Washington Tree Fruit Research Commission Fall Technology Research Review
October 25, 2012
WA Cattlemen's, Ellensburg

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	9:00	McFerson	**Introduction**
			Final Reports
1	9:05	Ashmore	Technology roadmap support: ***Final report and new proposal***
11	9:15	Gallardo	Cost estimation of producing Red Delicious Apples in WA
		Continuing Reports	
18	9:30	Eastwell	Evaluating a universal plant virus microarray for virus detection
25	9:40	Unruh	Protein-based foam for applying lacewings eggs to fruit trees: ***Extension***
26	9:50	Karkee	3D machine vision for improved apple crop load estimation*
32	10:00	Karkee	Design and development of apple harvesting techniques*
37	10:10	Zhang	Intelligent bin-dog system for tree fruit production
	10:20	Hoogenboom	Development of apple bloom phenology and fruit growth models*
45	10:30	Hoogenboom	Effect of early spring temperature on apple and sweet cherry blooms

FINAL PROJECT REPORT
WTFRC Project Number: TR – 10 - 100

Project Title: Technology roadmap support

PI: James Nicholas Ashmore
Organization: James Nicholas Ashmore & Associates
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Address: 400 North Capitol Street, Suite 363
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State/Zip: DC 20001

Cooperators: NONE

Percentage time per crop Across all crops
(Efforts focused on policy, program structure and procedures, and precedents for all crops)

Total project funding: $102,000

Year 1: $33,000 Year 2:$33,000 **Year 3:**$36,000

Other funding sources NONE

WTFRC Collaborative expenses: NONE

Budget
Organization Name: James Nicholas Ashmore & Associates
Contract Administrator: James Nicholas Ashmore
Telephone: 202 783 6511 **Email address:** nickashmore@cox.net

Item	**Year l** 2010	**Year 2** 2011	**Year 3** 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):

Generally speaking, the objectives set forth above were met or exceeded. There are some instances where there was progress toward the goal, but much remains to be done.

In addition to the above objectives, the project included on as needed basis work on several issues that affect Washington producers, and in those instances, there were contingent benefits from working collaboratively with industry partners and with other agricultural groups.

The three years covered by this project (2010 – 2012), covered a wide range of topics, focusing essentially on three major areas:

- Working with the Congress, the Administration, and our partners to ensure full and successful implementation of the Specialty Crop research provisions of the 2008 farm statute;
- Working with the Congress and the Administration(within the economic realities of a severe recession coupled with a strong political push to control Federal spending and reduce the Federal budget deficit), to secure funding for research programs/research areas important to the Washington State industry; and,

- At the same time working with our coalition partners, the Administration, the appropriate committees of jurisdiction in the House and Senate, and the Washington State Delegation to secure continuation of the Specialty Crop provisions in the reauthorization legislation passed by the Senate and reported by the House Committee on Agriculture.

We have, I believe, been remarkably successful in all three areas, and it is important to note that the Commission's willingness to work within the system and help insure that the 2008 Act was implemented successfully played a major part in securing the inclusion of strong specialty crop provisions, including language relative to the Clean Plant Network, in the reauthorization legislation that has passed the Senate and is pending in the House.

The Washington Delegation offices have been extraordinarily successful to us with respect to protecting to the extent possible appropriations legislation for research programs important to the industry.

It is important to note that the Congress has not completed action on farm bill reauthorization legislation. The controversial areas are outside of our control (the level of spending cuts for agriculture overall and also how and where those cuts are made and should the SNAP program face substantial cuts that will remove a number of people from food stamps). While this does not directly impact on our provisions, our programs could be vulnerable if the Congress or Administration demands further cuts in agricultural spending or changes how those cuts are proposed to be made.

It is also important to note that if the Congress and the Administration fail to reach agreement on farm bill reauthorization legislation in the current Congress, we will have to start over when the new Congress convenes in January 2013. If that happens, there will be a new adjusted baseline that will result in less money available to the Congress for any new reauthorization of Federal farm programs.

We did respond on an as needed basis in several significant areas. Specifically, we worked with the Commission Manager and U. S. Apple Association and senior officials in ARS to address problems that arose in the management of the apple rootstock breeding program. We were, I believe, able to work to insure that this kind of problems would not occur again and we were successful in limiting further fall out that could in fact have threatened the continuation of the program.

In another area, we were able to work with a broad-based coalition of agricultural groups to support restoration of funding for the chemical use survey program run the NASS, an agency of the Department of Agriculture. In a recent related matter, I have worked with Dr. Mike Willett of the Northwest Horticultural Council to develop language addressing timing issues for the chemical use survey that we propose to submit to the Congress for consideration should there be a conference on the differing versions of the farm bill reauthorization.

With respect to pear genome, genetics, breeding research we have made slow, but steady progress. At our request, Senator Murray included in an earlier Senate agriculture appropriations bill language directing USDA to provide a report to Congress about their plans/intentions in this area, asking specifically as to how the Department intended to be more responsive to the needs of the commercial pear producers.

Even though the Senate appropriations bill to which Senator Murray's report language was attached did not become law, ARS agreed to develop a report responsive to the Murray language. That report was eventually transmitted to the Senate by letter from Secretary Vilsack, and while it does not provide specifics, it does appear to endorse movement in this area. While I would like to see more specifics, the Vilsack letter provides a means of furthering the dialogue in this area; and, the

Department has asked for a “roadmap” of how the industry sees this moving forward. That “roadmap” is under development for review and submission to USDA.

Another area of activity involved cooperation with the Commission Manager and with the Northwest Horticultural Council in contacting and working with the Washington Delegation in support of the candidacy of Harold V. Austin to be named to the National Organic Standards Board. We were able to work on a bipartisan basis with the Delegation and with appropriate senior staff and with their support, Harold Austin was appointed and now serves on the NOSB.

We also worked with CropLife America relative to the tree fruit industry’s interest in developing a roadmap leading to the development of pesticide application technology leading to a closed end type of application that will significantly minimize the potential for pesticide drift to occur.

In a related matter, we worked with Dr. Mike Willett of the Northwest Horticultural Council relative to concerns about modifications to EPA spray drift policies and also relative to concerns over the use of science in the development of Biological Opinions pursuant to the Endangered Species Act. That effort involved working with a wide range of interest groups and included the Delegation offices as well as CropLife America.

With respect to trade matters and science debates regarding tolerance issues, we worked with Northwest Horticultural Council and with the Minor Crop Farmer Alliance to develop suggested language relative to the TASS program that will submitted to the Congress should the House and Senate actually get to conference on differing versions of the farm bill reauthorization. That language seeks to address issues associated with non-tariff trade barriers.

This effort involved discussion with CropLife America and others regarding interest in addressing possible questions arising from difficulties in getting tolerances established that will allow movement of U. S. commodities into foreign markets. Jim Cranney of California Citrus and others met with a CropLife America committee to discuss these matters and suggest possible involvement of CODEX. Mr. Cranney and Dan Botts and others from the Minor Crop Farmer Alliance were invited to the CropLife America annual meeting to continue and expand on these discussions in an effort to develop a way forward to obtain relief.

It has been an active and productive 3 years, and we have made remarkable progress. Much, however, remains to be done. While at this point it is reasonable to argue that specialty crops are in the best position that they have ever been in, we are in difficult times. Change is inevitable, and it is extremely important that we strengthen our ties, work closely with our partners and with our Delegation, remain flexible and prepare as best we can for any of the possible outcomes.

Discussion/Going Forward

This three year project has demonstrated the value of securing and maintaining the relationships with our Delegation offices and with the appropriate committees of jurisdiction and with the various agencies and appointed officials in the Administration.

This three year project has demonstrated the value of maintaining our strong commitment to openness and transparency, to a willingness to share information, and to our belief in the importance of having agricultural research awards made on a competitive basis recognizing the best available science and emphasizing multidisciplinary and multi-crop proposals that benefit a wide range of interest groups and regions. It has also demonstrated the value of being flexible to changing economic and political conditions so that adjustments can be made and we can continue to make progress toward our goals.

Because of the uncertainty surrounding the ability of this Congress to complete action on farm bill reauthorization legislation, it is important that in the last quarter of 2012 we continue to remain flexible and work to establish a factual base that will increase our chances for success in any of the possible outcomes, including deferring action on these issues until the next Congress.

That is a complicated process which we have already begun, especially with respect to the pear breeding issue, the baseline issue (how it might be adjusted), and how to move forward on the NASS chemical use issue and the TASS nontariff trade issues. We are prepared to remain helpful to the industry and to follow up as necessary dependent on the outcome of the meeting/discussion between the Minor Crop Farmer Alliance and CropLife America on the MRL/tolerance/CODEX issues.

In summary, we have come a long way and we have accomplished quite a bit. Much remains to be done in both the short and long term. Eventually, farm bill reauthorization legislation will be passed and signed into law. Following that, the industry will be faced with working with the Administration and Congress in implementing the new law and making it work.

We are likely to see changes in the economic and political situation (regardless of the outcome of the coming election). As such, we should "stay the course" and remain true to the principles and approaches that have gotten us to this point. We need to continue to emphasize the clarity of sound science, the importance of cooperation and consensus, and the commitment to work within the system and make the programs successful.

If we do this, I am convinced that we will continue to expand our opportunities and we will continue to have the contacts and channels of communication necessary to get the information necessary to formulate a consensus and move forward to work with political leaders in both parties to move forward toward our goals. This will result in significant and substantial benefits continuing to accrue to the Washington State tree fruit producers.

Executive Summary
Final Project Report
WTFRC Project Number: TR – 10 – 100
Project Title: Technology Roadmap Support

This three year project met all of its objectives and resulted in assisting the Commission be instrumental in the successful implementation of the 2008 farm bill; defending and securing funding for research programs important to the Commission and the growers; moving forward on new initiatives supported by the Commission; and supporting the inclusion of specialty crop research programs in the farm bill reauthorization legislation passed by the Senate and in the farm bill reauthorization approved by the House Committee on Agriculture.

In addition to achieving these major goals, this three year project included efforts to address problems in how USDA administers certain programs, including the apple rootstock breeding program and the NASS chemical use survey. This three year project also included efforts to assist the industry in addressing problems relative to the use and treatment of science in environmental and trade matters affecting the state tree fruit producers.

The three year project clearly demonstrated the importance of involvement with public policy individuals and agencies responsible for decisions affecting the Federal role in agricultural research priorities and funding. It was evident during the course of the project that economic and political changes outside of our control are determinants in directing the course of Federal agricultural research and agriculture policy affecting the ability of growers to make informed decisions and remain competitive in the market place.

Because economic and political conditions are essentially in flux and will inevitably change, it is reasonable to conclude from this project (and similar projects that preceded it), this industry will continue to need an informational gathering system and the ability to work together with our industry partners in formulating strategies to approach and participate in the system in such a way as to increase the likelihood of success.

In summary, this is the approach and attitude that the Commission has endorsed and remained committed to since we led the efforts to develop the National Technology Roadmap. My recommendation is that we stay the course and continue with this process and attitude. It has served us well, and I see no reason to change course.

NEW PROJECT PROPOSAL **PROPOSED DURATION**: 3 years

Project Title: Technology roadmap implementation

PI: James Nicholas Ashmore
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: Suite 363
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Cooperators: NONE

Total Project Request: $108,000
Year 1:$36,000 **Year 2:** $36,000 **Year 3:** $36,000

Percentage time per crop: Across Crops
(Efforts focused on policy, programs and procedures, and precedents for all crops)

Other funding sources: None

WTFRC Collaborative expenses: None

Budget
Organization Name: J. N. Ashmore & Associates **Contract Administrator:** James N. Ashmore
Telephone:(202) 783 6511 **Email address:** nickashmore@cox.net

Item	2013	2014	2015
Salaries	$36,000	$36,000	$36,000
Benefits			
Wages			
Benefits			
Equipment			
Supplies			
Travel			
Miscellaneous			
Plot Fees			
Total	**$36,000**	$36,000	$36,000

Justification:

The realities of the current situation as described in the following bullet points establish the need for the new project/proposal:

- Agricultural research is necessary for the Washington tree fruit industry to remain competitive in the domestic and world market;
- The Washington tree fruit industry has been and remains committed to seeking with its specialty crops partners a strong, multi-disciplined, multi-crop competitive research program on the Federal level;
- This commitment requires continued vigilance in gathering the information necessary to work with our partners and with other agricultural groups so that a consensus approach can be developed that is responsive to changing economic and political realities that will meet the needs and desires of the Washington state growers;
- We have come a long way since leading the effort to develop the National Technology Roadmap for the Tree Fruit Industry and are arguably in the best shape that we have ever been in terms of having a broad-base of support in the Congress and in the Administration for specialty crop research programs established in the 2008 general farm statute;
- While the Senate has passed and the House Committee on Agriculture has approved a reauthorization of the 2008 general farm act that contains language continuing specialty crop programs, it is not at all clear that this Congress will be able to complete action on the farm bill reauthorization when it reconvenes for a Lame Duck session after the November election;
- If the Congress is able to act, it will then mean that we will have to move into implementation of the new statute; if the Congress is unable to complete the reauthorization process prior to adjournment, then we will have to start the process over with a new political makeup and we will have to work from a new baseline and a new funding allocation;
- We are, essentially, at a crossroads, and it is important to continue the commitment to the change the research culture at USDA and move further in support of competitive-based research grants that emphasize a multi-disciplinary, multi-crop approach to specialty crop research funding.

