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Influence of Spray Volume on Spray Deposition and Coverage within Nursery Trees[1]

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Abstract

Information on better utilizing airblast sprayers to achieve high pesticide spray application efficiency in nursery tree production is needed. Foliar spray deposition and coverage at different heights inside crabapple tree canopies were investigated for a conventional airblast sprayer operating at four different application rates ranging from 230 to 900 L/ha [24 to 94 gallons per acre (GPA)]. Deposition on the ground at various distances from the sprayer was also measured at the 700 L/ha (73 GPA) application rate. Foliar deposition and coverage on targets below 2.6 m (8.5 ft) inside tree canopies increased as the application rate increased, but the increase in the coverage was much lower than the deposition. For trees taller than 2.6 m (8.5 ft), the sprayer could not deliver uniform spray deposition and coverage across the tree height. The portion of trees below

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2.1 m (6.9 ft) was well covered by the spray deposits with 230 L/ha (24 GPA) application rate while higher application rates resulted in over spray application. Less than 30% of total spray volume was deposited on target trees while over 34% of the total spray volume was lost on the ground. The tree-row volume method should include foliage density and tree-row gaps to avoid excessive estimation of spray application rates for nursery tree crops.

Index words: Pesticide reduction, nursery, airblast sprayer, application rate.

Species used in this study: *Malus* 'Winter Gold', *Malus* 'Robinson' and *Malus* 'Spring Snow'.

Significance to the Nursery Industry

The conventional air blast sprayer is one of the most commonly used sprayers to apply pesticides in ornamental nursery crops. Many nursery growers have used one sprayer to cover a wide variety of crop shapes and sizes, and they have been misled that better spray coverage can be obtained with the spray volume at the point that the target areas are saturated. Without scientific spray application guidelines, most target areas of nursery crops are over sprayed, resulting in high production cost and potential environmental contamination. In this study, the relationship between spray application rate and deposition-coverage on target areas of nursery crabapple trees from a conventional air blast sprayer was investigated. Estimation of the application rate with the traditional fruit tree row volume method for nursery trees could cause extremely excessive spray deposits on target areas. Conventional air blast sprayers have many advantages to spray short nursery trees but are not the best method to achieve uniform spray deposition and coverage of pesticides for tall nursery trees. For tall nursery trees,

other spray systems such as tower sprayers should be used to discharge uniform spray deposition and coverage across the tree height inside canopies.

Introduction

The nursery and horticultural industries are among the fastest growing enterprises in U.S. agriculture. Application of pesticides and other production strategies have ensured high quality nursery crops to meet marketing requirements. Because of the high cosmetic requirements for ornamental nursery crops, production of ornamental crops uses more intensive pesticide applications than traditional agricultural crops. Little information is available to growers on what type of sprayers should be used and what spray volume should be applied to achieve effective pest and disease control with minimum chemical loss (9, 12).

Due to crop similarity, air assisted application technologies for apple and citrus orchards (3, 5, 7, 11) are normally adapted to nursery tree crops. The guideline for air assisted sprayer development is associated with the methodology that the amount of spray volume transported over a given distance is proportional to the air stream horsepower (4, 10).

The conventional airblast sprayer is one of the most commonly used sprayers to apply pesticides in ornamental and shade nursery crops. Its flexibility of turning nozzles on and off along with adjusting nozzle angles provides a suitability to be used for a wide variety of shapes and heights in the productions of many nursery trees. The tree-row volume (TRV) method for apple and citrus orchards has been used for determining spray application rates for nursery trees. The amount of spray application needed per unit area is determined by an estimation of the TRV along with a rule that it takes 0.1 to 0.13 L to

treat 1.0 m^3 of tree canopy to the point of runoff (8). The TRV method could be expressed as the TRV multiplied by 0.1 L/m^3 with the equation,

$$V = \frac{1000 \cdot D \cdot H}{S} \qquad (1)$$

where V is the spray application rate (L/ha), D is the tree width or diameter (m), H is the height (m), and S is the distance between rows (m).

