2014 Technology Research Review
March 13, 2014
Washington Cattlemen's Association, Ellensburg

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FINAL REPORT **YEAR**: 3 of 3
WTFRC Project Number: TR 11-100

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

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Cooperators: WA Producers, Yakima Valley Orchards

Total Project Request: **Year 1:** 99,397 **Year 2:** 69,454 Year 3: No Cost Extension

Other funding sources: None

Budget 1
Organization Name: WA State University **Contract Administrator: Carrie Johnston**
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Item	2011-12	2012-13	2013-14
Salaries[1]	65,352	47,966	--
Benefits	16,045	9,488	--
Wages	--	--	--
Benefits	--	--	--
Equipment[2]	7,000	--	--
Supplies & Fabrication Costs[3]	5,000	6,000	--
Travel (Zhang)[4]	2,000	2,000	--
Travel (Lewis)[4]	3,000	3,000	--
Miscellaneous[5]	1,000	1,000	--
Total	99,397	69,454	0

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

OBJECTIVES

This project is in the second phase of intelligent bin-dog concept research. The primary goal of this phase was to develop a research prototype of a self-propelled "bin-dog" usable in typical PNW tree fruit orchards. This "bin-dog" research prototype should have the following essential functionalities to be considered a success of this research: (1) capable of traveling in typical PNW tree fruit orchards using manually maneuvered electronic control systems; and (2) capable of carrying and placing an empty bin at target locations in harvesting zone, then picking and carrying a full bin away from the harvesting zone in the same run to support safer and more effective harvesting. One workable research prototype has been designed, fabricated and tested in both research and commercial orchards in Yakima Valley in 2012-13 (Year 2). Aimed at improving some identified limitations on the first research prototype from Year 2 field tests, a no-cost extension was requested and proved to address those issues through design, fabricate and test of the second research prototype. The following specific project activities have been conducted in this no-cost extension period:

1. Based on the identified limitations of prototype-one (as reported in 2013 Spring Progress Report), a prototype modification plan was specified, and a prototype-two was designed and fabricated. The limitations and defects being identified and to be removed included insufficient power, steering with limited controllability, unreliable bin-loading system, branch hitting due to the frame height and uneven traction force on wheels. Similar to prototype-one, prototype-two was also built using off-the-shelf components (both mechanical and electrical components); and
2. Conducted both laboratory and field tests to validate the improvements achieved from prototype-two, confirm that the identified limitations and defects were removed or at least reduced, and identify new challenges, if any, of the new prototype from testing in both research and commercial orchards.

In summary, this project was planned to develop and prove a concept of using a "bin-dog" to manage bins within modern orchard environment, and to validate its critical functionalities and assess its usability in PNW tree fruit orchards. To accomplish the goal, two manually maneuvered and electronically controlled "bin-dog" research prototypes have been fabricated and tested in both laboratory and research/commercial orchards in PNW region. Test results verified that both prototypes could fulfil the basic functionalities and the second prototype has removed a few limitations or defects that were identified from the field test of the first prototype, such as unreliable bin-loading system, branch hitting due to the frame height, and uneven and/or insufficient traction force, or at least partially removed, such as insufficient power, steering with limited controllability. This project provided us the necessary resources to explore an innovative concept, and to obtain the essential preliminary results adequately supporting our efforts to seek federal funds to complete the full-scale research and development. One full scale research proposal, collaborating with engineers, computer scientists and robot scientists from WSU and OSU, has been developed and submitted to the National Robotics Research Initiative for funding.

SIGNIFICANT ACCOMPLISHMENTS

Design of Prototype-Two of the "Bin-Dog"

In this extended research period, a new "bin-dog" prototype has been designed and fabricated (as shown in Figure 1) to provide the required critical functionalities, including orchard traversing, bin handling, and to overcome the limitations identified on prototype-one, such as insufficient power, poor steering controllability, unreliable bin-loading system, branch hitting due to the frame height and uneven and/or insufficient traction force. The mechanical structure of this new prototype consists of four subsystems; driving, steering, bin lifting and frame leveling.

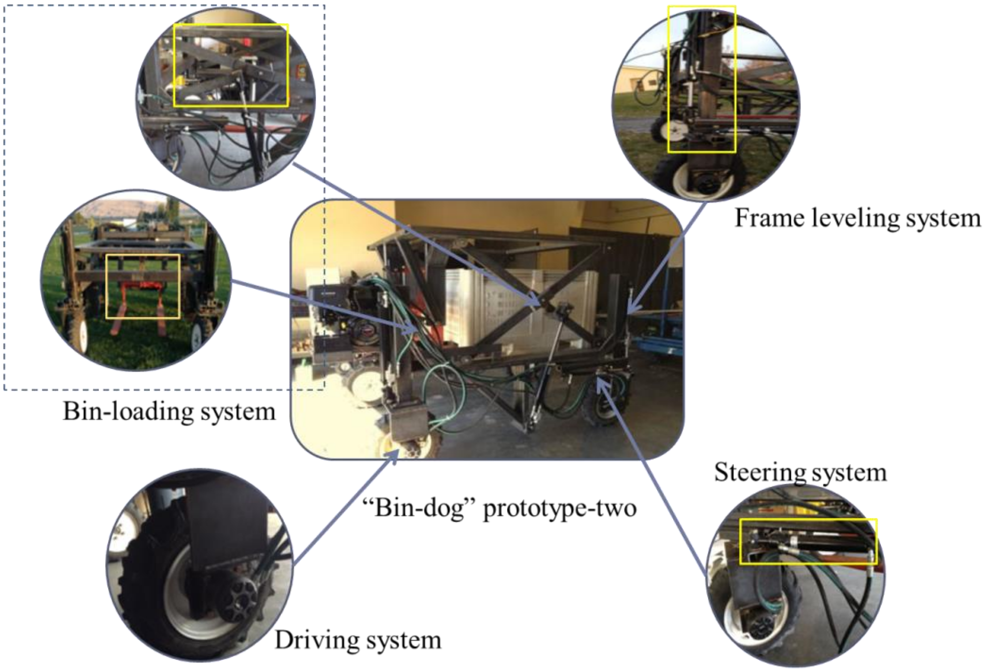


Figure 1 Fabricated "bin-dog" prototype-two

Design of the driving system addressing insufficient power and poor traction force

Insufficient power has been identified as a limitation for "bin-dog" prototype-one which was an electrical two-wheel-drive system driven using two 0.75 kW (1.0 hp) DC motors. To solve this problem, an electro-hydraulic driving system with a four-wheel-drive mechanism and an independent-wheel-tracking-control mechanism were designed for this new prototype. Each of the four independently-driven wheels was actuated using a hydraulic motor. To get either a higher speed or a higher torque, the motor arrangement could be switched between serial (for higher speed) and parallel (for higher torque) arrangement by changing the hose connection between motors. To address one of the major defects identified on prototype-one, the poor maneuverability of the "bin-dog" caused by poor traction force due to inability of all four wheels firmly engaging on uneven surface in orchards, an innovative hydraulic wheel-ground engaging mechanism has been designed (as illustrated in Figure 2) to gain this capability. In this design, the rod side chambers of the frame leveling cylinders on the front wheels are connected together as well as those of the bottom chambers. When driving on flat surface, the fluid in the four chambers is under an equilibrium status. Once a front wheel disengages from the ground due to uneven ground surface, pressure of rod side chamber of that wheel will be quickly reduced which will break the equilibrium. Then the hydraulic fluid in other chambers will push down the rod of the wheel until it engages to the ground again or until the rod extends to its limit. Similarly, when a front wheel runs over a bump, the imbalance of pressures will also adjust the extending lengths of rods on the two front wheels until equilibrium is established. Thus when within its workable range, the mechanism guarantees all four wheels will be firmly engaged on the ground. The functionality and control of frame leveling will be explained in a later section.

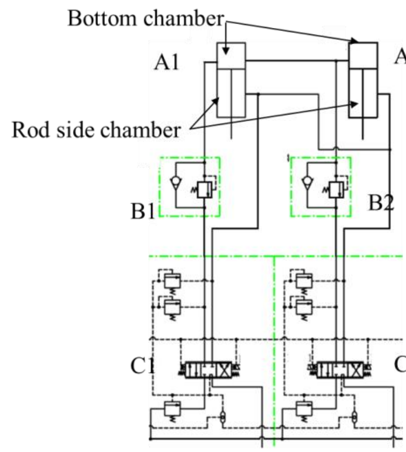


Figure 2 Hydraulic schematic of an active frame leveling and passive wheel-ground engaging system

Design of the steering system to improve steering maneuverability

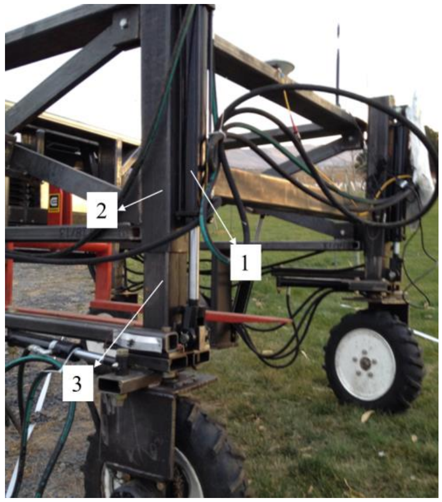
To improve the maneuverability of the "bin-dog" in confined orchard row space, one of the major identified limitations of prototype-one, a "programmable two-wheel steering control system" was developed which coordinately controls the steering of two individually actuated wheels. To steer an individually actuated wheel, an electronically controlled hydraulic system was used to extend or retract a linear hydraulic cylinder to get desired steering angles. The control system allows the operator to control whether those two individually actuated wheels turn synchronously or independently. In this new design, adding only control software without changing the mechanical structure and hydraulic systems design, noticeably improved the maneuverability of the "bin-dog". A feedback control scheme will be required to further improve the steering accuracy with minimal corrections. In addition, as the coordinate control scheme could improve both improve the maneuverability and steering accuracy, the field tests indicated that it was difficult, if not impossible, to achieve satisfactory maneuverability and steering accuracy within a very confined space between tree-rows using a traditional two-front-wheel steering (namely Ackermann steering), a common design for most field mobile equipment. An all-wheel steering mechanism may be essential for obtaining a satisfactory maneuverability in such a working environment.

Design of a new bin-loading system for improving the reliability of the pick and carry function

As the bin-loading system designed for prototype-one could not effectively and reliably pick and carry a bin in the orchard environment due to the limitation of the picking-finger mechanism, a forklift-type bin loading mechanism supported by a hydraulically actuated scissors-structured lifting mechanism was used to gain an effective and reliable bin handling capability under both light and heavy load conditions. In this design, two cylinders symmetrically installed on both sides of the scissors structure, and flow divider was used to ensure the two cylinders extend and/or retract at the same pace to effectively raise or lower a bin while the bin-dog is in motion. Field tests validated that this mechanism could reliably handle the bins, with some room to improve in the effectiveness.

Frame leveling system to further improve the maneuverability and safety

The frame leveling system is a new feature for "bin-dog" prototype-two. The frame leveling system serves the three purposes of allowing "bin-dog" to adjust (1) its frame vertically in parallel to the trees to gain the best accessibility between tree-rows; (2) the center of gravity increasing traction force on “steering” wheel when traveling uphill; and (3) the pose of bin on the fork avoiding weight shifting-induced machine rollover. As depicted in Figure 3, a hydraulically controlled sliding structure (consists of leveling cylinder, outer sliding tube and inner sliding tube) was designed to adjust the height from the frame. Using four individually controlled frame leveling control mechanisms, this “bin-dog” prototype could level the bin at 15° heading/tail slope and 15° side slope. A wider range of leveling ability could be achieved through system reconfiguration (either choosing longer cylinders or redesigning the structure). Currently this leveling system is controlled manually using an electro-hydraulic implementing system.



In the figure, 1: Leveling cylinder; 2: Outer sliding tube; 3: Inner sliding tube

Figure 3 Mechanical design of the bin leveling system (on one wheel)

Design of power and maneuvering system

To solve the insufficient power problem of prototype-one, the new prototype was powered using a 9.7 kW (13.0 hp) gas engine, with all the implementing systems (driving, steering, loading and leveling) driven by electronically controlled hydraulic systems via 8 bidirectional proportional control valves. Figure 4 shows the block diagram of this electro-hydraulic control system. In performing the manual maneuvering of this “bin-dog” research prototype, the operator inputs an implementing command via an electronic control panel, which will generate wireless signals and send those signals to corresponding electro-hydraulic control valves for performing the operation.

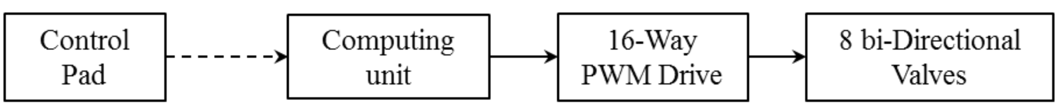


Figure 4 Block diagram of electrical maneuvering system

To actuate all 8 bidirectional control valves, a total of 16 control signals needed to be generated, distributed and converted into PWM (Pulse Width Modulation) format. To accomplish this complex signal processing and at the same time avoid premature design of a complicated controller, a simple 12-key control panel (Figure 5) was used as the input signal generator for the controller. A set of key combinations, representing different control commands will be sent to a custom built control box for implementation. Table 1 lists the definition of the key combinations for different control functions.

Table 1. Key combinations for control functions

Key	Function	Key	Function

(Page 1)		(Page 2)	
1, 2	Forward/Backward	1 , 2	Frame Leveling Cylinder 1 extending/Retracting
3, 4	Coordinated Steering Left/Right Turn		
5, 6	Fork Lifting/Lowering	3, 4	Frame Leveling Cylinder 2 extending/Retracting
7, 8	Left Wheel Left/Right Turn		
9, 10	Right Wheel Left/Right Turn	5, 6	Frame Leveling Cylinder 3, 4 extending/Retracting (Passive Suspension Adjustment)
11	Switch Page		
12	Stop all Functions	12	Stop all Functions

Figure 5 12-key control panel

Laboratory Functionality Tests and Field Validation Tests

To test the designed functionalities and validate the accomplished improvements on prototype-two, a set of laboratory functionality tests and another set of field validation tests were conducted both in CPAAS laboratory and in both research and commercial orchards near Prosser.

Maneuverability tests

The “bin-dog” steering control system was an open-loop system. A steering angle was achieved by setting the start time and stop time of the steering. As a few factors, such as internal and external resistances, would affect the response speed of the electrohydraulic steering system, the evaluation of control performance of “bin-dog” steering included the response time (time elapsed from command being sent to the initiation of according action) and time used to complete a steering action.

The time for the steering system responding to a steering command was 370 ms on average. Under current control system configuration, when the temperature of hydraulic fluid was 22°C (71°F), it took both left and right steering wheel 2 s to turn from the neutral position (0°) to the leftmost position (40°) or the rightmost position (-40°) on paved road.

An additional maneuvering test was set to test the driving and steering performance of prototype-two within confined space and on different ground surfaces. To create a confined space similar to the tree lane configurations in orchards, ribbons were used to set the boundaries of the driving path, as illustrated in Figure 6. During the test, the operator manually drove the “bin-dog” forward from point A, took a turn and stopped at point B. At point B, “bin-dog” started backward, took a turn and stopped at point C. All the actions were completed within the boundaries. Once “bin-dog" touched boundary, it would be stopped and driven back in the driving path. The locations of boundaries were all recorded using a RTK GPS. Then the GPS was mounted on the center line of "bin-dog" which recorded location and time information of "bin-dog" during tests. Three sets of maneuvering tests were carried out on paved road, on lawn and on side slope, all in IAREC campus.

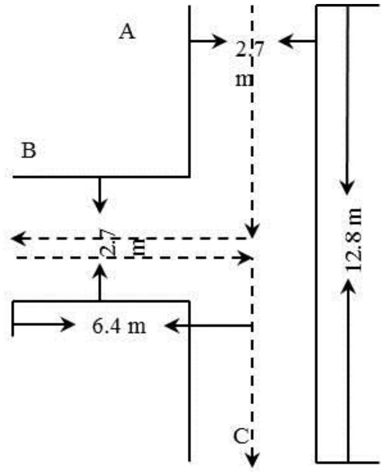


Figure 6 Laboratory driving test setup and test pathway configuration (unit: m)

Figure 7 shows the result in LTP (Local Tangent Plane) coordinates obtained from one of the maneuvering tests conducted on the lawn test pathway. Point A and C were selected so that the driving paths of forward and backward processes in all tests were the same. In forward motion the "bin-dog" was in a front-wheel-steering mode, and in backward motion it was in a rear-wheel-steering mode. As the recorded trajectory showed being smoother when driving forward when compared to driving backward, it indicated that front-wheel-steering provided better trajectory controllability than rear-wheel-steering on this "bin-dog" while maneuvered manually.

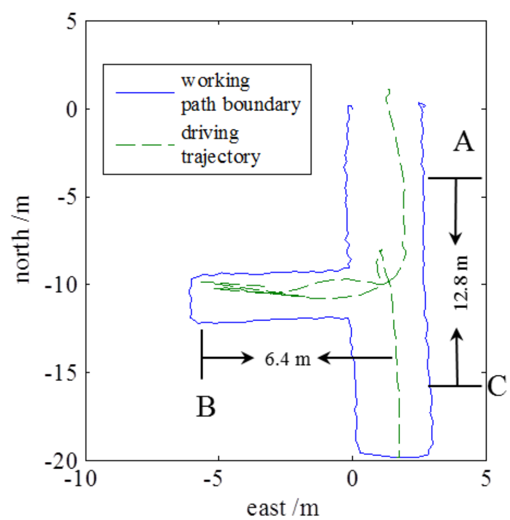


Figure 7 Working path boundary and working trajectory presented in LTP coordinates

To further compare the maneuvering performance of different driving modes (front-wheel steering from A to B, rear-wheel steering driving from B to C) and on different ground types (paved road, lawn and slope), equation (1) provides an additional measure of the "bin-dog" maneuverability.

$$\text{Maneuvering effective measure} = \frac{100}{t * \sum_i^n e / n} \tag{1}$$

In this measure, t is the time used to complete a drive path (A to B or B to C), n is total number of GPS sample points for the location of "bin-dog" being recorded during the driving and e is the distance between a GPS recorded trajectory point and the center line of the ideal driving path. As the operator tried to locate the center of "bin-dog" along the center during the test, $\sum_i^n e/_n$ could represent the average position error for the driving. Thus if an operation in a driving has a higher maneuvering effective measure value, as the patterns and lengths of the two driving paths are the same, it means the driving either uses less time or the average error is lower, and it will be regarded that the operator has a better driving performance in that driving. Table 3 lists the performance data obtained from 9 test runs.

Table 3. Maneuvering effective measure

	Maneuvering Effective Measure ($s^{-1}\cdot m^{-1}$)	
	Front-wheel steering (A to B)	Rear-wheel steering (B to C)
Paved road	9.2	3.6
Lawn	10.9	3.7
Slope	8.2	4.7

For the maneuvering effective measures on the 3 different ground surfaces, no large difference could be observed. It shows that the operator had stable maneuvering performances driving "bin-dog" on different ground types. But for all the 3 sets of tests, maneuvering effective measures of front-wheel steering were 142% higher than that of rear-wheel steering on average. It means that an operator could maneuver the "bin-dog" better using front-wheel steering in confined space than rear-wheel steering.

Speed test

In order to validate the drivability of prototype-two "bin-dog" in orchard environment, a speed test was set to test prototype-two in Yakima Valley orchards with fruiting wall tree architecture. The testing lanes were roughly 200 m long and were about 2.2 m wide. A GPS receiver was used to record the trajectories of "bin-dog" during the tests. The result showed that it took "bin-dog" 446 s at an average speed of 0.5 m/s to pass through those lanes, with a highest speed being recoded at 1.1 m/s.

To further test the drivability of "bin-dog", two supplemental tests were conducted on lawn in WSU station in Prosser. In the tests, "bin-dog" carried a light load and was driven to its highest speed. The locations of "bin-dog" were recorded using GPS. In the tests, "bin-dog" could drive up to 1.2 m/s on flat surface on lawn while the highest speed dropped to 0.9 m/s when driving on 15° slope on lawn.

Bin handling test

The bin transportation function is one of the core functions of the "bin-dog". To validate its go-over-the-bin capability and effectiveness within the confined space, a set of field tests was conducted within actual tree lanes in Yakima Valley commercial orchards. To test it under the worst case scenario, all those tests were conducted in "Y" trellis orchards with between tree-row lane spacing of 3.0 m. An empty bin was firstly placed at about 15 m away behind a target bin, then the "bin-dog" came back to pick the target bin and carry it away from the harvesting zone. The time used for each step, including loading an empty bin, driving to the harvest zone, going over the target bin, placing the empty bin, coming back to load the target bin, and carrying the target bin back to the loading area, was recorded. Results showed that it normally took about 4 s to load an empty bin, 10 s to lift an empty bin high enough to pass a target bin, and between 10-13 s to go-over the target bin depending on the space left between the tree-rows and the bin on both sides. The time needed traveling to the target bin and back the loading area was very much determined by the distance from the bin loading was to the target bin.

All those tests were manually controlled using an aforementioned 12-key control panel. From this series of field tests, it was found the maneuvering of "bin-dog" under the rear-wheel-steering mode is very much operator's skill related as the operator's sight was blocked when manually maneuvered from behind. An automated guidance of the "bin-dog" could be the solution to remove this obstacle.

DISCUSSION

Accomplished Improvements and Identified Additional Problems

Prototype-two was designed to remove or improve the limitations/defects identified on prototype-one through modifications on four major subsystems. Obtained test results verified that the new prototype had successfully removed some of the limitations/defects and improved a few others. It also revealed a few new problems.

Adequate driving power for a "bin-dog"

One major identified limitation of prototype-one was the insufficient power using two 0.75 kW (1.0 hp) DC motors to drive two wheels, and one 1.4 kW (1.9 hp) DC motor to drive the lifting system. To find out an adequate range of power requirement for all subsystems of a fully functional "bin-dog", prototype-two was powered by a 9.7 kW (13.0 hp) gas engine, which used to drive a 1.4 L/s (22.2 GPM) at 3000 rpm hydraulic power unit. This hydraulic unit provides hydraulic power to 4 hydraulic motors mounted on each of the four wheels reconfigurable for getting a higher speed or a higher torque through switching motor connections in a 2-motor serial (for higher speed) mode and an all motor parallel (for higher torque) mode. The hydraulic power unit will also provide hydraulic power to actuate the steering, bin lifting and frame leveling systems when needed. In the speed tests, prototype-two was capable of driving at 0.9 m/s speed on a 15° slope on lawn. Also when testing in Yakima Valley commercial orchards, prototype-two could get to a highest speed of 1.2 m/s under a light load compared to 0.8 m/s of prototype-one. If a higher speed and/or a heavier load were required, a higher power range would be needed. A method for configuring the adequate power range to design such a "bin-dog" was identified based on the lessons learned from this design process using the following equations.

$$Pressure = \frac{r\pi(Mgsin\theta + \mu_r Mgcos\theta)}{2a} \ ({}^{N}/_{m^2}) \quad (2)$$

$$Flow\ rate = \frac{120va}{\pi r} \ ({}^{m^3}/_{s}) \quad (3)$$

$$Engine\ power = \frac{Pressure \cdot Flow\ rate}{efficiency} = \frac{60v(gsin\theta + \mu Mgcos\theta)}{\mu_e} \ (W) \quad (4)$$

In which r is wheel radius, θ is the angle of the slope, a is the displacement of the hydraulic motor, μ_r is coefficient of rolling resistance, M is the mass of "bin-dog", v is the desired maximum speed of "bin-dog" and overall efficiency is μ_e.

Steering with limited controllability

To improve the steering performance of prototype-one which used two controlled driven-steering wheels and two uncontrolled swivel rear wheels to steer the vehicle, prototype-two made the two rear wheels fixed and made the platform four-wheel-driven (namely a standard Ackermann steering design for mobile equipment). After the modification, operator could gain much more controllability in steering the "bin-dog". Adding the coordinating control scheme to harmonize the turning of two independently actuated steering wheels had further improved the maneuverability of prototype-two in handling a bin. As validated in bin handling tests, the improved coordinating control scheme helped to reduce the average maneuvering time of loading a bin from 13 s to 4 s, and go over a target bin from 13 s to 12 s. The limited improvement on go-over the target bin was mainly attributing to (1) blocking the view of operator during the manual control which could be removed or improved by using a sensor-navigated automated guidance for this operation; (2) a large turning radius requirement of Ackermann steering system which could be improved by changing the steering mechanism to an all-wheel steering.

Unreliable bin-loading system

To improve the unreliable and very slow bin loading on prototype-one, a forklift-type bin loading system actuated using a scissors-structure hydraulic lifting system replaced the original pulley driven winch bin-lifting system. This new design worked satisfactorily on prototype-two in terms of both the reliability and efficiency in all laboratory and field tests.

Weight distribution and center of gravity

One new problem found on prototype-two from field tests was that its center of gravity was located in its rear part of the frame, which would lead to an insufficient traction on front steering wheels when traveling uphill on a big slope. Frame leveling system would allow prototype-two to move its center of gravity toward front wheels by extending the frame leveling cylinders on rear wheels. However, to completely remove this problem, some carefully calculated weight balance modifications are strongly recommended in design a product version of “bin-dog”.

Poor response of steering control caused by uneven traction force on wheels

To remove the defect of large slippage or poor response in steering identified on prototype-one, attributed to insufficient, or even no traction force on one of the four wheels while traveling on uneven ground surface, prototype-two has adopted a hydraulically actuated passive wheel-ground engaging system. While it worked well on ground with limited degree of unevenness, this wheel-ground engaging system was unable to respond quickly enough on really rough surface. Under such situations, some poor responses of steering control would frequently occur due to the imbalanced traction on four wheels. Some further improvement for obtaining more prompt response on traction force control via wheel-ground engaging would be needed.

Improved possibility of hitting branches by lowering the frame height

The height of prototype-one is 2.10 m which was about the height of two bins. It often hit the branches when traversing in “Y” trellis orchards. Prototype-two used a collapsible scissors structure which could reduce the “bin-dog” outer frame height to 1.50 m at all the time, and resulted in a narrow inner frame (about 0.10 m narrower than the outer frame) when the lifted bin was at its highest position (2.10 m during over-the-bin operation). This design has effectively reduced the possibility of the “bin-dog” hitting branches of “Y” trellised trees.

Executive Summary

During this no-cost extension period, a new research prototype of “bin-dog” has been designed, fabricated and tested in both laboratory and research/commercial orchard environments. Some of identified limitations/defects identified from prototype-one, such as slow and unreliable bin loading, poor in orchard reversibility due to prototype frame height and uneven and/or insufficient traction force have been removed, and some limitations/defects, such as insufficient power, poor steering control responses been improved. The maneuverability of newly developed prototype-two was tested under various scenarios, from paved road, lawn to commercial orchards with heading/tail or side slopes, and fairly consistent maneuverability performances was observed from those tests. However, when an operator manually maneuvered the prototype-two “bin-dog” implemented by a standard Ackermann steering mechanism, it showed a 142% higher maneuvering effectiveness measure value in forward motion (in front-wheel-steering mode) than in backward motion (in rear-wheel-steering mode). This performance difference could be attributed to the requirement of this mechanism of having a large turning radius and the confined space between the tree rows could not offer sufficient space, and to poor visibility when steering the “bin-dog” while in backward motion. In the bin handling performance test, the new prototype reduced the bin loading time from 12 s to 4 s, mainly attributed to be improved reliability in loading the bin. However, it still took 12 s to guide the new “bin-dog” to carry an empty bin over a target bin compared to 13 s for the old prototype because the new prototype was still maneuvered manually by a human operator using a remote controller, which relied on a good observation of the clearance between the “bin-dog” and the trees/filled bin. In addition, the standard Ackermann steering mechanism did show its limitation of needing a large space to be maneuvered effectively which did not exist in this confined environment. An active four-wheel steering mechanism is strongly recommended for such equipment in future designs.

