EFFECT OF TIME OF APPLICATION ON SPRAY COVERAGE USING SOLID SET CANOPY DELIVERY SYSTEM

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ABSTRACT

Permanent or solid set canopy delivery system (SSCDS) can be used for foliar application in tree fruit orchards. The emitters are placed along the tree rows and are very close to tree canopy. During spray application, droplets quickly get deposited on tree canopy and good coverage could be achieved. However concerns still exist regarding critical time required to achieve target coverage using SSCDS. This knowledge of selecting an appropriate application time could help growers achieve target coverage while potentially reducing chemical usage, off-canopy application and harmful environmental impacts. This study was conducted to study the effect of duration of spray application on spray coverage in super spindle apple trees in high-density orchards planting system. SSCDS was setup in a commercial orchard. Three emitters were selected for this study. Emitters were fixed in two different designs, one with to emitters mounted side by side at two (2x2 design) and second with s ame configuration emitters (2x3 design) mounted at three canopy height levels located in the middle of each tree along the tree rows. Spray system was calibrated and set to spray at three operating pressures of 35, 55 and 75 psi. Three locations were selected to locate Water sensitive cards to observe and record spray coverage development over time. To record coverage over time, a high-speed camera with 75 mm focusable lens. The camera was set to capture 10 frames per second with 200 ms and record images using HiSpec Control software. Images were then analyzed using ImageJ software to calculate percent coverage and plot percent coverage over time. The results indicated that spray drop deposited in less than 2 s to provide 100% spray coverage using 2x3 design at 75 psi. Therefore, for lower spray coverage lesser application times can be used. It was also interesting to note that any spray application greater than this time would result in chemical being loss to off-canopy target. Overall, a short spray time of less than 2 s can be selected to achieve desired coverage and reduce application cost.

Keywords: Precision Agriculture, Spraying, high speed imaging, liquid application

INTRODUCTION

Traditionally, spray application is accomplished by air-blast sprayers operation at around 1400 kPa to provide canopy coverage from 23% (Cross et al. 2003) to 75% (Landers, 2008) depending on canopy density and training system. Often, spray parameters are not adjusted to mach modern canopies like fruit wall apple architecture (Karkee and Zhang, 2012), resulting in substantial pesticide loss (Cross et. al., 2001a, b). To address these issues, fixed spray application systems consisting of hoses and emitters through which chemical is delivered have been studied in the past (Carpenter et al., 1985; Agnello and Landers, 2006). The system, also called Solid set canopy delivery system (SSCDS), provides an alternative method of precision and timely delivery of pesticides while providing equivalent spray coverage compared to orchard airblast sprayers in tree fruit orchards (Carpenter et al., 1985; Agnello and Landers, 2006).

In recent years, knowledge and awareness of adverse effects of chemicals on environment have been growing, emphasizing the need for more efficient and effective chemical application systems. This need has renewed the interest and focus on developing and commercializing SSCDS. A multi-state team of researchers was formed in US a few years ago, which is conducting trans-disciplinary research in further developing this technology for modern, high density tree fruit orchards. Washington State University Center for Precision and Automated Agricultural Systems (WSU CPAAS) is participating in this effort to assess the engineering designs and coverage with SSCDS (Sharda et al., 2013; Sharda et al., 2014a,b).

Lang and Wise (2010) studied a SSCDS with one emitter per tree canopy and reported that only limited pesticide coverage was achieved throughout the tree canopy. Sharda et al., (2014a, 2014b) studied the coverage with different types of emitters installed at different canopy locations. The study showed that four or more emitters placed at two canopy heights can achieve a uniform coverage in all parts of the canopies in a super spindle apple orchard. It was observed qualitatively that most of the areas in the canopy were fully covered with spray droplets within a few seconds of chemical application. As the spraying was continued to achieve a standard 970 L/ha rate, leaves were fully saturated by the spray and substantial amount of spray was dropped to the ground. This observation suggested that there may be an optimal time window in which application will reach a desired coverage and continual application will only increase chemical loss and adverse effects on environment.

