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 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 SSCD systems 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 Engineering/Coverage: *Prototype SSCDS are capable of providing adequate coverage for most foliar inputs. The consistent differences in coverage measures at MSU and WSU apple sites is likely due to differences in application pressure. The MSU system used application pressures in excess of 40 psi while the WSU system was limited to 30 psi.*

SSCDS Pest/Disease Management: *Codling moth management was acceptable using the SSCDS system, but not quite as good as with the airblast sprayer. Mildew incidence and severity was reduced in SSCDS and airblast plots, but airblast provided better suppression.*

Fruit Production Management: *SSCDS provided comparable sunburn protection, but less complete post bloom thinning compared with airblast applications.*

Ecosystem Services: *Beneficial mite populations were higher and pest mite populations lower in SSCDS compared with airblast treated plots.*

Grower Perspectives: *Growers in all three project states are enthusiastic about the technology and are adopting high-density planting styles. System cost, required knowledge, maintenance, and flexibility were identified as key issues.*

Engineering a Prototype SSCDS

Determining pressure differentials and time delays for different materials

WSU SSCDS Engineering: Two 237’ long SSCDS were installed at the WSU Prosser site to determine how piping material impacts flow rate, pressure loss and time delays in micro-sprayer activation. The SSCDS were constructed from 1” PVC or 1” flexible polyethylene (PE) hose. Microsprayers were positioned at 3’ intervals and placed on 3’ long drop downs (Fig. 1). Eleven manual shutoff ball valves were installed at 46’ intervals to change the length over which spray liquid was delivered. The spraying system was run for 30 s and pressure and system flow data recorded.

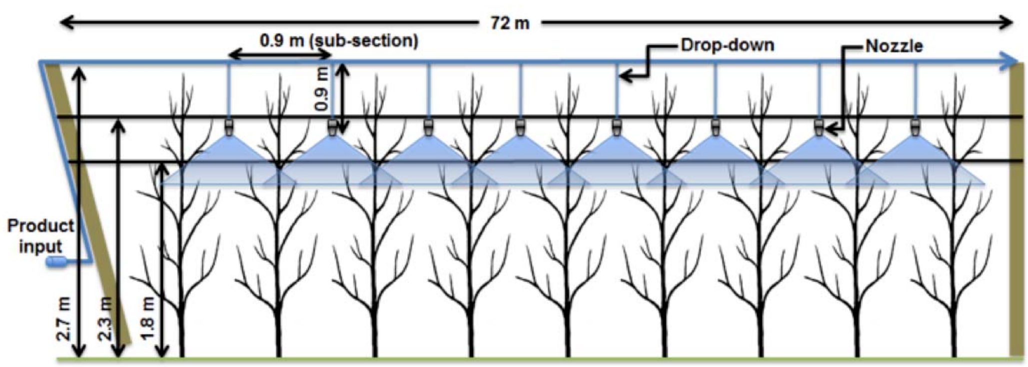


Figure 1 WSU Prosser engineering SSCDS design schematic

Results: The pressure differential between the first and the last nozzle was within 5 psi for 295’ and 243’ spray sections for PVC and PE, respectively. Time to develop stable target pressure at the first nozzle location occurred in less than 1 s for PVC hose while this time varied from 0.6 to 11.6 s for PE hose. These data suggest that PVC is a superior material for SSCDS plumbing; however, due to ease of installation and microsprayer availability, we opted to utilize PE materials in our initial test orchards. Data were used to develop a MATLAB model estimating system performance using additional materials.

Initial SSCDS Design

Prototypes installed by Washington State University and Michigan State University for Apple and Cherry Orchards

Prototype Solid-Set Canopy Delivery Systems (SSCDS) at all project sites followed design principles conceptualized by John Nye of Trickl-eez Irrigation and based upon work conducted by Art Agnello and Andrew Landers of Cornell University. Our systems consist of two major components: 1) the canopy delivery system (Fig. 2) and 2) the applicator (Fig. 3 and 4). 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 for the canopy delivery system.

