Development of Solid Set Delivery Systems for High Density Apples

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Apple orchards have been transforming from low density, freestanding tree systems to high-density, trellised tree systems. This has been accomplished by the careful engineering of tree canopy architectures from individual tall spheres into continuous narrow “fruiming walls” (Robinson, 2007). These intensive systems have greatly increased production efficiency and early returns on investment. However, the delivery of agricultural chemicals—pesticides, foliar nutrients and plant growth regulators—to these systems still relies on tractor-pulled airblast sprayers designed for large, broad canopies. Meanwhile, growers have been faced with an unprecedented range of challenges including: consumer demand for reduced pesticide inputs, increasing urban/rural overlaps, the promulgation of Maximum Residue Limits (MRLs) for international markets, loss of traditional pesticides to national regulations, rapid development of pest resistance, an influx of invasive insect pests, an increasingly volatile labor market and a less predictable climate. Growers’ responses to these issues have included the adoption of expensive technologies (e.g. insect netting for spotted wing drosophila $10,000+ per acre, wind machines $4,000+ per acre) and the development of mechanical replacements for human labor (e.g. picking platforms and harvest assist machines). Solid Set Canopy Delivery Systems (SSCDS) provide a single solution for many of the new problems growers are facing while replacing costs associated with tractor driven sprayers.

Solid Set Canopy Delivery Systems are a logical evolution of agricultural chemical delivery for modern, high-density orchards. Solid Set Canopy Delivery Systems consist of a network of microsprayers positioned in the tree canopy/trellis and connected to a pumping/mixing station. This approach was first demonstrated by Agnello and Landers (2006) in a small proof of concept study in NY. Application of inputs from a fixed system versus a tractor-based system provides many potential advantages to growers utilizing high-density apple systems. Targeted applications via the SSCDS could virtually eliminate applicator exposure problems common to tractor based sprayers, while increasing the ability to apply sprays during critical weather periods, including when the ground is too wet for heavy equipment. Our research team is convinced that SSCDS will make frequent applications at low rates possible for modern agricultural chemicals, including foliar nutrients, bio-pesticides, and reduced-risk pesticides, to improve efficacy of “soft impact” IPM programs. Commercialized SSCDS will also require less skilled labor to operate compared to tractor based sprayers due to a 4-10 fold decreased application time and because the systems will not rely on heavy machinery.

In 2011 we initiated a major exploration of SSCDS in a multiple year USDA SCRI funded project that took place in NY, WA and MI. The experiences shared in this article come from the project team based at Michigan State University (MSU) and cover some of our findings in the first three years of research and development of this revolutionary approach towards apple pest management.

Project Goals

The major initial project goals for our initial SSCDS project centered on the initial engineering of the system and the collection of proof of concept data. These included:
1. Develop, engineer, and optimize SSCDS for orchard-scale use and materials delivery
2. Evaluate coverage provided by SSCDS compared to standard airblast applications
3. Evaluate pest management provided by SSCDS
4. Determine relative costs of SSCDS vs. current airblast sprayers

System Design

The Prototype Solid Set Canopy Delivery Systems developed at Michigan State University, Cornell University and Washington State University consist of two major components: 1) the canopy delivery system (Figure 1) and 2) the applicator (Figure 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 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.

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.

The SSCDS at MSU were established in an apple orchard at the MSU Clarksville Research Center (Figure 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 (Figure 4). Twin vertically oriented microsprayers were inserted at 6’ intervals into a “T” bracket on the lower line (Figure 5). Microsprayers on the two lines were staggered providing fluid coverage every 3’ in the tree canopies.

**Coverage**

Coverage evaluation is of critical importance for any new input delivery system. Simply put, without adequate coverage, pest management relying on traditional insecticides and fungicides is likely to fail. We have evaluated 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. Spray cards allow us to characterize the coverage provided on both the top and bottom of leaves. Dye tests provide a robust test of leaf deposition. Bioassays provide data on how coverage translates into insect pest management.

**Water-Sensitive Cards:** Deposition tests at MSU utilized 1” × 3” water-sensitive cards (Figure 6). Cards were placed both face-up and face-down, at low (3’), middle (5’), and high (8’) levels within the canopy. Comparisons were made between SSCDS and airblast sprayer applications using 80 gallons per acre spray volume with cards collected immediately after application. Cards were returned to the laboratory, scanned, and coverage calculated following application. Over the course of the last three years we have run numerous coverage trials utilizing cards.