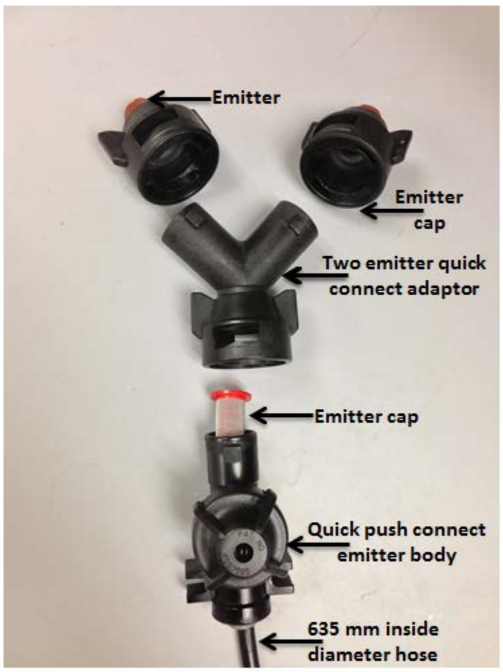
It was difficult to find any studies conducted in the past in understanding temporal pattern of spray coverage in apple orchards even with traditional air-blast sprayers. In addition, air-blast sprayers use high velocity air to transport spray droplets onto canopy surfaces, which is completely different from SSCDS that does not use any carrier other than spray droplets. Therefore, studies to understand the temporal spray coverage pattern with SSCDS is critically important for optimizing chemical application method with SSCDS. The specific objective of this work was to study the development of spray coverage over time with different configurations of a SSCDS.

MATERIAL AND METHODS

Experiments were conducted in a six year old commercial pacific rose variety apple orchard located in Prosser, WA. The tree rows were spaced at 2.4 m and trees within the row were spaced at 0.8 m. Tree heights of 15 randomly selected trees were measured and average tree height was found to be 2.8 m. A 9.0 m long spray section was installed in three consecutive tree rows. The 2.5 cm inside diameter polyvinyl (PVC) main hose carrying pressurized liquid was installed along the middle trellis wire at a height of 1.5 m from the ground. The installation covered nine trees in each of the three consecutive tree rows in the orchard. A tree in the middle row was randomly selected for coverage assessment during the time spray application was conducted. A centrifugal pump (Model 1538, Hypro, New Brighton, MN) powered by a gas engine (Model GX 120, Honda Engines, Alpharetta, GA) pressurized liquid into the spray system. The pumping system was mounted on an orchard tractor (Model 4210, Deere & Company, Moline, IL). Water was used as spray liquid in this study. Ambient conditions like wind speed, wind direction, and temperature were measured.

Teejet TXVS12 (Teejet, 2013) hollow cone spread pattern emitters were selected to conduct spray application. Emitters were mounted on the two emitter quick connect adaptor (Model QJ90-2-NYR, Teejet technologies, Wheaton, IL). The quick connect adaptor has two mirrored outlets oriented at 45° to the horizontal to install emitters (**Figure 1a**). A quick push connect emitter body (Model QJ98592-1/4-20, Teejet technologies, Wheaton, IL) was coupled with two emitter adapter. This two emitter adapter coupled on the quick push connect emitter body, emitter cap and emitters as shown in **Figure 1**, termed as twin emitter setup (TES) henceforth, was used to install two permanent spray systems called solid set canopy delivery system (SSCDS) design configurations (DC) (**Figure 2**). The TES was oriented vertically upwards to direct the droplets upwards into the canopy (**Figure 1b**). TES with Teejet TXVS12 was selected based on results of previous study which highlighted that TES provided greater coverage on the upper- and under-side of leaf within 0.8 height of tree canopy at 275 kPa application pressure as compared to others setups.