The canopy delivery system portion of the SSCDS presented us with most of our initial engineering problems. The first of these was the selection of suitable microsprayers and the second was a means to deliver material **at each microsprayer** with limited time lag along the length of the SSCDS lines.

Figure 3 SSCDS applicator

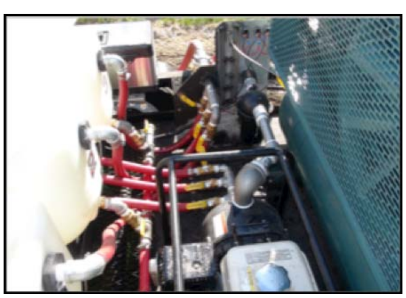


Figure 4 Applicator rig valves

Evaluation of commercially available and easily adaptable irrigation micro-emitters led us to Jain Irrigation Modular Group 7000 series microsprinklers with violet nozzle and yellow flat spreader as a good starting microsprayer. The second problem was trickier and involved the development of a four-stage charging, spraying, recovery and cleaning procedure and the addition of Jain 18 psi stop-drip devices to our microsprayers.

Figure 2 Canopy delivery system in cherries at MSU

Our four-stage spray procedure consists of the following steps: **1) Charging:** Spray material is pre-mixed in the spray applicator and then pumped through the mainline at low pressure (less than 18 psi). **2) Spraying:** the return line is closed and pressure increased to greater than 30 psi allowing the check valves to open and material to exit through the microsprayers for the time needed to apply 70-100 gal per ac (less than 15 s). **3) Recovery:** the return valve is re-opened, and the air compressor set at less than 18 psi to blow any fluid remaining in the mainline back into the spray applicator. **4) Cleaning:** the return valve is closed and the air compressor set to higher pressure (greater than 30 psi) to clear any remaining spray material out of the microsprayers.

MSU SSCDS Design: The MSU SSCDS were established in apple and sweet cherry orchards at the MSU Clarksville Research Center (Fig. 5). The apple planting was split into two sections, the first consisting of four 0.15 ac replicates of five-row SSCDS plots, airblast plots, and untreated controls, the second consisting of a similar arrangement with 0.08 ac experimental plots. The apple planting was trained to a super slender spindle system. Two buffer rows were maintained between each experimental plot. Cherry plots consisted of 18 contiguous rows with trees trained to Tall Spindle Axe (TSA), Super Slender Axe (SSA), Kym Green Bush (KGB), and Upright Fruiting Offshoots (UFO).

Figure 6 Upper microsprayer

Figure 7 Lower twin microsprayer

The canopy delivery system in both crops consisted of polyethylene hoses suspended from trellis wires at 8.5 ft (1” diameter) and 4 ft (3/4” diameter). Single horizontally oriented microsprayers were inserted at 6’ intervals on the upper hose (Fig. 6). Twin vertically oriented microsprayers were inserted at 6’ intervals into a “T” bracket on the lower line (Fig. 7). Microsprayers on the two lines were staggered providing fluid coverage every 3 ft in the tree canopies.

Figure 5 MSU SSCDS system spraying apple trees

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 an SSCDS-A or SSCDS-B, an airblast application, and an untreated control. A four-row unsprayed buffer was left between each replicate.

Both the SSCDS-A and SSCDS-B treatments had the same number of microsprayers. The SSCDS-A system had single horizontally oriented microsprayers at 3’ linear intervals while the SSCDS-B treatment had two, vertically oriented microsprayers mounted on a “T” bracket with 6’ linear intervals between microsprayers (Fig. 8). Both systems were tested for coverage and deposition, but only the SSCDS-A system was tested during season-long pest and fruit management trials.

Figure 8 SSCDS-A (left) and SSCDA-B (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. We tested 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. Cards allowed us to characterize the coverage provided on both the top and bottom of leaves. Dye tests provided a robust test of leaf deposition. Bioassays provided data on how coverage translates into insect pest management.