Given the facts outlined in the above bullet points, this new proposal/project is designed to achieve a number of significant and substantial benefits to the Washington State tree fruit industry, including but not limited to the following

- Strengthening the cooperative relationship with the Northwest Horticultural Council, U. S. Apple Association, and other specialty crops agricultural groups affected by public policy decisions relative to agricultural research on the Federal level; a major point of emphasis here will be to insure that agricultural research priorities are consistent with an overall industry approach that makes sense to the Congress and to the Administration;
- Strengthening the cooperative relationship with U. S. Department of Agriculture's research agencies and also with other Federal departments/agencies whose research and use of science affect growers in the State of Washington;
- Strengthening the channels of communication with House and Senate committees of jurisdiction and with the House and Senate offices of the Washington Delegation to insure full and transparent sharing of information pertinent to issues and concerns of the Washington State tree fruit industry;
- Securing the progress that has been made in implementing the National Technology Roadmap for the Tree Fruit Industry and enhancing that effort through implementation of the Specialty Crops Research programs established by the general farm bill;

- Supporting the extension of these Specialty Crops Research programs in any reauthorization of general farm legislation considered by the Congress; and,
- Securing continuation and funding of research programs identified and supported by the Washington tree fruit industry and seeking funding for new initiatives identified and supported by the Washington state industry.

Objectives:

The outcomes identified in the above Justification section will be realized by completing the following tasks:

1. Establish and maintain contacts necessary to have a meaningful cooperative relationship with the previously identified groups, agencies, and offices and establish that relationship based on transparency and a mutual commitment to sound science awarded on a competitive basis that will produce meaningful results that benefit a wide range of interest groups;
2. Gather and evaluate information pertinent to issues of interest/concern to the industry, evaluate that data, and work with the Commission Manager and others to develop strategies that will lead to a consensus approach that meets the needs of the Washington State producers;
3. Insure that position documents are developed carefully,, formatted properly, and submitted to staff and Administration officials in a timely fashion;
4. Where possible, work with Commission Manager and with partners like Northwest Horticultural Council and U. S. Apple to insure direct constituent contacts and, where necessary and appropriate, be prepared to represent and follow up offices and Administration agencies; and,
5. Insure sufficient flexibility to allow such other action as may be necessary and appropriate to support the interests of the tree fruit producers of the State of Washington.

Methods:

To meet the goals and objectives set forth above, it will be essential that we demonstrate the following characteristics:

- Patience based on an understanding that changing culture takes time, that we are moving in the right direction;
- Cooperation based on an understanding that we are stronger as a group, that working together has given specialty crops a “seat at the table” in determining national agricultural policy;
- Recognition based on an understanding that our problems are not unique, that in fact there are common problems that face us and our specialty crop partners;
- Openness based on an understanding that this is necessary for sharing of information and that without full sharing, it is arguably difficult if not impossible to reach a decision based on sound science and verifiable facts;
- Transparency based on an understanding that we are building and strengthening a reputation as a trustworthy and dependable party to the process of moving forward to address our common interest;
- Flexibility based on an understanding that there usually are a number of different ways to achieve an identified objective;
- Continued willingness to work within the process and prove that we are in fact on the right track with respect to changing the research culture and embracing a competitive approach to research awards, and,

- Appreciation based on an understanding that it is extraordinarily important to recognize and thank our partners and our Delegation for their help and their continued support in moving forward.

We have built an outstanding reputation and are in a good position going forward. Our leaders are recognized and consulted and are themselves appreciated for their work. We have open channels of communication. It is essential all of this be maintained.

Having said all of this, because of circumstances beyond our control primarily fights over efforts to reduce the Federal deficit and control spending), we must remain vigilant and we must continue to be prepared to work together to move forward towards our goals.

It has been a distinct privilege for me to work with the Commission and with its Manager and with our industry partners. I look forward to continuing to move forward with you as we seek to secure and expand on the progress that we have made to date.

FINAL PROJECT REPORT

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

PI:	Karina Gallardo	**Co-PI (2):**	Suzette Galinato
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City:	Wenatchee	**City:**	Pullman
State/Zip:	WA 98801	**State/Zip**:	WA 99164-6210

Cooperators: Tom Auvil (Washington Tree Fruit Research Commission, Wenatchee, WA)

Percentage time per crop: Apple: 100%

Other funding sources: None

Total Project Funding: $6,727

Budget History:

Item	**Year 1: 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] Included food and beverages to be served during the meeting. [3] Included researchers' travel to attend the focus group meeting and to conduct additional meetings with growers for validation of data.

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.*

SIGNIFICANT FINDINGS

Objective 1: *Develop an up-to-date enterprise budget for Red Delicious apples that will reflect current modern practices.*

The last enterprise budget on Red Delicious was published by Washington State University in 1992. We updated the study to provide an estimate of the costs of producing Red Delicious in Washington State given current practices and market prices.

We organized focus group meetings with four Red Delicious growers (two in the Wenatchee/Basin area and two in the Yakima area) in March 2012. During the meetings, we established baseline assumptions on production that served as a guide in identifying the production cost categories and in estimating the associated costs, and gathered preliminary data. We also consulted two more Red Delicious growers (one in Yakima and another in Wenatchee/Basin) as well as other industry representatives (e.g., Washington Growers Clearing House Association managers, Yakima Valley Growers and Shippers Association, WSU tree fruit extension specialists) to help us validate the gathered data and define the most representative cost estimates for the state of Washington.

The final enterprise budget shows a positive net return estimate during full production, based on the assumed production specifications and costs. More details and data underlying the cost estimation are discussed in the following section.

Objective 2: *Disseminate the updated information with growers, other stakeholders in the tree fruit industry and researchers.*

The manuscript and supplementary spreadsheets of the enterprise budget were submitted to the Washington State University Extension for publication as a WSU Extension Fact Sheet. The fact sheet underwent external peer review and has been accepted for publication. It is currently in the editorial stage of review. The study will be published online and available for download from the WSU School of Economic Sciences – Extension Economics website: http://extecon.wsu.edu/pages/Enterprise_Budgets, in both PDF and Excel® formats.

RESULTS & DISCUSSION

The assumed production specifications for a 25-acre Red Delicious block within a 300-acre diverse-cultivar orchard are presented in Table 1. Based on these specifications and growers' input, we estimated the costs associated with major activities in the production of Red Delicious apples. A detailed accounting of costs and net returns are presented in Table 2. Note that the yields reported (during Year 3 to Full Production) take into consideration an 85% pack-out. The price per bin refers to FOB price, which means no warehouse charge deduction.

Soil preparation and investment on trees comprised most of the total production costs during Year 1. The cost of orchard activities increase yearly as more labor hours on pruning, training and green fruit thinning and additional chemical application are required as trees start to mature and bear fruit.

Harvest activities begin in Year 3 through Full Production and the associated costs range between 5% and 8% of total production costs during the said period. The categories of maintenance and repairs, and other variable costs do not significantly vary every year beginning Year 3 (2-3% and 7-8% respectively). Warehouse packing charges comprise an increasing and significant portion of the total production costs — 34% in Year 3, 46% in Year 4, 53% in Year 5 and 58% during Full Production. The estimated total packing charge is $185/bin given a pack-out of 85% and considering 850 pounds per bin and 40 pounds per box of apples (Table 3).

The study assumed that a Red Delicious orchard could achieve full production in the 6th year. Total production costs for Red Delicious during full production are estimated at $22,102 per acre. Given a net yield of 59.5 bins per acre during full production and a price received of $400/bin, the estimated net return is about $1,698 per acre. A positive net return implies that a grower is able to cover all cash and opportunity costs, including returns on management and financial risk. Results thus indicate that Red Delicious production in Washington, under the planting assumptions cited in this study, is economically sustainable in the long run under current production conditions and assuming no catastrophic unexpected events.

Potential net returns are sensitive to different combinations of crop yield and Table 4 shows the sensitivity of net returns to different price and yield scenarios. Different combinations of price and yield levels suggest that when both levels are high (e.g., price at $400/bin and net yields from 50 to 90 bins/acre), positive returns are likely.

Table 1. Red Delicious Block Specifications.

Architecture	Three dimensional system (planar canopy), randomly trained with 24" radius from tree center.
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 per acre

Table 2. Cost and Returns per Acre of Establishing, Producing and Packing Red Delicious on a 25-Acre Orchard Block.

	Establishment Years					Full Production[1]
	Year 1	Year 2	Year 3	Year 4	Year 5	
Estimated Net Production (bins/acre)[2]			12.75	25.50	42.50	59.50
Estimated FOB Price ($/bin)[3]			400.00	400.00	400.00	400.00
Total Returns ($/acre)			5,100.00	10,200.00	17,000.00	23,800.00
Variable Costs ($/acre):						
Establishment						
Soil Preparation	376.50					
Trees (including labor)	6,163.20					
Orchard Activities						
Pruning & Training[4]	132.00	264.00	324.00	300.00	420.00	420.00
Green Fruit Thinning[4]			216.00	276.00	540.00	540.00
Irrigation Labor[5]	130.00	130.00	130.00	130.00	130.00	130.00
Chemicals[5],[6]	526.00	565.00	656.00	856.00	1,056.00	1,082.00
Fertilizer[5],[6]	150.00	150.00	190.00	151.00	101.00	101.00
Frost Protection (Labor)[5]				5.20	5.20	5.20
Beehives			45.00	45.00	45.00	45.00
General Farm Labor[7]	125.00	125.00	300.00	300.00	300.00	300.00
Irrigation/Electric Charge	137.50	137.50	187.50	187.50	187.50	187.50
Harvest Activities[8]						
Picking Labor			240.00	480.00	800.00	1,120.00
Other Labor (checkers, tractor drivers)			45.00	90.00	150.00	210.00
Hauling Apples			75.00	150.00	250.00	350.00
Warehouse Packing Charges[9]			2,756.09	5,512.17	9,186.96	12,861.74
Maintenance and Repairs						
Machinery Repair	125.00	125.00	125.00	125.00	125.00	125.00
Fuel & Lube	85.00	95.00	125.00	180.00	180.00	180.00
Wind Machine & Alarm System Repair					24.00	48.00
Mainline, Pump & Pond Maintenance						8.93
Other Variable Costs						
Overhead (5% of VC)	397.51	79.58	270.73	439.39	675.03	885.72
Interest (5% of VC) [10]	417.39	83.55	284.27	461.36	708.78	697.50
Total Variable Costs	8,765.10	1,754.63	5,969.58	9,688.63	14,884.47	19,297.59
Fixed Costs ($/acre):						
Depreciation						
Irrigation System	64.95	64.95	64.95	64.95	64.95	64.95
Mainline & Pump	16.67	16.67	16.67	16.67	16.67	16.67
Pond	10.00	10.00	10.00	10.00	10.00	10.00
Trellis	48.70	48.70	48.70	48.70	48.70	48.70
Wind Machine				72.25	72.25	72.25
Machinery & Building Annual Replacement Cost	100.00	100.00	100.00	100.00	100.00	100.00
Interest						
Irrigation System	59.54	59.54	59.54	59.54	59.54	59.54
Land	400.00	400.00	400.00	400.00	400.00	400.00
Machinery & Buildings	55.41	55.41	55.41	55.41	55.41	55.41
Mainline & Pump	12.50	12.50	12.50	12.50	12.50	12.50
Pond	7.50	7.50	7.50	7.50	7.50	7.50
Trellis	36.53	36.53	36.53	36.53	36.53	36.53
Wind Machine				66.23	66.23	66.23
Establishment Costs (5%)		503.51	681.68	826.50	916.44	
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[11]						1,320.66
Total Fixed Costs	1,305.18	1,808.69	2,026.85	2,310.15	2,400.09	2,804.32
TOTAL COSTS	10,070.27	3,563.32	7,996.44	11,998.78	17,284.57	22,101.91
ESTIMATED NET RETURNS	(10,070.27)	(3,563.32)	(2,896.44)	(1,798.78)	(284.57)	1,698.09
Accumulated Establishment Costs	10,070.27	13,633.59	16,530.02	18,328.81	18,613.38	

Table 2 footnotes:
[1] The full production year is representative of all the remaining years the orchard is in full production (Year 6 to Year 30).
[2] Estimated net production considers an average packout of 85%.
[3] These prices reflect gross FOB prices (no warehouse charges deduction).
[4] Hand labor rate is $12/hour and includes all applicable taxes and benefits.
[5] Tractor/machinery, irrigation and frost protection labor rate is $13/hour and includes all applicable taxes and benefits. Rate includes all applicable taxes and benefits.
[6] Includes materials and labor.
[7] General farm labor rate is a lump sum per acre and applied to miscellaneous/all other labor. Rate includes applicable taxes and benefits.
[8] Picking rate = $16/bin; Checkers & tractor drivers rate = $3/bin; Hauling rate = $5/bin.
[9] Charges per bin consider receiving charges per bin plus charges per box. To estimate the charges per box we considered an 85% packout.
[10] Interest expense on full year during establishment years and for 3/4 of a year during full production.
[11] Represents the costs incurred during the establishment years (minus revenues during those years) that must be recaptured during the full production years.

