Development & Optimization of Solid-Set Canopy Delivery Systems for Resource-Efficient, Ecologically Sustainable Apple & Cherry Production

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PROJECT OVERVIEW

We are an interdisciplinary team from Michigan State University, Washington State University, and Cornell University developing and optimizing resource-efficient Solid-Set Canopy Delivery Systems (SSCDS) for multiple uses by tree fruit producers. Our long-term goal is to help growers better manage chemical inputs, improve pest and crop management, and reduce labor and fuel costs, thereby enabling tree fruit producers to remain globally competitive and environmentally responsible.

PROJECT RATIONALE

The horticultural aspects of tree fruit production have undergone a revolution over the past four decades. Tree density has increased from 25 to as many as 2500 trees per acre (ac) and tree stature and canopy volume have shrunk accordingly. Foliar input technologies have not kept up with this change and growers still rely on tractor-driven airblast technologies designed to apply inputs to massive, spherical tree volumes although modern orchards present narrow linear canopies. The SSCDS being developed by our team promise to revolutionize foliar input application. Systems consisting of fixed microsprayers distributed throughout the orchard canopy have the potential to: increase spray coverage, reduce application time, reduce on-farm use of fossil fuels, and allow growers to make foliar applications when the orchard floor is impassable by tractors.

PROJECT OBJECTIVES

1) Develop, engineer, and optimize SSCDS for orchard-scale use and materials delivery
2) Integrate and evaluate SSCDS with innovative apple and cherry pest management technologies
3) Integrate and evaluate SSCDS with innovative apple and cherry horticultural technologies
4) Determine the impact of SSCDS-based management practices on ecosystem services
5) Determine the economic impacts of optimized, integrated SSCDS on apple and cherry production system components and resultant ecosystem service values
6) Determine the sociological benefits of, and barriers to, grower adoption of optimized, integrated SSCDS into their production systems
7) Develop and deliver extension and education activities and materials to increase producer knowledge and adoption of optimized, integrated SSCDS technologies

Executive Summary

SSCDS Coverage: *Prototype SSCDS can provide adequate coverage for most foliar inputs. Consistent differences in coverage between MSU and WSU apples could be due to differences at the two sites in: microsprayer arrangement or ambient temperature and relative humidity.*

SSCDS Pest/Disease Management: *Insect and disease management was comparable between SSCDS and airblast sprayers at the MSU site but not at the WSU site, this is likely a reflection of the differences in coverage between the two sites.*

Microclimate Modification: *SSCDS used for evaporative cooling delayed bloom in cherries by 11 days and apples by 8 days at MSU sites —while using 6 fold less water than traditional evaporative cooling approaches.*

Engineering: *In WA, SSCDS was used to explore high speed cameras and leaf wetness meters to measure deposition in real time. A reservoir type SSCDS is being developed at the NY site.*

Economics: *Initial economic data suggests that life time costs of SSCDS are more expensive than airblast type applications due to higher initial establishment costs; this model does not incorporate the unique services that SSCDS can provide.*

Overview of the SSCDS Concept

Phase I SSCDS Prototypes at MSU and WSU

Our systems consist of two major components: 1) the canopy delivery system (Fig. 1) and 2) the applicator (Fig. 2). The canopy delivery system is a network of polyethylene irrigation tubing run through the orchard block in a continuous loop with an input and output line that attaches to the applicator. The applicator consists of three major components: 1) a pumping system, 2) an air compressor and 3) a tank for mixing, providing and recapturing spray material. Our Phase I prototypes utilize Jain Irrigation Modular Group 7000 series microsprinklers with violet nozzles and yellow flat spreaders and 18 psi stop drip devices. Our present system uses a four-stage charging, spraying, recovery and cleaning procedure.

Figure 1 Canopy delivery system in cherries at MSU

Our 4-stage spray procedure consists of: **1) Charging:** Material is pumped through the mainline at low pressure (<18 psi). **2) Spraying:** the return line is closed and pressure increased to >30 psi, and material applied (70-100 gal/ac in <15 s). **3) Recovery:** the return valve is re-opened, and the air compressor set at <18 psi to blow residual material back into the spray applicator. **4) Cleaning:** the return valve is closed and the air compressor run at >30 psi to clear the microsprayers.