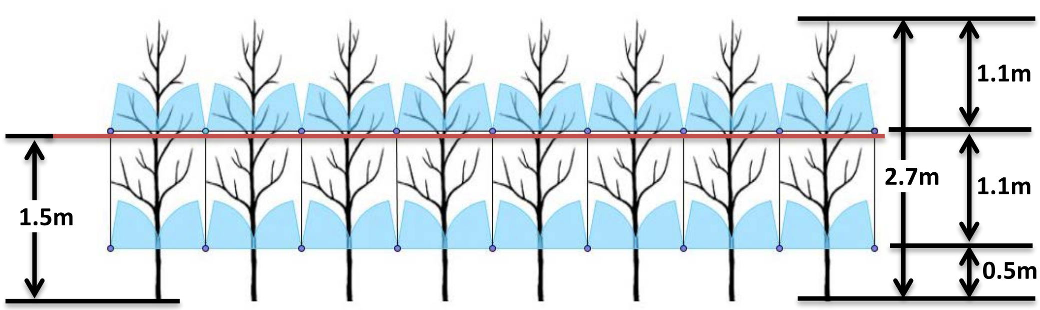
SSCDS in two DC (**Figure 2a and 2b)** was installed to study spray coverage on tree canopy over time. This study was carried out to determine real-time spray coverage during the time of application. The TES was placed at 0.5 m and 1.6 m height from ground in DC1and at 0.5 m, 1.2 m and 1.9 m height for DC2. Since there was no foliage in the lower 0.5 m of tree canopy, one of the TES was fixed at 0.5 m height from ground. Additional TES locations were determined by dividing the tree height with canopy in two parts for DC1 and three parts for DC2. Therefore, each TES cover a half of tree canopy in DC1 and a third in DC2. The TES was fixed on to 6.3 mm PVC tubes placed in the center of two consecutive trees using zip ties (**Figure 1**). A 635 mm inside diameter polyethylene tube (Make, Manufacturer) was push connected to TES on one end and the other end of tune with barb connector (Model 250-TB, Jain Irrigation Inc, Fresno, CA) was inserted into main hose.



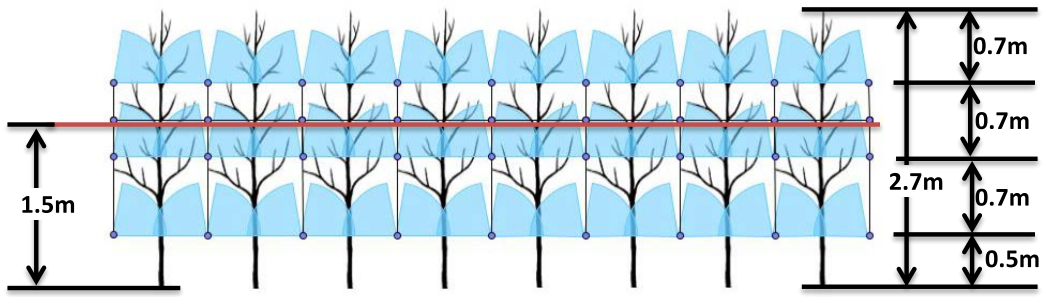
(a)

(b)

Figure 1. Twin emitter setup (TES) used to design SSCDS (a); and an example of TES installation in the orchard (b). A pressure transducer indicated in dotted circle (b) was mounted to monitor application pressure at a random location.



(a)



(b)

Figure 2. SSCDS design configurations (DC1) with twin emitter setup (TES) installed at heights 0.5 m and 1.6 m from ground (a); and DC2 with TES installed at heights of 0.5 m, 1.2 m and 1.9 m from ground and fixed equidistant from two adjacent trees. The solid red line indicates main hose to deliver pressurized liquid. Small circles indicate locations where TES was mounted; solid vertical lines indicate 635 mm hose connecting TES to main hose. The main hose was mounted at the height of 1.5 m from the ground.

