Washington Tree Fruit Research Commission
Winter Technology Research Review
December 3, 2009
Hal Holmes Center, Ellensburg

Page No.	Time	PI	Project Title	Funding period
	9:00	McFerson	**Introduction**	
			Continuing Reports	
1	9:10	Kantor	Dense distributed environmental sensing via wireless sensor networks ***teleconference***	09-10
5	9:20	Lewis	Platform and bin filler technologies	09
8	9:30	Schupp	Mechanized blossom and green fruit thinning ***teleconference***	08-10
			Final Reports	
13	9:45	Taylor	Economic analysis of technology adoption by WA apple growers: ***final report & new proposal***	09
21	10:00	Dhingra	Rosaceae micropropagation and tissue culture platform	09
28	10:15	Whiting	Investigating flower bud hardiness of tree fruit cultivars: ***teleconference***	09
33	10:30	Koselka	Robotic scout for tree fruit ***final report & new proposal***	09
52	10:45	Hoheisel	A database to aggregate research results and assess technologies	08-09
59	11:00	Jones	Expanding and stabilizing WSU-decision aid system	07-09
64	11:15	Ashmore	Technology roadmap support: final report and new proposal: ***teleconference***	09
70	12:30	Allard	Mobile linear asymmetric fruit transport system: ***final report***	09

CONTINUING PROJECT REPORT **YEAR**: 1 of 2
WTFRC Project Number: TR-09-909

Project Title: Dense distributed environmental sensing via wireless sensor networks

PI: George Kantor
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Cooperators: Jim McFerson (WTFRC), Jay Brunner (WSU-Wenatchee)

Total Project Request: **Year 1:** $25,000 **Year 2:** $10,000

Other funding sources

Agency Name: USDA Specialty Crops Research Initiative
Amt. awarded: $5.4M (plus $5.5M non-federal match)
Notes: Dr. Kantor is a Co-Project Director on the project titled *Precision Irrigation and Nutrient Management for Nursery, Greenhouse and Green Roof Systems: Wireless Sensor Networks for Feedback and Feedforward Control (PINM)*. A major objective of this project is the commercialization of a sensor network system for specialty agriculture with partner Decagon Devices.

Agency Name: USDA Specialty Crops Research Initiative
Amt. awarded: $6.1M (plus $6.1M non-federal match)
Notes: Dr. Kantor is also Co-Project Director on the project titled *Comprehensive Automation for Specialty Crops (CASC)*. CASC has a broad charter to investigate and develop automation technologies for specialty crops, with a specific focus on the apple industry.

Agency Name: The Technology Collaborative (Pittsburgh, PA)
Amt. awarded: $200,000 (plus $100,000 match from ZedX, Inc.)
Notes: Dr. Kantor is a Co-Investigator on a project titled *Sensor Networks for Disease Management in Specialty Crops,* led by ZedX, Inc. This project is investigating the use of distributed measurements from sensor networks for the purpose of disease modeling and prediction in apple orchards.

WTFRC Collaborative expenses:

Item	9/1/2009-9/1/2010	9/1/2010-9/1/2011
Stemilt RCA room rental		
Crew labor	$3,120	$3,120
Shipping		
Supplies		
Travel		
Miscellaneous		
Total	$3,120	$3,120

Footnotes:

Budget 1
Organization Name: Sensible Machines, Inc. **Contract Administrator:** Stephan Roth
Telephone: 412-398-2694 **Email address:** sroth@sensiblemachines.com

Item	9/1/2009-9/1/2010	9/1/2010-9/1/2011
Salaries	$5,000	$2,500
Benefits		
Wages		
Benefits		
Equipment	$16,000	$4,500
Supplies	$500	$500
Travel	$3,500	$2,500
Miscellaneous		
Total	**$25,000**	$10,000

Footnotes:

Objectives

1. Establish a 12-node sensor network to sense temperature in a Washington orchard. The network will cover an area of approximately 20-40 acres (fall 2009).
2. Demonstrate real-time frost/freeze monitoring during the spring seasons of 2010 and 2011.
3. Demonstrate reliable, continuous operation over two-year period (fall 2009 – fall 2011).
4. Work with WSU and WTFRC scientists to integrate data stream with scientific modeling efforts that make use of temperature data.
5. Build relationships with other scientists (Zhang, Whiting, WSU Prosser; Jones, Brunner WSU Wenatchee; Lewis, Hoheisel, WSU Extensions) and private sector technology providers and identify new applications for sensor networks in orchards.
6. Use data from this installation to develop proposals for additional funding through the USDA Specialty Crops Research Initiative and other agencies.

Significant Findings

No significant findings to date.

Methods

The basic steps that we will take to achieve our objectives in this project are:

1. Install a sensor network that takes continuous temperature and relative humidity measurements at a set of locations distributed over the WSU Sunrise research orchard.
2. Provide collaborating WTFRC and WSU scientists access to resulting real-time data stream
3. Preliminary evaluation of results, specifically regarding performance for frost/freeze monitoring during Spring 2010.
4. Expand sensor network to include a more diverse set of measurements
5. Formulate advanced research agenda
6. Pursue external funding
7. Finalize and report

Results & Discussion

This project has just started in October 2009, so there are no significant results to report at this time. With the exception of minor modifications to the scope and equipment source (see below), the project is proceeding according to the proposed plan. All of the necessary sensor network equipment has been purchased and is currently being tested in Pittsburgh. The PI will travel to Wenatchee, WA to install the system at the WSU Sunrise orchard on Dec. 9-10, 2009.

Proposal Modifications: The original proposal called for the use of the sensor network developed at CMU to collect and transmit temperature data. Since writing that proposal, the PI has begun in earnest his collaboration with Decagon Devices (Pullman, WA), and in the course of that collaboration he has learned that the Decagon Em50R wireless data logger system is a better fit for the needs of this project. This system is commercially available, and will provide a more reliable data collection platform than the CMU sensor network. For these reasons, we have decided to use the Decagon system instead of the CMU system on this project.

There are two disadvantages to using the Decagon system, both of which are outweighed by the advantages of its stability and commercial availability. First, the EM50R does not use a multihop networking protocol, rather it only provides point-to-point communication. However, the radios in the Em50R provide a line of sight range of about 5 miles, and a proven range through foliage of about 1 mile, making it sufficient for the needs of this project. Also, Decagon will be adding multihop capability in a future product that is being developed as part of the USDA SCRI grant for Precision Irrigation and Nutrient Management described above. The second disadvantage is the cost: the Decagon system is a bit more expensive than the CMU system. Specifically, the Decagon nodes are

$675 each, compared to the $600 each budgeted for CMU nodes. The sensors that go with the Decagon nodes are also more expensive: the Decagon Temperature/RH sensors are $150 each, compared to $100 each that was budgeted for CMU temperature sensors. To account for this, we have scaled down the size of the proposed deployment: we will deploy 10 nodes with 3 sensors at each node instead of the proposed 12 nodes with 4 sensors at each node. This will allow us to meet the needs of the project while staying within the originally stated budget. The off-the-shelf Decagon system does not provide for remote internet access of the data, however we have made some modifications to the system to provide the required remote access capability.

CONTINUING PROJECT REPORT **YEAR**: 1 of 1
WTFRC Project Number: TR-09-910

Project Title: Platform and bin filler technologies

PI: Karen Lewis
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State/Zip: WA. 98837

Cooperators: Qin Zhang, WSU; Bill Messner, CMU; Tara Baugher, PSU; Gregg Marrs, Blueline Mfg. WTFRC; Mykel Taylor, WSU; Rich Fenske, UW, Sanjiv Singh, CMU

Total project funding request: **Year 1**: 13,000

Other funding sources

Agency Name: USDA - CSREES
Amt. awarded: 620K / 4 years
Notes: CASC project does specifically support optimization and utilization of mobile platforms and fruit harvest augmentation and bin filling

WTFRC Collaborative expenses:

Item	2009	2010
Stemilt RCA room rental		
Crew labor	500	2000
Travel	200	800
Miscellaneous		
Total	700	2800

Budget 1
Organization Name: Washington State Univ. **Contract Administrator:** M.L. Bricker
Telephone: 509.335.7667 **Email address:** mdesros@wsu.edu

Item	2009	2010
Equipment [1]		2000
Supplies[2]	3000	6000
Travel[3]	500	1500
Total	3,500	9,500

Footnotes:
[1] Equipment – augment OTR/ laser guidance
[2] Supplies – 7K – Bin Filler
[3] In state

Objectives:

Platform Technologies:

1) Develop core team and identify needs and priorities including economics, health and safety (WTFRC and SHIP funding)
2) Identify current options for meeting specific needs (light duty, hybrid)
3) Begin initial design of light duty and or hybrid equipment or begin initial procurement of light duty and or hybrid equipment
4) Determine best protocol for assessing multi row, over the row platform in the field

Bin Filler Technologies:

1) Construct prototype of the Energy Absorbing Grate Bin Filler
2) Construct prototype of the Self Adjusting Bin Filler
3) Field test both bin fillers

Significant Findings:

Platform Technologies:

1) Economics (ROI and equipment costs), ergonomics (ID and mitigation of pinch points and stress), safety (employee constraints) are all priorities. Interest in 2 person electric platform is high.
2) Options are being identified – domestic options are not fully commercialized, international options are on the shelf
3) 4 Wheel electric Earth Utility Vehicle (EUV=ATV) purchased and delivered

Bin Filler Technologies:

1) Experiments with existing bin fillers revealed that collisions between apples as they exit the bag and pass down the chute to the bin filler causes a lot of bruising, even though the passive bin fillers themselves show promise.
2) Apples must be separated from each other as they exit the bag (re-singulation).

Methods:

Platform Technologies

Objective 1 – Field tours for key researchers and systematic determination of needs and priorities

Objective 2 – Public / private concerted effort to identify and critique current options

Objective 4 – Field evaluation of OTR with Qin Zhang and industry advisors

Bin Filler

Objective 1& 2 – Construction of compact, rugged prototypes in PA.

Objective 3 – Field test during harvest. Speed of harvest and fruit damage will be measured for both prototypes and a control.

Results and Discussion:

The team is under construction and activities are now underway. UW – PNASH is currently making field visits will cooperators to observe operations and discuss goals of project. They have 5 cooperators and are fully staffed to complete their study. Mykel Taylor and economist colleagues from UW will find common goals and determine if there is opportunity to partner.
Qin Zhang will work with 2 growers and Blueline to identify options for a laser guidance system on commercial platform. The ATV purchased with CASC funding is in WA. Assessments will be made over the winter with special emphasis on power source (Li Batteries) and gearing. The ATV and our Blueline platform will be housed at WSU Prosser to facilitate projects.

Bin filler project started up a bit late – there was no prototype available for field testing in WA. 2 graduate students are on the project. Use of different construction materials re: peg board and bungee cords, has broaden the teams ability to quickly reconfigure design and look at additional materials

CONTINUING PROJECT REPORT **YEAR**: 2 OF 3

WTFRC Project Number: TR-07-706

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

PI: (PA)	James R. Schupp	**PI:(WA):**	Karen Lewis
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Co-PI (PA):	Tara A. Baugher	**Co-PI (PA):**	James Remcheck
Organization:	Penn State University	**Organization:**	Penn State
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City:	Gettysburg	**City:**	Gettysburg
State/Province/Zip	PA 17325	**State/Province/Zip:**	PA 17325

Cooperators: Tory Schmidt and internal program - WTFRC, Katie Ellis, Penn State University; Steve Miller, USDA-ARS; 4-6 Pennsylvania Fruit Growers; Craig Hornblow, New Zealand First, 6 Washington State Growers, Michael Blanke, Dennis Hennan, University of Bonn

Total project funding request: **Year 1**: 17,172 **Year 2**: 17,803 **Year 3**: 18,262

Other funding Sources

WSU – USDA CSREES / SCRI – Innovative Technologies for Thinning of Fruit
WSU – WTFRC – Mechanized Cropload Management with Mueller String Thinner
PSU – USDA CSREES / SCRI – Innovative Technologies for Thinning of Fruit
PSU – PA Peach and Nectarine Board (Objectives 3 and 4)

WTFRC Collaborative expenses:

Item	**2008**	**2009**	**2010**
Stemilt RCA room rental	0	0	0
Crew labor	5,000	5,250	5,500
Shipping	0	0	0
Supplies	0	0	0
Travel	3,000	3,250	3,500
Miscellaneous	0	0	0
Total	8,000	8,500	9,000

Budget 1:

Organization**:** Penn State Univ — Contract Administrator: Timothy M. Stodart

Telephone: (814)865-1027 — Email**:** tms21@psu.edu

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

Footnotes: Estimated salary costs are based on current salary rates (fiscal year 2007-08) escalated approximately 3.5% beginning July 1 of each subsequent year. University policy has been to award salary increases on the basis of merit only.

Fringe Benefits: Rates are computed using the rates of 25.8% applicable to Category I salaries; 15.7% applicable to Category II graduate assistants; 8.2% applicable to Category III non-student wages and fixed-term II salaries; and 0.4% applicable to Category IV student wages for the current fiscal year of July 1, 2007 through June 30, 2008. If this proposal is funded, the rates quoted above shall, at the time of funding, be subject to adjustment for any period subsequent to June 30, 2008 if superseding Government approved rates have been established. The fringe benefit rates are negotiated and approved by the Office of Naval Research, Penn State's cognizant federal agency.

Budget 2:

Organization**:** WA State Univ — Contract Administrator: Mary Lou Bricker

Telephone: (509) 335-7667 — Email**:** mdesros@wsu.edu

Item	2008	**2009**	2010
Salaries	0	0	0
Benefits	0	0	0
Wages	1,700	0	0
Benefits	282	0	0
Equipment	0	0	0
Supplies	500	2,000	1,500
Travel	1,500	2,832	3,500
Miscellaneous	0	0	0
Total	3,982	**4,832**	5,000

Objectives:

1. To evaluate the effect of timing on efficacy of mechanical blossom thinning, relative to peach / nectarine and apple bloom stages.
2. To evaluate several labor-efficient thinning methods in various combinations.
3. To evaluate the effect of pruning strategies to influence hanger orientation on peach cropload and on the efficacy of the Darwin vertical string thinner.
4. To compare the efficacy of a prototype horizontal mechanical blossom thinner or a rope thinner in traditional vase shaped peach canopies, relative to hand thinning
5. To evaluate the effect of Darwin string thinner in apple varieties and systems
6. To evaluate the Uni Bonn string thinner in apples and cherries
7. Establish best management practices for string thinners.

Significant Findings:

Stone Fruit (Multi State)

- String thinner trials to assess optimum operational parameters for varying growing regions and tree forms showed reduced labor costs compared to hand thinned controls and increased crop value due to a larger distribution of fruit in higher market value sizes.
- Blossom removal ranged from 20-55%, hand thinning requirement was reduced by 25-65%, and fruit size distribution improved in all but one trial.
- Net economic impact at optimum tractor and spindle speeds was $462-$1490 and $230-$847 per acre for processing and fresh market peaches, respectively.
- Trials with the string thinner at varying bloom stages showed the thinning window is from pink to petal fall.
- Trials on modifications in tree training to improve access by the string thinner indicated detailed pruning for targeted crop loads was superior to standard pruning.
- Studies with a new drum shaker prototype adapted from a blackberry harvester demonstrated increased thinning consistency compared to previous research with a citrus drum shaker.
  - Yield was reduced in some fresh fruit trials, and future trials will address this concern.
  - Several combination treatments—the string thinner + hand blossom thinning, the string thinner + the drum shaker, and string thinner treatments on both the sides and tops of trees—suggested additional strategies for achieving the most desirable thinning results.

Apricot (WA)

- The Darwin at 3 mph and 215-240 rpm is an effective bloom thinner of both ‘Goldbar’ and ‘Robada’ varieties.
- Effective blossom thinning reduced green fruit thinning by 40-60%
- Final fruit size is larger in both hand bloom thinned and Darwin bloom thinned.

Apples (WA)

- Darwin rpm setting does impact the number of surviving flowers.
- UniBonn (Bonner) rpm did not impact the number of surviving flowers.

Methods:

Stone Fruit (Multi State)

Trials with a mechanical blossom string thinner were performed Spring 2009 in 13 PA, 3 SC, 2 WA, and 4 CA commercial and research orchards. A USDA drum shaker was tested in 3 PA orchards during the bloom and green fruit stages. Conventional hand thinning at the green fruit stage was the control treatment. Varying operational speeds, blossom stages, and pruning modifications to improve access by the thinner were assessed. Data were uniformly collected across all regions to determine blossom removal rates, fruit set, labor required for follow-up hand thinning, fruit size distribution at harvest, yield, and economic impact.

Apricot (WA)

One Darwin data trial was conducted in 'Goldbar'. Treatments included Darwin at 237 rpm, hand (rake) bloom thinning and hand green fruit thinning. Demonstration trials were conducted in 'Robada'.