Table 3. Estimated Warehouse Packing Charges

Packing Charges	Cost per unit
Charges per bin	
Receiving Charge	$77.50
Total	*$77.50*
Charges per box	
Industry Charge	$0.33
Marketing Charge	$0.88
General Packing Charge	$4.68
Total	*$5.88*
Total Packing Charges Per Bin*	**$183.74**

*Charges per bin consider receiving charges per bin plus charges per box. To estimate the charges per box we considered an 85% packout. It is assumed further that there are 850 pounds per bin, and 40 pounds per box of apples.

Table 4. Estimated Net Returns ($) per Acre at Various Prices and Yields of Red Delicious during Full Production[1]

Net Yield (bins/acre)[2]	FOB Price ($/bin)[3]				
	250	300	350	400	450
40	(6,910.19)	(4,910.19)	(2,910.19)	(910.19)	1,089.81
50	(7,072.61)	(4,572.61)	(2,072.61)	427.39	2,927.39
60	(7,235.03)	(4,235.03)	(1,235.03)	1,764.97	4,764.97
70	(7,397.45)	(3,897.45)	(397.45)	3,102.55	6,602.55
80	(7,559.87)	(3,559.87)	440.13	4,440.13	8,440.13
90	(7,722.29)	(3,222.29)	1,277.71	5,777.71	10,277.71

Notes:
Shaded area denotes a positive profit based on the combination of yield and price.
[1] Includes amortized establishment costs.
[2] Assumes an 850-pound bin. Takes into account an average packout of 85%.
[3] Price represents gross FOB price (no warehouse charges deduction).

EXECUTIVE SUMMARY

In this study, we estimated the costs on establishing, producing and packing Red Delicious apples in Washington. We collaborated with experienced and knowledgeable growers of Red Delicious apples in defining the baseline assumptions on production and in estimating the production costs. Results show an estimated total production cost for Red Delicious of $22,102 per acre, and net return of $1,698 per acre during full production. These amounts were estimated under production specifications assumed for the study (density of 900 trees per acre, M106 rootstock, 25-acre block), net yield during full production at 59.5 bins per acre (considering 85% packout), FOB price of $400 per bin, and given packinghouse charges.

The positive net return implies that a grower of Red Delicious apples is able to cover all cash and opportunity costs in producing this apple variety, including returns on management and financial risk. Therefore, under the planting assumptions, current production conditions and no catastrophic unexpected events, it is economically sustainable in the long run to produce Red Delicious apples in Washington.

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

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

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Total Project Request: **Year 1:** $35,165 **Year 2:** $34,584 **Year 3: N/A**

Percentage time per crop: Apple: 35% Pear: 10% Cherry: 35% Stone Fruit: 20%

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. 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. awarded: $44,522 (2011); $ 46303 (to February 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	additional year
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	**N/A**

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

- Frequent occurrence of multiple viruses in a single fruit tree was documented
    - Next Generation Sequencing (NGS) effectively resolved complex mixtures of viruses in tissue samples, including multiple strains of the same virus in a single sample.
    - Accurate interpretation of Universal Plant Virus Microarray (UPVM) data from samples with multiple infections was limited.
- NGS can identify virus sequences in samples without any prior knowledge of viruses that may be present, and can reveal previously uncharacterized viruses.
- Both UPVM and NGS technologies require careful interpretation of raw data, particularly if previously uncharacterized pathogens are present.

METHODS

Our previous results had indicated that Next Generation Sequencing (NGS) of plant samples offered superior resolution of the virus content of infected fruit trees relative to that achieved using microarray technology. For this reason, the number of samples subjected to NGS was expanded to further assess the utility of this technology. Additional samples included trees affected by known pathogens or diseases, as well as samples obtained from trees in grower blocks that exhibited declining production. RNA was extracted from leaves of each tree sample, and a “bar-coded” cDNA library prepared from the RNA in the laboratory at WSU. “Bar-coding” allows multiple samples to be analyzed on a single lane of the sequencing instrument and hence, significantly reduces the cost per sample. Our results from the first year of this study indicating that this bar-coding was reliable and did not diminish the accuracy of sequence analysis. The prepared samples are submitted to one of several outside service laboratories to perform the sequencing. Raw data captured from the sequencer were analyzed at WSU.

Whereas NGS directly produces the genetic code of the constituents in the sample, microarray analysis yields a pattern of fluorescent signals that must be compared to a stored library of known standards for identification. Specific computer software is required to interpret the patterns produced by dozens of fluorescent dots on the microarray and correlate that pattern to a specific virus or group of viruses. A new release of the analytical software in 2012 would improve the ability of the analytical programs to resolve patterns created by multiple infections. To re-evaluate the UPVM, 66 samples are being prepared for analysis. After sample processing, the results will be analyzed by the new release of the T-predict software.

RESULTS & DISCUSSION

This investigation is comparing two emerging technologies with existing methods for the detection and identification of viruses. Proper virus identification is crucial for proper disease management in growers blocks. Although there are few alternatives available once an otherwise productive tree has become infected with virus, correct identification of the pathogen will allow growers to make economically sound decisions about tree removal and replanting, and about measures that can be taken to minimize further spread of the virus to adjacent plantings.

Next generation sequencing (NGS) is a procedure that allows researchers to look at the entire genetic composition of a plant sample, including any viruses or microorganisms that might be associated with the tissue. Since NGS looks at all genetic information in the sample simultaneously and indiscriminately, prior knowledge of specific disease agents present is not required. This is the underlying power of the technology. The ability of NGS to correctly identify pathogens in fruit tree tissue was evaluated by comparing results with those obtained by virus-specific reverse transcription polymerase chain reaction (RT-PCR) (Table 1).

A significant backlog of samples at the sequencing facility has delayed obtaining some key results. Labeled cDNA libraries have been prepared for ten samples and submitted to the facility, but results are still pending. However, for the nine samples for which data is available, the results indicate that NGS is very effective in detecting all pathogens in tissue samples. With two exceptions, the correlation between the results obtained from a single NGS reaction were consistent with those detected by multiple virus-specific RT-PCR assays. In the case of apple samples 1 and 2, the NGS revealed 6 and 2 small fragments, respectively, of sequence that were very similar to the sequence of Apple latent virus. This virus is very closely related to Apple stem pitting virus. We were unable to verify the presence of Apple latent virus by other means in the samples. It is believed that the identification of Apple latent virus arises from short segments of sequence that these two related viruses share in common.

NGS has been effective in confirming the association between diseases and particular viruses. For example, cherry samples #5 and #6 were from trees expressing cherry rusty mottle disease. Conventional cloning and sequencing strategies had suggested that a member of the family *Betaflexiviridae* was the causal agent of the disease; the virus is referred to a cherry rusty mottle associated virus (CRMaV) in this study. Tests for previously identified viruses indicated that this was the only virus that was uniquely associated with the symptoms. However, because of the frequent occurrence of multiple infections within a single cherry tree, the potential for the presence of yet another previously unknown virus could not be eliminated. Since NGS does not require prior knowledge of the existence of a pathogen, it was applied in this case to demonstrate that indeed there were no previously uncharacterized viruses, and the virus associated with disease expression was CRMaV. This is pivotal data in defining the causal agent of this disease that frequently reduces the profitability of cherry production in Washington State.

In addition to the samples listed above, 24 additional samples representing apples, cherries, nectarines and plums have been submitted for NGS at a separate facility (Table 2). RT-PCR analysis of these samples was also performed. These samples are representative of fruit trees being brought to the Clean Plant Center – Northwest at Washington State University for virus testing and virus elimination. Again there is good correlation between multiple virus-specific RT-PCR assays and NGS results. The group specific TriFoCap RT-PCR assay was effective in detecting a wide array of viruses, however the precise identification of the virus cannot be determined directly from this assay. NGS offers more specific virus identification.

It is particularly important to note that NGS of several of the samples revealed virus sequences that are not consistent with known viruses, and thus suggest the revelation of new virus species. In some instances, this is indicated by the term "-like" where sequence identity suggests a close relationship to a known virus, but there is enough sequence diversity to suggest that it may be a distinct but closely related virus species. This is illustrated by a CVA-like virus sequence detected in samples 25, and 29, and an APLPV-like sequence detected in sample 26. In addition to significant sequence diversity, all three samples would constitute a new host for the respective virus. A Citrus leaf blotch virus-like sequence was revealed in samples 23 and 29, both from Israel. *Prunus* and *Malus* are not known to be hosts for Citrus leaf blotch virus and this sequence variant likely represents a new virus species that infects temperate climate fruit trees. Again, the combination of divergent sequences and different host plants would suggest that these viral sequences represent novel virus species. A previously uncharacterized Marafivirus was detected in samples 35 (from U.S.A.) and 36 (from Spain). At this time, there is no information regarding the association of these viruses with disease symptoms, or their ability to spread. This illustrates the power of NGS to reveal the presence of virus sequences with no prior knowledge of the pathogens present at the initiation of the test. Because these viruses are previously undescribed, no virus-specific assay system exists that will detect them. Further research is needed to fully characterize these apparently novel viruses and to determine their potential to impact fruit production.

One of the limitations observed in the preliminary assessment of the Universal Plant Virus Microarray (UPVM) was the ability of the software to appropriately resolve the signals when several viruses were present in a single sample. As seen by the results of the RT-PCR and NGS analysis (Table 1), it is common for fruit trees to be infected by multiple viruses. However, it was proposed that the new version of the T-predict software would address the resolution of mixed virus infections more accurately and reliably. To that end, a scientist from the Dr. Claude Fauquet group at the Danforth Plant Science Center is in our laboratory for two weeks preparing additional samples for analysis by the UPVM. RNA is extracted from sixty fruit trees samples. The products will be analyzed at the Danforth Center using the UPVM and the new version of the T-predict software. Results will be compared to RT-PCR results of specific viruses. The samples originate from 22 cherry, 20 apple, 6 plum, 5 peach, 4 pear, 2 apricot and 1 quince trees. Included in these samples are trees affected by diseases with unknown etiology. Among the diseases included are apple rubbery wood, apple green crinkle, Stayman blotch, green newton, apple rough skin and Bisbee internal bark necrosis. All of these diseases are graft transmissible suggesting a virus may be a causal agent. A selection of these samples will be submitted for NGS sequencing to provide a full comparison of the technologies.

The power of these newer technologies continues to be demonstrated in their ability to detect viruses. Increased capabilities associated with them will greatly influence the fruit tree industry. Agents responsible for declining production in many grower blocks could be identified more effectively than is currently possible. The application of these tools will also improve the efficiency of the plant quarantine and certification programs while increasing the availability to growers of new fruit tree selections in an accelerated process.

Table 1. Comparison of reverse transcription polymerase chain reaction (RT-PCR) assay and Next Generation Sequencing (NGS) (50bp single end Illumina deep sequencing).