Overview of the SSCDS Concept (continued)

During the 2nd year of the project we continued to test two different SSCDS — one at MSU and one at WSU.

MSU SSCDS Design: The MSU SSCDS were established in apple and sweet cherry orchards at the MSU Clarksville Research Center (Fig. 3). The canopy delivery system in both crops consisted of polyethylene hoses suspended from trellis wires at 8.5' (1" diameter) and 4' (3/4" diameter). Single horizontally oriented microsprayers were inserted at 6' intervals on the upper hose (Fig. 4). Twin vertically oriented microsprayers were inserted at 6' intervals into a "T" bracket on the lower line (Fig. 5). Microsprayers on the two lines were staggered providing fluid coverage every 3' in the tree canopies.

Figure 2 SSCDS applicator

Figure 3 MSU SSCDS spraying apple trees

Figure 4 Upper microsprayer

Figure 5 Lower twin microsprayer

WSU SSCDS Design: The WSU SSCDS was established in a modern high-density apple orchard at the WSU Sunrise Research Orchard located near Wenatchee, WA. Three test plots were established in 1.3 ac blocks, subdivided into three 0.03 ac treatment areas that were replicated four times. The treatments included SSCDS-D treatment, an airblast application, and an untreated control. A four-row unsprayed buffer was left between each replicate.

In 2012, the initial WSU SSCDS design (SSCDS-A) used single microsprayers, with a flat spreader, placed at four heights in the tree canopy – 10', 8', 6', and 4' above the ground —two microsprayers between each tree (Fig 6). In 2013 SSCDS-D used two microsprayers, with a one-sided swivel, located on trees at 9' and 4' above the ground —two microsprayers between each tree (Fig 6). In 2013, pressure was increased to 50 psi for all SSCDS treatments and water volume was increased to 200 gallons per ac in the season-long insect and disease plot.

Figure 6 SSCDS-A (left) and SSCDA-D (right) at WSU

SSCDS Coverage

Comparing SSCDS and Airblast Sprayer coverage

Determining Spray Coverage: Spray coverage is the most critical aspect of any foliar delivery system. In 2013, we repeated our tests of SSCDS coverage using three approaches: 1) water-sensitive cards, 2) tartrazine dye, and 3) laboratory bioassays of insect pests exposed to foliage treated with insecticides in the field.

Water-Sensitive Cards: At all project sites, trials were carried out on 4 trees in the center of each experimental plot. We used Tee Jet water-sensitive cards (1" X 1") for deposition tests (Fig. 7). Cards were placed both face-up and face-down, at low (3'), middle (5'), and high (8') levels within the canopy. Cards were scanned with a desktop scanner and analyzed using DepositScan software to determine the percentage coverage. Based on our results in year one —we did not take measurements in cherries. We will resume this activity once we have developed a Phase II SSCDS prototype. In 2013, we maintained application pressures >45 psi at both sites.

Results: Coverage was once again variable between the two states. At MSU, SSCDS coverage was fairly consistent across the canopy. However, the airblast provided higher coverage on the undersurface of leaves (Fig 8).

At WSU, there was less coverage on the undersides of apple leaves in the SSCDS plots compared with the airblast sprayer plots. Although the SSCDS-D microsprayer improved coverage on the bottom surfaces of foliage compared to 2012 results, the coverage on the top surface was reduced relative to the initial design (Fig. 8 and 13 next page). The airblast sprayer provided better coverage on both top and bottom surfaces of foliage when compared to SSCDS-D.

The consistent differences between the two sites remains puzzling. Our 2013 hypothesis was that it was the result of lower application pressures at WSU. Our 2014 hypotheses are that it is due to abiotic differences between the sites or due to the use of risers at WSU.