Water-Sensitive Cards: Deposition tests at MSU utilized 1” × 3” water-sensitive cards. Cards were placed both face-up and face-down, at low (3’), middle (5’), and high (8’) levels within the canopy. For apples, comparisons were made between SSCDS and airblast sprayer applications. In cherries, comparisons were made among the SSA, TSA, UFO, and KGB canopy architectures.

WSU trials were carried out on 4 trees in the center of each experimental plot. Cards were placed at the top west, top east, mid west, mid east, bottom west, and bottom east of the trees. Tee Jet water-sensitive cards (1” X 1” squares) were attached to the top and bottom of one leaf in each zone using a stapler (Fig. 9). Cards were returned to the laboratory, scanned, and coverage calculated following application.

Results: Coverage was variable between the two states with MSU coverage much higher in the SSCDS apple foliage versus the airblast apple foliage. This difference was consistent for both top and bottom surfaces at all three tested heights (Fig. 10). Cherry coverage was poor for all four training systems with higher coverage on the upper surfaces at the tops of the canopies.

In contrast, in WSU plots, there was less coverage on the undersides of apple leaves in the SSCDS-A and SSCDS-B plots compared with the airblast sprayer plots. Spray deposits on water-sensitive cards revealed that the SSCDS-A had better coverage on the tops of leaves than the SSCDS-B design (Fig. 10).

Figure 9 Water-sensitive card on leaf and airblast sprayer

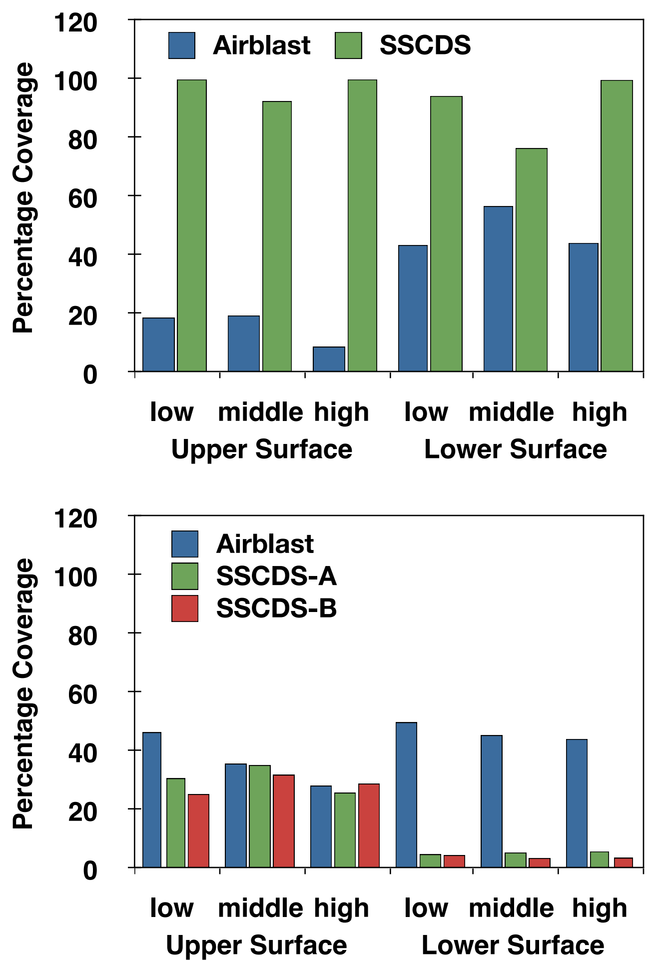


Figure 10 Percentage coverage on apple leaves in canopy levels provided by SSCDS and airblast spray application at MSU (top) and WSU (bottom)

Comparing SSCDS and Airblast Sprayer coverage (continued)