Pumping system for SSCDS was calibrated and set to spray at 517 kPa. The spray application pressure of 517 kPa was selected based on previous studies which indicated an average of 92 % coverage on water sensitive cards (WSC) (Syngenta Crop Protection AG, Switzerland) placed on upper-side and 78% on WSC located on the under-side of leaf from 25 sampling locations (SL) (**Figure 3**). To study the relationship between spray application time and coverage, three SLs namely 4, 6 and 9 were selected in the low canopy regions (**Figure 3**). Height of each SL from ground, lateral distance from the central leader, and orientation angle (**Figure 4**) with respect to trellis wire around central leader was measured (**Table 1**). The height and lateral distance was measured using tape measure and orientation angle was measured using digital angle finder (Model DAF220K, Bosh, Mount Prospect, IL). The selected locations in the earlier studies exhibited nearly 100% coverage. The SL 4 was aligned along the trellis wire and close to central leader, SL6 was on a branch extending in the aisle transversely to tree row, and SL9 was located vertically up. Selected SLs were located in three distinct canopy regions based on their orientation (Table 1) and were farthest from TES fixed at 0.5 m height from ground. It was assumed that since all other SLs in low canopy region were closer to TES, coverage at these SLs would be achieved in a time less than what would be observed for SL4, SL6 and SL9. It was also assumed that since each TES covered equivalent canopy heights to deposit spray droplet, the time versus coverage will hold true for other canopy regions (Medium and high) as well.

A monochrome high-speed camera (HiSpec 1, Fastec Imaging, San Diego, CA) was utilized to record spray coverage on the WSC during spray application using two DCs. A 75 mm focusable imaging lens was used on the high speed camera (Model 750 TechSpec Focusable Double Gauss lens, Edmund Optics, Barrington, NJ). The positioning of camera in the orchard is presented in **Figure 5.** Camera mounted on the tripod was programmed to capture 10 fps with 200 µs exposure time and was placed 760 mm away from the WSC resulting in the field of view of 84. 4 mm x 68.6 mm. Tests were conducted by placing a WSC at SL4, SL6 and SL9 only in the upper-side of leaf for SSCDS with DC1 and DC2. WSC were placed only on the upper-side as putting them on under-side of leaf was not feasible because of spray droplet would hit high speed camera lens resulting in loss of imaging ability. Application was conducted using two pressures of 241kPa and 517 kPa. Spray application (**Figure 6**) was conducted at 1870 L/ha application rate. Time of spray in DC1 and DC2 was calculated to conduct application at 1870 L/ha (**Table 2**).

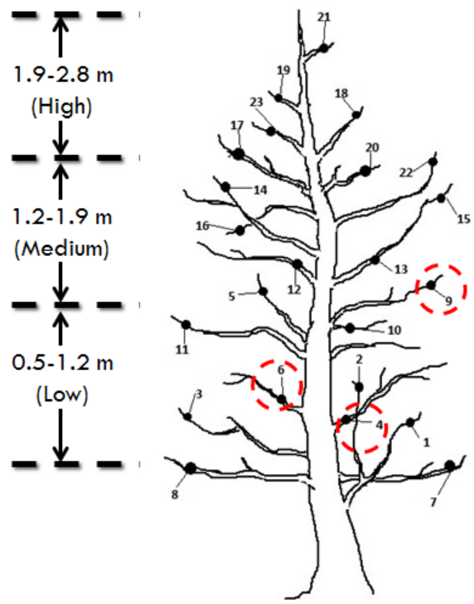


Figure 3. Sampling locations used for coverage assessment in a tree canopy. A total of 23 samples were collected from low, medium and high canopy regions on an example tree3.

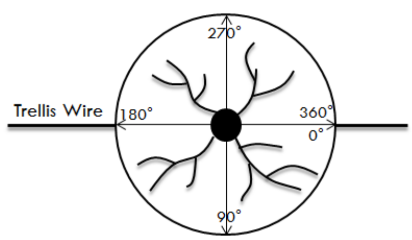


Figure 4. Top view of a tree canopy showing orientations of the sampling locations. Orientation was measured starting from trellis wire on the right side of the tree starting at 0° and moving clockwise around the central leader.