Sample description	**Analysis by RT-PCR**	**Analysis by NGS**	
Host (disease)	Viruses detected[3]	# of reads	Viruses detected[3]
1.Apple[1] (green crinkle)	ASPV	7,469,983	ASPV, <u>ApLV</u>
2. Apple[1] (green crinkle)	ASPV, ASGV	8,097,306	ASPV, ASGV, <u>ApLV</u>
3. Apple[1] (non-symptomatic)	ASGV	7,722,042	ASGV
4. Apple[1] (green crinkle)	ASPV+ASGV	8,097,306	ASPV, ACLSV, ASGV
5. Cherry[2] (rusty mottle)	CRMaV, CVA, PDV, PNRSV	18,658,856	CRMaV, CVA, PDV, PNRSV
6. Cherry[2] (rusty mottle)	CRMaV, CVA	16,567,098	CRMaV, CVA
7. Cherry[2] (twisted leaf)	CTLaV, CGRMV, ACLSV, CMLV	18,202,096	CTLaV, CGRMV, ACLSV, CMLV
8. Cherry[2] (twisted leaf)	CTLaV, CGRMV, CVA, LChV-2, PDV, PNRSV	18,818,955	CTLaV, CGRMV, CVA, LChV-2, PDV, PNRSV
9. Cherry[2] (apricot ringpox)	CNRMV, CGRMV	18,662,069	CTLaV, CGRMV
10. Cherry[2] (Grower Acc 8865)	CVA	pending	pending
11. Cherry[2] (Grower Acc 8863)	CGRMV, PDV	pending	pending
12. Cherry[2] (Grower Acc 8816)	Unknown foveavirus	pending	pending
13. *P. lusitanica*[2] (Grower Acc 8804)	CRMaV	pending	pending
14. Cherry[2] (Grower Acc 01E2R2)	CGRMV, PDV, PNRSV, CVA	pending	pending
15. Apple[2] (green crinkle)	ASGV, ASPV, ACLSV	pending	pending
16. Apple[2] (green crinkle)	ASGV, ASPV	pending	pending
17. Apple[2] (green crinkle)	ApMV (by ELISA)	pending	pending
18. Apple[2] (apple decline)	nt	pending	pending
19. Nectarine[2] (unknown)	nt	pending	pending

1. Sequence analysis was performed with double stranded RNA isolated from sample tissues.
2. Sequence analysis was performed with total RNA extracted from sample tissues.
3. ACLSV=Apple chlorotic leafspot virus; ApLV=Apple latent virus; ApMV=Apple mosaic virus; ASGV=Apple stem grooving virus; ASPV=Apple stem pitting virus; CGRMV=Cherry green ring mottle virus; CRMaV=Cherry rusty mottle associated virus; CTLaV=Cherry twisted leaf associated virus; CVA=Cherry virus A; LChV-2=Little cherry virus 2; PDV=Prune dwarf virus; PNRSV=*Prunus* necrotic ringspot virus, nt=not tested

Table 2. Comparison of reverse transcription polymerase chain reaction (RT-PCR) assay and Next Generation Sequencing (NGS) (100bp double end Illumina deep sequencing, minimum 18 million reads per sample).

Sample description	**Pathogen/RT-PCR result[1]**	**Analysis by NGC[1]**
20. Apple	ApMV	ASPV (20+ strains), ACLSV, ASGV, ApMV
21. Plum	PLMVd	CVA like, CRLV, PLMVd
22. Apple	ASSVd	ACLSV, CVA, CRLV, PLMVd, APLPV-like, ASSVd
23. Apricot (Israel)	CVA, PBNSPaV, TriFoCap	APLPV, PBNSPaV, CVA, ASPV, Citrus leaf blotch virus-like
24. Apple (rubbery wood disease)		ASPV (20+ strains), ACLSV, ASGV
25. Apple (flat apple)	CRLV	CRLV, ACLSV, ASPV, CVA-like
26. Apple (New Zealand)	TriFoCap[2]	APLPV-like
27. Apple (Brazil)	TriFoCap	ASGV, ASPV, ACLSV, CVA, CRLV
28. Pear (New Zealand)	TriFoCap	ASPV (strains), PDV, CRLV, APLPV, CVA
29. Apple (Israel)	TriFoCap	ASPV, ACLSV, ASGV, CRLV, APLPV, CVA-like, Citrus leaf blotch virus-like
30. Cherry (Post Entry)	TriFoCap	CVA, PDV
31. Cherry	PDV	PDV, CVA
32. Peach	nt	PLMVd
33. Almond (Spain)	none detected	none detected
34. Apple (France)	TriFoCap	ASPV,ACLSV, ASGV, ApMV
35. Nectarine	none detected	unknown Marafivirus
36. Peach (Spain)	TriFoCap, PLMVd	ACLSV, PLMVd, unknown Marafivirus
37. Peach (Australia)	PLMVd	ASPV, PLMVd
38. Nectarine (South Africa)	nt	ASPV
39. Apricot (Australia)	none detected	none detected
40. Pear (France)	TriFoCap	ASPV (several strains)
41. Pear (Spain)	none detected	ASPV
42. Apricot (Israel)	none detected	none detected
43. Apple (Italy)	nt	none detected

1. ACLSV=Apple chlorotic leafspot virus; APLPV=American plum line pattern virus; ApMV=Apple mosaic virus; ASGV=Apple stem grooving virus; ASPV=Apple stem pitting virus; ASSVd=Apple scar skin viroid; CGRMV=Cherry green ring mottle virus; CRLV=Cherry raspleaf virus; CRMaV=Cherry rusty mottle associated virus; CTLaV=Cherry twisted leaf associated virus; CVA=Cherry virus A; LChV-2=Little cherry virus 2; PBNSPaV=Plum bark necrosis and stem pitting associated virus; PDV=Prune dwarf virus; PLMVd=Peach latent mosaic viroid; PNRSV=Prunus necrotic ringspot virus; nt=not tested.
2. TriFoCap = a group specific assay designed to detect members of the virus genera Trichovirus, Foveavirus and Capillovirus.

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

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

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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

Unruh contacted WTFRC to request a no-cost extension on this project. The project will not be requesting additional funding for second year.

No report was submitted. We will follow-up to request a final report and send via email to all committee members.

CONTINUING PROJECT REPORT **YEAR**: 2 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

Percentage time per crop: Apple: 100%
Other funding sources: None

Budget 1
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	1,000	1,000
Travel[4]	517	552
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.

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

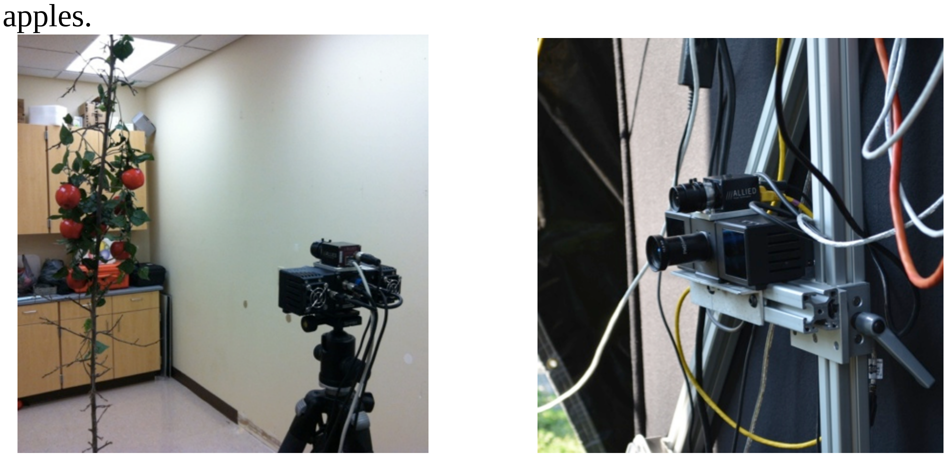
- Visibility of apples increased substantially when images were taken from two sides of a row of apple trees, which shows promise for improved crop-load estimation.
- Mapping algorithm developed in laboratory settings has shown promise for co-registering 3D images to avoid repeated counting of apples.
- Over-the-row sensor platform with a tunnel structure minimized variability in lighting condition and background, which will help improve image processing techniques.

METHODS

In the past, the performance of apple crop-load estimation techniques have been adversely affected by occlusion due to branches, leaves and other fruits leading to a substantial underestimation of crop load. 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, the platform, and algorithms we have been developing to capture images and analyze them for improved crop-load estimation.

Sensors and Calibration:

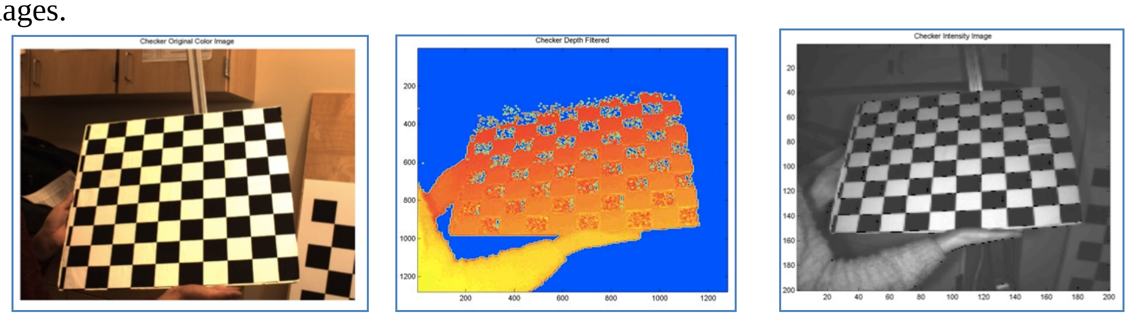
The sensor system used consisted of a color camera and a 3D camera (Fig. 1). A Prosilica camera (GigE 1290c, Allied Vision Technologies, Stadtroda, Germany) was used to capture color images of apple trees with fruits. A PMD camera (CamCube 3.0, PMD Technologies, Siegen, Germany) was used to take 3D images. 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) b)

Fig. 1: Sensors used for image acquisition in laboratory setup (a) and in field tests (b). Prosilica GigE 1290c color camera is on the top of the camera mount and PMD CamCube 3D camera is on the bottom.

Checkerboard-based 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 for 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.



a) b) c)

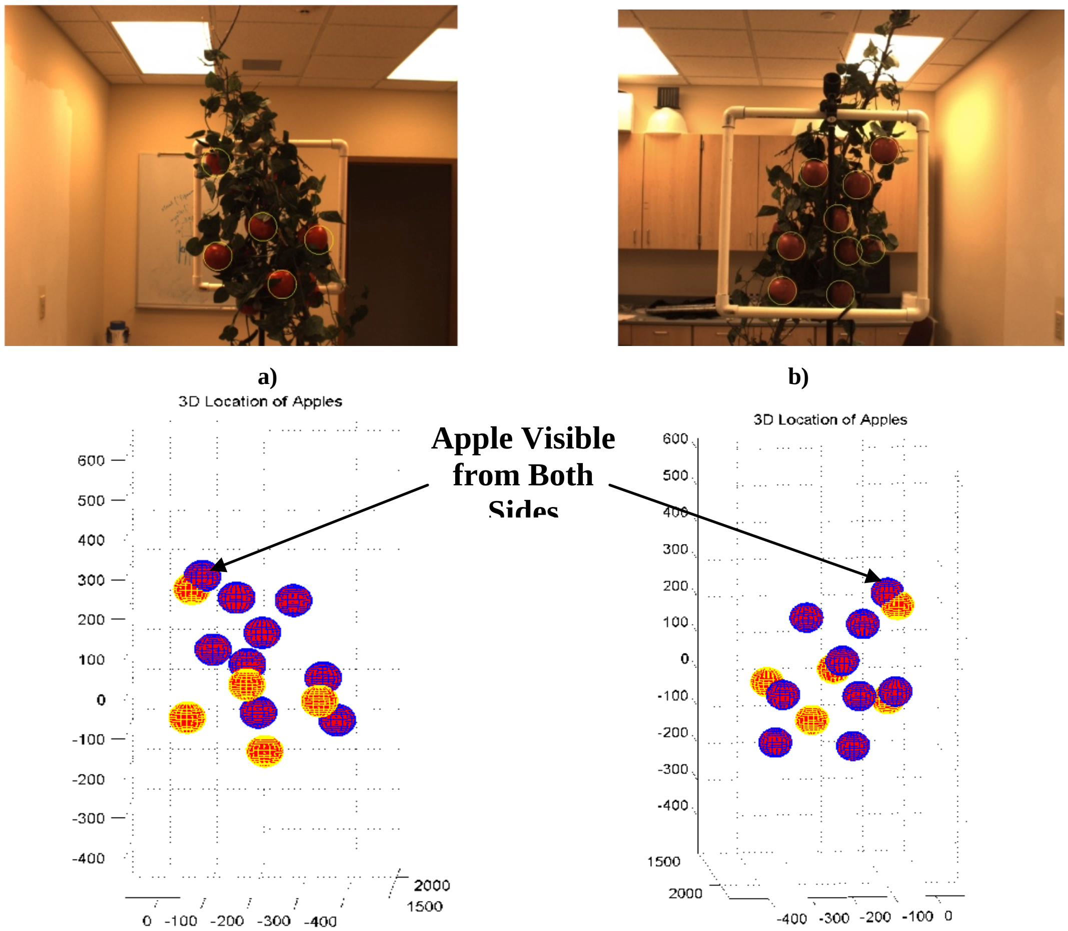
Fig. 2: Checker board based camera calibration a) Original color image of checker board, b) Checker depth image, and c) Checker intensity image

3D Mapping Algorithm Development

Images captured from two sides of a row in 2011 and 2012 harvest seasons have shown substantially increased visibility (Fig. 3). However, it is also evident that some apples are visible from both sides and thus requiring 3D mapping of apples to avoid repeated counting.