Tracer Dye: Distribution of spray material within the tree canopy was evaluated using the food-safe tracer dye, Tartrazine. The dye was pre-mixed in tanks of the SSCDS spray application equipment and applied through the SSCDS-A and -B designs, and an airblast sprayer. After application, leaves from treated trees were collected, bagged, and returned to the lab for analysis. At the MSU site, 5 leaves from low, middle, and high strata from 4 trees per plot were collected. At WSU, 5 leaves from each zone (top west, top east, mid west, mid east, bottom west, and bottom east) from 4 trees were collected from each plot. The amount of dye washed from leaves in each sample (Fig. 11) was quantified using a multi-plate reader. Average leaf area was calculated for each zone by picking 20 leaves per zone and scanning them with a LI-COR leaf area meter (LI-3100C)). Dye concentrations were paired with leaf areas and results recorded as PPM of day/cm^2 leaf area.

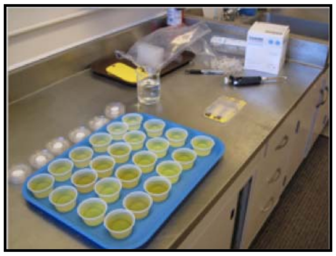
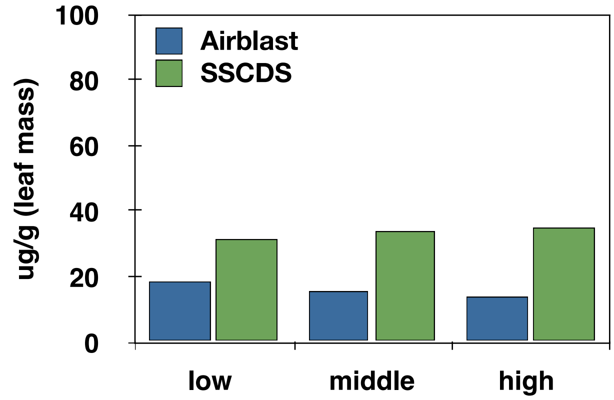


Figure 11 Dye samples

Results: Deposition results were comparable with coverage results. MSU results showed much higher deposition on SSCDS compared with airblast treated leaves. WSU showed that the SSCDS-A design had the highest deposition of the three application methods tested; however, there was not a statistically significant difference between the three application methods (Fig. 12).



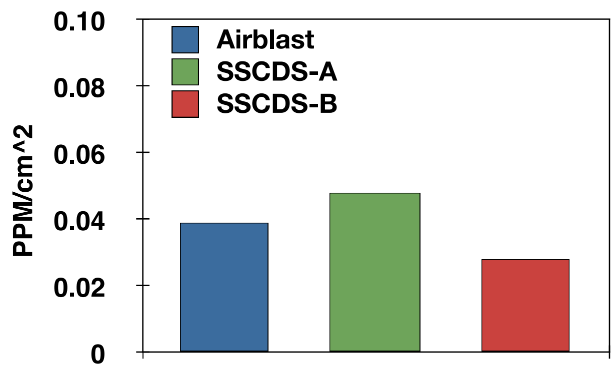


Figure 12 Dye deposition on leaves in SSCDS and airblast plots at MSU (top) and WSU (bottom)

Figure 13 Oblique-banded leaf roller

Insect Pest Bioassay: Oblique-banded leaf roller (OBLR) larvae (Fig. 13) 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), 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: Results from the two sites were largely consistent with previous coverage measurements. The WSU study showed 27% and 62% average corrected mortality of larvae from SSCDS-A and airblast application, respectively. In contrast, 100% of all larvae in both treatments died in both the MSU SSCDS and airblast treatments.

Pest Management Efficacy

Managing insect and disease pests using SSCDS

Figure 14 Codling Moth

Season-long Insect Management: Season-long management was not possible at the MSU site due to state-wide, frost induced tree fruit crop failure. Thus, all season long data was collected at WSU.