Based on equation (1), a typical application rate in commercial nurseries is recommended from 1,000 to 4,000 L/ha (100 to 400 GPA). Many applicators usually simply increase number of nozzles or sizes of nozzle orifices to meet the estimated application rate. Compared with orchard crops, ornamental nursery crops have a wide variety of canopy structure characteristics. They are usually narrower and sharper with less canopy volume, and spaces with no canopies between tree rows is usually larger than in orchard crops. With the estimated spray rate, most target areas of nursery crops are saturated. Additionally, the excessive rates cause extra time for tank mixture preparation, large amount of off-target loss, waste of pesticides, increased risk of chemical exposure to applicators, and low spray application efficiency, resulting in high production cost and potential environmental contamination.

Nurseries are usually small acreage operations dealing with a very wide range of crops. Many spray application problems confronted by small-scale farmers are also commonly encountered in nurseries. Because of complicated growing circumstances, it is more difficult to apply pesticides to nursery crops than fruit crops with conventional spraying systems (2). Many nursery growers have used one sprayer to cover a wide variety of crop shapes and sizes, and they have been misled that better spray coverage can

be obtained with the spray volume at the point that the target areas are saturated. In many cases, customer-designed sprayers are required to control pests for specific dense crops (13). There have been concerns on how much spray application rate is high enough to provide sufficient spray deposition and coverage on target areas while the off-target loss is minimized, and what adjustments to sprayer settings are needed to obtain uniform spray deposits across the tree height in nursery applications. Information is also needed on the volume of spray lost on the ground with existing sprayers.

The objectives of this research were to evaluate the relationship between spray application rate and deposition-coverage inside nursery crabapple trees using a conventional airblast sprayer, and to determine the volume of spray lost on the ground.

Materials and Methods

Experiment 1. A model 1500 airblast sprayer (Durand-Wayland, Inc., LaGrange, Georgia) operated with six identical conventional hollow cone nozzles equally spaced on one side of a 0.91-m (3 ft) diameter air deflector was used to apply treatments. The center of the air deflector was 0.91 m (3 ft) above the ground. The top nozzle on the air deflector was 1.2 m (3.9 ft) above the ground, and the bottom nozzle on the air deflector was 0.65 m (2.1 ft) above the ground. This type of sprayers and similar models has been widely used in nurseries. Followed the normal operation procedures used by nursery sprayer applicators, nozzle angles were visually adjusted to discharge the spray to cover trees from the ground to the top of trees.

The sprayer produced 40 m/s (131 ft/s) average air velocity near the nozzles when operated at the high gear setting. The air velocity was much higher than the minimum

required air velocity for all air assisted sprayers investigated by Randall (10) who reported that air velocity of 12.2 m/s (40 ft/s) from an air assisted sprayer was sufficient to allow sprays to penetrate the densest part of bush apple trees.

Foliar spray deposits and coverage inside crabapple trees (*Malus* 'Winter Gold' and *Malus* 'Robinson') were investigated at four different application rates: 230, 440, 725, 900 L/ha (24, 46, 76, 94 GPA) in a commercial nursery field. Four different sizes of conventional hollow cone nozzles were used to obtain the four application rates (Table 1). These types of nozzles are commonly used in airblast sprayers to produce small droplets for better coverage of leaves with contact pesticides.

The field used in the experiment was 200-m (656 ft) long and 30-m (98 ft) wide and was planted with three rows of *Malus* 'Winter Gold' and *Malus* 'Robinson' crabapple trees and four rows of shrubs. All trees were well trimmed in early spring and maintained in similar shape to meet market requirements. Spacing between trees within a row was 1.5 m (5 ft). Two rows of crabapple trees were selected as the sprayed targets (Fig. 1). One row was the variety 'Winter Gold', and the other row was 'Robinson'. Spacing between the rows was 2.74 m (9 ft). The test was conducted in the middle of summer, and tree canopies were fully developed with a cone shape. The average height of the sprayed trees of both varieties was 3.2 m (10.5 ft), the average height of the lowest branches was 0.90 m (3 ft), and the average maximum tree width which occurred at about 1.2 m (3.9 ft) height was 1.9 m (6.2 ft). The field was surrounded by other plantings with different species of trees. The crabapple trees used in this test were selected because canopies of these trees were tall and dense, which could provide informative test results affecting application rates, potentially recommended for other species.