Treatments:

Robada
Hand Thinned (Raked)
Darwin @ 237 rpm
Green Fruit Thinned

Apple (WA)

Darwin trials were conducted at open king bloom stage on 'Gala', 'Honeycrisp' and 'Granny Smith'. Darwin rpm treatments were determined at the time of treatment based on short runs and corresponding goals of cooperator. Across all apple trials, target bloom stage was open king, balloon sides. Groundspeed was set at 3 mph. Flower counts to measure removal are conducted within an hour of treatments. To determine if a post treatment secondary drop occurs, we recounted 7 days post treatment in the 'Gala' Darwin trial.

Treatments:

GHO Honeycrisp / M.9
Darwin 200 rpm
Darwin 220 rpm
Darwin 240 rpm

Radar Hill Gala / M.9
Darwin 200 rpm
Darwin 215 rpm
Darwin 230 rpm

Weipert Granny Smith / M.9 (337)
Darwin 240 rpm lower
Darwin 240 rpm upper
Darwin 260 rpm lower

Darwin 260 rpm upper
Darwin 280 rpm lower
Darwin 280 rpm upper

UniBonn (new name: Bonner) trial was conducted by Dennis Henan (Univ. of Bonn). Two data sets were collected for this one trial. One data set reflects data collected from all limbs, whether struck by machine or not. The second data set reflects data from only limbs struck by the machine.

Treatments:

Uni Bonn Gala / Nic. 29
Uni Bonn 260 rpm
Uni Bonn 260 rpm; MaxCel + Sevin
Uni Bonn 360 rpm
Uni Bonn 360 rpm + hand thin

Cherry (WA) (new name: Bonner) trial was conducted by Dennis Henan (Univ. of Bonn). Only one trial at one location was conducted.

Treatments:

UniBonn Sweetheart / Mazzard
Unibonn 560rpm fast
UniBonn 560rpm slow
Unibonn 620rpm fast
Unibonn 620rpm slow
Control

Results:

Stone fruit results are presented in significant findings. Data summary tables are being finalized and will be presented at WTFRC Stone fruit committee meeting, winter industry meetings and poster sessions.

Apple harvest data is still being analyzed and tabulated. Early estimations are that we did positively impact fruit size with Darwin treatments and that we did not reduce yield. No additional drop of flowers was recorded in our first effort to evaluate post treatment secondary drop.

The Bonner cherry trials yielded interesting and significant data. The Bonner was highly effective at removing flowers and reducing fruit set. Corresponding data for fruit weight, firmness, fruit diameter and row size was mixed and while significance was found, it did not correlate strongly with the percent bloom removed. No significance was found in evaluations for pitting or color. Total yield was reduced in all Bonner treatments – expressed as TCSA or per limb.

FINAL PROJECT REPORT

Project Title: Economic analysis of technology adoption by Washington apple growers

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Cooperators: Tom Auvil – WTFRC
Karen Lewis - WSU Extension
Norman Suverly - WSU Extension

Total Project Funding: $23,368

Budget History for 2009:

Item	Budgeted ($)	Expenditures ($)	Encumbrances ($)
Salaries	0.00		
Wages	15,557.00	3,074.20	8,561.00
Benefits	2,111.00	28.39	615.02
Equipment	0.00		
Supplies (survey)	0.00		
Travel	3,000.00	456.50	180.00
Survey	200.00		10,000.00
Extension Support	2,500.00		
Total Budget	23,368.00	3,559.09	19,356.02
Remaining Balance			**452.89**

Notes on Budget: The cost of administering the survey was much greater than we anticipated when we planned the project budget. We therefore, reduced our expenditures in other areas (travel, extension support, and wages) to allow this survey to be completed as promised.

Original Goals of Project:

The purpose of this research project was to determine the factors that impact technology adoption by Washington apple growers. The focus of the research was on labor-augmenting technologies, specifically platforms. The specific objectives of the study are as follows:

1. Evaluate the economic and managerial factors that contribute to a grower's decision to adopt automation and mechanization technologies.
2. Use the data collected during this project to support other educational programs and decisions aids focused on technology adoption.
3. Establish a program for continuously collecting production and management data from tree fruit growers.
4. Disseminate research results to tree fruit growers, packing houses representatives, researchers from other disciplines, and interested parties.

Significant Findings:

This project was designed around a two-year implementation plan. Therefore, all the objectives listed above have not been completed. Rather than summarizing findings, we list the current status of the objectives at the mid-point of the project calendar.

1. Economic analysis of technology adoption: not completed. We are in the process of finalizing the grower survey that will be administered by the Social and Economic Sciences Research Center (SESRC). The survey will be sent out in January 2010 and results are expected in March.
2. Sharing data collected: partially completed. We have shared the cost of production numbers from the Gala budget with Clark Seavert. The budget data will also be used for presentations and break-even analysis at the 2009 WA Horticulture Meetings and two WSU Fruit Schools.
3. Collection of production costs data: completed. With the creation of a current Gala apple orchard budget and the planned update of a cherry orchard budget in December 2009, we are well on our way to establishing a portfolio of enterprise budgets that reflect current costs or production for modern orchards in Washington.
4. Dissemination of results: not completed. This will not be started until the platform survey is completed and the data are analyzed.

Results and Discussion:

It is difficult to discuss findings at this point in the project. After completion of the grower survey, we will combine the information we have gathered on costs of production and include a scenario analysis of implementing platforms and the changes in costs and efficiency.

Executive Summary:

This project is progressing in a manner consistent with the two-year horizon outlined in the initial proposal. We have completed the Gala orchard budget and will be working on an updated budget for cherries in December 2009. These budgets have already been useful in preparing for presentation of break-even analysis at the Washington Horticulture meetings and two WSU Fruit Schools to be held in February 2010.

The grower survey is being finalized and will be ready to sent out on January 1, 2010. Data from the survey are expected in March and the subsequent economic analysis will commence. The graduate student that was funded by the project, a second-year PhD student, has been very involved in planning the survey will be responsible for several of the modeling and estimation components of the analysis. We anticipate being ready to present final results of the grower survey in Fall 2010.

The work we have planned for 2010 will be presented in new project proposal to the Tree Fruit Research Commission. We will request funding to continue supporting the graduate student working on this project. It is highly likely that the work we complete for this project will suggest other topics for future research and we plan to consider those for future projects.

NEW PROJECT PROPOSAL **PROPOSED DURATION**: 1 year

Project Title: Economic analysis of technology adoption by Washington apple growers

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Cooperators: Tom Auvil – WTFRC
Karen Lewis - WSU Extension
Norman Suverly - WSU Extension

Total Project Request: **Year 1:** $17,036

Budget 1
Organization Name: SES-TFREC-WSU **Contract Administrator:** B. Weller/ML. Bricker
Relephone: 509-335-5557/335-7667 **Email address:** wellerb@wsu.edu/mdesros@wsu.edu

Item	**2010**		
Salaries	0		
Benefits	0		
Wages	15,558		
Benefits	1,478		
Equipment	0		
Supplies	0		
Travel	0		
Miscellaneous	0		
Total	**17,036**		

Footnotes:

Justification
The purpose of this research project is to determine the factors that impact technology adoption by Washington apple growers. The focus of the research will be on labor-augmenting technologies, specifically platforms. The motivation for this study was the observation that although automation and mechanization technologies are becoming more readily available to growers and positive impacts on profitability may be realized by implementing them, there is a lack of comprehensive understanding of the factors that may affect grower's decisions to invest in these technologies. Hence, the economic analysis aims to provide information that will be useful to Washington tree fruit growers as well as researchers who are focused on the future of the tree fruit industry. Moreover this study will give insights on Tree Fruit Research Commission priorities, by focusing specifically on profitability of technologies augmenting labor and improving worker safety.

Budget Justification

1. *Full-time student time-slip.* A graduate student, who has begun work on the survey by developing questions and reviewing the literature, will be working for one semester plus three summer months in 2010. Her primary tasks will be to complete survey implementation, coordinate data from the surveys, and develop an economic model to estimate.

Objectives

5. *Evaluate the economic and managerial factors that contribute to a grower's decision to adopt automation and mechanization technologies.*
    - The focus of this objective will be to evaluate the interactions of production cost structures, economies of size and scope, labor issues, and other relevant managerial strategies that define the business structure of an orchard. All the information collected from a grower survey will be used to develop a model of technology adoption by Washington tree fruit growers. Results from the economic analysis will be disseminated via industry publications, extension presentations and publications, and peer-reviewed agricultural economic publications.

6. *Use the data collected during this project to support other educational programs, decisions aids focused on technology adoption*
    - The data used to conduct the economic analysis described in this project are also required for the continuation of the Technology Economic Assessment Model (TEAM) decision aid. This software is highly dependent on up-to-date cost of production data. Therefore, all the relevant data collected in this project will be incorporated into the TEAM software with the assistance of the cooperators associated with this project.
    - The production cost data collected for this project will also be used to generate current enterprise budgets for Washington tree fruit growers. These budgets are useful to growers as benchmarks for their own profitability measures, as well as to agricultural lenders evaluating investment returns and researchers doing comparisons on cost saving technologies to existing practices in the tree fruit industry. Enterprise budgets completed thus far are being disseminated via WSU Extension publications.

7. *Establish a program for continuously collecting production and management data from tree fruit growers*
    - Collection of production costs data was completed in year 1 of this project. With the creation of a current Gala apple orchard budget and the planned update of a cherry orchard budget in December 2009, we are well on our way to establishing a portfolio

of enterprise budgets that reflect current costs or production for modern orchards in Washington.

8. *Disseminate research results to tree fruit growers, packing houses representatives, researchers from other disciplines and interested parties*
   - The extension and outreach component is crucial for this study and will enhance Extension activities of researchers Taylor and Gallardo. It would also add to collaborators Lewis and Suverly extension efforts in TEAM training.

Methods

To achieve objective 1, we will implement a grower survey that will ask relevant questions regarding cost and management decisions that may affect their decision to use labor-augmenting technologies (platforms). Data collection can be very sensitive to the survey instrument used for asking interview questions. This instrument will be carefully planned in advance of conducting the actual interviews. Input from project cooperators will be used to ensure the instrument used during interviews is efficient and effective for collecting relevant data. The extent of the research questions that can be investigated will depend on the detail of data that are collected from growers. This will be determined not only by the survey instrument, but also the level of detail that growers are able to provide. We will encourage growers to refer to any farm management records that will be helpful in answering the survey questions.

Once the survey is completed, we will use several options to model technology adoption. First, we will use an hedonic model measuring the impact of grower characteristics on technology adoption, which will be useful for understanding differences in management style or perceptions of different technologies. Second, we will follow Baerenklau (2005) and use a model of risk aversion that incorporates risk preferences of growers to measure perceived changes in risk from new technologies. Third, we will apply a more complex model of adoption choices in a dynamic decision making framework (Baerenklau and Knapp, 2007). A dynamic model will allow for information updating over time and would more accurately reflect the dynamic nature of production and management decisions made by growers in the tree fruit industry. With these models in mind, data collection will be focused on asking questions that will allow for the greatest flexibility in modeling choices.

Objective 2 will be completed using relevant information collected from a targeted group of growers representing modern orchards in across several regions of the state (Othello, Yakima, and Okanogan). For the Gala budget completed during the summer of 2009, the group was identified with the assistance of the project cooperators. A similar strategy is currently being employed to gather cost of production information from a group of cherry growers. This work is expected to be completed in early 2010.

To achieve objective 4 we will provide periodical reports of this study to the Tree Fruit Commission. Final results from this project will subsequently be submitted for publication as Washington State University Extension bulletins available at the Washington State University Extension website. These bulletins will summarize the technology adoption research mentioned above as well as case studies of growers who have chosen to adopt certain technologies with a full discussion of the economic factors that impacted their decisions. These bulletins will serve as the technical basis of a series of presentations on technology adoption by the researchers at the end of the second year of the project.

Timeline of Activities

Year 1

Jan-Feb: Survey is sent out to growers and responses are collected for subsequent analysis. Cherry budget update is completed and results are presented at WSU Fruit Schools.

Mar-May: Data cleaning, summarization, and model estimation.

Jun-Aug: Final analysis and write up of results.

Sep-Dec: Dissemination of results via industry presentation and publications as well as WSU Extension publications.

Literature Review

A great deal of research exists addressing technology adoption rates in agriculture. This literature provides a theoretical basis for investigating various questions related to adoption: economic returns to adoption, characteristics of technology adopters, and economic, political, or social hurdles to adoption (Feder, Just, and Zilberman, 1985). Despite the large literature on adoption, little research has been conducted that focuses on labor augmenting technology adoption by the tree fruit industry.

A recent study by Skolrud, et al (2008) used an aggregate approach to characterize the growth and diversification of four major agricultural industries in Washington, including the apple industry. Their analysis used U.S. Census of Agriculture data and focused on the measureable differences in the economies of size and scope for Washington orchards versus the national industry. This gives an aggregated view of economies of size and scope, which suggests a propensity to adopt technologies across the industry. However, it cannot not reveal orchard-level measures of technology adoption or the characteristics of growers who choose to adopt. The research proposed in this project will fill this information gap with more detailed orchard-level information specific to Washington's apple industry.

Ridgely and Brush (1992) studied adoption of integrated pest management (IPM) technology by California pear growers and focused on the definition of adoption and how best to measure it. They note a large existing literature that describes how technology adoption by growers is usually measured as an all-or-nothing choice, with no allowances for partial adoption or modification of technologies to fit existing orchard structures. We believe the acknowledgment that growers may adopt technologies in manners that are not exactly in line with the intent of developers could be important. Therefore, the survey we develop will ask some questions in a manner that allows respondents to describe how they use platforms, rather than just a simple yes or no question of whether or not they are used. The literature also suggests that certain social factors may play a role in technology adoption beyond measures of returns to investment: education, influence of agricultural extension, market strategy, and diversity of the operation. The methodologies given in the literature will influence the data collection process for this project with the intent of gaining a fuller understanding of technology adoption rates by Washington apple growers.

References

Baerenklau, K. "Toward and Understanding of Technology Adoption: Risk, Learning, and Neighborhood Effects." *Land Economics*. 81(2005):1-19.

Baerenklau, K. and K.C. Knapp. "Dynamics of Agricultural Technology Adoption: Age Structure, Reversibility, and Uncertainty." *American Journal of Agricultural Economics.* 89(2007): 190-201.

Feder, G., R.E. Just, and D. Zilberman. "Adoption of Agricultural Innovations in Developing Countries: A Survey." *Economic Development and Cultural Change*. 33(1985): 255-298.

Ridgely, A.M. and S.B. Brush. "Social Factors and Selective Technology Adoption: The Case of Integrated Pest Managment." *Human Organization*. 51(1992): 367-378.

Skolrud, T.D., E. O'Donoghue, C.R. Shumway, and A. Melhim. "Washington Farm Growth and Diversification." Washington State University - School of Economic Sciences Working Paper. October 2008.

FINAL PROJECT REPORT

Project Title: Rosaceae micropropagation and tissue culture platform

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Cooperators: Tom Auvil, WTFRC; Nnadozie Oraguzie, WSU; Gennaro Fazio, USDA-ARS; Herb Aldwinckle, Cornell, Geneva; Bill Howell, Northwest nursery improvement institute; Todd Einhorn, OSU; Helios Nursery - Tye Fleming and Todd Erickson

Other funding Sources

Agency Name: Helios Nursery
Amount awarded: $15,000
Notes: Funding provided for personnel and operational support in May, 2009

Agency Name: Washington State University
Amount awarded: $60,000
Notes: Funding provided for setting up a 12x10ft walk in growth room to fit tissue culture infrastructure including LED growth chambers and temporary immersion systems

Total project funding request: **30,000**

Budget History

Item	**2009**		
Salaries	18,440		
Benefits	7,560		
Wages			
Benefits			
Equipment			
Supplies	2500		
Travel	1500		
Miscellaneous			
Total	**30,000**		

Footnotes:

Note: The term "in vitro" repeatedly used in this project means "in tissue culture"; Magenta boxes are tissue culture vessels made of clear polypropylene material. It is a trademark and does not represent a magenta colored box. LED – Light Emitting Diode; RITA – Temporary immersion system

OBJECTIVES

Major goal of the project: This project addresses the ever-increasing time gap between development of new rootstock or scion genotypes by several breeding programs and their commercial utilization by the growers. This delay represents a financial burden both to the program that develops them and the fruit industry.

The original objectives of the proposal were:

1. Refine or formulate micropropagation protocols for Geneva rootstocks (apple), Pear rootstock OH x F and Polish Quince (Pear)
    - Objective 1A: Finalize the protocol for obtaining rooted rootstocks of G41 and develop similar protocols for G935 apple, OH x F and Pear Quince rootstocks.
    - Objective 1B: Third-party validation of the micropropagation protocols.
    - Objective 1C: Perform a cost-analysis of agar-based or temporary immersion system protocols to assess implementation of the methods in a commercial setting.
2. Define special light conditions for micropropagation of rootstocks and scions.
    - Objective 2A: Identify the most efficient light wavelength combinations for apple and pear rootstocks.
    - Objective 2B: Assess the cost-benefits of utilizing specialized growth chambers in micropropagation.
3. Transition the micropropagation research to the field – sustaining the Rosaceae micropropagation platform.

The objectives were revised as the funding from WTFRC was adjusted and a post-doctoral research scientist could not be hired at the start of the project.