At WSU the SSCDS-A was compared with airblast applications of pesticides for season-long codling moth (CM) control (Fig. 14). Pesticide treatments began at petal fall and continued through the second CM generation. During the first generation, plots were treated with novaluron (Rimon) at 287 CM degree days (DD), and chlorantraniliprole (Altacor) at 550 and 834 DD. During the second generation, plots were treated with spinetoram (Delegate) at 1448, 1840, and 2222 DD. Damage evaluations consisting of 100 fruit per experimental plot were made at the end of each generation. In addition to fruit injury evaluations, cardboard bands were used after the first CM generation to assess the number of surviving larvae in each treatment. Bands were first placed in the orchard on July 9 (1234 DD) and then collected and replaced weekly for four consecutive weeks. The numbers of live larvae collected in the bands were counted each week and moth emergence was followed for 5 weeks from each collection date.

Results: Both the airblast and SSCDS-A methods of pesticide delivery provided better suppression of CM than the untreated control in the season-long evaluation (Fig. 15 and 16). Under very high pressure from CM, the airblast applications provided superior numerical suppression of CM compared with SSCDS-A, but these differences were not statistically different (Fig. 15 and 16). The number of live larvae recaptured after the first generation also revealed that there was not a significant difference between SSCDS-A and airblast treatments (Fig. 15 and 16). These results suggest coverage of fruit with SSCDS-A may be sufficient to control CM in commercial orchards where populations are typically much lower than observed in the small plots used in our study.

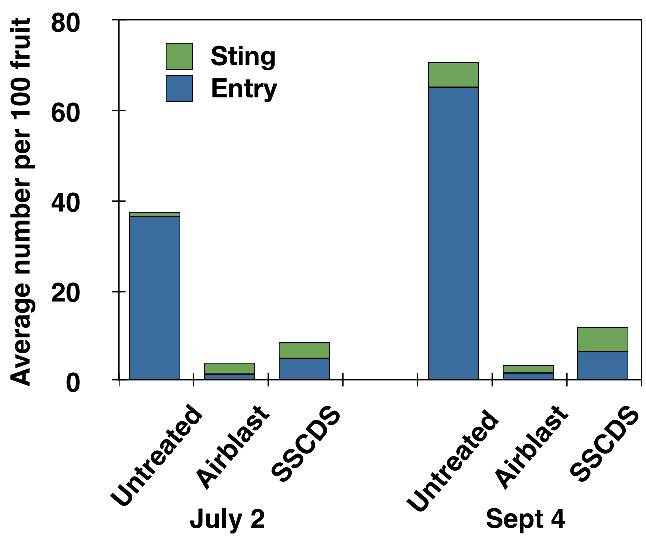


Figure 15 Mean number of codling moth stings and entries on fruit in treated and untreated plots at WSU

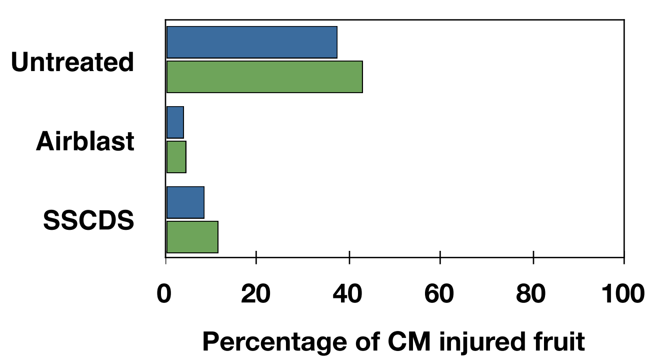


Figure 16 Mean percentage of codling moth injured fruit at WSU

Managing insect and disease pests using SSCDS (continued)