Figure 7 Water-sensitive card on leaf and airblast sprayer

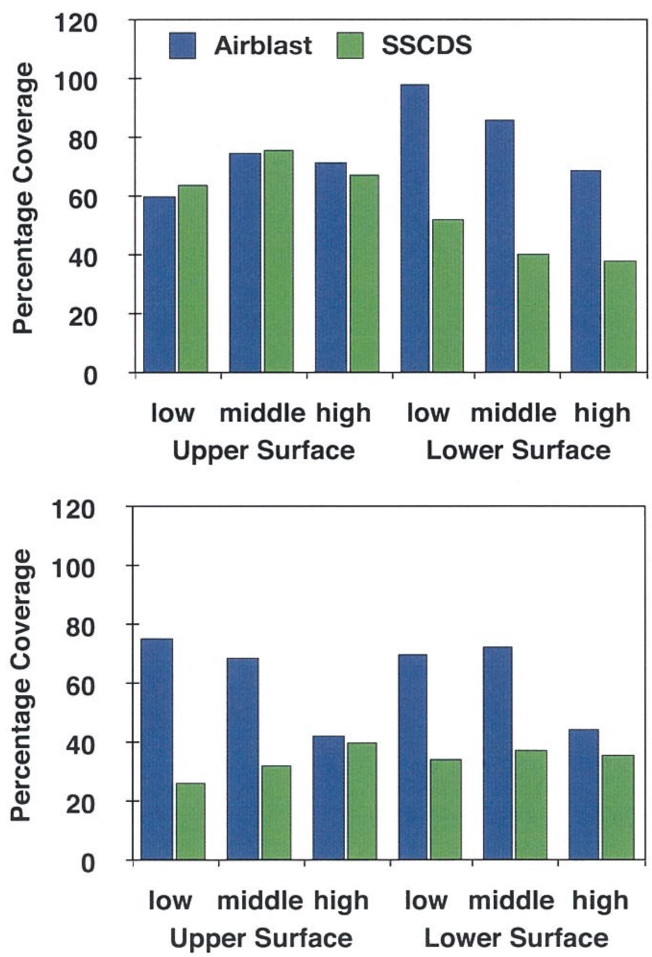

Figure 8 2012 % spray card coverage provided by SSCDS and airblast spray applications at MSU (top) and WSU (bottom)

Comparing SSCDS and Airblast Sprayer coverage (continued)

Figure 9 OBLR on leaf disk

Insect Pest Bioassay: Oblique-banded leaf roller (OBLR) larvae (Fig. 9) from WSU and MSU colonies were used to provide a biological check for coverage data. Our test insecticide, *Bacillus thuringiensis* (Bt- Dipel 2X at 100 gal per ac MSU and 200 gal per ac WSU), was applied at both sites through the SSCDS and airblast sprayer. Leaf disks (1" diameter) removed from leaves, collected from the interior canopy of each plot were placed in a petri dish with five 1-2 day-old OBLR larvae. After 4 days, mortality of the larvae was recorded.

Results: In 2013 the MSU study showed an average of: 0.47, 0.57 and 0 larvae surviving from airblast treated leaves at low, medium and high strata, respectively; 0.42, 0.16 and 0.16 larvae surviving for SSCDS treated leaves at low, medium and high strata, respectively; and 5.0, 5.0 and 5.0 larvae surviving for untreated (UTC) leaves at low, medium and high strata, respectively (Fig. 10). In contrast the WSU study showed an average of: 0.68, 0.62 and 1.00 larvae surviving from airblast treated leaves at low, medium and high strata, respectively; 0.83, 0.96 and 1.48 larvae surviving for SSCDS treated leaves at low, medium and high strata, respectively; and 3.91, 4.12 and 4.18 larvae surviving for untreated (UTC) leaves at low, medium and high strata, respectively (Fig. 10). The slightly lower survivorship of OBLR at MSU is consistent with the higher coverage measurements at that SSCDS site. The WSU data represented a great improvement over 2012 where an average of 4 out of five larvae survived on SSCDS treated leaf disks. 2012 spray card coverage and associated OBLR mortality are presented in figures 13 and 14.