Revised Objectives

Objective 1: Rootstock production: Finalize the protocol for obtaining rooted rootstocks of G41

Objective 2: Rootstock acclimatization: Establish protocols for transfer of material from the lab to the green house

Objective 3: Standardize micropropagation of G-935 (apple), OHXF 87 (pear) and Gisela 6 (Cherry)

SIGNIGFICANT FINDINGS

Apple rootstock:

Geneva 41 rootstock propagation has moved all the way to the greenhouse tests. We have tested first batch of micropropagated plant material in mist beds achieving a survival rate of 65%. These plants were not rooted in the lab but directly transferred to the greenhouse.

Rooting standardized:

We have also worked on resolving the rooting issue with G-41. In tissue culture plants, we can now obtain 100% rooting of explants. Tissue culture media established for G-41 was tested on G-935 micropropagation. The G-935 genotype does not respond well to G-41 media. There is a need for new media formulations for G-935. We have made progress on G-935 micropropagation in agar and are able to achieve 4-6X multiplication on temporary immersion system-based micropropagation.

Pear rootstock:
We have established OHXF 87 micropropagation system both in agar as well as in temporary immersion system. In addition, we have also obtained rooted pear rootstocks.

Cherry rootstock:
Four rootstocks namely Gisela 5, 6, 12 and Krympsk have been successfully established in agar based media. We are able to obtain multiple shoot formation.

RESULTS AND DISCUSSION

Objective 1: Rootstock production: Finalize the protocol for obtaining rooted rootstocks of G41.
Personnel:
Scott Schaeffer – Graduate student funded through an NIH fellowship assisted in project coordination.
Undergraduate students: Salma Tariq, Maureen McFerson, Tammy McGrath, David Rockefeller

An in vitro liner consisting of 4 nodes is placed horizontally on the tissue culture media. After 6-8 weeks when each node develops into one or two individual shoots, the basal liner tissue is excised. Individual shoots are moved to rooting media placed in square transparent boxes called Magenta boxes. The normal light conditions are the conditions used in tissue culture room with 30 micro moles per m2 per sec with 16h day and 8 h dark periods. Under these conditions the rooting media used was supplemented with IBA and no sucrose.

Rooting has been obtained by using modified nutrient salts (MS media) and IBA. Prolific root formation is observed in 4 weeks.

1. Geneva – 41 rootstock micropropagation pipeline is in place. We have established that each new genotype of apple rootstock requires special media formulation. This would explain lack of success in micropropagation in other labs.
A rooted G-41 explant can be obtained in 8-10 weeks with our method. Figure 1 shows a rooted G-41 rootstock after 10 weeks from start of micropropagation.

Figure 1: Rooted G-41 in rockwool placed in liquid rooting media.

2. Geneva – 935 rootstock. As mentioned above, G-935 needs its own media formulation. A derivative media of G-41 has been utilized to multiply G-935 successfully.

The table below summarizes the number of plants currently in the laboratory for G-41 and G-935. All data is tabulated starting August 2009.

Most of the G-41 plants available are in clumps with each clump having at least 3-4 individual shoots. Prior to next subculture, the plants will be divided into individual shoots and placed on media to be stored at 40 deg F for providing chilling requirement. APM is the shoot regeneration media for G-41 and RITA is the temporary immersion system. G-41 is hard to elongate after initiation and most of our efforts have been to devise media or methods to enable elongation of the individual plants.

Date	Step Taken	Total Number of Plants on agar	Amount of time	Multiplication Factor
8/31/2009	Initiation in solid APM	100	1 month	~*3
9/24/2009	elongation in solid APM	293	1 month	
11/5/2009	elongation in solid APM	290	current	

G-41 (11/20/09)	Total plants
Solid APM	290
Rita System	0
Glass Beads	0
Rock Wool	0
	290 clumps

Similarly for G-935 plants where we recently had good success in rapidly multiplying plants in agar, the numbers are tabulated below. RG is the shoot regeneration media and RITA is the temporary immersion system. The individual plants counted here are clumps of 2 or 3 individual shoots. Not all steps listed below are for multiplication.

Date	Step Taken	Total Number of Plants	Amount of time	Multiplication Factor
8/11/2009	Initiation in solid RG	20	1 week	
8/20/2009	Multiplication in Rita (liquid RG media)	40	2 weeks	2X
9/9/2009	liquid RG Starch and sorbitol	40	1 week	0
9/14/2009	Glass beads	40	1 week	Contamination
9/18/2009	Rock Wool	1	Still in rock wool	
8/19/2009	Initiation in solid RG media	20	2 weeks	
8/24/2009	Multiplication in Rita (liquid RG)	40	2 weeks	2X
9/9/909	liquid RG Starch and sorbitol	40	1 week	
9/16/2009	Glass beads	20	1 week	
9/28/2009	Rock Wool	2	Still in rock wool	
9/22/2009	Initiation in solid RG media	20	7 weeks	
10/1/2009	multiplication in RITA (liquid media)	40	2 weeks	2X
10/16/2009	liquid RG starch and sorbitol	80	1 week	
10/23/2009	Glass beads	40	1 week	
11/2/2009	Rock Wool	10	1 week	

10/9/2009	Initiation in solid RG	18	8 weeks
10/22/2009	Multiplication in Rita(liquid RG)	120 (80 plants still in Rita)	2 weeks
11/2/2009	Glass Beads	40	

G-935	Total plants
Solid RG	340
Rita System	80
Glass Beads	40
Rock Wool	15
	475 clumps

Objective 2: Rootstock acclimatization: Establish protocols for transfer of material from the lab to the green house.

One of the major reasons for tissue culture derived plant mortality is sudden drop in relative humidity. To avoid humidity related mortality, the explants will be moved towards rooting while enclosed in Magenta boxes. In cooperation with Tye Fleming and Todd Erickson, multiplied rootstock shoots were moved to mist beds to be tested for survival. It was found that 65% of the plants survived.

Objective 3: Standardize micropropagation of G-935 (apple), OHXF 87 (pear) and Gisela 6 (Cherry)
Personnel:
Tyson Koepke, Derick Jiwan and Chris Hendrickson – Graduate students assisted in project coordination.
Undergraduate students: Noelle Podlich, Ashley Koepke, Matt Allan, Jake Abel, Aaron White, Valeria Lopez-Lozano, Amanda Medina, Christina Duncan and Cory Druffel

The micropropagation of G-935, OHXF 87 and Gisela 5, 6 and 12 is well standardized.

News from other micropropagators: Gennaro Fazio is planning a teleconference to put together a combined teleconference to measure our individual progress on micropropagation of G-41 and other Geneva roots. Currently no other information is available to us regarding what other groups are doing.

Role of Cooperators:

Previous Cooperators: These cooperators were listed for the original project. However, in the currently revised framework we will only work with Tom Auvil and Gennaro Fazio.
Tom Auvil, WTFRC – Coordinate tissue culture activities with the nursery industry and enable acclimatization of tissue culture derived plant material.
Nnadozie Oraguzie, WSU – Identify scions and rootstocks that should be multiplied in vitro to support the breeding program activities.
Gennaro Fazio, USDA-ARS – Implementation of standardized protocol to commercial nurseries.
Herb Aldwinckle, Cornell, Geneva – Validation of protocols established in our laboratory.
Bill Howell, Northwest nursery improvement institute – Supporting the research activities based on micropropagation and utilizing in vitro multiplied rootstocks in orchards.
Todd Einhorn, OSU – Micropropagation of Quince rootstocks.

New cooperators: Tye Felming and Todd Erickson
Tye Fleming and Todd Erickson will utilize in vitro multiplied G-41 rootstocks and help in greenhouse based rooting and acclimatization. We have tested a set of G-41 roots and have been in contact for future transfer of materials.

CAHNRS Undergraduate Research funding:

There are two undergraduate students working on this project under supervision of Amit Dhingra and Scott Schaeffer. Salma Tariq and Maureen McFerson are heading the G-41 and G-935 projects respectively. The project was selected for CAHNRS Undergraduate Research Fellowship and will specifically support establishment of rooting under RBG light spectra. The results were presented at the annual CAHNRS awards banquet on April 4th 2009. The results of this project were presented at the annual Sunrise Orchard Field day.

Executive Summary

Overview: Micropropagation of new rootstocks and scions takes substantial experimentation especially for difficult genotypes. Over the past two years of funding, our program has formulated media specific to some of the desirable rootstocks and scions of apple, pear and cherry. In addition, we have built infrastructure like Temporary immersion systems and LED-growth chambers to accelerate plant growth. We are now set to utilize carbon dioxide in our growth systems to accelerate plant growth even more without the impediment of vitrification and other tissue culture stresses.

Progress: We have over 290 G-41 and 475 G-935 plants. They have not crashed in growth. However, in order to avoid any such issues all the tissue culture plants will be transferred to 40 deg F for a month to provide chilling requirement. We are excited about our success with sweet cherry scion and rootstock progress. A total of 4 rootstocks have been multiplied in agar-based media. In Pears, only OHXF 87 has been tested and successfully multiplied. We have also tied up with the nursery industry to take the methods from the lab to the field. A total of 110 G-41 plants were tested. Additional plants have not been tested as we are in the stage of multiplying more roots. The plants tested in the nursery were derived from agar based media as well as RITA system. There were four treatments that worked for plants multiplied in RITA system. This method needs to be refined further but holds most promise in terms of speed and multiplication capacity.

Future Direction:
Resources: WSU has provided $60,000 for renovation of a freezer into a growth room specifically for supporting our tissue culture activities. Currently we are constrained by space that limits how many roots we can produce. With the new facilities that will not be an issue and we can expand our production capacity.
Funding: With all the methods established we are all set to take the next step. However, there is a need for a full time scientist to assist us in multiplying all roots in large numbers for experimental work. These funds were requested last time but not granted. The funds obtained from WTFRC and Helios Nursery were used to hire several undergraduate students to continue the work on method development and meet the revised objectives. Most of these undergraduate students are enrolled in 18-hour credits at WSU. A post-baccalaureate Physics student was also hired to develop LED-based growth chambers as well. Helios Nursery funding arrived when we were four months into the project and it was impossible to hire a post-doc for 8 months.

Plan for sustaining the micropropagation platform:
The methods developed in the laboratory are the property of WSU. We are very eager to share these with willing partners. The University is extremely flexible in any arrangements we want to make. Our vision is to utilize these methods to provide a rapid multiplication system to our industry. In return a revenue stream of 5 cents per every plant sold can come back to the program to sustain future research. To realize this potential we require at least three years of committed funding to support a scientist and undergraduate students with some operation funds.

FINAL PROJECT REPORT

Project Title: Investigating flower bud hardiness of new tree fruit cultivars

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Cooperators: David Ophardt, Markus Keller, Lynn Mills

Other funding sources: None

Total Project Funding:

Budget History:

Item	Year 1: 2009	Year 2:	Year 3:
Salaries	$12,479		
Benefits	$10,358		
Wages			
Benefits			
Equipment	$12,163		
Supplies			
Travel			
Miscellaneous			
Total	**$35,000**		

Footnotes: salaries include an Associate in Research (@ 42% FTE plus benefits at 83%) responsible for region-wide program coordination, bud collection, data collection and analyses, development of extension material, and equipment maintenance and oversight. Equipment includes a Tenney T2 temperature test chamber with installed humidity control, datalogger, thermoelectric modules and a computer.

OBJECTIVES:

The objectives of this research project directly address the second highest rated research priority of the cherry industry[1], bud hardiness.

1. Establish new fruit bud hardiness standards by phenotyping several genotypes throughout the dormant season and anthesis

2. Partner with DAS to disseminate bud hardiness data to industry as rapidly and conveniently as possible

3. Develop preliminary data and framework for pursuing federally-competitive funding for further research & outreach

SIGNIFICANT FINDINGS:

- differential thermal analysis (DTA) is an effective method for determining dormant cherry and apple bud hardiness
- cherry and apple cultivars exhibit significant variability in hardiness
- DTA is not effective when buds lose hardiness in mid-March
- we can double the capacity for DTA in the freezer from 35 plates to 70 plates
- there is tremendous variability (≈ 20 F) in hardiness among buds on a tree/limb/spur
- Delicious and Golden Delicious were advanced in flowering compared to Gala and Fuji
- Bing, Chelan, and Sweetheart were similar in flowering and advanced compared to Benton
- Overall, Sweetheart was the least hardy cultivar and Benton was the most hardy
- Fuji was overall the least hardy cultivar and Gala was the most hardy
- Hardiness is gained and lost during bloom, depending upon temperature

RESULTS AND DISCUSSION:

We have confirmed the effectiveness of differential thermal analysis for assessing apple and cherry bud hardiness, using our newly setup freezer system. Clearly discernible high and low temperature exotherms are observable (data not shown) and up to 5 dormant buds can be measured per analysis plate. With modification however we were able to double the capacity of the freezer and utilize up to 70 plates. This will allow greater replication and the ability to compare more cultivars at once, up to ca. 350 buds per freezer run. The exotherm data can be analyzed and presented as LT_{10}, LT_{50}, and LT_{90} readily (Fig. 1). From discussions with growers it is clear that LT_{10} is the most relevant data for frost protection decision-making. We posted on our website the up to date LT_{10} under the "what's new" section.

We have identified significant differences among cherry cultivars in their minimum hardiness level (Fig. 2). It appears, from our preliminary analyses, that 'Chelan' is hardier than other test cultivars and that 'Sweetheart' is the least hardy. There is about a 12 F (6.5 ^{o}C) difference among the cultivars tested in their LT_{50} (Fig. 2). These relative differences did not persist during budbreak and flowering however.

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[1] Cherry Industry Priority Setting Session, Prosser, WA, 19 August, 2008

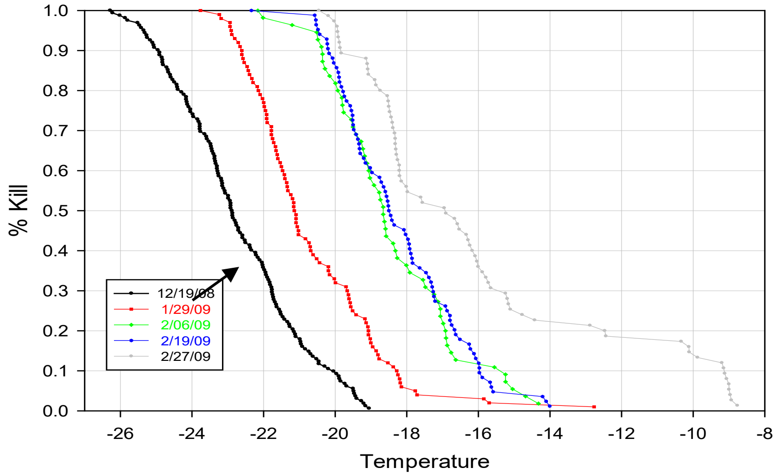

Figure 1. Variability in 'Chelan' fruit bud hardiness over time. Each data point is a recorded low temperature exotherm. Arrow indicates LT_{50} on 12 Dec.

Interestingly, we observed significant variability in hardiness of individual buds within a tree. This hardiness range was as high as 18 F (10 ºC) between the temperature which killed the least hardy flower to the temperature which killed the hardiest flower. Among flowers within a single bud however, there is very little variability in hardiness (i.e., all flowers are killed at a similar temperature, ±0.2 F). This phenotypic diversity in hardiness within a tree/limb/spur is an issue we intend to pursue further.

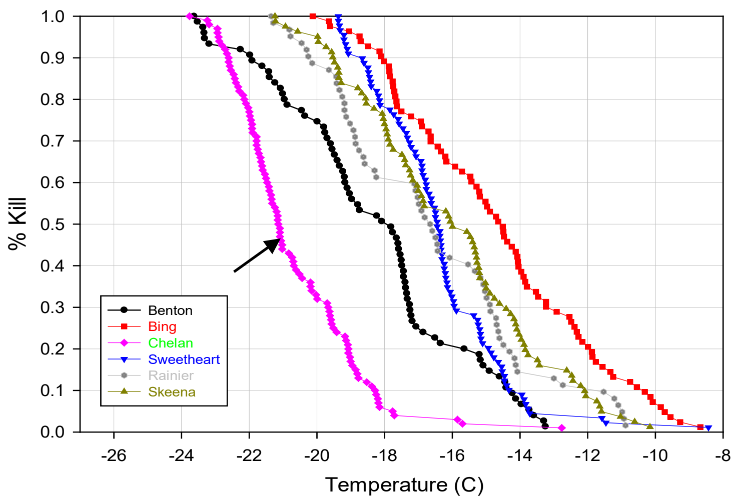

Figure 2. Comparison of fruit bud hardiness among sweet cherry cultivars. Hardiness was assessed on 29 Jan. 2009. Each data point is a recorded low temperature exotherm. Arrow indicates LT_{50} of 'Chelan'.