Foliar spray deposits and coverage were measured at different heights inside 4 randomly selected trees in each row. Monofilament nylon screens (Filter Fabrics Inc., Goshen, Indiana) were used to simulate leaves to collect foliar spray deposits within 8 crabapple tree canopies. Each screen size was 5 by 5 cm (2 by 2 inch). The screen had a nominal porosity of approximately 56% or fiber frontal area percentage of 44%. Fox et al. (6) reported the airborne collection efficiency of spray droplets for this type of screen ranged from 50 to 70% which was much better than flat solid collectors. Ten screens were located at four different heights [1.2, 1.7, 2.1, and 2.6 m (3.9, 5.6, 6.9 and 8.5 ft)] inside each tree and each screen was hung with a clip attached to a branch of the tree.

Adjacent to the middle screen at each height, a water sensitive paper was used to collect the spray deposits for coverage measurement. The water sensitive paper was 5 cm (2 inch) wide and 7.5 cm (3 inch) long (Syngenta Crop Protection AG, CH-4002 Basel, Switzerland), and faced the spray direction.

A portable weather station located at 30 m (98 ft) west of the test plot was used to monitor wind velocity and azimuth at one-second intervals. During the test, average wind velocity was 2.3 m/s (5.1 mile/hr) and wind direction was 281 degree azimuth. Ambient air temperature was 25°C (77°F), and relative humidity was 54%.

Each spray treatment was repeated twice because visual observation of spray coverage on water sensitive papers at same locations indicated no more replication was needed. The spray mixture was 3 g of a fluorescence tracer, Brilliant Sulfaflavine (MP Biomedicals, Inc., Aurora, Ohio) per liter of water for all tests. All field target samples were collected 15 min after each spray. The nylon screens were placed in 125-ml wide-

mouth glass bottles stored in non-transparent boxes, and water sensitive papers were stored in sandwich bags.

Experiment 2. The amount of sprays from the model 1500 airblast sprayer deposited inside crabapple tree canopies and on the ground was investigated in a different field from Experiment 1. Experiment 2 was applied with the identical spray mixture used in Experiment 1. However, only five identical nozzles were used in the Experiment 2 because of shorter trees. The nozzle at the bottom of the sprayer was closed. The nozzles were five conventional D5-DC45 hollow cone nozzles which were previously used to produce the 725 L/ha (76 GPA) rate in Experiment 1. Nozzle angles were adjusted to permit coverage of the entire tree height. The total flow rate from the sprayer was adjusted to 24.2 L/min (6.4 gallon/min) by adjusting the spray operating pressure to 1660 kPa (240 psi). The sprayer travel speed was 6.4 km/h (4 mile/hr), resulting in an application rate of 700 L/ha (73 GPA).

The field for Experiment 2 consisted of seven rows of *Malus* 'Spring Snow' crabapple trees and five rows of short shrubs. The two species were alternately planted with one row of crabapples and one row of shrubs after the first three rows of crabapples at the south side of the field. The fourth row of crabapple trees was selected for the spray test. The crabapple trees averaged 2.5-m (8.2 ft) tall and the average width of trees 0.9-m (3 ft) above the ground was 1.05 m (3.4 ft). Within the first 0.9 m (3 ft) from the ground, there were very few leaves on the stem. Spacing between trees within a row was 1.5 m (5 ft). The shrubs averaged 1.2 m (4 ft) tall and 1.1 m (3.6 ft) wide. All trees were well shaped by the nursery grower at early spring.

A total of 10 crabapple trees in the sprayed row was randomly selected for sampling. Foliar deposits were collected with the same size nylon screens used in the Experiment 1. Each tree had 12 screens located at four different heights [0.9, 1.2, 1.6, and 2.0 m (3, 3.9, 5.2, and 6.6 ft) and each screen was hung by a clip attached to a branch of the tree. The screens at the 0.9 m (3 ft) elevation were near the bottom edge of the canopy. Screens were placed as close as possible to the tree row centerline.