FINAL REPORT **YEAR**: **2012**

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

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Sinthya Penn, Beneficial Insectary, Redding CA

Other funding sources
WTFRC/ Apple Crop Protection
Amt. requested/awarded Total Project Request:
Requested: $239,663 / awarded: Year 1 (2010): $79,117; Year 2(2011): $79,866;
Year 3 (2012): $80,680. **Notes:** The lacewing portion of this grant overlaps with the foam project

Pending:
Western SARE: Total request: $ 178,954
WTFRC Crop Protection: Total Request $ 237, 702

Budget History

Organization Name: USDA-ARS

Item	2012-Unruh	2012-Dunlap	TOTAL
Salaries			
Benefits			
Wages GS-3 (90/90 days)	$7431	$7431	
Benefits	$569	$569	
Equipment	$ 400		
Supplies	$600	$1200	
Travel		$800	
Miscellaneous			
Total	$9000	$10000	$19, 000

Footnotes:

OBJECTIVES

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

   We have tested *keratin and whey protein hydrolysates, saponin-containing Yucca extract and Qullaja sopninaria extract as foaming agents were tested using off-the-shelf foam sprayers and a sprayer under development. The latter device drops dry lacewing (LW) eggs into the foam stream after it leaves the pressurized portion of the sprayer and appears close to a final product. The remaining problem is in the geometry of the egg delivery system which allows the eggs to be blown out ahead of the foam and falling before the target is reached.*

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

   Initial efforts have been restricted to tests on artificial surfaces including Tyvec sheets plastic cafeteria trays (Wapato) and Plexiglass (Peoria. We have found that the foam produces by keratin, Yucca and Quillaja stick well to tree trunks

3. **Test survivability of lacewing eggs in laboratory conditions when eggs are immersed in and sprayed with these foams**
   With each new formulation of foam producing liquid, measurement of survival after 30 minute submersion in the product is compared to submersion in water. With new spray technique where eggs are dropped into a trough and swept up in a stream of foam, survival has been tested with egg sprayed onto Tyvec surface or sprinkled into foam

4. **Test adherence of LW eggs in foam on apple, pear and cherry trees in the greenhouse and the field and estimate hatch rates of eggs in those settings.**
   In field experiments using tarps below trees, collect and estimate bounce-off and drop of sprays are desirable but have not yet been addressed.

5. **Estimate colonization rates (proportion of eggs recollected as larvae) on test trees.**
   Studies remain to be conducted in pears and in apples infested with aphids and pear psylla at the Moxee Farm. Preliminary studies could not be made in 2012 because of lack of aphids in our experimental farm orchards and our incapacity to apply eggs in foam during June-July

SIGNIFICANT FINDINGS

- ✓ Keratin and whey protein hydrolysates, *Quillaja* and *Yucca* saponins can produce rich foam suitable for initial contact adherence to water repellent surfaces and tree trunks
- ✓ Passage of eggs through rotary diaphragm pumps damages >25% eggs requiring eggs be introduced into the stream of the foaming agent distal to the pump
- ✓ Eggs e introduced in a suspension medium separate from the foaming medium using Venturi aspirator has proven problematic accurate
- ✓ Eggs can be dropped into the spray stream of foam after foam leaves spray nozzle.
- ✓ Mixing of eggs with dry bulking material is necessary to meter eggs for above gravity feed.
- ✓ Long term adherence depends on volume deposited, concentration of foaming agent and presence of other additives
- ✓ Psyllium husk (Metamucil), a potential bulking agent, expands on wetting, absorbs water as foam collapses and causes eggs to stick securely to Tyvec substrate

- ✓ A two trigger spray gun has been developed which has a sliding plate that collects a fixed amount of eggs with bulking material, drops eggs into a trough, and toggles the spray.
- ✓ The addition of eggs to the foam stream after it leaves the spray nozzle eliminates mechanical damage from pressure and shearing in the pump, and from long term submersion of eggs in the foaming agent or other liquids. Optimization of this spray device is required.

RESULTS & DISCUSSION

Objective 1 - Initial testing evaluated the suitability of a variety of natural products and proteins to serve as a foaming agent in this application. A variety of food grade or OMRI approved proteins or natural surfactants were evaluated to serve as foaming agents. Preliminary screening evaluated keratin hyrdolysate, egg albumin, gelatin, whey protein isolate and concentrate (Glanbia inc.), β-lactoglobulin and α-lactalablumin (Davisco foods inc.) and *Yucca schidigera* extract and recently *Quillaja saponaria* extract.. The suitability was evaluated by measuring their physical properties including dynamic surface tension, expansion ratio, half-life, and density using standard procedures. This analysis was conducted us a pestifoamer PF-2 (Richway Industries) to generate foam in continuous mode.

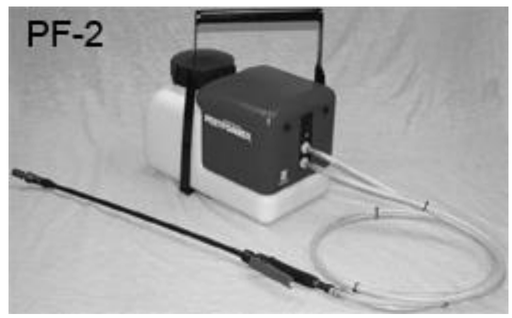

Figure 1. Richway Pestifoamer.

In general, full size proteins evaluated lacked sufficient dynamic surface tension to produce suitable foam under these conditions. The protein hydrolysates (keratin hydrolysate and whey protein isolate) provided better dynamic surface tension due to their smaller molecular size and faster diffusion rates. Still only keratin hydrolysate produced acceptable foam characteristics under these conditions. While keratin hydrolysate had the potential to serve a suitable foam agent, it had other potential limitations. Keratin hydrolysate, while derived from agricultural products (bovine hooves and horns), is not currently OMRI approved. In addition, while it is produced on a commercial scale for fire-fighting foams, it is not readily available without antimicrobial biocides included as preservatives. These limitations and the need to use OMRI products in some field testing sites caused to take a closer look at existing OMRI certified surfactants that could be adapted with other adjuvants to serve as suitable foaming agents. This search identified *Yucca schidigera* and *Quillaja saponaria* extracts, both of which are OMRI approved agricultural surfactants(with a reputation of undesirable tank foaming in standard spray applications). Initial screening identified it as having acceptable dynamic surface tension to meet our requirements. Preliminary screening of hatch rate of eggs after being submerged in the yucca extract showed no appreciable differences from water controls up to 5% yucca. These studies suffered from low survival of eggs in the water control. The following foaming systems were evaluated Moultrie MFH-SPR15P ATV sprayer (Moultrie inc), Pump up bullet foamer, model#925008 (LaffertyEquipment) Pestifoamer (Richway Industries LTD), a variety of TeeJet venturi spray tips on a generic variable pressure sprayer. In each case these sprayers were used with 3.5% keratin hydrolysate. **Mixtures have not been tested.**

The secondary goal under this objective was to determine the best method to introduce lacewing eggs to foam. The solution to this objective was confounded by the competing engineering requirements needed for foam generation and introducing the lacewing eggs. After much trial and error, we concluded that the ideal system would produce a transient pulse of foam with some ability to cast it and introduce the eggs in a batch mode. The eggs would be metered in a dry state on a tree by tree basis. **Figure 2** shows a prototype design of an applicator sprayer that fulfills these design requirements.

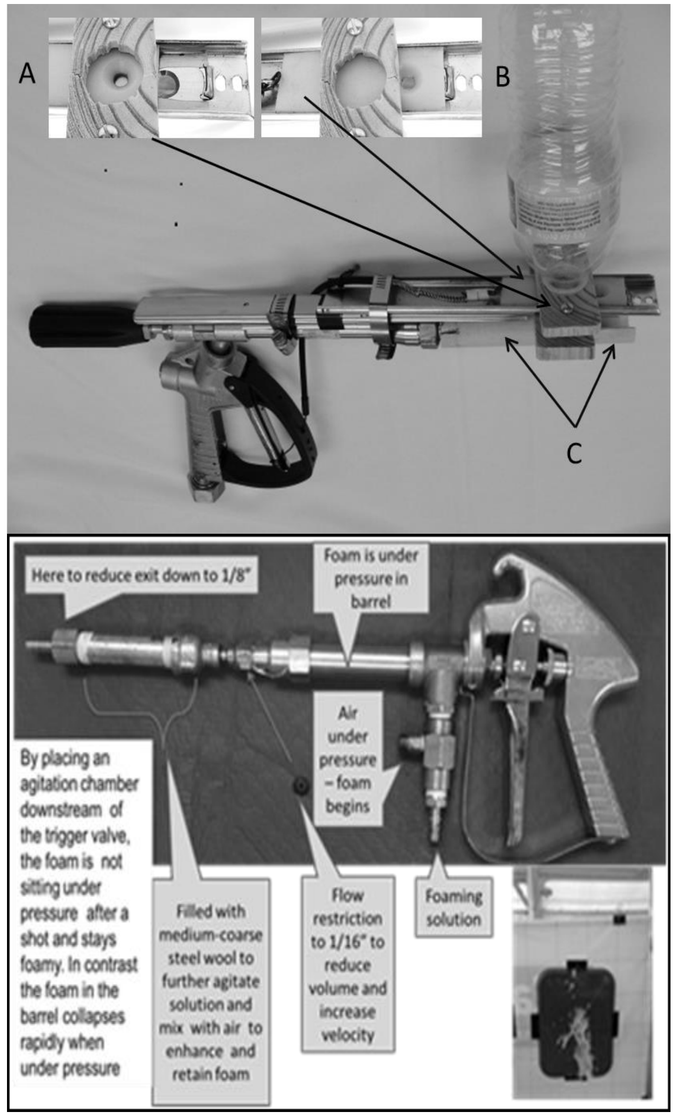

Figure 2. Two prototype designs of a two stage foam generating LW egg sprayer are shown. Sprayer in upper panel shows: A) sliding plate in the refill position - when the beveled hole would be below and this refilled by the hopper (=the plastic bottle which would contain eggs mixed with dry bulking agent); simultaneously the trigger fully squeezed (foam spray is on) or trigger is half depressed; B) sliding plate is above spray trough and has released the eggs – at this time the spray is off and the trigger is at rest; C) spray trough, inside are found air induction nozzles that produce the foam and a trough that the spray slides across picking up the LW eggs on the way out. Sprayer in lower panel does not show the egg delivery system but instead shows and describes a new design where foam quality is improved by introducing compressed air and adding a sparging system(mixing chamber)

Objective 2 was to test of adhesion of foam to waxy, water repellent surfaces in the laboratory in Peoria using a foam generator/sprayer. Fulfilling this objective was limited by the ability to settle on a preferred method of foam generation and egg introduction, which greatly impact the physical properties (such as velocity and droplet size) of the emitted foam solution. However, efforts were made to identify suitable materials that mimic the properties of apple tree surfaces. A literature survey and analysis of local tree stock determine apple leaves are generally considered easy to wet with water contact angles in the 60-80o range. The bark of local apple trees, at the estimated site of application, was variable with an average water contact angle of $74 \pm 9\ ^{o}$. It was decided to use Plexiglas with a water contact angle of 76 ^{o} as the leaf mimic, due to its low cost and wide availability. The branches of the canopy will imitated with small diameter polyvinyl chloride pipe, which has a water contact angle of 85 ^{o}. Once a suitable foam generation system has been identified these mimics will be used to evaluate the influence of additional adjuvants on adhesions. These adjuvants will include viscosity modifiers, polymers to promote egg suspension and adhesion. Recent tests using psyllium as a dry bulking agent for metering out eggs shows exceptional promise in assisting sticking of the foam because the water leaving the foam as it collapses is taken up by the psyllium. In preliminary tests it appears the larges problem from psyllium is using too much, then eggs become trapped in a mat of cross-linked psyllium fibers. Finer grinding of the psyllium husks may also alleviate this problem.

Objective 3. Tests of LW egg survival following submersion in protein hydrolysates show promise, but survival less than 50% has been seen in the firefighting foam and in both the two saponin extracts from Yucca and Quillaja solutions. We have found that lower survival is cause by excessive storage of eggs prior to use for testing. Additional testing will be done once a foam generation and spraying system is finalized. The most recent test (Dec 17, 2012) is shown in Figure 3.

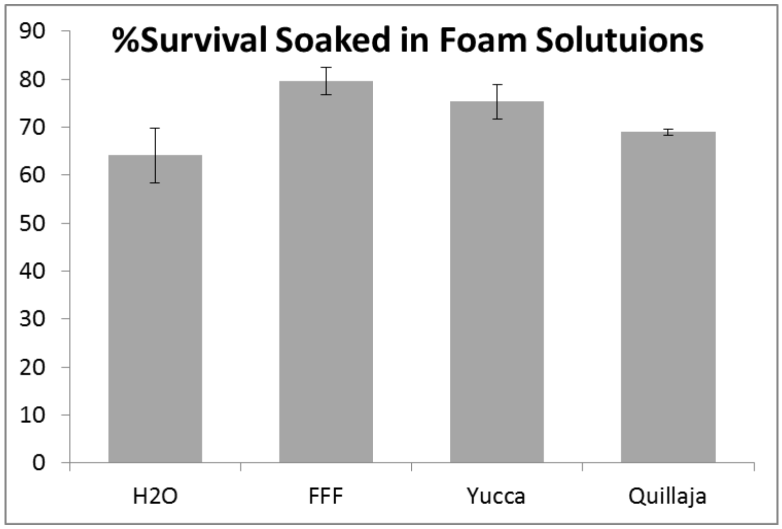

Figure 3. Survivorship of lacewing eggs following 30 minute immersion in three foaming solutions and a water control. Eggs were dried following immersion by placement on a towel and allowed to dry and then dropped on a dry adhesive (back side of an adhesive label) which allows hatch but prevents lacewing larvae from moving to other eggs and feeding on unhatched eggs.

Objective 4 and 5. A preliminary study was conducted at the Moxee farm which consisted of sprinkling dry eggs onto fresh foam solution, wet white glue and water alone painted onto leaves. Best retention of eggs occurred on leaves with glue, followed by foam and no retention at 3 days was observed with water. Improvements in adhesiveness of foam is provided using bulking agents (Metamucil) as observed by greenhouse studies subsequent to field tests. Objectives 4 and 5 remain incomplete until we have an optimal foam and egg sprayer.

EXECUTIVE SUMMARY

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

Participants: Tom Unruh and Christopher Dunlap; USDA-ARS

Budget: $19,000 for 1 year.

Second year is not being requested and a no-cost extension of funding is requested for continued on project with funds remaining from year 1.

OVERVIEW

This project was designed to discover a organically useful foaming agent that could be used to apply lacewing eggs onto trees using an ATV that is only mildly modified from standard spray programs they are currently used for in apple and cherry orchards. There have been two sides to our efforts: 1) chemical, specifically to find an OMRI-approved foaming agent that preserves the health of the lacewing eggs and provides adhesion to foliage or tree bark; 2) mechanical, develop a sprayer that both produces the foam and delivers the lacewing eggs to the trees while an applicator is on the ATV. We have made progress on both fronts, but have not completed the project. We do not ask for funds for a second year because we received funds rather late in the granting cycle and had delays in hiring assistants. Given that, we intend to reach the goals stated with the funds provided in year 1.

Accomplishments:

Keratin hydrolysates, *Yucca* and *Quillaja* saponin extracts all produce suitable foam which adheres well to foliage and tree bark in test application. Only the saponin extracts are OMRI approved.

Survival of lacewing eggs in foaming agents exceeds 80% in many trials in the laboratory.

A modified hand gun that sprays foam through a cylinder where dry lacewing eggs are placed can accurately deliver the eggs in foam to a target 6-8 feet distant. Additiono of compressed air to this system has provided a very rich foam.

Eggs are dropped in the cylinder after a single spray cycle (=trigger pull and release) and addition of bulking agents (ground rice hulls or sphagnum) together with a sticking agent (dry chopped psyllim hulls – the ingredient of Metamucil) result in significant adhesion of the foam.

Work Needed:

The mechanical sprayer needs to be optimized to have reliable retrieval and carrying of the eggs from the spray gun and in metering the egg numbers accurately.

Demonstration of the utility and efficacy of application of LW eggs in foam must be demonstrated in the field

FINAL REPORT

Project Title: New woven pesticide applicator protective garments with repellent

PI: Carol (Ramsay) Black
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Cooperators: Dr. Anugrah Shaw and Courtney Harned, University of Maryland Eastern Shore; Ofelio Borges and Flor Servin, WSDA Farmworker Education Program; Dr Hamilton Ramos, Instituto Agronômico (IAC), Campinas. Brazil

Percentage time per crop: Apple: 65% Pear: 10% Cherry: 20% Stone Fruit: 5%

Other funding sources: None

Total Project Funding: $15,000

Budget History

Item	2013		
Salaries	0		
Benefits	0		
Wages	1500		
Benefits	30		
Equipment	0		
Supplies	3470		
Travel	10000		
Miscellaneous	0		
Plot Fees	0		
Total	15000		

Footnote: Plan to continue efforts, but travel funding supported by WSU Urban IPM and Pesticide Safety Education Program.

OBJECTIVES

Year 1 Objectives

1. Assess current requirements of pesticide manufacturers and EPA by categorizing garment, headgear and glove label statements for products used in tree fruits.
    a. complete
2. Conduct training meetings (extension in-service and grower) to discuss the risk mitigation provided by garment/glove requirements found on pesticide labels for tree fruits, current protective clothing use practices, and the concerns for overprotection (heat stress), as well as the need for applicators to be protected from wetness due to airblast sprayers
    a. worked directly with industry to assess common practices and reasons for decisions
    b. developed draft presentation on risk assessment, tree fruit pesticide labels, and the disconnect between label requirements and garments worn in industry
3. Use audience response systems to survey the interest in this new technology to protect applicators and any needs for specific style and function of the apparel during grower meetings -- present garment materials (textiles) used by pesticide applicators in Europe and Brazil.
    a. worked directly with industry to assess common practices and reasons for decisions
    b. conducted wear study of disposable garments and worked directly with small group of applicators instead of participating in winter training meetings.
    c. discussed risk assessment issues.

Year 1 – Change in process to a wear study for disposable garments

After meeting with managers, supervisors, and applicators from eleven different orchards, it was obvious that the research team (see list of cooperators) needed to better understand why applicators made their protective garment decisions. One operation also grew many other crops, and we visited one vineyard. By conducting an intermediate wear study of disposable garments, we could assess lighter weight materials and better understand durability and comfort factors. It also provided the opportunity to develop trust. The group of applicators from the 12 farms we worked with was initially not interested in wearing the garments with water-repellent finish. At the end of the season, those who participated in the wear study were ready to give garments with water-repellent finish a try.

For your information – project will continue

Funding provided by WSU Urban IPM and Pesticide Safety Education – 2014 garments/travel

1. *Evaluate for comfort, durability, quality, and cleaning for water-resistant, two-piece garments produced in Brazil that meet the ISO 27065 Level 2 requirements. .*
2. *2014 Schedule and Anticipated Findings*
    a. *March – obtain garments from Brazilian collaborator*
    b. *March – obtain IRB clearance from WSU*
    c. *March - Develop protocol and data collection methodology that will work for the cooperating applicators*
    d. *May – Deliver garments and instructions to cooperating applicators*
    e. *June – Visit with applicators*
    f. *July – Visit with applicators*
    g. *August – Collect garments and applicator reports*
    h. *September – Analyze findings and write final report*
    i. *November – Meet with applicators to share findings and discuss garment styles/design for improvements.*

SIGNIFICANT FINDINGS

<u>Tree Fruit Pesticide Label Assessment</u>;

Insecticides, fungicides, miticide labels from the Crop Protection Guide for Tree Fruits in Washington (EM0419) were analyzed; a subset of Dr. Shaw's database of 1,868 labels from Crop Data Management Systems (Shaw 2013).

- Signal words on tree fruit pesticide fruit insecticide, fungicide, and miticide labels (n=129)
  - 7% Danger-Poison (9)
  - 8% Danger (10)
  - 20% Warning (26)
  - 65% Caution (84)
- PPE garment requirements on tree fruit labels (n=130)
  - Chemical Resistant Coverall –Guthion® Solupak was the only product requiring chemical resistant coverall.
  - 11% Coverall over <u>long</u>-sleeved shirt, <u>long</u> pant
  - 7% Coverall over <u>short</u>-sleeved shirt, <u>short</u> pant
  - 82% Long sleeved shirt, long pant
- 42% of labels with chemical-resistant headgear requirements, only require long-sleeved shirt, long pant

<u>Pesticide Label Issues</u>

- Term "chemical resistant" for headgear or garments is poorly defined by EPA in relation to the spray solution or concentrated product – The federal Worker Protection Standard (40 CFR 170.240) defines "chemical resistant" as "made of material that allows no measurable movement of the pesticide being used through the material during use." Plan to continue dialogue with EPA on this significant shortcoming – meetings scheduled for March and Mary 2014.
- The term "coverall" is also poorly defined – type of fabric, quality, finish, thickness. etc.
- There is a glaring disconnect between the risk assessors' determination of required PPE (as stated on the labels) and most pesticide handlers who are required to comply with the requirements.
- Risk assessment applicator training must address protections of key routes of exposure: head, body, arms, legs, feet, and hands and why different PPE is required on labels.

<u>Assessment of PPE Practices in Orchards - April 2013</u>

- Protection is #1 priority
  - Farm supervisor – support applicators' desires to be protected (comfort/expense) but in some cases recognize overprotection in practice.
  - Most farm supervisors have at some point been applicators themselves.
  - Applicators – want to feel protected against wetness and pesticide exposure and want an impermeable barrier; they desire zero exposure. Risk assessment is not based on zero exposure, but wetness is an issue that must be addressed (PPE, application volumes, equipment, and methods).
- Becoming wet from spray was a significant concern by applicators
- Most applicators wore relatively thick rain suits (hood and bibs) for protection. Disposable Tyvek™-like suits were worn by some applicators (choice of applicator themselves) for low toxicity blossom thinning sprays or micronutrient (leaf-feed) applications.
  - Protection, comfort and clean-ability were the major concerns when rain suits are worn.
    - One applicator wore a disposal Tyvek® suit over his rain suit to prevent its contamination/grime from an organic nutrient application.

        - One vineyard had applicators wear an extremely heavy-duty PVC coverall, approx. 0.35 mm.
    - Heat was managed by stopping spraying when temperature thresholds were met, such as 80-85°F.
    - Oil added to spray mixture affects ability to clean PPE.
    - Greatest exposure zones were noted as back, head, forearm, neck and the crotch area in contact with the tractor seat.
    - Ball cap contamination is a significant issue. Binder clip on hood was a great idea.

<u>Disposable Coverall Wear Study - July 2013</u>

Four disposable garments were worn by 12 tree fruit applicators

- New taped garments now in US marketplace
- One garment was removed from study when “too much heat” was noted.
- Reported design features to manufacturers to assist them in design changes.
    - Taped seams were durable and performed well.
    - Glued zipper covering was a failure since it ripped the fabric when opened during the day – must be addressed, but realize to meet international spray-tight performance standards the manufacturers must eliminate penetration from zipper area.
    - Preference for lighter colors, not dark colors
- Considerations and needs for the future.
    - Developing two-piece, disposable spray-tight suits could improve comfort by offering a better potential for cooling. It would also improve fit because differences in height can be better adjusted in two-piece suits. Two-pieces would also eliminate the need to unzip a one-piece suit to go to the bathroom.
    - Consider a design feature that relies on separate spray-tight headgear, like a Sou’wester or one that covers the cap’s brim since most people wear ball caps or.
    - In some garments, crotch area needs to be addressed to ensure adequate roominess.
    - A durability test is needed for rubbed areas, tears and punctures.

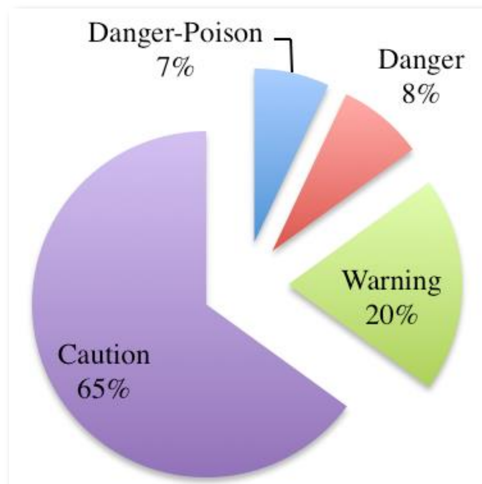
<u>Education is Needed</u>

- EPA and product manufacturers
    - Need to receive the findings for this work and address term “chemical resistant” related to garments, headgear and footwear and the term coverall
    - Need more information from the risk assessment process for “typical number of hours” for the application process to address the reported wetness, especially in the tractor seat
- Educators – university, regulatory, industry
    - Provide more in-depth professional development training for educators on the risk assessment process, applicator exposure/protections, and low toxicity products to improve risk management education.
    - Develop resources, like brochures, to convey dermal exposure/toxicity information using non-technical terms.
- Garment industry
    - Provide garment industry with input for the applicators about preferred design styles and features for PPE

RESULTS & DISCUSSION

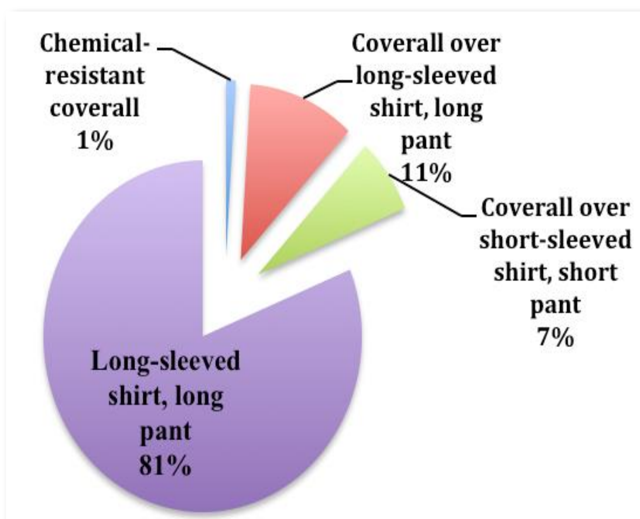
Several definitions are important to best understand the scope of the project and the collaborators involved.

- PPE - personal protective equipment
- Farm Supervisor – oversees and directs the spraying operations
- Applicator - the person mixing, loading and applying pesticides who is working under the supervision of a farm supervisor – may or may not be a WSDA-certified applicator
- Garment types
    - "Chemical-resistant" garment is not based on performance standards by US Environmental Protection Agency. *EPA 40 CFR 17.240: When "chemical-resistant" personal protective equipment is specified by the product labeling, it shall be made of material that allows no measurable movement of the pesticide being used through the material during use.*
    - Water-impermeable garment allows no measurable movement of water or aqueous solutions through the material during use.
    - Disposable garments – worn for the day, then discarded. The performance of these garments is dependent on the material and garment design, such as Kleenguard™, Microguard®, or Tyvek™.
    - Rain suit – washable, reusable and water-impermeable; most are made of coated fabric or sheeting that may also be chemical resistant.



Label Data for Personal Protective Equipment

Dr. Shaw maintains a label database detailing the PPE requirements for 1,868 product labels, which were provided by Crop Data Management Systems (CDMS) in 2012 (Shaw 2013). She extracted the PPE data for most pesticides in the Crop Protection Guide for Tree Fruits in Washington (EM0419). The data from 130 insecticide, fungicide, and miticide labels were analyzed for signal word and PPE requirements. The majority (65%) of product labels analyzed were low-hazard products with the signal word Caution. Twenty percent were moderately toxic with the signal word Warning. Fifteen percent were highly toxic with signal words 8% Danger and 7% Danger-Poison.



Signal words do not directly correlate with the PPE requirements on labels. The basic requirement for long-sleeved shirt and long pants was on 81% of the insecticide, miticide, and fungicide labels analyzed. Coveralls over short-sleeved shirt/short pant or long-sleeved shirt/long pants were 7% and 11%, respectively. Only one product, Guthion® Solupak, required a chemical-resistant coverall.

Of the 130 products, 31 required chemical-resistant headgear. These 31 were paired with 13 requiring long-sleeved shirt/long pants, 8 requiring coverall over short-sleeved shirt/short pant, and 10 requiring coveralls over long-sleeved shirt/long pants. Thus, 42% of labels required minimal dermal protection, but required significant head protection.

These tree fruit label PPE findings were very similar to the findings that Shaw found with the 1,868 labels analyzed. There was no indication that the tree fruit industry product labels required products with greater protective levels of PPE when compared to the sample of labels analyzed nationally. However, the question remained as to why the applicators were typically wearing high levels of protection when the risk assessments that drive the label language did not result in requirements for impermeable garments.

Applicator Garment Selection

To assess why the applicators chose their selections of PPE, eleven operations were visited in April 2013 in the following areas: Wenatchee, Quincy, Royal Slope, Gleed, Moxee, Sunnyside, Alderdale, Burbank, and Prescott. They produced the following crops: apples, cherries, pears, hops, blueberries, and grapes. Acreages varied from 9 to 4,500 acres. Open cab airblast sprayers are still commonly used for tree fruit application; however, a couple ranches had all or some enclosed cabs. Rears sprayers were the most common for foliar conventional or organic insecticide, fungicide and micronutrient (leaf feed) applications. Typically, foliar applications were made for 6 - 12 hours from 1-3 days/week; however, large operations or emergencies, such as fireblight, pest outbreaks, or late season hops, required continuous applications. An application rate of 200 gallons per acre by airblast sprayer was quite common (range: 100-400 GPA). As a result there is considerable exposure.

High exposures occur at turns and when wind is blowing the same direction/speed as the tractor. Wetness is a concern especially when applying at 400 GPA even for one load that typically takes 20 minutes to apply. Some applicators and farm supervisors mentioned that they get very wet, and the liquid starts collecting on the tractor seat (we were not there long enough to evidence this). There was no visible evidence of “running of liquids” (but dry droplets) on the safety glasses or windows of enclosed tractor cabs. Greatest exposure zones were noted as back, head, forearm, neck and the crotch area in contact with the tractor seat.