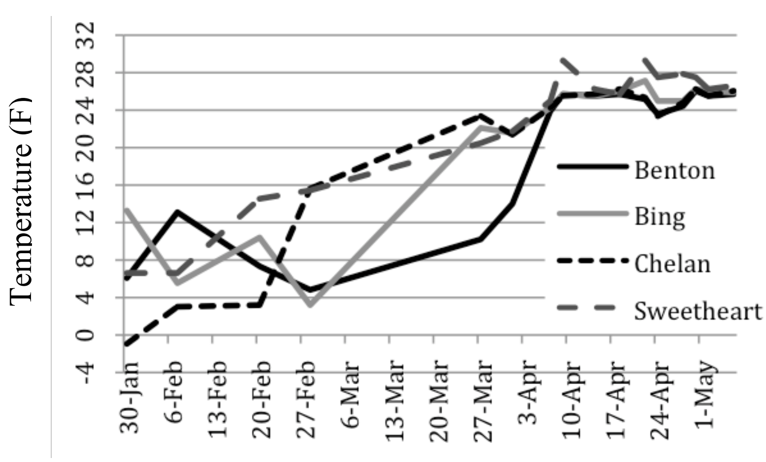

Figure 3. Comparison of LT_{10} of fruit bud and pistils among sweet cherry cultivars. Data prior to 26 March are low temperature exotherms. Data after 26 March are observational for pistil death.

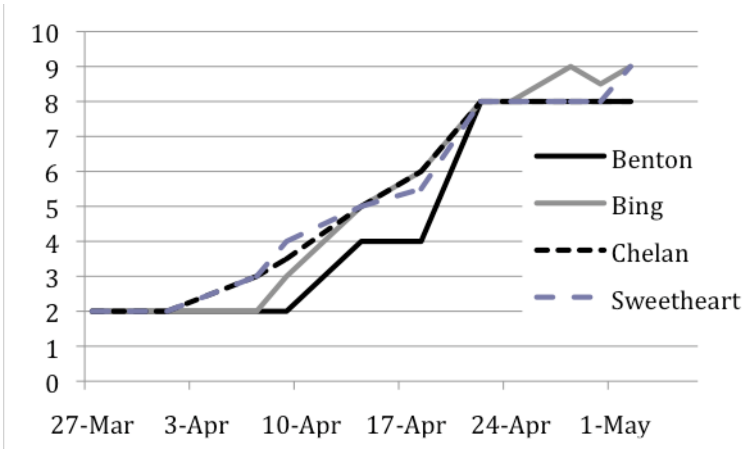

Figure 4. Comparison of fruit bud/flower development among sweet cherry cultivars.

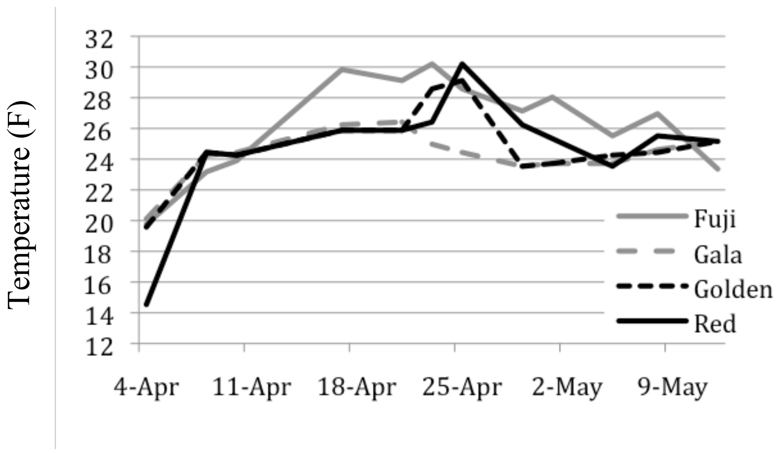

Figure 5. Comparison of LT_{10} of fruit bud and pistils among apple cultivars. Data are observational for pistil death.

We recorded subtle variability among apple cultivars in their hardiness prior to bloom (Fig. 5). Differences became apparent in mid-April with Fuji losing hardiness rapidly compared to other cultivars. Interestingly, the warm weather in mid-April caused a loss of hardiness for Delicious and Golden Delicious but not for Fuji and Gala.

EXECUTIVE SUMMARY

This project has documented the hardiness of dormant buds of economically important apple and cherry cultivars. We have built and utilized a system for determining dormant tissue hardiness by differential thermal analysis. We have documented variability in minimal hardiness level among cherry cultivars with Chelan exhibiting the greatest hardiness and Sweetheart the least. We have identified a range in bud hardiness of ca. 18 F among buds sampled on the same date. The next steps for this research are to 1) model bloom development with appropriate environmental data, 2) relate stage of bloom development with susceptibility to cold damage, 3) better understand factors accounting for the variability in hardiness among bus/flowers, and 4) disseminate hardiness data effectively.

FINAL PROJECT REPORT

Project Title: Robot scout for tree fruit

PI: Tony Koselka
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Cooperators: Sanjiv Singh, Carnegie Mellon University

Other funding sources

Agency Name: USDA
Amount awarded: $250,000
Notes: Part of the SCRI, CASC project

Total Project Funding: $200,000

Budget History:

Item	2009
Salaries	$117,985
Benefits	$45,000
Wages	
Benefits	
Equipment	
Supplies	
Travel	$19,061
Materials and CMU Sub-contract	$17,661
Miscellaneous	$293
Total	**$200,000**

OBJECTIVES

2009 was the first year of a three-year project to develop a Scout system for crop load estimation, with the goals of improving the crop load estimates and creating a market-ready system; the project builds upon earlier work where VRC demonstrated a proof of concept Scout, detecting and sizing apples in production orchards. Vision Robotics' 2009 goals were to advance the project in three directions:

1. Refine and improve the detection performance
2. Build the next generation Scout prototype (hardware)
3. Integrate with other systems under development as part of the Specialty Crop Research Initiative's (SCRI) Comprehensive Automation of Specialty Crops (CASC) project.

The task of improving the detection has many parts, the specifics of which were not all known at the beginning of the project. However, prior work had identified the need to enhance the lighting system to enable robust operation regardless of the environmental conditions. Thus, a goal in 2009 was to introduce enhancements to both the hardware and the software to combat difficult lighting situations. Additionally, the software was to be refined to, in general, improve the detection algorithms.

The main 2009 objective for the next generation Scout mechanical prototype was to design and build a system which was rugged and robust like true farming equipment, and would be towed by typical farm machines. This includes a start at weatherization. The next generation Scout should:

1. Operate at speeds up to approximately 1 mphFunction in all lighting conditions Mechanically reflect the production design, with the capability of two-sided operation; however only a single mast mounted on one side would be used in 2009.

The main goal for integration with other CASC projects in 2009 was to couple the Scout with Carnegie Mellon University's Autonomous Prime Mover (APM). The APM would serve as the towing vehicle for the Scout and would issue basic commands to the Scout, directing the start and stop of scanning. Additionally, the APM would provide GPS information to the Scout so that GPS referenced data could be produced for inclusion in a GIS database.

This project will enable the creation of a pre-production Scout in 2010 – 2011. The Scout will provide valuable data for use in precision farming and is a significant step towards mechanization.

SIGNIFICANT FINDINGS

During the course of the project, Vision Robotics made substantial progress with respect to the three main 2009 goals and thus towards its ultimate goal of a production Scout. More specifically, at the conclusion of this year's project:

- The crop estimation performance has improved through the use both software and hardware refinements, in particular through the use of flash units
    - In the Jazz apple scan, computer derived crop load estimates had an error of less than 2%
    - Nearly 100% of the apples were visible to the human eye in images captured by the Scout cameras
- A robust, full Scout prototype has been constructed
- Basic integration with the Carnegie Mellon University's Autonomous Prime Mover has been achieved.
- All aspects of a commercial apple Scout are now proven

RESULTS & DISCUSSION

Improved Estimation Performance

To achieve the 2009 goal of improving performance of this system's crop load estimation, both the Scout hardware and software underwent modifications. Experiments were then conducted to test the effectiveness of the enhancements and evaluate the system as a whole. This section describes the refinements and the setup used to evaluate the system. It then presents and analyzes performance results. Finally, some comments on processing times are presented.

Hardware Refinements

One class of modifications to the Scout hardware to improve estimation performance was introduced to improve the camera and lighting systems. First, a new generation of cameras was developed to increase image quality and facilitate the use of different contexts, where a context is a set of camera settings which can be dynamically controlled by the Scout software; the system utilizes multiple contexts to adapt to varying lighting conditions. Figure 1 shows results of preliminary testing done to validate the potential of the use of multiple contexts, showing the difference in visibility that can be achieved.

Figure 1: Two pairs of pictures taken at high and low exposure levels.

Next, a visor consisting of a flat plate with rectangular viewing holes was placed in front of each camera to shield the camera lenses from oblique and direct sunlight, which can cause flaring. Figure 2 shows the results of preliminary testing done to validate the use of the visor, showing the achieved reduction of flaring. When coupled with the camera mast's pivoting capability, the amount of time in which the sun directly strikes the camera lenses can be significantly reduced.

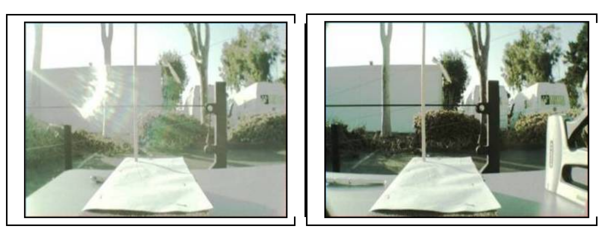

Figure 2: Effect of flaring on image quality.

The final and key enhancement to the Scout hardware was the introduction of flash units to provide active illumination of the fruit to be counted. A flash normalizes the lighting throughout an entire image and provides a consistent lighting situation that is largely independent of the ambient light. Figure 3 gives an example of the difference between a non-flash and a flash image. As seen in the figure, the use of a flash when imaging green apples makes the apples stand out significantly against the remainder of the tree. It is clear visually that this result has major impact in improving the performance of crop load estimation for green apples.

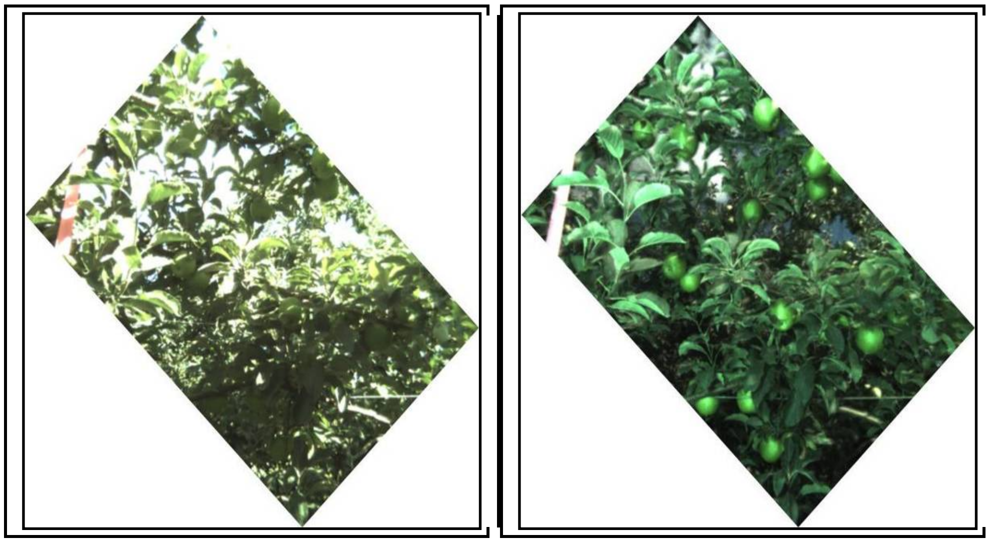

Figure 3; Similar pictures taken without and with a flash.

Software Refinements

To estimate a crop load, the Scout software analyzes the images captured by the mast cameras, searching for apples contained within. This detection consists of two main software components, which are referred to as the back and and the front end of the detection algorithm. The front end considers images on an individual basis and classifies regions which could potentially be parts of apples. Combining information from left and right stereo image pairs, it passes a list of candidate apples to the back end portion of the software. The back end portion tracks these candidate apples between frames and across cameras, and ultimately decides which candidate apples are actual apples. Both the front and back ends of the software were improved during 2009. For the case of green apples, the introduction of the flash units allowed the front end processing to use the same approach for both red and green apple classification, as opposed to an alternate, slower method that was used in past years for green apples.

Setup of Evaluation

To determine the performance of the Scout system, a field test in each of July and September was conducted in central Washington. In each case, the Scout primarily scanned two, one hundred foot sections of rows for each two varieties, Fiji and Red Delicious in July and Jazz and Granny Smith in September. Figure 4 shows representative pictures of the trees scanned during the second field tests, which were conducted at the Allan Brothers' orchard in Othello; the first tests were conducted at the Valley Fruit Orchards near Royal City. The Jazz sections used vertical trellises and contained relatively sparsely growing apples in a thin canopy. Conversely, the Granny Smith sections used the angled-V configuration and contained fruit which were growing in tight clusters with a dense canopy.

Figure 4: Trees used for field tests.

To enable a concrete analysis, a team from the WTFRC collected data from 100' sections in each of the four rows. Each 100' section was divided into segments, and the number and size of apples contained within each was recorded. Table 1 gives the collected yield information.

Table 1: Hand collected yields for the four 100' test sections.

Row Description	Number of Apples
Jazz – Row 1	393
Jazz – Row 2	678
Granny Smith – Row 1	1748
Granny Smith – Row 2	2209

Evaluation Results and Analysis

The Scout scanned each of the four test sections multiple times in order to experience different lighting conditions as well as examine the effects of various system configuration parameters. During each scan, the scout simultaneously (between cameras) and continuously (in time) captured images with eight pairs of stereo-cameras (16 cameras total) at approximately eight frames per second. Up to five different camera contexts were employed, some of which included the synchronized flash. Upon further analysis of the data, it was determined that the uppermost cameras on the mast were tilted too far downwards to properly image the tallest portions of the trees. This issue should be solved by simply tilting these cameras correctly, and thus the comparisons with the hand collected data made in this section exclude this region.

The first aspect of the Scout system which was evaluated was the ability of the cameras to capture images which were deemed to contain enough information for the software to provide crop load estimates. Images from an approximately 15' long portion of one Jazz and one Granny Smith section were examined by hand to determine a count of the number of apples that were human-identifiable in the images captures by the Scout. The hand examination consisted of reviewing pictures from all eight camera pairs and distinguishing unique from duplicate apples between cameras (since the cameras have overlapping fields of view), as well as following apples in successive images captures by individual camera pairs as the Scout moves down the row. Consequently, this evaluation was limited to 15'. Table 2 tabulates the number of apples identified by a human from the images in each of the five approximately 3' sections comprising the 15' portion for the Jazz section, as well as the true hand counts. Table 3 contains the corresponding results for 15' of the Granny Smith section. Averaging over the five sections, it is seen that the Scout system collected images in which a human could identify 91.53% and 98.77% of the actual fruit for the Jazz and Granny Smith sections, respectively. Consequently, with strong software performance, the Scout should be capable of producing accurate crop load estimates.

Table 2: Count of apples identified by a human in captured images and true count for the Jazz section.

	Section 0 - 1	Section 1 - 2	Section 2 - 3	Section 3 - 4	Section 4 - 5
Apples Counted In Images	9	19	11	4	11
True Counts	9	20	13	4	13

Table 3: Count of apples identified by a human in captured images and true count for the Granny Smith section.

	Section 0 - 1	Section 1 - 2	Section 2 - 3	Section 3 - 4	Section 4 - 5
Apples Counted In Images	26	37	36	39	22
True Counts	27	37	36	39	23

The next portion of the Scout system to be evaluated was the front end portion of the estimation software. To do so, 33 images were selected at random from scans of one of the Jazz sections and another set for scans of one of the Granny Smith sections. For each image, a human identified the number of human-visible fruit which were correctly detected by the software and the total number of human-visible apples. A representative image for this analysis is given in Figure 5. Here, squares denote regions of the image which were marked by the front end processing as candidate portions of apples. As can be seen in the image, the front end admits many more regions than are truly apples (since the back end will determine which are true apples based on information across multiple frames) with very few missed fruit. The total numbers of fruit and correctly detected fruit are given in Table 4.

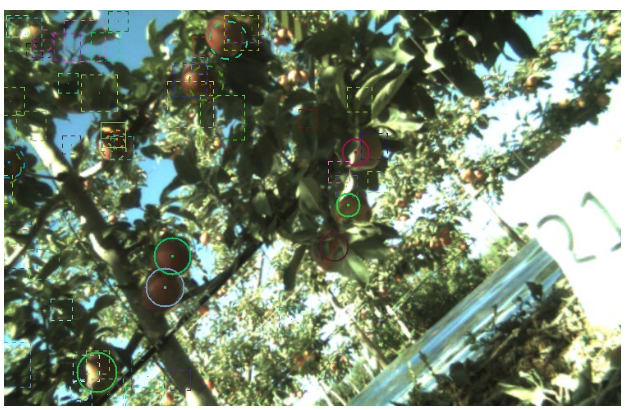

Figure 5: Representative image showing regions identified by the front end processing (squares) and regions remaining after the back end processing (circles).

Table 4: Counts of total and number of fruit correctly detected by the front end for the Jazz section.