Fig.3: Apples visible from both sides (orange) and from only one side (yellow)

An algorithm was developed using a laboratory set-up to register images captured from two sides. Color and 3D images were captured of a model of an apple tree (a real, dead tree with fake leaves and fruits in it; Fig. 4a). The 3D coordinates of objects in the field of view were transformed from the 3D camera coordinate to project the imaging plane of the color camera so as to obtain a depth-mapped color image. Each pixel in this depth-mapped color image included color information with the corresponding 3D location information. Center of apples visible from each side of the canopy were located as shown in Fig. 4a and 4b. 3D locations of four corners of the reference frame (GI pipe square in Fig. 4a,b) 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 was transformed to the coordinates in the other side. Fig. 4(c) show 3D locations of apples viewed corresponding to Fig. 4a (yellow) and Fig. 4b (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.



a) b)

c)

Fig. 4: a) and b) Color images from front and back side of the tree; c) 3D-mapped apples of corresponding color images in (4a) as yellow and (4b) as blue (all axes in millimeters).

Platform Modification and Data Collection:

Field data was collected in 2011 harvest season with first prototype of over-the-row sensor platform. An improved sensor platform was designed and fabricated this year (Fig. 5) based on last year's experience. The new platform was lighter and more robust than the earlier platform. A fixed platform width was used in the new design to reduce unnecessary degrees of freedom. The platform provided sliding mechanism for convenient mounting and positioning of cameras in the platform. The images acquired during day-time in 2011 harvest season were affected by variation in lighting conditions such as presence of direct sunlight and shadows. To eliminate such variations in lighting condition, a tunnel structure was added to block direct sunlight in the tree canopies during imaging. Artificial lighting system was also integrated to provide controlled lighting environment while taking images. Artificial lighting system also added capability for night-time operation (Fig. 5 (b) and (c)). The first set of data with improved platform was collected in the week of Sep 24th with Jazz apples in Tall Spindle architecture (row spacing 9'0" and inter-plant spacing 3'10") in Prosser, WA (commercial orchards of Allan Bros., Inc.). This data collection will continue in the remainder of this harvest season. As we progress through this data collection, continual improvement in the platform will occur as necessary.

Fig. 5 New over-the-row platform taking images of Jazz apples in a commercial orchard of Allan Bros., Inc. in Prosser, WA during day-time (a) and night-time(b and c)

RESULTS AND DISCUSSIONS

The algorithm developed to co-register 3D and color images as well as 3D images from two side of a canopy was able to register images captured in the laboratory set up. Results from the laboratory tests field images showed that apple visibility can be enhanced from the dual sided images. Also, repeated counting of apples can be avoided by using distance between apples presented in a co-registered 3D map (Fig.6).

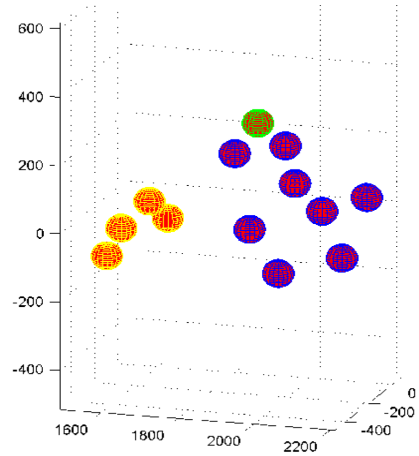


Figure 6: 3D mapped apples visible from front (yellow), back (blue) and both (green) sides (axes in millimeters).

The improved sensor platform increased the efficiency of data collection in the field. It was easier to move in the orchards since it was lighter and robust. New sliding mechanism improved camera mobility. Images could be taken from different heights to ensure proper overlapping between images to stitch images together for further processing. The use of tunnel helped to reduce variability in lighting condition. Images were taken in controlled lighting environment which will make image processing much easier. Images taken at night-time with LED lights had more controlled environment and has potential to be more effective in image processing.

The mapping algorithm developed in the laboratory over the spring has shown promise for the application to field data. However, because the student working in this project unexpectedly decided to leave, the plan for applying mapping algorithm to field data has been postponed from spring and summer 2012 to fall 2012 and spring 2013. A new student, Ms. Aleana Gongal, has joined our graduate research program starting this fall and she has already started working in this project. Once the data collection for this year is completed, mapping algorithm will be applied to the dataset collected in harvest seasons 2011 and 2012.

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

WTFRC Project Number: TR-12-103

Project Title: Design and development of apple harvesting techniques

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City/State/Zip: Prosser, WA 99350

Cooperators: None

Total Project Request: **Year 1:** $53,395

Percentage time per crop: Apple: 100%

Other funding sources: NONE

Budget 1
Organization Name: WSU **Contract Administrator:** Carrie Johnston
Telephone: 509.335.4564 **Email address:** carriej@wsu.edu

Item	2012		
Salaries[1]	$30,534		
Benefits[1]	$1,997		
Wages[2]	$6,240		
Benefits	$624		
Equipment			
Supplies[3]	$10,000		
Travel[4]	$4,000		
Plot Fees			
Miscellaneous			
Total	**$53,395**		

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 sensor platforms
[4] Travel cost for field data collection and testing

Objectives

Our long term goal is to improve the sustainability and productivity of tree fruit production through reduced labor use and associated costs. Originally, this project was proposed for three years with the following specific objectives.

1. Design and develop two prototypes for semi-automated apple harvesting techniques.
2. Characterize the efficiencies of harvesting in two variations of fruiting wall architectures.

However, the project was funded for only the first year to demonstrate the feasibility of the concept. The scope for the first year for the project involves prototype development and preliminary evaluation in lab and field environment. New pre-proposal will be submitted for the second phase of the project when the concept is successfully demonstrated during the first phase.

Significant Findings

- Rolling apples between tires can remove them from a spur.
- Vertical twisting with compressive pressure can remove apples from a limb.
- Damage can occur if the apple is rolled against the limb.
- A separation barrier can reduce limb punctures during rolling.

Methods

Two methods for apple removal are being investigated and evaluated based on fruit removal effectiveness and damage. The preliminary results have been used to modify and continually update the apple harvesting system design. The two methods focus on twisting apples in vertical and horizontal directions.

We are working on the first proof-of-concept prototype this fall. To construct this prototype, two six inch rubber tires, from a 1/8-scale radio-controlled truck, were mounted on two DrilMaster 18V, 3/8" drives, cordless hand drills as shown in **Error! Reference source not found.**. Initial tests, on Gala apples, show that twisting in a vertical direction has the potential to remove fruit from limbs. It was also observed that rolling an apple across a branch can cause damage to the apple. More specifically, uncontrolled rolling across a limb can puncture the fruit. Based on this observation, a separation barrier was fabricated to facilitate a controllable shoulder to roll the apple on. A simple wireframe structure separated the apples from the limbs (Figure 2).

Figure 2 First apple twisting prototype was built with rubber tires mounted on electric hand drills.

The two wheels are place on either side of an apple. Adequate pressure is applied so that the wheel does not slip on the apple skin. Both wheels should spin in the same direction, imposing a twisting motion about the stem. Speed, pressure, and positioning are variables that will be considered as the parameters to evaluate of this prototype.

Figure 2 Wireframe separation barrier that minimizes rolling of apples over limbs.

In efforts to reduce the number stem pulls, razor blades were mounted to the separation barrier to slice or cut the stem entirely. This concept deviates slightly from the initial proposal but collectively focuses on the overall objective of fruit removal. Tests will be continued throughout the 2012 apple harvest season. The prototype was tested on gala apples grown in a central leader fruiting wall architecture with moderate success. Jazz apples will be tested on during the first and second weeks of October with and without the separation barrier. Structural modifications will take place continuously during the 2012 harvest season. Additional adjustments in the structural design are expected throughout the remainder of the project.

Progress expected for the rest of the harvest season is to remove the individual hand drills and upgrade to the scissor structure, as shown in Figure 3. This design will take out the variability of third dimensional movement that commonly occurred during the initial tests. The third dimensional movement is the reactive movement of the operator's hand and drill during the test. The speed controls will be moved to a controller box closer to the operator's waist. Also, independent speed controllers (potentiometers) will replace the hand drill squeeze trigger.

Figure 3 Design of an intermediate step for Prototype 1 apple harvester to be tested in 2012 harvest season.

Rotational speed will be varied for the individual wheels in an effort to reduce the uncontrolled rolling onto branches and limbs. The hypothesis is that when different angular velocities of the wheels act upon the apple, the apple will in turn experience a downward force (assuming clockwise rotation). We expect that stem pulls will continue to be a challenge but we will investigate different ways to minimize them as we develop and evaluate improved prototypes.

Results and Discussion

These initial tests with the first apple harvesting prototype showed promise for the vertical twisting method. Figure 4 shows five Jazz apples that were harvested from a trellis using the current testing module shown in Figure 5 (right). Three of the apples removed had no stem and two apples retained their stem. One apple, shown in the middle, was removed with the spur. The third dimensional movement of the operator's hand, while holding the drill engaged on an apple, could attribute to the stem pulls. A more rigid structure, like that in Figure 3, will be implemented to reduce this extraneous source of variation.

Figure 4 Early Jazz apples showing 3 stem pulls, 1 "good" harvest, and 1 apple removed with spur.

The look ahead for the remainder of year 1 continues with the implementation of this harvesting prototype for trellised orchards (both formal and random training systems). Progress is being made towards realization of this concept. During the winter season, the focus will be on developing a multiple wheel structure, and the addition of the bioyield pressure applicator (Fig. 5, left).

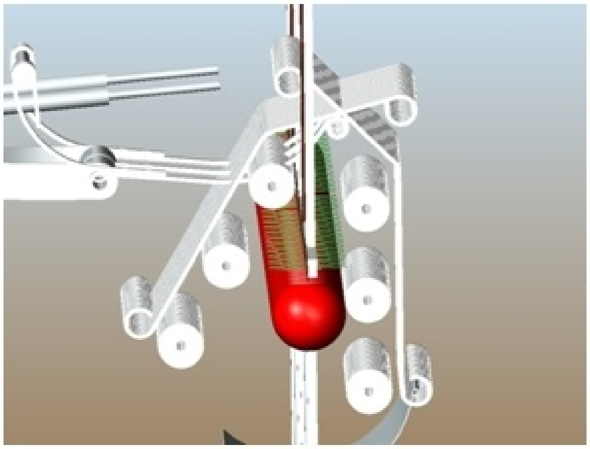


Figure 5 Proposed prototype apple harvester (left) and current testing module (right).

Table 1 shows the project timeline for the originally proposed duration of the project. Year one focuses mainly on hand harvest evaluation, prototype design and evaluations. All of these tasks are currently being carried out and will be continued through the 2012 harvest season. The prototype end effector design and improvement will continue through the winter. Complete evaluation of the prototype will be during the 2013 and 2014 harvest seasons. Grower feedback, suggestions, and evaluation will continue to occur in informal interviews and a symposium during the winter. It is noted that the activities proposed for Year 2 and Year 3 are contingent upon our success on securing further funding for this project.

Table 1 Project timeline for years 1 through 3*

	Year 1	Year 2	Year 3
Grower Input	■	■	■
Grower Feedback		■	
Grower Evaluation			■
Hand Harvest Evaluation	■		
Prototype End Effector Design	■		
End Effector Phase 2		■	
Lab and Field Evaluations	■	■	■
Preliminary Economic Evaluation	■	■	■
Machine Integration and Demonstration			■

****Note:** Activities in Year 2 and Year 3 are contingent upon our success on securing further funding for this project.*

CONTINUING PROJECT REPORT **YEAR**: 2 of 2
WTFRC Project Number: TR-11-100

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

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Cooperators: WA Producers, Yakima Valley Orchards

Percentage time per crop: Apple: 70% Cherry: 30%

Total Project Request: **Year 1:** 99,397 **Year 2:** 69,454

Other funding sources: None

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 in the second phase of intelligent bin-dog research. The primary goal of this phase is to develop a prototype of a self-propelled "bin-dog" implementable in typical Washington State tree fruit orchards. To achieve this goal, the 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 an empty bin at target locations in the row to support efficient picking and transporting a full bin to the designated bin landing area. 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 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" or off the shelf, readily available components, and test the integrated bin-dog research platform in terms of functionality, usability and efficiency in both research and commercial orchards.

Please note that we have made the following three major modifications to our original specific objectives:

1. Focus the bin-dog functionality to place empty bins at the target sites in the row and transport full bins out the rows to the bin landing area;
2. Drop the functionality of fruit loading from picker's hand to the bin; and
3. Add 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.

