Development of Two Intelligent Spray Systems for Ornamental Nurseries©

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INTRODUCTION

The ornamental industry produces an abundance of flowers, nursery shrubs, and trees to beautify our environment and improve our lifestyle. This abundance is predicated on the use of pesticides to protect them from pests. However, the application efficiency of conventional pesticide spray technologies for crop protection is very low. Consequently, excessive pesticides are often applied to target and non-target areas, resulting in greater production costs, worker exposure to unnecessary pesticide risks, and adverse contamination of the environment. The industry has constantly demanded the development of new advanced intelligent sprayers that delivers pesticides economically and accurately and requires minimum human inputs during the entire spray application process.

The capabilities of conventional sprayers are limited and unable to optimize spray outputs and thus cannot compensate for the rapid changes of growth characteristics in nursery crops. Although traditional ultrasonic sensors coupled with variable-rate sprayers are an improvement (Giles et al., 1987; Molt et al., 2000; Solanelles et al., 2006; Gil et al., 2007; Balsari et al., 2008), they are usually used for relatively uniform orchard trees but cannot evaluate nursery trees with wide growth diversities. Consequently, the high-speed ultrasonic sensors or laser scanners are needed for advanced sprayers that automatically adjust spray outputs based on canopy sizes. The laser scanners offer promising opportunities to detect tree canopy characteristics due to their fast response to the target surfaces (Wei and Salysni, 2004; Lee and Ehsani, 2008; Rosell Polo et al., 2009).

The objective of this research was to develop advanced and affordable spray systems that employ intelligent technologies to continuously match system operating parameters to crop characteristics during pesticide applications. Significance of this research would be to provide critical technology to increase application efficiency and reduce uncertainty associated with current pesticide sprayers used in nursery crop production, and to achieve real cost benefits to producers, consumers, and environments with new pesticide application strategies.

MATERIALS AND METHODS

Two types of experimental variable-rate precision sprayers were developed as an introduction of new generation sprayers for nursery crop applications. The first one was an economic, hydraulic vertical boom spraying system which was proposed to spray relatively small narrow trees such as liners, and the second one was an air-assisted spraying system which was proposed to spray wide range of nursery crops.

Variable-Rate Hydraulic Boom Sprayer. The intelligent variable-rate boom sprayer (Fig. 1A) integrated a 20 Hz detecting frequency ultrasonic sensing system, a custom-designed sensor-signal analyzer and variable-rate controller, and variable-rate nozzles. The sensing system detected the occurrence of a plant, its size and volume, and the sprayer travel speed. The controller along with a microprocessor analyzed sensor signals and actuated pulse width modulated (PWM) solenoid valves in real time to automatically provide variable flows to nozzles. Laboratory tests were conducted to verify deposition uniformity inside canopies with various sizes of trees at different travel speeds. The laboratory field consisted of two rows of six different taxa of trees (*Acer rubrum* 'Franksred', *A.* ×*freemanii* 'Jeffersred', *A. palmatum*, *Carpinus betulus*, *Malus toringo* subsp. *sargentii,* and *Prunus* ×*cistena*). Tree taxa had different heights which ranged from 0.8 to 2.5 m, and their calipers

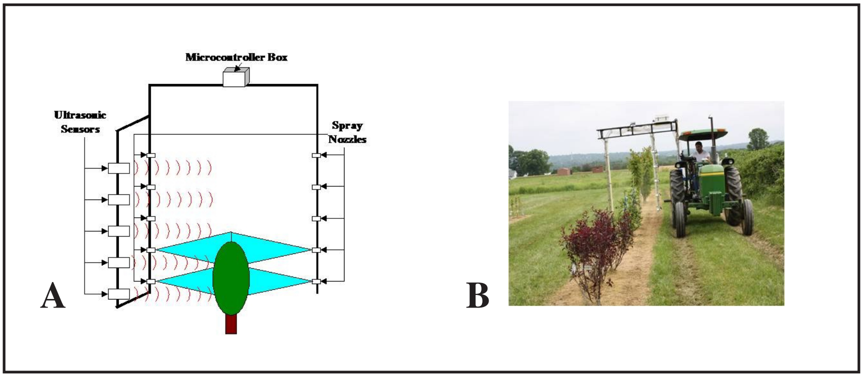

Figure 1. Ultrasonic sensor-controlled hydraulic vertical boom sprayer to provide variable-rate functions based on tree size, shape, and occurrence.

A) Schematic diagram of ultrasonic sensors to detect canopy and control spray nozzles.