Table 1. Orientation of sampling locations (SL) based on the height from the ground, linear distance from the central leader and angle around the central leader.

SL	Height (m)	Lateral Distance (m)	Angle (°)
4	0.8	0.1	32
6	0.9	0.4	319
9	1.2	0.2	0

Figure 5. High speed camera setup in the orchard.

Figure 6. Example illustration of spray application for DC2 at 517 kPa.

Table 1. Application time for DC1 and DC2 when conducted spray application at 241 kPa and 517 kPa.

Application Presure (kPa)	Application Time (s)	
	DC-1	DC-2
241	7.3	5.0
517	5.0	3.0

High speed camera was control using the HiSpec Control software (Fastec Imaging, San Diego, CA). The images for each test were recorded in a *.Tiff format. Additionally application pressure (Model 1502B81EZ100psiG, PCB Piezotronics Inc., Depew, NY), flow rate (Model 90-50230, 801series, Teejet technologies, Wheaton, Illinois, USA) and environmental parameters including temperature, humidity, wind speed (Model 014A, Met One Instruments, Grants Pass, OR) and wind direction (Model 024A, Met One Instruments, Grants Pass, OR) were also measured and monitored at 10 Hz using a DAQ system (NI9201 and NI 9403, National Instruments, Austin, TX, USA). The environmental parameters during the experiment were measured following ISO 22522 Standard (ISO, 2007). All the tests were carried out when the wind speed was under 2.2 m/s using water as spray material. The images (as shown in **Figure 7)** illustrating time of application (**Table 2**) were analyzed using a program written in the LabVIEW vision module to quantify spray coverage.

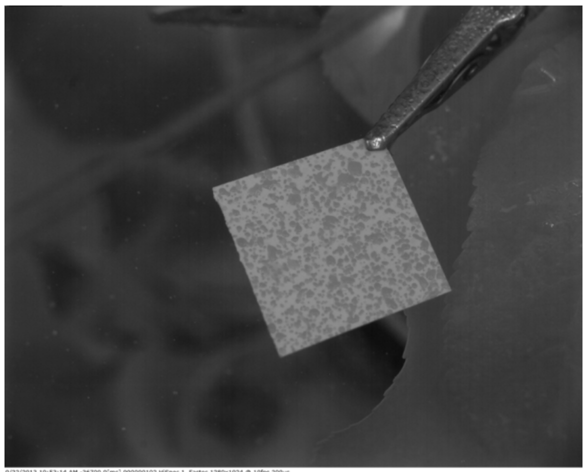


Figure 7. Example image of Water Sensitive Card (WSC) during spray application.

RESULTS AND DISCUSSION

The results of the study are shown in Figures 8 through 11. The results indicated that spray coverage in different sections of the tree was achieved in 3 s (Figure 11) with DC2 at 517 kPa application pressure. The spray droplets were distributed uniformly within different canopy regions to establish approximately equal coverage. This kind of uniformity in coverage is desired for effective pest control. The spray droplets penetrated into the canopy during 3 s second as can be seen from the temporal development of coverage at SL4, because SL4 was located close to the central leader. Spray penetration (SL4) was greater with DC2 and 517 kPa application pressure as compared to other DCs and application pressure. Overall, results indicated that spray coverage can be achieved with SSCDS in a short duration and temporal development at different SLs was uniform.