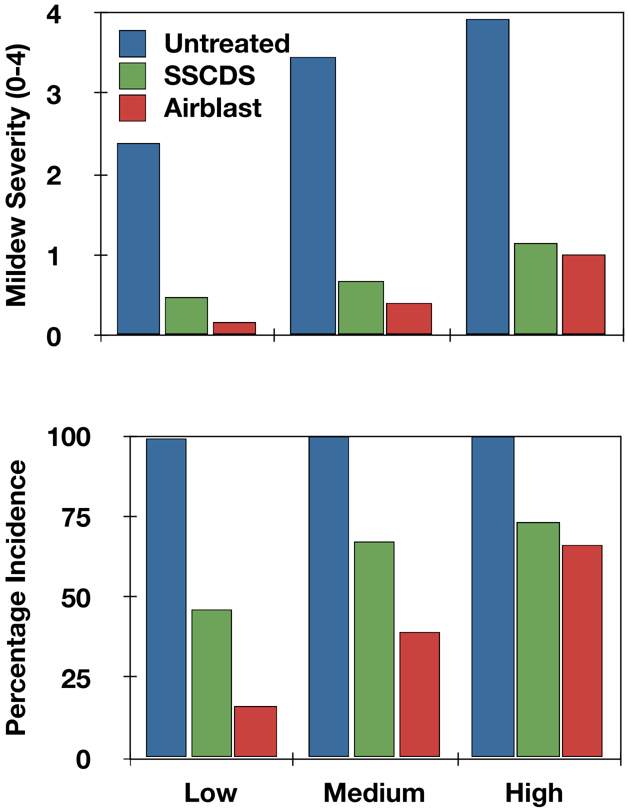


Figure 18 Severity of mildew (top) and percentage mildew incidence in canopy levels (bottom) in treated and untreated plots

Season-long Powdery Mildew Management: This experiment was conducted on Jonagold apple trees at the WSU Sunrise Orchard. Three treatments (each with 4 reps) were used to determine the relative effectiveness of SSCDS for apple powdery mildew management. A traditional airblast application was used to provide a field standard benchmark to compare with the SSCDS application. The same rate of a flutrialfol (Topguard) and sulfur mix was applied to both treatments (12 fluid oz per ac and 10 lb per ac, respectively) at 14-day intervals beginning at green tip until terminal growth ceased. Foliar incidence and severity of powdery mildew were evaluated following each spray (Fig. 17). Two *in situ* evaluations and one leaf collection/evaluation were performed at three levels in the canopy: 1 m, 2 m, and 3 m from the ground (low, medium, and high).

Figure 17 Mildew severity from 0 (left) to 4 (right). Photo by A. B. Groves

Results: Both airblast and SSCDS applications provided better powdery mildew management than the untreated control at all canopy heights (Fig. 18). Disease incidence was significantly lower in low and medium foliage heights treated with an airblast sprayer compared with SSCDS treated foliage.

SSCDS and Ecosystem Services

Preserving non-target beneficial arthropods

Season-long comparisons of beneficial and pest mite populations in the MSU SSCDS, airblast sprayer, and untreated control plots were made to investigate each system's overall ecological health as judged by beneficial mite abundance and diversity. Plots at the MSU site received regular applications of pyrethroids to manage leafhopper and aphid pests throughout the growing season. Mites collected from leaf samples were used as indicators of pesticide effects on non-target beneficial species.

We found that beneficial predator mites were most abundant in unsprayed orchard plots, followed by SSCDS plots, and were least abundant in the airblast delivery plots. Furthermore, more pest mites survived in airblast plots where predator mite populations were reduced presumably because of better pesticide coverage on the undersides of leaves.

Fruit Production Management

Managing apple sunburn and thinning using SSCDS for evaporative cooling and application of plant growth regulators

Sunburn Management: Researchers at WSU compared sunburn protection provided by SSCDS-A and a standard evaporative cooling system on Gala, Fuji, and Golden Delicious cultivars. On days with max temperatures predicted to exceed 90°F, the systems completed 12 applications of the same amount of water per area between 1200 and 1800h. The SSCDS-A ran for 35 s and standard EC system ran for 15 min per cycle. On July 2, initial sunburn readings based on the Schrader/McFerson sunburn scale (Fig. 19) were taken on fruit in four levels of six trees per plot, where level 1 was the highest and level 4 the lowest part of the tree canopy. These readings were followed by monthly readings through harvest.