B) Ultrasonic sensor-controlled variable-rate sprayer in a laboratory field.

at 18 cm above the ground ranged from 0.5 to 5.4 cm. The travel speeds for the test were 3.2, 4.8, 6.4, and 8.0 km/h. Water-sensitive papers were mounted inside canopies to measure the spray coverage, and a fluorescent tracer brilliant sulfaflavine was mixed with water to form spray solution to quantify spray deposits.

Variable-Rate Air-Assisted Sprayer. The intelligent variable-rate air-assisted sprayer (Fig. 2B) integrated a high speed laser scanning system, a custom-designed sensor-signal analyzer and variable-rate controller, variable-rate nozzles, and a multi-channel air-assisted delivery system. The sprayer intended to have the capability to achieve variable spray rates for different canopy volumes and densities, by using nozzles of one size to obtain different flow rates instead of changes of nozzles of different sizes. Spray consumptions between the intelligent sprayer and a conventional air blast sprayer in an orchard were compared at three different growing stages. The comparison tests were conducted in April when trees just started sprouting, in May when trees developed half foliage, and in June when trees developed full foliage. Application rate for the conventional sprayer was 470 $L \cdot ha^{-1}$ (50 gpa) which was determined by a tree-row volume method.

RESULTS AND DISCUSSION

Tables 1 and 2 show the mean spray deposits and coverage inside canopies of six different taxa from the variable-rate hydraulic boom sprayer at travel speed of 3.2, 4.8, 6.4, and 8.0 km/h, respectively. The mean spray deposit and coverage inside canopies slightly varied with the changes in tree species (or tree size) and travel speed. For example, at 4.8 km/h travel speed for the six taxa of trees with their heights ranged from 0.8 to 2.5 m, the mean spray deposit ranged from 0.38 to1.08 $\mu L \cdot cm^{-2}$ and the mean spray coverage ranged from 9.2% to 20.4%. Moreover, for the travel speed ranging from 3.2 to 8.0 km/h, the spray deposit inside the *A. rubrum* 'Franksred' canopy varied from 0.82 to 1.21 $\mu L \cdot cm^{-2}$ and spray coverage varied from 13.7% to 18.5%. However, compared to the variations in field condi-

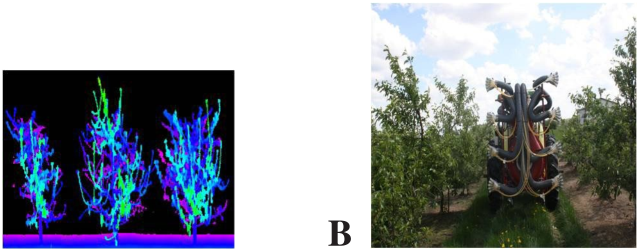

Figure 2. Laser-scanning sensor-controlled air assisted sprayer to provide variable-rate functions based on tree sectional canopy volume, density and occurrence

A) Images of trees scanned by a laser scanning sensor.
B) Laser-scanning sensor-controlled air-assisted sprayer.

tions, this variation in spray deposition and coverage from the variable-rate boom sprayer was very small and was acceptable for quality spray applications. That is, the sprayer achieved its anticipation that spray deposit and coverage were relatively uniform regardless of changes in the canopy size and travel speed.

Table 1. Mean spray deposits inside canopies of six different varieties from the variable-rate hydraulic boom sprayer at travel speed of 3.2, 4.8, 6.4, and 8.0 km/h. Values in parenthesis present the standard deviation.

	Spray deposit (μL·cm^{-2}) Travel speed (km/h)			
Trees	3.2	4.8	6.4	8.0
Acer palmatum	0.78 (0.21)	1.08 (0.47)	1.23 (0.41)	0.97 (0.30)
Acer ×*freemanii* 'Jeffersred'	0.67 (0.29)	0.68 (0.56)	1.13 (0.27)	0.91 (0.24)
Prunus ×*cistena*	0.96 (0.34)	0.92 (0.34)	0.68 (0.21)	0.72 (0.30)
Malus toringo subsp. *sargentii*	0.86 (0.35)	0.56 (0.26)	0.84 (0.30)	0.82 (0.33)
Carpinus betulus	0.77 (0.30)	0.38 (0.23)	0.53 (0.41)	0.49 (0.25)
Acer rubrum 'Franksred'	1.21 (0.60)	0.88 (0.46)	0.82 (0.31)	0.97 (0.41)
Mean	0.90 (0.41)	0.72 (0.43)	0.81 (0.38)	0.79 (0.35)

Table 2. Mean spray coverage inside canopies of six different varieties from the variable-rate hydraulic boom sprayer at travel speed of 3.2, 4.8, 6.4, and 8.0 km/h. Values in parenthesis present the standard deviation.