Spray deposits on the ground beneath trees and between two trees in the sprayed row were collected with two rows of 15 by 33 cm (6 by 13 inch) plastic plates. The first row of plastic plates was placed 15 cm (6 inch) in front of the tree centerline and the second row of plastic plates was 15 cm (6 inch) behind the tree centerline. Each plastic plate was stabilized on a 15 by 33 cm (6 by 13 inch) wooden board with two clips to prevent the plate from being moved by the air from the sprayer. Spray deposits on the ground beyond the sprayed row were collected with 5-cm (2 inch) wide and 2.45-m (8 ft) long plastic tapes at four different distances downstream from the sprayer centerline. The distances of the four rows of tapes were 4.5, 7.5, 10.5 and 15.0 m (14.8, 24.6, 34.4, and 49.2 ft) from the sprayer, respectively. Except for the first row of plastic tapes, each row had five plastic tapes placed near the front of trees. The first row of plastic tapes was placed near the front of short shrubs. The second-row tapes were placed near the front of the crabapple trees of the same size as the first sprayed row trees. Third-row tapes were near the front of the shrubs of the same size as the shrubs near the first row tapes. Fourth-row tapes were near the front of the crabapple trees of the same size as the first sprayed row trees.

Similar to the Experiment 1, the test of spray deposits within tree canopies and on the ground were repeated twice. All target samples were collected 15 min after each spray. The nylon screens and plastic tapes were stored in 125-ml wide-mouth glass bottles, and the plastic plates were stored in 4 liter (1 gallon) plastic bags, and then the bottles and bags were placed in non-transparent boxes.

During the test in Experiment 2, average wind velocity was 3.1 m/s (6.9 mile/hr) and wind direction was 316 degree azimuth. Ambient air temperature was 28°C (82°F), and relative humidity was 62%.

Sample analysis. Spray deposits on all targets (screens, plastic tapes and plastic plates) from both Experiments 1 and 2 were washed with distilled water immediately after they were brought to the laboratory. Peak fluorescent intensity of each wash solution was determined with a Model LS 50B luminescence spectrometer (Perkin-Elmer Limited, Beaconsfield, Buckinghamshire, England) at an excitation wavelength of 460 nm. The amount of spray deposited on targets was then converted to the volume of spray per hectare, or L/ha.

The spray coverage on each water sensitive paper was analyzed with a computer imaging system which includes a desktop computer, an HP Scanjet 5530 photo-smart scanner (Hewlett-Packard Company, Palo Alto, California) and imaging software "Imaging Tool" Windows Version 3.00 (The University of Texas Health Science Center, San Antonio, Texas). The resolution for the image analysis was 600 dpi. However, when over 70% water sensitive paper surface was covered by the spray mixture, it was very difficult for the software to identify the coverage image caused by droplet deposits or by

the moisture diffusion on a water sensitive paper. Therefore, for any spray coverage data higher than 70% reported in this paper later would not be very accurate.

All field data were first analyzed by one-way ANOVA to test null hypothesis that all treatments had equal means with Duncan's methods using ProStat version 3.8 (Poly Software International, Inc., Pearl River, New York). If the null hypothesis was rejected, the multiple comparison procedure was used to determine differences among means. All differences were determined at the 0.05 level of significance.

Droplet size measurement. Droplet size distributions from the nozzles used in Experiments 1 and 2 were determined with a particle/droplet image analysis system (Oxford Lasers VisiSizer and PIV, Oxfordshire, United Kingdom). The measurement was conducted under laboratory conditions for nozzles taken away from the sprayer to produce droplets without any air assistance. Therefore, the measured droplet size distributions were not exactly the same as the size distributions of droplets actually discharged from the airblast sprayer. During the tests lens option 3 was selected at the magnification setting 2. At this setting, the system was able to measure droplets from 21 μm to 1732 μm. Droplet samples were taken 50 cm (20 inch) below the nozzle orifice and across centerline of the spray pattern. Droplet sizes were counted only from 5 cm (2 inch) cone spray sheet on both sides because a very small portion of spray volume was found in the center of the hollow cone spray pattern. At least 10,000 droplets were sampled at each point.

Results and Discussion

Ground deposition. In Experiment 2, the average spray deposit on the ground beneath the sprayed trees was 55.8 L/ha (5.8 GPA) or about 8% total application rate (Fig. 2). Runoff from leaves and direct spraying contributed to the deposits under trees.

