 0	$ 3,000
Plot Fees			
Miscellaneous	$ 2,060	$ 0	$ 2,060
Total	$ 40,000	$ 0	$ 40,000

*A no-cost extension of the project was approved.

OBJECTIVES

1. *Develop orchard-level enterprise budgets for tree fruits, in particular, sweet cherries, organic apples (Gala), Honeycrisp apple, Anjou pear and Bartlett pear;*
2. *Develop a procedure for representing and analyzing costs of activities beyond the orchard level; and*
3. *Interact with the tree fruit industry and other Pacific Northwest university researchers.*

SIGNIFICANT FINDINGS

Objective 1: *Develop orchard-level enterprise budgets for tree fruits, in particular, sweet cherries, organic apples (Gala), Honeycrisp apple, D'Anjou pear, and Bartlett pear.*

The following enterprise budgets have been developed and published as Washington State University Extension Fact Sheets. They are available at the WSU School of Economic Sciences – Extension Economics website: http://extecon.wsu.edu/pages/Enterprise_Budgets, in both PDF and Excel® formats:

1. Galinato, S.P., R.K. Gallardo, and M.R. Taylor. 2009 Cost Estimates of Establishing and Producing Sweet Cherries in Washington. *Washington State University Extension Fact Sheet FS022E*, August 2010.
2. Galinato, S.P. and R. K. Gallardo. 2010 Estimated Cost of Producing Pears in North Central Washington. *Washington State University Extension Fact Sheet FS031E*, July 2011.
3. Galinato, S.P. and R.K. Gallardo. 2010 Cost Estimates of Producing Bartlett Pears in the Yakima Valley, Washington. *Washington State University Extension Fact Sheet FS034E*, July 2011.
4. Galinato, S.P., M.R. Taylor and D. Granatstein. 2010 Cost Estimates of Producing Organic Gala Apples in Washington. *Washington State University Extension Fact Sheet FS041E*, October 2011.
5. Galinato, S.P. and R.K. Gallardo. 2011 Cost Estimates of Establishing and Producing Honeycrisp Apples in Washington. *Washington State University Extension Fact Sheet FS062E*, January 2012.

The studies show that the net returns for all crops, except those of Anjou and Bartlett pears, are positive based on the assumed production specifications and costs. Break-even returns are highlighted in the pear budgets to illustrate the scenarios at which it would be profitable to produce pears in the short and long run. More details and data underlying the cost estimation can be found in the bulletins and supplementary Excel® workbooks.

Objective 2: *Develop a procedure for representing and analyzing costs of activities beyond the orchard level.*

We started this effort with the Honeycrisp apple enterprise budget, and requested producers in the focus group to provide values for main packinghouse charges. Results show that these charges represent 48 percent of total production costs, for Honeycrisp apples.

We obtained packing cost information of conventional and organic apples, sweet cherries, and pears, from the Washington State Department of Agriculture-Commission Merchants Program during 2004-2011. All packinghouses in the state of Washington are mandated by the Washington State Legislature (RCW 20.01) to report their packing costs. Because different packinghouses have different accounting of costs, reports varied across packinghouses and within the same packinghouse across years. We identified, to the best of our capacity, common cost categories across packinghouses and years, and aggregated categories to obtain an estimate of packinghouse charges per box or pound of fruit.

Our study shows that packinghouse charges represent approximately 48%, 43%, 35% and 41% of the total production costs of Gala, organic Gala apples, Sweetheart cherries, and Anjou pears respectively. For future enterprise budgets, collection on packinghouse charges will be part of the focus group discussion, and will be included in the Extension Factsheets.

Objective 3: *Interact with the tree fruit industry and other Pacific Northwest university researchers.*

The enterprise budgets were developed with input from knowledgeable and representative tree fruit producers in Washington State. The published extension factsheets were shared with researchers from Oregon State University to be used as input for the AgTools™ software. The published Extension Factsheets, from these studies, are posted in the WSU-SES Extension Economics website and are available, in both PDF and Excel®, for free to the public. Outreach efforts included nine regional presentations in the state of Washington and one in the state of New York:

1. Gallardo, R.K. 2012. Production Costs in Tree Fruit. What have we learned? Presentation given in Spanish at:
    - Kyle Mathison Orchards Employees. Wenatchee, WA. March 8.
    - WSU Douglas-Chelan County Extension Seminar on Pesticide Application, Spanish Section. Wenatchee, WA. February 7.
    - New York Fruit and Vegetable Expo. Syracuse, NY. January 26.
2. Gallardo, R.K. 2011. Economic Reality. Apples, Pears, Cherries. Are the Costs of Planting, Producing, Storing, Packing, and Shipping Being Adequately Covered by FOB Pricing? Presentation given at the WA Horticultural Association Annual Meetings. Wenatchee, WA. December 6.
3. Gallardo, R.K. 2011. "Production Costs for Sweetheart Cherries, Gala Apples and Anjou Pears, and Platform Use Survey Results," Presentation in Spanish given to Visiting Chilean Growers as part of the Fruit Growing Technological Tour organized by WeCu, Inc. Wenatchee, WA. June 23.
4. Gallardo, R.K. 2011. "Cost of Establishing a Fruit Orchard and National Fruit Market Trends," Presentation given at the Washington State Chapter of the American Society of Farm Managers and Rural Appraisers. Leavenworth, WA. May 5.
5. Gallardo, R.K. 2011. "What Does It Cost to Bartlett Pears? Recent Grower Based Study." Presentation given at the Washington-Oregon Canning Pear Association Annual Meeting. Yakima, WA. February 15.
6. Gallardo, R.K. 2011. "What Does It Cost to Grow Cherries, Gala Apples and Anjou Pears? Recent Grower Based Studies." Presentation given to Sales Personnel – Domex Superfresh Growers. Yakima, WA. February 14.
7. Gallardo, R.K. 2011. "What does it Cost to Grow Cherries? A Recent Grower Based Study." Presentation given at the North Central Washington Stone Fruit Day. Wenatchee, WA. January 20.

RESULTS & DISCUSSION

Enterprise budgets

Based on assumed specifications related to production (orchard and block size, architecture, cultivar, life of planting and tree density) and producers' input we estimated total costs and net returns for producing fruit crops in Washington State (Table 1). Note that prices considered for the estimation of net returns when packinghouse charges were not included, are FOB discounted prices (FOB minus packinghouse charges). The net returns are positive for all fruit crops studied except for pears. Hence we estimated the break-even returns to illustrate the scenarios at which it would be profitable to produce pears in the short and long run.

If the short-run break even return is not covered by the actual returns received it is uneconomical to produce the crop because the cash expenses are not being covered. Results in Table 1 show that given the actual production costs it is feasible to produce pears in the short run. However, long-run break even returns are not covered, meaning that there is no return on capital contributions equal to what could be earned in alternative uses (opportunity costs) and no return on management. For the other fruit crops (Sweetheart cherries, organic Gala and Honeycrisp apples) the net returns exceed the total production cost breakeven levels meaning that in addition to covering all cash and opportunity costs, the owner-operator will receive a return on management and on the financial risk assumed in fruit production.

Table 1. Estimated production costs* and returns by crop

Crop	Assumed Yield/acre*	Assumed Price per unit	Total production costs/acre	Net returns/acre	Break-even returns per unit
Sweetheart cherries	8 tons	$2,800/ton	$10,120	$12,280	
D'Anjou pears	32 bins	$250/bin	$9,684	-$1,684	$167.01/bin (SR) $302.63/bin (LR)
Bartlett pears	30.25 tons	$255/ton	$8,785	-$1,072	$150.93/ton (SR) $290.42/ton (LR)
Organic Gala apples	50 bins	$300/bin	$11,407	$3,593	
Honeycrisp apples**	60 bins	$500/bin	$19,754	$10,246	

Note: *Refers to the yield and total production costs during the full production years. **Total production costs and net returns of Honeycrisp already include warehouse packing charges. SR – short run (returns over variable costs); LR – long run (returns over total production costs).

Packing Costs

Packinghouses in the state of Washington are mandated to report packing cost charges to the Washington State Department of Agriculture-Commission Merchants Program. There is no established format to report these data, thus each packinghouse report charges following their very own guidelines and even the same packinghouse does not report the exact same cost centers across years. We used the following criteria to include the cost categories in our summary report for packinghouse charges: First, we used as a guide the categories producers indicated for the Honeycrisp and Red Delicious apple enterprise budgets. Second, we excluded charges on specific types of packing materials, and charges for which the units were not clear. Third, we identified and aggregated common cost categories across packinghouses so we could calculate the packing charge per box or per pound of fruit produced.

Tables 2 to 9 show the descriptive statistics of all cost categories found in the reports for apples (conventional and organic), sweet cherry and pears from 2004 to 2011. The panel data set was unbalanced meaning that the blocks of cost categories data for each year were different across packinghouses. In other words, for a given cost category in most cases, we do not have the data from all packinghouses and/or we do not have complete time series data. For example in Table 2, we found only 7 out of 43 packinghouses reported data on the category "Bin in Charge", totaling 30 observations for the years 2004 to 2010. As another example, in Table 4, 4 packinghouses reported the cost category “Bin Handling Diverted Fruit” not consistently across years yielding only 6 observations.

From the information in Tables 2 to 9, we identified and aggregated common packing cost categories, so we could calculate a packing cost per box or per pound of fruit. Tables 10-13 show the aggregated averages and ranges of packinghouse charges. The Wenatchee Valley Traffic Association Executive Director, in consultations with anonymous packinghouse representatives, verified the adequacy of the aggregations. Table 14 presents the summary of charges by crop. The estimated packing charges are then added to the production costs of Gala apples, organic apples, Sweetheart cherries and Anjou pears. Note that this might be a caveat in the study, as different from orchard level production costs; aggregated packinghouse charges were not specific to a fruit cultivar, but an aggregation across cultivars. Figure 1 compares the total production costs and net returns with and without the inclusion of packing costs. Given the budget assumptions for fruit production and the packinghouse charges considered, break-even returns for fruit crops have changed. See Table 15. When packing costs are included, returns for Gala apples and Anjou pears cover all cash expenses but not all opportunity costs, management and financial risk. This implies that these fruit operations might not be economically sustainable in the long run. Returns for organic Gala apples and Sweetheart cherries decreased by 71% and 61%, respectively, however all cost categories (cash expenses, opportunity costs, management, and financial risk) are covered as net returns per acre remain positive, see Figure 1. In sum, this study provides an illustration of the importance of including packinghouse charges when analyzing the profitability of fruit production, as these costs impact considerably the net returns received.

Table 2. Warehouse Packing Charges per Bin, All Categories, Conventional Apple.

Charges	Obs	No. of Packinghouses Reporting Data	Years with Data (Unbalanced)	Average	Std. Dev.	Min	Max
Bin In Charge	30	7	2004-2010	$57.48	19.97	$31.50	$96.47
Receiving Charge	20	5	2004-2010	$50.69	37.15	$2.50	$95.00
Handling	15	4	2004-2010	$23.34	7.33	$3.03	$32.67
Sorting	17	4	2004-2010	$29.31	12.41	$12.50	$50.00
Washing	7	2	2004-2010	$7.43	2.44	$6.00	$11.00
Washing and Sorting	33	7	2004-2010	$27.38	19.07	$2.50	$57.50
Drenching	21	6	2004-2010	$4.85	1.45	$3.25	$10.00
Waxing	30	7	2004-2010	$5.97	2.93	$3.50	$14.00
Regular Storage	60	14	2004-2010	$36.35	25.72	$14.00	$98.00
CA Storage	79	16	2004-2010	$33.60	21.20	$5.00	$98.00
Storage	39	8	2004-2010	$19.37	8.97	$2.00	$30.86
MCP Treatment	28	5	2004-2010	$12.23	4.52	$4.50	$22.00
Receiving, Washing, Sorting and Storage	15	5	2004-2010	$54.98	24.99	$24.50	$100.00
Storage and Handling-CA	6	2	2005, 2007-2010	$29.41	5.85	$25.00	$38.14
Storage and Handling-Regular	6	2	2005, 2007-2010	$21.41	2.47	$18.00	$24.64
Cull/Processor Charge	12	2	2004-2010	$11.63	6.09	$5.00	$20.00
Line Spray	3	2	2007-2008	$5.93	0.26	$5.63	$6.08
Presize and Special Handling Fee	4	2	2007-2010	$49.13	39.51	$15.00	$86.75
Packinghouse ID (1-43)	301					1	43
Year (2004-2010)	301					2004	2010

Table 3. Warehouse Packing Charges per Box, All Categories, Conventional Apple.

Charges	Obs	No. of Packinghouses	Years with Data (Unbalanced)	Average	Std. Dev.	Min	Max
Apple Commission	3	2	2007-2008	$0.05	0.04	$0.03	$0.10
Assessment Fee	5	3	2004, 2007-2010	$0.12	0.04	$0.08	$0.15
Industry Charge	20	5	2004-2010	$3.84	3.20	$0.35	$8.25
Inspection	16	3	2004-2010	$0.57	0.58	$0.08	$1.75
Selling Charge	11	3	2004-2010	$0.79	0.16	$0.45	$1.00
Stickering Charge	9	3	2004-2010	$0.37	0.07	$0.31	$0.54
Packinghouse ID (1-12)	301					1	12
Year (2004-2010)	301					2004	2010

Table 4. Warehouse Packing Charges per Bin, All Categories, Organic Apple.

Charges	Obs	No. of Packinghouses Reporting Data	Years with Data	Average	Std. Dev.	Min	Max
Assessment/ Inspections/Advertising	1	1	2004	$0.39	.	$0.39	$0.39
Bin Handling-Diverted Fruit	6	1	2004-2009	$16.32	8.95	$5.00	$24.40
Bin Handling-Orchard Run	6	1	2004-2009	$16.32	8.95	$5.00	$24.40
Bin in Charge-26 Box	1	1	2004	$66.30	.	$66.30	$66.30
Bin in Charge-Plastic	1	1	2004	$68.30	.	$68.30	$68.30
Bin Running Charge	5	1	2004-2007, 2009	$44.00	4.18	$40.00	$50.00
Cold Storage	5	1	2004-2007, 2009	$36.80	0.45	$36.00	$37.00
Early, Mid and Late	4	1	2008-2010	$87.58	7.24	$76.83	$92.50
Packing	6	1	2004-2009	$4.13	0.31	$3.80	$4.63
Regular Storage	4	1	2006, 2008-2010	$81.23	7.63	$70.90	$87.00
Repacking	2	1	2004-2005	$2.25	0.00	$2.25	$2.25
Shipping	4	1	2006-2009	$0.35	0.00	$0.35	$0.35
Wash, wax, and sort (CA. Storage)	4	1	2008-2011	$98.13	6.94	$92.75	$108.25
Wash, wax, and sort (Reg. Storage)	4	1	2008-2011	$87.75	6.22	$82.75	$96.75
Wash, wax, and sort (Special. Storage)	4	1	2008-2011	$97.75	6.22	$92.75	$106.75
Packinghouse ID (1-4)	32					1	4
Year (2004-2010)	32					2004	2011

Table 5. Warehouse Packing Charges per Box, All Categories, Pears.

Charges	Obs	No. of Packinghouses Reporting Data	Years with Data	Average	Std. Dev.	Min	Max
Cull charge	5	1	2006-2010	$0.65	0.07	$0.55	$0.70
In-house advertising/promotion	2	1	2007-2008	$0.33	0.02	$0.31	$0.34
Inspection Costs	2	1	2007-2008	$0.08	0.00	$0.08	$0.08
Pear Assessment	2	1	2007-2008	$0.57	0.16	$0.46	$0.68
Research	2	1	2007-2008	$0.03	0.00	$0.03	$0.03
Seconds	1	1	2007	$2.30	.	$2.30	$2.30
Selling charge	2	1	2007-2008	$0.52	0.03	$0.50	$0.54
Standard Bag Pack	4	2	2005-2007, 2011	$4.60	0.64	$4.25	$5.55
Standard Box	5	1	2004-2007, 2009	$4.80	0.21	$4.70	$5.18
Standard Carton	8	1	2004-2011	$3.49	0.29	$3.10	$3.74
Standard Tight Fill	3	1	2004, 2006, 2009	$4.08	0.14	$4.00	$4.25
Standard Tray Pack	12	5	2004-2011	$4.70	0.64	$3.70	$5.90
Standard Wrap Pack	3	2	2007-2008, 2011	$5.85	0.38	$5.50	$6.25
Stickering	2	1	2007-2008	$0.40	0.02	$0.38	$0.41
Packinghouse ID (1-8)	64					1	8
Year (2004-2011)	64					2004	2011

Table 6. Warehouse Packing Charges per Pound, All Categories, Pears.

Charges	Obs	No. of Packinghouses Reporting Data	Years with Data (Unbalanced)	Average	Std. Dev.	Min	Max
Culls from Packing	5	2	2004-2007, 2011	$0.01	0.001	$0.01	$0.01
Culls from Packing, Percentage							
0%-10%	9	3	2004-2005, 2008-2011	$0.02	0.005	$0.01	$0.02
10%-20%	9	3	2004-2005, 2008-2011	$0.03	0.007	$0.02	$0.04
20%-25%	9	3	2004-2005, 2008-2011	$0.04	0.010	$0.03	$0.06
25%-30%	9	3	2004-2005, 2008-2011	$0.05	0.007	$0.04	$0.06
over 30%	9	3	2004-2005, 2008-2011	$0.06	0.005	$0.05	$0.06
Orchard Run Bins Delivered to Warehouse	4	1	2004-2007	$0.01	0.001	$0.01	$0.01
Orhard Runs Bins Direct from Orchard Processor	4	1	2004-2007	$0.01	0.000	$0.01	$0.01
Packing	4	1	2004-2007	$0.13	0.030	$0.12	$0.18
Regular Storage	4	1	2004-2007	$0.02	0.001	$0.02	$0.02
Sorting and Bin Usage	4	1	2004-2007	$0.04	0.002	$0.04	$0.04
Storage	4	1	2004-2007	$1.10	0.086	$1.00	$1.21
Packinghouse ID (1-6)	47					1	6
Year (2004-2011)	47					2004	2011

Table 7. Warehouse Packing Charges per Bin, All Categories, Pears.

Charges	Obs	No. of Packinghouses Reporting Data	Years with Data (Unbalanced)	Average	Std. Dev.	Min	Max
Bin Handling-Diverted Fruit	3	1	2005-2007	$15.00	8.66	$5.00	$20.00
Bin Handling-Orchard Run	3	1	2005-2007	$15.00	8.66	$5.00	$20.00
Bin In 26 Box Bin	5	1	2006-2010	$51.16	3.16	$46.00	$53.20
Bin In Phillipphi Bin	5	1	2006-2010	$45.66	3.16	$40.50	$47.70
Bin Pre-Cooling	3	1	2005-2007	$2.00	0.00	$2.00	$2.00
Bin Rental	8	2	2004-2007, 2009-2011	$7.99	2.68	$2.58	$11.15
Bin Running Charge	5	1	2004-2007, 2009	$38.60	2.66	$35.00	$42.50
Bottom Pads	6	1	2004-2005, 2008-2011	$0.50	0.00	$0.50	$0.50
Bottom Sleeves	6	1	2004-2005, 2008-2011	$0.40	0.00	$0.40	$0.40
CA Storage	10	3	2004-2007, 2009	$22.36	11.60	$1.20	$30.50
Chemicals	5	1	2004-2007, 2009	$8.20	0.45	$8.00	$9.00
Cull Handling	5	1	2004-2007, 2009	$5.00	0.00	$5.00	$5.00
Drenching	5	1	2004-2007, 2009	$5.00	0.00	$5.00	$5.00
Full Wrap	7	1	2004-2006, 2008-2011	$7.60	1.57	$6.00	$9.35
In Charge	8	2	2005-2010	$57.93	22.45	$31.50	$80.50
Loose Bin washed and Sorted	9	3	2004-2005, 2008-2011	$50.26	11.08	$33.00	$62.50
Loose Bin washed and Sorted 12" Plastic Bin	1	1	2011	$28.00	.	$28.00	$28.00
Loose Bin washed and Sorted 24" Wood Bin	1	1	2011	$65.00	.	$65.00	$65.00
Loose Half Bin Washed and Sorted	2	1	2008, 2010	$20.64	1.17	$19.81	$21.47
Packing	7	2	2004-2007	$22.90	22.77	$4.55	$47.25
Packing and Selling	7	1	2004-2010	$0.24	0.02	$0.20	$0.26
Packing Lug	2	1	2009-2010	$6.70	0.00	$6.70	$6.70
Pre-Storage Treatment-DPA&Drench	6	1	2004-2005, 2008-2011	$5.00	0.39	$4.50	$5.25
Pre-Storage Treatment-Smartfresh	6	1	2004-2005, 2008-2011	$10.00	0.00	$10.00	$10.00
Receiving	5	1	2006-2010	$89.80	6.42	$80.00	$96.00
Regular Storage	20	4	2004-2011	$18.71	12.95	$1.25	$38.00
Repacking	1	1	2004	$2.25	.	$2.25	$2.25
Shipping	3	1	2005-2007	$0.37	0.06	$0.30	$0.40
Sorting	12	2	2004-2011	$23.89	11.64	$13.00	$52.02
Sorting, Sizing, Handling	3	1	2005-2007	$38.67	1.15	$37.34	$39.34
Storage & Handling - CA	1	1	2008	$38.14	.	$38.14	$38.14
Storage & Handling - RG	1	1	2008	$24.64	.	$24.64	$24.64
Storage, Sorting, Handling	2	1	2007, 2009	$69.50	6.36	$65.00	$74.00
Summer storage	4	1	2008-2011	$28.86	0.00	$28.86	$28.86
Washing	5	1	2004-2007, 2009	$6.00	0.00	$6.00	$6.00
Washing & Sorting	1	1	2008	$24.64	.	$24.64	$24.64
Waxing	6	2	2004-2009	$5.88	0.30	$5.27	$6.00
Winter storage	4	1	2008-2011	$30.86	0.00	$30.86	$30.86
Packinghouse ID (1-16)	120					1	15
Year (2004-2011)	120					2004	2011

Table 8. Warehouse Packing Charges per Bin, All Categories, Sweet Cherry.