The majority of applicators stated it was their choice to wear either rain suits or disposable coveralls when applying insecticides, fungicides, and micronutrients through airblast equipment. Some preferred reusable as the overall cost of the garment is lower; whereas, others preferred disposable garments for convenience.

Most applicators wore relatively thick rain suits (hood and bibs) for protection. All rain suits were made of multi-component materials - polyurethane or PVC coating on top of the fabric, inside, or on both sides. Rain suits were typically washed by placing them onto concrete and then scrubbing with a brush. Applicators in one farm wore extremely heavy suits for emergency spraying as the farm supervisor was under the impression that 0.35mm thick garments are required to be “chemical resistant.” This was the only location with extra-heavy-duty suits. (This practice is not representative, but of significant concern)

- **FINDING – Sales catalogs do not reference the term “chemical-resistant” in relation to pesticides, but do for other toxic hazards. This is problematic and EPA needs to address it.**

Disposable Tyvek®-like suits were worn by some applicators (choice of applicator themselves) for low toxicity blossom thinning sprays or micronutrient (leaf-feed) applications. Typically, applicators in enclosed cabs wore disposable garments and those in open cabs wore reusable clothing. Those using ground booms for herbicides did not wear rain suits. The durability of the materials, leakage through seams, and tears were the main concerns expressed by the farm supervisors and applicators. In one farm, two applicators were wearing disposable coveralls that were ripped in the crotch area. The crotch in these coveralls was very low. The top coating of the coverall was also ripped and punctured. Different types of Tyvek®, Kleenguard® and other brands were called "tyvek," so it was not possible to obtain feedback about the different types of disposable garments. All disposable garments used were one-piece coveralls.

Most applicators wore hooded rain suit/coveralls over either a fabric ball cap or waterproof hat (Sou'wester). In most cases, wearing a cap under the hood provides for visibility when the head is turned, as compared to having the view blocked by the hood when looking back at the spray system (one orchard used a binder clip to secure the rain suit hood to their ball cap). In many cases the hat helps block the sun and prevents spray from running off down the hood onto the respirator or face.

The applicators reported they would like protective, affordable and lighter-weight garments that are durable. New garments would need to provide for comfort and prevent heat stress. Heat was managed by stopping spraying when temperatures exceeded 80°F.

Garments with repellent finish were passed around and discussed with the applicators at the 11 operations. Though curious, the majority stated they still wanted a garment that was water-impermeable and would keep wearing their rain suits and disposable coveralls. Also not a single person would wear just pant and shirt, even with repellent finish. The majority of applicators do not trust that the PPE on labels provides sufficient protection. Some questioned why the regular pant and shirt is required for whole body when chemical-resistant material is required for headgear. The WSDA-trainers also mentioned that some labels have contradicting requirements (maximum protection for one part and minimal for another). An example is stringent requirements for gloves and headgear and lenient requirements for the body.

- **FINDING – Applicators showed no interest garment with garments with repellent finish (except the hat) during the visit/discussions; thus, we refocused our efforts by conducting a "wear study" in July 2013 for light-weight, disposable garments that might provide sufficient protection.**
- **FINDING – The risk assessment process addresses the fact that the head area contributes significantly to exposure; thus, educational resources on dermal exposure and PPE should be developed for the tree fruit industry.**

WSDA-trainers, farm supervisors and pesticide applicators believe that for airblast spraying, work-attire (coveralls and/or long pants and long-sleeved shirt) does not provide sufficient protection for wetness and pesticide exposure, regardless of what the product label states. Often total protection was the goal that applicators and farm supervisors tried to achieve due to concern of health implications as a result of lifetime (chronic) exposure. Individuals expressed concern about the adequacy of PPE required by pesticide labels considering exposure scenarios (deposition amounts, applications methods and length of exposures).

- **FINDING - There is a glaring disconnect between the risk assessors' determination of required PPE (as stated on the labels) and most pesticide handlers believe they needed for protection from wetness or product hazard.**

Protection, comfort and clean-ability were the major concerns when rain suits are worn. Protection (against pesticides, oils, sticky materials, and wetness) provided by these suits is the main reason for wearing them despite the comfort issues. At one operation a disposable Tyvek® suit was worn over the rain suit to prevent the rain suit from getting dirty; at the end of the day the disposable suit was discarded and the reusable rain suit reused the next day without washing.

From the farm supervisors' perspective, protection of the applicator was their top priority – over comfort and expense. All those we interviewed stated they would provide any PPE their applicators desired to have available. They noted concerns for both acute and chronic effects from pesticide exposures. Two supervisors commented they wanted some training classes to educate their crew about the safety of wearing fewer layers since they were unable to effectively communicate the message.

- **FINDING: There is a need for risk communication education.**

Applicators stated they want to feel protected against wetness and pesticide exposure and want an impermeable barrier. They stated zero tolerance for any penetration of spray. They also noted that when oil is added to spray mixture, it significantly affects their ability to clean PPE.

- **FINDING: If garments with water-repellent finish are to be considered in the future, the effects of oil in the spray solution must be addressed.**

Disposable Coverall Wear Study – July 2013

After learning that durability and protection provided by the disposable suits were mentioned as the major concerns and there was little interest in garments with water repellent finish, we planned and conducted a wear study to determine the user acceptance, durability and overall performance of new-to-the-market spray-tight garments (European certified Type 4 – spray tight) as these coveralls could potentially provide a balance between protection and comfort. In the study, 12 experienced operators wore four different types of disposable, one-piece coveralls for their regularly-scheduled applications to tree fruits. Also, the garment was worn over their regular clothing. The applicators performed their normal application duties that included starting at their normal times and stopping when the job was complete or cut-off temperatures (heat concerns) were reached.

Responses were collected from the applicators on the positive and negative attributes of the garments as well as performing visual inspections and photographing all garments. Findings were reported back to the manufacturers for them to consider improvements. In addition, the garments are being tested at the Instituto Agronômico in Campinas, Brazil, to determine the performance level in accordance with ISO 27065. Lessons learned from the wear studies will be used for ongoing discussions to revise the standard.

	Coverall A	**Coverall B**	**Coverall C**	**Coverall D**
Material Description	Flash spun high density polyethylene	Microporous film laminated to spunbond nonwoven	Polyethylene coated bi-component PP/PE spunbond nonwoven	Microporous film laminated to spunbond nonwoven
EN Type	4/5/6	4/5/6	4/5/6	4/5/6
Weight (GSM)	41.5	65	65	65±5%
EN ISO 13934 Tensile Strength (N)	>60	108.1 MD)/48.3 (CD)	110 (MD)/63 (CD)	48.3 MD
EN ISO 9073- 4 Tear Resistance (N)	>10	40.7 MD/18.6 CD	32.6 MD/63.3 CD	108.1 CD

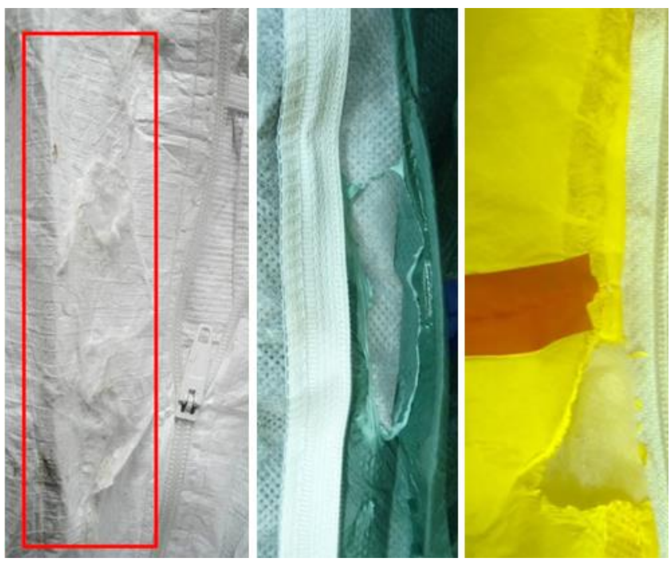
EN 863 Puncture Resistance (N)	>10	8.2	10	6.95

Table 1. Coverall details.

Scenarios varied considerably from orchard to orchard. Tree ages varied widely, which affects droplet dispersion, thus applicator exposure. Canopy densities/style varied as well; some orchards had open tree rows while others had dense canopies and closed tree rows, which caused branches to drag across garments. Applications were made in July with daily temperatures from lows of 54, 63, 51 °F to highs of 87, 99, 97 °F measured at nearby WSU AgWeatherNet stations. Applicators made typical decisions on when to start and stop an application based on air temperatures and wind speeds. Humidity was below 40% during the entire week.

Overall condition of the garments - Dirt/deposit on the garments ranged from minimal to very dirty. Some were very clean, whereas some had visible dirt and grease. In colored, especially green garments, spray deposit when calcium was being applied was very visible. As expected, the calcium deposit was not visible on the white garment.

Garment Design/Fit – The overall garment design of all four coveralls was very similar. In general the participants liked the garment fit over the body. There is sufficient design ease to allow them to move freely. Participant responses also reflected some examples about fit as it related to certain parts of the body. For example, applicators felt that one type of coverall leg "rode up." Some of the participants commented on the fit of the hood over the baseball cap. Some were satisfied by the way the hood covered their cap, whereas some found the hood too small. The satisfaction varied even for the same type of garment. The elasticized cuff was a feature that they liked.



The flap with glue along the edge to secure the flap over the zipper was one feature that all applicators found problematic. Participants removed or partially removed garments to have lunch or to go to the bathroom during the 2 to 5 hours of making applications. In several coveralls, glue from the flap stuck to the fabric, resulting in fabric damage/tear on the non-glued surface. After experiencing this with multiple garments, some applicators opted to leave the paper strip over the glue strip in tact to avoid the problem with the glue ripping the garment. It is strongly recommended that the manufacturers consider ways to resolve the issue with the glue strip (quality of seal is important internationally where garment certification is required).

Garment Protection – Most noted the garments provided sufficient protection as they could not feel the spray. However, they also said they would use it while applying calcium but not for pesticides. On the one windy day, some operators claimed they could feel the wet spray. Note: Garment penetration cannot be assessed accurately using applicator response.

Garment Durability – Garment durability varied considerably based primarily on garment material. Garment damage could be broadly grouped into four categories. 1. Abrasion due to rubbing against a surface such as seat belt connector on the tractor. 2. Tear as a result of garment getting caught on a branch or in one case a piece of barbed wire near a water spigot. 3. Damage along the seam in the crotch area. 4. Minor scratch marks that did not tear the garment. Garment material and quality of garment construction affected durability. The frequency of tear was higher in Coverall 4. Some of the tears were significant enough to affect the protection of the garment. In some of the garments made with microporous film laminated to spunbond material, damage due to stress was observed in the crotch area.

Garment Comfort – The normal work attire for participants was typically long sleeved knit or woven shirt and jeans or pants. Some wore sweatshirts or fleece the entire day, even when the temperature was relatively high. Since they wear the same attire during regular work days, they were not asked to make any changes in the work attire for the study. Response to comfort varied considerably. Comfort is a complex phenomenon to measure. Although each individual wore the same types of garments, other factors such as climatic conditions and duration of work varied. As a result, comments related to comfort may not be applicable for other scenarios where the regular work attire or climatic conditions are different.

In general, material did not matter on Day 1 when the temperature was cooler than on other days. No comfort issues were reported on Day 1. On subsequent days the responses related to comfort varied for three garments.

Being hot was a complaint with the garment coated with polyethylene and the garments with microporous membrane. Testing of the garment coated with polyethylene had to be discontinued due to excessive sweating reported by two participants. One of the participants discontinued the use of that garment after approximately 1 hour, and the other took measures to cool down during the day. Some of the individuals who wore garments with microporous membrane also complained of it being hot. One participant mentioned that comfort is the same as when he is wearing his rain suit. A two-piece suit may assist in dissipating the heat in hot weather. Several garment labels were damaged from being wet (sweat).

CONCLUSIONS

The trend in tree fruits is to use lower toxicity pesticides today. Application volumes are commonly 200 gallons per acre or higher. Applicators state they get wet from spray. The perception of high risk is prevalent in the applicator community. The lack of understanding dermal exposure principles has resulted in confusion for why chemical-resistant headgear is required when the label only requires long-sleeved shirt and long pants.

The disconnect between labeling language and PPE-use practices needs to be addressed. EPA and chemical manufactures must be engaged to assess their current use of label terminology and the risk assessment process. Both parties also need to provide evidence that the risk assessment process adequately measures the exposure concern for applicators using open cab tractors with airblast sprayers at high volumes and applying many consecutive hours. The term “chemical-resistant” on labels needs to be defined for headgear, boots, and garments and this then conveyed to the marketplace so they can respond and provide appropriate PPE. Use of the term coverall needs to be discussed and better defined.

To improve concerns for heat and comfort, applicators applying with open cab tractors and airblast sprayers should consider wearing two-piece disposable garments to provide more air movement and cooling when off the tractor and to improve fit of the pants (crotch/pant length). The industry should engage suppliers to locate/make two-piece disposable, water-resistant or water-impermeable garments that might improve cooling.

Risk assessment education curricula need to be developed and educators trained in the science of dermal exposure (head, arms, trunk, legs, neck). Trainers need the resources and information to explain the differences in PPE requirements on labels.

Garment manufactures who design garments must continue to strive to maintain protections from liquid penetration with considerations for the comfort of the wearer. Applicators currently wear two-piece rain suits when concerned about excessive spray deposition (wetting) or toxicity. Development of two-piece, disposable suits could improve comfort and provide for a wider choice of protective gear. The two-piece design offers a better potential for cooling of the fabric types that were found to be most-heat prone. There was a preference for lighter colors. When designing the garment, designers must understand that there are times the suits are temporarily removed, at least from the upper torso, and consider other options for protecting the zipper area other than glue, such as a wider flap or snaps. Since most people wear ball caps, consider independent headgear styles or a hood that could cover the cap's brim but provide for visibility when turning to look back. The elasticized cuff was a preferred feature. The crotch area needs to be addressed to ensure adequate roominess. A durability test is needed for rubbed areas, tears and punctures.

WSU, University of Maryland Eastern Shore, and WSDA Farmworker Education plan to continue the work in 2014 by conducting a wear study with water-resistant, two-piece garments and headgear that are manufactured in Brazil. The study will begin in May 2014 after dormant oil and chlorpyrifos treatments. The water-resistant garments will be used for water-based spray solutions.

LITERATURE

A. Shaw. 2013. Analysis of Personal Protective Equipment Requirements on Labels of Pesticides for Agricultural Use. JPSE 15:17-19.

EXECUTIVE SUMMARY

This project analyzed the personal protective equipment (PPE) required on insecticide, fungicide, and miticide labels from the Crop Protection Guide for Tree Fruits in Washington (EM0419); from a subset of Dr. Shaw's database of 1,868 labels from Crop Data Management Systems (Shaw 2013). The basic pesticide label requirement for long-sleeved shirt and long pants was on 82% of the tree fruit labels analyzed. Chemical-resistant headgear was required on 31 labels and 42% of those required only long-sleeved shirt and long pants. The tree fruit industry is using more low-toxicity pesticides today with little change in their use patterns for protective garments.

In April 2013, the research team visited 11 agricultural operations to discuss PPE use practices and the possibility of wearing garments with repellent finish. For open cab tractors with airblast sprayers, not a single applicator would wear just pant and shirt or a garment with repellent finish (except the hat); thus, in July we refocused our efforts by conducting a "wear study" of 4 light-weight, disposable coveralls with taped seams that might provide sufficient protection and be cooler than rain suits.

From the discussions in April, we learned there is a glaring disconnect between the risk assessors' determination of required PPE (as stated on the labels) and those who are required to comply with the pesticide label requirements (risk managers, farm supervisors, and applicators); this needs to be addressed. The perception of high risk and the wetness factor from any exposure is prevalent in the applicator community. The lack of understanding about dermal exposure principles results in confusion for why pesticide labels require chemical-resistant headgear and only long-sleeved shirt and long pants. Wetness is an issue that was not sufficiently assessed and was faced by applicators using airblast sprayers; more information is needed to address this.

EPA and chemical manufactures must be engaged to assess their current use of label terminology and the risk assessment process; both parties need to provide evidence that the risk assessment process adequately measures the exposure concern for applicators applying many consecutive hours. The term "chemical-resistant" on labels needs to be defined for headgear, boots, and garments and this conveyed to the marketplace so it can respond and provide appropriate PPE. Sales catalogs do not reference the term "chemical-resistant" in relation to pesticides, but do for other toxic hazards; this is problematic and EPA needs to address it through label changes. Coveralls also needs to be addressed.

Risk assessment education curricula need to be developed and educators trained in the science of dermal exposure (head, arms, trunk, legs, neck) and PPE.

For the wear study, all findings were reported, including images, to the three manufacturers. One disposable coverall was removed from study when "too much heat" was noted. Taped seams were durable and performed well. Glued zipper covering was a failure since it ripped the fabric when opened during the day. The zipper closure must be addressed, but are needed to meet spray-tight performance standard - manufacturers must eliminate penetration from zipper area. Applicators preferred lighter colors. The manufacturers could develop/modify two-piece, disposable suits for pesticide applicators to improve comfort by offering a better potential for cooling when the applicator is off the tractor. A two-piece suit could improve fit because it adjusts for differences in height of the applicator. Two-piece suits would also eliminate the need to unzip to go to the bathroom. Manufacturers should consider a design feature that covers the cap's brim since most people wear ball caps or have a separate headgear. In some single-piece coveralls, the crotch area needs to be addressed to ensure adequate roominess. Lastly, a durability test is needed for disposable garments to address for rubbed areas (seatbelt), and the potential for tears (limbs) and punctures.

FINAL PROJECT REPORT **YEAR**: 2013

WTFRC Project Number: TR-10-110

Project Title: High resolution weather forecasting for freeze prediction in WA

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Cooperators: None

Total Project Request: **Year 1:** $90,000 **Year 2: Not Funded** **Year 3: Not Funded**

Percentage time per crop: Apple: 50% Pear: 10% Cherry: 30% Stone Fruit: 10%

Other funding sources

Indirect support through the existing infrastructure of AgWeatherNet and its 151 weather stations

WTFRC Collaborative expenses: NONE

Organization Name: CAHNRS- WSU **Contract Administrator:** Carrie Johnston

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

Item	2013	2014	2015
Salaries	56,361		
Benefits	22,588		
Supplies	10,051		
Travel	1,000		
Miscellaneous			
Plot Fees			
Total	90,000	*Not funded*	*Not funded*

Footnotes: The budget requested includes support for a Postdoctoral Research Associate who will be responsible for evaluation and implementation of the Weather Research and Forecasting (WRF) model for three years. We also have requested partial support for an application programmer for integration of the WRF model outputs with the web site of AgWeatherNet (www.weather.wsu.edu), integration with various models and overall information delivery. Additional budget items include operating expenses for computer software, additional harddisk storage, and related costs and travel to participate in meetings with producers and stakeholders and workshops on the WRF modeling system.

Objectives

The overall goal of this project is to evaluate the potential of implementing the state-of-the-art Advanced Weather Research and Forecasting (WRF-ARW) model as a tool for AgWeatherNet for weather and freeze predictions for Washington, specifically for regions where tree fruits are vital.

Specific objectives include the following:

- To evaluate the performance of the WRF model for local conditions using the data and observations collected by AgWeatherNet.
- To develop a protocol for implementing the WRF model as a weather and freeze prediction tool for AgWeatherNet and associated decision aids.
- To develop freeze protection advisories for dissemination via the web, phone applications and other information technologies.

Progress

In 2011, the Washington Tree Fruit Research Commission provided a one-year preliminary grant to explore how well a weather prediction model performed for Washington, especially the main fruit tree growing region of the state. This grant allowed us to purchase a small High Performance Computer on which the state-of-the-art Advanced Weather Research and Forecasting (WRF-ARW) has been implemented (Figure 1a). Since August 1, 2012 preliminary runs are being made for initial testing. Evaluation of the 2010 "Thanksgiving" frost event and for several of the spring frost events predictions have been promising (Ghidey et al., 2012). However, further research was needed in order to evaluate the model for the unique terrain and conditions in Eastern Washington.

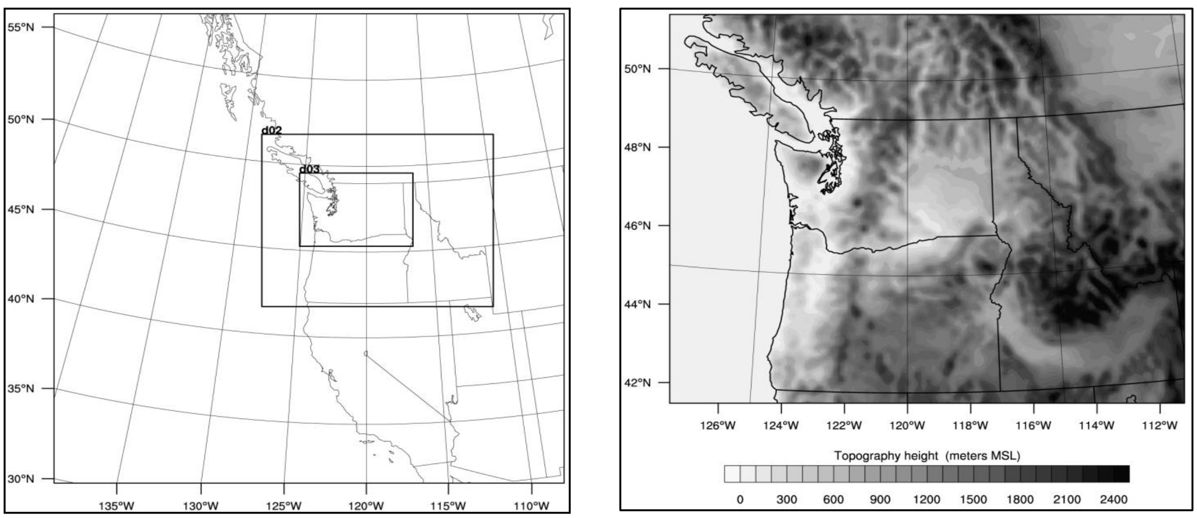
A successful implementation of a high resolution weather forecasting model with AgWeatherNet could have multiple outcomes, such as linking it to the many models and decision aids that are available on AgWeatherNet as well as for freeze and extreme high temperature forecasting. The model can also predict wind speed and direction that could potentially influence decisions associated with pesticide applications and the potential risks of drift. Request also have been received to include an hourly weather prediction for up to several days with the pollen tube growth model for apples, that is currently being developed in collaboration with Virginia Tech and WTFRC with funding provided through the Apple Research Review.

Introduction

The numerical weather prediction (NWP) models are being widely used for the purpose of aiding in agricultural decision making (e.g. Prabha and Hoogenboom 2008), wind energy assessment studies, air quality modeling and analysis, climate studies and other applications. In order to accurately model the weather phenomena of a certain region, researchers match the best combination of modeling setups that is compatible to their region of interest. Prabha and Hoogenboom (2008) used, for example, WRF over Georgia, USA with three nested horizontal domain resolutions to evaluate the performance of the model for frost forecasting, and found that the high resolution horizontal grid spacing to simulate the two frost events produced a good deal of accuracy. Following the previous scientific studies, this project investigated the different possible combinations of physics options to compare and contrast physics schemes that predict surface meteorological variables more accurately over Washington agricultural area. The modeling was particularly focused on the accurate prediction of the freeze/frost and heat-wave temperatures over the complex terrain regions of eastern Washington.

WRF Methodology and Verification

The NWP model used in this study was the Advanced Research dynamics core of the Research and Forecasting (*ARW-WRF*, or *WRF*) model version 3.3.1. The model is a state-of-the-art, next-generation NWP system and portable enough for use as operational forecasting and research tool (Skamarock *et al*. 2008). Our WRF model centered at 45.0ºN latitude, 124.5ºW longitude, was configured with three nested domains at 16.9, 5.6, and 1.9 mile horizontal resolutions, with grid spacing of 109x110, 148x121 and 208x151, respectively. The coarse domain encompassed the western US, British Columbia of Canada and eastern Pacific Ocean, with the inner most nested domain covering the state of Washington (Fig. 1a&b). The WRF model requires several static and dynamic input variables to run. The Global Forecast System (GFS at 1-deg grid-resolution) and North American Model (NAM at 24.9 mi resolution) analyses output provided "first guess" initial and boundary (ICs and BCs) at 6-hr intervals for six extreme temperature events. The four freeze/frost events that were considered are the February 25-26, the April 7, the October 26-27, 2011 and the November 24-25, 2010 events. The two extreme high temperature events were July 23-24, 2006 and August 27-28, 2011. The performance of the WRF model was evaluated for these events using the AgWeatherNet (www.weather.wsu.edu) observations. The AgWeatherNet temperature sensors are situated at 4.9 ft and the WRF model provides temperature predictions at 6.6 ft above ground level.



a) b)

Figure 1. WRF model configuration in three nested domains, coarse domain (D01) has 109x110, D02 has 148x121, and D03 has 208x151 horizontal grid points with 16.9 mi, 5.6mi, and 1.9mi grid spacing, respectively (a). Pacific Northwest (WA, OR and ID) topographic heights (b).

Therefore, a set of seven WRF combinations with different physics schemes was run for the six short-range temperature events across eastern Washington. Each temperature event was run by initializing the model 5-days, 3-days and 1-day before the start of the event. Every run was simulated twice with the same physics schemes, but with and without the analysis (grid) nudging of the Four Dimensional Data Assimilation System (FDDA). In all cases, any of the three microphysics schemes were used: the Kessler "warm rain" scheme that excludes the ice phase (Thompson *et al*. 2004), the WRF Single-Moment 3-Class (WSM3) simple ice scheme (Hong *et al*. 2004) and the Ferrier scheme (1994). Four PBL schemes were also used: the Yonsei University (YSU) scheme (Hong *et al*. 2006), the Mellor-Yamada-Janjic TKE (MYJ-TKE) scheme (Janjic 2001), the MYNN 2.5 level TKE scheme (Nakanishi and Niino, 2004), and the UW boundary layer scheme (Park and Bretherton, 2008). The three convective parameterization treatments used were the KF scheme (Kain and Frisch 1992), the Betts-Miller-Janjic scheme (Betts and Miller 1986), and the Modified TiedTKE (MT-TKE) scheme (Zhang *et al*. 2011). The three surface layer physics options used were the MM5 Monin-Obukhov (MO) scheme (Janjic 1996), the Monin-Obukhov-Janjic (MOJ) scheme (Janjic 1996), and the MYNN surface layer scheme (Nakanishi and Niino 2004). Two combinations of shortwave and longwave atmospheric radiation schemes – the Dudhia (1989) and the Goddard shortwave schemes (Chou and Saurez 1994), and the Rapid Radiation Transport Model (RRTM; Mlawer *et al*. 1997) and Goddard longwave schemes (Chou and Saurez 1994) – were also used. Table 1 shows a summary of the physics options that were used in our study.

Table 1. Physics schemes used for WRF configuration (numbers are WRF name-list codes).

	Microphysics schemes	Planetary Boundary Layer (PBL)	Surface Layer	Cumulus Parameterization s schemes	Shortwave Atmospheric Radiation	Longwave Atmospheric Radiation
1.	Ferrier, **5**	MYJ-tke, **2**	MO, **1**	BMJ, **2**	Dudhia, **1**	RRTM, **1**
2.	Kessler, **1**	MYNN, **5**	MOJ, **2**	KF, **1**	Godard, **5**	Godard, **5**
3.	WSM3, **3**	UW BL, **9**	MYNN, **5**	MT-tke, **6**		
4.		YSU, **1**				

The statistical methods used include: the Mean Bias (MB, has a unit), the Normalized Mean Bias (NMB, in %), the Root Mean Square Error (RMSE, has a unit), the Correction Coefficient (r, unitless) with its Coefficient of Determination (r^2, %) and the Skill Score (SS, unitless), as defined below.

$$MB = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i); \quad NMB = \frac{\sum_{i=1}^{n}(P_i - O_i)}{\sum_{i=1}^{n} O_i}.100 \qquad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2}\ ; \quad r = \frac{\sum_{i=1}^{n}(O_i - \overline{O}).(P_i - \overline{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \overline{O})^2.\sum_{i=1}^{n}(P_i - \overline{P})^2}} \qquad (2)$$

$$SS = 1 - \frac{MSE(P,O)}{MSE(\overline{O},O)} \qquad (3)$$

Where,

$MSE(P,O) = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2$, & $MSE(\overline{O},O) = \frac{1}{n}\sum_{i=1}^{n}(\overline{O} - O_i)^2$.

P_i & O_i are, respectively, WRF predicted and observed meteorological parameters (e.g., temperature), where *i* represents a given time and/or station location with a total number of *n* samples. The averages of forecast results and observations are also defined, respectively, as: $\overline{P} = \sum_{i=1}^{n} P_i$ & $\overline{O} = \sum_{i=1}^{n} O_i$. The coefficient of determination is the square of the correction coefficient (r^2). Murphy (1988) has defined skill scores as measures of the relative accuracy of forecasts produced by two forecasting systems, one of which is “reference system”. He has also defined accuracy as the average degree of association between individual forecasts and observations, in which it’s mainly represented by the mean absolute error. Referring to equation (5) above, the skill score (SS) can be positive (negative) when the accuracy of the forecasts is greater (less) than the accuracy of the reference forecasts. SS =1 when MSE(*P*,*O*) = 0 implying a perfect forecast, and SS = 0 when MSE(*P*,*O*) = $MSE(\overline{O},O)$.