Apple Variety	Total Apples	Number Correctly Detected in Front End
Jazz	169	169

The next stage in analyzing the system performance was to determine the number of human-identifiable apples that were correctly identified by the back end portion of the software as well as the number false positives produced by the system, as identified by a human. Due to time considerations, analysis was restricted to the Jazz section, with the same 33 randomly selected images. A representative images is given in Figure 5. Here, solid circles represent apples identified by the back end portion of the software. The total numbers of fruit, correctly detected fruit, and falsely detected fruit in the analyzed images are given in Table 5. Falsely detected fruit are primarily caused by misalignment between camera pairs and the fact that the background dirt is red in color; both issues are easily resolved.

Figure 5: Representative image showing apples identified by the (back end) software.

Table 5: Counts of total, correctly detected, and falsely detected fruit for the Jazz section.

Apple Variety	Total Apples	Number Correctly Detected in Back End	Number Falsely Detected in Back End
Jazz	169	155	27

The final analysis performed on the crop load estimation aspect of the Scout system was to compare the load estimates produced by the software with the true values determined by the WTFRC team. Table 6 gives the load estimate and hand-collected yield for the first five of the approximately 3' wide segments of one of the Jazz test sections, while Table 7 gives the corresponding results for one of the Granny Smith test sections. The average relative error

$$\frac{\left(estimated\ yield - true\ yield\right)}{true\ yield}$$

in the crop load estimate over the entire 100' sections segments was 1.77% the Jazz section. For the Granny Smith section, only the first five segments have currently been analyzed, however, the average relatively error in crop load was -14.81%. For the Jazz sections, the estimates were observed to be above and below the true counts per 3' region, suggesting a close match to the true yield distribution. For the Granny Smith sections, the estimates tended to be lower than the true counts, in part due to the software missing individual fruit in the centers of large clusters. These observations help guide the planned improvements to the estimation software. It is believed that, in addition to enhancements to both the front and back ends of the software, the incorporation of a statistical model will improve load estimates, particularly for fruit growing in clumps. The potential value of accurate crop load estimates is illustrated by observing the variation in true yield from row to row as given in Table 1; thus, hand counting a small region of an orchard may not be representative of the crop load as a whole.

Table 6: Crop load estimate and actual crop load for first five 3' regions from the Jazz section.

	Section 0 – 1	Section 1 – 2	Section 2 – 3	Section 3 – 4	Section 4 – 5
Yield Estimate	7	22	10	5	12
True Yield	9	20	13	4	13

Table 7: Crop load estimate and actual crop load for first five 3' regions from the Granny Smith section.

	Section 0 – 1	Section 1 – 2	Section 2 – 3	Section 3 – 4	Section 4 – 5
Yield Estimate	23	29	36	31	19
True Yield	27	37	36	39	23

An evaluation of the sizing ability of the Scout software was also performed. More specifically, a distribution of apple sizes was determined for both the 100' Jazz and Granny Smith sections. The estimated means and standard deviations, in meters, for the Jazz and Granny Smith sections were 0.0303 and 0.0062, and 0.0294 and 0.0043, respectively, while the corresponding values for the true data were 0.0369 and 0.0039, and 0.0370 and 0.0027. These distributions are plotted in Figures 6 and 7 for the Jazz and Granny Smith sections, respectively, along with the distribution of the hand collected data. Comparing the estimated distribution with the true curve illustrates that the sizing estimates appear slightly low. It is believed that, in addition to refinements to the underlying sizing algorithms, the future introduction of statistical models into the sizing estimation will improve the accuracy of the estimates.

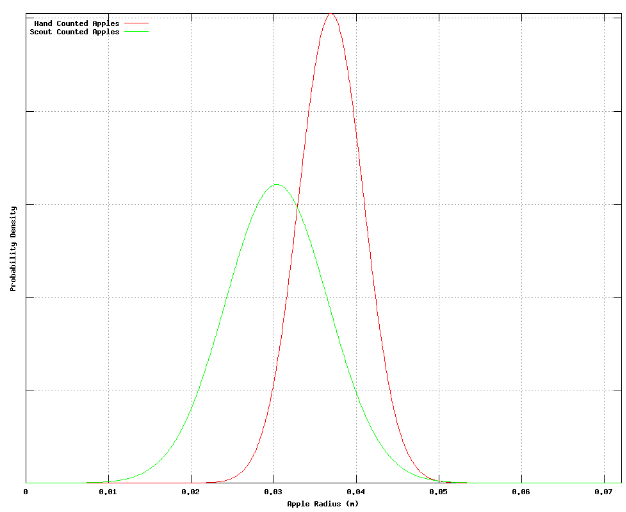

Figure 6: Estimated and true distributions of apple sizes for the Jazz section.

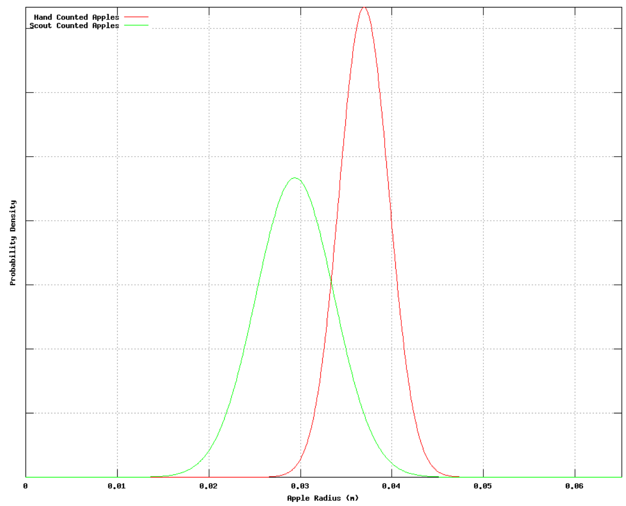

Figure 7: Estimated and true distributions of apple sizes for the Granny Smith section.

Processing Time

Currently, the Scout captures data in real-time to be processed offline. In production, processing will occur in near real-time. Currently, the analysis software is approximately an order of magnitude slower than real-time. This factor, however, represents a substantial performance improvement over past years for the case of green apples, which was made possible by the use of the flash units. Our analysis concludes that through major software optimization near real-time operation should be possible with current computers. However, Intel, AMD, ASUS and other semiconductor manufacturers have recently introduced and announced processors specifically aimed at this type of analysis. For example, the Intel Larrabee processor is approximately five times as powerful for this type of analysis as the computers currently being used. This new class of processors significantly reduces the amount of optimization required to reach production, saving both time and development cost.

Construction of Full Scout Prototype

The 2009 goal of designing and building a new Scout prototype, as shown in Figure 8, was achieved. This section describes some of the attributes incorporated into the new design. A goal in the development was to create a prototype which was a solid evolutionary step between the proof-of-concept prototype and a finished production design. The basic platform will remain the same for the remainder of the project, and new and refined sub-systems will be incorporated as they become available.

The platform is a trailer that is easy to convert from four-wheeled (for scouting) to two-wheeled (for road towing). As requested by the Commission, the Scout is electrically powered with a generator integrated into the design. While VRC only used a single mast in 2009, the new hardware has mountings for masts on both sides for future use. The mast can be moved in-and-out, tilted and pivoted through adjustable steel bracing.

The production Scout will be fully weatherized, and many of the production features were implemented this year. The camera mast is the biggest exception because the adjustability required this year made it impractical to seal, but it will be weatherized in the future. Also, active cooling was specifically not included in this year's project. As such, the computers experienced overheating in the high temperatures during the summer field tests. This issue will be addressed in 2010.

During the July field tests in Royal City, the Scout completed several runs being towed at speeds in excess of 1 mph and as fast as 2.5 mph. The images at 1 mph were of quality sufficient for crop load estimation.

The flash units used in the new prototype were selected for their adjustability and high power intensity, which were desired for design and testing purposes. However, these units are designed for photography and their use on the Scout exceeded their design capabilities with respect to flash rate. Fortunately, their full intensity was not utilized and, moreover, the intensity which proved most effective is within the capability of industrial LED flashes, which are practical for incorporating into a production Scout.

Figure 8: 2009 Scout Prototype.

<u>Integration with CASC Project</u>

As part of the CASC project, the Scout was integrated with the Carnegie Mellon APM. The APM was used exclusively and successfully to tow the Scout during the three day field test in Royal City in July.

Control information, signals to direct the Scout to either start or stop collecting data, was sent from the APM to the Scout using an Ethernet connection. This information allowed the Scout to only capture and analyze data when the APM was moving down a row, and allowed the Scout to be paused and resumed if warranted.

GPS information was also passed from the APM to the Scout to enable accurate land based reference of the data collected for each orchard. This data can also be used to better determine the positions of the Scout's cameras, which is relevant information when detecting fruit. Additionally, GPS data allows the crop load estimates output by the Scout software to be more easily tied to particular locations within an orchard, through the use of real-world coordinate information. Moreover, such information will more easily allow the inclusion of the data output by the Scout in GIS databases. Also as part of the CASC project, CMU is working on such a GIS database, and Scout will output data in a format that will allow statistics to be observed on a 0.5 meter scale.

Summary of Results

The three main goals in 2009 for the robotic Scout for tree fruit of improving estimation performance, constructing a full hardware prototype, and integrating the Scout with other members of the CASC project have all had significant success this past year. Basic integration with the CMU APM was achieved, and the groundwork for further information transfer has been laid. The new Scout prototype has demonstrated robust operation and is a strong step towards a production versions. While numerically the crop load and sizing estimation performance has room for improvement, the refined lighting system, in particular due to the significant benefits of the flash units, along with accompanying software enhancements yielded a vast step forwards from previous years. Moreover, limitations of the current approaches have been identified and a plan for both software and hardware refinements is already in place. Thus, it is believed that the Scout system will achieve its ultimate goal of providing valuable, accurate information that can assist both in areas such as harvest timing and precision farming.

EXECUTIVE SUMMARY

2009 was the first year of a three-year project to develop a crop load estimation system. Previous work demonstrated a proof of concept Scout, detecting and sizing apples in production orchards. This year's goals were to advance the project in three directions:

1. Refine and improve the detection performance including operation in difficult lighting conditions.
2. Build the next generation Scout prototype (hardware).
3. Integrate with other CASC project sub-system.

During the course of the project, Vision Robotics made significant progress towards its ultimate goal of a production Scout including improved apple detection and sizing including operation in all lighting conditions; a robust, full Scout prototype; and integration with the Carnegie Mellon University's Autonomous Prime Mover. In particular:

- The crop estimation performance has improved through the use both software and hardware refinements, in particular through the use of flash units
    - In the Jazz apple scan, computer derived crop load estimates had an error of less than 2%
    - Nearly 100% of the apples were visible to the human eye in images captured by the Scout cameras
- A robust, full Scout prototype has been constructed
- Basic integration with the Carnegie Mellon University's Autonomous Prime Mover has been achieved.
- All aspects of a commercial apple Scout are now proven

With the inclusion of a flash and other modifications, the Scout now uses the same detection algorithms for red and green apples and achieves similar performance. In operation, the "front-end" of the detection system uses classifiers to identify potential regions in an image which may be apples. Each candidate apple is compared against previously identified candidate apples where the goal is to identify any possible apple. The "back-end" analysis prunes this large number of candidate apples to a much smaller subset of actual apples. The more often a candidate apple is identified, the more likely it is an actual apple. By only making final decisions on which candidate apples are actual apples once all data have been analyzed, the system is achieves better performance.

The field tests consisted primarily of multiple data collection runs through 100' sections of rows with hand-counted data. By conducting multiple runs, VRC was able to test a variety of different hardware parameters and to experience different lighting conditions. The hand-counted data enabled accurate comparison of the visibility of apples in the images captures during scanning with ground truth. Images displaying the fruit detection results where then analyzed by hand to determine the percent of fruit seen in each image that were detected. Refinement of the detection algorithms is primarily related to improved apple visibility, a more sophisticated process to track possible apples between multiple images and improved filters for detecting fruit.

The Scout will determine the size distribution for all apples for which it sees enough of the perimeter to accurately estimate the size. Even in orchards with lightly clustered apples, a percentage of the apples will be obscured enough to prevent accurate sizing. However, the distribution should be accurate when applied across the full crop. The actual sizing results will be the size distribution plus the number of fruit sized.

NEW PROJECT PROPOSAL **PROPOSED DURATION**: 2 years

Project Title: Robot scout for tree fruit

PI: Tony Koselka
Organization: Vision Robotics Corporation
Telephone/email: 858-523-0857 / tkoselka@visionrobotics.com
Address: 11722 Sorrento Valley Road
Address 2: Suite H
City: San Diego
State/Zip: CA 92121

Cooperators: Sanjiv Singh, Carnegie Mellon University

Total Project Request: **Year 1:** $275,000 **Year 2:** $275,000

Other funding Sources

Agency Name: USDA / CSREES
Amount awarded: Awarded as matching funds
Year 1: $250,000 **Year 2:** $250,000

Notes:
The USDA / CSREES has accepted this project as part of the "Comprehensive Automation for Specialty Crops" project funded through the SCRI program.
Agency Name: USDA
Amt. requested/awarded: $250,000
Notes:

WTFRC Collaborative expenses:

Item	**2010**		
Stemilt RCA room rental			
Crew labor	$1875		
Shipping			
Supplies			
Travel	$1000		
Miscellaneous			
Total	**$2875**		

Footnotes:

Budget 1

Organization Name: Vision Robotics Corp **Contract Administrator:** Derek Morikawa

Telephone: 619-200-4865 **Email address:** dmorikawa@visionrobotics.com

Item	**2010**	**2011**
Salaries	$166,076	$167,233
Benefits	$62,937	$63,548
Wages		
Benefits		
Equipment		
Supplies		
Travel	$11,500	$8500
Miscellaneous		
Scout Prototype	$9,237	$10,719
Subcontract to CMU (field expenses for integration)	$25,000	$25,000
Total	**$275,000**	$275,000

Footnotes:

Justification

Vision Robotics Corporation (VRC) has been working closely with the Washington Tree Fruit Research Commission (WTFRC, or the Commission) for the last 3 years to develop a robotic harvester for tree fruit. The Commission has been concerned with the long term availability and cost of field labor due to 1) recent efforts to restrict immigration and enforce the legal status of immigrants already in the US, 2) increases in minimum wage, and 3) competition for the same labor force from the construction and service industries. While the recent recession has temporarily eased competitive demands for labor, it is clear that, as the economy picks up, demand for labor from competing industries will resume. The Obama administration has put the burden on employers to prove the legal immigration status of their employees and already has required federal contractors to use the E-verify system.

At the same time, the tree fruit industry has been moving beyond just labor savings from mechanization and sensor systems to data collection for precision farming and is putting an emphasis on sensor and data-collection packages that can work together to provide a comprehensive picture of crop health, crop yield, pest and disease infestations, and other key crop management inputs.

VRC's robotic harvester system can help with both the labor saving need as well as play a part in data collection for precision farming. As previously presented to the commission, the robotic harvester system consists of two machines: a Scout that scans the trees with cameras and locates, counts, sizes, and grades the fruit, and a Harvester that uses the location information from the Scout to cost-effectively pick the fruit. Both VRC and the Commission have decided to develop the Scout first since it is the quicker of the two robots to develop and it can provide key data for crop yield estimation on its own. A longer term project to develop the Harvester will then yield labor savings.

VRC and the Scout development project is part of a collaboration of industry and academia that received a USDA grant from the Specialty Crop Research Initiative (SCRI). This project, "Comprehensive Automation for Specialty Crops," (CASC) is led by Sanjiv Singh at Carnegie Mellon University, and includes eleven different automation programs. The goal is to build an integrated suite of technologies for use in specialty crops. One key aspect of the program is the integration of work of the different groups enabling significant leveraging of the various tasks.

For the SCRI projects, the USDA matches industry funding for the projects. VRC will use the SCRI program to create a "Production Ready" Scout. This represents a three-year, $1.5 million project, of which the USDA will fund $750,000. Beginning in 2009, the USDA contributed $250,000 and the matching funds are committed for a total of three years. Thus, each year, for $275,000 the WTFRC will receive the benefit of a $525,000 project.

Finally, VRC would like to mention to the Commission that it is developing an intelligent robotic pruner for grape vines that has generated technology that benefitted the Apple Scout project in 2009 and will continue to benefit the Apple Scout in 2010. Specifically, work done to optimize the cameras for lighting conditions, and work done in tracking of objects from image to image as well as some overall software architecture changes are benefitting the Apple Scout project. It is estimated that roughly $50,000 of software effort was added to the Apple Scout from work done on the vineyard pruner project. Longer term, the tree fruit industry stands to gain far more from the vineyard pruner project when VRC turns its attention to pruning machines for the tree fruit industry. Much of the work done on the vineyard pruner will be directly applicable to pruning tree fruit including identification and modeling of the tree and branch structure as well as the pruning rule engine and control of robotic arms and hydraulic (or electric) pruning shears.

OBJECTIVES

In 2009 VRC built a second Scout prototype incorporating the improvements to lighting, camera angles and fruit detection software. VRC has been very pleased with the performance of this second prototype and feels that it now has a system that will effectively count and size fruit. The second prototype consists of a trailer with eight stereo camera pairs mounted on a twelve foot camera mast. The mast is also equipped with four programmable high intensity strobes that flash synchronously with the stereo cameras. The Scout cameras capture pictures of the tree as it is towed along the row. After completion of the scan, the system analyzes the images to detect apples on the trees.