Average ground deposits collected by the plastic tapes at 4.5, 7.7, 10.6 and 14.6 m (14.8, 24.6, 34.4, and 49.2 ft) from the sprayer for the two trials were 123.1, 43.9, 13.2, and 1.1 L/ha (12.9, 4.6, 1.4, and 0.1 GPA), respectively. That is, approximately 18% of the total spray volume was lost on the ground at 4.5 m (14.8 ft) downstream from the sprayer, about 6% of the total spray volume was lost on the ground at 7.7 m (24.6 ft) from the sprayer, about 2% of the total spray volume was lost on the ground at 10.6 m (34.4 ft) from the sprayer, and 0.2% total spray volume was lost on the ground at 14.6 m (49.2 ft) downstream from the sprayer. Over 34% of the total spray volume was deposited on the ground beyond the treated tree row with the airblast sprayer.

Foliar deposition. Results from Experiment 1 illustrated the spray deposit inside tree canopies was significantly different among the four application rates, and nearly linearly increased as the total application rate increased (Fig. 3). The average spray deposit across four heights inside tree canopies was 33 L/ha (3.4 GPA) or 14.3% total application rate, 71 L/ha (7.4 GPA) or 16.2%, 110 L/ha (11.5 GPA) or 15.2%, 170 L/ha (17.8 GPA) or 18.9% for 230, 440, 725, and 900 L/ha (24, 46, 76, and 94 GPA) spray application rates, respectively. Thus, using the airblast sprayer to spray 3.2 m (10.5 ft) tall and 1.9 m (6.2 ft) wide crabapple trees at the application rate ranging from 230 to 900 L/ha (24 to 94 GPA), there was about 16% spray application rate deposited inside canopies.

The operating pressure for 230 and 725 L/ha (24 to 76 GPA) rates were higher than that for 440 and 900 L/ha (46 to 94 GPA) rates (Table 1), resulting in slightly

smaller droplet sizes from the sprayer with the 230 and 725 L/ha rates (24 to 76 GPA) (Table 2). Although there were slight differences in droplet sizes among the four application rates, the amount of spray deposits on targets inside canopies were mainly influenced by the application rate.

Results from Experiment 1 also illustrated spray deposits varied with target heights inside trees (Fig. 3). Targets at 2.6 m (8.5 ft) height received significantly less spray deposits than those at the other three heights for all four application rates. For the same application rate, the spray deposit on targets at 1.2 m (3.9 ft) height was not significantly different from the targets at 1.7 m (5.6 ft) height. The spray deposit on targets at 2.1 m (6.9 ft) height was not significantly different from the deposit on targets at either 1.2 or 1.7 m (3.9 or 5.6 ft) height for the 230 L/ha (24 GPA) rate, but was significantly lower than the deposit on targets at either 1.2 or 1.7 m (3.9 or 5.6 ft) height for the other three application rates.

In general, average spray deposit inside tree canopies decreased as the target height increased for all four application rates (Fig. 3). For example, at the 440 L/ha (46 GPA) application rate, the spray deposit on targets was 124 L/ha (13 GPA) or 1.24 $\mu L/cm^2$ at 1.2 m (3.9 ft) height, 90 L/ha (9.4 GPA) or 0.90 $\mu L/cm^2$ at 1.7 m (5.6 ft) height, 52 L/ha (5.4 GPA) or 0.52 $\mu L/cm^2$ at 2.1 m (6.9 ft) height, and 20 L/ha (2.1 GPA) or 0.20 $\mu L/cm^2$ at 2.6 m (8.5 ft) height above the ground, respectively. The amount of spray deposits on targets at 1.2 m (3.9 ft) height was six times the spray deposits on targets at 2.6 m (8.5 ft) height. For airblast sprayers, it is very important to properly adjust nozzle angles to obtain uniform spray deposition across the tree height inside canopies. However, for tall trees, even though nozzle angles were visually adjusted to cover the entire height

from the ground to the top of trees in this experiment, spray deposits were not equal across the target heights.