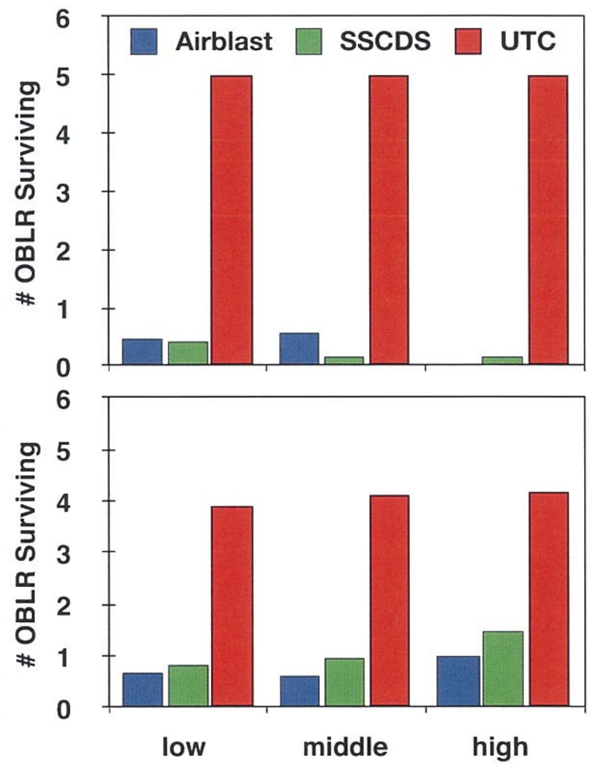

Figure 12 Surviving OBLR on leaf disk

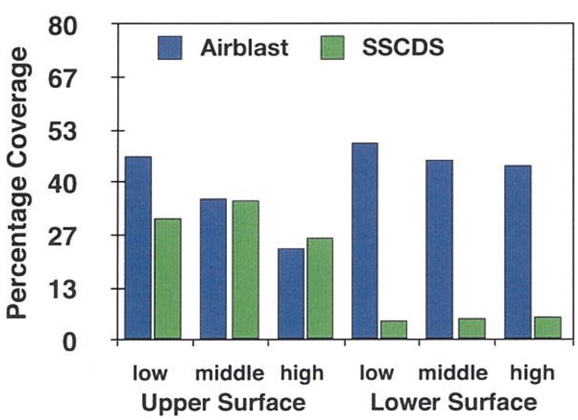

Figure 13 2012 % spray card coverage provided by SSCDS and airblast spray application at WSU

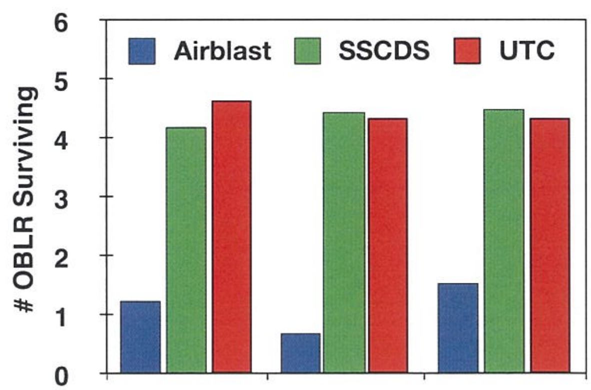

Figure 14 Average surviving OBLR in 2012 WSU leaf disk bioassay

Pest Management Efficacy

Managing insect and disease pests using SSCDS

Figure 15 Codling Moth

Season-long Insect Management: The SSCDS was directly compared with conventional airblast application of materials in the apple research plots at Clarksville, MI and the Sunrise Orchard plots near Wenatchee, WA to evaluate efficacy of insect pest management programs using the two methods of delivery. Trees in each system plot received the same treatment applications on the same day. Insect damage was evaluated once mid-season and again just prior to harvest.

Insecticide programs at both locations utilized reduced risk products (*e.g.* Assail @ 7 oz/ac, Altacor @ 3.5 oz/ac, Dipel @ 1 lb/ac, and Calypso @ 6 oz/ac). In MI, assessments were made for codling moth (Fig. 15), Oriental fruit moth, plum curculio and obliquebanded leafroller (Fig. 16). In WA, season long codling moth control and injury evaluations were made at the end of each generation.

Results: Results from both states were very promising with SSCDS plots providing insect control statistically equivalent to airblast sprayers. In MI, the level of fruit protection in the SSCDS-applied program was equivalent to that achieved using a standard airblast sprayer. An average of 12.8% of the fruit were damaged by internal feeding insects in the unmanaged check plots, while the SSCDS and airblast plots incurred 1.5% or 2.8% damage, respectively (Fig. 17). An average of 11% of the fruit were damaged by external feeding pests in the control, while the SSCDS and airblast plots incurred less than 3% damage (Fig. 17).