Figure 5: The Scout Prototype During Field Tests

In late July 2009 the Scout was field tested in Royal City (at Valley fruit) to optimize exposure settings and to obtain new fruit image data to use with upgraded fruit recognition algorithms. Then in late September, 2009 the Scout was tested on two rows of Jazz and two rows of Granny Smith apple trees at Allan Brothers orchard in Othello to obtain quantitative data on the accuracy of fruit detection. When comparing the Scout counts with accurate hand counts, the results were very encouraging. For the Jazz sections, the estimates were observed to be slightly above and below the true counts per 3' comparison region, suggesting a close match to the true yield distribution. For the Granny Smith sections, the estimates tended to be lower than the true counts, in part due to the software missing individual fruit in the centers of large clusters. These results are a significant improvement from our 2008 tests and give us confidence that the hardware configuration and lighting are now sufficient to make accurate statistical counts of fruit – and that software refinement in the 2010

Table 4: Crop load estimate and actual crop load for first five 3' regions from the Jazz section.

	Section 0 – 1	Section 1 – 2	Section 2 – 3	Section 3 – 4	Section 4 – 5
Yield Estimate	7	22	10	5	12
True Yield	9	20	13	4	13

Table 5: Crop load estimate and actual crop load for first five 3' regions from the Granny Smith section.

	Section 0 – 1	Section 1 – 2	Section 2 – 3	Section 3 – 4	Section 4 – 5
Yield Estimate	23	29	36	31	19
True Yield	27	37	36	39	23

Significant software development remains before the Scout is ready for production. For example:

- The sizing software requires further improvement to better accurately size the occluded apples.
- The detection software detects apples in clusters, but needs refinement to achieve an accurate count.

- The tracking software requires refinement, particularly when tracking fruit between cameras.
- The software needs optimization in order to achieve real time results.

The goal for 2010 is to continue to improve Scout detection and sizing accuracy for both red and green fruit. In addition VRC will modify the 2nd generation prototype that will bring us close to a production configuration:

- Software refined such that the Scout will:
  - meet the yield accuracy requirement of less densely packed orchards;
  - have an error in yield estimate of less than 15% for highly clustered trees.
- Upgrade the prototype robustness. Specifically,
  - design the system to operate in a wider temperature range (especially hot summer days).
  - incorporate a new flash lighting system with industrial rather than studio strobes
  - redesign the mast and vision system for increased robustness, stability, and production handling.
- Increase operational speed to between 1 and 2 mph.
- Scans GPS referenced and data fed into the Carnegie Mellon GIS database.
- Increase analysis speed to where data from a 100' scan of less densely packed fruit can be completed within 30 minutes.

As noted, this project is part of the CASC project and has synergy with the other project tasks. As appropriate, the Scout will be integrated with the other project systems such as the Carnegie Mellon University Autonomous Prime Mover and GIS database. The Scout may also incorporate sensors used for other tasks (such as GPS) and multi-spectral and NIR cameras.

The main goal for this year is to improve performance, so unrelated tasks have been eliminated as much as possible. This means that the system will continue to scan only on one side, eliminating the significant cost of a second boom (boom mechanics, 8 more cameras, additional set of strobe lighting, additional set of processing computers).. These features are straightforward and do not add to the fundamental system viability, so this development and the associated costs will not occur until the Scout meets the production specifications.

Once the production performance requirements are achieved, it will be straightforward to finalize the production hardware. The production Scout will in turn, assist the WTFRC in meeting its goal of reducing the costs of fruit production. The Scout will provide valuable data for use in precision farming that will decrease costs by creating a tree-by-tree database for use in precision farming. These data will enable a decrease in chemicals by targeting them to the small areas where they are specifically required. The incorporation of additional sensors would help identify problems much quicker than today's methods, which will improve fruit quality. For example, the Scout could incorporate the CASC sensor for detecting insects and scan as often as desired, while reducing the labor and improving pest damage identification resulting in more effective pest monitoring, higher fruit quality and nursery stock as well as reduced pesticide application. In the long term, the Scout is essential to other mechanization such as harvesting and pruning.

METHODS

Multiple passes of the same rows were conducted in October, and while key scans have been thoroughly reviewed, there remains data that have not been fully analyzed. Because of the dense clusters in the Granny Smith trees, the analysis has created a first pass at the results, but further refinement is required. With respect to sizing, VRC has determined the distribution and tied some specific results to certain hand counted quadrants in the block, but further review is needed to fully define the performance. Therefore, the first step for 2010 is to further quantify the existing detection and sizing performance.

More specifically, the current software will be used to perform crop yield and size estimation for the remaining scans collected in October for the hand-counted rows. These scans include tests of a small number of hardware parameters (such as mast height and pivot) whose favorable values were not determined in earlier field tests. Analysis of the additional runs will also confirm the accuracy of estimation over a wider range of conditions. In each case, performance will be determined by computing the error in the yield estimate and by comparing the observed size histogram with that from the hand-collected data.

Based on these numerical results, the team will analyze the software to determine which algorithms require refinement. This consists of identifying the scans for which poor quantitative performance occurred and examining the corresponding images to visually determine what caused apples to be missed, apples to be falsely detected, and the system to produce poor size estimates.

In addition, VRC will review all the system and product specifications for the Scout. Updating the specifications based on the current system implementation and understanding of performance enables the team to properly plan the project.

Once the analysis is complete in early 2010, VRC will structure the development plan as appropriate. Through the early part of the year, the hardware and software development tasks are largely independent. For the hardware, the team will review various options for a new flash system such as those manufactured by Perkin Elmore and Smart Vision Lights and select one that meets the illumination and reliability requirements. VRC will procure, test, and integrate the selected system. Most of the companies that manufacture industrial flash systems allow purchasers to buy, test and return the system, so VRC will have the ability to try several models if required.

Another critical hardware task is to ruggedize the camera system. This ultimately will include sealing the cameras to protect the lenses from dirt and dust as much as possible. Stereo-camera systems are calibrated to determine the exact locations of the two cameras relative to each other. Inherently, this calibration is very sensitive, with the lenses, lens holders and system mounting each being susceptible to drift. Over the years, VRC has refined the mechanical system and can build cameras that are extremely well calibrated. However, the calibration is closely monitored and is occasionally lost for some cameras. VRC will analyze and perform controlled tests to determine the parts and variables that cause the drift. This includes temperature, vibration, shock and stress relieving of the lenses, lens holders, camera pcb and mounting frames. All results will be incorporated into an updated design as appropriate.

The remainder of the mast redesign is to incorporate the new flashes, to seal the mast from the elements and simplify the mechanical and electrical attachment to the Scout. To date, the mast has been a closed box section. It is possible that this configuration will remain, however, we anticipate moving towards a design where each camera pair is in a smaller sealed housing that are mounted on a more open frame. This configuration should create a lighter mast that is easy to assemble and seal, while being as strong or stronger as the existing mast.

The final major hardware modification is to incorporate environmental control in the electrical box. The current Scout prototype includes an off-the-shelf electrical cabinet. The manufacturer, Hoffmann, sells a heating and cooling unit to control the temperature. VRC and our manufacturing partner, AIM, will retrofit the environmental control unit onto the Scout.

When the above modifications are complete, VRC will perform a final prototype evaluation with special attention focused on reliability in field condition. Per this evaluation, the team will upgrade the system to improve the ruggedness and robustness as required.

The results of the analysis to be completed in early 2010 will guide the development of the Scout software; however a plan for many possible improvements is already in place. The current crop load and size estimation software consists of "front end" and "back end" processing modules. The front end portion mainly analyzes images on an individual basis to determine which regions of an image may represent portions of apples. The software then identifies candidate apple centers and radii. While this concept produces reasonable results, in reality, apples are not completely circular for which VRC plans to incorporate additional techniques. Additionally, the classification portion will be refined, if necessary, to accommodate changes to image properties occurring with the introduction of the new flash system. These refinements will improve the candidate apples output by the front end software.

The back end software is responsible for tracking candidate apples over multiple images, including between cameras. The current software is a basic implementation, with many potential improvements possible. In analyzing the collected data, VRC has identified tracking difficulties that can be combated by including known techniques. Other planned refinements will improve matching of new candidate fruit and pruning of tracks. VRC is also considering incorporating a statistical model in the back end processing. Using the results of the analyses of the October scans, as well as additional scans to be conducted in 2010, statistics which reflect the output of the estimation software as well as the collection software with respect to true conditions (e.g., if the estimated size distributions consistently have a shifted mean, if the cameras only observe a consistent fraction of apples in densely packed settings, etc.) could be incorporated to enhance performance. VRC will also begin to modify the algorithms to detect smaller green apples.

A final portion of the planned refinements to the Scout software consists of increasing the processing speed to ultimately achieve production requirements. The focus of the development thus far has been estimation performance as opposed to speed. Thus, there is significant room for modifications, including parallelizing the detection algorithms over multiple cores and/or computers. Moreover, Intel, AMD, ASUS and other chip manufactures are currently introducing hardware such as Intel's Larrabee processor which will be well suited for the Scout software and is expected to yield appreciable speed increases.

The system will undergo field trials in production orchards during the late summer and early fall of 2010. We anticipate one trip in the summer to scan orchards that are near harvest as well as to collect data from orchards with small fruit. This data will all be used to help further refine the software and improve performance.

The final field tests will occur in late September. At that time, the Scout will output preliminary results from low density orchards shortly after the data is collected. Upon completion of the processing of the collected data, VRC anticipates demonstrating a 20-25% improvement in performance. In addition, the results will be structured such that they can be input into the GIS database under development for the CASC project.

CONTINUING REPORT **DURATION**: 2 Years

Project Title: A database to aggregate research results and assess technologies

PI: Gwen Hoheisel
Organization: Washington State Univ.
Telephone/email: 509-786-5609, ghoheisel@wsu.edu
Address: 1121 Dudley Ave
City: Prosser
State/Province/Zip: WA, 99350

Cooperators: Tom Auvil, Tory Schmidt and Ines Hanrahan, WTFRC
Kate Evans, Dorrie Main and Matt Whiting, WSU
Lynn Long, OSU

Total Project Request: **Year 1:** $9,078 **Year 2:** $1,000

WTFRC Collaborative expenses:

Item	2008	2009	
Stemilt RCA room rental			
Crew labor			
Shipping			
Supplies			
Travel			
Miscellaneous			
Consultation time[1]	2665		
Total	**2665**		

Footnotes:
1. Approximately 100 hours to aggregate, explain, and transfer existing datasets from Tom, Tory and Ines.

Budget 1:

Total Project Funding: $10,078

Budget History:

Item	**(2008)**	**(2009)**
Salaries		
Benefits		
Wages	$2605.38[1]	~$400[1]
Benefits	$235.11	~$40
Equipment		
Supplies		
Travel	$60.42	
Miscellaneous		
Database development [2]	$2000	
Database refinement		$500
Total (~$5841)	$4900.91	~$940[3]

Footnotes:
1. In 2008, salary for one full time summer person to assist with database entry and surveying. In 2009, salary is estimated because it has not finalized in the WSU system at the time the report was due.
2. Computer programming of the initial database will be contracted to specialists within WSU.
3. This is an estimated total because of the salary estimation.

Objectives:

1. Develop a searchable database that will capture rootstock-variety combinations for apples and cherries, as well as varietal characteristics, management practices, and environmental factors.
2. Aggregate data from existing sources (i.e. projects with OSU, WSU, WTFRC) on rootstock/variety trials and replant practices.
3. Publish to the web.
4. Generate reports and analyses to assist collaborators in assessing replant practices and the effects of management practices on production of targeted fruit.
5. Assess the status of the database and identify gaps where incorporation of new variables would assist in development of targeted fruit production.

Significant Findings and Accomplishments:

- We designed and vetted the architecture of the Orchard Conditions Database (OCD) that can be easily transferred to other systems.
- We created an online searchable database that has the capability to capture a wide breadth of information and linked with AgWeatherNet data.
- Relevant rootstock and variety data has been organized and entered for WTFRC, WSU Cherry Breeding Program, OSU Cherry research and most of WSU Apple Breeding Program.
- Despite the volumes of data entered, much of it is incomplete. Because of constraints of the previous research and lack of a place to aggregate data, some fields (i.e. yield, fertility program, etc.) were not always captured. This will improve with the collaboration of breeding programs and WTFRC.
- We will continue work and expand on the database through an SCRI grant on “Tree Fruit GDR: Translating Genomics into Advances in Horticulture” (PI Dorrie Main).

Results and Discussion:

As in any database, the first step was to create the architecture of the data. Our structure consists of 11 tables and 108 potential variables (Fig. 1). Both the structure and variables have been vetted by potential users and WTFRC. This systems was designed to be easily transferred to other entities or expand to incorporate other commodities.

The online database has 6 main links—home, basic search, advanced search, variety information, rootstock information, and administration page (Fig. 2).

Figure 2: Home page of Orchard Conditions Database. Shows an overview and 6 main links.

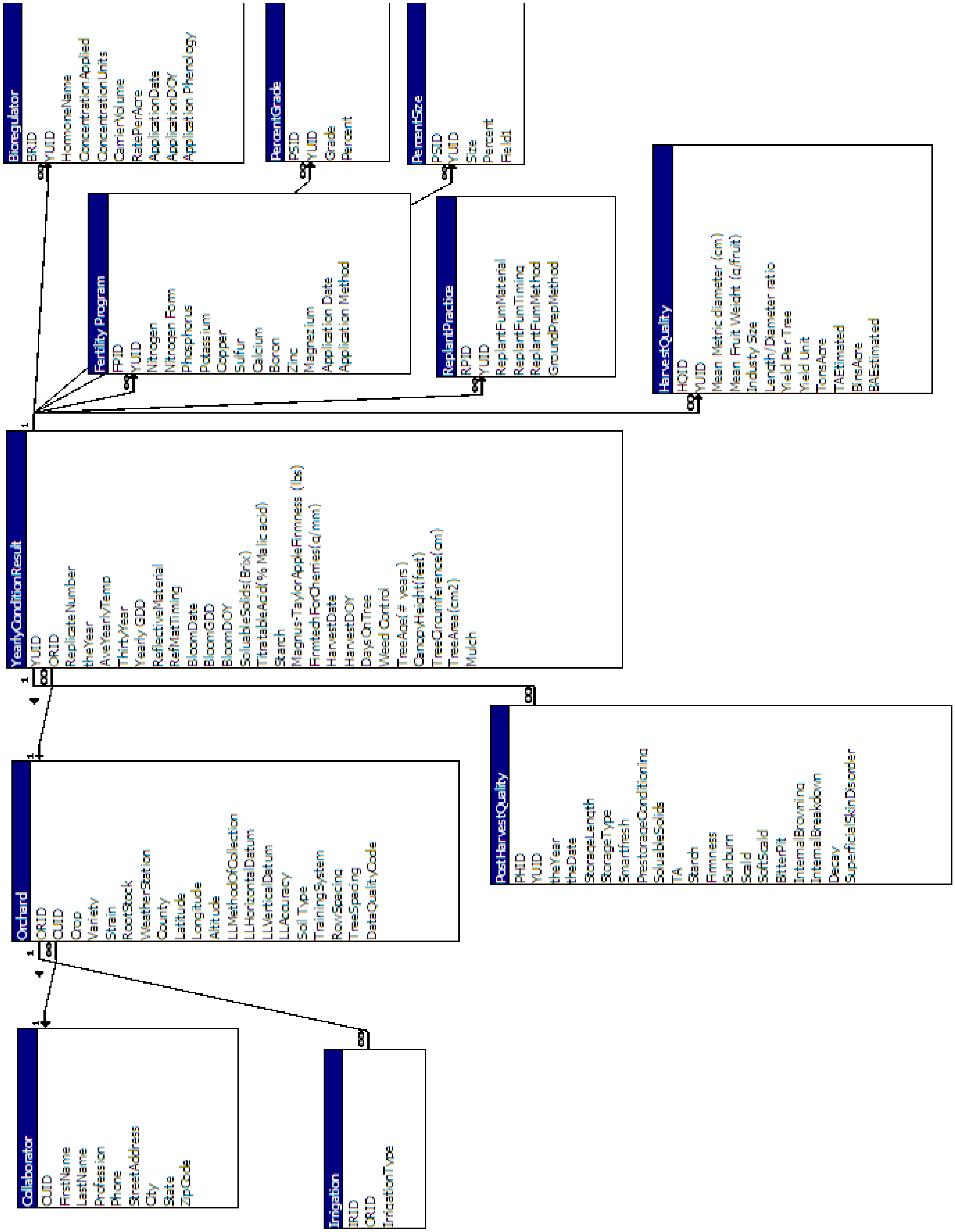

Figure 1: Architecture of the Orchard Conditions Database.

The basic search option has four criteria to select from—crop, rootstock and/or variety, county, size and/or yield. A limited amount of data is displayed (Fig. 3).