Results from Experiment 2 illustrated that average spray deposits in percentage of total spray application rate on targets inside canopies (Fig. 4) varied from 140.8 to 224.8 L/ha (14.7 to 23.5 GPA) or from 18 to 30% with the 700 L/ha (73 GPA) application rate discharged by five identical nozzles. However, statistical analysis demonstrated that there were no significant differences among deposits at four heights inside tree canopies. Compared to the 725 L/ha (76 GPA) rate in Experiment 1, Experiment 2 had shorter trees and smaller spray droplet sizes due to higher operating pressure (Table 2). However, in Experiment 1 with 725 L/ha (76 GPA) rate spray deposits on targets at 2.1 and 2.6 m (6.9 and 8.5 ft) heights were significantly lower than the deposits at the 1.2 and 1.7 m (3.9 and 5.6 ft) heights (Fig. 3). Also, spray deposits inside canopies in Experiment 1 were lower than that in Experiment 2 because of different tree heights. Therefore, for shorter trees when nozzle angles were well adjusted to fit the spray stream in the treated area, tree canopies could receive higher deposits with a noticeably consistent distribution across the tree height even with fewer nozzles. Besides the spray lost on the ground, the rest of spray volume reached to non-target trees or was lost in the air.

Foliar coverage. Similar to the deposition results, spray coverage on targets inside canopies varied with the application rate and target height (Fig. 5); however, the variation was not as great as the variation in spray deposits. At 1.2 and 1.7 m (3.9 and 5.6 ft) heights inside canopies, the spray coverage on targets between 230 and 440 L/ha (24 and 46 GPA) was not significantly different, which was also true for the 725 and 900 L/ha (76 and 94 GPA) application rates (Fig. 5). The spray coverage from the 725 and 900

L/ha (76 and 94 GPA) application rates was significantly higher than that from the 230 and 440 L/ha (24 and 46 GPA) application rates; however, because some droplets overlapped on the same spots on targets, the difference in the coverage between high and low rates was not as great as the difference in spray deposition. At the 2.1 m (6.9 ft) height, the average spray coverage increased as the application rate increased. At the 725 and 900 L/ha (76 and 94 GPA) application rates, many water sensitive papers at the 1.2, 1.7 and 2.1 m (3.9, 5.6 and 6.9 ft) heights were almost totally covered by spray droplets. At the 2.6 m (8.5 ft) height the average spray coverage increased as the application rate increased, but the difference was not strongly significant. Images of water sensitive papers also illustrated that targets at heights of 1.2, 1.7 and 2.1 m (3.9, 5.6, and 6.9 ft) were sufficiently applied by the spray with 230 and 440 L/ha (24 and 46 GPA) application rates, but were over applied by the spray with 725 and 900 L/ha (76 and 94 GPA) application rates.

Compared to the spray coverage on targets at the other three heights, the spray coverage at the 2.6 m (8.5 ft) height was low for all four application rates and was much less than that at the three lower heights; however, targets at the height (2.6 m or 8.5 ft) still appeared to be sufficiently applied at all application rates, compared to the "standard" water sensitive paper images (1).

The average spray coverage across the four heights inside the tree canopies was 42, 46, 56 and 58% for 230, 440, 725, and 900 L/ha (24, 46, 76 and 94 GPA) application rates, respectively. As indicated above, spray deposition inside canopies was almost doubled when the application rate was doubled, which was not true for the spray coverage. Increasing application rate could greatly increase the amount of spray deposits

on leaves, but not greatly increase the spray coverage on leaves. Using high application rates could result in low application efficiency. In field applications, increasing the spray rate to increase the control rate was often recommended; however, when the rate was over 440 l/ha (46 GPA), the coverage would not be increased greatly.

According to equation (1), the spray volume should be 2,252 L/ha (235 GPA) for the 3.2 m (10.5 ft) high and 1.9 m (6.2 ft) wide crabapple trees with 2.7 m (9 ft) row spacing in the Experiment 1. With such a high rate, the portion of trees below 2.6 m (8.5 ft) would be over sprayed because results from this study showed the application rate of 230 L/ha (24 GPA) could produce sufficient deposition and coverage on targets below 2.1 m (6.9 ft) inside canopies. For tall trees treated by airblast sprayers, high application rates could result in excessive spray deposition and coverage on most portions of tree canopies, but the increase in spray deposition and coverage on the top portion of canopies would be very little. Also, higher spray volume requires greater initial air velocity and air stream energy to transport droplets for a given distance. Therefore, overall application efficiency rates would be greatly reduced by applying high rates.