Figure 16 Obliquebanded leaf roller

In WA, SSCDS and airblast provided good codling moth control relative to very high pest pressure. An average of 76% of the fruit were damaged by codling moth in the unmanaged check plots, while the SSCDS and airblast plots incurred 5% and 2% damage, respectively (Fig. 18).

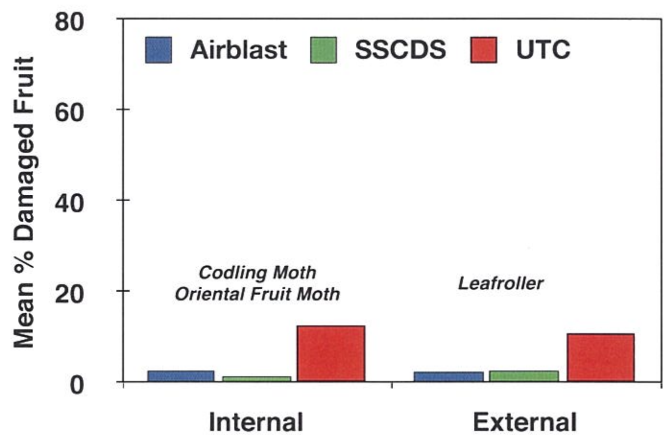

Figure 17 Mean % internally and externally damaged fruit in treated and untreated plots at MSU

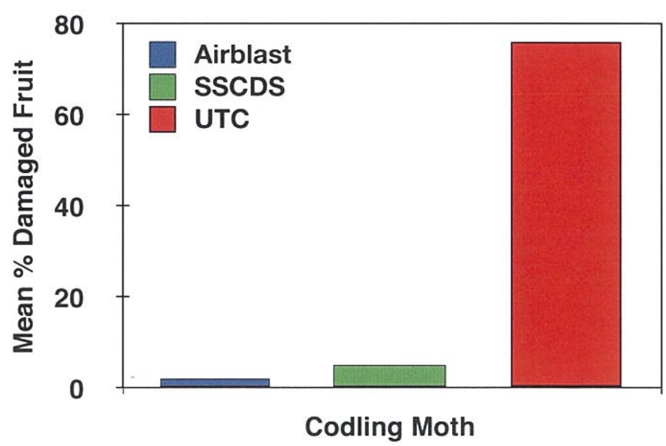

Figure 18 Mean % codling moth damaged fruit in treated and untreated plots at WSU

Managing insect and disease pests using SSCDS (continued)

Season-long Disease Management: Experiments evaluating apple scab and powdery mildew management were conducted at MSU Clarksville and the WSU Sunrise Orchard, respectively. Treatments included: an untreated control and fungicides applied via airblast sprayers or SSCDS. At MSU, a copper spray was applied at green tip followed by a series of fungicide applications made at approximately 1-week intervals for 4 weeks. The first two applications were of protectant fungicides (Manzate plus Captan tank-mix and Polyram + Captan tank mix, respectively) and the last two applications both consisted of Fontelis + Captan. The incidence of apple scab infection was rated on 24 Jul 2013. At WSU, a flutrialfol (Topguard) and sulfur mix was applied at 14-day intervals from green tip until terminal growth ceased. Foliar incidence and severity of powdery mildew were evaluated following the final spray at three heights (3', 6' and 9') within the canopy.

Results: At MSU, the SSCDS provided comparable apple scab control to the airblast treatment (Fig. 19). In contrast, at WSU, while both airblast and SSCDS applications provided better powdery mildew management than the untreated control, the SSCDS treated plots had a higher incidence of mildew than the airblast plots at all three heights (Fig. 19). These results are consistent with the differences in coverage measured at the MSU and WSU sites.