Results: No sunburn at any tree level in all varieties was found on the initial sample date (Fig. 20, Gala and Golden Delicious not shown). At harvest, all cultivars had developed significant amounts of sunburn and/or blush, at all tree levels (Fig. 20). Earlier activation of the cooling systems should result in clearer data next year.

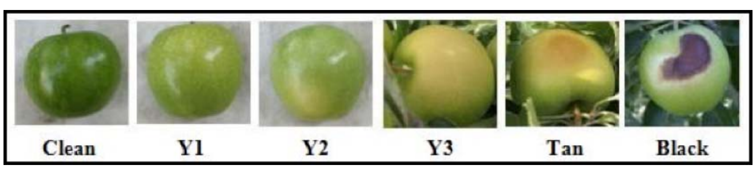


Figure 19 Schrader/McFerson sunburn scale

Chemical Thinning: Post-bloom thinning applications using SSCDS-A or airblast sprayer at two timings: 5 mm fruitlet size (May 7) and 10 mm fruitlet size (May 14) were compared. On both dates, 128 oz MaxCel (6-benzyladenine) + 5 oz Fruitone L (naphthaleneacetic acid) mixed into 100 gal per ac of water were applied.

Results: Airblast applications resulted in slightly better thinning effects in Gala and significantly more thinning in Fuji than did the SSCDS-A treatment. Both treatments achieved greater thinning effects relative to the untreated control in both cultivars.