SIGNIFICANT FINDINGS

1. Based on the experiments both in the laboratory environment and orchard environment, the developed Bin-dog prototype could work effectively according to the proposed concept. That is, carry one empty bin travelling to the full bin, place the empty bin ahead of the full bin, then pick up full bin and carry to the bin landing area.
2. If the full bin is at the distance of 50 ft to the bin landing area, about 3 minutes was required to achieve one cycle of the Bin-dog operation process (place the empty bin and carry the full bin to the station)
3. Electric maneuvering systems works well in the Bin-dog system. DC motor plus gear reducer as the drive system worked well and the electric winch achieved the bin lifting task.
4. Remote control system works well in both laboratory tests and field tests. An operator could operate the joystick by following the Bin-dog within about 50 feet. If one joystick is required for speed control of two drive wheels, the feedback control system should be added to the remote control system.
5. GPS was used to record the location of the bin-dog prototype. With an orchard map, the location of the Bin-dog in the orchard will be obtainable.

6. Based on the test process, the Bin-dog mechanical structure needs some modification. The spring of the lifting fingers should be lighter and a steering system needs to be added to make the driving system more efficient.

METHOD

Based on the row spacing in typical high density orchards of 8-11feet width and the typical bin size of 48×48 inches used in those orchards, and referencing existing platforms used in both WA and European countries, we have defined the initial design specifications for the bin-dog system as follows:

- Overall dimension (L x W x H): 8.0'× 6.0' × 7.0'
- Wheelbase (space between front and rear wheels): 6.5'
- Wheel space (space between two front (or two rear) wheels): 5.0'
- Maximum travel speed: 2.0 mph

Mechanical Design

To ensure the developed bin-dog prototype has the capability of performing all defined operation steps reliably and effectively, the structural design of the conceptual bin-dog has been through a few design iterations. As depicted in Figure 1, the basic structure of the 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 the 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 on a full bin or lifting a full bin for stacking it on another full bin at the collection area.

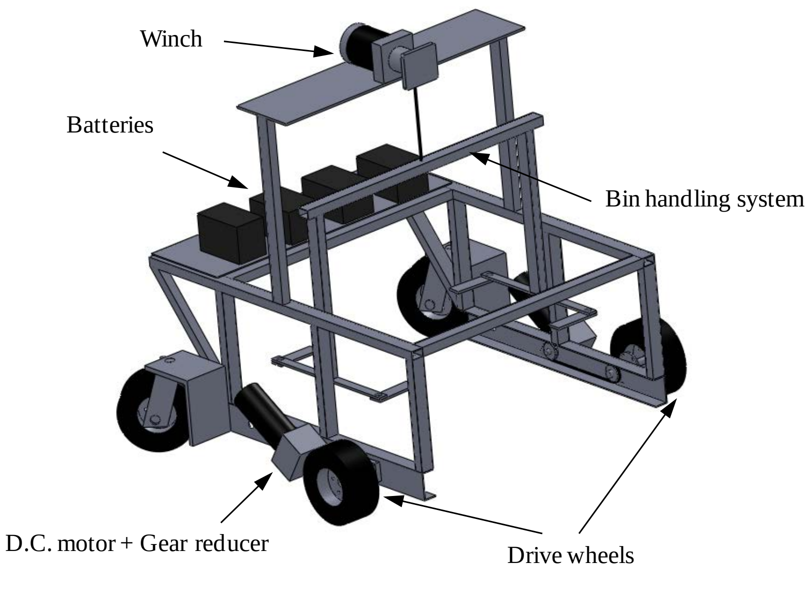


Figure 1. Schematic illustration of the concept-approval bin-dog structure

After finishing the mechanical design of the Bin-dog system, the dynamic analysis was conducted to calculate the force information and power requirement for the Bin-dog system. The maximum traction force for driving the Bin-dog is about 1350 N (304 lbf).

Maneuvering systems

1. DC motor for driving system

Electric DC motors are used for the drive system. From the dynamic analysis, we can get the maximum traction force of Bin-dog. And the traction force is provided by the torque of electric motor. By calculating, the required power for one drive wheel is 0.68 Kw. In the Bin-dog system, two 1.0 Hp (0.75 Kw) DC Motors were selected for the drive wheels at each side of Bin-dog prototype.

2. Electrical winch for bin lifting system

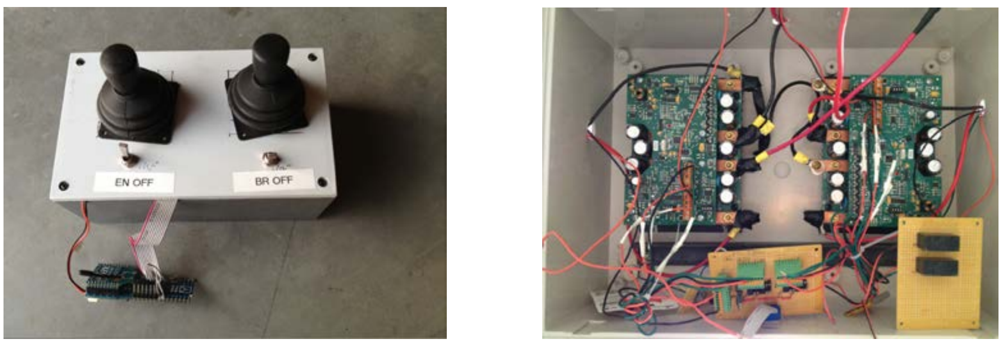
An electrical winch with a mechanical brake is used in prototype to lift bins up and down. A full bin plus the weight of the lifting frame, has a total mass of more than 1000 lb, and considering the friction force during the lift, a 3000 lb load capacity with mechanical brake electrical winch was selected for Bin-dog system.

3. Encoder and GPS

Two encoders with 360 pulses per rotation are installed on the motors. The number of pulses sent to the microcontroller is programmed to be recorded every second. Thus, the speed of the motor can be calculated using the following method: The speed of both motors will be sent to the laptop with a baud rate of 38400. A GPS records the location information of Bin-dog, and the data will be sent to the laptop using serial port.

Remote control system design

Based on the functionalities and the requirements of the Bin-dog system, the configuration of the remote control system for Bin-dog (Figure 2) consists of four major parts: A: Transmitter, which is used to send instructions to the receiver; B: Receiver, which is used to receive and interpret the instructions from the transmitter; C: Actuators, which can perform different actions according to the commands sent by receiver; D: Data collect system, which can collect the speeds of left and right wheels of Bin-dog with the encoders installed on the motors and the location information of Bin-dog using GPS.



(a) (b)

Figure 2. The transmitter (a) and receiver (b) of the remote control system

About 50 feet working distance can be achieved under current design. The program of the remote control system is written by C language. In order to reduce the time and complexity of developing the system, Arduino Fio is used in the system. The Arduino Fio is a microcontroller board based on ATmega328P.

Prototype fabrication and test

At the beginning of the September, the bin-dog prototype (Figure 3) was fabricated and ready to test in both laboratory and field.

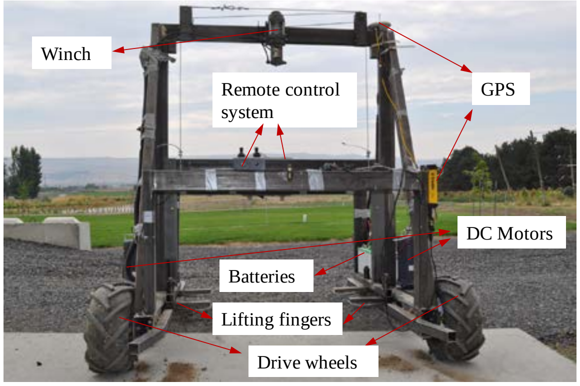


Figure 3. The fabricated Bin-dog prototype

On the September 13th, 2012, two series of Bin-dog tests were conducted on a paved road at the WSU Prosser station, (Figure 4(a)). Firstly, six repeated driving tests were conducted with the distance of 50 ft. Then, three repeated operation process tests were conducted. In the operation process tests, a bin with 900 lb load was placed about 50 ft away from an empty bin. On the 20th September, 2012, the same tests were conducted at Yakima Valley Orchards (Figure 4(b)), the only difference was two empty bins were used in the field tests.

(a) (b)

Figure 4. Bin-dog prototype tests at WSU station in Prosser (a) and apple orchard (b)

RESULTS AND DISCUSSION

Laboratory test results

From the drive test in WSU station, the speed of two wheels operated by two individual joysticks and one common joystick were recorded and shown in Figure 5.

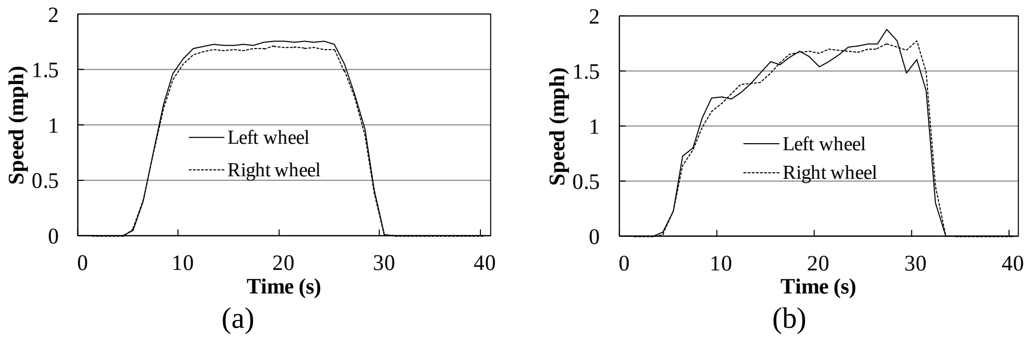


Figure 5. Speed of two wheels by one joystick (a) and two joysticks (b) control in driving test

Figure 5 (a) shows that the speeds of two wheels were different, which caused the Bin-dog could not drive straight. The main reason for this is because there is no speed feedback control in current control system. So if one joystick is required in operating the Bin-dog, speed feedback control for two DC motors should be added. Figure 5 (b) shows using two joysticks to control the two DC motors separately. The operator needs to adjust the speed of two sides constantly resulting in curves that are not very smooth.

From the Bin-dog operation process, the speed of two wheels operated are shown in Figure 6, with the time range for each step illustrated.

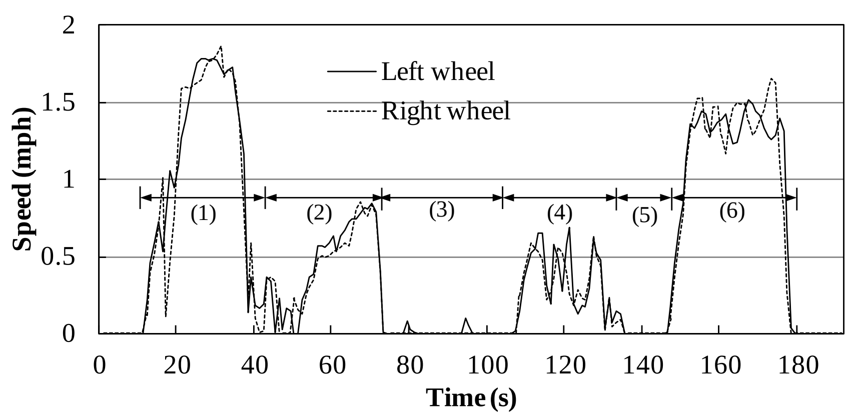


Figure 6. The drive speed of Bin-dog for the entire operation process test

In Figure 6, the time range for each step of Bin-dog operation could be expressed as (1): Bin-dog carries an empty bin to the position of full bin; (2): Bin-dog carries the empty bin drive over the full bin; (3): Bin-dog unloads the empty bin ahead of the full bin; (4): Bin-dog drives back to the full bin; (5): Bin-dog loads the full bin; (6): Bin-dog carries the full bin to the bin station. The period for step (3) is much longer than that for step (5), because the spring of the lifting fingers are too strong. When loading/unloading an empty bin, it is very hard to make the fingers turn 90 degree to make the bin go through the Bin-dog, but if the bin is full, the resistance of the bin will make the finger turning easier. In the next plan, lighter springs will be used in the lifting fingers to make the entire operation process smoother.

Field test results

The Bin-dog takes an empty bin down the row from the beginning to the end of the rows. Results from three test sets were recorded by the computer. Figure 7 shows the result of one test.

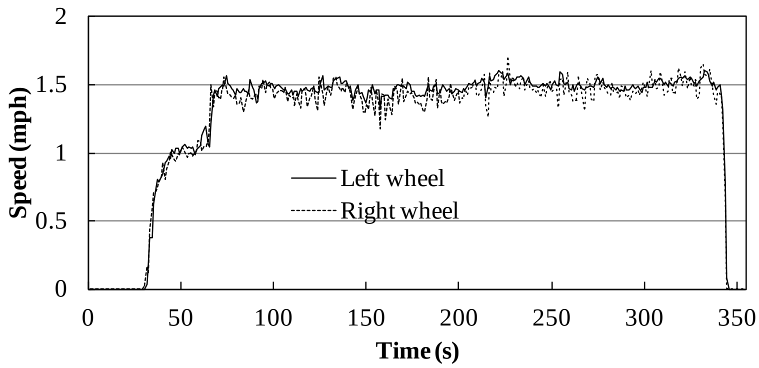


Figure 7. The Bin-dog drive speeds of travelling down the entire row

From Figure 7, it could be concluded that the Bin-dog prototype could drive basically straight in the orchard row by using two joysticks to control the speed of the left wheel and right wheel separately.