Table 2. Combination of configured physics schemes utilized in running the WRF model.

RUNS	Microphysics schemes	Planetary Boundary Layer (PBL)	Surface Layer	Cumulus Parameterizations schemes	SW Atmospheric Radiation	LW Atmospheric Radiation	FDDA grid nudging
Run1	Ferrier	MYNN	MO	MT-tke	Godard	Godard	No
Run2	Ferrier	MYNN	MO	MT-tke	Godard	Godard	**Yes**
Run3	Ferrier	UW BL	MO	MT-tke	Dudhia	Dudhia	No
Run4	Ferrier	UW BL	MO	MT-tke	Dudhia	Dudhia	**Yes**
Run5	Kessler	MYJtke	MOJ	BMJ	Dudhia	Dudhia	No
Run6	Kessler	MYJtke	MOJ	BMJ	Dudhia	Dudhia	**Yes**
Run7	Kessler	UW BL	MYNN	BMJ	Godard	Godard	No
Run8	Kessler	UW BL	MYNN	BMJ	Godard	Godard	**Yes**
Run9	WSM3	YSU	MO	KF	Dudhia	Dudhia	No
Run10	WSM3	YSU	MO	KF	Dudhia	Dudhia	**Yes**
Run11	WSM3	MYNN	MYNN	KF	Godard	Godard	No
Run12	WSM3	MYNN	MYNN	KF	Godard	Godard	**Yes**
Run13	WSM3	MYJtke	MOJ	KF	Dudhia	Dudhia	No
Run14	WSM3	MYJtke	MOJ	KF	Dudhia	Dudhia	**Yes**

Results

A number of experiments with different physics schemes and numerical option tests were conducted. These included the use of two large scale “first guess” analyses for model ICs and BCs, nested domain horizontal resolutions, compatible combinations of physics schemes and the use of FDDA grid (analysis) nudging at time intervals of the BCs input data for the coarser domains.

1. Impact of Large Scale Analyses as “first guess” Input

Two large scale “first guess” analyses were conducted to identify the model input data that provides the most accurate ICs and BCs for simulation. The NCEP GFS final and NAM were used to analyze the “Thanksgiving deep freeze” of 24-25 November 2010 and the summertime heat wave of 27-28 August 2011. To perform this test, one set of physics options (referred to as ‘Run1’ in Table 2) was implemented. For each event, three runs initialized at different days were performed, in which the model was initialized starting 5-days, 3-days and 1-day before the actual weather phenomena had occurred. Moreover, the runs were also repeated to include the FDDA analysis nudging in the first two coarser domains, bringing the total sum of simulations to six.

For the deep freeze of 24-25 November 2010, the model was unable to capture the low temperature patterns for both input data: NAM with overall 24-hr mean biases of 22.0^{o}F, 22.7^{o}F and 14.8^{o}F for the 5-day, 3-day, and 1-day initializations, and FNL with daily mean biases of 23.2^{o}F, 23.2^{o}F and 14.4^{o}F, respectively (Table 3). And hence the NAM initialized model results were slightly better than the ones from FNL data. During this event most stations recorded close to -4^{o}F, in that the WRF model was unable to capture the phenomenon. WRF, however, performed better for the 27-28 August 2011 extreme warm case. The daily MBs for WRF from NAM (FNL) were estimated to be -5.4^{o}F (-4.7) for the 5-day, -5.0^{o}F (-4.1) for the 3-day, and -0.4^{o}F (-1.4) for the 1-day model initialization before the event day. For the

August case study the WRF model forecasted slightly better when it was initialized with the FNL than NAM data. The MB results were similarly supported by the RMSE values as shown in Table 3. Another measuring parameter of model performance is the skill score (SS), in which the values close to *one* are the best skill to forecast more accurately (see Table 3). The SS showed clearly a better performance of the NAM "first guess" data for November at -10.1 (Vs. -11.5 from FNL), while FNL performed better for the August case at -0.2 (Vs. -0.4 from NAM) for the 5-day run. Interestingly, when analysis (grid) nudging method was switched on in the simulations of both cases, the SS showed that FNL performed better than NAM for the November (0.2 vs. 0.3) and the August (0.3 vs. 0.5) cases. The use of FNL data also showed better WRF performance than NAM in other cases.

Table 3. Statistical results of **NAM-** and **FNL-**initialized WRF runs.

		NAM-Initialized						**FNL**-Initialized					
		Run1			Run2-FDDA			Run1			Run2-FDDA		
		5-day	3-day	1-day	5-day	3-day	1-day	5-day	3-day	1-day	5-day	3-day	1-day
24-25 Nov 2010	**RMSE** (^oF)	**22.7**	**23.6**	**15.5**	**5.9**	**5.6**	**5.0**	**24.1**	**23.9**	**15.5**	**6.1**	**5.9**	**5.2**
	MB (^oF)	22.0	22.7	14.8	4.7	4.3	3.6	23.2	23.2	14.4	4.5	4.1	3.4
	S-score	-10.0	-11.1	-4.1	0.3	0.3	0.5	-11.5	-11.5	-4.1	0.2	0.3	0.1
	R^2	36	28	50	76	75	76	29	27	36	68	68	57
27-28 Aug 2011	**RMSE** (^oF)	**7.7**	**7.6**	**5.2**	**4.9**	**4.9**	**4.9**	**7.4**	**6.8**	**5.2**	**5.6**	**5.6**	**5.6**
	MB (^oF)	-5.4	-5.0	-0.4	-0.5	-0.4	-0.2	-4.7	-4.1	-1.4	-1.6	-1.6	-1.4
	S-score	-0.4	-0.1	0.4	0.5	0.5	0.5	-0.2	0.3	0.4	0.3	0.3	0.3
	R^2	53	61	63	63	62	63	58	59	64	59	59	59

2. Effect of Nested Horizontal Domain Resolutions

In this analysis, the two nested inner domains of 5.6mi (D2) and 1.9mi (D3) were discussed to infer the impact of use of high domain resolutions towards resolving accurately the sub-grid information of complex regions over the state of Washington. Two stations (CBC Pasco and Moxee) were selected to discuss the impact of domain resolutions for the 23-24 July 2006 summertime hot weather episode as well as the 25-26 February 2011 wintertime freeze. Both cases were simulated using FNL with model physics configurations and simulation setups referred to as 'Run1' in Table 2.

The daily MB in the July case in CBC Pasco from D2 (D3) were estimated to be -5.9^{o}F (-5.6) for the 5-day, -7.4^{o}F (-6.8) for the 3-day, and -6.7^{o}F (-6.3) for the 1-day model initialization. Similarly, the MB in Moxee from D2 (D3) were 3.8^{o}F (0.4), 0.5^{o}F (-0.7) and 0.4^{o}F (-0.4). In general, results from other stations also showed WRF reproduced temperatures more accurately from the higher horizontal domain resolution of 1.9mi (D3) than the 5.6mi domain resolution (D2). In the February freeze event, the daily mean biases in CBC Pasco from D2 (D3) were 6.8^{o}F (6.8) for the 4-day, 6.8^{o}F (7.2) for the 2-day, and 6.7^{o}F (6.7) for the 1-day model initialization. Similarly, the MB in Moxee from D2 (D3) were 6.8^{o}F (7.9), 7.2^{o}F (8.3) and 5.2^{o}F (6.3). Therefore, D2 slightly performed better than D3 for this freeze event. Results from other stations also showed that D2 took a slight edge at reproducing temperatures with smaller MB than D3.

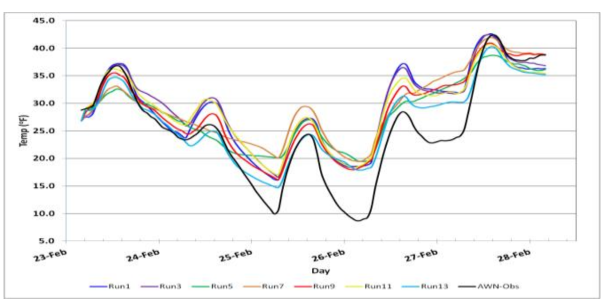
3. Use of FDDA Analysis (Grid) Nudging

The use of FDDA analysis nudging for temperature, wind vectors, and specific humidity (specific mixing ratio) in the upper vertical levels of WRF keeps the model from drifting away from the synoptic forcing. This is particularly helpful for 'hind-cast' model forecasting because the large scale 'first guess' information is usually reanalyzed by incorporating observational data. The analyzing nudging is performed for every model time interval of the BCs, in these cases every 6hr. Temperature scatter-plots of observations against model outputs with and without FDDA showed improved model results (not shown). Moreover, from Tables 3&4, the overall temperature mean bias had also improved with a coefficient of determination increase of up to10%.

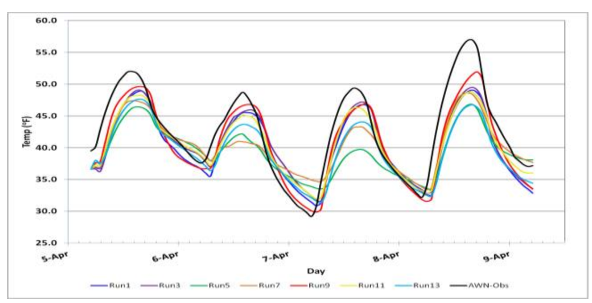
4. Impact of choice of Physics Schemes

Seven compatible combinations of model physics schemes were tested to identify a set of configuration that could be part of the modeling system in simulating short range weather predictions more accurately over complex topographic regions of the state of Washington (Table 1 and 2). To perform the project study, six extreme weather phenomena over eastern Washington were selected. Figure 2 shows a set of time series mean temperature plots of different runs of model results compared to each other and against observations for all the cases. The February 25-26, 2011 was a deep freeze event that represented the wintertime (Fig. 2a). The April 7, 2011 event was the one-night freeze that was considered damaging in a period when trees begin to blossom during a warming trend of the spring season (Fig 2b). The model had also simulated an event in the fall season of October 26-27, 2011 (Fig. 2c). The November 24-25, 2010 "Thanksgiving" deep freeze was such an extremely cold event that WRF was generally unable to reproduce observed temperatures (Fig. 2d). For the summer periods of July 23-24, 2006 and August 27-28, 2011, the WRF model was able to reproduce diurnal variations with underestimation of maximum observed temperatures (Figs 2e & 2f).

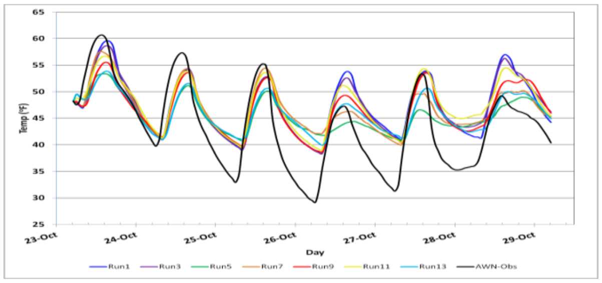
To examine WRF performance in a diurnal variation pattern, three mean biases were computed for a 24-hr (daily), daytime, and nighttime periods. Since the length of daytime and nighttime hours vary during a day from winter to summer seasons, a daytime in this study was defined as the time between 0800 – 1600 totaling nine hours and nighttime between 0000 – 0700 and 1700 – 2300 with a total of 15 hours were used for the period October – April. Between May – September, daytime was defined between the hours of 0700 – 1900, while the nighttime between 0000-0060 and 2000 – 2300.



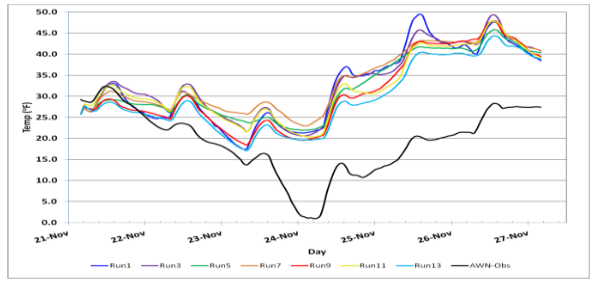
(a)



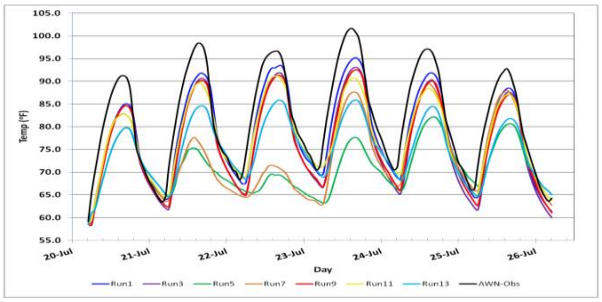
(b)



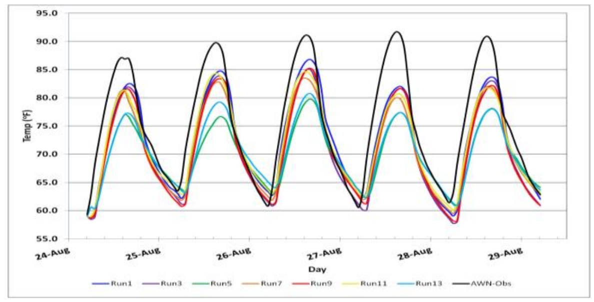
(c)



(d)



(e)



(f)

Figure 2. WRF output temperature results from seven physics configured schemes (labeled with color lines) against their corresponding station-average observations for the six cases. February 23-28, 2011 (a). April 5-9, 2011 (b). October 23-29, 2011 (c). November 21-28, 2010 (d). July 20-26, 2006 (e). August 24-29, 2011 (f). These runs were initialized 2-3 days ahead of the weather event date.

The results from the highest horizontal domain resolution of 1.9mi (D3) for 14 WRF runs were individually compared with their corresponding AgWeatherNet observations. The qualitative statistical plots (histograms) show the three categories of the diurnal variations: the daily, daytime and nighttime, averaged over all available stations. These histogram plots depict the temperature MB in a color-coded various model results. Table 4 also contains additional details of the daily statistical estimates of RMSE, NMB, SS and 'r'. Whereas the model runs with odd-numbers (Run 1-13) show the seven configured WRF runs, their consecutive even-numbers (Run 2-14) represent results from WRF-FDDA simulations.

The February 25-26, 2011 freeze event temperature MB estimates over 134 stations showed an over prediction (Figure 3). The model configurations used in 'Run13' predicted observed temperatures better with MB of 4.5^{o}F, RMSE of 5.6^{o}F and daily SS of -0.3 (Table 4). For WRF-FDDA runs, 'Run10' (the clone of 'Run9') reproduced observations most accurately. The April 7 MB estimate over the 134 stations showed that 'Run3' scored the least daily MB (-0.2^{o}F), (Fig. 3b). Based on the RMSE estimate, the 'Run9' predicted most accurately at 5.2^{o}F. 'Run9' scored the daily SS of -1.6, as the best value (Table 4). The October 26-27 RMSE over 136 stations showed that 'Run11' performed better with a value of 6.8^{o}F (Fig. 3c). However, the daily skill score (at SS = -2.0) indicated that 'Run9' performed well. When WRF-FDDA runs were considered, 'Run10' (the clone of 'Run9') reproduced observed values most accurately with the least MB, RMSE and SS (Table 4). As was shown in the previous subsection for the November 24-25, 2010 'Thanksgiving' deep freeze, all statistics also showed that all model setups for the simulations had significantly overestimated temperature observations during both day- and night-time periods with an average error of 21.6^{o}F calculated over 134 stations (Fig. 3d). 'Run13' had the least MB and RMSE estimates. Its skill score also showed that the model's accuracy relative to the reference system of average observations was too far apart and hence drew the lowest magnitude. However, the FDDA method influenced the WRF model strongly for all model setups (Table 4).

During the heat wave event of July 23, 2006, maximum mean temperature over the 44 AgWeatherNet stations averaged at 101.7°F (Fig. 2e). Figure 3e shows that 'Run1' performed better in predicting observed temperatures with the least MB value of -4.1°F. Likewise, the RMSE (6.5°F), SS (0.2), NMB (-5%) and the 'r' (0.82) for this event had also supported the lowest errors computed from 'Run1' (Table 4). From the WRF-FDDA results, 'Run2' (the clone of 'Run1') also reproduced observed values. In the case of 'Run2', the use of FDDA method did worsen errors as the event was more influenced by local effects of the sub-grid processes rather than the synoptic large scale effects. In Figure 3e, we can also observe that the largest errors came from daytime as WRF underestimated maximum temperatures due to the strong effects of subsidence heating. For the extreme high temperature event of August 27-28, 2011, the average maximum temperature over 136 stations was 91.8°F on August 27 (Fig. 2f). The scheme in 'Run1' performed better in predicting observed temperatures with MB value of -4.1°F. The RMSE (6.8°F), SS (-0.1), NMB (-5%) and the 'r' (0.78) estimates also supported MB results (Table 4). The use of FDDA in 'Run2' also reduced the errors.

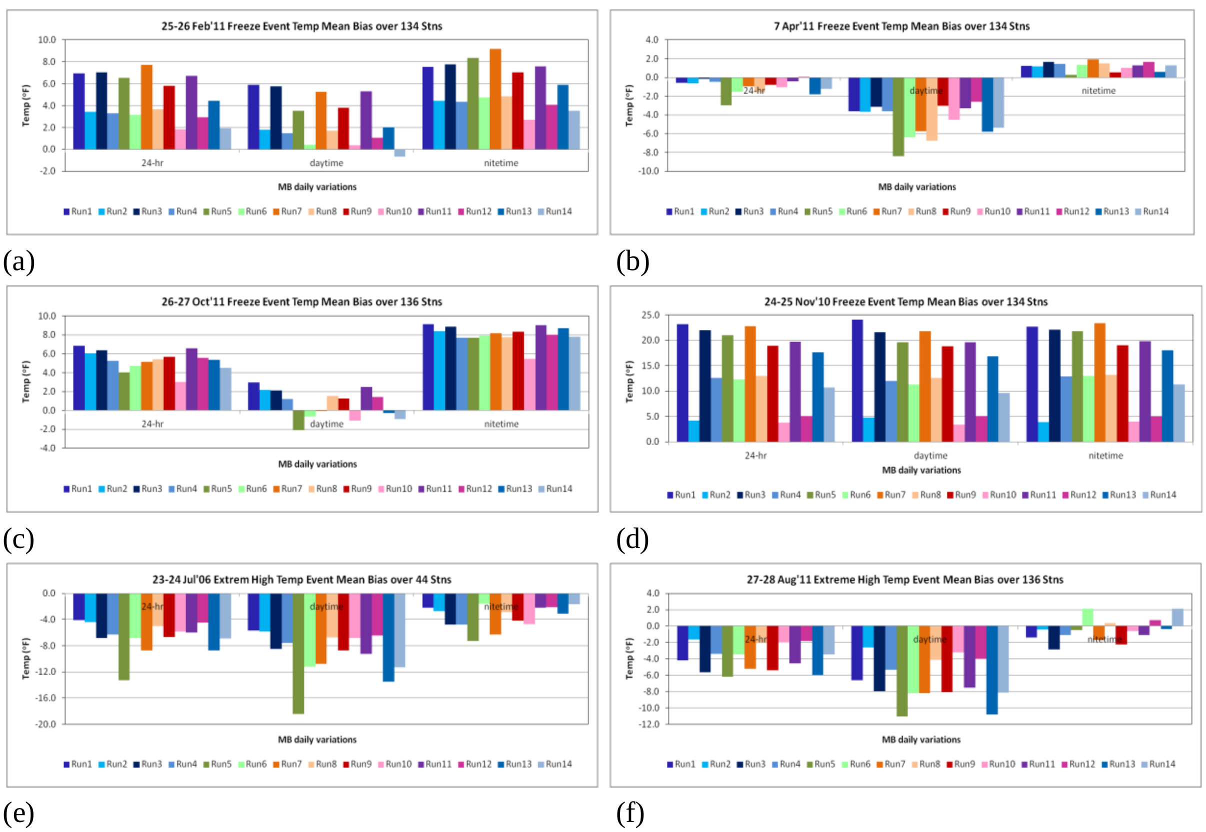


Figure 3. WRF output temperature Mean Bias over all available stations for seven physics configured schemes (deep colored lines with odd numbers) and their corresponding FDDA-incorporated runs (light colored lines with even numbers). February 25-26, 2011 (a). April 7, 2011 (b). October 26-27, 2011 (c). November 26-27, 2010 (d). July 23-24, 2006 (e). August 27-28, 2011 (f).

Table 4. WRF temperature statistical results against available AgWeatherNet stations for Feb, Apr, Oct, Nov, Jul and Aug of the studied events (bold digits are best results).

<table>
<tr><th rowspan="2">WRF Runs</th><th colspan="5">25-26 Feb 2011 | 7 Apr 2011 | 26-27 Oct 2011 | 24-25 Nov 2010 | 23-24 Jul 2006 | 27-28 Aug 2011</th></tr>
<tr><th>RMSE (^oF)</th><th>MB (^oF)</th><th>NMB</th><th>SS</th><th>Corr. Coef. (r)</th></tr>
<tr><td>**Run1**</td><td>7.2 | 5.8 | 8.1 |
23.9 | **6.5** | **6.8**</td><td>6.8 | -0.5 | 6.8 |
23.2 | **-4.1** | **-4.1**</td><td>47 | -1 | 19 |
166 | **-5** | **-5**</td><td>-1.3 | -2.0 | -2.7 |
-11.5 | **0.2** | **-0.1**</td><td>0.81 | 0.25 | 0.41 |
0.50 | **0.82** | **0.78**</td></tr>
<tr><td>**Run2**</td><td>4.7 | 5.6 | 7.7 |
5.9 | **6.8** | **5.6**</td><td>3.4 | -0.5 | 6.1 |
4.1 | **-4.5** | **-1.6**</td><td>25 | -1 | 17 |
26 | **-5** | **-2**</td><td>0.1 | -1.9 | -2.4 |
0.3 | **0.0** | 0.3</td><td>0.83 | 0.27 | 0.37 |
0.82 | **0.78** | 0.76</td></tr>
<tr><td>**Run3**</td><td>7.7 | 6.1 | 7.7 |
22.9 | 8.3 | 7.7</td><td>7.0|**-0.2** | 6.3 |
22.0 | -6.8 | -5.6</td><td>48 | 1 | 18 |
156 | -8 | -7</td><td>-1.3 | -2.4 | -2.4 |
-10.1 | -0.5 | -0.4</td><td>0.81 | 0.18 | 0.45 |
0.49 | 0.78 | 0.75</td></tr>
<tr><td>**Run4**</td><td>4.7 | 5.8 | 7.2 |
13.5 | 8.5 | 6.1</td><td>3.2 | -0.5 | 5.2 |
12.6 | -6.3 | -3.4</td><td>25 | **0.2** | 15 |
84 | -7 | -4</td><td>0.2 | -2.1 | -1.9 |
-3.0 | -0.5 | **0.1**</td><td>0.83 | 0.24 | 0.40 |
0.58 | 0.76 | **0.79**</td></tr>
<tr><td>**Run5**</td><td>7.4 | 6.5 | 7.6 |
21.8 | 14.9 | 9.0</td><td>6.5 |-3.1 | **4.0** |
20.9 | -13.3 | -6.3</td><td>49 | -5 | **13** |
147 | -15 | -7</td><td>-1.2 | -1.6 | -2.6 |
-9.0 | -2.3| -1.0</td><td>0.78 | **0.43** | 0.48 |
0.56 | 0.53 | 0.73</td></tr>
<tr><td>**Run6**</td><td>4.9 | 5.8 | 7.2 |
13.5 | 9.5 | 7.7</td><td>3.1 | -1.6 | 4.7 |
13.2 | -6.8 | -3.4</td><td>25 | -2 | 14 |
83 | -7 | -4</td><td>0.1 | -2.1 | -2.2 |
-2.9 | -0.9 | -0.4</td><td>0.81 | **0.39** | 0.42 |
0.58 | 0.74 | 0.77</td></tr>
<tr><td>**Run7**</td><td>8.5 | 6.3 | 7.2 |
23.6 | 10.3 | 7.9</td><td>7.7 | -0.9 | 5.0 |
22.9 | -8.8 | -5.2</td><td>55 | -1 | 15 |
161 | -10 | -6</td><td>-1.8 | -2.6 | -2.3 |
-10.8 | -1.2 | -0.4</td><td>0.73 | 0.26 | 0.49 |
0.47 | 0.76 | 0.70</td></tr>
<tr><td>**Run8**</td><td>5.0 | 6.5 | 7.0 |
14.4 | 7.4 | 5.6</td><td>3.6 | -1.6 | 5.4 |
13.0 | -5.0 | -2.2</td><td>27 | -2 | 15 |
89 | -6 | -3</td><td>**0.01** | -3.1 | -2.0 |
-3.3 | -0.1 | 0.3</td><td>0.80 | 0.22 | 0.41 |
0.54 | 0.76 | 0.78</td></tr>
<tr><td>**Run9**</td><td>6.7 | **5.2** | 7.2 |
19.8 | 8.3 | 7.7</td><td>5.8 | -0.7 | 5.8 |
18.9 | -6.7 | -5.4</td><td>42 | -2 | 16 |
135 | -8 | -7</td><td>-0.7 | **-1.6** | **-2.0** |
-7.6 | -0.5 | -0.4</td><td>**0.83** | 0.25 | **0.51** |
0.50 | 0.81 | 0.76</td></tr>
<tr><td>**Run10**</td><td>**3.8** | 5.8 | **5.9** |
5.6 | 7.7 | 5.8</td><td>**1.8** | -1.1 | **3.1** |
3.8 | -5.8 | -2.0</td><td>**16** | -2 | **9** |
23 | -5 | -3</td><td>0.5 | -2.1 | **-1.1** |
0.3 | -0.3 | 0.3</td><td>**0.84** | 0.27 | **0.45** |
0.83 | 0.78 | 0.77</td></tr>
<tr><td>**Run11**</td><td>7.6 | 5.9 | **6.8** |
20.5 | 8.5| 7.4</td><td>6.7 | -0.4 | 6.5 |
19.8 | -5.9 | -4.5</td><td>47 | **0** | 18 |
138 | -7 | -6</td><td>-1.2 | -2.1 | -2.6 |
-8.0 | -0.4 | -0.2</td><td>0.78 | 0.21 | 0.45 |
0.55 | 0.74 | 0.73</td></tr>
<tr><td>**Run12**</td><td>4.5 | 5.6 | 7.2 |
6.5 | 7.0 | **5.6**</td><td>2.9 | **0.1** | 5.6 |
5.0 | -4.5 | -1.8</td><td>23 | 1 | 16 |
33 | -5 | -2</td><td>0.2 | -1.8 |-2.1 |
0.1 | 0.0 | 0.3</td><td>0.81 | 0.26 | 0.43 |
0.81 | 0.77 | 0.78</td></tr>
<tr><td>**Run13**</td><td>**5.6** | 5.4 | 7.6 |
18.5 | 10.6 | 8.8</td><td>**4.5** | -1.8 | 5.4 |
17.6 | -8.6 | -6.1</td><td>**34** | -3 | 16 |
120 | -10 | -7</td><td>**-0.3** | -1.9 | -2.5 |
-6.2 | -1.4 | -0.9</td><td>0.82 | 0.40 | 0.50 |
0.54 | 0.78 | 0.74</td></tr>
<tr><td>**Run14**</td><td>4.1 | **5.4** | 7.2 |
12.8 | 9.5 | 7.7</td><td>2.0 | -1.3 | 4.5 |
10.6 | -6.8 | -3.4</td><td>18 | -2 | 14 |
70 | -8 | -4</td><td>0.3 | **-1.8** | -2.2 |
-1.9 | -0.9 | -0.4</td><td>0.83 | 0.37 | 0.43 |
0.64 | 0.74 | 0.77</td></tr>
</table>

Discussion

The sensitivity study on WRF mesoscale meteorological model in terms of verifying the compatible physics schemes for the complex regions of the state of Washington was performed. The model was tested over many different project setups involving the use of a couple of large scale "first guess" analyses, examination of the effects of model horizontal resolutions and configurations of several physics schemes, as well as the use of FDDA grid (analysis) nudging. Six extreme temperature events were simulated using all the options specified. The four freeze/frost events were February 25-26, April 7, October 26-27, 2011 and November 24-25, 2010; and the two extreme high temperature events were July 23-24, 2006 and August 27-28, 2011. The Global Forecast System (GFS at 1-deg grid-resolution) and the North American Model (NAM at 24.9 mi resolution) analyses provided "first guess" data. WRF results from the physics configurations tabulated in Tables 1 and 2 were used to do the sensitivity analyses using AgWeatherNet observations.