Charges	Obs	No. of Packinghouses Reporting Data	Years with Data (Unbalanced)	Average	Std. Dev.	Min	Max
Bin Rental	4	1	2004-2007	$2.03	0.62	$1.10	$2.40
Hauling	3	1	2005-2007	$2.17	0.29	$2.00	$2.50
Hydro-cooling	8	2	2005-2010	$3.06	0.62	$2.50	$4.00
Reefer Hauling	1	1	2007	$3.50	.	$3.50	$3.50
Packinghouse ID (1-3)	18					1	3
Year (2005-2010)	18					2005	2010

Table 9. Warehouse Packing Charges per Pound, All Categories, Sweet Cherry.

Charges	Obs	No. of Packinghouses Reporting Data	Years with Data (Unbalanced)	Average	Std. Dev.	Min	Max
Excess cull charge	14	2	2004-2010	$0.06	0.05	$0.01	$0.10
In Charge	22	4	2004-2010	$0.30	0.14	$0.14	$0.50
In Charge-Non Rainier Varieties (per lb delivered)	4	1	2004-2007	$0.26	0.05	$0.19	$0.30
Material Charge	4	1	2008-2011	$0.15	0.00	$0.15	$0.15
Out Charge	3	1	2008-2010	$0.20	0.00	$0.20	$0.20
Overhead Charge	4	1	2008-2011	$0.30	0.00	$0.30	$0.30
Cull Charge	9	3	2008-2011	$0.65	0.57	$0.15	$1.25
Cull Charge by Proportion of Culls							
5%-7%	3	2	2005-2006, 2008	$0.04	0.02	$0.02	$0.06
8%-10%	4	2	2004-2006, 2008	$0.08	0.02	$0.06	$0.10
11%-13%	4	2	2004-2006, 2008	$0.12	0.02	$0.10	$0.15
14%-16%	4	2	2004-2006, 2008	$0.16	0.04	$0.12	$0.20
17%-19%	4	2	2004-2006, 2008	$0.20	0.04	$0.17	$0.25
20%-22%	4	2	2004-2006, 2008	$0.24	0.05	$0.19	$0.30
23%-25%	4	2	2004-2006, 2008	$0.27	0.07	$0.20	$0.35
26%-28%	4	2	2004-2006, 2008	$0.31	0.09	$0.21	$0.40
29%-31%	4	2	2004-2006, 2008	$0.35	0.10	$0.24	$0.45
32%-34%	3	2	2004, 2006, 2008	$0.41	0.14	$0.25	$0.50
35%-37%	3	2	2004, 2006, 2008	$0.45	0.16	$0.26	$0.55
38%-40%	3	2	2004, 2006, 2008	$0.50	0.18	$0.29	$0.60
41%-43%	3	2	2004, 2006, 2008	$0.54	0.19	$0.32	$0.66
44%-46%	3	2	2004, 2006, 2008	$0.59	0.21	$0.35	$0.72
47%-49%	3	2	2004, 2006, 2008	$0.64	0.22	$0.39	$0.79
50%-52%	1	1	2008	$0.80	.	$0.80	$0.80
Cull Charge by Proportion of Culls							
10.1%-12%	6	1	2006-2011	$0.02	0.00	$0.02	$0.02
12.1%-14%	7	2	2005-2011	$0.06	0.06	$0.04	$0.20
14.1%-16%	7	2	2005-2011	$0.07	0.06	$0.05	$0.20
16.1%-18%	7	2	2005-2011	$0.10	0.07	$0.07	$0.25
18.1%-20%	7	2	2005-2011	$0.11	0.06	$0.08	$0.25
20.1%-22%	7	2	2005-2011	$0.14	0.07	$0.12	$0.30
22.1%-24%	7	2	2005-2011	$0.17	0.06	$0.15	$0.30
24.1%-26%	7	2	2005-2011	$0.21	0.06	$0.19	$0.35
26.1%-28%	7	2	2005-2011	$0.24	0.05	$0.22	$0.35
28.1%-30%	7	2	2005-2011	$0.27	0.04	$0.26	$0.35
Percent of Fruit Packed							
92%-100%	4	1	2004-2006, 2010	$0.29	0.07	$0.22	$0.38
90%-91%	4	1	2004-2006, 2011	$0.29	0.07	$0.22	$0.39
85%-89%	4	1	2004-2006, 2012	$0.30	0.07	$0.23	$0.40
80%-84%	4	1	2004-2006, 2013	$0.31	0.07	$0.24	$0.41
70%-79%	4	1	2004-2006, 2014	$0.32	0.07	$0.25	$0.42
69% or less	4	1	2004-2006, 2015	$0.34	0.07	$0.27	$0.45
Advertising (packed)	2	1	2007-2008	$0.20	0.01	$0.19	$0.20
Advertising (processed)	2	1	2007-2008	$0.01	0.00	$0.01	$0.01
Fumigation Charge	5	2	2004-2007	$0.76	1.07	$0.03	$2.50
Hydro-cooling (Packed)	2	1	2007-2008	$0.01	0.00	$0.01	$0.01
Inbound Charge (packed & processed)	2	1	2007-2008	$0.25	0.01	$0.24	$0.26
Industry Charge (per lb delivered)	5	2	2005-2006, 2008-2010	$0.02	0.00	$0.02	$0.03
Inspection Costs	2	1	2007-2008	$0.01	0.00	$0.01	$0.01
Packing and Selling	7	1	2004-2010	$0.46	0.01	$0.45	$0.47
Packing Charge (per lb of packed weight)	13	3	2004-2010	$0.24	0.13	$0.13	$0.50
Packing Charge (per lb delivered)	18	4	2004-2010	$0.20	0.07	$0.07	$0.33
Packing Supplies	2	1	2004-2005	$0.50	0.00	$0.50	$0.50
Selling	2	1	2005, 2008	$0.03	0.01	$0.02	$0.04
Sorting (Packed)	9		2006-2011	$0.30	0.05	$0.22	$0.35
Sorting (Packed), Percentage							
87%-100%	7	1	2004, 2006-2011	$0.00	0.00	$0.00	$0.00
84%-86%	7	1	2004, 2006-2011	$0.01	0.00	$0.01	$0.01
81%-83%	7	1	2004, 2006-2011	$0.02	0.00	$0.02	$0.02
78%-80%	7	1	2004, 2006-2011	$0.02	0.00	$0.02	$0.02
75%-70%	7	1	2004, 2006-2011	$0.03	0.00	$0.03	$0.03
72%-74%	7	1	2004, 2006-2011	$0.03	0.00	$0.03	$0.03
69%-71%	7	1	2004, 2006-2011	$0.04	0.00	$0.04	$0.04
66%-68%	7	1	2004, 2006-2011	$0.04	0.00	$0.04	$0.04
Transportation Charge	1	1	2007	$0.01	.	$0.01	$0.01
Packinghouse ID (1-14)	112					1	14
Year (2004-2011)	112					2004	2011

Table 10. Total Average Warehouse Packing Charges, Conventional Apple.

Charges	Obs	Average	Std. Dev.	Min	Max
Charges per bin					
Receiving	50	$54.76	27.97	$2.50	$96.47
Handling, sorting, washing, drenching, and waxing	123	$16.95	15.50	$2.50	$57.50
Storage (Regular, CA, MCP)	218	$28.62	20.88	$2.00	$98.00
Other (cull processor charge, line spray, presize and special handling fee)	19	$18.63	23.43	$5.00	$86.75
Sub-total charge (per bin)		*$118.96*	44.81	*$12.00*	*$338.72*
Charges per box					
Industry charges (WAC, assessments)	28	$2.77	3.19	$0.03	$8.25
Inspection	16	$0.57	0.58	$0.08	$1.75
Selling Charge	11	$0.79	0.16	$0.45	$1.00
Stickering Charge	9	$0.37	0.07	$0.31	$0.54
Sub-total charge (per box)		*$4.50*	3.24	*$0.87*	*$11.54*
Total charge per 925-lb bin		$208.91	47.10	$29.40	$569.52
Number of packed boxes per 925-lb bin		20			
Average charge per box		**$10.45**	**3.94**	**$1.47**	**$28.48**

Table 11. Total Average Warehouse Packing Charges, Organic Apple.

Charges	Obs	Average	Std. Dev.	Min	Max
Bin running charge	12	$16.32	8.53	$5.00	$24.40
Wash, wax, and sort	9	$94.92	7.64	$82.75	$108.25
Storage	9	$56.54	23.88	$36.00	$87.00
Packing, repacking	8	$3.66	0.91	$2.25	$4.63
Total charge per 925-lb bin		$171.44	26.50	$126.00	$224.28
Number of packed boxes per 925-lb bin		18			
Average charge per box		**$9.52**	**1.47**	**$7.00**	**$12.46**

Table 12. Total Average Warehouse Packing Charges, Pears.

Charges	Obs	Average	Std. Dev.	Min	Max
Charges per bin					
Bin handling	49	$26.35	28.78	$0.40	$96.00
Storage	52	$19.03	12.15	$1.20	$38.14
Washing, sorting, sizing	34	$30.71	18.37	$6.00	$65.00
Packing (packing, selling, repacking, packing lug, full wrap)	24	$9.62	14.86	$0.20	$47.25
Sub-total charge (per bin)		*$85.71*	*39.16*	*$7.80*	*$246.39*
Charges per box					
Inspection Costs	2	$0.08	0.00	$0.08	$0.08
Pear Assessment	2	$0.57	0.16	$0.46	$0.68
Selling charge	2	$0.52	0.03	$0.50	$0.54
Packing material (bag pack, box, carton, tight fill, standard tray pack, wrap pack)	35	$4.47	0.80	$3.10	$6.25
Stickering	2	$0.40	0.02	$0.38	$0.41
Sub-total charge (per box)		*$6.04*	*0.82*	*$4.52*	*$7.96*
Pounds per box		44			
Pounds per bin		1100			
Total charge per box		**$9.46**	**1.77**	**$4.83**	**$17.82**

Table 13. Total Average Warehouse Packing Charges, Sweet Cherry.

Charges	Obs	Average	Std. Dev.	Min	Max
Charges per Bin					
Bin Rental	4	$2.03	0.62	$1.10	$2.40
Hauling	4	$2.83	0.29	$2.00	$2.50
Hydro-cooling	8	$3.06	0.62	$2.50	$4.00
Sub-total charge (per bin)		*$7.92*	*0.93*	*$5.60*	*$8.90*
Charges per pound					
Excess cull charge	14	$0.06	0.05	$0.01	$0.10
Industry Charge (per lb delivered)	5	$0.02	0.001	$0.02	$0.03
Packing and selling (includes sorting and packing supplies)	51	$0.27	0.13	$0.02	$0.50
Sub-total charge (per pound)		*$0.35*	*0.14*	*$0.06*	*$0.63*
Pounds per bin		300			
Total charge per pound		**$0.37**	**0.14**	**$0.07**	**$0.66**

Table 14. Summary of Warehouse Packing Charges per Unit.

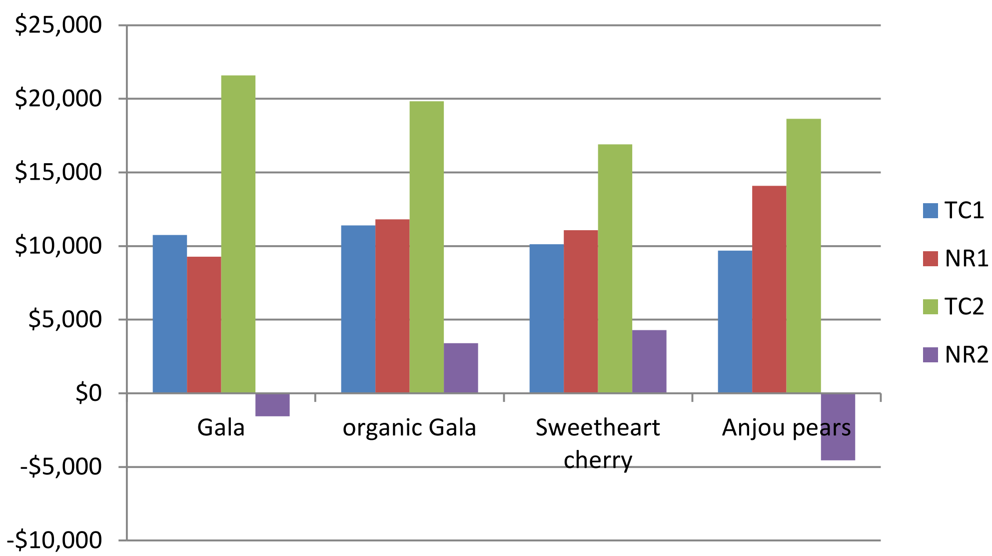
Crop	Unit	Average	Std. Dev.	Min	Max
Conventional apples	box	$10.45	3.94	$1.47	$28.48
Organic apples	box	$9.52	1.47	$7.00	$12.46
Pears	box	$9.46	1.77	$4.83	$17.82
Sweet cherries	pound	$0.37	0.14	$0.07	$0.66

Table 15. Estimated production costs and returns (including packinghouse charges) by crop.

Crop	Yield/acre*	Assumed FOB/unit**	Total production costs/acre	Net returns/acre	Break-even returns per unit
Gala	50 bins	$400.80/bin	$21,597.05	-$1,557.05	$343.91/bin (SR) $431.94/bin (LR)
Organic Gala	50 bins	$464.58/bin	$19,830.02	$3,398.98	
Sweetheart cherries	8 tons	$2,650/ton	$16,897.04	$4,302.96	
Anjou pears	32 bins	$440/bin	$18,637.10	-$4,557.10	$428.48/bin (SR) $582.41/bin (LR)

Note: *Refers to the yield and total production costs during the full production years.
**FOB average obtained from the Washington Growers Clearing House Association for Gala (2009), Sweetheart cherries (2009), Anjou (2010) and organic Gala (2010).
SR – short run (returns over variable costs); LR – long run (returns over total production costs).

Figure 1. Total Production Costs and Net Returns With and Without Warehouse Packing Charges.



Note: TC1 and NR1 are total production costs and net returns without packing costs. TC2 and NR2 are total production costs and net returns calculated after accounting for packing costs. The estimated net returns in this figure uses FOB average for the price of the tree fruit.

EXECUTIVE SUMMARY

In this study we gathered production costs at the orchard level for Sweetheart sweet cherries, organic Gala and Honeycrisp apples, and Anjou and Bartlett pears. The methodology used to develop these studies was to form a focus group consisting of 4 to 5 producers, representing most important production regions in the state (Yakima, Columbia Basin, and Wenatchee).

During the focus group, production assumptions of what would be the typical growing scenario were made. Cost categories were then identified and producers provided values for each category by consensus. Results indicate that cherry and apple operations in the state of Washington are covering all cash and opportunity production costs, including returns on management and financial risk. This implies that, under current production conditions and assuming no catastrophic unexpected events, apple and sweet cherry operations are economically sustainable in the long run. However, this is not observed in pears, where operations are covering all cash but not all opportunity costs (i.e., returns on management and financial risk). This implies that pear operations might not be economically sustainable in the long run under current production conditions.

We collected data on packinghouse charges from the Washington State Department of Agriculture-Commission Merchants Program. After a long process of data tabulation and analysis, and with the support of industry representatives, we identified major categories of packinghouse charges for conventional and organic apples, sweet cherries, and pears. Packinghouse charges were not reported exclusively for a fruit cultivar. Nonetheless, we added this information to the orchard level production costs for conventional and organic Gala apples, Sweetheart sweet cherries, and Anjou pears. Results show that when taking into consideration packinghouse charges, returns for Gala apples and Anjou pears do not cover all opportunity and management costs. In other words, when packinghouse charges are included, the owner-operator is not receiving a return on management and on the financial risk assumed in fruit production, implying that the operation might not be economically sustainable in the long run. Sweetheart cherry's net returns decreased by 61% and organic Gala by about 71% when packing costs are taken into account, yet net returns remain positive. In sum, this study provides an illustration of the importance of including packinghouse charges when analyzing the profitability of fruit production, as these costs impact considerably the net returns received.

CONTINUING PROJECT REPORT **YEAR**: 3 of 3
WTFRC Project Number: TR – 10 - 100

Project Title: Technology Roadmap Support

PI: James Nicholas Ashmore
Organization: James Nicholas Ashmore & Associates
Telephone: (202) 783 6511
Email: nickashmore@cox.net
Address: 400 North Capitol Street, Suite 363 :
City: Washington
State/Zip: DC 20001

Cooperators: None

Total project funding request: **Year 1**: $33,000 Year 2:$33,000 **Year 3:$36,000**

Other funding Sources None

WTFRC Collaborative expenses: None

Budget 1
Organization Name: James Nicholas Ashmore & Associates
Contract Administrator: James Nicholas Ashmore
Telephone: **Email address:**

Item	2010	2011	**2012**
Salaries	$33,000	$33,000	$36,000
Benefits			
Wages			
Benefits			
Equipment			
Supplies			
Travel			
Miscellaneous			
Total	$33,000	$33,000	$36,000

Objectives:

1. To protect funding for ongoing research programs and to seek funding for new proposals identified as significant and beneficial to the Washington tree fruit industry;
2. To work with the Northwest Horticultural Council to insure that Commission research initiatives are integrated with and complement other tree fruit industry goals and objectives;
3. To continue cooperative efforts with the Northwest Horticultural Council, the U. S. Apple Association, and other specialty crop stakeholder groups in working with the Congress and the Administration in their efforts to reauthorize the General Farm Act; and to seek collaboration and assistance from other agricultural groups on shared concerns, and work to educate the Congress, the Administration, and the public about the significant benefits accruing from the Specialty Crops research programs as well as emphasizing the unique position of the Washington tree fruit industry and its economic importance to the Region and to the nation;
4. To insure that Federal research activities and requests for research proposals are strategically targeted and responsive to the needs of the Washington state industry and to insure that the Commission has the flexibility to choose to participate fully in the process;
5. To keep the Commission informed of developments in the Congress and the Administration that impact on ongoing and/or future research funding;
6. To pursue specific activities related to high priority research initiatives, including but not limited to the following:
    a. USDA-ARS apple rootstock breeding program, Geneva, New York;
    b. Expansion and enhancement of pear genomics, genetics, and breeding efforts and insure that those efforts address the needs of the Pacific West Region;
    c. Development and implementation of the newly-funded Roadmap project to identify and prioritize engineering technology research to develop new pesticide application technology and its implementation for orchard structures;
    d. Expansion of automation and precision agriculture research efforts that will benefit the Pacific Northwest; and,
    e. Expansion of research and extension efforts in sustainable tree fruit production and handling, including the implications for proposed regulations affecting such handling.

Significant Findings/Results (To Date):

- As I pointed out in my last Continuing Report, with respect to appropriations funding for existing programs in the current fiscal year (2012), we were not asked to take unfair reductions in our programs;
- The Administration has submitted its recommended budget for fiscal 2013 (based on an agreement reached in the previous Session with respect total spending); the House of Representatives has passed its version of the Congressional Budget Resolution for fiscal 2013, recommending deeper cuts to both entitlement programs and discretionary spending levels;
- At the present time, it is unlikely that the Senate will attempt to write a version of congressional budget resolution; as such, the current congressional session is likely to track last year's process, which means that in all likelihood final decisions with respect to appropriations bills and major reauthorization measures (like the scheduled reauthorization of the General Farm Act), will be delayed and may not take place until a Lame Duck Session after the November elections;

- In my last Continuing Report, I had indicated some degree of optimism that the Joint Committee on Deficit Reduction (the "Super Committee), would be able to reach agreement on its efforts to develop a deficit reduction package cutting at least #1.5 trillion over the next ten years from the Federal budget; my optimism was unfortunately not realized and no agreement was reached, and that failure (unless Congress provides otherwise), will lead to a series of mandatory cuts (sequestration) that are generally seen as draconian in nature;
- The failure of the Joint Committee on Deficit Reduction effectively killed an agreement reached by both the House and Senate Agriculture Committees to a farm bill reauthorization package that would have reduced Federal spending on farm programs by $23 billion; that agreement reflected a strong commitment to specialty crops research programs, although at a slightly reduced funding level;
- At this point in time, no final decisions have been made with respect to how much "savings" will be expected from reauthorization of the farm bill; however, it does appear that it will be significantly more than the $23 billion in savings achieved by the earlier agreement between the House and Senate Agriculture committees; the number most often heard in discussions with Hill staff is somewhere around $32 to $33 billion in savings;
- What this means is that there will likely be much greater stress on the amount of funding that will be available for the Specialty Crops research programs; what I have sought to build on and emphasize is the importance of maintain the specialty crops research delivery mechanisms and in effect leave to a later date the question of how much money will be made available;
- I have emphasized the values from changing the culture of research programs within USDA and stressed that this change is in large part due to the new research delivery mechanisms that emphasize collaboration and sound science with grower and industry involvement; I continue to believe that there is a strong interest in continuing those programs in the upcoming legislation; there appears to be strong support for protecting the integrity of the existing specialty crops programs, with the outstanding issues focusing on the nature, level, and type of funding.
- It is important to note that there is also continued debate as to whether funding for these programs will be considered "mandatory" or "discretionary" or some mix of "mandatory" and "discretionary" funding; I have continued to press gently for continued "mandatory" funding if at all possible;
- With respect to cooperation with the Northwest Horticultural Council, the Commission Manager and I worked to support the successful candidacy of Harold Austin, who was named to the National Organic Standards Board; Mr. Austin was supported by the Washington State Congressional Delegation;
- With respect to cooperation with the Northwest Horticultural Council and the Minor Crop Farmer Alliance, I have worked with both groups to assist in addressing the concerns over the process and procedures governing the science data used by Administration agencies in developing Biological Opinions under the Endangered Species Act; this effort necessarily included working closely with other agricultural groups and with Members of the Washington State Congressional Delegation and with the committees of both the House and Senate;
- I have also initiated efforts to work with the Northwest Horticultural Council and the Minor Crop Farmer Alliance to strengthen efforts to cooperate on issues involved with MRLs and how they are established and how there can be further progress with respect to harmonization of these standards;
- With respect to specific research interests of the Washington State industry, I am continuing to work with the Commission Manager and the Northwest Horticulture Council dealing with ARS Administrator Dr. Ed Knipling and his agency relative to both our interests in the long-

term future of the pear research programs and also our strong concern over problems that have surfaced in the administration of the apple rootstock program out of Geneva; the Commission Manager and I met with Dr. Knipling and his staff late last year and had a good meeting that was encouraging on both issues;;

- We continue to emphasize our interest in a responsible resolution of the complex and complicated issues involved that will insure that an adequate research delivery system can be maintained but also enhanced so that these programs are administered in a sound scientific manner and so that these programs are in fact more responsive to the interests and needs of the Washington tree fruit industry;

Methodology:

I believe that our success to date has been based on the ideas and concerns of the Commission and Washington Tree Fruit Industry and our emphasis on our commitment to sound science and an open, fair, and transparent process that is responsive to grower needs and involves growers and their organizations in the review and decision process.