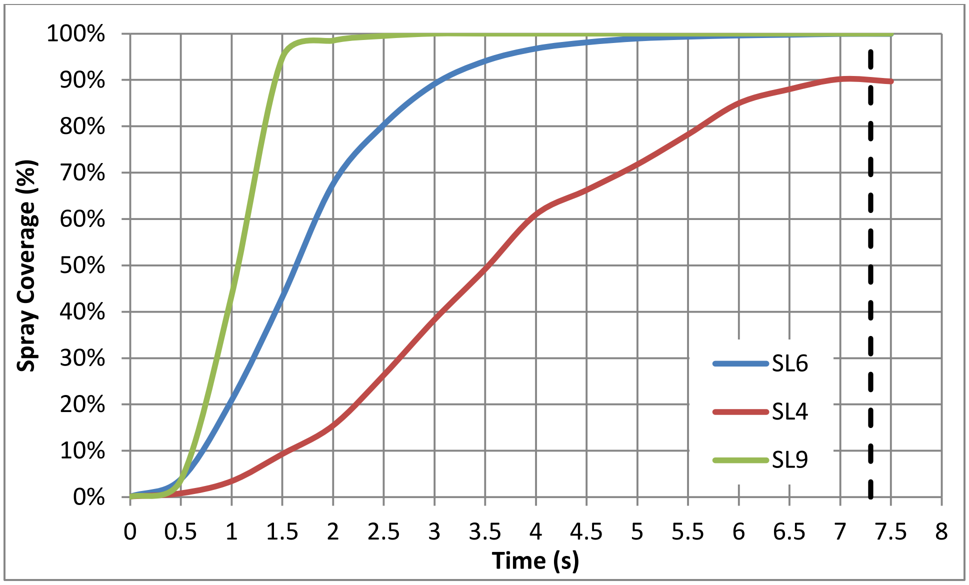


Figure 8. Spray coverage over time at 241 kPa application pressure with SSCDS DC1. Vertical dotted line indicates time of application for 1870 L/ha application rate

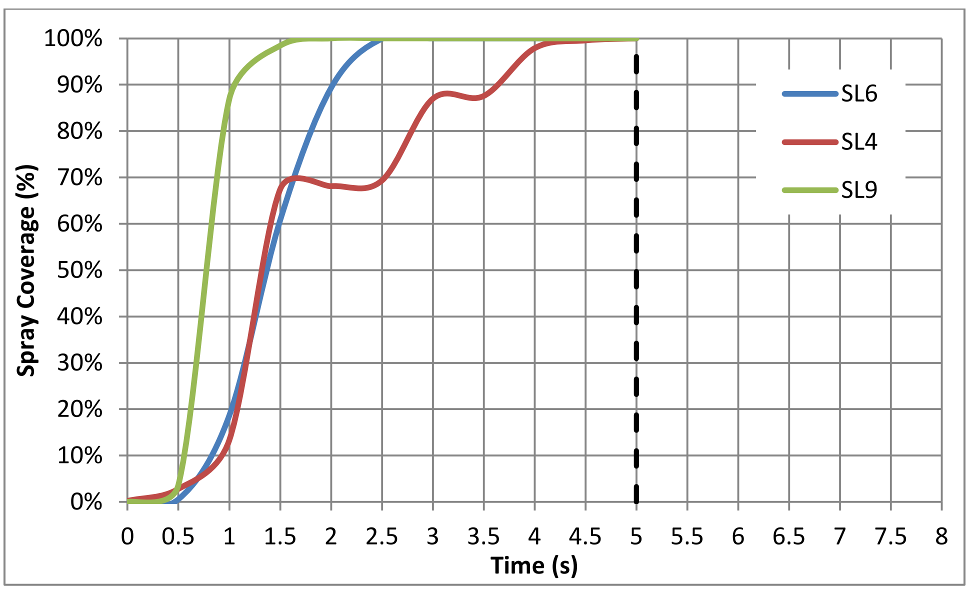


Figure 9. Spray coverage over time at 517 kPa application pressure with SSCDS DC2. Vertical dotted line indicates time of application for 1870 L/ha application rate