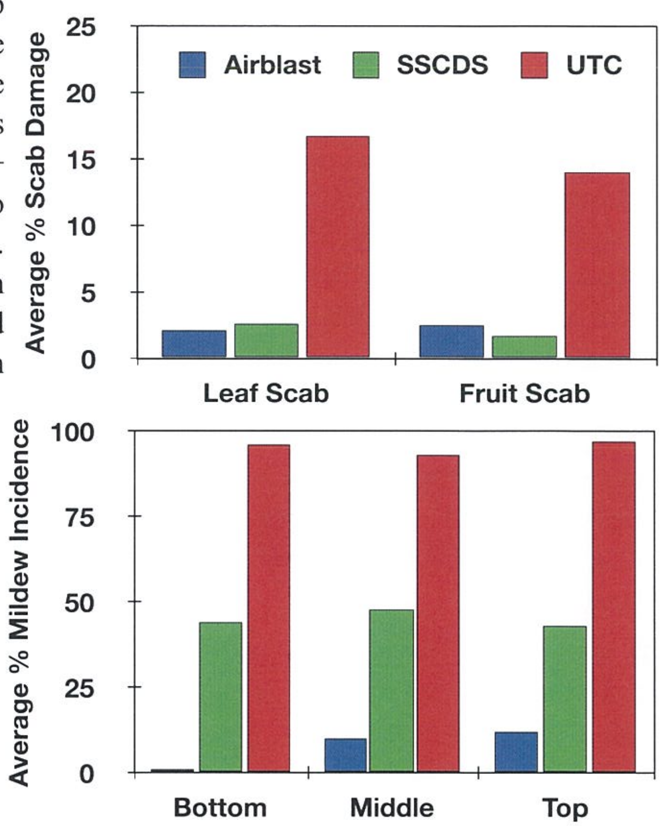

Figure 19 Average % scab damage at MSU (top) and Average % incidence of mildew at three heights at WSU (bottom) in treated and untreated plots

SSCDS and Mating Disruption

Improved delivery of micro-encapsulated pheromones

Codling Moth Mating Disruption: Pheromone was applied via: 1) SSCDS at a high rate (20 g/acre) and a low rate (1 g/acre) and 2) a low-volume ground sprayer application. We compared average male moth captures in treated and untreated plots.

Results: No moths were captured in 3 out of the 4 weeks and for 2 of the 4 weeks after treatment in the high and low SSCDS plots, respectively (Fig. 20). Ground applied pheromone application resulted in reduced codling moth captures for 2 weeks post- treatment but failed in week 3.

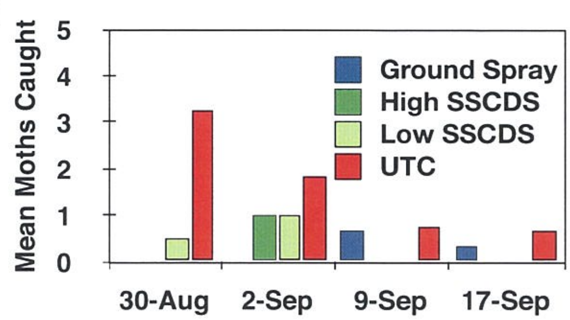

Figure 20 Mean codling moth males caught in mating disruption plots at MSU

Microclimate Management

Delaying Bloom Using SSCDS to Provide Evaporative Cooling

Evaporative Cooling in Apples and Cherries: Unprecedented warm temperatures in Spring 2012 led to the near total loss of MI apple and cherry production —trees entered bloom 7-14 days prior to the last frost events. Evaporative cooling has a long history of use to delay bloom but relies on high volume irrigation using up to 36 acre-inches of water to delay bloom by up to 14 days. The shear volume of water needed for traditional systems makes this an untenable approach for Michigan growers.

The SSCDS could provide new approach to evaporative cooling through the application of water mists during the early spring. Our hypothesis was that the many low water volume microsprayers used in our SSCDS could provide cooling at a fraction of the rates used by conventional sprinklers. We set up small scale SSCDS at two different apple and cherry sites in Michigan. Microsprayers were placed above and within the canopy and a CR 1000 data logger and controller were used to deliver misting based on ambient air temperature and humidity. We established three treatments: 1) an untreated control, 2) misting operated for ~30 days and 3) misting operated for ~20 days.

Figure 21 Apple (top) and cherry (bottom) buds, delayed buds on left.

Results: Our mist cooling system delayed bloom by 7-10 and 4-10 days in apples and sweet cherries, respectively (Fig 21 and Table 1). Furthermore our systems provided this delay using a range of 6-9 ac inches of water. This is a 4-6x reduction in water compared to previous evaporative cooling systems! Fruit maturity dates for apples and cherries were not affected by cooling. We are confident that with further refinement this system could provide 7-14 days of bloom delay with only 3-5 acre-inches of water.