Because of our approach and our patience and the fact that we "practice what we preach," we have developed an outstanding reputation and we have excellent channels of communication with other agricultural groups, with the Congress, and with the Administration.

We are widely recognized as leaders in the development of a roadmap process and an integrated approach to research within the Department of Agriculture. We have worked hard to get to this point, and I am committed to continuing to work with the Commission and its Manager to protect and enhance this reputation.

We have had remarkable support from the Washington State Congressional Delegation in both the House and Senate.

Discussion/Going Forward

This session of Congress is very likely to test our patience. There will be a lot of noise as the two political parties move forward toward the upcoming Election. Relatively speaking, I continue to believe that we are in good shape and positioned well to continue our efforts. We will, I believe, have to continue to be vigilant and continue to be open and factual in our dealings with the Congress and the Administration and with the public.

The outlook essentially remains the same as I indicated in my previous Continuing Report. It may well have worsened in terms of political conflict. As a result, we will be faced with continuing controversy and we will have to work with all parties in an effort to establish a climate where a rational agreement can be reached.

We are in an age of reduced expectations, and we need to continue to stress our willingness to do our part; however, we do need to continue to press to have a viable structure that will enable valuable research efforts to continue and to build on the new partnerships that we have formed over the last several years. We have come a very long way and we have accomplished a lot. I look forward to continuing to work with you on these efforts as we go forward.

CONTINUING PROJECT REPORT **YEAR**: 1 of 1
WTFRC Project Number: TR-12-101

Project Title: Cost estimation of producing red delicious apples in Washington State

PI:	Karina Gallardo	**Co-PI (2):**	Suzette Galinato
Organization:	School of Economic Sciences, Tree Fruit and Research Extension Center, WSU	**Organization**:	IMPACT Center, School of Economic Sciences, WSU
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Cooperators: Tom Auvil (Washington Tree Fruit Research Commission, Wenatchee, WA)

Total Project Request: **Year 1:** $6,727

Other funding sources: None

WTFRC Collaborative expenses: None

Budget 1
Organization Name: WSU TFREC **Contract Administrator:** Carrie Johnston
Telephone: 509-335-4564 **Email address:** carriej@wsu.edu

Item	**2012**
Salaries[1]	$4,156
Benefits[1]	$1,471
Wages	$0
Benefits	$0
Equipment	$0
Supplies[2]	$100
Travel[3]	$1,000
Plot Fees	$0
Miscellaneous	$0
Total	**$6,727**

Footnotes: [1] One-month salary at 95% FTE for research associate Suzette Galinato ($4,156), plus $1,471 in benefits. [2] Fee for the room where the focus group meeting will be conducted. The budget includes food and beverages to be served during the meeting. [3] Includes $600 for researchers' travel for the focus group meeting (hotel, per diem, car rental/mileage reimbursement). The remaining $400 is to cover travel expenses for participants, at a rate of $100 per participant. We are expecting to have 4 participants in the focus group.

OBJECTIVES

1. Develop an up-to-date enterprise budget for Red Delicious apples that will reflect current modern practices; and
2. Disseminate the updated information with growers, other stakeholders in the tree fruit industry and researchers.

Goal and anticipated activities:

- The last enterprise budget on Red Delicious was published by Washington State University in 1992. Our *goal* is to update the said study and provide an estimate of the costs of producing Red Delicious in Washington State given current practices and market prices.
- *Anticipated accomplishments:* We gathered preliminary data from four Red Delicious growers (two in the Wenatchee and two in the Yakima area). In both focus groups, the exact same assumptions were made, however there were discrepancies on the values associated with cost centers in the two areas. Thus, we will meet in person with a fifth grower to help us define the most representative cost center estimates for the state of Washington. We will write a WSU Extension factsheet to report our findings (June 2012 to July 2012). A final report will be submitted to the Washington Tree Fruit Commission at the Winter Technology Review.

SIGNIFICANT FINDINGS

Preliminary findings are showing that under the production assumptions made (density of 900 trees per acre, M106 rootstock, 25-acre block), yield during full production at 70 bins per acre, FOB price of $400 per bin, and considering packinghouse charges, net returns for Red Delicious ranges from $817 to $6,954 per acre.

METHODS

We conducted two focus groups and meet with a total of four growers. Due to discrepancies in the estimates for cost categories from the two groups, we will meet in person with a fifth grower to define the most representative cost center estimates for Red Delicious production in the state of Washington. This fifth person was contacted through the Washington Tree Fruit Research Commission.

RESULTS & DISCUSSION

Table 1 presents the assumed specifications of a 25-acre Red Delicious block within a 300-acre diverse-cultivar orchard. Preliminary data on production costs are shown in Table 2 to Table 4. These tables provide a snapshot of low to high ranges of Red Delicious production costs. The total cost of producing Red Delicious during full production years range from $21,046 to $27,183 per acre. The net returns are positive and ranges from $817 to $6,954 per acre. Work will continue to finalize and publish the Red Delicious enterprise budget.

Table 1. Red Delicious Block Specifications.

In-row spacing	4 feet
Between row spacing	12 feet
Variety & Root stock	M106
Block size (productive)	25 acres
Life of planting	30 years
Tree density	900 trees

Table 2. Cost and Returns per Acre of Establishing, Producing and Packing Red Delicious on a 25-Acre Orchard Block (based on data from Wenatchee Focus Group).

	Establishment Years					Full Production	
	Year 1	Year 2	Year 3	Year 4	Year 5	Years 6 to 30	Your Costs
Estimated Production (bins/acre)			15.0	30.0	50.0	70.0	
Estimated Price ($/bin)[1]			400.00	400.00	400.00	400.00	
Total Returns			6,000.00	12,000.00	20,000.00	28,000.00	
Variable Costs ($/acre):							
Establishment							
Soil Preparation	326.00						
Trees (including labor)	6,730.00						
Orchard Activities							
Pruning & Training	121.00	242.00	297.00	275.00	220.00	198.00	
Green Fruit Thinning			198.00	253.00	330.00	352.00	
Chemicals[2]	94.00	165.00	334.00	414.00	444.00	518.00	
Fertilizer[2]	150.00	150.00	189.00	149.00	99.00	74.00	
Beehives			45.00	45.00	45.00	45.00	
General Farm Labor	125.00	125.00	300.00	300.00	300.00	300.00	
Irrigation/Electric Charge	50.00	50.00	100.00	100.00	100.00	100.00	
Irrigation Labor	165.00	165.00	330.00	330.00	330.00	330.00	
Frost Protection (Labor)				4.80	4.80	4.80	
Harvest Activities							
Picking Labor			240.00	480.00	800.00	1,120.00	
Other Labor (checkers, tractor drivers)			45.00	90.00	150.00	210.00	
Hauling Apples			75.00	150.00	250.00	350.00	
Warehouse Packing Charges [3]			2,816.80	5,633.60	9,389.34	13,145.07	
Maintenance and Repairs							
Machinery Repair	125.00	125.00	125.00	125.00	125.00	125.00	
Fuel & Lube	85.00	95.00	125.00	180.00	180.00	180.00	
Wind Machine & Alarm System Repair					24.00	48.00	
Mainline, Pump & Pond Maintenance						8.62	
Other Variable Costs							
Overhead (5% of VC)	398.55	55.85	260.99	426.47	639.56	855.42	
Interest (5% of VC) [4]	313.86	43.98	205.53	335.85	503.65	673.65	
Total Variable Costs	8,683.41	1,216.83	5,686.32	9,291.72	13,934.35	18,637.56	
Fixed Costs ($/acre):							
Depreciation							
Trellis	43.83	43.83	43.83	43.83	43.83	43.83	
Irrigation System	64.95	64.95	64.95	64.95	64.95	64.95	
Mainline & Pump	15.00	15.00	15.00	15.00	15.00	15.00	
Wind Machine				72.23	72.23	72.23	
Pond	9.00	9.00	9.00	9.00	9.00	9.00	
Machinery & Building Annual Replacement Cost	100.00	100.00	100.00	100.00	100.00	100.00	
Interest							
Land	400.00	400.00	400.00	400.00	400.00	400.00	
Machinery & Buildings	53.58	53.58	53.58	53.58	53.58	53.58	
Irrigation System	59.54	59.54	59.54	59.54	59.54	59.54	
Wind Machine & Alarm System				66.21	66.21	66.21	
Pond	8.25	8.25	8.25	8.25	8.25	8.25	
Establishment Costs (5%)		504.38	660.65	748.20	731.83		
Other Fixed Costs							
Miscellaneous Supplies	100.00	100.00	100.00	100.00	100.00	100.00	
Land & Property Taxes	100.00	100.00	100.00	100.00	100.00	100.00	
Insurance Cost (all farm)	50.00	50.00	50.00	140.00	140.00	140.00	
Management Cost	400.00	400.00	400.00	400.00	400.00	400.00	
Amortized Establishment Costs[5]						775.89	
Total Fixed Costs	1,404.15	1,908.52	2,064.79	2,380.79	2,364.41	2,408.47	
TOTAL COSTS	10,087.55	3,125.36	7,751.11	11,672.51	16,298.76	21,046.04	
ESTIMATED NET RETURNS	(10,087.55)	(3,125.36)	(1,751.11)	327.49	3,701.24	6,953.96	
Accumulated Establishment Costs	10,087.55	13,212.91	14,964.02	14,636.53	10,935.29		

[1] These prices reflect gross sales with no warehouse charges deduction.

[2] Includes materials and labor.

[3] Assumes a 925-lb bin with 21 packed boxes per bin.

[4] Interest expense on full year during establishment years and for 3/4 of a year during full production.

[5] Represents the costs incurred during the establishment years (minus revenues during those years) that must be recaptured during the full production years.

Table 3. Cost and Returns per Acre of Establishing, Producing and Packing Red Delicious on a 25-Acre Orchard Block (based on data from Yakima Focus Group 1).

	Establishment Years					Full Production	
	Year 1	Year 2	Year 3	Year 4	Year 5	Years 6 to 30	Your Costs
Estimated Production (bins/acre)			15.0	30.0	50.0	70.0	
Estimated Price ($/bin)[1]			400.00	400.00	400.00	400.00	
Total Returns			6,000.00	12,000.00	20,000.00	28,000.00	
Variable Costs ($/acre):							
Establishment							
Soil Preparation	626.50						
Trees (including labor)	6,136.00						
Orchard Activities							
Pruning & Training	131.50	254.25	318.00	301.25	437.50	446.25	
Green Fruit Thinning			198.00	253.00	495.00	495.00	
Chemicals[2]	525.50	563.75	653.00	853.00	1,053.00	1,078.50	
Fertilizer[2]	150.00	150.00	189.75	150.50	100.50	100.50	
Beehives			45.00	45.00	45.00	45.00	
General Farm Labor	125.00	125.00	300.00	300.00	300.00	300.00	
Irrigation/Electric Charge	50.00	50.00	100.00	100.00	100.00	100.00	
Irrigation Labor	191.25	191.25	382.50	382.50	382.50	382.50	
Frost Protection (Labor)				4.40	4.40	4.40	
Harvest Activities							
Picking Labor			300.00	600.00	1,000.00	1,400.00	
Other Labor (checkers, tractor drivers)			60.00	120.00	200.00	280.00	
Hauling Apples			75.00	150.00	250.00	350.00	
Warehouse Packing Charges [3]			2,708.14	5,416.28	9,027.13	12,637.98	
Maintenance and Repairs							
Machinery Repair	125.00	125.00	125.00	125.00	125.00	125.00	
Fuel & Lube	175.00	175.00	175.00	475.00	475.00	475.00	
Wind Machine & Alarm System Repair					24.00	48.00	
Mainline, Pump & Pond Maintenance			8.93	8.93	8.93	8.93	
Other Variable Costs							
Overhead (5% of VC)	411.79	81.71	281.92	464.24	701.40	913.85	
Interest (6% of VC) [4]	389.14	77.22	266.41	438.71	662.82	863.59	
Total Variable Costs	9,036.68	1,793.18	6,186.64	10,187.81	15,392.17	20,054.50	
Fixed Costs ($/acre):							
Depreciation							
Trellis	66.12	66.12	66.12	66.12	66.12	66.12	
Irrigation System	64.95	64.95	64.95	64.95	64.95	64.95	
Mainline & Pump	19.50	19.50	19.50	19.50	19.50	19.50	
Wind Machine				72.00	72.00	72.00	
Pond	23.10	23.10	23.10	23.10	23.10	23.10	
Machinery & Building Annual Replacement Cost	100.00	100.00	100.00	100.00	100.00	100.00	
Interest							
Land	480.00	480.00	480.00	480.00	480.00	480.00	
Machinery & Buildings	93.39	93.39	93.39	93.39	93.39	93.39	
Irrigation System	71.45	71.45	71.45	71.45	71.45	71.45	
Wind Machine & Alarm System				79.20	79.20	79.20	
Pond	25.41	25.41	25.41	25.41	25.41	25.41	
Establishment Costs (6%)		633.94	871.30	1,028.91	1,085.12		
Other Fixed Costs							
Miscellaneous Supplies	100.00	100.00	100.00	100.00	100.00	100.00	
Land & Property Taxes	80.00	80.00	80.00	80.00	80.00	80.00	
Insurance Cost (all farm)	105.00	105.00	145.00	145.00	145.00	145.00	
Management Cost	300.00	300.00	300.00	300.00	300.00	300.00	
Amortized Establishment Costs[5]						1,273.74	
Total Fixed Costs	1,528.92	2,162.85	2,440.21	2,749.02	2,805.23	2,993.86	
TOTAL COSTS	10,565.59	3,956.03	8,626.85	12,936.83	18,197.41	23,048.36	
ESTIMATED NET RETURNS	(10,565.59)	(3,956.03)	(2,626.85)	(936.83)	1,802.59	4,951.64	
Accumulated Establishment Costs	10,565.59	14,521.62	17,148.48	18,085.31	16,282.71		

[1] These prices reflect gross sales with no warehouse charges deduction.

[2] Includes materials and labor.

[3] Assumes a 925-lb bin with 21 packed boxes per bin.

[4] Interest expense on full year during establishment years and for 3/4 of a year during full production.

[5] Represents the costs incurred during the establishment years (minus revenues during those years) that must be recaptured during the full production years.

Table 4. Cost and Returns per Acre of Establishing, Producing and Packing Red Delicious on a 25-Acre Orchard Block (based on data from Yakima Focus Group 2).

	Establishment Years					Full Production	
	Year 1	Year 2	Year 3	Year 4	Year 5	Years 6 to 30	Your Costs
Estimated Production (bins/acre)			15.0	30.0	50.0	70.0	
Estimated Price ($/bin)[1]			400.00	400.00	400.00	400.00	
Total Returns			6,000.00	12,000.00	20,000.00	28,000.00	
Variable Costs ($/acre):							
Establishment							
Soil Preparation	626.50						
Trees (including labor)	6,136.00						
Orchard Activities							
Pruning & Training	288.50	521.25	585.00	513.25	594.50	548.25	
Green Fruit Thinning			297.00	352.00	594.00	594.00	
Chemicals[2]	525.50	563.75	653.00	853.00	1,053.00	1,078.50	
Fertilizer[2]	150.00	150.00	189.75	150.50	100.50	100.50	
Beehives			60.00	60.00	60.00	60.00	
General Farm Labor	175.00	175.00	350.00	350.00	350.00	350.00	
Irrigation/Electric Charge	275.00	275.00	275.00	275.00	275.00	275.00	
Irrigation Labor	191.25	191.25	382.50	382.50	382.50	382.50	
Frost Protection (Labor)				8.00	8.00	8.00	
Harvest Activities							
Picking Labor			300.00	600.00	1,000.00	1,400.00	
Other Labor (checkers, tractor drivers)			60.00	120.00	200.00	280.00	
Hauling Apples			75.00	150.00	250.00	350.00	
Warehouse Packing Charges [3]			3,292.50	6,585.00	10,975.00	15,365.00	
Maintenance and Repairs							
Machinery Repair	125.00	125.00	125.00	125.00	125.00	125.00	
Fuel & Lube	175.00	175.00	175.00	475.00	475.00	475.00	
Wind Machine & Alarm System Repair					24.00	48.00	
Mainline, Pump & Pond Maintenance			8.93	8.93	8.93	8.93	
Other Variable Costs							
Overhead (5% of VC)	433.39	108.81	341.43	550.41	823.77	1,072.43	
Interest (6% of VC) [4]	409.55	102.83	322.66	520.14	778.46	1,013.45	
Total Variable Costs	9,510.69	2,387.89	7,492.77	12,078.72	18,077.66	23,534.56	
Fixed Costs ($/acre):							
Depreciation							
Trellis	55.05	55.05	55.05	55.05	55.05	55.05	
Irrigation System	64.95	64.95	64.95	64.95	64.95	64.95	
Mainline & Pump	19.50	19.50	19.50	19.50	19.50	19.50	
Wind Machine				72.00	72.00	72.00	
Pond	23.10	23.10	23.10	23.10	23.10	23.10	
Machinery & Building Annual Replacement Cost	100.00	100.00	100.00	100.00	100.00	100.00	
Interest							
Land	540.00	540.00	540.00	540.00	540.00	540.00	
Machinery & Buildings	93.39	93.39	93.39	93.39	93.39	93.39	
Irrigation System	71.45	71.45	71.45	71.45	71.45	71.45	
Wind Machine & Alarm System				79.20	79.20	79.20	
Pond	25.41	25.41	25.41	25.41	25.41	25.41	
Establishment Costs (6%)		665.31	943.17	1,186.40	1,368.45		
Other Fixed Costs							
Miscellaneous Supplies	100.00	100.00	100.00	100.00	100.00	100.00	
Land & Property Taxes	80.00	80.00	80.00	80.00	80.00	80.00	
Insurance Cost (all farm)	105.00	105.00	145.00	145.00	145.00	145.00	
Management Cost	300.00	300.00	300.00	300.00	300.00	300.00	
Amortized Establishment Costs[5]						1,879.22	
Total Fixed Costs	1,577.85	2,243.16	2,561.02	2,955.45	3,137.50	3,648.26	
TOTAL COSTS	11,088.53	4,631.05	10,053.79	15,034.17	21,215.16	27,182.82	
ESTIMATED NET RETURNS	(11,088.53)	(4,631.05)	(4,053.79)	(3,034.17)	(1,215.16)	817.18	
Accumulated Establishment Costs	11,088.53	15,719.58	19,773.37	22,807.54	24,022.70		

[1] These prices reflect gross sales with no warehouse charges deduction.

[2] Includes materials and labor.

[3] Assumes a 925-lb bin with 21 packed boxes per bin.

[4] Interest expense on full year during establishment years and for 3/4 of a year during full production.

[5] Represents the costs incurred during the establishment years (minus revenues during those years) that must be recaptured during the full production years.

CONTINUING PROJECT REPORT **YEAR:** 3 of 3
WTFRC Project Number: TR-10-101

Project Title: Evaluation of environmental data used for IPM models

PI:	Vincent P. Jones	**Co-PI(2)**:	Ute Chambers
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Co-PI(3): Gary G. Grove
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State/Zip: WA 99350

Cooperators: George Kantor, Carnegie Mellon University

No additional funds requested, progress report only

Total Project Request: **Year 1:** $ 58,432 **Year 2:**$47,031 **Year 3: $48,715**

Other funding Sources: None
WTFRC Collaborative expenses: None

Budget 1

Organization: WSU-TFREC	Contract Administrator: Carrie Johnston, Kevin Larson		
Telephone: CJ 509-335-4564, KL 663-8181 x221	Email: CJ: carriej@wsu.edu, KL: kevin_larson@wsu.edu		
Item	**2010**	**2011**	**2012**
Salaries[1]	24,622	28,833	26,000
Benefits [2]	7,810	12,948	10,833
Wages	0	0	5,100
Benefits [3]	0	0	882
Equipment [4]	21,000	0	0
Supplies	3,000	3,150	3,500
Travel [5]	2,000	2,100	2,400
Miscellaneous	0	0	0
Total	58,432	47,031	**48,715**

Footnotes:
[1]4 months Ute Chambers (Y1-Y2) 3 month Y3, 2 Months T. Melton Y1, 3 Months Y2, 5 months@0.7FTE year 3
[2]Ute Chambers 34.9%, T Melton 49.2%
[3] 18%
[4]Weather stations and sensor costs
[5] within-state travel

Objectives:

1. Evaluate the validity of virtual weather stations using a combination of regional and site-specific (in-orchard) weather monitoring systems and NOAA site-specific forecasts.
2. Evaluate the differences between AWN and within-orchard environmental conditions on model accuracy.
3. Compare the effect of high and low-density plantings as well as overhead cooling on environmental monitoring and how those horticultural and operational changes affect model accuracy.