Despite its coarser horizontal resolution compared to the higher resolution dataset from NAM, FNL-initialized runs performed slightly better in the control run and with the use of FDDA method. Although the highest grid resolution of 1.9 mi slightly resolved simulations better than the 5.6 mi, the significance was not statistically important. On the other hand, WRF model results from the six analyzed cases showed that the FDDA grid nudging improved errors by more than 10%. The use of FDDA analysis nudging scheme can thus assist in correcting model forecast errors when the large scale analysis data is reanalyzed with observations and the large scale synoptic conditions are one of the dominant dynamic forcings in driving the weather phenomena. It is expected that the WRF model responded differently for the different physics scheme combinations used for the freeze/frost and heat wave events. The physics combination implemented in 'Run13' predicted temperature observations most accurately compared to the other six setups, for both the February 25-26, 2011 event and the November 24-25, 2010 deep freeze case. For both the April 7 and the October 26-27, 2011 freeze cases, the physics combination of 'Run9' predicted observations most accurately. On the other hand, the physics combination schemes of 'Run1' predicted observed temperatures most accurately compared to the other physics setups in both summertime heat wave cases of July 23-24, 2006 and August 27-28, 2011.

Therefore, the WRF model reproduces a more accurate prediction for winter, late spring and early fall seasons when the WSM3 microphysics and the KF convective (cumulus) parameterization schemes were configured with either YSU PBL and MO surface layer physics or MYJtke PBL scheme and MOJ surface layer physics over the Washington state topographic structures. In contrast, for the summertime heat wave cases the configuration of Ferrier microphysics and MT-tke cumulus schemes combined with the PBL scheme of MYNN and MO surface layer physics helped the model to predict more accurately. Hence, while further studies to confirm performances are needed, the configuration of WSM3-YSU-MO-KF for freeze/frost weather conditions and that of Ferrier-MYNN-MO-MT-tke for hot weather conditions are recommended for WRF modeling system for areas with geographic structures such as Washington.

Outcome and Recommendations

Further model forecasting accuracy can be achieved if the continuously growing AgWeatherNet stations data become part of the initial and boundary conditions of the WRF model initialization, which is the next ongoing project to be implemented on the operational (real-time) 80-hrs daily forecast. Besides, the post-processing and web-development is also under continuous construction and improvement, and will be available to end-users online (www.weather.wsu.edu) once the ongoing in-house tests are cleared. In Figure 4, samples of the web-based model results, which are available on the AgWeatherNet developmental page, are shown for the 2-dimensional Pacific NW weather and the WSU TFREC temperature (^{o}F), dew-point (^{o}F), precipitation (Inch) and wind speed (mph) for 3-day forecast initialized on February 24, 2014 at 4pm (February 25, 2014 at 00Z).

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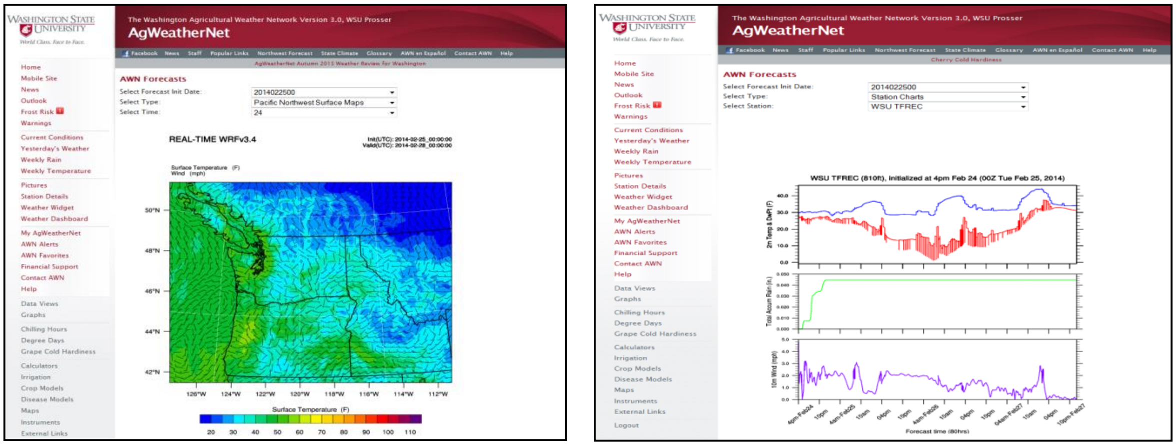

Figure 4. WRF model temperature (color-shaded) and wind vector (wind-barbs) forecast over the PNW for February 27, 2014 at 4:00pm (a). Time-series WRF 3-day forecast for WSU TFREC initialized on February 24, at 4:00pm PST and ending on February 27, at 4:00pm PST (b).

Executive Summary

The main goal of this project was to evaluate the potential for implementing the state-of-the-art Advanced Research Weather Research and Forecasting (WRF-ARW) model as a new tool for freeze prediction for AgWeatherNet, specifically for regions where tree fruits are an important crop.

Specific objectives of this project included the following:

- To explore the feasibility of running the WRF model for Washington.
- To evaluate the performance of the WRF model for local conditions using the data and observations collected by AgWeatherNet.
- To develop a protocol for implementing the WRF model as a freeze forecasting tool for AgWeatherNet.

We evaluated the performance of the WRF-ARW model on the AgWeatherNet High Performance Computer (HPC) for selected frost/freeze and extreme high temperature events that occurred in 2006, 2010 and 2011. Model outputs were analyzed with AgWeatherNet (www.weather.wsu.edu) meteorological observations. The sensitivity study performed with the WRF model included: (1) Verification of compatible physics schemes, (2) Choice of large scale "first guess" analyses for initialization, (3) Examination of the effects of model domain horizontal resolutions, and (4) Use of the FDDA grid (analysis) nudging. For the six extreme temperature events that were evaluated, WRF reproduced observed temperatures, with biases varying from -5.9^{o}F (under estimation) during the day to 5.5^{o}F (over estimation) at night. While the bias and the error (RMSE) increased with an increase of terrain complexity, the model reproduces observations within overall average error of +/-5.4^{o}F during extreme temperature cases.

The evaluation process of WRF indicated that the Global Forecast System (GFS) analyses "first guess" data provides better model initialization. It was also inferred that the higher the model horizontal domain resolution, the better it resolves the sub-grid information over complex terrain and hence provides a better forecasting accuracy. The current highest domain resolution is 1.9 mi. The FDDA analysis nudging method also found to perform better if the weather event was mainly driven by a synoptic upper-air dynamic forcing and/or the large scale analysis data were reanalyzed with observations. The WRF model responded differently for the different physics scheme configurations used for different temperature extremes. It was found that WRF model reproduces a more accurate prediction for the winter, late spring and early fall seasons when the WSM3 microphysics and the KF convective (cumulus) parameterization schemes were configured with either YSU PBL and MO surface layer physics or MYJtke PBL scheme and MOJ surface layer physics over the Washington state topographic structures. In contrast, for the summertime heat-wave cases the configuration of Ferrier microphysics and MT-tke cumulus schemes combined with the PBL scheme of MYNN and MO surface layer physics helped the model to predict more accurately.

Hence, while further studies to reaffirm performances are needed, the configuration of WSM3-YSU-MO-KF for freeze/frost weather conditions and the Ferrier-MYNN-MO-MT-tke for hot weather conditions are recommended for WRF modeling system for areas with complex geographic terrain such as Washington. The post-processing and web-development that contains the three-day weather prediction is under continuous construction and improvement, and will be available to end-users online (www.weather.wsu.edu) once the ongoing in-house tests are completed.

FINAL PROJECT REPORT

Project Title: Developing new natural enemy and pest models for WSU-DAS

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Percentage time per crop: Apple: 40% Pear: 25% Cherry: 25% Stone Fruit: 10%

Other funding sources: None

WTFRC Collaborative expenses: None

Total Project Funding: $151,887

Budget History:

Item	2013
Salaries	90,378
Benefits	33,252
Wages	20,016
Benefits	1,941
Equipment	0
Supplies	3,500
Travel	2,800
Plot Fees	0
Miscellaneous	0
Total	$151,887

Objectives:

1. Validate phenology models for *C. plorabunda*, *E. fummipennis* and *D. brevis* in non-bearing blocks.
2. Develop and implement new models for aphids, mites, and natural enemies.
3. Develop a molecular test to differentiate the different *Chrysoperla* species present in the SCRI grant collections to improve the phenology and lure information for that species complex.

Significant Findings:

- Phenology models for *C. plorabunda* and *E. fumipennis* predict limited first-year emergence data from non-bearing apple blocks fairly well. Spray records and rain events account for some observed deviations from the models. More NE data is needed, in particular for *D. brevis*.
- Models based on literature data for the European red mite (ERM) and the two-spotted spider mite that predict population growth rate have been completed.
- Further evaluation of the ERM model suggest that we can get a more complete picture of phenology than previously thought (at least until mid-June), which may simplify management.
- We have obtained five members of the *Chrysoperla plorabunda* species complex that have been identified as separate species using song analysis by Dr. Charles Henry for evaluation of genetic methods to separate the different species.
- Of the five members of the *C. plorabunda* species complex, *C. downesi* can be readily distinguished from the other four species using mitochondrial genes.
- New PCR primers have been developed and purchased, but have not yet been evaluated because of significant health issues in two of Unruh's technicians that process PCR samples. A further progress report will be available when the new primers have been tested.

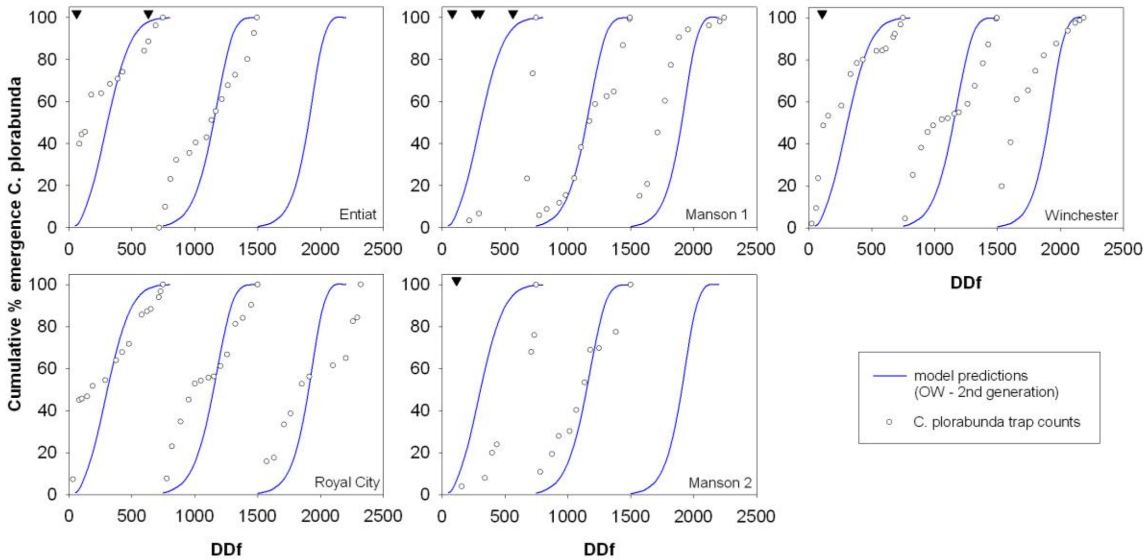
Results and Discussion:

Objective 1. Five non-bearing apple orchards were monitored for natural enemies 1-2 times a week using HIPV lures as well as beat samples. These trap catches were then analyzed in combination with in-orchard temperature records and compared to model predictions. Spray records were received for all orchards, except for Royal City.

Overall, model predictions for the lacewing *C. plorabunda* and the syrphid fly *E. fumipennis* matched HIPV trap captures quite well (Figs. 1, 2). The last emergence of *C. plorabunda* (3^{rd} flight) and *E. fumipennis* (4^{th} flight) were only partial in two orchards (Entiat and Manson 2) and all five orchards, respectively, and hence not plotted. These locations did not accumulate enough heat units by the end of the season to complete the last generation. In addition, cumulative trap counts were not plotted when less than 20 individuals were caught within a generation, which occurred frequently with *E. fumipennis* at all our sites (Fig. 2).

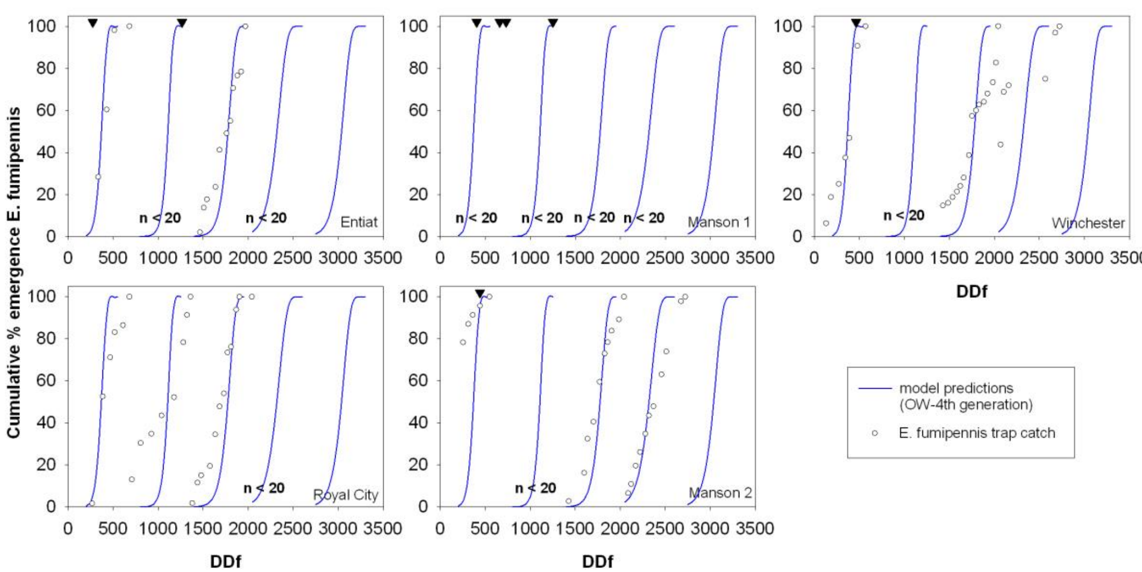
The model comparison graphs also nicely show where the trap captures deviated from the model predictions and can provide a clue as to what might have caused these deviations. Pesticide applications, for example, can delay the emergence of natural enemies as seen during the first emergence of *C. plorabunda* in Manson 1 and Manson 2, where fungicides + insecticides and a fungicide were applied, respectively. Pesticide applications also possibly reduced the number of syrphid flies in some orchards, in particular during the second flight (Fig. 2). In addition, rain and other spray applications can explain reduced natural enemy activity and, consequently, trap catch as observed at the Winchester orchard during the second *C. plorabunda* flight in July (Fig. 1). A second and third year's monitoring data (including additional locations) are important to finalize the model validation.

Fig. 1. Comparison of observed and predicted lacewing (*Chrysoperla plorabunda*) emergence in five non-bearing apple orchards in 2013. Generations not plotted if DD for last generation not reached. Triangles indicate insecticide and/or fungicide application.



Regarding additional natural enemies that we monitored, *Deraeocoris brevis* was not caught in sufficient numbers to validate the model with this year's data. However, we found the highest numbers of *D. brevis* in the older grafted orchard (Royal City). Therefore, future data collection will need to focus on older non-bearing grafted orchards to achieve the necessary natural enemy numbers for model validation. The woolly apple aphid parasitoid *Aphelinus mali* also only occurred in larger numbers in the grafted orchard that was notably infested with woolly apple aphid. The minute pirate bug *Orius* is another predator that was abundant in the two medium-sized non-bearing orchards (Entiat and Winchester).

Fig. 2. Comparison of observed and predicted syrphid fly (*Eupeodes fumipennis*) emergence in five non-bearing apple orchards in 2013. Generations not plotted if less than 20 individuals caught or DD for last generation not reached. Triangles indicate insecticide and/or fungicide application.



We also conducted beat samples to supplement lure trap catches with numbers of juvenile natural enemies. Except for the grafted orchard, the beat samples yielded very low numbers of natural enemies throughout the year, indicating that natural enemies were not established and did not reproduce in those young orchards. Except for the grafted orchard, which had a high number of woolly apple aphid colonies, all other orchards showed little signs of aphid or mite infestations that would sustain predacious syrphid fly, lacewing, or *Deraeocoris* larvae. The observed HIPV trap catches in the younger orchards then likely reflect an influx of adults from surrounding orchards looking for mates and/or food sources for their offspring.

Objective 2. The models for aphids and mites are based on extensive literature searches and compilation and analysis of the resulting data. We have focused on two pest mites, the two-spotted spider mite (TSSM), *Tetranychus urticae* and the European red mite (ERM), *Panonychus ulmi*, both of which can be serious pests in all of our orchard crops in Washington State (and throughout the world). Because both species are worldwide pests, the literature data was extensive and analysis generally showed good agreement on all the different parts of the life history needed for model development.

European red mite:

ERM overwinters in the egg stage on spurs and cracks in the bark. Data in the literature include the development time for overwintering eggs, effect of low temperatures on survival of overwintering eggs, and the development rates of all the other (non-overwintering) stages. In addition, we found complete life tables by five authors that were run at 10 different temperatures, so that we could synthesize developmental rates (including upper and lower thresholds for development), population growth, and other parameters that would be useful in predicting risk over time.

Overwintering Eggs: The overwintering eggs showed the greatest variability in developmental time between studies. Our data set was composed of six studies that together tested development times at 24 temperatures. The studies were published from 1961 to 2000 and the locations of the studies varied from Greece, Japan, Canada, and Great Britain. Normally, we put all the data together on a common axis for the analysis, but when we did that, the fit was relatively poor (for this sort of analysis) (Fig. 3). Analysis of each study separately gave somewhat similar results for threshold and development times, but visual inspection showed basically two groups of data. The first group came from two studies (one of the Canadian studies and the study from Great Britain (open circles)) and the other group came from four different studies (Greece, two from Canada, and Japan). The group I studies estimated the lower threshold for development was 40.6°F the egg stage duration was 278 DDF, while group II studies provided the estimate of 43.5 °F and 394 DDF as the duration. If the data are corrected for the different thresholds, there is little difference in duration on a DD scale (about 24 DDF). The differences between the different studies mean that before we start to use the egg hatch predictions that we need to collect overwintering eggs and see which threshold appears to work best in Washington State – this should be a relatively simple study.

Fig. 3. Development rate of ERM overwintering eggs at different temperatures from literature data.

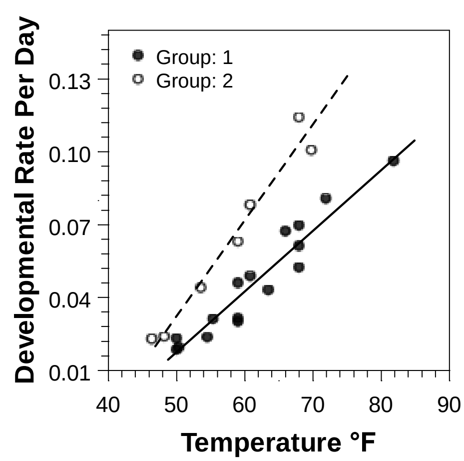
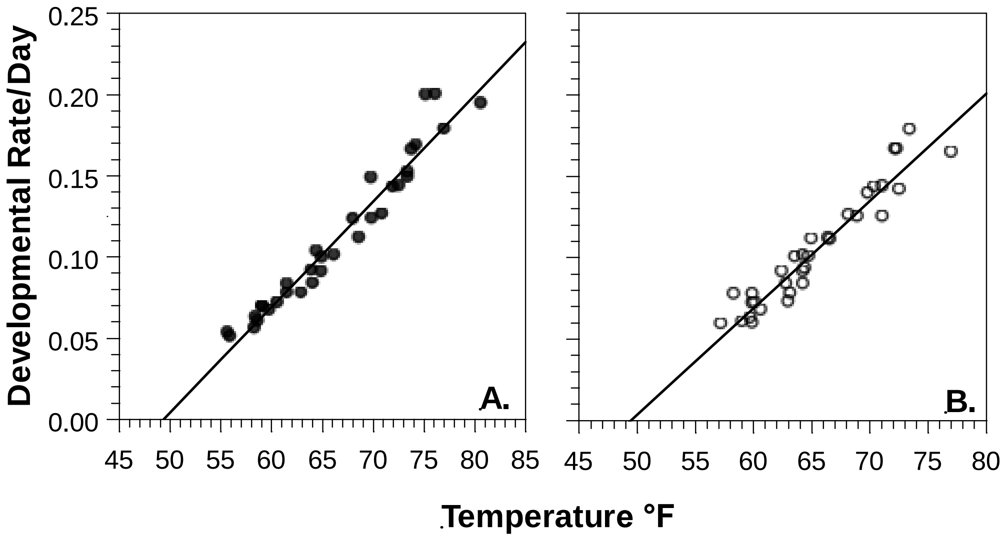


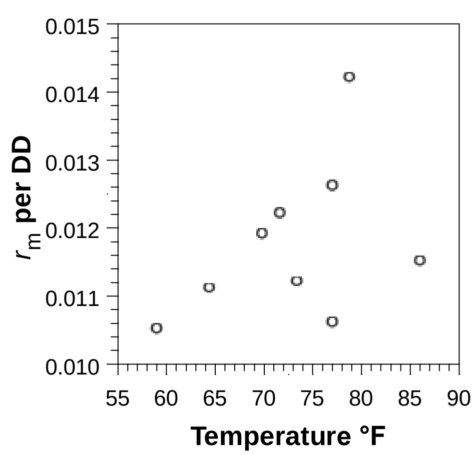
Fig. 4. Development rates versus temperatures from literature data for ERM. A. non-overwintering eggs B. immature stages.



Other stages: In contrast to the overwintering egg data, the studies for all other stages showed good agreement between the different studies (Fig. 4A,B). The non-overwintering eggs and the immature stages both showed the lower threshold for development was about 49.2°F and the duration required for both were very similar (158 and 152 DDF for eggs and immatures, respectively).

Population growth rate: The population growth rate was estimated from life tables done at nine different temperatures. The growth rate number is called r_m and indicates the change in population size per female on a daily basis. However, we can't use the daily growth rate to estimate change in population directly because temperature in the field varies greatly over time and mites (like insects) develop based on temperature units (DD). However, by dividing the raw r_m values by the number of DD accumulated per day at the temperatures at which the study was done, we can estimate the population growth rate on a DD basis, which allows us to estimate population growth in the field based on DD accumulations. This can then be combined with our knowledge of the length of time required for completion of each stage and forecast weather to see how much the population grows in the next week (or more). One of the assumptions of this model is that there is no particular pattern of the growth rate with temperature; thus for this to work, we need to plot the corrected r_m data versus temperature and we should see no statistical relationship. If this is true, then we estimate the corrected growth rate by just taking the average growth rate over the different temperatures.

Fig. 5. The growth rate of the population on a DD scale versus temperature. The lack of any statistical trend means we can use the average growth rate to predict population growth.



Our corrected r_m data showed no statistical relationship with temperature (Fig. 5) and the average corrected r_m values was 0.0062 individuals per DD. By using the weather forecast for the next week-10 days, we can then project how fast the population grows. Our data shows that generation time (T) is 462 DD and the population doubling time is 109 DD. The population doubling time is the time required for the population to increase by a factor of two, but it is important to realize that this is primarily how long the females take to lay enough eggs to double the population. Those eggs then have to hatch and the immature stages need to complete development before the next generation of individuals occurs. Thus 109 DD from any point in time, all of those "new" individuals are in the egg stage (since it takes 158 DD for non-overwintering eggs to hatch). By evaluating the temperature predictions, we can estimate what stage the new individuals are in and how long before the next generation of adults appear and begin reproduction.

While the discussion above is somewhat technical, what is important is that the details of the population growth can be summarized both graphically and in a simple table to give the consultants a good idea of how quickly the population could potentially grow in the next period of time and when management might be required. We can also project a sample estimate (e.g., we have 0.5 adult females/leaf) into the near future to help understand when the next sample should be taken. There is also further information that can be gleaned from the underlying heat-driven development, including potentially a much more complete picture of phenology than previously thought. Evaluating this data shows that it may be possible to predict phenology relatively accurately at least until mid-June. Combined with longer-ranged forecasts, the phenology should simplify management tactics.

Two spotted spider mite:
Unlike the ERM, the two spotted spider mite (TSSM) overwinters as an adult female in diapause under the bark or in at the base of the trees. Data in the literature was extensive and provided good information on duration of each stage (4 studies at 12 temperatures) and population growth studies (r_m values from six studies at 11 temperatures).

Duration and thresholds: The lower developmental threshold for TSSM was nearly identical to the ERM, at 49.3°F and the duration required was 97 and 275 DD for the eggs and immature stages. Like the ERM temperature-development data, there was little variation between studies for either eggs or immatures.

Population growth rate: Similar to the ERM, life table studies showed the population growth rate on a DD scale (r_m corrected) was independent of temperature, and the average growth rate was 0.0078 individuals per DD. This value is ≈25% higher than that of ERM and is one of the reasons that TSSM are considered one of the most important mite pests on a wide range of crops. The population doubling time is 82 DDF, or about 30% faster than ERM and the generation time is ≈ 504 DDF or slightly longer than ERM. The population projections can be easily done with forecast data, and like the ERM, we can also give how long is required for the different stages to be completed and provide the information on management in both graphic and tabular form.

We have not evaluated the TSSM model for phenology predictions as we have the ERM model. It is possible that the phenology predictions are possible, but it is likely they are more difficult to implement because the overwintering stage is a mated female in diapause, so we would need to evaluate the breaking of diapause, which is likely much more variable than emergence from the overwintering eggs.

Objective 3. Specimens of five different populations of lacewings in the *Chrysoperla plorabunda* species complex that were differentiated by song analysis were received from Prof. Charles Henry of the University of Connecticut in mid-April 2013. These were identified by Dr. Henry as *C. plorabunda, C. adamsi, C. johnsoni, C. mohave and C. downesi.*

Studies in this grant initially focused on evaluation of Genbank accessions of Western *Chrysoperla* "species" sequences to determine if there were unique variations that would allow the development of diagnostic PCR primer sets. The Genbank data showed that there were very few nuclear DNA sequences for *Chrysoperla*, but there were 823 accessions available from the mitochondrial genome with 90% of those focused on four mitochondrial genes. The four gene regions combine to yield 4,630 bases in length for each species to evaluate differences. Multiple single base substitutions were found to distinguish *C. downesi* from the other four species. Similarly, multiple unique single base substitutions in a subgroup of *C. plorabunda* can distinguish them from other populations of *C. plorabunda* as well as *C. adamsi*, *C. johnsoni*, *C. mojave* and *C. downsei*. New PCR primers have been designed and purchased for the nuclear ribosomal gene complex and the spaces between these genes (ITS), but these have not been tested. Delays in the laboratory evaluation of these primers occurred because the two technicians in the Unruh laboratory have required significant medical leave (4 months total) from late summer to the fall. No funds from the WTFRC have yet been spent on this objective and a further progress report will be made available as the work is finished up.

Executive Summary:

This grant was initially submitted as a three-year grant, but reduced to a one-year project. In view of that, the work we performed is commensurate with progress that would be expected in one year. We collected and processed a single year's data from five non-bearing blocks that can be used to help validate the models for *Chrysoperla plorabunda* and *Eupeodes fumipennis*. Examination of that data suggests that we need to focus more on older non-bearing blocks or grafted non-bearing blocks where more pest pressure and natural enemy activity is occurring.

The development of models for secondary pests (aphids and mites) this year focused on European red mite (ERM) and two-spotted spider mite. For both species, literature data from numerous sources showed good agreement in terms of threshold and duration for the different stages. Further, population growth was shown to be predictable on a degree-day scale, which allows us to provide a relatively simple population projection using degree-days that can be obtained from our NOAA forecasts. In addition, because we know the duration of each stage on a DD scale, we can predict life history information important for management such as the time of egg hatch or next adult generation. Our current 7-10 day forecasts are useful, but for such a quick growing pest, management is still difficult to implement – longer-range forecasts should greatly expand the importance of the models for ERM and possibly TSSM. The literature analysis showed that some simple lab data will be required to help clarify the hatch of overwintering eggs for ERM (two choose between the two groups shown in figure 3). Work on the programming of the models into DAS has not yet started (the models were just finished), but we are in the process of designing an interface that could be shared by a number of these secondary pest models.

The molecular work to detect which species of *Chrysoperla plorabunda* species complex has shown that one member of the complex can be readily separated out of from the others. The primers to separate the others based on nuclear ribosomal genes have been designed and purchased, but not yet tested.

Overall, while good progress was made, we did not and cannot finish all three objectives in a project designed as a three-year project in a single year. Our work to date shows the validity of our approaches and has suggested some changes that might be required (as outlined in our new proposal).

FINAL REPORT **PROPOSED DURATION**: 1 year

Project Title: Forecasting the demand and supply for tree fruit farm labor

PI:	Karina Gallardo, PhD	**Co-PI**:	Michael Brady, PhD
Organization:	School of Economic Sciences TFREC, Center for Precision and Automated Agricultural Systems - WSU	**Organization**:	School of Economic Sciences Washington State University
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City/State/Zip:	Wenatchee, WA 98801	**City/State/Zip**:	Pullman, WA 99164

Cooperators: David Allan and Charlie De la Chapelle.