Table 1: Phenological timing (& days delay) for apples and cherries treated with SSCDS mist cooling

Apple				Cherry			
Pheno-logical Stage	***Treatments***			***Pheno-logical Stage***	***Treatments***		
	Control	SSCDS off May 15	SSCDS off May 04		Control	SSCDS off May 15	SSCDS off May 07
Bud	4/20/2013	4/16/2013 (**4 d**)	4/16/2013 (**4 d**)	Green Tip	4/19/2013	4/30/2013 (**11 d**)	4/30/2013 (**11 d**)
Green Tip	4/28/2013	5/2/2013 (**4 d**)	5/2/2013 (**4 d**)	Open Cluster	4/25/2013	5/2/2013 (**7 d**)	5/2/2013 (**7 d**)
Pink	5/8/2013	5/17/2013 (**9 d**)	5/15/2013 (**7 d**)	Full Bloom	5/3/2013	5/14/2013 (**11 d**)	5/10/2013 (**7 d**)

SSCDS Engineering

Advances in Research Approaches and System Prototypes

A Novel Approach For Measuring Coverage: Water sensitive cards (WSCs) are the historical approach for measuring spray coverage. While WSCs have served as a valuable tool, they are labor intensive due to the need for extensive post processing time. They are also only capable of providing single time-point estimate of spray deposition. In 2013, project team members at WSU Prosser explored the feasibility of high speed digital photography of WSCs and leaf wetness sensors as efficient, alternative means of assessing coverage.

Figure 22 High Speed Camera

For the first approach, a high-speed camera was used to acquire images of water sensitive paper during a test application (Fig. 22). Images (Fig. 23) were collected at the rate of 10 images per second from the WSCs placed on upper-side of leaves at three target locations. Data were collected from an SSCDS installed at an experimental orchard in Prosser, WA. 2 tier and 3 tier microsprayer configurations (Fig. 24) were evaluated at 35, 55 and 75 psi using both Jain and traditional cone pattern microsprayers (Fig. 25).

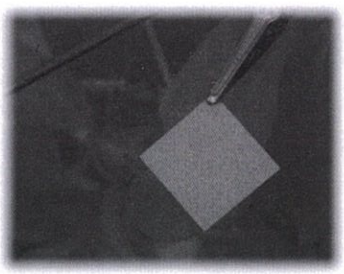

Figure 23 Image of WSC

In a separate experiment, we studied the feasibility of using Leaf Wetness Sensor (LWS) to quantify spray coverage in a small scale spray simulator. Eight microsprayers were selected for the tests and evaluated using a grid of 4 LWS and 4 WSCs. A control system was developed to spray the material for 150 ms (Fig. 23).

Results: We found that micro-sprayers located at three canopy height levels (3-tier design) at 75 psi provided coverage of 90% on upper-side and 75% on the under-side of leaves. Microsprayers with a 80° hollow cone pattern and 75 psi provided the best overall coverage. Jain microsprayers provided their best coverage at 55 psi with coverage decreased at 75 psi. Analysis of high-speed images indicated that the 3 tier system operated at 75 psi with 80° hollow cone microsprayers achieved 100% spray in <2 seconds. This is likely because the flow rate through these microsprayers is much higher than through the Jain microsprayers.

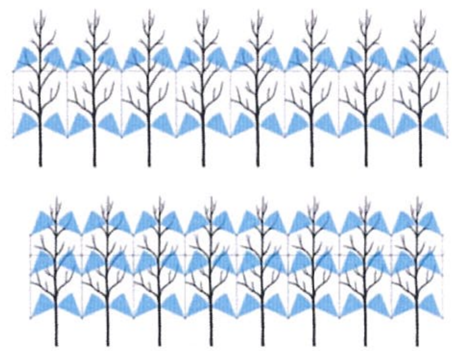

Figure 24 Schematic of 2- and 3-Tier SSCDS Test Systems

Lab experiments conducted with LWS indicated a strong correlation (r=0.85) between sensor output and percent area covered with red colored spray droplets. Furthermore, the LWS were able to hold the spray droplet without distorting the droplet spread pattern over the sensor surface. This suggests that LWS could be used as a rapid alternative tool for spray coverage measurement.