Significant Findings:

- Differences in environmental parameters between orchard interior and AWN show large day-to-day variations and diurnal patterns that are similar between years.
- Degree-day accumulations and model predictions differ between high- and low-density orchards and can exceed the three-day threshold in the later part of the season. Wind speed within an orchard is reduced to favorable conditions for CM adult flight.
- Overhead cooling as used in our study reduces daily maximum temperatures, but has no significant effect on model predictions or CM longevity. However, this year was unusually cool and we had few days over the insect upper thresholds.

Progress:

Objective 1 – We completed analysis of the 2009-2011 NOAA (National Oceanic Atmospheric Administration) site-specific weather forecasts known as the National Digital Forecast Database (NDFD) for possible use as virtual weather stations and reported on it in the last progress report.

Objective 2 – Microclimate parameters have been recorded in the interior of five orchards with adjacent AWN stations for the second season. The data was analyzed similarly to the NDFD/AWN comparison in Objective 1 to determine the effect of sensor position on model predictions by comparing degree-day accumulations for seven insect models and predictions of nine key events for each model (Table 1). Previously, we showed that the relationship between the DD calculated using AWN and orchard data was consistent between both years for most models at most locations and that AWN predicts insect events later than orchard data.

Comparison of microclimate between AWN data and orchard interior.

Air temperature: Overall, the average difference in air temperature between orchard interior and AWN ranged between 0.4 ± 1.2 and -1.6 ± 2.9°F (Table 2). However, we observed large day-to-day

Table 1. Insect models and events tested to compare model accuracy using the 1-day NDFD forecasts and real data from WSU-AWN and Wilbur-Ellis Stations in NC Washington.

Model	Events tested
Apple Maggot (AM)	Adult Emergence: 1, 10, 20, 30, 40, 50, 60, 80, and 90%
Codling Moth (CM)	1st moth; 10, 25, 50, 75% egg hatch in 1st generation; 10, 25, 50, and 75% in second
Lacanobia (LAC)	Egg hatch: 1, 10, 25, 50, 75% in 1st generation; 10, 25, 50, and 75% in second
Obliquebanded Leafroller (OBLR)	Larvae in 4th instar: 1.5, 10, 25, 50, 75% in first generation; 10, 25, 50, and 75% in second
Pandemis Leafroller (PLR)	Larvae in 4th instar: 1.5, 10, 25, 50, 75% in first generation; 10, 25, 50, and 75% in second
Peach Twig Borer (PTB)	Egg hatch: 1,10, 25 50, 75% in first generation; 10, 25, 50, and 75% in second
Western Cherry Fruit Fly (WCFF)	Adult Emergence: 1, 10, 20, 30, 40, 50, 60, 80, and 90%

Fig. 1. Difference in hourly air temperature between orchard interior and AWN at five sites in May and July 2010 and 2011. Zero (0) indicates no difference, positive difference indicates orchard temperature is higher than AWN, negative values indicate orchard temperature is lower than AWN.

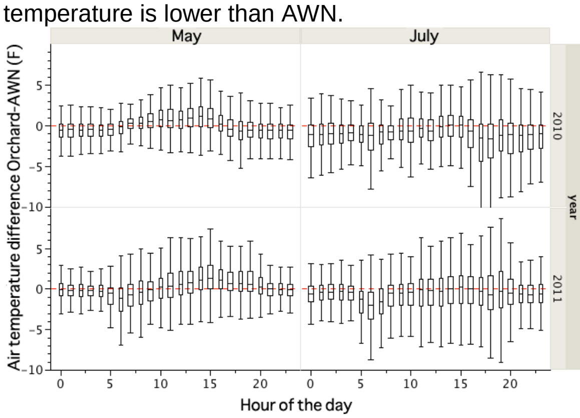
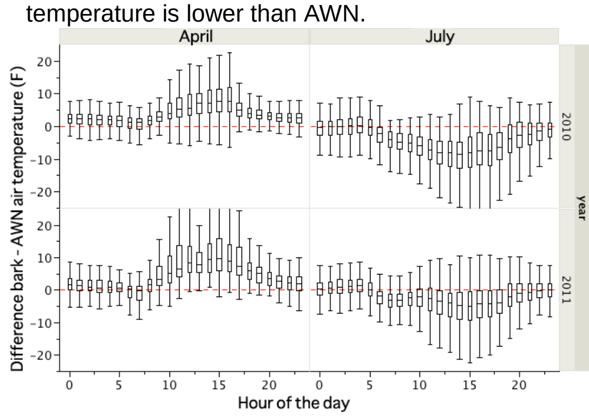


Fig. 2. Difference in hourly bark temperature versus AWN air temperature at five sites in April and July 2010 and 2011. Zero (0) indicates no difference, positive difference indicates bark temperature is higher than AWN, negative values indicate bark temperature is lower than AWN.



variations and diurnal pattern in the difference of air temperature between the tree canopy and AWN. In both years, mean air temperature within orchards exceeded air temperature outside of orchards (AWN) during the day in the early part of the season (April-May, Fig. 1). Although the average canopy air temperatures are only slightly higher than AWN air temperatures (Table 3), daily maximum temperatures within orchards were higher in the spring than those recorded at AWN stations. This resulted in increased DD and, consequently, in key insect events being predicted earlier when using orchard data compared to AWN data. Once the canopy was fully developed, the temperature within orchards was below that of AWN (June-August) throughout the day (Fig. 1, Tables 2, 3).

Bark temperature: Our data showed that bark temperatures differed from AWN air temperature and that these differences changed during the season. During February through April, bark temperature was markedly higher than AWN air temperature (Fig. 2, Table 3). We recorded temperature differences of up to 44.4°F at Sunrise in February 2011. During June through August, on the other hand, the average bark temperature was lower compared to AWN air temperature (Fig. 2, Table 3). This pattern in bark temperature is caused by solar radiation and the change in foliage. Elevated bark

Table 2. Mean (± SD) difference of environmental parameters between orchard interior and AWN per site averaged over the season (April-August) 2010 and 2011. Positive differences indicate higher values and negative differences indicate lower values in the orchard compared to AWN. *Bark temperature data are summarized for the period of Feburary through August.

Site	Distance (m)	Elevation difference (m)	Air temperature (F)	Bark temperature (F)*	Relative humidity (%)	Solar radiation (W/m^2)
Malaga[a]	120	4	-1.6 ± 2.9	-1.2 ± 6.2	8.5 ± 7.6	-31.7 ± 130.7
N Cashmere[b]	40	0	0.4 ± 1.2	0.9 ± 4.3	1.7 ± 2.8	-8.3 ± 65.8
Quincy[b]	75	0	-0.2 ± 2.5	0.4 ± 6.0	3.8 ± 8.3	-9.5 ± 124.2
WSU Sunrise[a]	436	0	-0.9 ± 2.8	0.6 ± 6.4	6.7 ± 8.0	-9.8 ± 102.2
WSU TFREC[b]	39	0	0.1 ± 2.3	1.1 ± 5.0	4.2 ± 5.3	8.2 ± 119.9

[a] overhead irrigation; [b] micro-sprinklers under canopy.

Table 3. Mean (± SD) difference of environmental parameters between orchard interior and AWN per month averaged over all 5 sites in 2010 and 2011.

Month	Air temperature (F)	Bark temperature (F)	Relative humidity (%)	Solar radiation (W/m^2)
January	-0.2 ± 1.3	1.6 ± 4.4	4.2 ± 4.9	-0.9 ± 38.1
February	0.0 ± 1.3	3.4 ± 6.1	3.7 ± 4.1	-5.2 ± 57.4
March	0.1 ± 1.3	2.9 ± 4.9	1.9 ± 4.4	-4.2 ± 71.6
April	0.3 ± 1.5	4.3 ± 5.1	1.3 ± 4.5	-4.5 ± 95.0
May	0.1 ± 2.3	1.7 ± 4.0	4.0 ± 6.1	-5.6 ± 114.2
June	-0.2 ± 2.1	-0.6 ± 3.9	5.8 ± 6.5	-8.3 ± 117.2
July	-1.0 ± 2.9	-3.1 ± 5.6	6.6 ± 7.8	-13.4 ± 108.5
August	-1.4 ± 3.1	-3.1 ± 5.3	7.1 ± 8.4	-27.7 ± 119.9

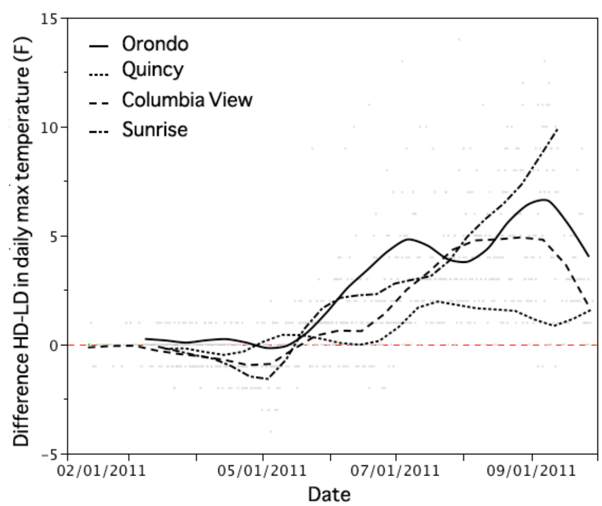
temperatures can affect insects that live or overwinter under bark, for example codling moth pupation and emergence in spring.

Objective 3 – Environmental data was recorded in four orchard pairs with adjacent high-density (HD) and low-density (LD) apple blocks starting 11 February, 2011. The data was analyzed similarly to the NDFD/AWN comparison in Objective 1 to determine the effect of orchard density and overhead cooling on model predictions. Analysis of the data focused on the comparison of temperature conditions and resulting degree-day accumulations for the seven insect models and predictions of nine key events for each model (Table 1). DD accumulations and model predictions using the data from HD and LD plantings were also compared to those using data from the nearest AWN station. In addition, other environmental parameters were compared between HD and LD blocks as well as data recorded by the nearest AWN station.

Overhead cooling was set up in our high-density apple block at Sunrise along with two sets of data loggers to record microclimate parameters in that plot. In the west end of the same block, another pair of data loggers was set up to measure conditions without cooling. Overhead cooling was used on 32 days over the period of July 29 until September 13, 2011, when daily maximum temperatures were predicted to be above 86°F and the sunburn browning model estimated medium or high risk for sunburn to occur. When activated, the overhead cooling applied water from noon (12:00pm) until 5:00pm at 15-min intervals (a common practice in WA orchards). In the non-cooled section, Kaolin was sprayed for sunburn protection on July 14, 2011.

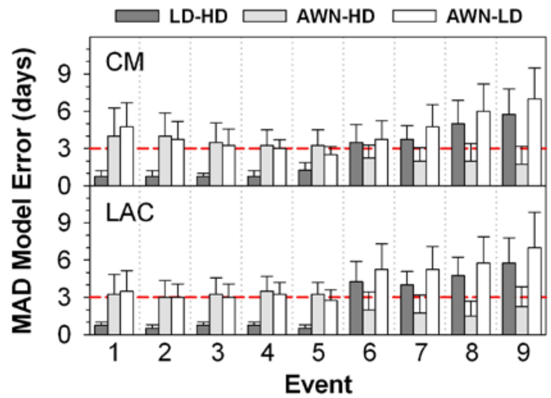
Comparison of temperature and model predictions in high- and low-density plantings. For all four sites, daily maximum temperature did not significantly differ in the early part of the season. However, later in the season the daily maximum temperature was higher in the HD plots compared to LD (Fig. 3). This pattern in temperature difference is reflected in the difference in insect model predictions where we

Fig. 3. Average difference in daily maximum temperature (F) between high-density (HD) and low-density (LD) orchards at four sites. Values of 0 - HD = LD, positive difference - HD > LD, negative difference - HD < LD.



saw small deviations in model predictions early in the season and an increases in model error later in summer (Fig. 4). This causes key insect events to be predicted to occur later in low-density than in high-density plantings. In particular for insect stages that occur in July and August (CM, LAC, PTB), the model error can increase above the 3-day threshold. Overall, the average error in per model ranged between 0.5 and 2.8 days.

Fig. 4. Deviation in model predictions (in days) between low-density (LD) and high-density (HD), AWN and HD, and between AWN and LD data for codling moth (CM) and *Lacanobia* (LAC) in 2011.

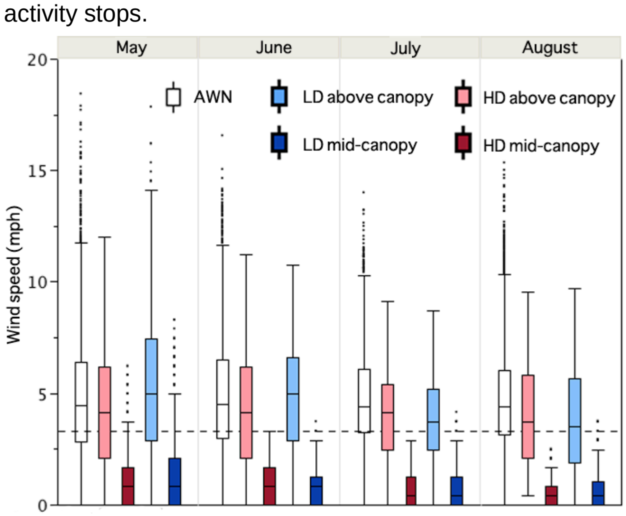


Effect of orchard density on other environmental parameters. Similarly to Objective 2, the differences in environmental parameters between HD and LD orchards showed large day-to-day variations as well as seasonal and diurnal patterns. Mean air, bark, and soil temperature differences were typically larger in the summer months (June-August) than in the spring (e.g. *July*: 1.3±3.1ºF, 2.7±7.9ºF, and 3.8±5.0ºF, respectively; *April*: -0.1±1.6ºF, 0.2±5.9ºF, and -1.3±2.2ºF, respectively).

Bark temperature differed between HD and LD blocks during the day due to differences in penetration of solar radiation. Overall, daytime bark temperature was higher in HD blocks compared to LD blocks. During February and March, this difference was smaller than during May-August, after the canopy was fully developed and provided more shade in the LD blocks. At night, bark temperature in HD trees was similar to or slightly lower than that in LD trees.

Wind speed within an orchard is dramatically reduced compared to the wind speed outside an orchard (measured by AWN) or above the orchard canopy. This can have an effect on the flight activity of insects. Codling moth has been shown to cease virtually any flight activity at wind speeds of 3.3 mph. Average wind speed above the canopy or outside the orchard was above 3.3 mph during the flight period (sunset + 3 hours, 7-11pm) from May through August 2011. Wind speed between the trees, on the other hand, was below 3.3 mph (Fig. 5). This indicates that while CM adults are unlikely to fly in the open because of the higher wind speed, they are still capable of dispersing within orchards. Models that include wind speed as a measure to predict the likelihood of CM flight and oviposition will need to take this difference in wind speed between orchard interior and the outside into consideration.

Fig. 5. Wind speed (in mph) between 7pm and 11pm measured at four low-density (LD) and high-density (HD) orchards mid-canopy and above the canopy (Sunrise only) and at the nearest AWN stations in 2011. The dashed line indicates the threshold of 3.3 mph above which CM flight activity stops.



Overall, AWN measurements outside orchards reflect conditions within HD orchards more closely than conditions in LD orchards, in particular in the later part of the season, when the larger canopy in LD orchards has an insulating effect.

Table 4. Mean difference, standard deviation, minimum and maximum difference in environmental parameters between high-density (HD) and low-density (LD) orchards as well as between HD and nearest AWN and between LD and AWN in 2011 (March-September).

	HD-LD				HD-AWN				LD-AWN			
Parameter	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Air temp (F)	0.7	2.8	-14.2	23.4	-0.5	2.8	-17.7	13.1	-1.2	3.1	-24.0	12.0
Bark temp (F)	1.4	7.5	-23.7	38.0	0.4	7.2	-25.5	35.3	-0.5	6.2	-29.8	30.7
Soil temp (F)	1.4	4.3	-11.9	26.1	-4.5	6.5	-19.6	20.9	-6.0	6.5	-22.8	22.4
RH (%)	-2.4	7.5	-62.6	45.2	5.4	8.9	-47.9	59.8	7.7	10.4	-39.4	67.2
Wind speed mid-canopy (mph) 7-11pm	0.1	0.8	-4.2	7.0	-3.4	2.3	-16.9	6.3	-3.5	2.3	-16.9	3.4
Wind speed above canopy (mph) 7-11pm	0.5	2.2	-8.7	13.3	-1.3	2.7	-12.6	10.4	-1.8	1.7	-10.9	4.0

Effect of overhead cooling on model predictions. Figure 6 shows the air temperature difference between our overhead cooling and kaolin blocks on a typical day. Overhead cooling reduced the daily maximum ambient temperature by 2.2 ± 1.4°F. However, within the HD orchard setting, this temperature reduction had no significant effect on model predictions (difference ≤ 1d), because on most days, the cooling did not cause the maximum temperature to stay below the insects' upper threshold to keep accumulating degree-days. There is no difference in DD between the kaolin block and overhead-cooled block on days when the overhead irrigation was off. However, on several overhead-cooling days we observed that the temperature kept rising after 5pm when the cooling turned off. During the cooling period (noon-5pm) alone, the maximum temperature was 3.1 ± 1.0ºF lower in the overhead cooled plot compared to the kaolin plot. Using the 15-min heat summation method for DD calculation, the overhead-cooled block accumulated on average 2 DD more per day (when cooling was on) than in the kaolin block (Fig. 7). Over a period of 32 days, the difference accumulated to 52 DD and 62 DD for CM and OBLR, respectively, and can shift insect development by 2-3 days.

Fig. 6. Canopy air temperature in an overhead-cooled and kaolin-treated high-density block on 12 September 2011. Horizontal lines represent upper developmental thresholds for CM (88ºF) and OBLR (86ºF).

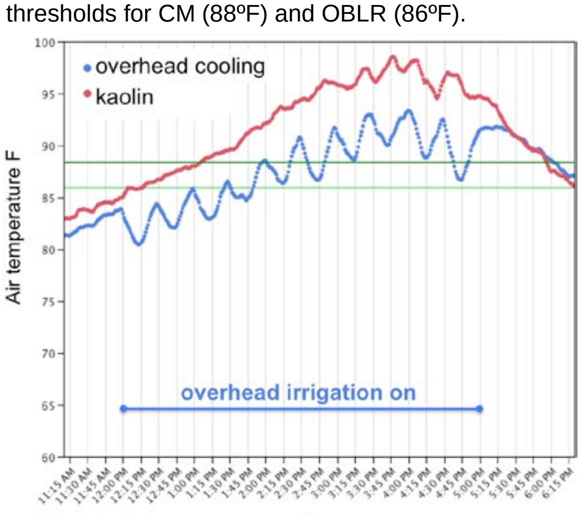
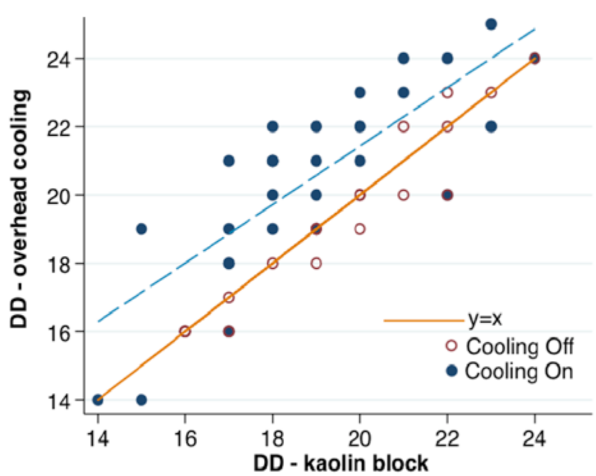


Fig. 7. Relationship between codling moth DD in overhead-cooled vs. kaolin-treated high-density block.



Codling moth adult longevity is dependent on temperature and heat units and can be calculated as DD without upper threshold. The average CM longevity is 57 DD and 56 DD for females and males, respectively (maximum longevity 130 DD and 126 DD). When comparing DD without the upper threshold between kaolin and overhead cooling, we found that the kaolin block accumulated, on average, 1 DD (1-minute method) and 3 DD (15-minute method) more per day due to higher temperature. This difference in DD is too small to cause significant differences on mortality.

Next steps: This last year we will continue to collect data for objectives 2 and 3 and finalize data analyses for all objectives. For our comparison of overhead cooling vs. kaolin, we will adjust the cooling time (interval and length) to keep the air temperature clearly below that in the kaolin plot and more continuously below the upper threshold for CM development (88ºF).

CONTINUING PROJECT REPORT **YEAR**: 1 of 2
WTFRC Project Number: TR-11-103

Project Title: Evaluating a universal plant virus microarray for virus detection

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Cooperators: Bill Howell, Washington State University

Total Project Request: **Year 1**: $35,165 **Year 2**: **$34,584**

Other funding sources

WSU is including this information on other funding available for the support of similar research undertaken by the faculty member proposing this research. These resources are listed to identify other support granted for this research and are not included as a commitment of cost-share by the institution.

Agency Name: **National Clean Plant Network (NCPN)**
Amt. requested/awarded: $49,902 (Sept 2011 to Sept 2012)
Notes: Support was provided for a Master's student working on apple green crinkle disease and a Ph.D. student investigating the etiology of cherry viruses. This is part of a larger comprehensive grant from the NCPN to the WSU Clean Plant Center - Northwest.

Agency Name: **WTFRC Cherry Research**
Amt. requested/awarded: $44,522 (2011); $ 46303 (2012)
Notes: Whereas the major focus of WTFRC Project Number CH-10-108 is the management of cherry leaf roll virus and related viruses in the orchard, a small portion of the funds (ca. 10%) are directed to characterization of the complete genomes of members of the virus family *Betaflexiviridae* that infect cherry.