Variety	Rootstock	County	Strain	Year	Harvest Date	Soluable Solids	TA	Firmtech (g/mm)
Bing	Mazzard	Yakima		2006		11.00	0.35	
Sweetheart	Mazzard	Chelan		2006		12.50	0.67	
Sweetheart	Gisela 6	Chelan		2006				
Bing		Douglas		2006				
Skeena	Mazzard	Okanogan		2006				
Rainier	Mazzard	Douglas		2006				

Figure 3: Output of a "basic search"

The advanced search in OCD allows the user to select nearly any of the variables in the database (i.e. crop, rootstock/variety, location, yield and quality, management practices, temperature, and post harvest). The results of this search are exported directly to excel for easy sorting and comparison.

Variety information is adapted, with permission, from the extension publication Sweet Cherry Cultivars for the Fresh Market PNW 604 (Fig. 4). Apple variety information is adapted from various sources and covers basic information about bloom and maturity. The rootstock information is still being developed, but will be added shortly.

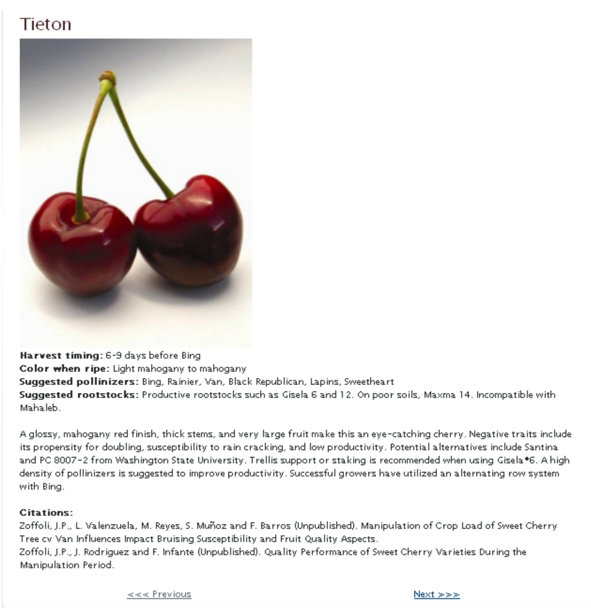

Figure 4: Example of a cherry variety page.

The administration page is password protected to track users. Here authorized users can enter data directly or upload excel spreadsheets. I will work annually with the breeding programs and WTFRC to incorporate their data and keep the system up to date. Theoretically, the upload of data should be quick, since the bulk of the information is already entered.

OCD has cherry data from the 1980's and almost half a dozen years of apple data from the breeding and WTFRC programs. Nonetheless, there are significant gaps in the data particularly in yield, fertility and plant growth hormone applications. Most of the researchers did not keep this information unless it was relevant to the project.

I will continue to maintain, improve and annually enter data into the OCD. In addition, I am collaborating with Dorrie Main and team members of the successful SCRI grant on "Tree Fruit GDR: Translating Genomics into Advances in Horticulture" to incorporate this database into their efforts so that genotypic and phenotypic characteristics are housed in one site.

Executive Summary:

The Orchard Conditions Database (OCD) is designed to systematically aggregate data collected from previous and ongoing research trials in cherries and apples. The OCD captures location, management, and fruit performance variables to serve as a tool for orchard establishment and horticultural research. Aggregated information includes rootstock, variety, fruit characteristics, management practices, yield, soil type, weather, and year.

Through this project we have developed an architecture and online searchable database that can be easily transferred and expanded to other systems and/or commodities. OCD is linked with AgWeatherNet and aggregates relevant data from WTFRC trials, WSU cherry and apple breeding programs, OSU Cherry research and most of WSU Apple Breeding Program.

The online database has 6 main links—home, basic search, advanced search, variety information, rootstock information, and administration page. The basic search allows the users to select from four criteria—crop, rootstock and/or variety, county, size and/or yield—with a limited amount of data output. The advanced search allows the user to select nearly any of the variables in the database (i.e. crop, rootstock/variety, location, yield and quality, management practices, temperature, and post harvest). The results are exported directly to excel for easy sorting and comparison. The variety and rootstock information is adapted from various information and resources to provide a basic description of information. Lastly the administration page is used to directly enter or upload data from excel.

OCD has cherry data from the 1980's and almost half a dozen years of apple data from the breeding and WTFRC programs. Nonetheless, there are significant gaps in the data particularly in yield, fertility and plant growth hormone applications. Most of the researchers did not keep this information unless it was relevant to the project. It is our hope that with a centralized repository, the data will be collected for specific areas and treatments in future research.

I will continue to maintain, improve and annually enter data from WTFRC and the breeding programs. In addition, I am collaborating with Dorrie Main and team members of the successful SCRI grant on "Tree Fruit GDR: Translating Genomics into Advances in Horticulture" to incorporate this database into their efforts so that genotypic and phenotypic characteristics are housed in one site.

FINAL PROJECT REPORT **YEAR**: 2 of 2
WTFRC Project Number: TR-07-703 (WSU # 13C-3643-5368)

Project Title: Expanding and Stabilizing WSU-decision aid system

PI: **Vincent P. Jones**
Organization: WSU-TFREC
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State/Province/Zip WA 98801

Co-PI(2): **Jay F. Brunner**
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State/Province/Zip: WA 98801

Co-PI(3): **Gary Judd**
Organization: Agriculture & Agri-Food Canada
Telephone/email: JuddG@agr.gc.ca
Address: 4700 Hwy 97
City: Summerland, BC
State/Province/Zip Canada V0H 1Z0

Cooperators: Jerry Tangren, WSU-TFREC; Leo Garcia, Wenatchee Valley College

Total Project Request: **Year 1:** $80,965 **Year 2:** $79,960

Other funding Sources

Agency Name: Washington State Commission on Pesticide Registration
Amount awarded: $22,834
Notes: This supplements WTFRC funding for DAS.

Budget 1:
Organization: WSU **Contract Administrator:** ML Lou Bricker, Kevin Larson
Telephone: MLB 509-335-7667, **Email:** mdesros@wsu.edu, kevin_larson@wsu.edu

Item	Year 1: 2007	Year 2: 2008
Salaries[1]	58,093	57,297
Benefits[2]	20,372	20,063
Wages	0	0
Benefits	0	0
Equipment	0	0
Supplies[3]	2,000	2,080
Travel[4]	500	520
Miscellaneous	0	0
Total	$80,965	$79,960

Footnotes: [1]Programmer 1 FTE, Web Programmer, 4 mo. 50% FTE, Callie Baker 16.7% FTE
[2]Programmer 35%, Web Programmer 36%, Callie Baker 34%.
[3]Cell phone charges are allowed
[4]Within State Travel

Objectives:

Stabilize and extend the current DAS program, including extensive documentation, help files, improving the overall interface, and better integration with AWN.

Improve the current disease models and add the model for shot-hole of stone fruit.

Develop organic control recommendations.

Once the program is stabilized, implement a bilingual interface for Spanish-speaking users.

Investigate methods to improve the codling moth model.

Significant Findings:

- Our short narrated video tutorials are nearing completion, with ten videos done and two left to finish.
- An on-line text tutorial has been finished and added to the help center.
- We have completed a stable, fast, and reliable iPhone version of DAS and are working on a blackberry version.
- The shot-hole model is online for our beta users and awaiting the final approval from Gary Grove before release to the general user base.
- Organic control measures have been completed and on-line for the last six months.
- A Spanish version of the recommendations is ready for beta testing; we are awaiting confirmation of our translation's accuracy from Leo Garcia and expect to have it on-line next spring.
- We are in the process of setting up a Spanish-speaking beta user group.

Significant Progress:

Objective 1. We have met all of the goals of this objective. Since the last progress report, new additions include:

Help Center. The help center has been the focus of our efforts since Dr. Chambers has taken over management of DAS in Sept 2009. She has currently finished ten narrated video tutorials that show users how to use the different features of DAS. The planned videos (italics with dot) and completed ones (black with check mark) are:

Getting Started

- *What is DAS?*
- *Introduction (main menu features)*

4. User Login and Registration

Managing Weather Stations

5. Setup a new weather station
6. Edit and delete weather stations
7. Add a custom weather station
8. Import data to custom station
9. .xls to .txt/.csv file conversion

Insect and Disease Models

10. View model options
11. Model output

✓ Spray Guide

✓ Historic Weather Data

We expect most of the planned videos to be finished by the presentation in early December. The spray guide video will likely have to be re-done as we are working to incorporate new features to help reduce spray effects on natural enemies and implement resistance management information (the video can't be made until those features are implemented). All videos will provide closed caption text as well as the audio explanations.

We have also completed the DAS text tutorial that users can access that has the same information as the videos. Further work will implement features to allow the users to follow the logic of why we are making particular recommendations at different times and to increase the integration with broader information on management and specific sections in the on-line *Orchard Pest Management*.

Mobile Web Browsers. Other progress on this objective has been the development of an iPhone version of DAS. This version is fast, reliable, and has no known issues. We have begun working on a blackberry version, but the quality of the display and browsers on many blackberries is poor and we may need to restrict it to only certain models. We will also begin working on a version for Android phones (Google's mobile phone OS) which use a high quality web browser similar to the iPhone.

Codling moth model changes. Next year we will finish the changes in our codling moth model to eliminate the resetting of degree-days (DD) after the first moth is predicted to occur. The use of "degree-days from biofix" causes large amounts of problems in programming, and logically no longer makes sense. This year, some users were looking at the DD accumulations and were confused because you would go from 175 to 0 degree days. The change will bring the model in line with all the other models where only DD since 1 January are used, and we will provide users information on DD with explanation such as 500 DD (=325 DD after biofix using old model); the following year the parenthesis will be eliminated. There will be help files available that show changes and explanations for why they were made.

Introductory page. Our programmer has developed routines that will allow us to automatically change the introductory page so that the information there is seasonally appropriate. We have also been working with the Pest Management Transition Program to develop the content for that page. We expect to have this finished and on-line before the start of the season.

Objective 2. The shot-hole model is on-line in the beta page and we are waiting for final approval from Gary Grove before opening the model to all users.

Objective 3. The organic control recommendations have been available for the last six months including the ability to switch back and forth between the different options. All objectives were met.

Objective 4. We have added the ability to translate DAS on the fly using the Google Translate option. However, because of some of the vagaries of that system, we have translated the conditions and management recommendations by hand. Leo Garcia (WVC) and Malaquias Flores (WSU small farms project) are currently reviewing our translations. We expect the Spanish translation to be on-line this spring. We have started the process of recruiting a Spanish-speaking beta group to help insure that the system is useful and contains features those users need. As mentioned above, our video help system is able to provide closed captions and we can implement Spanish translations of those as soon as we can get the scripts translated.

Objective 5. As mentioned in the last progress report, our data showed that the length of pre-chilling period larvae were held at did not significantly affect the emergence curve when done on either a calendar data basis or a DD basis for either males or females. However, surprisingly, the temperature that they were held at (before the cold period) made a significant difference in both the mean emergence period and the variability around that emergence period on both calendar date and DD scales. *That result was completely unexpected and not predictable from the literature data we reviewed*. Recall that the larvae enter diapause in the last instar larval stage, so that development after the chilling period should be similar and occur with a given mean and standard deviation of times. As all moths entering the chilling period were held the same time at the same temperatures both during and after the chilling period, we would expect very little change in emergence period, because they are all overwintering in roughly the same physiological state.

Our data suggest that there is a sensitive period in the fifth instar that must occur within 7 days of the larvae molting to the fifth instar when the temperature affects the timing of emergence from diapause. We have collected more larvae this year from bands in the field and are re-running this experiment. However, we have changed the experiment to expose larvae to temperatures of 15, 20, 25, and 30°C in the pre-chilling period for a fixed period and then evaluate emergence patterns after chilling to determine if we can predict emergence variability by the holding temperatures. We have currently collected the larvae, exposed them to the different temperature regimes, and the larvae are now being transferred to the cold period. The larvae will be brought out of the cold sometime in January and we will have results sometime next spring.

We have also made great strides in improving the prediction of CM first emergence across the US. We initially found that emergence could be predicted using a combination of latitude and altitude. However, data this year showed that the latitude and altitude were really just expressing the amount of solar radiation. Our current models allow prediction of the average date of emergence based on heat units and accumulated solar radiation (Fig. 1). The solar radiation is important, because we found the bark temperature (CM overwinter under the bark) is up to 30°F higher during the winter compared to air temperature measurements (Fig. 2).

Overall Impact of this Project. WSU-DAS has improved significantly over the past two years and will likely continue to improve in the future. In 2008, we surveyed users and found that they managed 2,888 orchards (≈ 3,000 in industry) and 250,000 acres (≈ 225,000 bearing acres in the industry). The figures are higher than the industry estimates because they do not account for multiple people making recommendations on a single orchard. Regardless, WSU-DAS is used on a large portion of the industry. Users also estimated that the value of WSU-DAS was ≈ $17M/year. Our survey indicates that WSU–DAS has changed the information flow in the industry and for its full impact to be realized, the current educational process needs to be re-designed to emphasize portions of pest management that are not provided directly by DAS (e.g., sampling, model assumptions, life history and management of pests not predicted by DAS).

Fig. 1. Prediction of first moth emergence at 8 different sites across the US using degree-days and solar radiation.

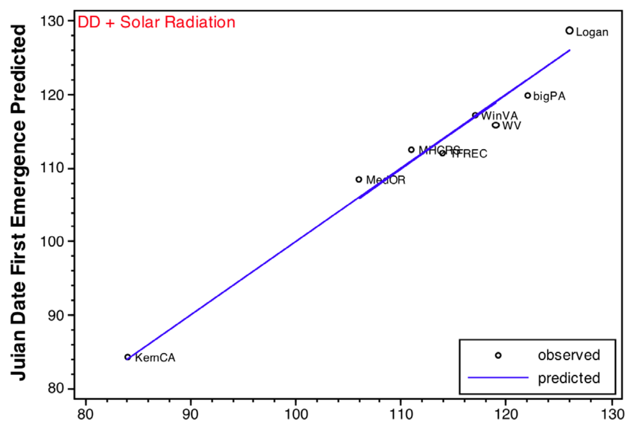
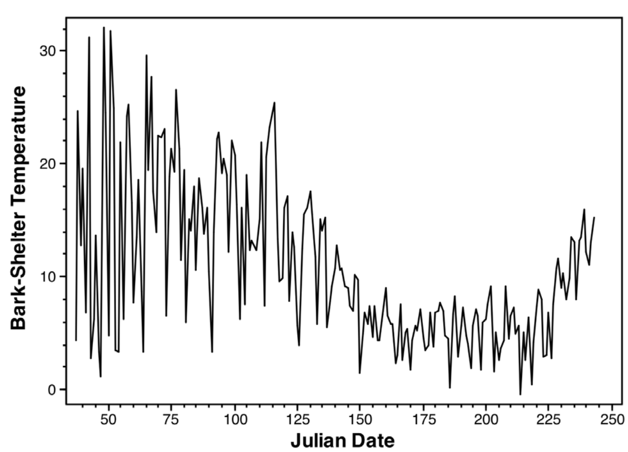


Fig. 2. Difference between bark temperature and air temperature at WSU-Sunrise from February through August 2009.



Executive Summary:

Significant Progress or Outcomes

4. We have met all the objectives of our project during the past two years. DAS is now much more user friendly, has extensive documentation, help files, video help files, the ability to look back at past years data, and has been integrating AWN data in new and innovative ways. We have implemented a mobile version for the iphone and other smart phones will be added as time and hardware quality permits.
5. Our changes to the system have also allowed us to enhance the educational experience of the users.
6. We have made all changes suggested by Dr. Gary Grove and Tim Smith to the disease models and are awaiting the final approval from Dr. Grove to release the shot-hole model.
7. Organic control recommendations were implemented this past season for all models.
8. The Spanish language version is complete and we are waiting for the final approval for our translations from Leo Garcia and should have it on-line next spring.
9. We are setting up a Spanish-speaking beta user group to help with implementation and features of the Spanish version of DAS.
10. We have made several changes to the codling moth model, primarily eliminating biofix, better defining the factors influencing diapause and how that affects phenology. We are also currently finishing studies to determine if we can better predict emergence in the spring based on conditions when larvae enter diapause in the fall.
11. Our user survey in 2008 showed that DAS was used for recommendations on the majority of the industry's orchards and acreage (≈2,880 orchards and 250,000 acres). Those values are high because we cannot correct for situations when multiple people are making recommendations for the same block; thus duplication of acreage and orchards are possible.
12. The respondents indicated that they felt the value to the industry of DAS was roughly $17M/year.

Summary of finding and future directions

DAS is not strictly a research project where objectives are met and the project is done. It has a very important role in the future implementation of new strategies and technologies for pest management in tree fruits. For it to be successful, it must continue to evolve to add new features of use to the users. We expect to continue the current trend of adding new useful features and models, speeding access to time-critical information, and serving the needs of the user base.

The future directions for DAS can be broken into the scientific directions and those needed for long-term survival. In the area of science, we feel the primary needs are to evaluate how the AWN weather data reflects in-orchard conditions, the effects of new orchard architectures and overhead cooling on model accuracy, the importance of solar radiation on model predictions (see objective 5 of this report) and whether we can use the NOAA 1-day site specific forecasts as virtual weather stations. A proposal to evaluate these concerns will be forthcoming at the December meeting.