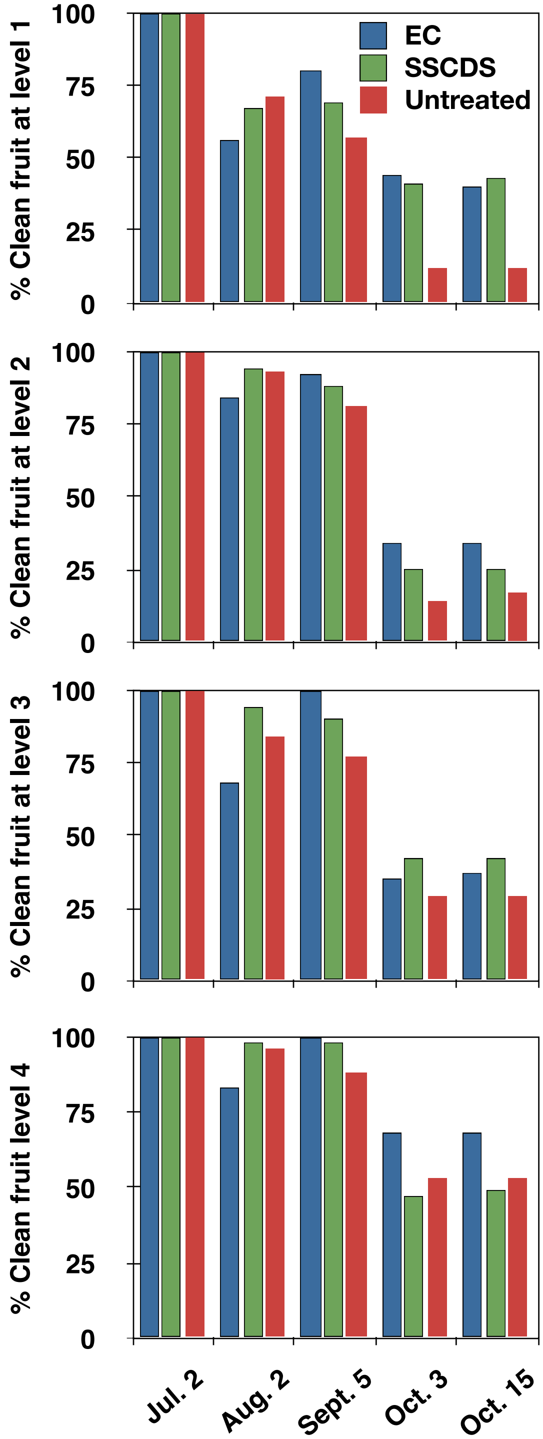


Figure 20 Percentage fruit without sunburn in treated and untreated plots

Grower Perspectives

Grower Adoption of SSCDS Technology

Sociological Research Overview: Understanding grower perspectives of the benefits and barriers of adopting SSCDS is a critical component for planning and executing effective project extension and education activities. In 2012, Jean Haley (Haley Consulting Services, LLC) conducted a mail-back survey of apple growers in Michigan and Washington. Growers provided baselines of current commercial apple and cherry orchard management practices and initial barriers of SSCDS adoption. In addition to the survey, Jean conducted focus groups with growers in NY, MI, and WA to discuss concerns about implementing SSCDS (Fig. 21).

Figure 21 SSCDS focus group

Survey and Focus Group Findings: A total of 2,306 surveys were mailed to MI and WA apple growers with a response rate of 22%. The 496 growers who returned surveys represent 40% of the apple acreage (77,500 total acres) in MI and WA. Michigan respondents managed between one and 1,000 acres, with an average of 32 acres. Washington respondents managed between one and 6,500 acres of apple orchards, with the average of 222 acres. Growers in MI and WA are more likely to implement the SSCDS system technology if they already have a trellis system in place.

Focus groups in NY, MI, and WA revealed four key areas of concern: 1) the economics of establishing and maintaining the system, 2) the complicated physical maintenance of the system, 3) the adaptability of the system to different sized blocks and trees, 4) the level of knowledge and training needed for managers and field workers to properly operate and maintain the system.

Extension and Education

Field days, webpage updates, grower meetings and conferences

Initial extension efforts by the Project Team have focused on field days at the MI and WA field sites (Fig. 22). The Cornell team is working in conjunction with a commercial grower in New York to develop a grower field site that will serve as a proving ground and grower demonstration site. Team members from all three states have also made numerous presentations at regional and national grower and scientific conferences — e.g. the Great Lakes Fruit, Vegetable, and Farm Market Expo and the Washington State Horticultural Association Annual Meeting and Trade Show. Poster presentations and presentation abstracts can be downloaded from the project website: www.canopydelivery.msu.edu. Future extension activities include additional field days, webinars and printed bulletins.

Figure 22 Growers learning about SSCDS technology at a field day

Next Steps

Where do we go from here?

SSCDS Engineering/Coverage: *Optimization of SSCDS design and coverage will continue in 2013. We will evaluate higher pressures that are expected to generate smaller droplet sizes, improve residue management and recapture of spray materials, and investigate the impact of windspeed and tree architecture on coverage.*

SSCDS Pest/Disease Management: *Improved coverage is expected to lead to better pest/disease management. We will continue to evaluate pest and disease management using SSCDS applications of insecticides, biopesticides, and fungicides in apple and cherry orchards. We are also working with industry and regulatory groups on input label compatibility with SSCDS application.*

Fruit Production Management: *Delivery of growth regulators will be evaluated in 2013. We will also explore the use of SSCDS for evaporative cooling to delay bloom and prevent sunburn.*

Ecosystem Services: *In 2013 we will monitor the abundance and diversity of above-ground pest and beneficial arthropod species. This information will prepare us for 2014 plans to investigate below-ground beneficial arthropods and possible effects on pollinators.*

Grower Perspectives: *We will continue to provide growers with up-to-date information regarding SSCDS performance and technologies. Grower feedback will be received from participants of field days, round table discussions, surveys, and personal communications at grower and extension meetings.*

Acknowledgements

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