WTFRC Collaborative expenses: None

Budget 1

Organization Name: **Washington State University** **Contract Administrator: Carrie Johnston**

Telephone: **(509) 335-4564** **Email address:** **carriej@wsu.edu**

Item	2011	**2012**
Salaries[1]	$13,464	**$14,003**
Benefits[1]	$5,655	**$5,881**
Wages		
Benefits		
Equipment		
Supplies[2]	$13,250	**$14,700**
Travel	$2,796	
Plot Fees		
Miscellaneous		
Total	$35,165	**$34,584**

Footnotes:

1. Salary and benefits are required for 0.33 FTE Postdoctoral research associate position to perform molecular analysis.
2. Next generation sequencing: RNA isolation and labeling, deep sequencing and basic bioinformatics evaluation: 10 samples at $1,400 each.

   Additional computer RAM needed to facilitate analyses of sequencing data approx. $300.

OBJECTIVES

This project evaluates the effectiveness of utilizing contemporary technology for detection of viruses found in fruit trees. The most appropriate technology will be adapted for the detection and rapid identification of viruses associated with diseases of fruit trees, and for delivery of virus-tested fruit tree cultivars to the industry in an efficient and safe manner.

SIGNIFICANT FINDINGS

- Foveaviruses can exist as complex genetically diverse populations within a single tree. This phenomenon challenges current disease diagnostic methods.
- The frequent infection of fruit trees by multiple viruses was documented and shown to obscure the presence of some disease causing agents.
    - Next Generation Sequencing (NGS) more effectively revealed constituents of disease complexes.
    - Accurate interpretation of Universal Plant Virus Microarray (UPVM) data from samples with multiple infections was limited.
- NGS is capable of identifying various strains of the same virus in a single sample.
- Both UPVM and NGS technologies require careful interpretation of raw data, particularly if previously uncharacterized pathogens are present.

METHODS

The Universal Plant Virus Microarray (UPMV) was developed to assist in the diagnosis of virus-like agents critical to the floriculture industry. Although the UPVM was designed to detect a wide range of viruses and also to reveal even previously uncharacterized viruses, the database and diagnostic target molecules are biased in favor of viruses most common in floriculture. Performance of the UPVM for detection of viruses that infect fruit trees must be validated. If the UPVM is adopted for fruit tree virus analysis, the composition of sequences on the micro-array may need to be modified.

Total nucleic acids were isolated from eleven samples infected with viruses. The virus content of these samples was confirmed by reverse transcription polymerase chain reaction (RT-PCR) and the samples were then analyzed by the UPMV technology.

In initial experiments, samples from infected apple trees were first enriched for double stranded RNA (dsRNA) in preparation for Next Generation Sequencing (NGS) analysis. The dsRNA sequences were then individually labeled with separate bar coding sequences to allow four samples to be combined into a single reaction for NGS. The sequences associated with each tag and hence with each sample are separated by computer analysis post-sequencing.

In a subsequent experiment, total RNA was isolated from twelve different samples (seven stone and five pome fruit) and labeled with sample-specific bar-coding tags as above. These samples were then subjected to NGS.

In both experiments, samples from the same source trees were also tested by a series of virus-specific reverse transcription polymerase chain reaction (RT-PCR) assays. Amplification products of RT-PCR were cloned and subjected to conventional sequencing.

RESULTS & DISCUSSION

The UPVM was originally conceived and developed for the detection of many different plant virus species encountered in the floriculture industry. Results of that USDA-ARS project demonstrated that this technology can be applied successfully to members of many different plant families and to all known plant virus genera. This project was the first attempt to apply this technology to perennial fruit trees.

The UPVM utilizes 9,556 virus target sequences plus 44 plant-specific sequences anchored to a silicon chip. The total RNA from the subject plant is labeled and the fragments allowed to hybridize to the sequences on the silicon chip – they should only bind to sequences on the chip that match those of the sample. During the interpretation of the microarray data, the associated software will rank the probabilities that specific viruses are present in the sample based on the pattern of individual spots on the microarray that hybridize to the labeled sample fragments. In the present study, the identification of viruses utilizing the UPMV technology was attempted with eleven samples. In all cases, the technology reliably revealed the presence of virus in the samples. When eight samples infected with a single virus as indentified by RT-PCR were analyzed, the technology was effective in accurately identifying the virus family. However, in only three cases did the technology correctly associate the virus species in the sample with the species with the highest probability. In the remaining five samples, the correct virus species was listed amongst the possible viruses present in the sample, but not as the most likely virus in the sample. Three samples contained mixed virus populations since this is a common occurrence in fruit trees. The software that interprets the microarray results was unable to interpret the pattern in one case and consequently did not produce a list of potential viruses. Of the remaining two samples with mixed virus populations, one was incorrectly identified and the virus constituents of the other were correctly identified, although not with the highest probability.

The effect of the overlapping signals generated by the presence of mixed infections and their interpretation by the UPVM and its associated computer algorithm was a major concern as we entered this project. This concern was substantiated with this preliminary trial of samples with mixed infections. Extensive redevelopment of the UPVM will be necessary to adapt this technology to fruit tree virus diagnosis. It is uncertain whether the problem in identification created by mixed infections could be corrected.

Analyses by NGS were initially performed on samples by first isolating dsRNA from infected apple tissues. DsRNA is produced in plants as an intermediate during the replication of RNA-containing viruses whereas non-infected plants contain relatively little dsRNA. This strategy would therefore preferentially select for virus sequences present in tissue. DsRNA samples from four trees were analyzed by NGS. In comparison, total RNA isolated from the same trees was analyzed by the more conventional RT-PCR cloning and sequencing strategy. Overall, the two strategies were in agreement (**Table 1**). Initial screening of the samples by RT-PCR revealed that two samples were infected with both apple stem pitting virus (ASPV) and apple stem grooving virus (ASGV), and two trees were singly infected with either ASPV or ASGV only. RT-PCR did not detect a third common virus of apple trees, apple chlorotic leafspot virus (ACLSV), in any of the samples. These results were then compared to data obtained by NGS analysis of the isolated dsRNA. NGS produced results for ASPV and ASGV in all four samples that were consistent with the RT-PCR results. However, NGS also revealed the presence of ACLSV in one of the samples that previously tested negative for that virus by RT-PCR. The discrepancy in the detection of ACLSV is under further investigation and could be the consequence of several factors. Erratic virus distribution in fruit trees is common and may contribute to inconsistencies in sampling. Isolation of dsRNA prior to NGS utilizes a much larger sample size than the sample extracted for total RNA used in RT-PCR (7 g versus 0.1 g), so a greater representative sample was used in the NGS. Another key consideration that differentiates RT-PCR and NGS is that RT-PCR requires precise prior knowledge of virus genetic sequences in order for the test to succeed, whereas NGS requires no such knowledge. The ACLSV isolate detected by NGS may be a sequence variant that is not recognized by the current sequence specific RT-PCR reaction. Further analysis is in progress to evaluate this possibility.

In addition to greater sensitivity, NGS also provided a more detailed picture of the virus content of infected trees. RT-PCR analysis indicated the presence of ASPV in three trees. Cloning and sequencing of individual clones (ten clones were sequenced per sample) revealed ASPV genome variability within each sample. The reliability of this strategy is limited by the number of related sequences amplified in a RT-PCR reaction and the relatively small percentage of the genome considered by RT-PCR. However, NGS immediately revealed a much more complete spectrum of all sequences related to ASPV in the samples. Moreover, because a greater portion of the virus genome was obtained from each NGS reaction, it became evident that two of the sequences, although related to ASPV, are actually associated with two different, previously uncharacterized viruses. Thus, the presence of unknown pathogens can be detected, and complex mixtures of viruses can be resolved. This powerful tool not only accelerates virus detection, but also accelerates the process of identifying pathogens associated with diseases with unknown etiology.

Table 1. Comparison of reverse transcription polymerase chain reaction (RT-PCR) assay and Next Generation Sequencing (NGS) results of double stranded RNA from apple trees.

Samples	Virus status by RT-PCR	Sequencing Data (Mb)	# of reads	Scaffolds	Virus contigs detected[1] (number of contigs)
Apple 1	ASPV	268.92	7,469,983	444	ASPV (22) + ApLV (6) + CTLV (1)
Apple 2	ASPV+ASGV	291.50	8,097,306	475	ASPV (45) + ASGV (2) + ApLV (2) + CTLV (1)
Apple 3	ASGV	277.99	7,722,042	527	ASGV (5) + CTLV (1)
Apple 4	ASPV+ASGV	291.50	8,097,306	506	ASPV (146) + ACLSV (23) + ASGV (10) + CTLV (3)

1. Apple stem pitting foveavirus (ASPV); Apricot latent foveavirus (ApLV); Citrus tatter leaf capillovirus (CTLV); Apple stem grooving capillovirus (ASGV); Apple chlorotic leafspot trichovirus (ACLSV).

The meaning of data obtained by NGS is not always immediately apparent – careful interpretation of the raw data is required. As indicated in our initial data set, two virus sequences were detected that were not anticipated: apricot latent foveavirus (ApLV); and citrus tatter leaf capillovirus (CTLV). However, further examination revealed that these sequences appear with relatively low frequency (only 1 or 2 virus contigs in each case). These viruses are closely related to other viruses that are present in the trees, so the positive results likely originate from short, highly conserved sequences present in viruses belonging to the same genus. Additionally, as mentioned above, careful subsequent examination of the raw data revealed that several of the ASPV-like sequences actually represent a virus that is related to ASPV but represents a previously uncharacterized virus.

The isolation of dsRNA followed by NGS provided excellent results, but much of the raw data were redundant because each virus sequence was represented many times in the sequencing output; only 35 to 40% of the sequences were unique. With four samples per sequencing lane, over 268 million nucleotide bases of data were obtained for each sample and these were represented by 7.5 million individual fragments (**Table** 1). A second set of samples were prepared in which total RNA was extracted from plants. This process is much more expedient than prior selection of dsRNA and provides fewer possibilities of sample contamination. In total RNA preparations, virus RNA is diluted by the presence of plant RNA in the sample but the extreme redundancy observed in our earlier trial suggested that this would not interfere with analysis. In this process, the raw data is filtered to remove all sequences that are not recognized as virus-like (**Table 2**). In this experiment, we also improved project efficiency by analyzing twelve different samples (seven stone and five pome) combined into a single sequencing reaction compared to four in the previous trial.

Samples used in the second trial (**Table 2**) were derived from trees known to be infected with various viral pathogens commonly associated with fruit trees (prune dwarf virus, *Prunus* necrotic ringspot virus, cherry virus A, cherry necrotic rusty mottle virus, cherry green ring mottle virus, cherry mottle leaf virus, little cherry virus 2, apple stem pitting virus, apple stem grooving virus, apple chlorotic leaf spot virus). Different software was utilized to evaluate the millions of individual sequences obtained from the NGS. The results obtained from six cherry tree samples are used to highlight the data obtained from NGS of fruit tree samples (**Table 2**). It is noted that in each case, the pathogen associated with the disease is not listed in the results. For example, the tree in sample 1 expresses symptoms of cherry rusty mottle disease, but a virus of that name does not appear in the virus sequences detected. This situation occurs because the etiological agent is not yet reported in the public nucleotide database. However, our research program has recently identified these agents and established their relationship to cherry necrotic rusty mottle virus (CNRMV). Therefore, the appearance of CNRMV in the NGS results suggests the presence of the etiological agent that is related to but not the same as CNRMV. The NGS also confirms the presence of multiple infections within these cherry samples. The presence of multiple viruses is consistent with the results obtained by conventional RT-PCR, cloning and sequencing.

As noted in the interpretation of the previous experiment, review of the sequence data obtained by NGS and subsequent computer analysis revealed several additional viruses that were not anticipated (*italicized* results in **Table 2**). Careful examination of data is required to determine their relevance. Low values for the "average contig length" is an indication that the virus identification is based on very short sequences that may be conserved in a large number of virus species and genera. A combination of a relatively low frequency (hits) in the pool of sequence data obtained and short contig length suggests a questionable interpretation based on these short sequences. Therefore, further interpretation of data is required to confirm analysis. In practice, this may require further analysis by conventional molecular techniques. The appropriate cut-off levels for frequency and length will be determined empirically; development of these parameters is dependent on further analysis of results obtained for NGS and their comparison to results obtained by other test methods.

In both experiments, NGS revealed viruses present in mixed infections that were not detected by RT-PCR. Our data from related studies demonstrated that mixed infections can lead to the suppression of one or more components of the virus complex, and that these reduced virus levels may not be detected by RT-PCR whereas the entire virus population would be revealed by NGS. This is crucial during efforts to determine the etiological agents associated with disease. Although NGS and UPVM technologies do not require prior knowledge of the pathogens present, NGS provides a highly refined analysis and reveals the presence of multiple sequence variants of a single virus species, a capability that is not offered by the UPVM. As previously noted, NGS provides sensitivity that is not matched by other techniques, including RT-PCR or the UPVM. This is critical in mixed infections where one virus may suppress the accumulation of another virus to the extent that it is no longer detectable by conventional assay methods. NGS provides the complete genomic sequences of the pathogens, whereas those pathogens detected by UPVM require extensive subsequent analysis, including NGS, to reveal the genomic data.

Analysis of the raw data (**Table** 2) was used to assess the accuracy of bar-coding sequence tags for correlating sequencing data with the origin of the sample. The reliability of this strategy was supported by two lines of evidence. 1) The prevalence of virus sequences known to occur in cherry were reported in only cherry samples and sequences of apple viruses are prevalent in samples derived from apple trees. Thus, the bar-coding of samples in a multiplex system permitted reliable segregation and association of data with the appropriate sample identification. 2) In several cases, NGS detected multiple strains of viruses and/or closely related viruses in a single tissue sample and permitted assembly of the near complete genomic sequences regardless of whether the original samples consisted of dsRNA or total RNA. Thus, the presence of the plant RNA in total RNA extracts did not reduce the sensitivity of the NGS relative to the results obtained after initial dsRNA isolation. Therefore, the simpler, less time consuming use of total RNA will be used for future applications, and the greater degree of multiplexing will be used in continuing studies as we establish parameters for efficient use of this technology. The ability to multiplex the reactions will greatly enhance cost efficiency of sample analysis for growers and for the introduction of new cultivars.

As previously indicated, the rapid advances in NGS technology are challenging the future utility of the UPVM for virus detection and identification. Samples known to be infected with different plant viruses were assayed and the known viruses present in the samples were identified. Although it's a promising technology, UPVM requires further standardization and simplification for diagnostic applications. The NGS is a very sophisticated process, but various portions of the analysis are routinely outsourced to specialized service laboratories that have access to the necessary equipment and facilities. The remaining time and facilities required for sample preparation is not out of line with many standard laboratory practices, so the burden on "in house" resources is reduced. In the current format, NGS technology offers many clear advantages over the UPMV but with a significant cost disadvantage. The latter is substantially controlled by the bar-coding strategy that allows samples to be multiplexed. This was demonstrated in our current experiments.

Based on these comparative notes of the available technology, we are pursuing NGS technology as a method of choice for fruit tree diagnostics. Further refinements in technology and the parameters for data analysis will expand the limits and provide cost benefits for the use of this technology for standard applications.

Table 2. Total RNA extracted from five 'Bing' cherry trees expressing diseases were analyzed by Next generation sequencing. All sequences were screened for similarity to viruses present in the public gene database; all other sequences were removed from the results before further analysis. Results shown in *italics* are not considered valid interpretation of raw sequencing data because of a combination of low sequence frequency and short contig lengths.

Sample description (results)	Number of "hits"	Average contig length
Sample 1: Cherry rusty mottle disease (3,807 virus sequences)		
Cherry virus A	212	2,868
Prunus necrotic ringspot virus	112	2,587
Prune dwarf virus	111	2,557
Cherry necrotic rusty mottle virus	150	423
Cherry mottle leaf virus	*51*	-
Sample 2: Cherry rusty mottle disease (16,328 virus sequences)		
Cherry virus A	1,438	1,279
Cherry necrotic rusty mottle virus	*187*	*22*
Cherry green ring mottle virus	52	165
Apple chlorotic leafspot virus	*46*	*22*
Cherry leaf roll virus	*48*	*24*
Cherry mottle leaf virus	*8*	*18*
Prune dwarf virus	*12*	*25*
Sample 3: Cherry twisted leaf disease (18,956 virus sequences)		
Cherry mottle leaf virus	143	466
Cherry green ring mottle virus	166	2,856
Cherry necrotic rusty mottle virus	430	413
Apple chlorotic leaf spot virus	420	408
Cherry raspleaf virus	*150*	*22*
Apple latent spherical virus	*102*	*23*
Apricot latent virus	*115*	*22*
Cherry leaf roll virus	*75*	*21*
Sample 4: Cherry twisted leaf disease (16,203 virus sequences)		
Little cherry virus 2	242	1,722
Prune dwarf virus	213	838
Prunus necrotic ringspot virus	76	1,320
Cherry virus A	111	1,553
Cherry green ring mottle virus	225	611
Cherry necrotic rusty mottle virus	176	610
Cherry raspleaf virus	*76*	*22*
Cherry mottle leaf virus	*87*	*20*
Cherry leaf roll virus	*66*	*18*
Sample 5: Apricot ringpox disease (14,554 virus sequences)		
Cherry green ring mottle virus	142	5,368
Cherry necrotic rusty mottle virus	234	309
Cherry raspleaf virus	*168*	*22*
Prune dwarf virus	*24*	*24*

CONTINUING PROJECT REPORT **YEAR**: 1 of 2

Project Title: Intelligent bin-dog system for tree fruit production (Phase II)

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Cooperators: None

Total project funding request: **Year 1:** 99,397 **Year 2: 69,454**

Budget 1
Organization Name: WA State University **Contract Administrator: Carrie Johnston**
Telephone: 509.335.7667 **Email address: carriej@wsu.edu**

Item	**2011-12**	**2012-13**	
Salaries[1]	65,352	47,966	
Benefits	16,045	9,488	
Wages	--	--	
Benefits	--	--	
Equipment[2]	7,000	--	
Supplies & Fabrication Costs[3]	5,000	6,000	
Travel (Zhang)[4]	2,000	2,000	
Travel (Lewis)[4]	3,000	3,000	
Miscellaneous[5]	1,000	1,000	
Total	99,397	**69,454**	

Footnotes: [1] one Post-doctoral research associate (12 months) and one Ph.D. graduate student (12 months) for yr-1; one Post-doctoral research associate (12 months) for yr-2; [2] Budget for purchasing an existing bin-carrier platform; [3] Budget for fabricating bin-dog prototypes (yr-1 for the research prototype and yr-2 for the demonstration prototype (including NAPA parts); [4] Budget for travel will cover the expenses for research personnel traveling to experiment sites for conducting project activities; [5] A small miscellaneous budget is for all other project related expenses.

OBJECTIVES

This project is the second phase of intelligent bin-dog research, and the primary goal of this phase is to develop a concept-approval prototype of a self-propelled “bin-dog” implementable in typical WA tree fruit orchards. To achieve this project goal, this bin-dog prototype should have the following critical functionalities to be considered a success of this research: (1) capable of traveling in typical WA tree fruit orchards using electrical maneuvering systems; and (2) capable of placing empty bin at appropriate place between two rows for supporting efficient picking and transporting full bin to a collection station in harvest operations. The following specific project activities were planned to fulfill the tasks:

1. Define a set of design specifications based on the studies on existing orchard mobile platform products and the special in-orchard bin management needs of WA tree fruit growers;
2. Design a concept-approval prototype of bin-dog based on the defined specifications for accomplishing the designated critical functionalities of in-orchard bin management;
3. Design a remote control system for maneuvering the bin-dog prototype; and
4. Fabricate both the bin-dog prototype and the remote control system by maximally using “NAPA” components, and test the integrated bin-dog research platform in terms of functionality, usability and efficiency in both research and commercial orchards.

It is worthy to bring to the Commission’s attention that we have made the following three major modifications to our original specific objectives:

1. Focusing the bin-dog functionality to place empty bins at an appropriate place between two rows and transporting full bins out the rows to a collection station;
2. Dropping the functionality of fruit loading from picker’s hand to the bin; and
3. Adding a remote control system to allow a human operator to operate the bin-dog.

The first two modifications to the original proposal were suggested by the Commissioners in the 2011 Winter Review Meeting. The third modification is to improve the maneuverability of the prototype for better demonstration of its capabilities.

MAJOR ACCOMPLISHMENTS AND KEY PROGRESS

Project activities began in September 2011. Table 1 summarizes the up-to-date project management plan and major accomplishments.

Table 1. Up-to-Date Project Management Plan and Major Accomplishments

No.	Planned Milestone	Time Period	Planned Deliverables	Accomplishments
1	Create an initial bin-dog concept	09-10/2011	Basic requirements for a self-propelled fruit bin carrier and concept for a self-propelled bin-dog system	Completed design specifications.
	Revise bin-dog system based on concept analysis	11-12/2011		1^{st} conceptual system designed
2	Design concept-approval bin-dog system	10/2011-03/2012	System and structure design of the bin-dog prototype	Completed system and structure design
3	Design the research prototype	01-03/2012	Sub-systems for core functions and its integration	3D drawings and main components selection

In the past six months, the project team was focused on (1) **creating and modifying the conceptual bin-dog system** and (2) **designing the concept-approval prototype of the bin-dog**. The major up-to-date accomplishments during this period are summarized as follows:

1. We have finalized the self-propelled concept as the base design for the conceptual bin-dog system.
2. We have finalized a simple design which consists of mechanical bin picking, carrying and releasing functions for the bin-dog prototype.
3. To furnish an easy-to-use maneuvering system for the bin-dog, we have designed a remote control system capable of controlling and/or adjusting travel speed, turning, and bin handling actions. A concept-approval system has been fabricated and tested off-line in the laboratory, with results leading to further design modification.

In addition, we have made key progress summarized as follows:

(1) *Basic Concept of Bin Handling Using a "Bin-Dog"*

As one of the core tasks of this research, we have conceptualized an optimal way of using the bin-dog system for in-orchard bin handling. As illustrated in Figure 1, the conceptual scheme of the bin-dog system operation will include a six-step process: (1) pick up an one empty bin from the station; (2) carry the empty bin to the harvesting corridor between tree rows; (3) pass over the full bin laying in the corridor and place the empty bin at an appropriate location in front the full bin; (4) move back to the full bin and pick it up; (5) carry the full bin to the full bin collection station; and (6) place the full bin at an appropriate position.