The Bin-dog entire operation process tests were conducted on 21th September, 2012 at Yakima Valley Orchard. The GPS recorded information is shown in a Google Map (Figure 8).

Figure 8. The Google Map information of the test area, red line is the locations of the Bin-dog prototype during test

Table 1 shows the time for each step of the Bin-dog operation process. Figure 9 shows the speed of two wheels during the bin-dog entire operation process.

Table 1. Time record for each step of the Bin-dog operation process

Test set	Time for each step of Bin-dog operation process (s)							Total time (s)
	Load an empty bin	Drive to full bin	Lift up empty bin	Go over full bin	Unload empty bin	Back to load full bin	Back to landing area	
1	11	42	4	17	15	22	40	151
2	12	38	4	12	12	19	38	135
3	15	35	4	10	18	22	40	144

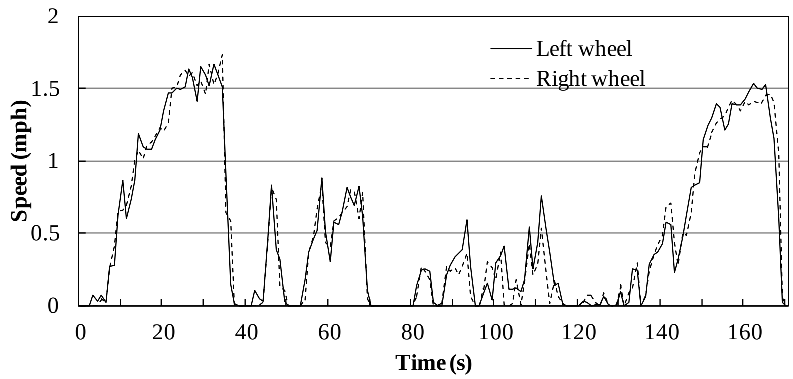


Figure 9. The drive speed of Bin-dog for the entire operation process (Field test)

The time for each step in Table 1 was recorded by stopwatch. When compared to Figure 9, the total time is a little bit shorter. The reason for that is because some stop time may not have been taken into account by using a stopwatch to record the time of each step.

The results of the tests both in the laboratory and field verified that the developed Bin-dog prototype could achieve the functionalities of the concept. There are identified problems that need to be addressed, e.g., the springs of the lifting fingers should be lighter, steering system is necessary to make the driving system more efficient. More field tests will be conducted in this harvest season.

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

Percentage time per crop: Apple: 50% Pear: 0% Cherry: 50% Stone Fruit: 0%

Other funding sources

Indirect support through the existing infrastructure of AgWeatherNet and its 138 weather stations.

Organization Name: ARC-WSU **Contract Administrator:** Carrie Johnston
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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
RCA Room Rental	0	0	0
Equipment	10,000	0	0
Supplies	10,204	2,605	2,874
Travel	8,500	8,000	8,500
Plot fees	0	0	0
Miscellaneous	0	0	0
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 developmental stages and to determine the hardiness. We propose to use a traditional methodology through exposure to freezing temperatures, and 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.
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

- Differences in hardiness and lethal temperature were found during different phenological stages for the same cultivar as well as among the cherry cultivars that were initially evaluated.
- We developed a prototype automated sampler, sometimes referred to as the "vending machine", to determine cold hardiness of fruit crops when differential thermal analysis (DTA) is not effective and cannot be used due to the size of the plant tissue such as expanding buds and flowers.
- The preliminary results indicate that there are differences among cultivars and crops.
- The results from preliminary dissection indicate that there is a variation in cold hardiness for different bud sizes of apples for the same sampling date.
- Growth chamber data revealed differences in hardiness of flower bud progression for the three temperature environments that were evaluated.

Methods

Bud samples were collected throughout late winter and early spring in 2012 to determine the effect of low temperature on bloom development for different apple and sweet cherry cultivars. We started our measurements in February 2012. For apples we evaluated the cultivars Gala, Red Delicious and Fuji, while for cherries we evaluated the cultivars Bing, Chelan and Sweetheart. Samples were obtained at different bud development stages and taken to the laboratory for further testing.

Cold hardiness was assessed using differential thermal analysis (DTA) for the early phenological stages. Beyond the "open cluster" stage DTA was not effective. As part of this project we developed a prototype automated sampling device sometimes referred to as the "vending" machine. In this new device, tissue samples are placed in color coded canisters and the plant material is exposed to preset low temperatures of the freezer. Dependent on the setting, the temperature slowly decreases and at certain temperature set points one or more canisters are released. After exposure to these low and freezing temperatures the tissue is dissected to determine if freeze damage has occurred.

Simultaneously to the process described above we collected dormant apple and cherry shoots that were 6 to 10 inches long with terminal flower buds. The shoots were kept in large buckets filled with water. The base of the shoots was cut every week and water was replaced every other day. The buckets with the shoots were placed in three growth chambers for temperature forcing under different temperatures. The day/night temperature settings were 54/39°F, 64/43°F, and 75/54°F and were similar to the procedures of Proebsting and Mills (1978). These three temperature settings corresponded to potential weather conditions that can be experienced during late spring. The samples were processed at three-day intervals and classified according to their hardiness.

Digital pictures were taken for the different growth stages to illustrate, identify, and define the key growth stages for apple and sweet cherry. These pictures will be combined with the data obtained from the cold hardiness exposure described previously. 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, and via smart and hand-held devices.

Results and Discussion

In this progress report we only discuss the results for the cherry cultivar Chelan. However, the same procedures were used for the other two sweet cherry cultivars and the three apple cultivars and similar results were obtained. Critical injury temperatures for buds of Chelan were evaluated for three different sampling dates during February 2012. The relationship of the cumulative percentage of dead buds and the temperature was analyzed using a logistic function or model (Fig.1). The following equation represents the final model that was fitted to the data:

$$CDF = c + \frac{(d-c)}{1+e^{-K(t-G)}} \qquad (1)$$

Where CDF is the cumulative number of dead flower buds. In a logistic growth curve (Eq. 1), *c* and *d* represent the lower and the upper boundary of the asymptote or curve, respectively. (*c)* is the mean percentage of mortality that was found in the field, while (*d*) is the maximum percentage of mortality. *K* is the so called 'slope parameter', t is the gradient of temperature in the freezer and *G* is the temperature where the inflexion point of the curve occurs. In Figure 1, the sigmoid curves adjusted for the three different sampling dates, e.g., February 17, 21, and 27, 2012, and the resulting 10, 50 and 90 percent of mortality or lethal temperature (LT) for Chelan are shown. The parameters of the final model are presented in Table 1. The PROBIT procedure of SAS was used to calculate the values for LT_{10}, LT_{50}, and LT_{90}. LT_{10} is the temperature when potentially 10% of flower buds are dead, LT_{50} is the temperature when potentially 50% of the flower buds are dead and LT_{90} is the temperature when potentially 90% of the flower buds are dead. For the three sampling dates of February the LT_{10} ranged from 3.28°F to 14.8°F, the LT_{50} ranged from -4.22°F to 2.65°F and the LT_{90} ranged from -6.87°F to -2.55°F.

Hardiness was greatly influenced by the actual stage of bud development, since the temperature at which the buds become injured changes over time. These results support the earlier report that changes in hardiness were observed for the same day of sampling between crops, cultivars and size of the buds. Buds from the first two sampling dates were less sensitive to cold temperature as compared to the last sampling date (Fig.1), which means that the buds sampled on the final harvest date were less cold hardy.

Deacclimation of Chelan flower buds resulted in a moderate increase in the LT temperatures when sampled through the end of winter and early spring. However, a progressively larger increase was observed as the season advanced. The results presented here are consistent with the previous data reported by Proebsting (1987). There was a linear relationship between LT and the day when the sampling was conducted. With the advancement in bud development, the LT increased, which indicated that the buds were more sensitive to cold temperatures (Fig.2). Each point represents the value of the temperature when the bud was frozen and thus dead for that sampling date. For each LT, a simple linear regression was adjusted to estimate the mortality trough time or bud development; per each ten days the temperature to get the LT_{10} increases in 3.26°F, for the LT_{50} was 3.11°F and for LT_{90} was 2.4°F. In general the goodness of fit of the curves representing the models was sufficient since the less R^2 was equal 80%.

Morphological changes were observed for Chelan flower buds after two and a half weeks of acclimation in three different temperature environments using growth chambers (Fig. 3).The data revealed differences in hardiness of dormant flower bud among the temperature environments that were evaluated. The buds that were placed in the chamber with the highest temperature had a faster development and consequently greater sensitivity to freezing temperatures compared to the buds that were placed in other two temperature environments (Fig. 4).

To update the charts for apples and sweet cherries, digital pictures were taken for the different growth stages for cherries and apples (Fig.4 and Fig.5 respectively).

Limitations

To plan activities for the coming winter and spring season, the project would like to cooperate with local orchards for sample collection of sweet cherry and apple trees in order to expand the range of environments and cultivars.

Table 1. Parameters of the model fitted for each of the different sampling dates for Chelan.

Date	*d*	*c*	*K*	*G*	95% Confidence Limits (*G*)	
17-Feb	1	0.05	-1.6	-0.81	-0.92	-0.71
21-Feb	1	0.05	-0.8	1.30	0.96	1.64
27-Feb	1	0	0.7	1.95	1.75	2.16

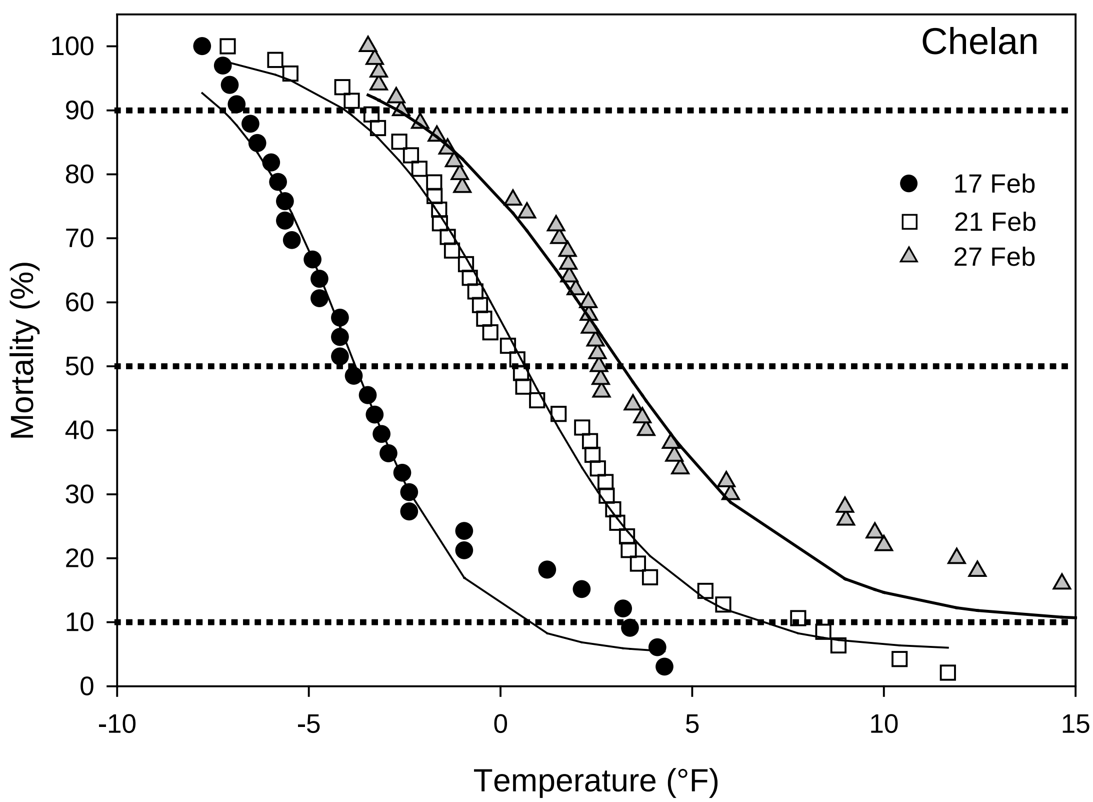


Figure 3. Critical injury temperatures for the sweet cherry cultivar Chelan evaluated on February 17, 21 and 27, 2012.