Figure 25 Hollow cone microsprayers

SSCDS Engineering (continued)

Improved Efficiency Using a Reservoir System: Team members in NY spent 2013 developing an alternative reservoir based SSCDS. This is expected to be the first step in eliminating "carrier" product in the SSCDS lines. The system was constructed in a 1.1-acre section of a super-spindle dwarf (M.9) apple orchard in its 5th leaf, in Wolcott (Wayne Co.), NY. Microsprayers are supplied by 1" diameter tubing hung at 105" height. Alternating single or double microsprayers were suspended on 8" or 28" tubing reservoirs alternating every 3' along the lateral tubing (Fig. 26). The spray operation proceeded as follows: water is pumped from a supply through an input manifold, filling all the tubing reservoirs and then compressed air at 15 psi is used to push the excess liquid through return lines and back into the tank. Finally, compressed air at 40 psi is used to open the check valves and spray out the liquid.

Figure 26 Prototype Reservoir SSCDS at NY Research Site

Results: In April 2013, the system was used to apply one of the first fungicide sprays of the season. During this spray session, some design inefficiencies were identified including keeping the check valves from opening during the initial system fill and leakage was noted from the nozzle body fittings during the spray-out phase. We have installed leak proof fittings and 30 psi check valves for 2014.

SSCDS Economics

What are the costs and benefits associated with SSCDS?

Results: SSCDS require significant up-front capital investment. Capital investment costs can vary, depending on the presence or absence of trellis training system, the capacity of that training system, and the design of the SSCDS. Initial estimates of SSCDS operating costs including system installation exceed conventional systems. Conventional air-blast applications of pesticides generally require \$36.38 per ac including equipment. Costs for operating the MSU Phase I SSCDS were estimated at \$60.88 per acre. We expect commercialization is conservatively expected to reduce SSCDS costs by 20% or more yielding an expected cost of \$48.70 per acre. While more expensive to operate, it is important to note that SSCDS may provide additional value to growers in the form of services that airblast sprayers cannot provide. These include: protection from frosts or sunburn, potential irrigation applications as well as the ability to more rapidly apply inputs under adverse ground conditions. The next step in economic evaluation will depend on collecting data on the relative value of these services.

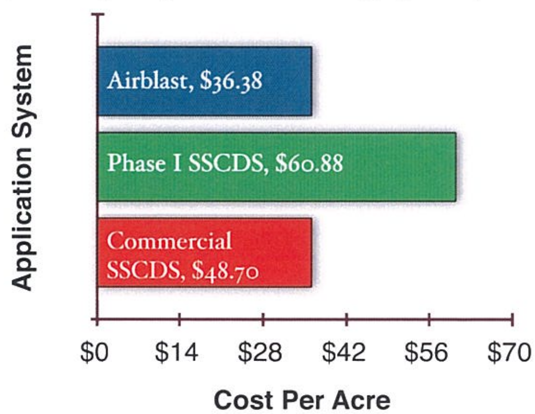

Figure 26 Comparative costs per ac for airblast, phase I SSCDS and projected Commercialized SSCDS

Next Steps

Where do we go from here?

The first two years of our project produced Phase I prototype SSCDS for both apples and cherries. Our first efforts produced a system capable of not only matching airblast sprayer performance but also capable of providing valuable microclimate modification services. Project activities will continue at the MI and NY sites through August of 2014.

SSCDS Engineering/Coverage: *The NY team members will evaluate and refine the reservoir SSCDS for a full field season. In MI, project researchers will evaluate coverage provided by microsprayers directly plugged into the SSCDS lines (i.e. MSU), microsprayers mounted to 1/4" tubing allowing them to be repositioned (i.e. WSU) and microsprayers attached to reservoirs (i.e. NY).*

SSCDS Pest/Disease Management: *Season long pest management evaluations will take place at the MI and NY sites.*

Fruit Production Management: *The MI team members will continue to evaluate the use of SSCDS as a means evaporative cooling to delay bloom.*

Economics: *The partial budget analysis will be expanded to include novel microclimate modification aspects of the SSCDS.*

Extension: *We will continue to report our progress to our stakeholders via the webpage, presentations, field days and a summary newsletter.*

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Project GREEEN

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