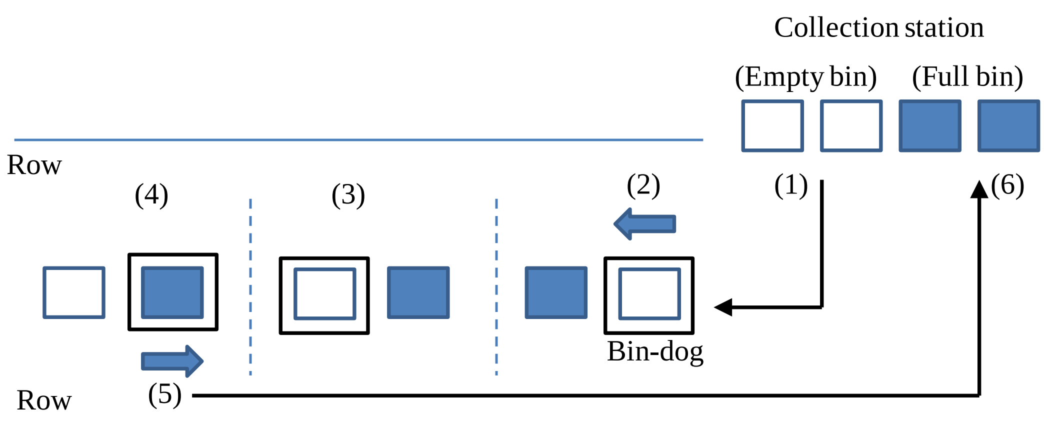

Figure 1. Conceptual scheme of the bin-dog system operation as a harvest-assist system in orchards

(2) *Basic Design Specifications of the Concept-Approval Bin-dog System*

Based on the typical row spacing in WA high density orchards and typical bin size, with reference to existing bin-moving platforms used in both WA and European countries, we have defined the initial design specifications for this concept-approval bin-dog system as follows:

- Overall dimension (L x W x H): 6.5'× 6.0' × 5.5' (Note: 6.0' width for wheels, with a 5.0' width for the frame)
- The wheelbase (space between front and rear wheels): 5.0'
- Wheel diameter: 1.6'
- Maximum speed: 2.0 mph

Based on the defined initial design specifications, the estimated maximum drive torque and required power are as follows:

- Maximum torque on each driving motor: 1,400 in-lbs
- D.C. Motor power: 1.0 hp.
- Winch power: 1.1 hp

(3) *Structural Design*

To ensure the developed concept-approval bin-dog prototype has the capability of performing all defined operation steps reliably and effectively, a structural design of the conceptual bin-dog has been through a few design iterations. As depicted in Figure 2. the basic structure of the concept-approval system will be fabricated using the following five modules: (1) the main frame on which all other modules will be installed; (2) a power unit consisting of a set of batteries and three DC motors with speed and direction control capabilities; (3) a front-wheel-driven electrical drive-train system with two DC motors installed directly on two driving wheels; (4) a passive turning system accomplished using the speed difference of motors at both sides to push/pull two idle wheels making a desirable turn; and (5) an electro-mechanical bin handling system for picking up the bin as well as either lifting an empty bin for passing a on corridor full bin or lifting a full bin for staking it on another full bin at the collection station.

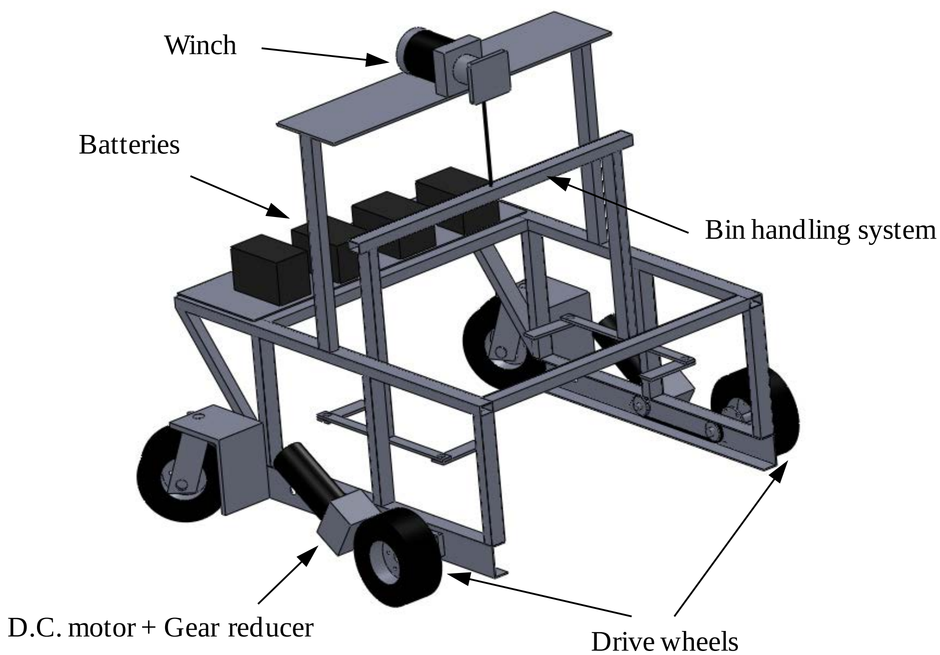

Figure 2. Schematic illustration of the concept-approval bin-dog structure of current design

(4) *Power and Maneuvering Systems*

To prove the concept of this bin-dog system without complicated full-function drive-train system design, this research prototype plans to use an electric system for both drive-train and bin-handling system. As illustrated in Figure 3, the power and maneuvering system for the concept-approval bin-dog platform will consist of three independently maneuverable electrical drive systems, each has its own speed and directional control capabilities to realize the traveling, turning, and bin handling functions. All those functions will be controlled using a remote controller operated by a human operator in this concept approval research. In addition, a safety control system will also be developed to ensure the safety of the pickers working in the vicinity of the moving bin-dog.

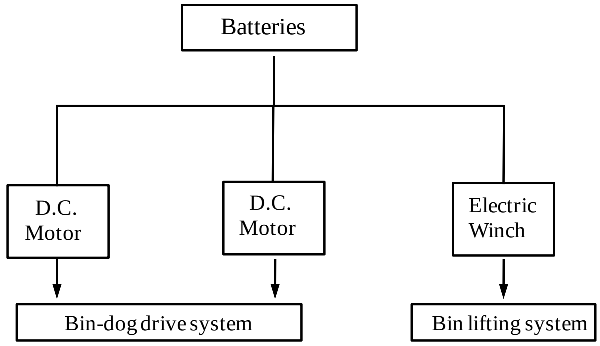

Figure 3. System diagram of the power and maneuvering systems

As the basic design of the concept-approval bin-dog prototype has is completed, we have started the materials and components procurement. Up-to-date, we have procured D.C. motors and Gear reducers for constructing the electric drive systems (Figure 4).

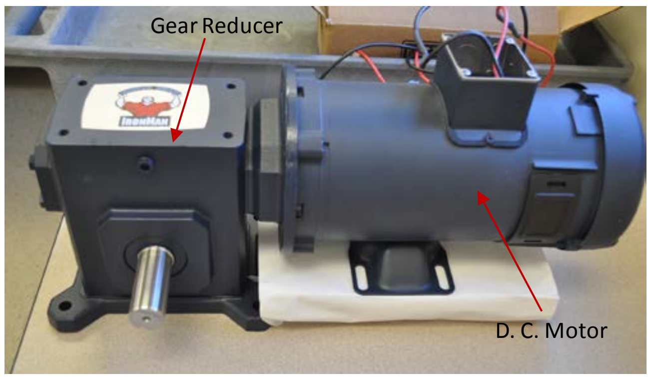

Figure 4. Electrical drive system (D.C.motor + Gear reducer) procured for the bin-dog prototype

(5) *Remote Control System*

We have also completed the design, fabrication and laboratory test of the first remote controller prototype for the robotic bin-dog. As shown in Figure 5, the developed remote control system consists of (1) a joystick; (2) a control signal transmitter; and (3) a control signal receiver. This remote controller was developed to provide human operator a convenient means in maneuvering the bin-dog in orchard.

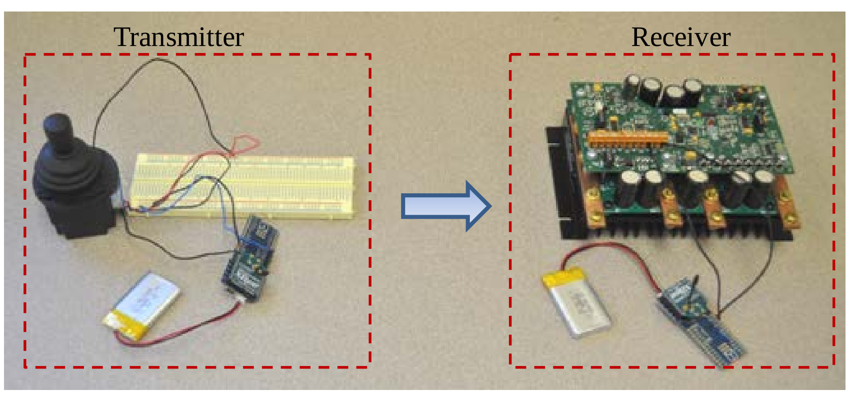

Figure 5. Illustration of a bin-dog remote control system with a joystick

PLANS FOR THE NEXT STEP

(1) *Proposed Schedule and Up-to-Date Accomplishments*

The main task of the next step is to fabricate the bin-dog platform and make it available for concept approval tests, beginning with off-field tests and followed with in-orchards validations. Table 2 summarizes the proposed project management plan and the expected accomplishments for the next review period (rest of 2012).

Table 2. Project Management Plan, Expected Outcomes

No.	Planned Milestone	Time Period	Planned Deliverables	Expected Outcomes
1	Fabricate the research platform (continue)	04-09/2012	A research platform that can test the functionalities & a remote controller for bin-dog	A research platform and a remote controller ready for integration
2	System tuning and preliminary tests	10-12/2012	Optimize system parameters and test the completed bin-dog system in orchard environment	An integrated research platform ready for testing in orchards

CONTINUING PROJECT REPORT **YEAR**: 1 of 2
WTFRC Project Number: TR-11-101

Project Title: 3D machine vision for improved apple crop load estimation

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Cooperators: None

Total Project Request: **Year 1**: $33,104 **Year 2: $34,402**

Other Funding Sources: None

WTFRC Collaborative Expenses: None

Budget
Organization Name: WSU **Contract Administrator:** Carrie Johnston
Telephone: 509.335.4564 **Email address:** carriej@wsu.edu

Item	**2011**	**2012**
Salaries[1]	$22,901	$23,817
Benefits[1]	$1,821	$1,893
Wages[2]	$6,264	$6,515
Benefits[2]	$601	$625
Equipment		
Supplies and Fabrication Cost[3]	$1,000	$1,000
Travel[4]	$517	$552
Miscellaneous		
Total	$33,104	**$34,402**

Footnotes:
[1] Salary and benefit for a graduate student
[2] Wages and benefits for hourly help to fabricate sensor platform and collect field data
[3] Cost to purchase materials and build a sensor platform
[4]Travel cost for field data collection and testing

OBJECTIVES

The following were the specific objectives of this project. During the first year of this project, we focused on objectives 1 and 2 in the list below.

1. Develop a sensor system with 3D and color vision cameras for imaging apple trees from two sides of a row
2. Develop an image processing technique to create 3D maps of fruits and estimate crop-load
3. Evaluate and improve the accuracy of crop-load estimation

SIGNIFICANT FINDINGS

- Over the row platform was valuable to capture and register images from two sides of a row of apple trees.
- Visibility of apples increased substantially when images were taken from two sides of a row of apple trees, which shows promise for improved cropload estimation.
- Mapping algorithm developed in laboratory settings showed promise for co-registering 3D images from two sides for enhanced visibility and reducing repeated counting.
- Location information from 3D camera can distinguish redundant apples by measuring distance between corresponding apples obtained from two sides of canopy.

METHODS

Apple cropload estimation is essential to improve the efficiency of orchard management. In the past, apple cropload estimation have been attempted using color image processing, thermal imaging, multispectral imaging, and hyperspectral imaging techniques. The performance of these techniques was adversely affected by occlusion due to branches, leaves and other fruits leading to a substantial underestimation of cropload. To reduce the occlusion, images of apple trees were taken from two sides of a row. However, some of the apples were visible from both sides of the row resulting in repeated counting. A 3D camera was incorporated with the system to measure distance to each apple from the camera, which will help to minimize recounting of the same apple. In the following paragraphs, we will describe the sensors and the platform we developed to capture images in lab settings as well as in the field for the development and testing of 3D mapping and cropload estimation techniques.

Sensors: The sensor system used consisted of a color camera and a 3D camera (Fig. 1). A Prosilica camera (GigE 1290c, Allied Vision Technologies, Stadtroda, Germany) was used to capture color images of apple trees with fruits. A PMD camera (CamCube 3.0, PMD Technologies, Siegen, Germany) was used to take 3D images. These 3D images provided exact positions of apples on the tree and are used in conjunction with the color images to minimize repeated counting of apples. A white galvanized iron pipe was used as a mapping reference frame to co-register 3D locations of apples (Fig. 2). The 3D coordinates of the reference frame were obtained for images captured from both sides. A rigid transformation between two images was found using two sets of coordinates of the reference frame. Using this rigid transformation all the corresponding locations of apples from one side of the canopy were transformed to the coordinates in the other side.

1(a) 1(b)

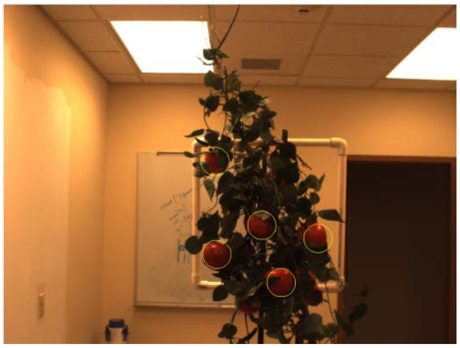
Fig. 1: a) Over the row platform taking images of Jazz apples in a commercial orchard of Allan Bros., Inc. in Prosser, WA ; b)The sensor system used for image acquisition for laboratory test: Prosilica GigE 1290c color camera (top), PMD CamCube 3D camera (bottom).

Fig. 2: Sample Image frame showing apples within a square frame of reference visible from both sides.

Camera Calibration: Checkerboard-based stereo vision camera calibration technique was used to identify intrinsic and extrinsic parameters of color camera and 3D camera. A checkerboard was placed in front of the imaging system in such a way that it appeared within the imaging field of view of both the cameras. The intensity image obtained from the 3D camera and the image from color camera were used to calibrate intrinsic and extrinsic camera parameters. The extrinsic parameter gives relative position of two cameras. Using these parameters 3D coordinates from 3D camera were projected onto the image plane of color camera to obtain depth mapped color images.

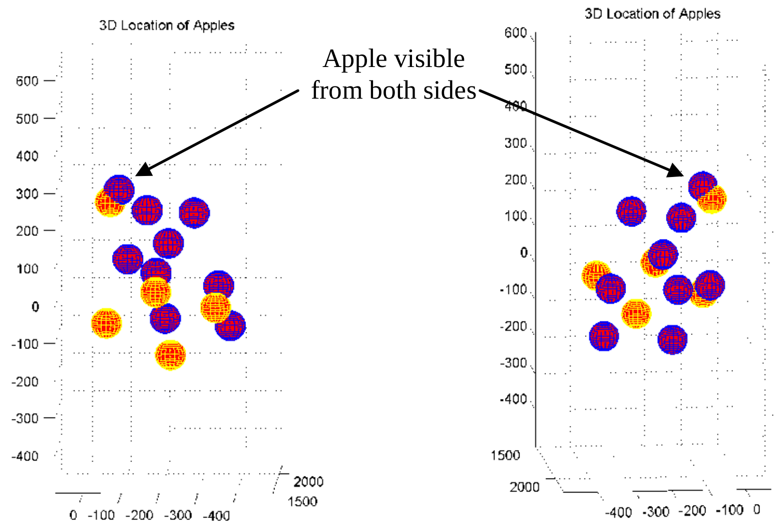
3D Mapping of Apples: Color and 3D images were captured in laboratory settings from two sides of a model of an apple tree (a real, dead tree with fake leaves and fruits in it; Fig. 2). The 3D coordinates of objects in the field of view were transformed from the 3D camera coordinate to projection onto the imaging plane of the color camera to obtain a depth-mapped color image. Each pixel in this depth-mapped color image included the corresponding 3D location. Center of apples visible from each side of the canopy were located as shown in Fig. 3a and 3b.

One image was captured from each of the two sides of the canopy. 3D locations of four corners of the reference frame (GI pipe square in Fig. 2) were used to obtain the rigid transformation between these two camera positions. Using the rigid transformation all the corresponding location of apples from one side of the canopy were transformed to the coordinates in the other side. Fig. 3(c and d) show 3D locations of apples viewed corresponding to Fig. 3a (yellow) and Fig. 3b (blue) respectively. The apples visible from both side of the canopy can be seen overlapping with each other. Apples separated by a distance less than the diameter of an apple were considered as the same apple mapped from the opposite sides. Redundant apples in Fig. 3(b and c) are shown as green apple in Fig. 4.



3(a)

3(b)



3(c)

Fig. 3: a) and b) Color images from front and back side of the tree; c) 3D-mapped apples of corresponding color images in (3a) as yellow and (3b) as blue (all axes in millimeters).

RESULTS AND DISCUSSIONS

From the previous field data collection, over the row platform showed to be convenient way of speedy data collection in apple orchards. However, the camera mounting system needed some improvement to make it robust. We designed a sliding rail mechanism to slide imaging platform by a stepper motor, which will improve the efficiency of data collection while increasing the accuracy of relative location estimation. Fig. 4 shows the new sliding mechanism for camera mount that is under development.

Apple visibility was increased when images were taken from two sides of a row of apple trees. Fig.5(a and b) show two images of the same tree taken from the opposite sides of the row. A substantial number of apples occluded by other apples, branches and/or leaves when imaged from the one side could be seen from the other side of the row. This increased visibility will improve the accuracy of identifying and counting apples through image analysis.

Fig. 4: New sliding mechanism under

5(a) 5(b)

Fig.5: a) Apples identified from front side of the row, and b) apples identified from back side of the row. Apples highlighted with yellow circles are not visible from the other side.

A laboratory setup was designed, closely mimicking images taken in the orchard during the previous season (Fig . 5a and b), to develop registration technique to co-register 3D and color images. Results from laboratory tests showed that apple visibility can be enhanced using dual sided imagery. Also, repeated counting of apples can be avoided as they appear at a distance less than their size (Fig. 6). A reference frame was used to map images from two sides of the canopy. In future work, we will use an alternative approach to identify relative location and orientation of camera at two different sides of the canopy.

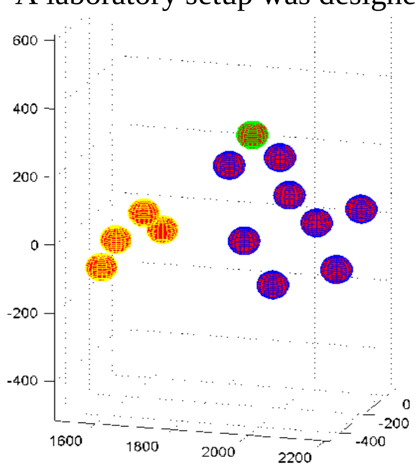


Figure 6: 3D mapped apples visible from front (yellow) , back (blue) and both (green) sides (axes in millimeters).

SUMMARY AND PLAN FOR YEAR 2

Efficient crop yield estimation is essential for efficient and effective pre- and post-harvest orchard management. We developed an algorithm to co-register color and 3D images for improved apple cropload estimation. Images from two sides of the canopy were co-registered to obtain a 3D map of apples. These 3D-mapped apples showed increased visibility and potential for improved cropload estimation. Also, the technique showed promise to avoid repeated counting of the same apple as they appear closer to each other than their size.

The next step will be to apply this technique to the images collected during the last harvest season. In addition, the next year's work will focus on techniques for obtaining position and orientation of the cameras on one side relative to the cameras on the other side of a canopy. Geometric information of the over the row sensor platform and attitude sensors will be used to obtain relative position and orientation information. RTK GPS-based localization of imaging system will also be used to complement the information obtained from the sensor platform geometry and attitude sensors.

The imaging platform will be modified to improve the accuracy and efficiency of data collection. A tunnel structure will be used to reduce the effect of ambient light for day time imaging. Night time imaging with artificial lighting will also be tested this coming season to avoid the complexity associated with daylight variations.

CONTINUING PROJECT REPORT **YEAR: 1 of 2**

Project Title: Protein-based foam for applying lacewings eggs to fruit trees by ATV

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Address 2:		**Address 2**:	1815 N University St
City/State/Zip:	Wapato WA 98951	**City/State/Zip**:	Peoria IL 61604

Cooperators: David Horton, USDA-ARS Wapato, WA
Gene Miliczky, USDA-ARS Wapato, WA
Sinthya Penn, Beneficial Insectary, Redding CA

Total Project Request: **Year 1**: $19,000 **Year 2**: $15,000

Other funding sources

Agency Name: WTFRC/ Apple Crop Protection **CP-10-104A**

Amt. requested/awarded Total Project Request:
Requested: $239,663 / awarded: 2010: $79,117; **2011**: $79,866; 2012 $ $79,895

Notes: Unruh, Horton, and Miliczky have been conducting laboratory and field studies with commercially produced lacewing eggs provided by Beneficial Insectary. The work has been supported by award CP-10-104A to Unruh, Horton and Beers, of which ~ $40,000 has been devoted to work with lacewings over the last 2 years.