In terms of the long-term survival, that issue has not been resolved at this point. WSU administration has expressed no interest in supporting DAS, so it is likely that a number of different tactics will be needed for long-term survival. We are currently investigating subscriptions, sponsored advertising, and other ideas with industry input.

FINAL PROJECT REPORT

Project Title: Technology Roadmap Support

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

Cooperators: None

Other funding sources: None

Total Project Funding: $30,000

Budget History:

Item	**Year 1:** 2009
Salaries	$30,000
Benefits	
Wages	
Benefits	
Equipment	
Supplies	
Travel	
Miscellaneous	
Total	**$30,000**

Justification for Contract:
Working within the general structure of the four major research initiatives identified by the National Technology Roadmap for the Tree Fruit Industry, act to continue to build on the progress made to date in developing funding mechanisms and obtaining actual funding for specific research proposals benefiting the tree fruit industry in the State of Washington. The national fiscal situation in the next three year period will be more challenging than ever; so, it is important not only to defend existing programs but also to strategically target new initiatives. Equally important is defending the integrity of the USDA-CSREES Specialty Crops Research Initiative and carefully monitor the establishment of the proposed Agricultural and Food Research Institute as the organizational replacement for CSREES.

General 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 continue cooperative efforts with other specialty crop stakeholder groups and work to educate and inform the new Administration about the unique position of the Washington tree fruit industry and its economic importance to the Pacific Northwest and to the nation;
3. To insure that research activities and requests for research proposals made by the Administration are constructed in such a way as to address the needs of Washington state industry and to give the flexibility to the Commission to participate in the process;
4. To keep the Commission informed of developments in both the Congress and the Administration that impact on ongoing or future research funding; and,
5. To pursue specific activities related to high priority research initiatives
   a. USDA-ARS apple rootstock breeding program, Geneva, New York
   b. Expansion of pear genomics, genetics, and breeding efforts to support the pear industry in the Northwest, with emphasis on possible expansions within the region
   c. Expansion of automation and precision agricultural efforts in the Pacific Northwest
   d. Expansion of research and extension efforts in sustainable tree fruit production and handling.

Significant Findings:

1. In 2009, the Congress moved quickly to provide significant "stimulus" funding to address the economic problems of the country. It appears that the domestic economy has begun to recover; however, economic problems are continuing. In addition, congressional action on the "stimulus" package and other legislation designed to help the economy recover, has significantly increased the size of the Federal That action, taken together with other actions by Congress to address the domestic economic situation, has resulted in a significant increase in the size of the Federal deficit and led to growing concerns over the size of the national debt.
2. In response to these growing concerns over the increase in the Federal deficit and the corresponding increase in the national debt, the Administration has indicated that the FY 2011 budget that will be submitted to Congress early next year will tend toward a "freeze" on discretionary spending levels. It is not clear at this point what this means for USDA research funding and how this will be translated to the "mandatory spending" or baseline funding for specialty crops research activities.
3. While the Administration has endorsed the competitive grants approach to research funding, it has also sought to change the focus of attention, moving toward efforts to address issues like environmental issues, alternative energy research and research addressing problems of hunger, nutrition, and obesity in society. This effort is likely to further emphasize cross discipline research and is likely also to change the emphasis for the research requests. We will need, for example, to emphasize worker safety standards, a better educated workforce,

and also environmental benefits that accrue from our interest in automation and technology research efforts.

4. The recently-enacted Agriculture Appropriations legislation for fiscal 2010 extends funding for existing research programs, including the clean plant network. That measure also continues language addressing the problems that have surfaced regarding the "matching grant" provisions of the Specialty Crops Research Competitive Grants program.
5. Working with Northwest Horticultural Council, U. S. Apple Association, and other agricultural groups, we were able to obtain full funding for the chemical use survey program contacted by NASS. That funding was also included in the Agriculture Appropriations Act.
6. There continues to be strong support in the Congress and in the Administration for the Specialty Crops Research programs. The recently-issued press release from USDA detailing those grant awards indicates clearly that the State of Washington and the Pacific Northwest industry have done quite well and that this process has expanded our horizons and enabled us to reach out and partner with a wide range of interest groups.
7. There are efforts underway to further strengthen the Specialty Crops Research effort itself and there are also efforts to reinvigorate research interests within the specialty crops research team. Those efforts being led by the Northwest Horticultural Council will, I believe, enhance our ability to move forward and continue to build on the progress made to date.
8. The Administration's announced "Science Policy Initiative" and its emphasis on sound science, presented in a transparent manner also provides us with another tool in going forward to lay out research priorities in a clear, logical manner.
9. We continue to build on and expand our ties to the Congress and to the Administration. We have established open lines of communication at senior levels of the Congress, and we continue to be perceived as objective and careful and committed to sound science as the way to move toward our goals.
10. There have been developments in other areas, especially in the environmental arena, that might provide opportunities for directed or mission-oriented research and could provide an additional source of funding for that type of research. Working with Northwest Horticultural Council and U. S. Apple, we have been able to reach out to and establish what is likely to be a beneficial relationship with a wide range of groups.
11. The Agricultural and Food Institute has been established and a selection has been made to head this institute.
12. The current Under Secretary for Research at USDA, Dr. Shah, has been selected to head AID. Dr. Shah's background is in world hunger issues. He was formerly with the Bill and Melinda Gates Foundation. His replacement at USDA has not as yet been selected. That choice is likely to influence to some degree the course of research efforts at the Department.

Results and Discussion:

While much remains to be done and there are potential issues that we will have to deal with over time, we have had a good year. We have maintained our positions and we have expanded our opportunities, especially as a result of the awards that were recently announced for the Specialty Crops Competitive Grants program.

Our position supporting competitive research programs is generally supported in the Congress and in the Administration, and we have protected and enhanced our reputation as fair, objective participant in the process.

We have met the defined objectives and where we have not finally successful in all areas (particularly enhancing pear genome, genetics, and breeding research), we have made significant progress. We will have to continue to be persistent without being offensive and we will have to continue to show how this research initiative relates to and complements other areas.

I believe that we have in fact kept the door open and we have validated our seat at the table in discussing and implementing agricultural policy in the United States. It is my view that we have actually expanded our options and significantly broadened our base of support.

There are, however, problems that we are going to have to address. We do need to pursue avenues to strengthen the relationships that we have within the specialty crops industry and continue to emphasize to our colleagues of standing together as a group committed to emphasizing the value of research.

We are going to have to insure that the public and the Administration and Congress have adequate tools to evaluate the benefits of our research projects. This is a difficult area and is quite complex and one that has to be approached carefully, but as we prepare for efforts to address the Federal budget deficit and the growing national debt, we are going to need to be able to demonstrate what the government is getting for the money it is spending in research.

I am convinced that we have strong support from our state delegation and from the delegations of the other states that make up the Pacific Northwest. To maintain that support, however, will require that we be understanding and that we work cooperatively to move the issue forward. There are remarkable opportunities that are before us. To take advantage of those opportunities, however, we will have to continue to show patience and understanding of the political and economic realities that are facing our country.

It has been a distinct privilege to work with the Commission and with the associated groups in this effort, and I look forward to having an opportunity to help carry this forward in the coming years.

Executive Summary

The Commission will expend a total of $30,000 over calendar year 2009 to support efforts working within the general structure of the four major research initiatives identified by the National Technology Roadmap for the Tree Fruit Industry to build on the progress made to date in developing funding mechanisms and obtaining actual funding for specific research proposals benefiting the tree fruit industry in the State of Washington. This expenditure also supported efforts to defend the integrity of USDA-CSREES Specialty Crops Research Initiative as well as efforts to monitor the establishment of the Agricultural and Food Research Institute as the organizational replacement for CSREES.

Continuing to follow the established general strategy emphasizing openness and transparency and a strong commitment to sound science and working through and with tree fruit industry groups, especially the Northwest Horticultural Council, and other specialty crop organizations, much has been accomplished. Most of the objectives listed in the approved project proposal were in fact achieved. For those specific research projects that were not funded, progress was made in moving to achieve the necessary support to ultimately achieve the goals set forth.

Commission funding has helped us continue to enhance our reputation as a reliable, careful, and responsible partner with the Congress and the Administration in shaping agriculture policy and in designing research efforts that fulfill congressional intent by reaching out in a multidisciplinary approach that benefits producers in a wide range of regions in this country.

We have in fact justified our seat at the table. We have kept the door open and we have maintained the progress that we have made to date. We as a region have demonstrated our competence and our abilities in the recently-announced Specialty Crops Competitive Grants awards.

We have maintained and expanded our channels of communication with our own congressional delegation and with the delegations from the Pacific Northwest. We have also met with and opened channels of communication with key staff on important committees in both the House and Senate.

While much has been accomplished, much remains to be done and we do face significant hurdles. We need to insure that we strengthen our partnership with the specialty crops group so that we can continue to speak with one voice in support of competitive research efforts that recognizes that we share common problems and that we all should seek to design research that benefit a broad range of agricultural commodities and regions.

We also need to explore options that will prepare us to define and explain the economic and environmental and social benefits that will accrue as a result of the research that we are seeking. If we do this, we will be prepared to work with the Congress in evaluating and deciding how to best address budget problems as a result of the increased budget deficit and growing national debt.

Simply put, we need to be prepared to face these challenges in defending the progress that we have made and taking advantage of the exciting opportunities that are available to us to go forward.

It is my sincere hope and strong desire to continue to work with the Commission in moving these issues forward.

FINAL PROJECT REPORTWTFRC
Project Number: TR-09-05

Project Title: Mobile linear asymmetric fruit transport systems

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Cooperators: Oxbo International Corporation, WTFRC, Familigia LLC, Washington State Growers Councils, Stemilt Growers, Washington Fruit, Oasis Farms

Other funding Sources

Agency Name: Picker Technologies, LLC, Oxbo International Corporation
Amount awarded:
Notes: WTFRC Grant represents < 5% of total R&D costs to date

Total Project Funding: $200,000.00

Budget History:

Item	System	Scan	Dry Bin	Total
Salaries	$70,020.68	$14,916.68	$15,062.64	**$100,000.00**
Benefits	$20,110.09	$4,125.98	$3,763.93	**$28,000.00**
Wages	$21,776.58	$8,223.42	$ --	**$30,000.00**
Benefits	$1,500.00	$1,000.00	$500.00	**$3,000.00**
Equipment				
Supplies	$7,379.08	$6,620.92	$ --	**$14,000.00**
Travel	$20,773.32	$3,058.88	$1,167.80	**$25,000.00**
Miscellaneous				
Total	$141,559.75	$37,945.88	$20,49437	**$200,000.00**

Objectives:

1. Develop and test one (1) pilot fully integrated mobile fruit transport harvest system that increase the economic efficiency of harvest and post harvest, 2.5 to 6 times over traditional methods.


2. Develop and test an in-field cull sorter and bin storage (management) system (to decrease storage costs and increase revenue opportunities for the grower).

3. Develop and test a ‘Dry Bin Filler’ that minimizes damage to fruit while safely loading a bin in-field at a minimum of 8 apples per second (profitability).


Siginificant Findings:

Objective 1. Mechanical harvesting of apples works and is viable.

Objective 2. In-field Scanning/Sorting on a mobile Harvester is viable at a significantly lower cost point than delaying all fruit for Scanning/Sorting in a Packing House.

Objective 3. The bruise incidence for the Dry Bin Filler can be 0 to 4% depending on the Apple variety when the level-fill sensor and speed sensor are properly adjusted along with an even load balance for picking.

Results and Discussion:

Objective 1. After approximately 1000 hours of endurance testing, the pilot, integrated mobile fruit transport harvest system, which was developed is comprised of three main technology areas: 1. labor assist Picking Platforms; 2. fruit singulation for Scanning/Sorting; and 3. gentle Dry Bin filling. Testing and Orchard evaluations for the Harvester occurred in plantings of Vertical Axis; Slender Spindle; and V-Trellis which exhibited varying terrain, different degrees of pruning, and tree training. Several varieties of Apples: Gala, Golden Delicious, Red Delicious, Granny Smith, Fuji, Braeburn, and Pink Lady were harvested and each expressed its own unique characteristic during the Harvester development. Gala, Red Delicious, and Fuji were hardy varieties to mechanically harvest and showed the promise for the pilot system. Golden Delicious, Granny Smith, and Pink Lady acted like a spot light for specific areas within the pilot Harvester which needed the most attention and updates during the 2009 Fall Harvest. Pink Lady's for this year appeared to be the most sensitive to mechanical damage. With only 10 weeks of harvest time to perform the testing and in-field evaluation, improvements and design changes had to be done simply and quickly. There was a compromise made related to the ideal design changes needed and the ability to gather important information and orchard experience within the relative short season.

Objective 2. In-field Sorting and Scanning of cull defects occurred and was demonstrated to be effected in detecting sub-surface bruising along with cuts, stem puncture, limb rub, scars, depressions, hail, bin scuffing, Bitterpit, Lenticel breakdown, Russet, codling moth, and general decay. Some in-field challenges were discovered which showed the need to adjust lighting between the 'picking lanes'; sunlight penetration protection; fruit 'calming' to enable adequate scanning; software updates, and hardware configuration adjustments.

Objective 3. Several varieties of Apples: Gala, Golden Delicious, Red Delicious, Granny Smith, Fuji, and Pink Lady were harvested and each presented itself during their inherent times of maturity but not necessarily during the optimal times of development and in sync with design improvements. This objective focused on the Dry Bin Filler and its ability to deliver fruit at 8 per second and with minimal bruise damage. The following table depicts the progression of improvement in bruise incidence associated with design improvements discovered in a variety of testing environments.

Table: Dry Bin Filler Bruise Assessment Tests

2009	Apple Variety	Qty Tested	Assessment	Comments
		PREVIOUS TESTS		
March	Electronic IRD	8 Passes	Low Impacts	worst case drop
June	Golden Delicious	80 Apple Shop Test	10% out of grade	Wash Xtra Fanc
		HARVEST 2009 TESTS		
August	Gala	~ 3 Bin: Orchard Test	no significant bruises indicated	
August	Red Delicious	~ 5 Bin: Orchard Test	no significant bruises indicated	
August	Golden Delicious	~ 5 Bin: Orchard Test	Some bruising indicated due to incorrect fill sensor calibration	3 different fill heights assessed for minimal damage
September	Granny Smith	~ 10 bin: Orchard test	Some bruising indicated due to incorrect speed calibration	Speed was faster than 8 Apples per second
September	Granny Smith	200 Apple: Shop Test	5% small impact bruising	deposited onto 3 layers of Apples
October	Fuji	25 Bin: Packing House – Packout Test	no significant bruises related to Dry Bin Filler noted. Sample from Pack-out: 3.88% Bruising 1.94% Cuts 1.55% Stem Puncture	Damage not necessarily attributed to Dry Bin Filler. Need to compare against 'hand harvest' for same time and block
October	Pink Lady	250 Apple: Orchard Test Sample	bruising related to even Dry Bin Filling was not detectable	28% of Apples on the trees within the Orchard exhibited pre-existing damage
October	Pink Lady	100 Apple: Shop Test	4% exhibited out of grade bruising	8 Apples per second fill rate

EXECUTIVE SUMMARY

WTFRC Project Number: TR-09-05

Project Title: Mobile Linear Asymmetric Fruit Transport Systems

Siginificant Progress and Outcomes:

The scope of this project was considerable and the WTFRC contribution helped enabl a fully integrated mobile fruit transport harvest system with an integral in-field cull sorter and bin management system to be developed and tested in a short time frame. The mobile fruit transport harvest system also exhibited a 'Dry Bin Filler' that safely loads a bin in-field at a speed up to 8 apples per second. The Harvester showed great promise in labor efficiency and the ability to transport and 'Dry Bin' fill fruit with minimal bruise incidence. A low cost scanning, culling, and sorting system in the field present the Grower with the opportunity to reduce bin handling expenses and packing house charges and transport higher quality fruit in the bins.

Summary of Findings:

Picking efficiencies and the ability to take full advantage of the load capacity of the system seems work most efficiently in evenly distributed modern fruiting walls or relatively evenly distributed fruit zones in more traditional orchards. A better qualification of the labor used during harvest and the individual anthropometrics of each picker which can be tracked with the on-board computer should enable the Grower to increase their orchard efficiencies or divulge inefficiencies in their harvest system. The Scanning system demonstrated it can effectively identify a majority of culls induced by nature prior to or created during harvest.

Future Directions:

The harvest knowledge, orchard experience, and input from growers will enable the updates to this harvest system to become a viable and major component for today's producers. Changes to the picking platforms will improve labor reach. Scanning integration will receive further fine tuning with more in-field experience but a very usable system should be available for the next harvest season. The Dry Bin Filler has shown that with the correct parameters, a low bruise incident fruit can be effectively packed in just under 5 minutes (optimal conditions).

The Mobile Linear Asymmetric Fruit Transport Systems will be updated to present a commercial version for Apple Harvest in 2010. It has been shown this technology platform has considerable appeal for Citrus and Peaches. The components and experienced gleaned may be used to leverage advances in harvesting Cherries.