Total Project Request: **Year 1:** 146,109

Percentage time per crop: Apple: 50% Pear: 25% Cherry: 25% Stone Fruit: 0%

Other funding sources: None

WTFRC Collaborative expenses: None

Budget 1
Organization Name: WSU TFREC **Contract Administrator:** Carrie Johnston/Kevin Larson
Telephone: 509.335.4564/509.663.8181 **Email address:** carriej@wsu.edu/kevin_larson@wsu.edu

Item	**2013-14**
Salaries[1]	$ 101,281
Benefits[2]	$ 25,827
Wages[3]	$ 4,313
Benefits[4]	$ 418
Equipment	0
Supplies[5]	$ 4,000
Travel[6]	$ 10,270
Miscellaneous	0
Plot Fees	0
Total	**$ 146,109**

[1] One month salary for PI Karina Gallardo ($6,875/mo), CoPI Michael Brady ($9,111/mo), Associate in Research ($60,000/year) and Master Student ($25,925/9-mos).
[2] Benefits for PI Karina Gallardo ($1,905), CoPI Michael Brady ($2,265), Associate in Research ($19,464) and Master Student ($2,183).
[3] Three-month summer wages for Master Student ($4,313/3-mos).
[4] Benefits for Master Student ($418).
[5] Materials such as paper, printing, postage, miscellaneous for the survey and supplies for focus groups ($2,000) and publication charges ($2,000)
[6] Travel to collect data in focus groups for PI and Associate in Research. Includes 4 trips for PI Karina Gallardo to Yakima ($488/4 trips), Chelan ($168/4 trips) and Royal City ($324/4 trips) summing $980. It also includes trips for Associate in Research based in Pullman to growers' sites in Yakima ($3,410/10 trips), Wenatchee ($2,784 /8 trips), and Chelan ($3,096/8 trips) summing $9,290.

Recap of Original Objectives

1. Forecast the seasonal demand and supply for labor for the Washington apple and pear industries.

2. Build support from industry stakeholders and legislators to procure funding for a research program to develop a total automation systems approach for apples and pears.

Significant Findings

- An estimated 12% of orchard acres are on farms large enough to consider mechanization.

- The number of migrant workers is forecasted to decrease by 1% per year.

- From the migration labor supply model we forecast a drop of 7% in the number of migrant workers in 5 years. We report upper and lower bounds on labor costs using 95% confidence intervals on the migration forecast, which extends between 11% and 2% for the model that had a point estimate of 7%. We report the results of the aggregate model assuming a capital/labor elasticity of substitution of 0.75 and a labor supply elasticity of 1.55. A 7% decrease in labor supply was estimated to increase wages 8.3%, and the 95% confidence interval of the wage increase was 5.6% and 10.5%. Output price for the final good increases by 3% if a 7% drop in labor supply occurs. The 95% confidence interval extends between 2% and 3.7%.

- A labor supply drop of 7% with a 95% confidence interval of 2% and 11% were modeled. Compared to the baseline, a 7% labor supply decrease results in output decreases of 3.84%, 2.91%, 2.36%, and 1% for cherries, pears, grapes, and apples, respectively. The associated projected price for cherries, pears, grapes, and apples increases by 1.5%, 1.62%, 1.60%, and 1.30%, respectively.

- The labor supply shock also creates consumer surplus loss because fruit prices increase. Consumer surplus losses are estimated to be approximately $91 million for apples, $99 million for grapes, $25.5 million for cherries, and $21million for pears when there is a 7% decline in labor supply. The corresponding confidence intervals are $26.06 million and $142.06 million for apples, $28.62 million and $155.16 million for grapes, $7.36 million and $39.78 million for cherries, $6.15 million and $33.30 million for pears

- Farm workers for the four major crops are predicted to account for 80% of total farm workers employment in Washington in 2034.

- The increase in additional workers for the apple industry over the next 20% is estimated to be 47%. Corresponding values for the cherry, grape, and pear industry are 34%, 53%, and 31%, respectively.

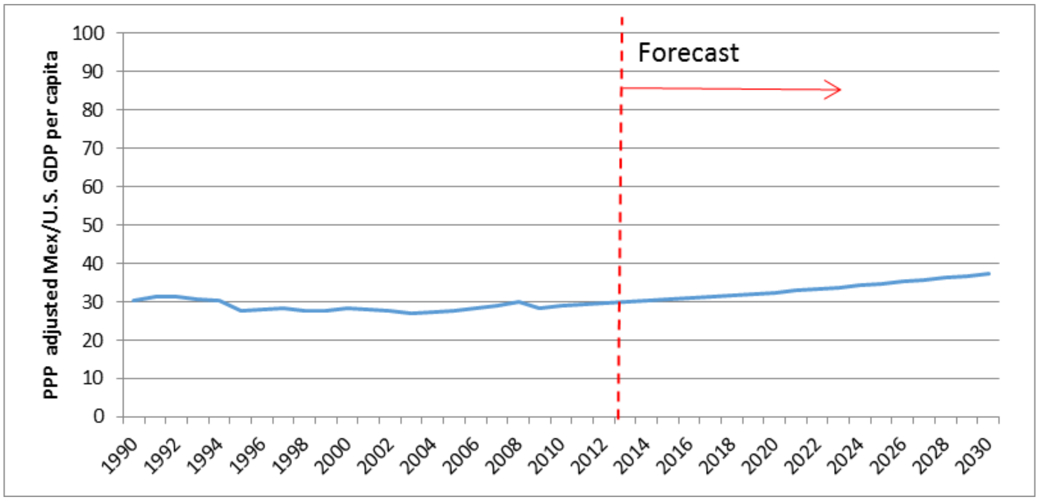
- The present value of operating expenses with mechanized harvesting are $75,190.08 over 20 years. The present value of labor cost with hand harvesting are $65,254.23 over 20 years. The present value of operating expenses for mechanized harvesting is between $5371.22/acre and $9935.85/acre higher than hand harvesting, so we conclude that the current technology is not adopted widely.

- Based on this information, improvements to the current technology would be needed either in terms of cost or productivity. We estimate that if the labor saving rate increases from 36% to 50%, and the machine cost is the same, then it is feasible to adopt the technology. Or with the current technology, it would be feasible to adopt the technology if the wage rate is between $16/hour and $17/hour.

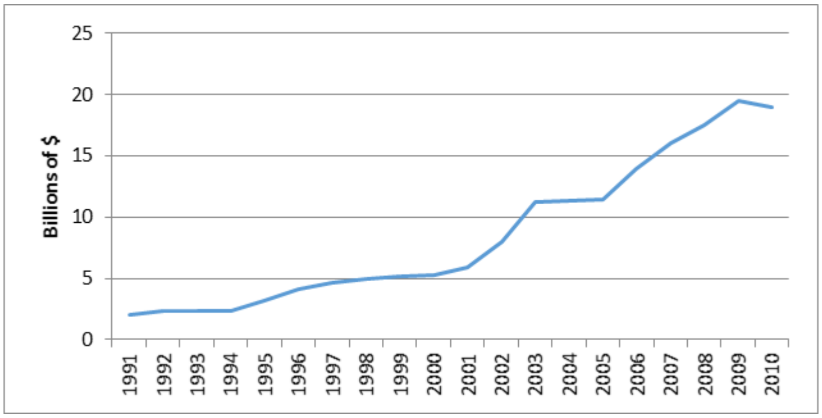
- With additional 1% of H-2A guest workers, the wage rate is 0.54% lower than without it. Consumers benefit from more fruit available at a lower price. We estimate consumer gains by estimating a consumer surplus of $33.57 million for apples, grapes, cherries, and pears produced in Washington State.

Results and Discussion

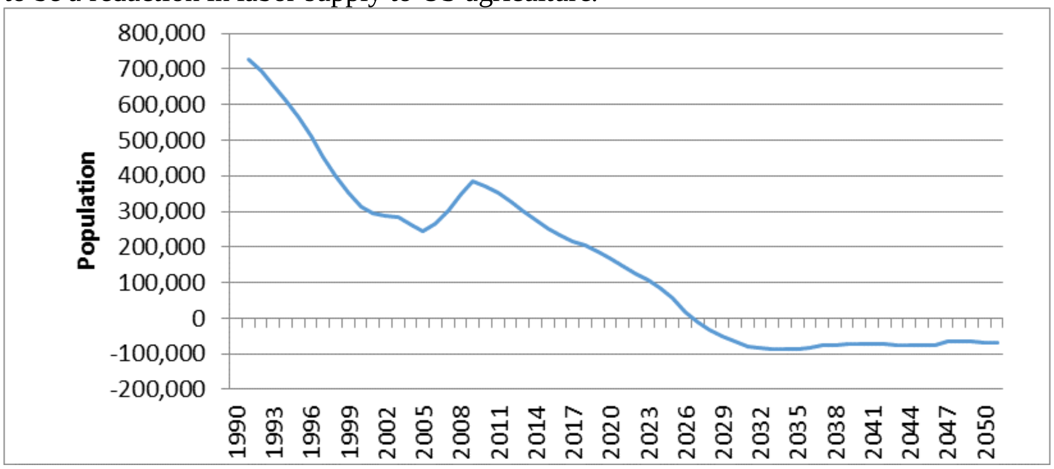
Increased competition for the workers that have traditionally migrated to work in the U.S. is coming from both the agriculture and non-agriculture sectors in Mexico. The Mexican economy is expected to grow faster than the US in the next couple decades.



At the same time increased border enforcement has reduced migration.



Together with a reduction in the growth of the number of working age adults in Mexico there is likely to be a reduction in labor supply to US agriculture.



We model the impact of the coinciding labor supply reduction on wages and production. From the migration labor supply model we forecast a drop of 7% in the number of migrant workers in 5 years. We report upper and lower bounds on labor costs using 95% confidence intervals on the migration forecast, which extends between 11% and 2% for the model that had a point estimate of 7%. We report the results of the aggregate model assuming a capital/labor elasticity of substitution of 0.75 and a labor supply elasticity of 1.55. A 7% decrease in labor supply was estimated to increase wages 8.3%, and the 95% confidence interval of the wage increase was 5.6% and 10.5%. Output price for the final good increases by 3% if a 7% drop in labor supply occurs. The 95% confidence interval extends between 2% and 3.7%.

We then take the projected wage change for labor intensive crops in the first stage as given (or fixed) and then in the second stage consider the change in production decisions in response to the change in the wage level of each individual crop. We account for consumer substitution which introduces interactions between the fnal demand for crops through the cross price elasticity. The effect of reduced labor supply on specific commodities is shown in the table below. The primary columns of interest are the change in the commodity price and output.

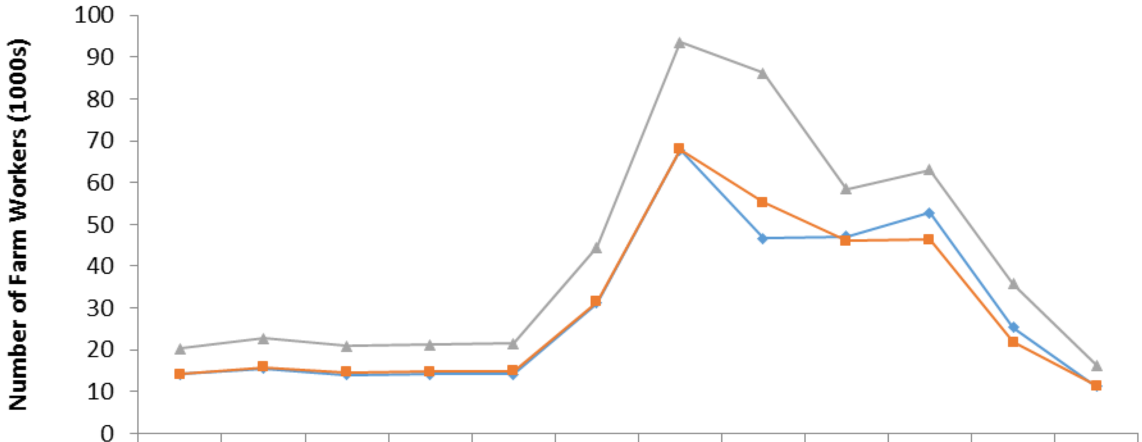
A labor supply drop of 7% with a 95% confidence interval of 2% and 11% were modeled. Compared to the baseline, a 7% labor supply decrease results in output decreases of 3.84%, 2.91%, 2.36%, and 1% for cherries, pears, grapes, and apples, respectively. The associated projected price for cherries, pears, grapes, and apples increases by 1.5%, 1.62%, 1.60%, and 1.30%, respectively.

The labor supply shock also creates consumer surplus loss because fruit prices increase. Consumer surplus losses are estimated to be approximately $91 million for apples, $99 million for grapes, $25.5 million for cherries, and $21million for pears when there is a 7% decline in labor supply. The corresponding confidence intervals are $26.06 million and $142.06 million for apples, $28.62 million and $155.16 million for grapes, $7.36 million and $39.78 million for cherries, $6.15 million and $33.30 million for pears

Labor shift	Commodity	Demand elasticity	Demand shift [b]	Labor share	Substitution elasticity	output change	Price change	Labor change
Baseline	Apples	-1.09	0.089	0.35	0.75	0.0849	0.0161	0.0625
2%						0.0821	0.0197	0.0547
7%						0.0749	0.0291	0.0344
11%						0.0691	0.0366	0.0182
Baseline	Grapes	-1.38	0.131	0.43	0.75	0.1521	0.0198	0.1324
2%						0.1455	0.0242	0.1215
7%						0.1285	0.0357	0.0929
11%						0.1148	0.0450	0.0701
Baseline	Pears	-1.5	-0.01	0.44	0.75	-0.053	0.02	-0.0721
2%						-0.0610	0.0245	-0.0845
7%						-0.0821	0.0362	-0.1166
11%						-0.0989	0.0455	-0.1424
Baseline	Cherries	-1.792	0.138	0.4	0.75	0.1989	0.0184	0.1783
2%						0.1883	0.0225	0.1630
7%						0.1605	0.0332	0.1231
11%						0.1383	0.0418	0.0912

[a] Wage shift is 4.6%, 5.6%, 8.3% and 10.5% for baseline, 2%, 7% , and 11% decline in labor supply, respectively.
[b] Demand shift was estimated by authors

We also forecast changes in apple varieties to look at the change in the period of peak labor demand, as shown below.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2011	14163	15615	14106	14183	14123	31123	67856	46605	47102	52843	25431	11297
2013	14180	15801	14621	14759	14899	31445	67954	55189	46044	46421	21880	11394
2034	20314	22752	20987	21179	21548	44467	93543	86244	58459	63008	35755	16401

This shows a clear increase in the relative demand in July compared to other months.

When facing higher prices, farm owners could adopt less labor-intensive practices by investing in labor saving machinery. It is difficult to assess this question with a great deal of specifics right now because there is uncertainty over the productivity and cost structure of available technologies, although some data was available. This information is used to answer the question: how high do labor costs have to get before the existing technology is a worthwhile investment? We use the present value method to estimate when the current mechanical harvesting technology is going to generate a positive economic return compared to hand harvesting.

Gallardo and Juraqulova (2013) provide an economic analysis of apple mechanical harvester aid. We use their statistical data on the apple mechanical harvester aid on honey crispy to estimate the timing of when mechanical harvester generate a positive economic return compared to hand harvesting. The machine's cost is $50,000 and estimated life is 20 years. The machine reduces labor inputs by 36%. For example, a 10 acre orchard requires 25 pickers to work 12 hours per day for 12 days to finish harvesting. With mechanical harvesting, it requires 16 pickers to work 12 hours per day for 12 days. The machine also saves the cost of ladders. The labor cost saving is estimated to be $1830.60 /acre. The estimated cost for one mechanical harvesting aid is $2788/acre each year. These costs include depreciation, interest, taxes, fuel, and maintenance. The operating expenses for machinery also includes labor with the machinery. The labor cost with machinery is assumed to be the same each year, which is approximately $2458/acre. The total operating expenses with machinery are $5246.2/acre in 2013. The present value of operating expenses for using machinery is $70,725.45 over the useful life of 20 years using a constant wage rate. We also estimated the present value of costs under hand harvesting versus and mechanical harvesting with wage increases from the equilibrium displacement model. The present value of operating expenses with mechanized harvesting are $75,190.08 over 20 years. The present value of labor cost with hand harvesting are $65,254.23 over 20 years. The present value of operating expenses for mechanized harvesting is between $5371.22/acre and $9935.85/acre higher than hand harvesting, so we conclude that the current technology is not adopted widely.

Based on this information, improvements to the current technology would be needed either in terms of cost or productivity. We estimate that if the labor saving rate increases from 36% to 50%, and the machine cost is the same, then it is feasible to adopt the technology. Or with the current technology, it would be feasible to adopt the technology if the wage rate is between $16/hour and $17/hour.

The H-2A program is a guest worker program that enables farm owners to apply to the Department of Labor (DOL) to bring in "low-skilled laborers" for agricultural work. H-2A workers only make up about 2-5% of the farm workforce. In 2011, there were roughly 79,794 H-2A workers certified by DOL. H-2A program connects farm owners and guest farm workers directly and has been considered as an important migration policy to alleviate regional or seasonal labor shortage. We model the effect of expanded H-2A on labor costs by keeping other factors constant, and then reduce the magnitude of the reduced labor supply. A lower wage rate induced by H-2A program relative to not having the program results in increased output at a lower price. We use a Muth model to quantify the impact of a scenario where the H-2A program generates 1% of total farm workers along with a 7% drop in labor supply. With additional 1% of H-2A guest workers, the wage rate is 0.54% lower than without it. Consumers benefit from more fruit available at a lower price. We estimate consumer gains by estimating a consumer surplus of $33.57 million for apples, grapes, cherries, and pears produced in Washington State.

Executive Summary

The objective of this study is to forecast labor costs to the Washington tree fruit industry and estimate the impact of higher labor costs on production, profitability, and the timing of labor saving harvesting technologies. The availability of abundant labor from abroad, primarily Mexico, has kept wages low in labor intensive agriculture in the U.S. for a number of decades. This has reduced incentives for developing labor saving technologies, particularly at the point of harvesting. While agriculture in the U.S. has shown a substantial ability to develop and adopt new technologies there are a number of significant obstacles to overcome for a number of crops that rely heavily on hand harvesting. The adoption of such technologies will also require significant capital outlays that will affect the financial structure and debt load of many operations. Thus, maintaining profitability in the tree fruit industry will require both farm-level planning in terms of production and finances, as well as concentrated R&D in new technologies at both the development and implementation phases.

The immediate cause for concern is that the number of available workers has been dropping. Demographic trends, increased competition for workers in Mexico, and continued high levels of border enforcement in the absence of comprehensive immigration reform are likely to continue to reduce the supply of workers to the labor intensive crop industries in the U.S. which will put upward pressure on labor costs. We forecast a drop of 1% in the number of migrant workers per year as the most likely scenario. Higher and lower estimates are also forecasted by considering other realistic outcomes for economic growth in Mexico and changes in immigration policy and border enforcement. Momentum in demographic trends are established and cannot change in a time frame relevant to this study. A range of scenarios are developed to account for uncertainty over future outcomes of relevant conditions with respect to the magnitude of the labor supply reduction (depending on immigration policy and competition for labor in Mexico), technological change in the productivity of harvesting technologies, and the baseline crop mix.

The modeling framework used to estimate the impact of reduced labor supply is as follows. Demographic trends, Mexican economic growth relative to the US, and border enforcement are analyzed to forecast the change in labor supply over time. The impact of the reduced labor supply is considered nationally for the U.S. under the assumption that if large wage differentials develop between production regions (e.g. Florida v. Washington) then workers will relocate. This model captures averages across labor intensive crops and reports an estimated percent change in wages along with percent changes in the price and quantity of labor intensive crops produced. It also incorporates expectations of changes in demand for fruit and vegetables produced in the U.S. The wage change is then used in a second-stage set of commodity specific models for Washington. This part of the analysis looks at the effect of a change in wages on production. Own and cross-price elasticities of each commodity considered at this stage account for the impact of higher labor costs on quantities produced and prices of final goods. This process is repeated for different scenarios as described in the previous paragraph.

Reduced labor supply is forecasted to increase wages by 8.31% in five years' time. The increase in the price of labor intensive crops on average (across all crops) is estimated to be 2.9% as a result. Based on this forecasted change in wage levels it is expected that existing harvesting technologies would not generate a positive return on investment in the next 20 years. Based on the information, we predict that a technology that increases the labor saving rate from 36% to 50% would be feasible given growth in labor costs. This corresponds to a wage rate between $16/hour and $17/hour. The optimal response for some orchard producers to this type of technology and wage level would be to switch crops. Analysis of individual landowner and cropland cover data showed that approximately 12% of all land in orchards is owned by an entity that is likely to be too small to make investments in harvesting technologies realistic. Increased mechanization would likely also lead to consolidation and increased farm size in orchard production. Based on a sample enterprise budget, the difference in profitability at the point where adoption of harvesting technologies occurs relative to now (current wages and input levels) is $957 per acre.

Sensitivity analysis focused on high and low labor supply shock scenarios shows the difference in the timing of technology adoption to be 4-5 years. The impact of an expanded guest worker program reduces the labor supply shock by 1-3% in Washington which delays the widespread adoption of harvesting technologies by 1-2 years. The model scenario with additional 1% of H-2A guest workers that accounts for changes in the crop mix find that the wage rate decreases by 0.54%. This scenario also corresponds to the hiring of more farm workers, increased output, and lower food prices. Labor saving harvesting technologies that represent a 36% to 52% increase in productivity are estimated to increase net returns by $578 per acre. An Excel spreadsheet has been developed to perform custom farm-level investment analyses for various crops and varieties.

CONTINUING PROJECT REPORT **YEAR**: 2014 (2 of 3)

WTFRC Project Number: TR – 13 - 100

Project Title: Technology Roadmap Implementation

PI: James Nicholas Ashmore
Organization: James Nicholas Ashmore & Associates
Telephone: (703) 517 5439
Email: nickashmore@cox.net:
Address: 9094 Blue Jug Landing
Burke, VA 22015-2106

Cooperators: NONE

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

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

Other funding sources: None

WTFRC Collaborative expenses: None

Budget
Organization Name: James Nicholas Ashmore & Associates
Contract Administrator: James N. Ashmore
Telephone: (703) 517 5439 **Email address:** nickashmore@cox.net

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

Objectives:

The basic objectives of this project continue to be to gather data/information from a wide range of sources, organize that information, and work with the Commission Manager and other specialty crops groups to identify and structure flexible options to work with the Congress that will lead to a successful effort to reach certain specified goals:

- secure and enhance the continued implementation of the National Technology Roadmap for the Tree Fruit Industry and the gains that have been made to date because of the funding made available for the Specialty Crops Research programs established by the 2008 general farm statute;
- support the extension of these Specialty Crops Research programs in any reauthorization of general farm legislation considered by the Congress; **DONE (Agricultural Act of 2014, P. L. 113-79)**
- work with the Commission Manager and other groups in the specialty crops coalition to monitor implementation of the Agricultural Act of 2014 to insure that the concerns of the Commission regarding any of these programs are considered and addressed;
- Work with the Commission Manager to continue to evaluate the relationship between the programs mandated by the Agricultural Act of 2014 and other actions taken by the Congress especially with respect to budget and appropriations issues;
- secure continuation and funding of research programs identified and supported by the Washington tree fruit industry;
- seek to obtain funding/support for new initiatives identified and supported by the Washington state industry; and,
- seek to broaden possible sources for funding for both established programs and for new initiatives.

Findings (To Date):

- Since my last Continuing Project Report (submitted October 31, 2013), a number of significant actions have been taken by the Congress and the Administration;
- As I indicated in my previous Continuing Report, as part of legislation raising the debt ceiling for a limited period of time and reopening the government, Congress mandated that a conference committee be established between the House and Senate to attempt to work out a deal to address pending budget issues and directed that a report be made no later than December 15, 2013;
- As you know, Senator Murray (chair of the Senate Budget Committee), and Representative Ryan (chair of the House Budget Committee), were able to reach an agreement and their agreement was written as the Bipartisan Budget Act of 2013; provisions of that legislative proposal were included in H. J. Res. 59, which was signed into law on December 26, 2013
- (P. L. 113-67);
- Significantly, the Bipartisan Budget Act of 2013 eases sequestration in fiscal 2014 (current year), and fiscal 2015 (beginning October 1, 2014), and sets appropriations caps for both fiscal years;
- As a result of this action, the Congress was able to complete action on overall legislation making appropriations for the current fiscal year, and the Congress considered and passed
- H. R. 3547, the Consolidated Appropriations Act of 2014. That measure was signed into law as P. L. 113-76.

- There is a sense that because the Bipartisan Budget Act of 2013 establishes appropriations caps for the upcoming fiscal year (2015), the Congress will be better able to move forward with the normal appropriations process;
- While there have been significant benefits from enactment of the Bipartisan Budget Act of 2013, it is important to note that this new statute "pays for" the easing of sequestration in FY 2014 and FY 2015, by extending sequestration provisions by an additional 2 years (through fiscal 2022 and fiscal 2023). What this means, in essence, is that absent another budget agreement, sequestration will kick in beginning in fiscal 2016.
- There was tremendous controversy surrounding provisions of the Bipartisan Budget Act of 2013 relative to certain military retirement benefits for younger veterans. Congress responded on a bipartisan basis and has enacted legislation (S. 25, P. L. 113-82) to repeal those particular provisions of the Bipartisan Budget Act of 2013.
- The measure enacted by Congress "paid for" restoration of these military retirement benefits by extending sequestration for an additional year, or through fiscal 2024 (absent a budget agreement to the contrary).
- It is important to note that the Congress has approved and the President has signed a "clean debt ceiling" increase adequate to cover government costs, thus insuring that this Congress can move through the Election without facing another "fiscal crisis."
- Finally, and perhaps most importantly, the farm bill conference was able to reach agreement on its remaining controversial issues, and the Congress has approved the conference agreement and the President has signed the Agricultural Act of 2014 into law (H. R. 2642,
- P. L. 113-79).
- The Agricultural Act of 2014 extends and provides mandatory spending for programs important to the Commission, including but not limited to the Specialty Crops Initiative; the Clean Plant Network; and the Specialty Crops Block Grant Program.

Actions (To Date):

- Continued to work closely with the Commission Manager and with Northwest Horticultural Council and other related industry groups on all issues of concern;
- Continued to work with the Commission Manager and with Dr. Mike Willett and others in support of the Pear Research Roadmap, and sought to explore all possible options to move forward toward addressing the interests of the pear growers of the Pacific Northwest;
- Worked with Dr. Mike Willett of the Northwest Horticultural Council and congressional staff to address possible concerns over the Clean Plant Network and especially with respect to the relationship between the Consolidated Appropriations Act of 2014 and the Agricultural Act of 2014 and how that program is addressed;
- Continued to maintain strong working relationships with Washington Delegation offices and where necessary took steps to keep them informed of the interests and positions of the Washington state industry;
- Continued to maintain good working relationships with Committee staff and with other offices to insure that they had all of the information necessary to consider specialty crops issues and how they impacted on the Washington state industry;
- Reported to the Commission Manager on developments as Congress moved successfully to complete action on the Agricultural Act of 2014 that contains mandatory spending for specialty crops research programs;and,
- Monitored other issues of possible concern to the state growers, including but not limited to on-going discussions about environmental issues of concern.

Actions (Anticipated):

- Continue to monitor and report on progress of the implementation of the Agricultural Act of 2014, and work with the Commission Manager and others to determine how actions being contemplated relate to each other, to the appropriations process, and to priorities of the Washington state growers;
- Continue to maintain contacts with Delegation offices and with Administration and committee personnel to insure that they are provided with the information that they need in proper form and in a timely fashion;
- Continue to maintain close contact with the staffs of the authorizing committees of jurisdiction and Delegation offices to determine how they expect to proceed with insuring that the new farm bill is implemented fairly and in a timely fashion so that these programs can be revitalized, research priorities identified, and funding made available so that we can move forward to achieve the research results that we are seeking;and,
- Follow other developments in Congress and report them as necessary to the Commission Manager to insure that he and the Commission have the best available information necessary to be responsive to the Congress and to the Administration.

Methods:

The beneficial provisions relative to specialty crop issues contained in the Agricultural Act of 2014 clearly demonstrate the extent to which there is a remarkable degree of bipartisan support for the Specialty Crops programs and a clear recognition that these programs have been very successful.

In my view, the best way that we can express our appreciation for that bipartisan support is to work collectively and collaboratively to insure that these new/reconstituted programs prove to be successful. We have, I believe, an obligation to stay united, to work together, and remain committed to continuing to change the culture governing agricultural research efforts.

We have helped create a climate where an agreement is possible. It is my sense that this is due to a number of things, not least of which is that we have demonstrated the following characteristics:

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

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

It would be my intent to continue to approach these matters in this way, realizing that we need to work together and with both the Congress and the Administration.

Results and Discussion

The events of early 2014 have been favorable. We are in a good place, and we have in effect gotten a "vote of confidence" in where we are headed and what we want to accomplish.