Budget 1

Organization Name: USDA-ARS
Telephone: (510) 559-6007

Contract Administrator: Janis Contento
Email address: janis.contento@ars.usda.gov

Item	2012	2013	
Salaries			
Benefits			
Wages GS-3 (90/90 days)	$7431	$7431	
Benefits	$569	$569	
Equipment	$ 400		
Supplies	$600		
Travel			
Miscellaneous			
Total	$9000	$8000	

Footnotes:

Budget 2

Organization Name:
Telephone: (309) 681-6630
Fax: (309) 681-6648

Contract Administrator: Kari Deppe
Email: kari.deppe@ars.usda.gov

Item	2012	2013	
Salaries			
Benefits			
Wages GS-3 (90/60 days)	$7431	$4953	
Benefits	$569	$379	
Equipment			
Supplies	$1200	$868	
Travel	$800	$800	
Miscellaneous			
Total	$10000	$7000	

Footnotes:

Justification: Early season aphids are a special challenge to apple, peach and cherry growers because they rapidly multiply before most predators have become active in the spring. There are no useful sprays to use in spring in organic production and the use of Provado or related neonicotinoids used in conventionally managed orchards early in the season may lead to irruption of mites and other insect pests and may now be restricted due to evidence of its involvement in honey bee colony collapse disorder. Two pest aphids, Rosy and Woolley apple aphids are considered high priority problem insects in the 2012 priority list by the WTFRC crop protection subcommittee.

OBJECTIVES

1) Test formulations of various foaming agents using a foam generator and adapt foam generation to a modified 12-volt pump sprayer suitable for use on an ATV.

2) Test adhesion of foam to waxy, water repellent, surfaces and leaves of seedling apples.

3) Test survivability of lacewing eggs in laboratory conditions when eggs are a) immersed in and b) sprayed with these foams

4) Test adherence of LW eggs in foam on apple, pear and cherry trees in the greenhouse and the field and estimate hatch rates of eggs in those settings

5) Estimate colonization rates (proportion of eggs recollected as larvae) on test trees.

We will adapt foaming agents to produce foam that can be sprayed on to trees using only modest changes to commonly used ATV-mounted sprayers. Our design requirements will include:
(1) Foam creation from readily available and relatively inexpensive constituents
(2) A method and solution to provide egg suspension that leads to even application rates
(3) An application method to propel the foam and eggs to the tree without damage to the eggs
(4) Spray adjuvant that will enhance adherence and persistence on the tree
(5) High egg hatch rates

SIGNIFICANT FINDINGS

None yet!

METHODS

Objective 1 - Initial testing will evaluate the suitability of a variety of natural products and proteins to serve as a foaming agent in this application. Examples include, but not limited to, keratin, gelatin, whey proteins, and natural extracts (maypon 4c). Our previous experience with keratin hydrolysate and its performance properties make it an attractive starting point. Keratin hydrolysate was originally developed as non-petroleum based foaming agent during World War II for use in firefighting which is still a major use for some foams produced by protein hydroslates. Keratin hydrolysate is produced on commercial scale from alkaline treatment (hydrolysis) of bovine hooves and horns. The suitability of this and other foaming agents will be evaluated by measuring their physical properties including expansion ratio, half-life, and density using standard procedures. Formulations with different properties will be produced by varying the viscosity and adding foam-modifying adjuvants to the hydrolysate base. Modifying adjuvants will be limited to those listed under the USDA's National Organic Program Inert Ingredients List, the USDA GRASS list or with a similar organic certification.

A secondary goal under this objective will be to determine the best method to introduce lacewing eggs to foam. If successful foam and high lacewing survival cannot be generated from a single solution that contains the eggs, a method to introduce the eggs downstream of foam generation will be engineered. This could be accomplished by introducing a solution of eggs into a stream of foam near the spray nozzle as it is being released.

Objective 2 –Tests of adhesion of foam to waxy, water repellent surfaces in the laboratory in Peoria using a foam generator/sprayer. Many properties affect the adhesion to plant surfaces, such as leaf morphology, leaf orientation, velocity of impact, surface tension during impact and other physical properties of the impinging droplet. The subsequent ability of the foam to remain attached to the plant surfaces is dependent of the surface area of contact and density of the foam. Application parameters that can be controlled will be evaluated for their ability to improve adhesion. Subsequently, promising foams will be tested apple seedlings in the greenhouse in Wapato by foam generation through nozzles driven by a 12-volt rotary membrane pumps (as used in ULV sprayers mounted on ATVs). Physical damage of LW eggs will be evaluated using frozen eggs produced at Beneficial Insectary by running eggs through the foam generation and spray procedure and examining them for visual damage.

Objective 3 **-** Foams to be considered will first be screened for potential chemical toxicity to LW eggs. A simple method of testing solutions on LW eggs immersing eggs in a test solution for 30 minutes or longer and then placing them on a sticky surface (we have found microscope slide labels work well), which allows the eggs to hatch but causes the larva to become mired in the adhesive before it can walk away or feed on other eggs. Testing damage through the sprayer consists of holding a vessel (large graduated cylinder) to recover stream as it leaves spray nozzle and transferring eggs to sticky surface for measuring hatch as above.

Objective 4 – Quantifying adherence of LW eggs applied in foam on apple, pear and cherry leaves is based on discovery of individual eggs after spray has dried and marking the leaf near the egg. These marked egg positions are then revisited daily until hatch is completed. This objective will require constructing a laboratory sprayer using a solution vessel and rotary diaphragm pump equipped with a spray wand, all corresponding to the ULV spray setup mounted on ATVs. The sprayer will be mounted on a cart with a 12-volt deep cycle battery and appropriate wiring and tubing. Pear, apple and cherry seedlings will be sprayed with competing foam formulations and leaves harboring LW eggs after the spray dries down will be placed in Petri dishes and hatch rate monitored.

Objective 5 – Colonization of eggs and larvae on test trees is the ultimate measure of efficacy of the system we propose. Potted trees in experimental setups in the greenhouse and on laboratory grounds will be sprayed with known numbers of LW eggs using the cart-mounted laboratory sprayer as described in objective 4. Test trees will be infested with pea aphids by adhering the aphids in streaks of cyanoacrylate glue (superglue). Aphids will provide food over 2 days for hatching LW larvae. Frequent inspection of the LW egg positions with nearby aphids will allow us to collect some portion of the larvae. From these data, we will estimate hatch rate and successful colonization. The same effort will be repeated on young trellised apple trees and branches of cherry and peach trees in field setting near the Wapato laboratory.

RESULTS AND DISCUSSION

Prior to proposal we showed:

1. A low-pressure rotary diaphragm pumps like that used for ULV applications of GF120 can be used to spray LW eggs with high survival rates.

2. Found spray adjuvants that increased retention of eggs on the foliage – **(but did not help sticking on contact thus the need for foam).**

3. Found adjuvant also contributed to suspension of eggs in solution in the sprayer allowing for even application rates. But improvement in application technology is greatly needed because few eggs adhere to apple or pear leaves on impact, reducing overall adherence to about 20%.

Since we received funds in March:

Dunlap has:

1. Started recruitment of a temporary laboratory assistant from regional Universities to work on the grant; candidate should be in place in late May
2. Broadened search for foaming agents that meet organic certification and has identified additional suppliers of protein based foaming agents. One example is an OMRI certified product we will test as a foaming agent: *Yucca shidigera* extract.
3. Through conference calls we have identified equipment needs and constraints and have ordered paired equipment so we have identical pumps, nozzles and connectors for testing in Peoria in the lab and in Wapato in the greenhouse and field.
4. Provisional constraints are to use pump equipment that is in common use on ATV and to work downstream from that for foam generation and lacewing egg delivery.

Unruh has:

1. Hired a student assistant who is working part time, full time beginning mid-May
2. Seeking orchards where we can collect aphids colonies to infest trees at USDA Farm
3. Begun testing of spray equipment for foam generation using a firefighting protein-based foaming agent.
4. Identified two simple, commercially-available, water-driven, foam generating sprayers used for applying foam on animals. Purchased one.

CONTINUING PROJECT REPORT **YEAR**: 1 of 3
WTFRC Project Number: AP-12-104

Project Title: Development of apple bloom phenology and fruit growth models

PI: Gerrit Hoogenboom
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Address: Department of Statistics
Address 2: Neill 103
City/State/Zip: Pullman, WA 99164

Cooperators: Karen Lewis (WSU-Extension), Felipe Castillo (WTFRC)

Total Project Request: **Year 1:** $70,000 **Year 2:** $82,500 **Year 3:** $85,000

Other funding sources

Indirect support through the existing infrastructure of AgWeatheNet and its network of 137 weather stations.

WTFRC Collaborative expenses:

Item	2012	2013	2014
Salaries	3,000	3,500	4,000
Benefits	1,200	1,400	1,600
Wages[1]	7,500	7,500	*0 or 7,500
Benefits			
RCA Room Rental			
Shipping			
Supplies			
Travel[2]	2,400	2,700	3,000
Plot Fees			
Miscellaneous			
Total	$14,100	$15,100	*$8,600 or $16,100

Footnotes: *Additional field data collected only if needed in 2014
[1] Labor calculated as 2 persons at $16.00/hr working 12 hrs per week for 13 weeks during the growth season.
[2] In-state travel to research plots

Budget
Organization Name: ARC-WSU **Contract Administrator:** Carrie Johnston
Telephone: 509-335-4564 **Email address:** carriej@wsu.edu

Item	**2012**	**2013**	**2014**
Salaries	53,936	65,536	67,496
Benefits	12,564	13,464	14,004
Wages			
Benefits			
Equipment			
Supplies	1,000	1,000	1,000
Travel	2,500	2,500	2,500
Miscellaneous			
Plot Fees	0	0	0
Total	$70,000	$82,500	$85,000

Footnotes: The budget that is requested through this proposal includes partial support for a Research Associate (Melba Salazar) who will be responsible for the overall evaluation and implementation of the various growing degree models that are applicable for conditions in the Pacific Northwest and partial support for an Application Programmer (Sean Hill) for integration of the model on the web portal of AgWeatherNet (www.weather.wsu.edu). We also have budgeted for a Graduate Student (to be hired) who will be responsible for the development of a physiological fruit growth model. The proposal includes a request for a computer for the graduate student during the first year of the project. Additional budget items include operating expenses for computer software and related costs and travel to participate in field data collection. Finally, this proposal includes support for Professor Dasgupta in the Department of Statistics to complete her statistical model development and evaluation (objective 2).

OBJECTIVES

1. Continue data collection on bloom phenology and fruit growth for selected sites and cultivars to enhance model accuracy and vigor. (Schmidt in collaboration with Castillo)
2. Continue refinement of statistical models for bloom phenology and fruit growth. (Dasgupta)
3. Develop physiological-based models for bloom phenology and fruit growth of apples. (Hoogenboom, Salazar)
4. Implement and evaluate models as decision support aids on the AgWeatherNet portal using industry beta-testers. (Hoogenboom, Salazar and Dasgupta in collaboration with Lewis)
5. Improve model/portal user interface based on feedback from beta-testers and other stakeholders. (Hoogenboom, Salazar in collaboration with Lewis)

Timetable for Project

Activities	**2012-2013**				**2013-2014**				**2014-2015**			
1. Experimental data collection		x	x			x	x			x	x	
2. Statistical model development and evaluation	x	x	x	x	x	x	x	x	x	x		
3. Physiological model development and evaluation	x	x	x	x	x	x	x	x	x	x	x	x
4. Web-based user interface development			x	x	x	x	x	x				
5. Web-based user interface evaluation by WSU Extension and stakeholders; final implementation						x	x	x	x	x	x	x

METHODS

1. Data collection

For the development of robust models, high quality data are needed incorporating a diverse range of environments and annual weather conditions. WTFRC staff will continue collecting bloom phenology and fruit growth data from established sites to augment data sets from the previous project. If data analysis and modeling suggest clear variability between cultivars with respect to bloom phenology and/or fruit growth patterns, new varieties (e.g. Fuji, Golden Delicious, and Honeycrisp) may be incorporated into the project.

2. Continue refinement of statistical models for bloom phenology and fruit growth

For the growth models, data have been compiled for Gala for 2010 and 2011, while for Red Delicious and Cripps Pink data have been compiled for 2010. For the bloom models, data have been compiled for 2010 and an ordinal logit model has been used to fit the data. All data for phenology, growth and temperature have will be compiled for 2011. For the growth model the data for 2010 and 2011 have to be combined and new parameters have to be estimated. For the bloom model similar procedures will be followed.

Following a successful development of both the statistical bloom phenology model and the statistical fruit growth model, they will be evaluated with the new data that will be collected during the 2012 and 2013 growing seasons.

3. Develop physiological models for bloom phenology and fruit growth

Although statistical models can play an important role in estimating phenology, physiological models are normally more robust as they eliminate the need for the development of a location-specific and time-specific model. This can be partially accomplished by using physiological time as input, sometimes referred to as Growing Degree Days (GDD) or growing-degree hours. The latter is a more sophisticated model, but also requires additional weather data observations.

In order to identify an appropriate model to estimate the GDD requirements for different phenological stages for apple, a comparison between three of the most traditionally methods for GDD accumulation will be used. This includes averaging, standard GDDs and the triangle method. Thermal-time, based on a two-step phenological model will be tested and a simple thermal-time (TT) model based on historical observations for the key phenological stages will be developed (Table 1).

Hourly temperature records from the AgWeatherNet will be used for estimating the requirements for the different phenological stages of the most important apple cultivars. Once the models have been applied for the calculation of heat requirements, an evaluation to determine the most accurate model using historical observed dates under different environmental conditions will be performed. The climatic requirements for the beginning of the season, pre-bloom, bloom and the end of the season, will be obtained as a result of this evaluation.

In addition to using the temperature data collected by AgWeatherNet, we will also compare the performance using the weather data collected with the Hobo data loggers that have been part of the data collected by WTFRC. Some concern has been expressed that the weather data collected by AgWeatherNet are not very representative for the conditions in an orchard.

We are planning to use the initial set of data collected as part of the WTFRC Project Number AP-09-908 for model development. Once additional data have been collected as part of the current project, we will use the new data for model evaluation and improvement.

4. Implement and evaluate models as decision support aids on the AgWeatherNet portal

In order to assist the growers for making decisions, an information delivery system and media tool will be developed using the statistical models developed under objective 2 and the physiological models developed under objective. This tool will provide, in an easy and user-friendly way, thermal time, cumulative chilling, and cumulative degree hours in real-time (current) for different environmental conditions where local weather data are available through tables and graphs. An example of a similar tool can be found on the AgWeatherNet portal (www.weather.wsu.edu) by selecting the "Chilling Hours" option. An example of a more complex physiological model can be found under "Cold Hardiness" which was developed in collaboration with WSU's Viticulture and Enology Program. This decision support tool will provide information about the current phenological and development stages and the climatic requirements to complete the next stage. In addition, this tool will be able to provide alerts to the growers when the crop can be at risk due to the actual temperatures in excess of the threshold temperatures.

The system will be available through a link created on the AgWeatherNet web portal and other web portals where information for apples is provided, including the Decision Aid System (DAS). We will also explore the development of alternative communication systems to support apple growers through cell phones applications and instantaneous message alerts for critical weather conditions or when threshold values have been reached. Furthermore, this web site and portal will offer a link to access the automated weather station and local weather predictions through tools that are being proposed in a parallel project that has been funded by the Washington Tree Fruit Research Commission for one year.

5. Improve model/portal user interface and release for general use

We will work closely with WSU Extension and industry representatives as beta testers during the second and third year of this project. We will try to incorporate all comments to help improve the tool and decision aid to the benefit of the local apple growers. The overall goal is to develop a web portal that will provide a guideline and advisory for the growers who are monitoring their individual apple orchards in terms of weather conditions and weather predictions. That will ultimately allow for better planning to improve fruit quality, increase yield, more efficient marketing and ultimately result in an increase in net returns.

RESULTS & DISCUSSION

1. Data collection

Observations of bloom phenology are currently being recorded by WTFRC internal staff every Monday, Wednesday, and Friday in 29 blocks clustered around 10 location nodes. Sites being utilized in 2012 are the same as in previous years of this project, with the exception of the Prosser area blocks, which were moved to more modern, well-maintained orchards (Table 1). As of 11 April, 2012 bloom development was generally lagging a few days behind phenology from corresponding dates from 2011 in the same sites.

Table 1. 2012 roster of sites utilized for apple bloom phenology observations and fruit growth measurements. (RD = Red Delicious, CP = Cripps Pink, G = Gala)

Location	Grower	Cultivar	Elev (ft)
S Shore Chelan	Easley	CP	1120
	Sunshine	RD, G	1450
Brays Landing	Podlich	RD, CP, G	900
S Orondo	C & O Nursery	RD, CP, G	755
E Wenatchee	Gausman	RD, CP	910
	Witte	G	1025
Rock Island	WSU-TFREC	RD	910
	WSU-TFREC	G	880
	Zirkle CRO	CP	775
Royal Slope	Delay	CP	1095
	Delay	RD, G	1055
Naches	Rowe	RD, G	1580
Parker	Brandt	RD, CP, G	879
Sawyer	WTFRC Rootstock	G	870
	Badgely	RD	870
	Weippert	CP	870
E Prosser	O’Brien	RD	1010
	Oasis	CP	920
	Oasis	G	1060

2. Continue refinement of statistical models for bloom phenology and fruit growth

Currently we are working on integrating three years data into one combined model. The estimation for the growth parameters from the Richard's curve for the cultivar Gala is given in Table 2. The model used to estimate growth was:

$$y_{it} = \frac{\beta 1 + ui}{1 + e^{(-\beta 3(t - \beta 2))}}$$

Where y_{it} is diameter of fruit i on Day of Year t, u_i represents the fruit i. We assume each fruit is a random variable following a normal distribution with a standard deviation of *su*. The parameter $\beta 1$ estimates maximum size of the apple, $\beta 2$ represents the time of maximum growth and $\beta 3$ is the rate of growth. The estimated parameters and the standard deviations are given in Table 2 for 2011, 2010 and 2009. The combined estimates show us that there is a difference among the years. Similarly if we examine the table across locations we see that there is a difference across locations as well.

The next step in the modeling process will be to look at the effect of weather and ambient conditions in the model. Using the Growing Degree Days (GDD) and other physiological measurements from AgWeatherNet we will look to see the effect of these parameters on the model and potential improvement of its predictive capacity. This means essentially to determine if the weather information predicts the parameter changes across location and years. Using this statistical model we should be able to incorporate weather information into the models which will allow for a predictive model depending upon time (in Day of Year Days) as well as weather information. We hope to build a robust model that can be used by practitioners for predicting harvest mid season.

In the table we highlight S Orondo as data were taken on all three years at this location and we can see the differences in the estimates in the table.

Table 2. Parameter estimates for the Richard's curve model to estimate apple growth for Gala for 2009, 2010 and 2011.

Year	**Location**	β1	β2	β3	σ2	σ2ε
2011	**S Orondo**	**2.7423**	**187.12**	**0.04627**	**0.05148**	**0.01629**
	East Wenatchee	2.6142	184.41	0.04530	0.04637	0.006857
	Naches	3.5890	193.03	0.02296	0.03905	0.002913
	Bray's Landing	3.0434	182.08	0.04584	0.04598	0.01449
	Royal Slope	2.5528	184.28	0.04388	0.0687	0.004629
	S Shore Chelan	2.626	183.78	0.04989	0.04951	0.009153
	Konnowac Pass	2.8851	182.09	0.03107	0.03126	0.01042
	Prosser	3.5801	175.95	0.01914	0.09991	0.001935
	Rock Island	2.8829	178.82	0.05225	0.03350	0.01719
	Parker	3.2458	185.41	0.0234	0.02916	0.002341
	Combined location	**2.8618**	**184.79**	**0.04566**	**0.003541**	**0.04067**
2010	Bray's Landing	2.96	182.44	0.025	0.04326	0.00211
	S Shore Chelan	3.0744	182.71	0.02868	0.03112	0.002123
	East Wenatchee	2.9324	176.62	0.02526	0.02884	0.0008
	Prosser	2.7638	171.22	0.0198	0.0177	0.00125

	Konnowac Pass	3.3945	177.42	0.02269	0.2556	0.01184
	S Orondo	**2.75**	**181.37**	**0.023**	**0.02549**	**0.001954**
	Royal Slope	3.058	179.28	0.0246	0.05139	0.003323
	Parker	2.9989	179.56	0.0244	0.025	0.001131
	Rock Island	2.6885	178.38	0.0233	0.0518	0.0018
	Combined location	**2.944**	**179.04**	**0.0253**	**0.0034**	**0.04696**
	Bray's Landing	3.2232	172.62	.0374	.0343	.00507
	S Shore Chelan	2.9065	173.59	.0379	.0211	.00432
	S Orondo	**2.9449**	**175.53**	**.0427**	**.0429**	**.00483**
2009	Konnowac Pass	2.9648	171.40	.0353	.0347	.00420
	Naches	2.8371	180.24	.0455	.0231	.00967
	Royal Slope	2.8649	172.69	.0471	.0149	.01100
	Parker	2.7016	175.12	.0433	.0194	.00826
	Omak	2.8335	180.20	.0365	.0190	.00184
	Combined location	**2.9766**	**174.63**	**.03491**	**.0026**	**.03489**

3. *Develop physiological models for bloom phenology and fruit growth*

As a start to the development of the more complex physiological models we calculated the number of growing degree days using the standard base temperature for apples at 43 ^{o}F. The results are shown in Table 3. Long-term climatologies for a few key sites, including those included in this study, are shown in Table 4. The differences among sites changes as we progress during the growing season.

Table 3. Growing degree days (GDD) using a base temperature of 43 ^{o}F starting on March 1 until present (April 18) for a few key sites in Eastern Washington. A comparison is shown between 2012 and the prior years of 2009 through 2011.