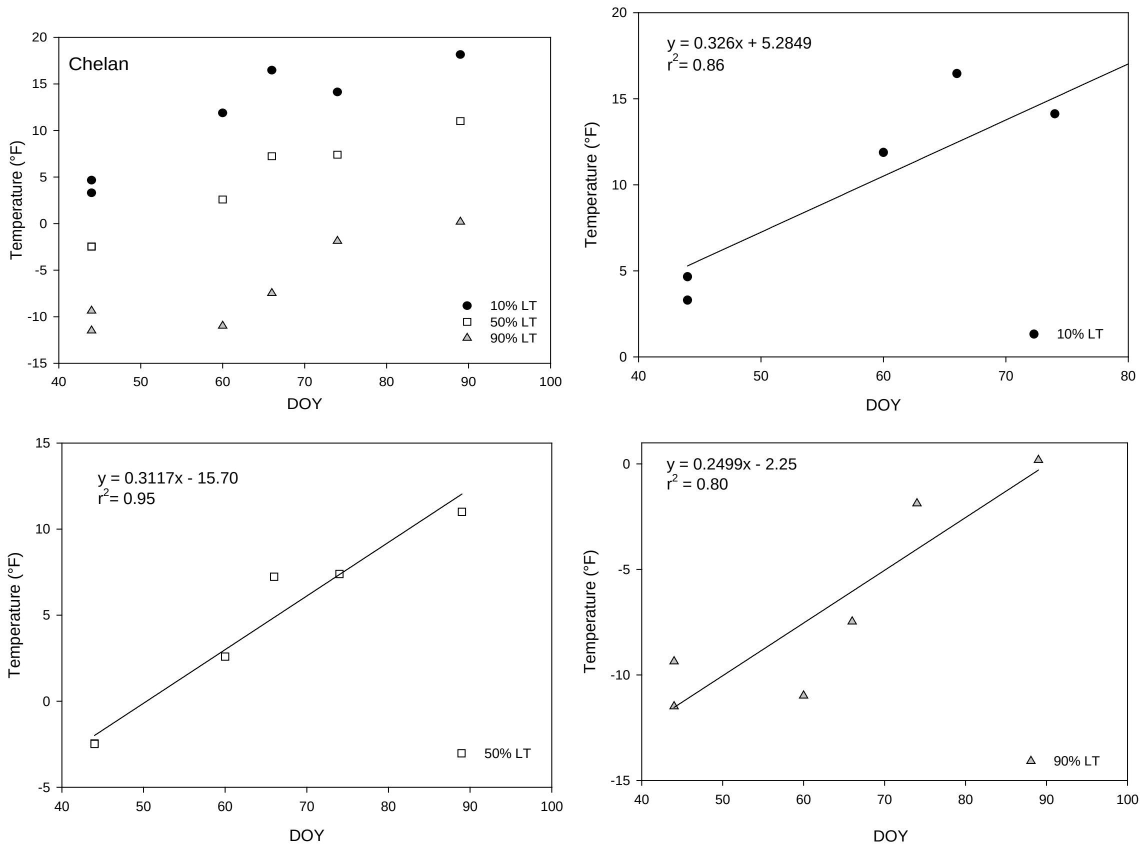


Figure 2. Relationship between Lethal Temperature (LT) for Chelan evaluated on different sampling dates (a), and LT_{10} (b), LT_{50} (c) and LT_{90} (d). Day of Year (DOY) 40 = February 9; DOY 90 = March 30.

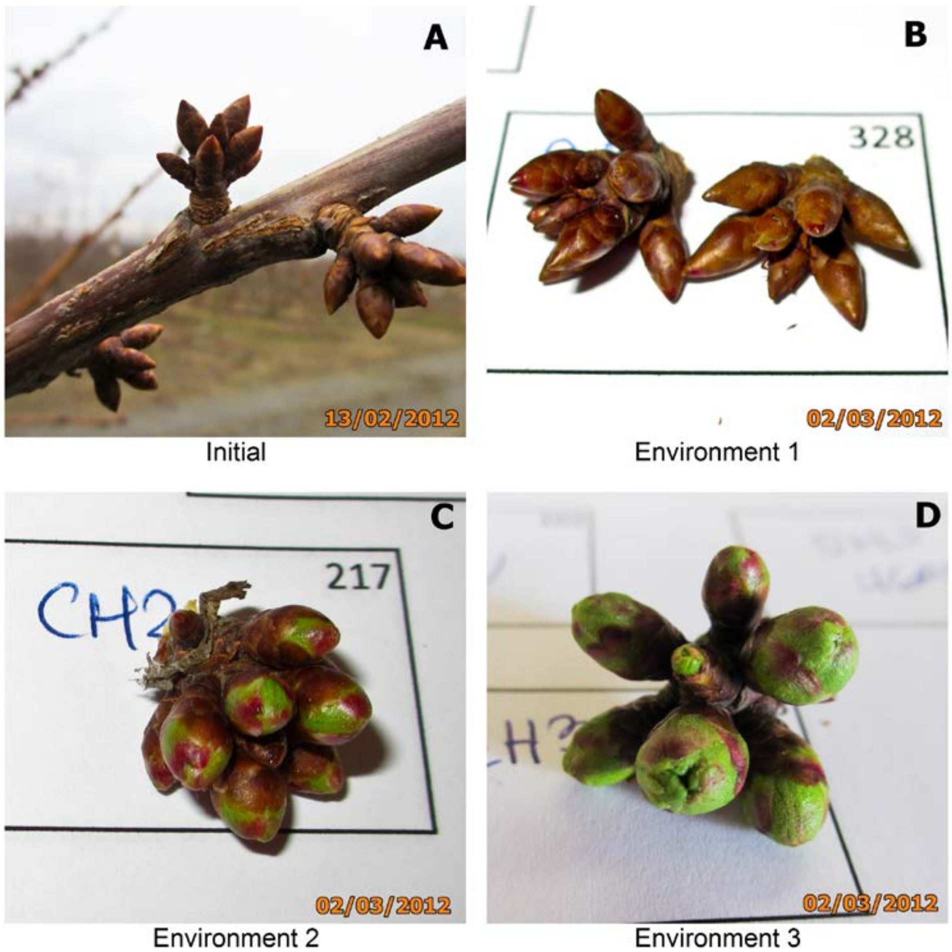


Figure 3. Selected buds of Chelan sampled in the field (a), and exposed to 54/39°F (b), 64/43°F (c), and 75/54°F (d) after 18 days of acclimation in a growth chamber.

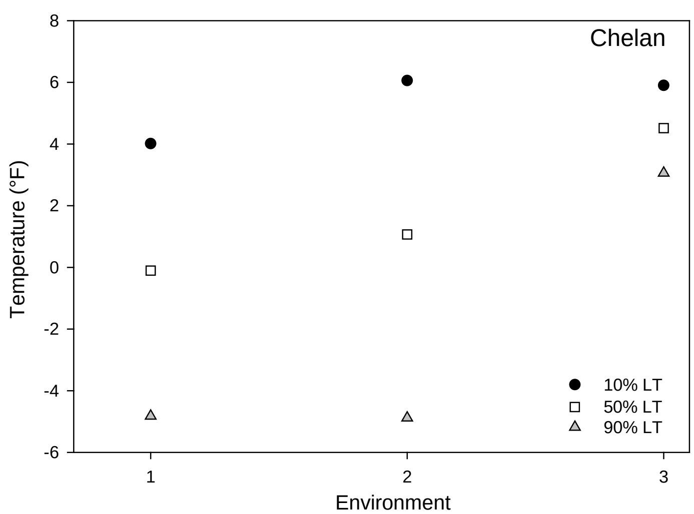


Figure 4. Lethal temperatures for Chelan for three temperature environments (54/39°F [1], 64/43°F [2], and 75/54°F [3]) evaluated on the same sampling day.

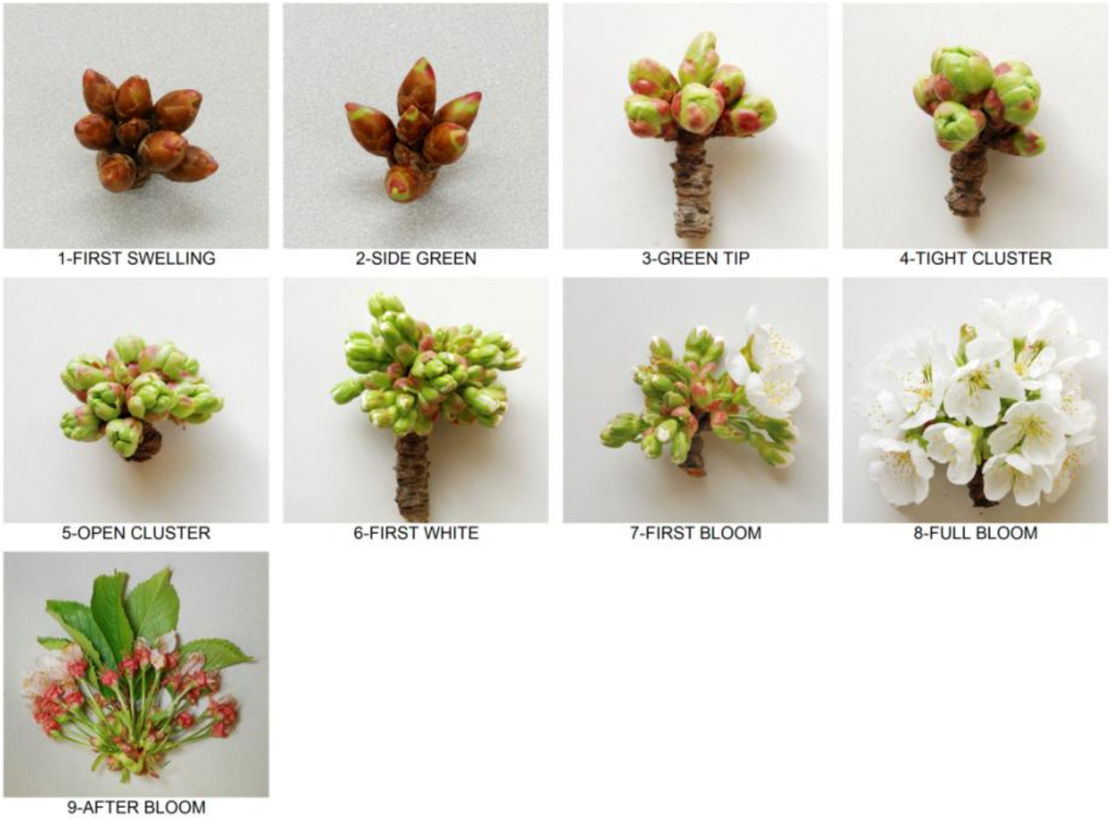
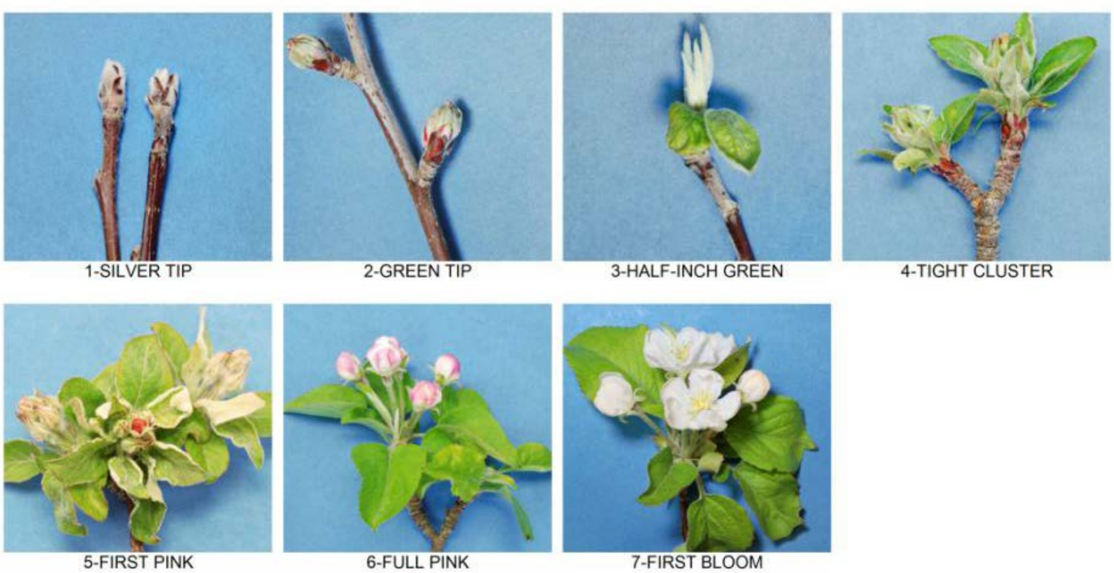


Figure 5. Development and phenological stages for sweet cherry.



Pictures by Jakarat Anothai

Figure 5. Development and phenological stages for apple.