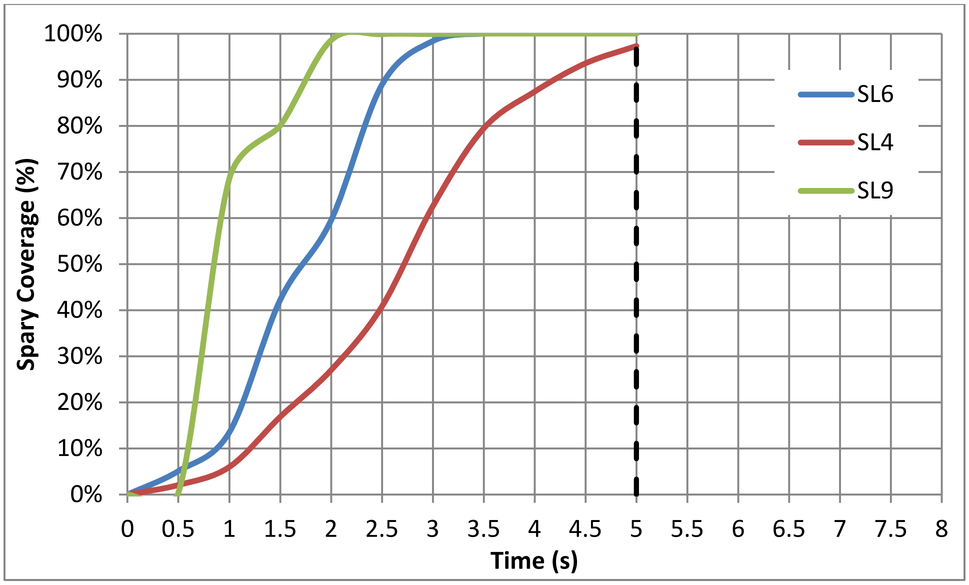


Figure 10. Spray coverage over time at 241 kPa application pressure with SSCDS DC1. Vertical dotted line indicates time of application for 1870 L/ha application rate

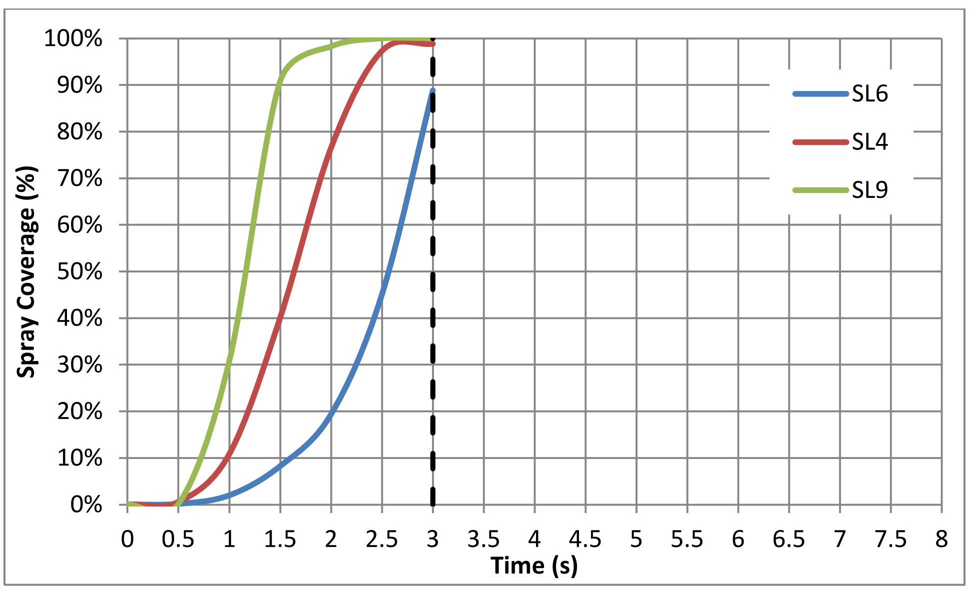


Figure 11. Spray coverage over time at 517 kPa application pressure with SSCDS DC2. Vertical dotted line indicates time of application for 1870 L/ha application rate

This work showed that spray coverage progresses non-linearly over time and there may be optimal duration that leads to a desired level of coverage for a give canopy type and given SSCDS configuration. Desired level of coverage for any type of pest control, however, can only be defined by biological efficacy studies and is outside the scope of this work. This work only focused on evaluating progression of spray coverage on target leave surfaces over time. To provide a better picture of the efficiency of SSCDS, temporal progression of spray deposition should be studied in the future.

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