March 1 to April 18 GDD (Base Temperature 43˚F)				
	Wapato	**Finley**	**Naches**	**Mabton East**
2012	172	298	117	195
2011	110	217	71	107
2010	170	326	146	147
2009	124	234	100	145
	East Wenatchee	**Chelan South**	**Konnowac Pass**	**Brays Landing**
2012	135	131	192	136
2011	80	71	139	59
2010	175	173	228	153
2009	112	132	156	109
	Brewster	**Malott**	**East Oroville**	**South Tonasket**
2012	169	134	177	148
2011	113	73	125	104
2010	206	167	238	191
2009	144	113	154	107
	Royal City East	**WSU Sunrise**	**Orondo**	**Pogue Flat**

2012	191	173	177	114
2011	102	126	125	66
2010	213	238	226	147
2009	138	189	190	103

4 Implement and evaluate models as decision support aids on the AgWeatherNet portal
No activity to report

5 Improve model/portal user interface and release for general use
No activity to report

Table 4. Monthly climatologies for a few key sites in Eastern Washington.

TFRC Study Sites Climatologies												
	Brewster			**Malott**			**East Oroville**			**South Tonasket**		
Month	Tmin	Tavg	Tmax	Tmin	Tavg	Tmax	Tmin	Tavg	Tmax	Tmin	Tavg	Tmax
January	23.3	28.1	33.4	22.2	27.6	33.0	24.6	29.4	34.3	18.8	25.7	32.7
February	26.5	32.8	40.6	24.9	31.8	39.6	28.5	34.2	40.9	25.0	32.4	41.2
March	33.4	42.5	53.1	31.3	41.2	51.7	35.0	43.0	51.9	30.7	41.7	53.6
April	39.3	50.9	62.9	36.1	48.6	60.5	40.1	50.1	60.4	34.1	48.4	61.8
May	46.6	59.4	72.4	43.7	58.3	71.5	48.5	59.7	71.0	42.9	58.5	73.2
June	52.6	65.9	79.0	49.6	64.8	78.3	55.7	66.6	77.8	50.1	65.5	80.2
	Wapato			**Finley**			**Naches**			**Mabton East**		
January	24.5	31.5	39.1	30.1	35.8	41.8	22.7	30.7	39.3	27.0	34.0	41.5
February	26.7	36.0	46.5	31.4	38.6	46.7	26.7	35.7	45.5	27.8	37.0	47.2
March	31.8	44.5	56.8	37.2	47.2	57.7	30.1	41.4	52.7	30.3	42.6	54.7
April	36.6	50.9	63.1	42.2	53.5	64.8	35.0	47.8	59.5	34.1	48.9	61.9
May	43.6	59.7	73.0	48.5	61.4	73.7	41.8	56.5	69.4	41.8	57.5	71.0
June	49.6	66.2	79.7	54.4	68.0	80.6	47.7	63.1	76.3	51.2	66.4	79.8
	Royal City East			**WSU Sunrise**			**Orondo**			**Pogue Flat**		
January	26.5	31.8	38.1	24.9	31.1	37.3	27.3	31.2	36.3	20.6	25.9	31.4
February	30.0	36.5	44.2	29.6	36.6	44.5	30.3	35.5	42.3	25.0	31.9	40.1
March	33.1	42.4	52.6	33.7	43.0	53.3	34.7	42.4	52.1	31.6	41.2	51.4
April	37.2	48.2	59.2	39.8	50.2	60.8	39.8	50.1	61.2	36.3	48.5	59.9
May	44.8	57.4	69.5	46.4	58.0	69.9	45.8	57.7	70.4	44.0	58.0	70.6
June	50.8	63.9	76.8	55.2	66.8	78.8	53.7	66.4	79.8	50.4	64.2	76.9
	East Wenatchee			**Chelan South**			**Konnowac Pass**			**Brays Landing**		
January	22.7	28.0	33.9	26.3	30.0	34.8	27.0	34.1	41.9	21.5	27.1	33.0
February	28.3	34.6	42.1	29.6	34.3	40.8	28.9	37.9	47.6	27.6	33.8	41.6
March	32.5	41.1	50.5	34.5	41.3	49.4	33.2	44.2	55.2	32.5	41.3	50.9
April	37.7	48.0	58.1	39.7	48.5	57.7	35.9	49.8	61.5	37.2	47.7	58.1
May	46.4	57.8	69.2	46.1	56.1	66.7	44.3	58.9	71.4	44.1	56.8	68.7
June	53.1	64.4	75.8	54.3	64.7	75.6	51.2	65.9	78.9	50.7	63.7	76.2

CONTINUING PROJECT REPORT **YEAR**: 1 of 3
WTFRC Project Number: TR-12-102

Project Title: Effect of early spring temperature on apple and sweet cherry blooms

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Cooperators: John Ferguson and Markus Keller, IAREC-WSU

Total Project Request: **Year 1: $95,000** **Year 2:** $80,000 **Year 3:** $80,000

Other funding sources

Indirect support through the existing infrastructure of AgWeatherNet and its 137 weather stations.

WTFRC Collaborative expenses: None

Organization Name: ARC-WSU **Contract Administrator:** Carrie Johnston
Telephone: 509-335-456 **Email address:** carriej@wsu.edu

Item	**2012**	**2013**	**2014**
Salaries	14,040	38,646	37,661
Benefits	5,616	7,803	7,102
Wages	42,400	20,860	21,694
Benefits	4,240	2,086	2,169
Equipment	10,000		
Supplies	10,204	2,605	2,874
Travel	8,500	8,000	8,500
Miscellaneous			
Total	**95,000**	80,000	80,000

Footnotes: Salary for a Post-doctoral Research Associate (Dr. Melba Salazar) for four months during the first and second year of the project and for three months during the final year of the project. Dr. Salazar will be supported by a Master of Science level graduate student, budgeted for two years of the project. One year of 0.5 FTE technical support (Mr. John Ferguson) to design and build the automated sampler system. The automated sampler will be integrated with a freezer, which is budgeted at $10,000. Additional budget items include part-time hourly labor to help with sample collection and sample analysis for all three years, goods and services for the parts associated with the automated sampler and travel for collection of the samples in the region.

Goal and Objectives

The overall goal of this proposal is to investigate the effects of early spring temperature on apples and sweet cherries at different early developmental stages and to determine the hardiness during early and late spring. We propose to use a traditional methodology through exposure to freezing temperatures, but to automate part of this procedure. The outcome will be updated hardiness charts for apples and sweet cherries.

The following are our specific objectives:

1. To determine the effect of early spring temperature on bloom development for different apple and sweet cherry cultivars and for different environments.
2. To develop a cold resistance curve from dormancy to bloom for apples and sweet cherry.
3. To update the charts for the different stages of blossom buds of apples and sweet cherry cultivars for local weather conditions in the Pacific Northwest.

Significant Findings

- We found differences in cold hardiness among different cherry and apple buds during the late winter months
- Chelan was the hardiest cultivar followed by Bing and Sweetheart
- We found differences in cold hardiness for the same cultivars as development progressed from dormant buds to initial development, including bud swell and green tip.
- We developed a prototype for a functioning automated freezer sampler to determine cold hardiness of apple and cherry flowers.

Methods

Although this research will concentrate on the impact of freezing temperatures during bud break and flowering, it is very important to also determine the sensitivity of the buds to low temperature during fall and winter. Therefore, bud samples will be collected throughout the winter and spring seasons to determine the effect of early spring temperature on bloom development for apple and sweet cherry cultivars. The sampling interval will slowly decrease as the winter season progresses, starting at 2 weeks in the fall to 2 days when bud swell and flowering is initiated. We propose to sample three sweet cherry cultivars, including Bing, Chelan and Sweetheart and three apple cultivars, including Red Delicious, Gala and Fuji. The initial selection of these varieties is based on the work that was conducted previously by Dr. Whiting but can be changed based on grower feedback. During the final year of the project we will also include new varieties and evaluate their cold hardiness, especially as it compares to the standard varieties. We propose to select intact spurs for cherry trees and a section of wood that includes multiple buds for apples. This will avoid some of the variability in cold hardiness response that was found previously by Dr. Whiting. The orchards where we will collect the apple and cherry shoots should preferably be located in the vicinity of an automated weather station of AgWeatherNet in order to be able to correlate the cold hardiness data with local temperature observations.

For the initial stage during fall and winter, we will use the DTA empirical method which is one of the most common methodologies for estimating cold hardiness based on local temperature observations (Mills et al., 2006; Ferguson et al., 2010). The successful use of this approach to determine cold hardiness for dormant cherry and apple buds was demonstrated in previous studies that were conducted to establish temperature thresholds for acclimation and deacclimation, acclimation and deacclimation rates. The changes of these thresholds and rates will be determined following the methodology proposed by Ferguson et al., (2010). For the final stage close to flowering, the buds will be exposed to different low temperature treatments during successive periods. Following exposure, the buds and flowers will be evaluated and dissected under the microscope to determine tissue damage. We are planning to develop an automated device that will select samples based on different exposure durations and temperature combinations. This would allow for a more detailed analysis compared to the previously conducted manual samplings.

In parallel to the process described above we will also use the methodology described by Proebsting and Mills (1978) to develop a cold resistance curve from dormancy to bloom for apples and sweet cherry. Dormant apple and cherry shoots that are 6 to 10 inches long with terminal flower buds will be collected from October to April. These shoots will be kept in a cold storage room in containers filled with water. The base of the shoots will be recut weekly and leaves will be removed when necessary. Water will be replaced every three days. The apple and cherry shoots will be forced in continuous light and at a controlled temperature similar to the procedures of Proebsting and Mills (1978). The shoots will be inspected at three-day intervals and classified. Seven bud development classes will be assigned based on Chapman and Catlin (1976). This includes 0 = dormant buds, 0.5 = silvertip, 1 = greentip, 2 = 1.2 cm (0.5 inch) green, 3 = tight cluster, 4 = pink, 5 = bloom, and 6 = petal fall.

In order to update the charts for the different stages of blossom buds of apples and sweet cherry cultivars, we will take digital pictures for the different growth stages to illustrate, identify, and define the key growth stages for apple and sweet cherry. The growth period will cover the dormant bud stage up to the initial fruit set as described in Chapman and Catlin (1976). The charts will be combined with the data obtained from the cold hardiness exposure described previously and will also include growing degree hours (GDH) (Anderson et al., 1986). These GDHs will be estimated assuming optimum temperatures and base temperatures for apple and cherry growth for each phenological stage. The accumulation of thermal time and the rate of change of thermal time will also be considered.

All information will be integrated to develop both traditional hard copy charts as well as digital systems that can be accessed via the web, including AgWeatherNet and apple and cherry decision aids, as well as via smart and hand-held devices.

Results & Discussion

The project was awarded in January, 2012. Therefore, only limited progress can be reported so far. We have concentrated our efforts on several aspects of the proposal. This includes:

- Determine the cold hardiness of cherry and apple buds during the late winter months using the Differential Thermal Analysis (DTA) methodology
- Development of a prototype automated freezer sampler for determining the cold hardiness of apple and cherry flowers
- Evaluate different procedures for determining cold hardiness of apple and cherry flowers
- Initial development of new charts using digital pictures

The sensitivity of apples and cherries buds to low temperature during the current growing season was evaluated from mid-winter (February) until tight cluster stage for apples and until first bloom for cherries. For apples we evaluated the varieties Gala, Red Delicious and Fuji. For cherries we evaluated the varieties Bing, Chelan and Sweetheart. Differential thermal analysis (DTA) and freezing tests were performed on the buds immediately following field sample collection. During controlled freezing, exotherms were detected for both crops. There were very distinct high and low exotherms for cherries for the three cultivars that were evaluated (Fig 1), while only high exotherms were observed in apples using DTA (Fig 2). The major exotherms are associated with the initial freezing and the low exotherms indicate complete tissue death.

The temperature at which the buds become injured is related to the start of the low temperature exotherm on the DTA profile. This profile changes depending on the cultivar, e.g., for the same day of sampling (February 15-2012) Chelan was the hardiest cultivar followed by Bing and Sweetheart (Figure 1). In general across all sampling dates, Sweetheart was the least hardy cultivar and Chelan was the most hardy cultivar. The thermal profiles changed as a function of sampling dates for each cultivar as shown in Figure 3 for Chelan. Differences in lethal temperature among phenological stages were also observed for Chelan (Figure 4). These are preliminary results and further analysis is currently being conducted.

Previous research has shown that DTA is not effective when bud swell occurs close to the flowering stage. We are in the process of developing a prototype freezer sampler, referred to as the "vending machine," that allows us to automatically select samples at preset freezing temperatures. At the time of reporting, only limited tests have been conducted with cherry buds and flowers for Chelan. A first sampling was conducted with buds and flowers for cherries (Chelan). After freezing, the buds and flowers were dissected under the microscope to determine tissue damage. In this moment statistical analysis is been doing for apples and cherries for different cultivars and dates.

To update the charts for apples and sweet cherries, some initial digital pictures have been taken for the different growth stages. The initial results are shown in Figure 5 and Figure 6.

Limitations

To plan the activities for the coming seasons, the project urgently requires cooperation with local orchards for sample collection of sweet cherry and apple trees for sample analysis.

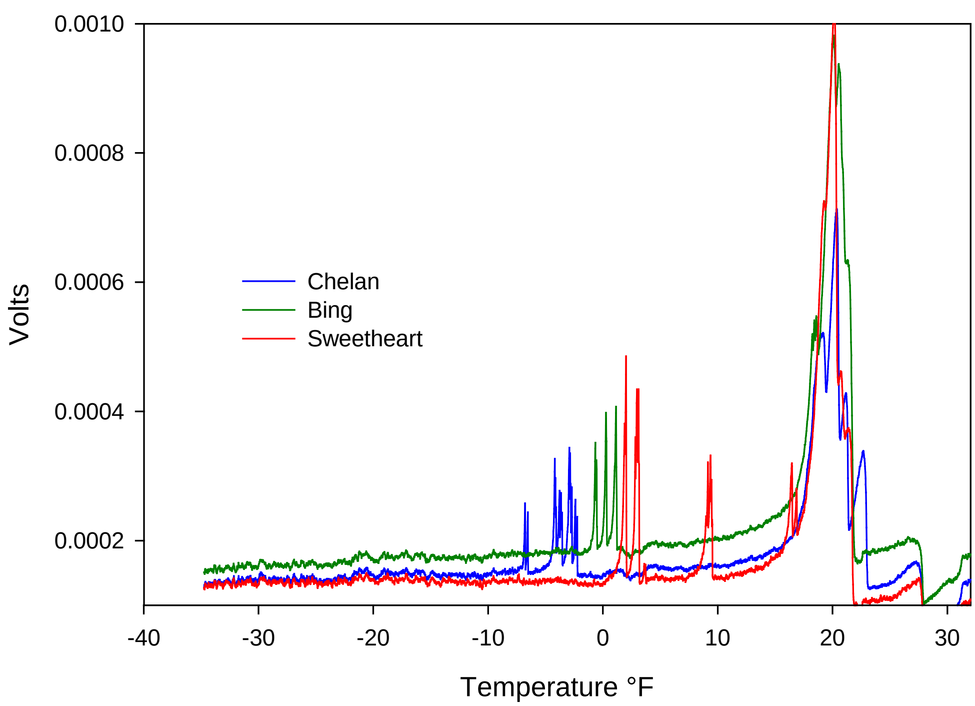

Figure 1. High and low exotherms for buds of three different cherry cultivars evaluated on February 13, 2012

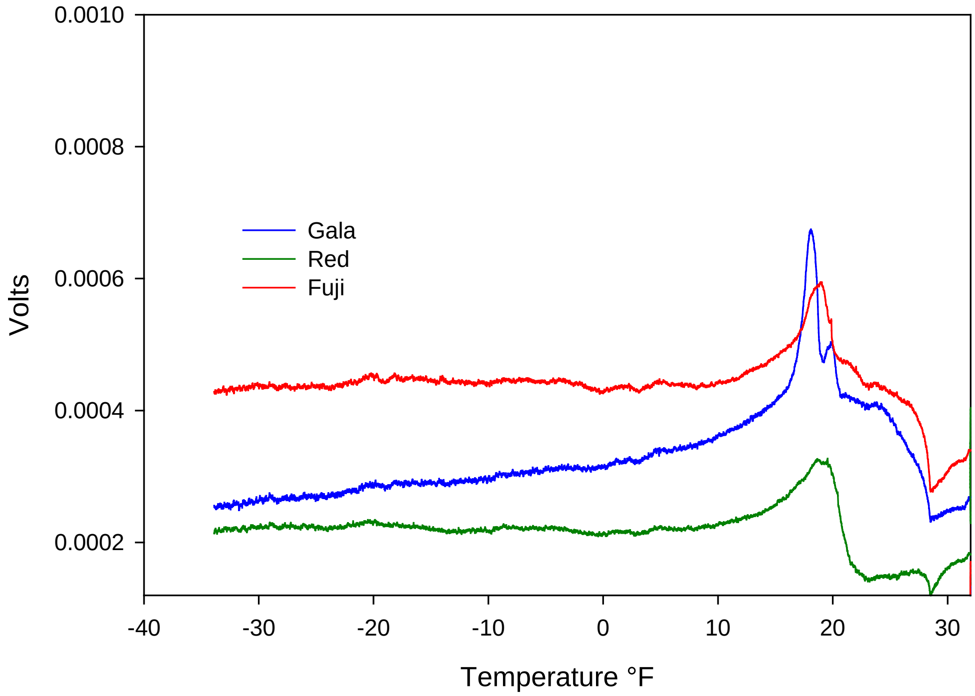

Figure 2. High exotherms for buds of three different apples cultivars evaluated on February 15, 2012

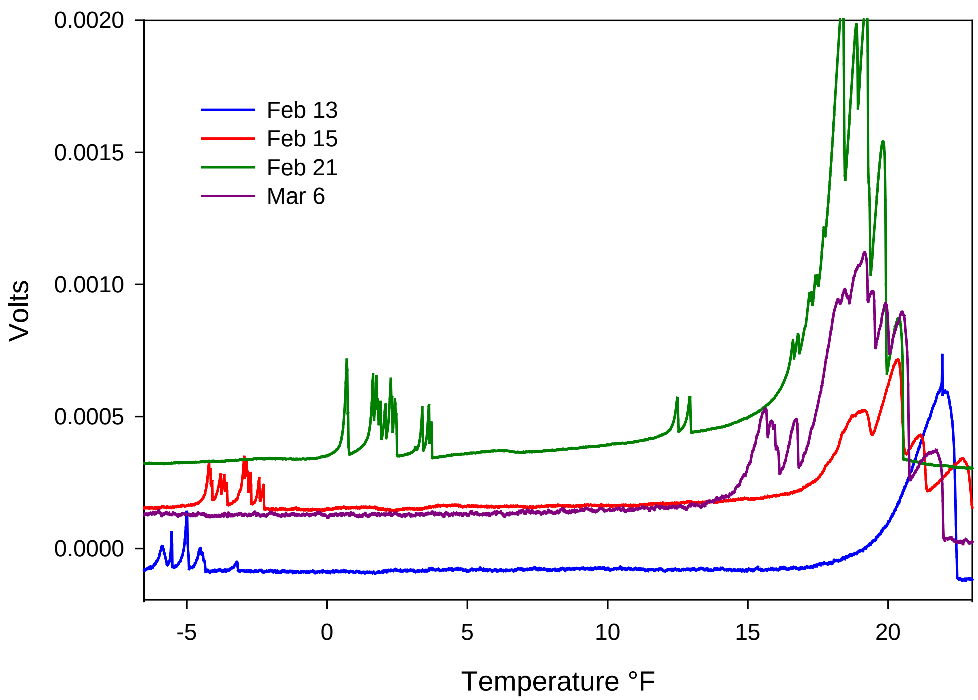

Figure 3. High and low exotherms for the cherry cultivar Chelan for four sampling dates.

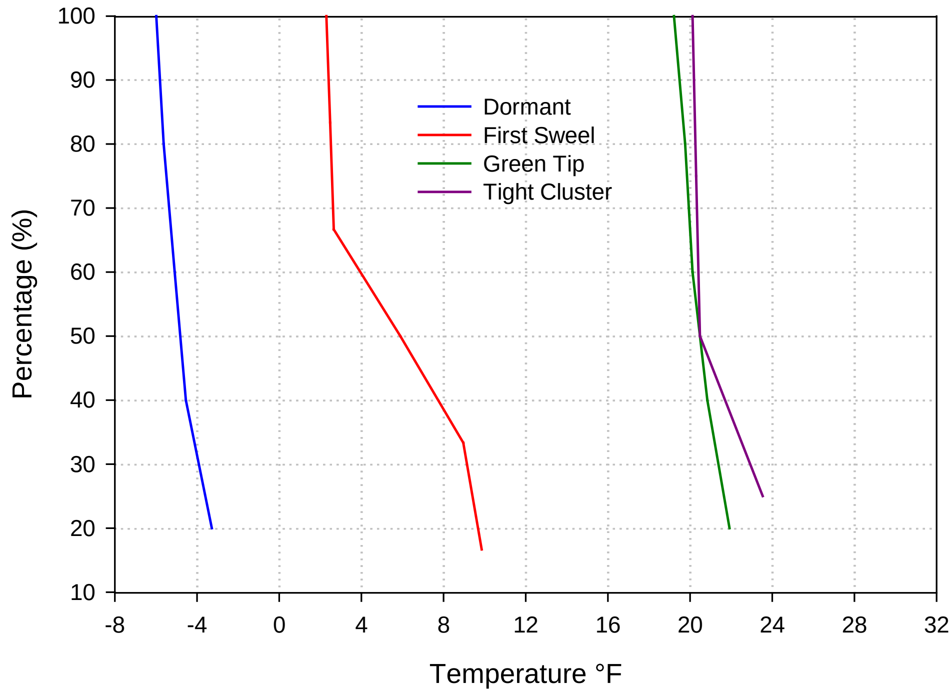

Figure 4.Variability in lethal temperature for different phenological stages of Chelan buds.

Pictures by Jakarat Anothai

Figure 5. Phenological stages for sweet cherries

Pictures by Jakarat Anothai

Figure 6. Phenological stages for apples