In a general sense, this is "where the rubber meets the road." The implementation of the Agricultural Act of 2014 will take some time and may prove in some instances to be difficult. It will be important that we stay active but that we remain patient and understanding.

While we will be interested in expediting the process, arguably we will need to proceed with deliberate speed and work to insure that we are maintaining the broadest possible support for broad-based research, based on sound science, and benefitting to the extent possible a diversity of crop and regional interests.

We are going to need to remember that actions outside of our interests could (and likely will), have some impact on us. My recommendation is that we focus on maintaining our reputation throughout so that we can continue to be perceived as transparent and committed to a competitive research process, stressing collaboration between interest groups and among scientific disciplines.

On other fronts, I continue to believe that we are well-positioned to make progress in our specific areas, such as protecting programs of interest to the industry as well as working with USDA to move forward on the pear research roadmap.

There is a lot to be done, and we will have to stay involved and continue to be responsible and responsive to both the Congress and the Administration.

I have enjoyed working with the Commission and its Manager and with others in the industry on these issues. I look forward to having the opportunity to continue to get these programs back up and running in the coming year and take such other action as possible to advance the interests of the Washington state tree fruit industry.

CONTINUING PROJECT REPORT **YEAR:** Year 1 of 2
WTFRC Project Number: TR-13-105A

Project Title: Improving tools for early detection of brown marmorated stink bug

PI: Jay F. Brunner
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Address: 103800 Baltimore Blvd.
City/State/Zip: Beltsville/MD/20705

Cooperators: Todd Murray, Skamania County Extension

Percentage time per crop: Apple: 65% Pear: 10% Cherry: 20% Stone Fruit:5%

Budget: **Year 1**: *$*110,927 **Year 2: $39,863**

Other funding sources

Agency Name: USDA SCRI awarded to Washington State University, Brunner
Amt. awarded: $67,693 over three years (2012-2014)
Notes: This SCRI grant provides funds to Washington State University to assess distribution of BMSB in WA and to evaluate pheromone technology. Some of the funding (≈ $40,000) from the WSU portion of the SCRI BMSB budget will be used to support the activities proposed here.

Agency Name: USDA SCRI awarded to Oregon State University, Shearer
Amt. awarded: $146,995 over three years (2012-2014)
Notes: This SCRI grant provides funds to Oregon State University to develop management strategies for BMSB across several crops. The funds requested here are not provided in the SCRI funding.

Agency Name: USDA SCRI awarded to USDA-ARS, Leskey
Amt. awarded: $559,072 over three years (2012-2014)

WTFRC Collaborative expenses: *None*

Budget 1:
Organization: WSU-TFREC **Contract Administrator:** Carrie Johnston; Joni Cartwright
Telephone: 509-335-4564; 663-8181 X221 **Email:** carriej@wsu.edu; joni.cartwright@wsu.edu

Item	**2013**	**2014**
Salaries	14,080	**0**
Benefits	5,562	**0**
Wages[1] (temporary labor)	11,520	**7,200**
Benefits [1]	1,118	**698**
Equipment	0	**0**
Supplies[2]	500	**1,000**
Travel[3]	5,032	**1,680**
Plot Fees	0	**0**
Miscellaneous	0	**0**
Total	37,812	**10,578**[4]

Footnotes:
[1] Temporary labor – (1FTE, $15/h, 12 weeks); benefits at 9.7%.
[2] Includes pheromone, traps and monitoring supplies.
[3] 3.000 miles @ $.56 per mile.
[4] *Justification for changed budget* – due to a delayed start to the project we missed the spring activity for BMSB so were not able to accomplish all the tasks identified for year one, therefore, we had carry over funding that extends into year two so are asking for less funding.

Budget 2:
Organization: Oregon State Univ. **Contract Administrator:** Kelvin Koong
Telephone: 541-737-3228 **Email:** L.J.Koong@oregonstate.edu

Item	**2013**	**2014**
Salaries	0	**0**
Benefits	0	**0**
Wages[1] (temporary labor)	11,250	**7,830**
Benefits (10%) [1]	1,125	**4,385**
Equipment	9,800	**0**
Supplies[2]	3,000	**5,500**
Travel[3]	1,000	**1,000**
Plot Fees	0	**0**
Miscellaneous	0	**0**
Total	26,175	**18,715**[4]

Footnotes:
[1] Temporary labor (1 FTE, $15/h, 3mo); benefits at 56%.
[2] Includes supplies for analyzing plant chemicals plus monitoring supplies.
[3] Within state travel.
[4] *Justification for changed budget* – the budget for OSU is slightly higher ($5,000) than was anticipated in the year two budget in the original grant. These extra funds are to cover work conducted by Elizabeth Tomasino for assistance with GC-Mass Spec analysis of host plants in OR and WA.

Budget 3:
Organization: USDA-ARS-NAA **Contract Administrator:** Ingrid Charlton
Telephone: (215) 233-6554 **Email:** ingrid.charlton@ars.usda.gov; naagrants@ars.usda.gov

Item	2013	2014
Salaries	20,822	**0**
Benefits (35%)	7,288	**0**
Wages[1]	13,565	**7,009**
Benefits (8%) [1]	1,085	**561**
Equipment	0	**0**
Supplies[2]	4,180	**2,000**
Travel[3]	0	**1,000**
Plot Fees	0	**0**
Miscellaneous	0	**0**
Total	46,940	**10,570**[4]

Footnotes:
[1] Temporary labor (0.5 FTE, 6 months); benefits at 8%.
[2] Includes construction and shipping of traps to WA and OR.
[3] Travel to WA to coordinate and consult on project activities.
[4] *Justification for changed budget* – the budget for USDA is significantly reduced as there was a significant amount of carry over funding from the year one budget. Funds that are requested are for additional traps and BSMB pheromone.

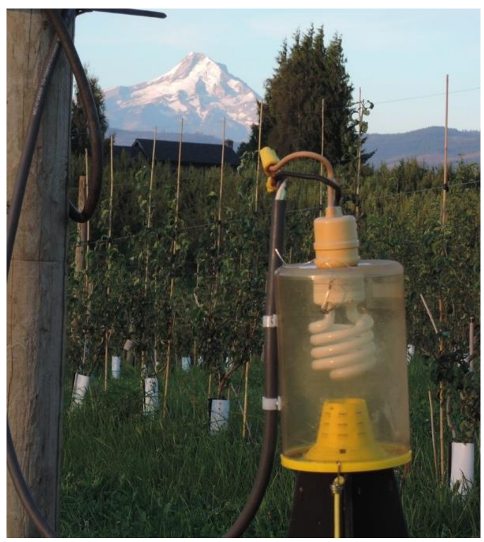
OBJECTIVES:

1. Compare a new BMSB light trap with standard pheromone-baited pyramid trap.
2. Determine the pheromone release rate that optimizes attraction to and capture of BMSB in traps.
3. Determine host-plant odors (kairomones) that enhance attraction/capture of BMSB in pheromone-baited and/or light traps.

SIGNIFICANT FINDINGS

1. BMSB were detected in site considered to have low populations and in three sites considered to have medium populations. At three of the four positive catch sites, BMSB were captured in pheromone-baited traps.
2. The release rate of the USDA#20 pheromone was no different when placed in polyethylene packets of different thicknesses and pheromone appeared to be gone in just a few days.
3. The release rate of USDA#20 pheromone from a commercial lure was low and lures appeared to be depleted after about one week.
4. The release rate of MDT pheromone from a commercial lure was higher than that of the USDA#20 lure and lures were releasing after 21 days.
5. Two compounds derived from English holly, which were also present in tree of heaven, (hexyl formate (hex) and cis-3-hexen-1-ol (cis3)) showed positive response by BMSB in Y-tube bioassays.
6. When hex and cis3 were placed alone in polyethylene lures there was no capture of BMSB.
7. When hex and cis3 were combined with aggregation pheromones (USDA#20 and MDT) there was some increase in BMSB capture.

METHODS



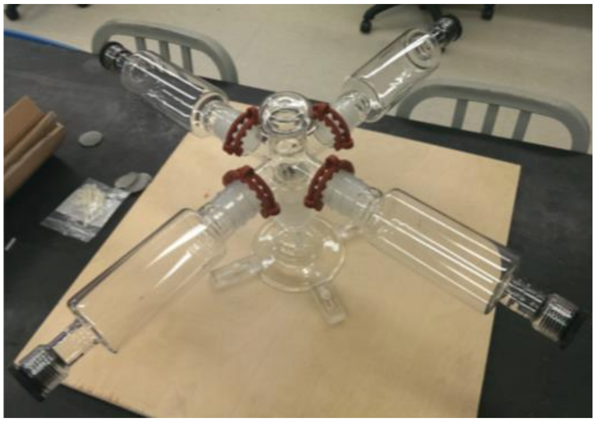
Light and pheromone traps provided by the USDA-ARS were set up in nine locations, five in WA and four in OR. A series of two light (see at right) and two pheromone-baited traps were established at each location starting in mid- to late-August and were monitored through October. Traps were checked approximately weekly and any BMSB captured were counted and sexed. Two lures were used in traps, the USDA #20 (a crude formulation which has performed the same the #10 lure) and a lure containing the pheromone of *Plautia stali*, methyl (2*E*,4*E*,6*Z*)-decatrienoate (MDT). Lures were changed every two to three weeks.

The USDA provide BMSB #20 pheromone that was placed in polyethylene packets of different thicknesses along with a cotton wick which was then heat-sealed The release of BMSB pheromone from these sealed polyethylene packets was assessed in a fume hood by measuring weight loss over time. We also assessed the release rate from commercial BMSB lures, one containing the USDA #20 pheromone and one containing the MDT pheromone. Release rate was again determined in the laboratory by following weight loss over time. Based on results of these tests we did not make additional lures containing the USDA #20 pheromone but will obtain more #20 pheromone in 2014 to evaluate the impact of release rate on BMSB capture in the spring and again in the summer. We will also evaluate the release rate of the MDT pheromone sealed in polyethylene packets in the laboratory prior to the 2014 season and make experimental lures to test in the field comparing BMSB capture results with the USDA #20 lure and with commercially available BMSB lures.

Initial studies on the response of BMSB to plant volatiles were conducted at OSU. The focus was on two host plants that consistently have BMSB populations early in their colonization of an area, English holly (*Ilex aquifolium* L.) and tree of heaven (*Ailanthus altissima* (Mill.)).

Extraction and analysis of plant volatiles. Approximately 1 lb. of ripe (red) holly berries was collected from three different trees in Corvallis, OR. After mixing, the berries were frozen with liquid N. A mortar and pestle was used to crush the berries into a fine frozen powder. Approximately one gram of material was added to six scintillation vials and was placed in the Shimadzu gas chromatography mass spectrophotometer. Analysis returned many compounds, but the primary volatiles and those that also occurred in the well-known host plant for BMSB, *Ailanthus* were selected for the volatile attraction bioassay. We also referenced The Pherobase (http://www.pherobase.com/) for potential behavioral activity of volatile compounds. The initial candidate compounds were: hexyl formate (hex), 1-octanol (oct), cis-3-hexen-1-ol (cis3), 1-heptanol (hept), 2-phenylethanol (phen). All chemicals were purchased from Sigma Chemical.

Preparation of lures. Membrane lures consisted of 1.5 in 2 mil poly tubing that was impulse sealed at one end. A 1 in. cotton pad was placed in the bag, 1 ml of the volatile compound was added, and the other end of the bag was sealed. For control lures, 1 ml of water was added instead of volatile compound.



Olfactometer bioassay. Stink bugs were collected from host plants in the Willamette Valley. Stink bugs were kept in cages in the laboratory and used in the bioassays within three days of collection. Individual stink bugs were only used in a bioassay one time. Subjects were held individually in 2oz cups prior to the bioassay. A cardboard box was designed to hold a 5cm diameter (2 in) glass Y-tube to minimize visual stimuli. Each side of the Y-tube was attached to a filter flask with a lure. One lure was the blank or control (water), and the other contained a volatile compound. The airflow into the flask was humidified with a water bubbler and air speed was maintained at approximately 0.3 m/s by a carbon-filtered regulator. Subjects were released into the bottom of the tube and were given 10 min to respond. A positive response meant that the BMSB entered the chamber connected to the flask containing the volatile odor, and a negative response meant that the insect went to the control side. If the bug did not move or leave the bottom of Y-tube, it was considered to be a non-responder. After three trials, the Y-tube was disconnected and washed first with soap and water and then rinsed in acetone. Once dry, the positive and control sides of the Y-tube were reversed from their previous configuration.

RESULTS

Light and Pheromone Trapping. Light and pheromone traps were set up in nine locations, five in WA and four in OR. A series of two light and two pheromone-baited traps were established at each location (Fig 1). Two locations were in Hood River, OR and two were in the Willamette Valley (Aurora and Talent, OR). There were three other locations in southwestern WA, one in Vancouver, one in Pringle and one in Underwood. The other two locations in WA were in the Yakima area near to where BMSB was detected in 2012, Wiley, WA and the Apple Tree Golf Course. Since our objective was to determine what traps might be best at detecting low levels of BMSB we focused on areas were we anticipated housed low to moderate populations. The anticipated BMSB population at each location based on previous detections was rated by the project participants and is shown in Table 1. The Vancouver location was at the WSU extension center on 78th street, which was known to have BMSB but not in high numbers. Traps were placed in an open field but near to habitats that would likely house BMSB. This location was not in the epicenter of BMSB in the area but it, along with the Aurora, OR site, was thought to be the most likely location to easily capture BMSB adults. Most other locations were considered to have low to very low BMSB populations. The low BMSB sites were known to have existing populations in the area but not necessarily at the location where traps were placed. The very low BMSB sites were where only one or two bugs had been previously detected.

Fig. 1. Arrangement of light and pheromone traps at one location.

Five of the nine sites provided no data, thus either the BMSB populations were very low and begin below the detection level of the monitoring system used or there were not sufficient BMSB within the attractive range of the monitoring system. The one site that was considered to have a low population but where a few BMSB were detected, Underwood, set a pattern noted in other sites where only the pheromone-baited traps captured bugs. The sites that were considered medium for BMSB did result in captures of BMSB, but primarily in pheromone-baited traps. Even in the one site that was considered between medium and low for BMSB populations, 88% of the bugs captured were in the pheromone-baited traps. (See Table 1)

Table 1. The location, estimated population level and captures in pheromone and light traps in 2013.

Location	BMSB Population	Pheromone trap	Light trap
Aurora, OR	Medium-low	216	29
Vancouver, WA	Medium	18	0
Prindle, WA	Medium	13	0
Underwood, WA	Low	4	0
Hood River 1	Low	0	0
Hood River 2	Low	0	0
Talent, OR	Very Low	0	0
Yakima 1	Very Low	0	0
Yakima 2	Very Low	0	0

Observation of BMSB at some of these sites suggests that the light traps might bring the adults into the area at night. However, because BMSB activity slows when temperatures drop below 65 ^{o}F, it is possible that the lights attract the insects, then the rapidly dropping temperature interferes with BMSB's ability to enter the traps. In this case, BMSB respond to the pheromone-baited traps as temperatures warm up the following day causing the BMSB to become attracted to and captured in the pheromone trap. This would make the light traps appear less effective than pheromone traps.

Plans for 2014 include obtaining some additional light traps so we can set up more locations and test the premise that the light traps are attracting BMSB from surrounding areas at night and that then these bugs move to and are captured in pheromone-baited traps. We may also combine light traps with pheromone attractants to assess the synergy between two attractant sources. It seems clear that the light traps alone are not as attractive, or effective at capturing BMSB, as pheromone-baited traps.

Optimized pheromone release. USDA #20 pheromone was placed in polyethylene packets, which were sealed and then weighed. Packets were then placed in a fume hood and weighed after 2, 5 and 8 days. The release rate from all packets was essentially the same on day 2, about 6 mg per day (Fig. 2). Release rate then declined sharply between day 2 and day 5 with an average of only about 0.3 mg release from each packet per day regardless of the thickness of the packet. Between day 5 and day 8 almost no change in weight (release of pheromone) could be detected. We did not have enough #20 pheromone to repeat this study so moved to an evaluation of commercial lures.

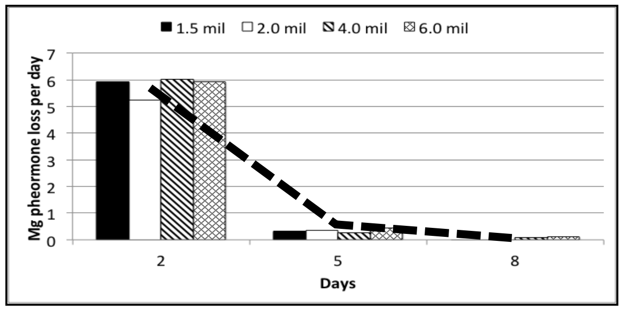


Fig. 2. Average weight loss (mg) of polyethylene packets over eight days when placed in fume hood in the laboratory.

USDA #20 lures were provided by the West Virginia laboratory for use in field monitoring associated with the light trapping study (Obj. #1). ChemTica International provided *Plautia stali* (MDT) lures were for use in the light trap study. Both of these lures, 10 of each, were weighed and then placed in a fume hood and weight loss recorded. These weight loss studies were not run concurrently but data are shown as the average weight loss per day for each lure in Fig. 3. The average weight loss in the #20 lures on day 4 was about 0.8 mg per day but the weight loss declined sharply and after day 7 was only about 0.1 mg or less through day 25. While the amount of weight loss was less than from the polyethylene packets the pattern of weight loss was similar (Fig. 2). Wight loss from the MDT lures averaged almost 3.5 mg per day between day 0 and day 3. Weight loss declined to about 1.5 mg per day between day 3 and day 10 and then declined only slightly between day 10 and day 21, 1.3 mg per day. Assuming weight loss from the polyethylene packet and commercially available lures represented the loss of stink bug pheromone it is concerning that the #20 BMSB pheromone seems to

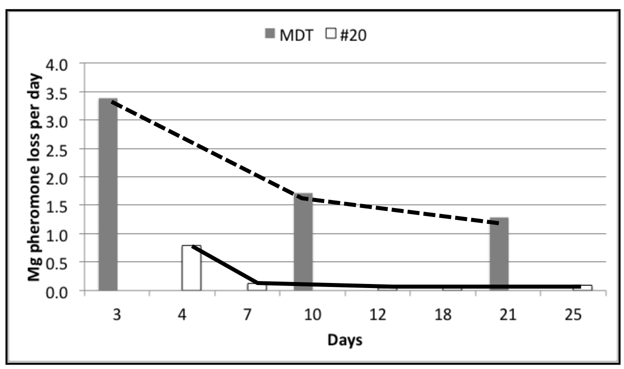


Fig 3. Average weight loss (mg) of commercially provided USDA #20 and MDT lures over twenty-five or twenty-one days, respectively when placed in fume hood in the laboratory.

be released very quickly or it is not being released at all or at very low levels after only a few days. Additional weight loss studies in laboratory are ongoing and will be reported at the technology committee to compliment these results.

Olfactometer bioassay. The initial studies evaluating different host plant volatiles were conducted in the spring. Two compounds, cis3 and hex showed greatest activity in Y-tube bioassays (Fig. 4). Future studies will focus on the use of adults of a known age either by collecting nymphs from the field and rearing them to adult or by using adults from laboratory colonies.

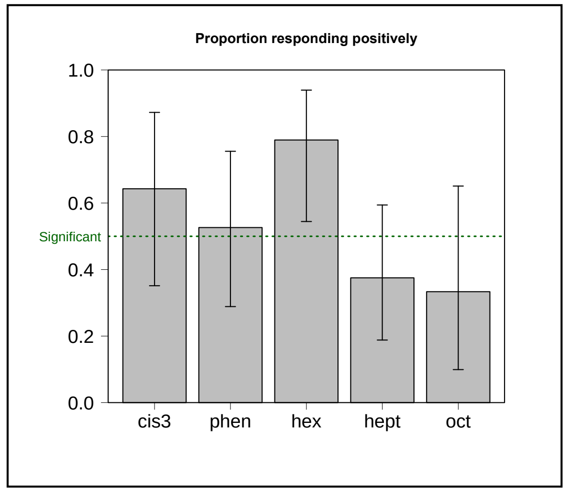


Fig. 4. Proportion response of BMSB in Y-tube bioassay to compounds derived from host plants.

Preliminary field evaluation. The hypothesis that host plant volatiles will provide enhanced capture of BMSB in the spring when the pheromone and synergist are marginally attractive could not be tested as olfactometer tests on candidate volatile compounds were being conducted during spring. However, toward the end of the season (9/12-10/23) some volatiles lures were deployed to the field to determine if they had any biological activity. Unfortunately, this was during the time when BMSB pheromone and synergist (MDT) are highly attractive so it was difficult to compare host plant volatiles with pheromone. Volatile lures were combined with synergist and sometimes with pheromone to examine potential synergy. Lures were placed into Rescue ® stink bug traps and hung in hazelnut trees in an abandoned orchard near Tualatin, OR. This orchard was located as a site of high BMSB activity in 2012 and permission was secured to conduct research. Traps were maintained at 50 ft spacing and were rotated weekly. Lures were changed every two weeks. Although the pheromone + synergist was the most effective lure tested, the candidate volatile lures cis3 and hex enhanced trap capture when used in combination with MDT compared to MDT alone or un-baited controls (UBC) (Fig. 5). The compounds cis3 and hex were not attractive on their own at this time of year. These data need to be considered as very preliminary, and compounds need to be tested prior to the onset of BMSB aggregation behavior in the spring when they leave overwintering sites.

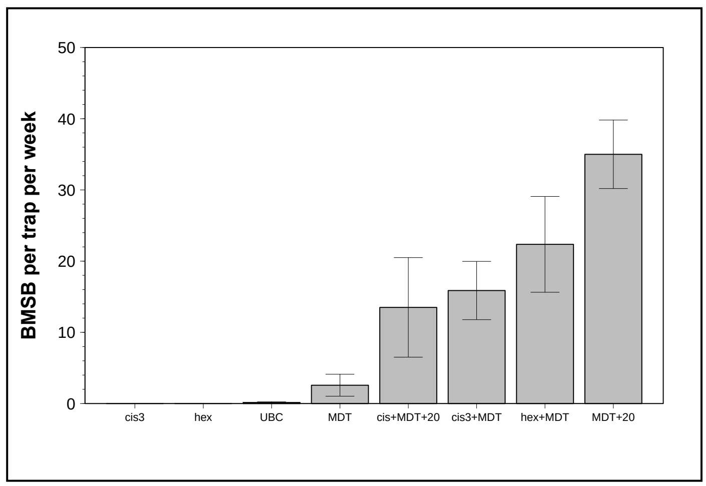


Fig. 5. Average capture of BMSB in traps baited with lures containing candidate plant volatile compounds, pheromones or combinations of volatiles and pheromones.

Plans for 2014. We have requested additional light traps from the USDA so we can conduct studies in more locations than in 2013. We will be evaluating the relative attraction of light versus pheromone-baited traps in the spring and summer. We will also evaluate test the hypothesis that light traps are attracting BMSB from a distance to the general area of the light traps but that bugs enter pheromone-baited traps in close proximity the following day. We will also assess the value of combining light and pheromone in the same trap to optimize attraction and capture.

Additional release rate studies of the USDA #20 and MDT pheromones will be conducted with commercial lures and from lures made from polyethylene packets of different thicknesses. Once a pattern of release rate has been established we will place lures with known different release rates in pyramid traps in areas where there are known BMSB populations. BMSB captured in traps baited with different lures will be recorded in the spring and summer to determine those that capture the most bugs.

Host plants already identified as attractive will be evaluated in the spring when BMSB adults are coming out of overwintering quarters. It is possible that the attraction to these sources differs throughout the season, which could mean that volatiles are different or the bug's attraction to them changes. Additional assessments of volatiles associated with different host plants will be conducted and bioassays on candidate compounds will be conducted using the new bioassay apparatus.

Budget for 2014. Because there were some delays in getting this project going in 2013 we have significantly reduced the budget request since there are carryover funds in accounts from two institutions that will be used for 2014 studies. Those funds that are requested are the best estimate of additional costs needed to complete the objectives of the project.

CONTINUING PROJECT REPORT **YEAR**: 1 of 3
WTFRC Project Number: TR-13-107

Project Title: Efficient strategy to diagnose important virus diseases

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Cooperators: Shulu Zhang, Senior Research Scientist, Research & Development, Agdia, Inc.

Total Project Request: $109,256 **Year 1:** $35,000 **Year 2: $36,400** **Year 3**: $37,856

Percentage time per crop: Apple: 10% Pear: 0% Cherry: 90% Stone Fruit: 0%

Other funding sources:

A gift grant of $10,000 was provided by Stemilt Growers Inc. to assist in the application of Recombinase Polymerase Amplification assay to the detection of *Little cherry virus 2*.

WTFRC Collaborative expenses: None

Budget 1
Organization Name: Washington State University **Contract Administrator:** Carrie Johnston
Telephone: (509) 335-4563 **Email address:** carriej@wsu.edu

Item	2013	2014	2015
Salaries	$17,717[1]	$18,426[1]	$19,163[1]
Benefits	$7,025[2]	$7,306[2]	$7,598[2]
Wages	$0	$0	$0
Benefits	$0	$0	$0
Equipment	$0	$0	$0
Supplies	$10,258[3]	$10,668[3]	$11,095[3]
Travel	$0	$0	$0
Miscellaneous	$0	$0	$0
Plot Fees	$0	$0	$0
Total	$35,000	**$36,400**	$37,856

Footnotes:

1. A Post Doctoral Research Associate at 33% of full time and a Scientific Assistant at 10% of full time.
2. Benefits calculated at the state standard rate.
3. Purchase of enzymes and primers; deep sequencing of virus and phytoplasma isolates.

OBJECTIVES:

With previous funding from the Washington Tree Fruit Research Commission (WTFRC), extensive sequence libraries of regional virus isolates developed in our project were married to a new diagnostic technology, the Recombinase Polymerase Amplification (RPA) assay. We are seeking funds to continue this translation research to provide reliable pathogen identification to growers so that they may take appropriate action to protect the capital investment in their orchards. We wish to further develop this method for other fruit tree viruses. Because of recent events in the cherry industry, the project focus is on diseases of cherry. However, the use of RPA could be expanded to include the detection of many diseases associated with a broad range of pome and stone fruit crops.

Specific and immediate objectives of this project are to complete development and validation of detection methods for the pathogens associated with little cherry disease in the Pacific Northwest: Little cherry virus 1, Little cherry virus 2 and Western X phytoplasma. This is the highest priority because of the recent escalation of disease in Washington State;

SIGNIFICANT FINDINGS:

- A prototype RPA assay for Little cherry virus 2 was successfully developed.
    - The sensitivity of the RPA assay was comparable to the reverse transcription polymerase chain reaction (RT-PCR) assay.
    - Samples for the RPA assay do not require specialized sample preparation. Crude plant extracts are suitable for analysis.
    - The simplicity of the RPA assay is amenable to deployment in field offices with minimal equipment.
    - The RPA kit for Little cherry virus 2 is being commercially produced and will be available in mid-May.

- A substantial library of sequences representing Little cherry virus 1 was developed.
    - This information permitted the development of more reliable RT-PCR test capabilities.
    - A prototype RPA assay was developed for Little cherry virus 1. Validation of this assay is being pursued.

- Little cherry disease caused by Western X phytoplasma resulted in an abrupt increase in the number of trees being removed because of this serious disease.
    - Significant sequence information was determined from the genomes of isolates of Western X phytoplasma obtained from regional orchards. Previously, no sequence information was available from regional strains of the phytoplasma.
    - Conserved regions of the genome were identified that could be amenable to the application of RPA technology.

METHODS:

1. Tissue samples were collected from numerous orchards where trees are expressing little cherry disease. Sequence analysis was performed to obtain nucleotide sequence data from these representative disease blocks.

2. The sequence information is used to design reagents specifically targeting the three pathogens predominantly associated with little cherry disease in the Pacific Northwest. The sequence-based components constitute selective elements of the RPA assay system.

3. Once the RPA assay has been optimized with representative isolates of pathogens, the assay system is applied to a wide range of orchard samples to verify the robustness of the assay system.

4. Biological material (positive and negative control tissue of various types) is provided to a commercial entity that will validate the assay system and produce user-friendly assay kits commercially.

5. Little cherry disease is presently the major cause of concern to cherry producers in the Pacific Northwest. However, other diseases caused by virus-like agents would benefit from the application of RPA technology. The agent that causes apple green crinkle disease is one of the most difficult pathogens to detect in fruit trees. As time and resources permit, the information learned from the incorporation of RPA into cherry disease diagnostics will be applied to the development of a detection strategy for apple green crinkle disease of apples.