Spray card coverage has been somewhat variable among trials at MSU, but the general pattern has been that SSCDS systems provide better coverage on cards facing up (upper surface) compared to cards facing down (lower surface) and tend to provide higher coverage higher in the tree rather than lower in the tree (Figure 7). In contrast, airblast sprayers tend to provide higher coverage on the lower surface of leaves and provide highest coverage lower in the trees compared to higher in the tree (Figure 7).

**Tartrazine Dye Deposition:** 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 and an airblast sprayer. After application, leaves from treated trees were collected, bagged, and returned to the lab for analysis. Five leaves from low, middle, and high strata from 4 trees per plot were collected. The amount of dye washed from leaves in each sample (Figure 8) 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/cm² leaf area. Deposition results showed much higher deposition on SSCDS treated leaves compared with airblast treated leaves (Figure 9).

**Insect Pest Bioassay:** Oblique-banded leaf roller (OBLR) larvae (Figure 10) from 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 from the two sites were largely consistent with previous coverage measurements. 100% of all larvae in both treatments died in both the MSU SSCDS and airblast treatments.

**Coverage Conclusions:** The results from our three coverage measurement evaluations strongly suggest that our prototype SSCDS provides equivalent coverage to an airblast sprayer. The spatial arrangement of coverage was variable between the two trials relative the tops and bottoms of leaves as well as distribution of coverage from the bottom to the top of the tree canopy (Figure 7), however SSCDS provided at least as much deposition as our airblast sprayer (Figure 9) as well as the ability to kill a target pest (OBLR). The next logical question was whether SSCDS could provide adequate, season long pest management.

**Pest Management Efficacy**

Season-long insect pest and disease management data were collected in 2013 and 2014 at our MSU Clarksville Research Center test site. The SSCDS was directly compared with conventional airblast application of materials in the apple research plots at Clarksville, MI in 2013 and 2014 to evaluate efficacy of insect and disease pest management programs using the two methods of delivery. Trees in each system plot received the same treatment applications on the same day.

**Insect Pest Management Efficacy:** 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). We made assessments for codling moth, Oriental fruit moth, plum curculio and obliquebanded leafroller. Damage evaluations were made in August during both years. Results from both years were consistently promising with SSCDS plots providing insect control equivalent to airblast sprayers. In 2013 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 and 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 (Figure 11). In 2014 an average of 29% of the fruit were damaged by internal feeding insects in the unmanaged check plots, while the SSCDS and airblast plots incurred 4.3% or 7.1% damage, respectively and an average of 7.8% of the fruit were damaged by external feeding pests in the control, while the SSCDS and airblast plots incurred less than .3% and .2% damage, respectively (Figure 12).
Disease Management Efficacy: Apple scab management was compared between SSCDS and airblast applicators at the MSU Clarksville Research Center in 2013 and 2014. 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 in late July or early August. The SSCDS provided comparable apple scab control to the airblast treatment in 2013 with 14% of fruit in the control and 1.7% and 2.5% of fruit in the SSCDS and Airblast treatments, respectively having visible scab lesions. (Figure 13). A similar pattern was observed in 2014 with 54% of untreated control apples, 1.6% of SSCDS apples and 5% of control apples having visible scab lesions (Figure 14).

Pest Management Conclusions: Our initial evaluation of SSCDS provide strong proof of concept supporting that this technology is capable of providing pest management services comparable to those provided by traditional airblast sprayers. One of the most striking differences we noticed in conducting these trials was the speed and quietness of SSCDS applications versus tractor based applications. Sprays delivered through SSCDS were put on in only 12 seconds of application time with two 5 hp water pumps! Our airblast applications took five to 10 minutes to apply and created a great deal more noise.

Implications and Economics

Implications: Our proof of concept data makes a strong case for further development of SSCDS technology. One of our next questions to address will be whether SSCDS could be used to make short interval reduced rate applications of pesticides to better manage coverage to meet both pest management and MRL needs. SSCDS also promise to provide growers with a unique opportunity to alter orchard microclimates through evaporative cooling.

Preliminary research conducted by Jim Flore has shown that SSCDS could provide a 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.

Our mist cooling system delayed bloom by 7-10 and 4-10 days in apples and sweet cherries, respectively (Figure 15). 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 evaporative cooling systems utilizing impact sprinklers! 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.

Economics: Solid Set Canopy Delivery Systems 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 acre including equipment. Costs for operating the MSU 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. For more information visit www.canopydelivery.msu.edu

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Literature Cited