	Spray coverage (%) Travel speed (km/h)			
Trees	3.2	4.8	6.4	8.0
Acer palmatum	13.0 (4.5)	20.4 (10.8)	19.4 (8.6)	18.2 (9.6)
Acer ×freemanii 'Jeffersred'	12.4 (6.1)	14.4 (26.6)	16.2 (7.3)	18.8 (6.8)
Prunus ×cistena	12.3 (8.8)	13.3 (8.0)	10.4 (7.9)	8.3 (6.5)
Malus toringo subsp. *sargentii*	15.8 (9.5)	10.9 (5.8)	11.9 (7.0)	14.7 (6.7)
Carpinus betulus	14.9 (8.9)	9.2 (8.7)	6.8 (5.5)	6.7 (5.1)
Acer rubrum 'Franksred'	18.5 (8.3)	14.5 (7.4)	13.7 (8.5)	16.6 (8.0)
Mean	14.5 (5.1)	13.8 (5.5)	13.1 (6.0)	13.9 (6.4)

Figure 3 shows consumptions and percent reductions of the sprays with the intelligent air-assisted sprayer in an orchard in April, May, and June. The percent reduction was based on the 470 L·ha^{-1} (50 gpa) used by the conventional air-blast sprayer. The intelligent sprayer used 140 L·ha^{-1} (15 gap) with 70% spray mixture reduction in April, 159 L·ha^{-1} (17 gpa) with 66% spray mixture reduction in May, and 224 L·ha^{-1} (24 gpa) with 52% spray mixture reduction in June. The pesticide consumption reduction with the intelligent sprayer is obvious.

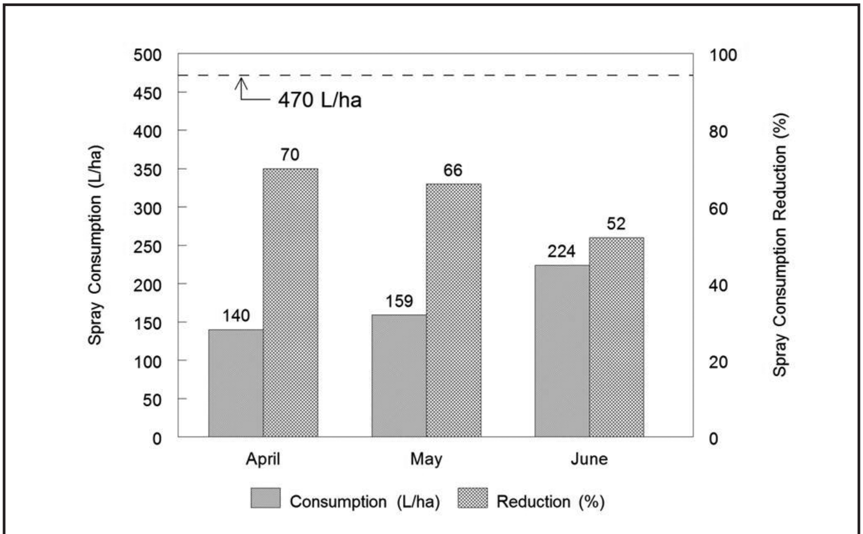

Figure 3. Spray consumption and percent reduction from intelligent sprayer, compared with the conventional 470 L·ha^{-1} (50 gpa) spray application rate.

SUMMARY

Current application technology for floral, nursery, and other specialty crop production wastes significant amounts of pesticides. Two different real-time variable-rate sprayer prototypes for ornamental nursery and tree crops were developed to deliver chemicals on target areas as needed. The first prototype was a hydraulic vertical boom spraying system that used 20 Hz ultrasonic sensors to detect tree size and volume, and the second prototype was an air-assisted spraying system that used a laser scanning sensor to quickly measure the entire tree structure. The automatic controllers developed for the prototypes consisted of a computer program, a signal generation and amplification unit, and pulse width modulated solenoid valves. The controllers analyzed sensor signals and actuated the solenoid valves to automatically provide variable flows to nozzles based on tree characteristics and plant occurrence. Preliminary laboratory and field tests demonstrated that both experimental sprayers had the capability to control spray outputs that continuously matched canopy characteristics in real time, and significantly reduce pesticide spray application rates.

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