RESULTS AND DISCUSSION:

Development of an RPA test for Little cherry virus 2 (LChV 2):
Preliminary assessment of an RPA test developed for Little cherry virus 2 (LChV 2) was successfully completed on a limited scale using trees maintained in the screenhouses of the Clean Plant Center Northwest (CPCNW) that are known to be infected with LChV 2. During the 2013 growing season, LChV 2 was observed in several orchards in Douglas and Chelan counties of Washington State (WA). A total of 150 leaf and wood samples from trees suspected to being infected with LChV 2 was tested for the presence of the virus by RPA and compared with the current standard for LChV 2 detection which is reverse transcriptase polymerase chain reaction (RT-PCR). The results in both RPA and RT-PCR tests are in agreement with each other. The sensitivity of RPA, measured in terms of dilution end point of the virus (the lowest dilution of the plant sap containing virus that is still detectable by the assay) was compared with RT-PCR. The RPA and RT-PCR assays were equally sensitive, detecting LChV 2 at 10^{-6} dilution of the plant sap. However, the main advantage of RPA over RT-PCR is its simplicity in the sample preparation process; by being amenable to crude preparations of plant sap extracts as compared to RT-PCR that requires purified nucleic acid (RNA) preparations. Moreover, with its simplicity, specialized equipment is not required to perform the RPA assay making it compatible with deployment to field offices. In this regard, a private company is currently commercializing the LChV 2 RPA test kit that should be available for growers and field persons by mid-May of this year.

An alternative platform of the RPA assay that allows for real-time detection and semi-quantitation of the virus was also evaluated. Preliminary assessment of this RPA platform was promising as it detected LChV 2 from both purified RNA and crude extracts from infected trees (Fig. 1). Further evaluation of this RPA platform is underway including optimizing of the conditions that would improve the differentiation between signals from healthy and infected samples. Alternate sources of reagents are also being evaluated to produce optimal test results.

Development of an RPA test for other pathogens of fruit trees:
Little cherry virus 1:
Little cherry virus 1 (LChV 1) is one of the three pathogens principally associated with little cherry disease (LCD). To develop an RPA assay for LChV 1, it is necessary to identify highly conserved regions of the virus genome from among different LChV 1 isolates. Because of the limited LChV 1

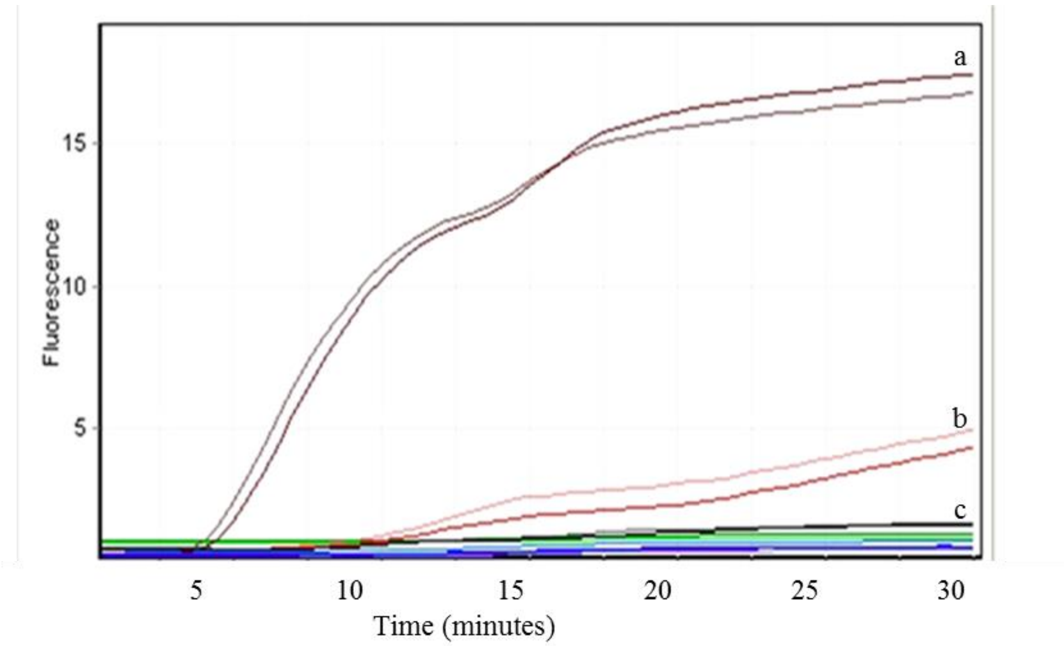

Figure. 1. Recombinase polymerase amplification (RPA) assay fluorescence units for detection of *Little cherry virus* 2 (LChV 2). (a) purified RNA preparations from LChV 2 infected tree; (b) crude extracts from LChV 2 infected tree; (c) purified RNA and crude extracts from non-LChV 2 infected tree.

sequences available in public databases coupled to the high sequence variability among different LChV 1 isolates, it became apparent that additional sequence information was needed. Near full genome nucleotide sequences of LChV 1 isolates were determined for two isolates collected from other states and from eight isolates collected within Washington State. These sequences plus three additional sequences from the public database were used to define target regions in the LChV 1 genome for the RPA assay. Six primer pairs were evaluated initially by RT-PCR to predict their suitability for RPA. The primers were evaluated for their ability to detect seven LChV 1 isolates maintained in CPCNW screenhouses as well as the absence of interfering non-specific background reactions with trees that are not known to be infected with LChV 1. One primer pair, designed from the coat protein region, yielded the most consistent result and was therefore chosen as the primer for the RPA assay. Preliminary assessment of the RPA assay for LChV 1 is presently underway. A functional assay should be available in summer 2014.

Western X phytoplasma:
A third agent that can cause LCD is the Western X phytoplasma. The disease caused by Western X has been relatively uncommon in Washington since the 1950s. However, there has been a dramatic increase in some areas since 2010. Current molecular assays are based certain regions of the genome that conserved among several bacteria. Assays targeting these regions frequently yield positive results to bacteria other than the phytoplasma. Because nucleotide sequence information in other regions of the Western X phytoplasma genome is limited only to one isolate that is not known to occur in Washington State, sequence information from two Washington isolates was pursued. Examination of sequences obtained from these isolates revealed a target region (the putative immunodominant coding region) in the genome of Western X phytoplasma that could be used in the RPA assay. Selection of DNA primers and probes in this region is underway.

Additional progress (related research but funded separately)

Cherry virus A:

Cherry virus A (CVA) is a relatively newly recognized virus that was serendipitously discovered in the mid-1990s as seemingly latent infections of sweet cherries. Although CVA does not cause consistent acute symptoms on sweet cherry trees, incidental field observations suggest that it may exacerbate symptom expression of other diseases of sweet cherries, particularly little cherry disease (LCD). Recently, it was discovered that this virus has infiltrated cherry trees in foundation and certification programs. This revelation led to significant regulatory issues that could limit grower access to trees that have been tested and found free of more deleterious viruses, but infected with CVA. With funding from other sources, conserved regions in the CVA genome determined from 100 short CVA sequences available from the public database plus 20 near full length CVA genome sequences determined in the Clean Plant Center Northwest were compared. Potential target sequences were identified that could be appropriate targets for the RPA assay. Availability of an RPA assay would facilitate obtaining much needed data on the prevalence of this virus in the industry and assist in identifying potential avenues by which CVA is entering orchards.

CONTINUING PROJECT REPORT **YEAR**: 2 of 3
WTFRC Project Number: TR-13-101

Project Title: Mechanical pruning in apple, pear and sweet cherry

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Cooperators: McDougall & Sons, Olsen Brothers

Total Project Request: Year 1: 77,536 **Year 2: 47,959** **Year 3:** 50,210

Percentage time per crop: Apple: 70% Pear: 10% Cherry: 20%

Other funding sources: None

WTFRC Collaborative expenses:

Item	2013	2014	2015
Wages	3,000	3,000	3,000
Travel	1,000	1,000	1,000
Total	4,000	**4,000**	4,000

Footnotes: Tractor / pruner operation and data collection

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

Item	2013	2014	2015
Salaries[1]	26,295	26,307	27,359
Benefits[2]	2,183	2,271	3,135
Wages	7,214	7,503	7,803
Benefits	844	878	913
Equipment[3]	25,000		
Supplies	5,000	2,000	2,000
Travel	7,000	5,000	5,000
Total	73,536	**43,959**	46,210

Footnotes: [1] Salary for student. [2]Medical costs include increase of 4% per year. [3] Purchase or lease of 1 sickle-bar pruner and 1 circular saw pruner and tractor attachments.

OBJECTIVES

The primary goal of this project is to determine best management practices for pruning PNW apple, pear and sweet cherry orchards with a sickle bar mechanical pruner.

(1) Identify and delineate tree architectures suitable for mechanical pruning
(2) Conduct trials to compare pruning technologies for their effects on tree response, return bloom, fruit yield and quality
(3) Conduct a preliminary economic assessment of mechanical pruning systems
(4) Train an M.S. student in horticulture with extensive exposure to tree fruit horticulture, agricultural engineering and applied economics

WORK SCHEDULE

Fall 2013

1) Graduate student was selected and completed Spring 2014 enrollment
2) Gillison Center Mount Sickle Bar Hedger was purchased – Delivery March 17

Spring 2014

1) Establish multi – year field trials in sweet cherry, apple and pears

METHODS

Replicated field trials have been flagged in 5 commercial blocks (1 cherry, 1 pear, 3 apple) Demonstration plots will be established in 2 commercial blocks and at WSU Sunrise and WSU Roza. Blocks will receive same treatments over the life of the project to better evaluate multiple year effects.

Data collection will include: time required to complete task, costs to complete tasks, return bloom, shoot growth, and standard fruit quality and yield measurements. Observations will be made around wood damage, fruit damage, insect and disease presence/absence, tree balance, use of platforms, mechanical thinners and harvest assist.

Field Trials

Apple: Fuji, Cripps Pink

Treatments

1) Mechanical 10-12 leaves
2) Mechanical 10-12 leaves + apogee
3) Mechanical 20 leaves
4) Mechanical 20 leaves + apogee
5) Mechanical Dormant
6) Mechanical Dormant + apogee
7) Mechanical Dormant + 12 leaves
8) Manual

Apple: Fuji (narrow)

Treatments

1) Mechanical Dormant + Mechanical 10-12 leaves
2) Mechanical Dormant + Mechanical 20 leaves
3) Manual + apogee

CHERRY: 2 year

Treatments

1) Yr 1 Manual + Yr 2 Manual
2) Yr 1 Mech + Yr 2 Mech
3) Yr 1 Mech + Yr 2 Mech + Hand

CHERRY: Timing / Tops Only

Treatments

1) Dormant
2) Dormant + 1 Month
3) Dormant + 2 Month
4) Dormant + 3 Month
5) Dormant + 4 Month

PEAR:

Treatments

1) Dormant
2) Manual

RESULTS AND DISCUSSION

Equipment has been purchased. Graduate student – Jacqui Gordon is enrolled and housed in Whiting lab. Trial blocks have been flagged, first pruning should be week of March 17.

CONTINUING PROJECT REPORT **YEAR**: 2 of 3
WTFRC Project Number: TR-12-102

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

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Cooperators: John Ferguson and Markus Keller, IAREC-WSU

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

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

Other funding sources:
Indirect support through the existing infrastructure of AgWeatherNet and its 151 weather stations.

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

Item	2012	2013	**2014**
Salaries	14,040	38,646	37,661
Benefits	5,616	7,803	7,102
Wages	42,400	20,860	21,694
Benefits	4,240	2,086	2,169
Equipment	10,000	0	0
Supplies	10,204	2,605	2,874
Travel	8,500	8,000	8,500
Total	95,000	80,000	**80,000**

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

Goal and Objectives
The overall goal of this project is to investigate the effects of early spring temperature on apples and sweet cherries at different developmental stages and to determine the hardiness. We are using a traditional methodology through exposure to freezing temperatures, and to automate part of this procedure. The outcome will be updated hardiness charts for apples and sweet cherries.

The following are our specific objectives:

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

Significant Findings

- Differences in hardiness and lethal temperature were found during different phenological stages for the same cultivar as well as among the sweet cherry and apple cultivars.
- We are using the automated sampler "vending machine" to determine the hardiness of the crops when DTA is not effective. Results indicate differences between apples and sweet cherries and among cultivars.
- The results from dissection indicate that there is a variation in cold hardiness for different bud sizes of apples for the same sampling date and differences among phenological stages.
- Preliminary results have been posted on the AgWeatherNet web site as well as on Facebook (Figure 4).
- One alert was distributed earlier this winter associated with a significant cold event.

Methods
Bud samples were collected throughout late winter and early spring in 2013 season to determine the effect of temperature on bloom development for apple and sweet cherry cultivars. We started our measurements in October 2012 and ended them around early bloom. For apples we evaluated the varieties Gala, Red Delicious and Fuji. For cherries we evaluated the varieties Bing, Chelan and Sweetheart. The sweet cherry and apple cultivars at different bud development stages were sampled from the field and tested in the laboratory. We restarted our sampling on October 2013 for the current growing season for both cherries and apples and for the same varieties.

Cold hardiness was assessed using differential thermal analysis (DTA) for the first phenological stages. When the DTA was not effective, beyond open cluster, a new automated sampling device was developed and used. For the new device we load the tissue samples into color coded cans and expose the material to different durations and controlled cold temperatures combinations in a freezer. After the cold temperature treatment has been completed each tissue sample is dissected to determine frost damage based on browning of the tissue.

Simultaneously to the process described above we collected dormant apple and cherry shoots that were 6 to 10 inches long with terminal flower buds. The shoots were kept in containers filled with water. The base of the shoots was recut every week and water was replaced every other day and forced in 3 different growth chambers with days/nights at a controlled temperature each one (54/39°F; 64/43°F; 75/54°F) similar to the procedures of Proebsting and Mills (1978), to simulate tree different spring environmental conditions. The samples were processed at three-day intervals and classified accordingly with its hardiness.
Digital pictures were taken for the different growth stages to illustrate, identify, and define the key growth stages for apple and sweet cherry to update the charts, these pictures will be combined with

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

Results and Discussion

This report refers to the results for apple only. The same procedures are being applied to cherries and data collection for both crops will continue in 2014. Critical injury temperatures for buds of Fuji, Gala, and Red delicious, have been evaluated weekly since October 1, 2013.

The relationship of the cumulative percentage of dead buds and the temperature was modeled using a logistic function (Fig 1). The following equation represents the fitted model:

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

where CDF is the cumulative dead bud flower, in a logistic growth curve (Eq. 1), *c* and *d* represent the lower and the upper asymptote respectively which means the percentage of mortality presented already in the field (*c*) and the maximum percentage of mortality (*d*), *K* is the so called 'slope parameter', t is the gradient of temperature in the freezer and *G* is the temperature where the inflexion point of the curve occurs.

Significant logistic curves ($p < 0.01$) were adjusted for each of the cherry cultivars and for each of the different dates of sampling (Fig 1). The estimated parameter values of the model and the corresponding dates are presented in Table 1. As the confidence intervals for the *G* parameter are different, the overlapping curves are different. This means that the cultivars are different with respect to their resistance to lethal temperature (Table 1.)

The Probit procedure was used to calculate the percent of mortality (LT) for 10, 50 and 90. The resulting LT_{10}, LT_{50}, and LT_{90} values for each cultivar and each date of sampling were then used to model the behavior over time. A quadratic function was initially developed. However, it will be necessary to complete the measurements until bloom to develop the full model. The comparison among cultivars shows that there are variations in the temperatures at which injury occurs for each of the cultivars. The pattern of the injury is different at 10, 50 and 90 for each cultivar (Figs 2 and 3).

The cold hardiness is greatly affected by bud development, since the temperature at which the buds become injured changes over time. These results support the earlier report that changes in hardiness were observed for different dates of sampling among cultivars and size of the buds. Buds from the first two sampling dates were less sensitive to cold temperature as compared to the latest sampling dates (Fig 3). This shows that plants at the latest dates had less hardiness and that the deacclimation process has begun.

Until now there is a quadratic relationship between LT and the day when the sampling was conducted (Fig 3), however we will wait until have all the data collected to adjust a preliminary model. Each point represents the value of the temperature where the buds was frozen and dead on that date.
A new experiment is planning to start at the end of February for apples and cherries for three different environments using growth chambers. The measurements will be done initially every week and then when a phenological change is observed, the measurements will be done every other day. The goal of this experiment is to determine the sensitivity of the buds assuming three different environmental conditions during spring.

Limitations

The results presented here for three cultivars of apples for one location (environment) and are limited to the conditions of the orchards where the samples were collected. Similar results have been obtained for cherries. Additional resources will be required to expand research sites and to determine the impact of relative humidity and dewpoint on cold hardiness.

Table 1. Estimated parameters values of the logit model fitted for each of the different sampling dates for the three apple cultivars that are being evaluated.

Cultivar	**Sample Date**	***d***	***C***	***K***	***G***	**95% Confidence Limits (G)**	
Fuji	10/23/2013	1	0.1	-1.0	11.8	10.6	13.0
	10/30/2013	1	0.0	-1.4	0.8	0.3	1.3
	11/7/2013	1	0.0	-0.6	-4.0	-5.3	-2.7
	11/13/2013	1	0.0	-0.6	-2.9	-3.4	-2.4
	11/18/2013	1	0.0	-0.6	-3.8	-5.3	-2.2
	11/19/2013	1	0.0	-0.6	-6.2	-6.7	-5.6
	11/22/2013	1	0.0	-0.6	-6.1	-7.1	-5.0
	11/25/2013	1	0.0	-0.6	-10.8	-12.2	-9.3
	12/2/2013	1	0.0	-0.6	-7.4	-8.8	-6.0
	12/3/2013	1	0.0	-0.5	-6.9	-8.6	-5.2
	12/9/2013	1	0.1	-0.7	-19.8	-20.7	-18.8
	12/10/2013	1	0.0	-1.0	-21.0	-21.4	-20.5
	12/16/2013	1	0.0	0.1	-25.1	-26.2	-23.9
	1/6/2014	1	0.0	0.1	-12.5	-13.3	-11.6
Gala	10/23/2013	1	0.0	-1.0	12.3	11.6	13.1
	10/30/2013	1	0.0	-0.7	4.2	3.3	5.2
	11/7/2013	1	0.0	-0.5	-1.9	-3.1	-0.7
	11/13/2013	1	0.0	-0.5	-2.6	-3.2	-2.1
	11/19/2013	1	0.0	-0.6	-5.4	-6.7	-4.0
	11/22/2013	1	0.0	-0.5	-4.8	-5.3	-4.2
	11/25/2013	1	0.0	-0.5	-7.7	-8.1	-7.2
	12/3/2013	1	0.0	-0.5	-6.3	-7.9	-4.7
	12/10/2013	1	0.0	-1.2	-11.3	-11.8	-10.8
	12/16/2013	1	0.1	-0.6	-18.3	-19.4	-17.2
	1/6/2014	1	0.0	-0.5	-8.9	-11.1	-6.6
Red Delicious	10/23/2013	1	0.0	-1.5	11.2	10.6	11.8
	10/30/2013	1	0.0	-0.8	3.1	61.5	3.6
	11/7/2013	1	0.0	-0.6	-3.6	-4.1	-3.1
	11/13/2013	1	0.0	-0.6	-4.4	-4.8	-3.9
	11/19/2013	1	0.0	-0.6	-6.3	-7.4	-5.3
	11/22/2013	1	0.0	-0.5	-4.9	-6.5	-3.3
	11/25/2013	1	0.0	-0.5	-7.8	-8.4	-7.2
	12/3/2013	1	0.0	-0.5	-6.5	-8.2	-4.9
	12/10/2013	1	0.0	-0.5	-7.5	-9.0	-5.9
	12/16/2013	1	0.0	-0.6	-13.8	-14.3	-13.2

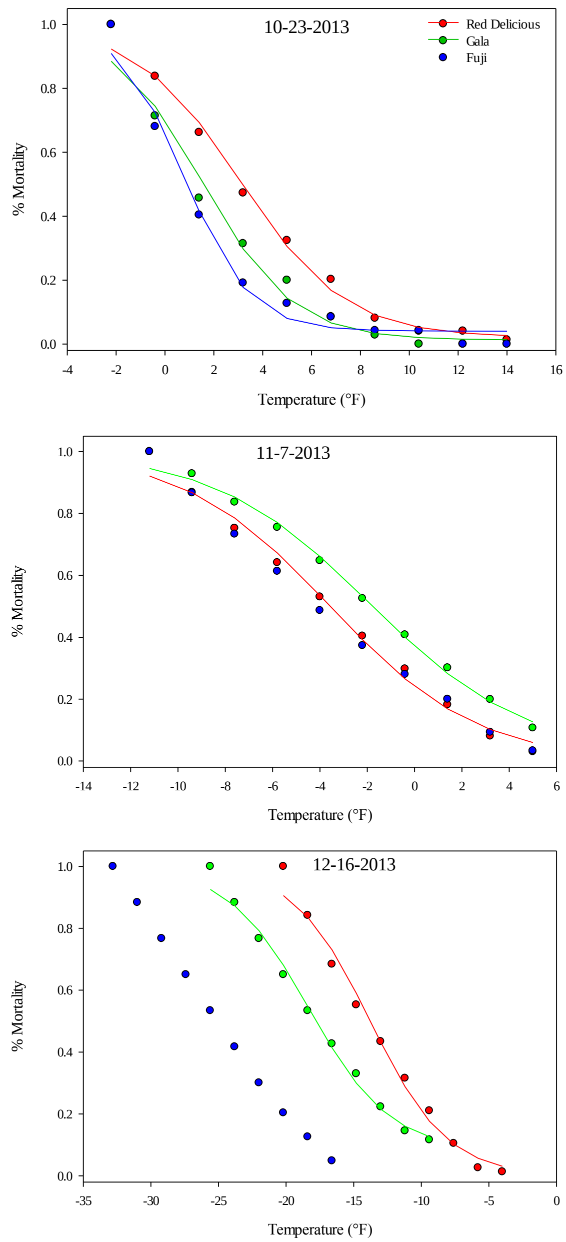

Figure 1. Probability of injured buds as function of temperature for apple cultivars at different evaluation dates.

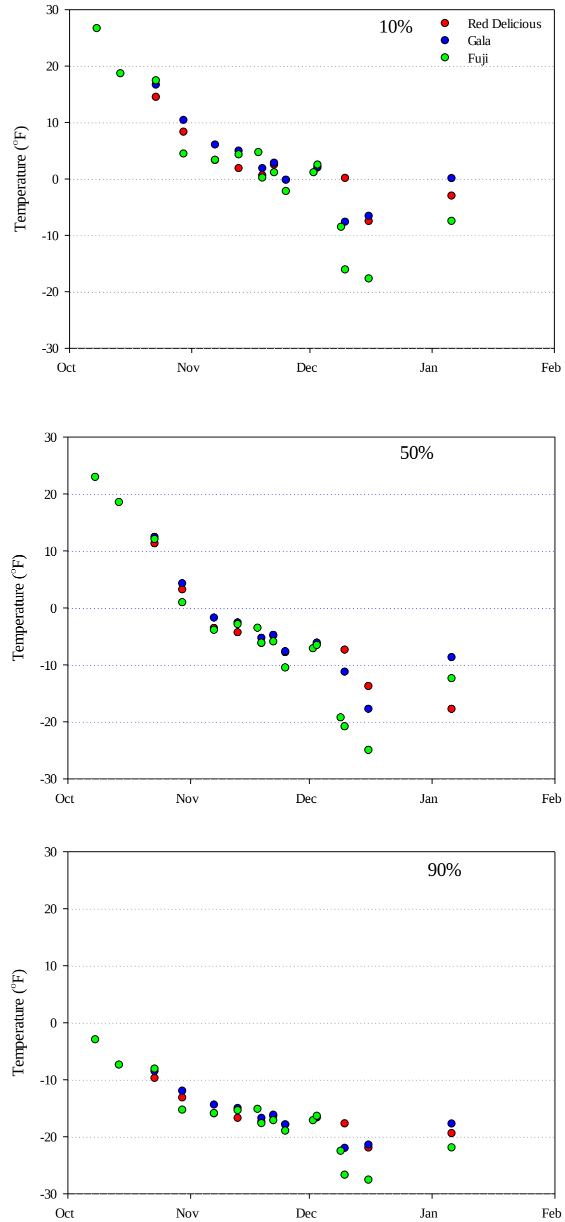

Figure 2. Seasonal pattern comparison of the LT temperatures (10, 50, and 90%) for the three apple cultivars evaluated on different dates.

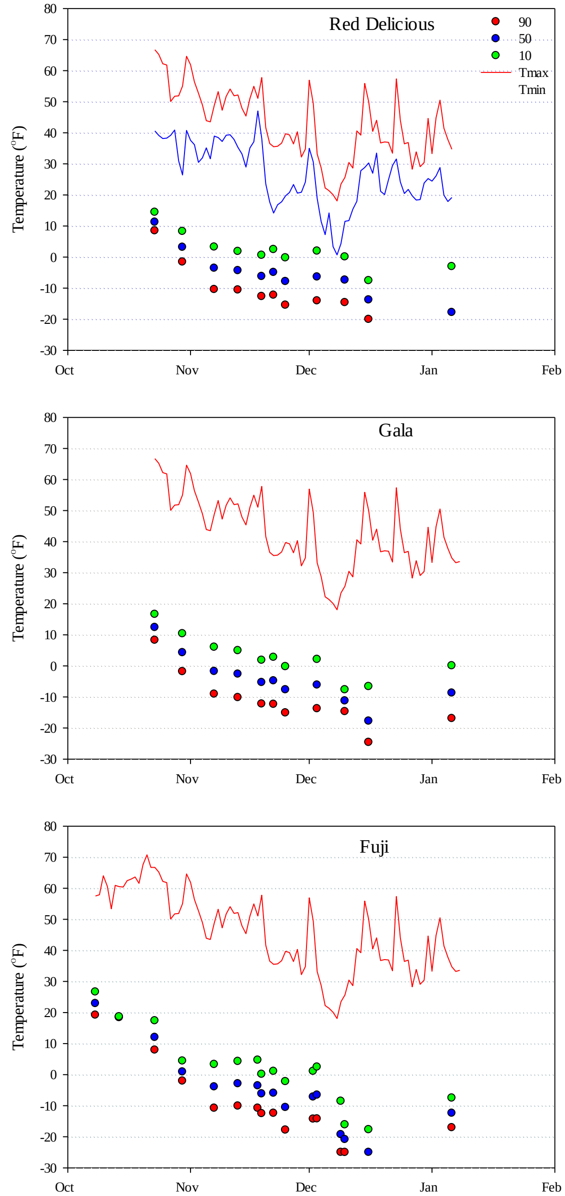

Figure 3. Seasonal air temperature (Tmax and Tmin) and LT temperatures (10, 50, and 90) of each of the apple cultivars buds evaluated on different dates

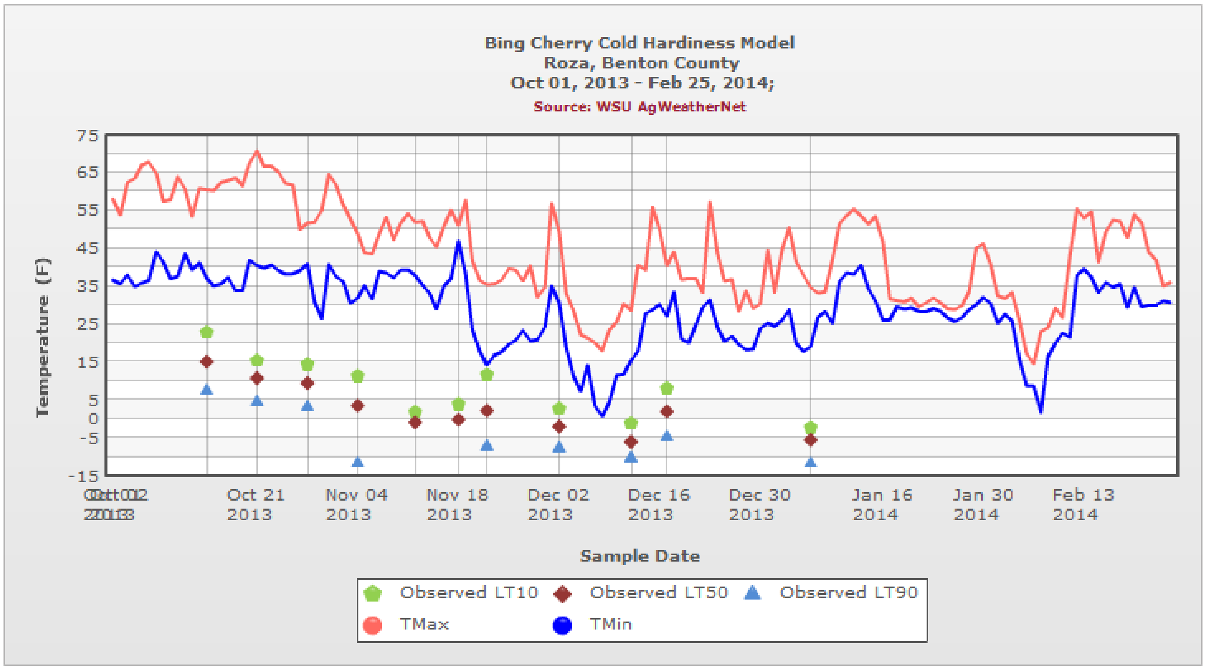

Figure 4. Prototype Cherry Cold Hardiness for 2013-2014 for Bing grown at an orchard on the WSU Roza farm as shown on the AgWeatherNet web site.