For the trees in Experiment 2, according to equation (1), the spray volume should be 970 L/ha (101 GPA). Experiment 1 indicated 230 L/ha (24 GPA) application rate could adequately cover the portion of trees at 2.1 m (6.9 ft) and below, which means that 230 L/ha (24 GPA) should be sufficient to cover the trees in Experiment 2. Equation (1) assumes that spacing between two rows is fully filled with tree canopies and also assumes that the volume of tree canopies in a row is a solid rectangular box, resulting in excessive estimation of spray volume actually needed by trees. Therefore, Equation 1 should be

modified to include the empty gap between two-row trees and the tree canopy foliage density when it is used to determine the application rates for spraying nursery trees.

Airblast sprayers have many advantages including easy maintenance, transportation and storage, and can be easily adjusted for different sizes of trees. However, airblast sprayers have limitations on delivering sufficient spray deposition to the top portion of tall trees. Within the spray coverage range, the majority of spray covering areas has relatively uniform spray deposition and coverage. Results from this study demonstrated that conventional airblast sprayers might not be the best application method for use if trees are taller than 2.6 m (8.5 ft); otherwise, either the top portion of trees beyond 2.6 m (8.5 ft) would not receive an adequate amount of pesticide or the portion of trees below 2.6 m (8.5 ft) would receive an excessive amount of pesticide. Within the spray coverage range, the application rate of 230 L/ha (24 GPA) can sufficiently cover the target areas. Increasing application rates would increase spray deposition on target areas in lower portions of trees, but not significantly increase the spray deposit on the portion above 2.1 m (6.9 ft). For trees taller than 2.6 m (8.5 ft), other sprayers such as tower sprayers should be used to discharge uniform spray deposition and coverage across the tree height inside canopies.

Another disadvantage associated with the airblast sprayer is that spray deposits across the tree height may not be uniform if the nozzle angles are not adjusted properly, resulting in great off-target loss. Airblast sprayers produce fan pattern shape spray clouds, it is inevitable that a considerable portion of these sprays will reach the ground because of the spray pattern angle. In this study, at the 700 L/ha (73 GPA) rate, there was about 26% of the spray volume lost on the ground before the second tree row, 4.5 m (14.8 ft)

from the sprayer. Therefore, selectively turning nozzles on and off to adjust application rates for short trees can help prevent excess spray loss on the ground.

In conclusion we observed that increasing application rate could greatly increase spray deposition but not greatly increase spray coverage on targets inside canopies. Relative differences in coverage on targets at different heights inside canopies were not as great as the differences for the amount of spray deposits.

For tall trees, the top portions might not receive sufficient spray deposition even with very high spray rate, and the tree canopy across the tree height could not receive equal spray deposits even though nozzle angles were properly adjusted to cover the whole tree height. Conventional airblast sprayers are not the best method to achieve uniform spray deposition and coverage of pesticides for trees taller than 2.6 m (8.5 ft). Increasing nozzle numbers to increase application rates was not effective on tall trees.

For the 700 L/ha (73 GPA) application rate, there was about 18 to 30% of the spray volume deposited inside tree canopies, and at least 34% of total spray volume lost on the ground.

Using the TRV equation to estimate the application rate for nursery trees could cause extremely excessive spray deposits on tree target areas. The equation should be modified including foliage density and empty space between tree rows.

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Table 1. Operating pressure, flow rate and travel speed for the application rate of four hollow cone nozzles tested in Experiment 1.

Hollow cone nozzle	Application rate (L/ha)	Pressure (kPa)	Flow rate (L/m)	Travel speed (km/h)
D2-DC25	230	1240	1.24	6.1
D4-DC25	440	2070	2.41	6.1
D5-DC45	725	1240	3.94	6.1
D7-DC25	900	2070	4.93	6.1

Table 2. Spray droplet size distributions at 50 cm (20 inch) below the hollow cone nozzles used in Experiments 1 and 2. The droplet sizes were measured under laboratory conditions without air assistance.

Nozzle	Experiment	Pressure (kPa)	$D_{V.1}$[z] (µm)	$D_{V.5}$ (µm)	$D_{V.9}$ (µm)
D2-DC25	1	1240	144	185	247
D4-DC25	1	2070	130	164	214
D5-DC45	1	1240	153	212	309
D7-DC25	1	2070	143	200	270
D5-DC45	2	1660	150	202	290

[z] $D_{V.1}$, $D_{V.5}$, and $D_{V.9}$ represent droplet diameter such that 10, 50, and 90% of total liquid volume that is in droplets smaller than $D_{V.1}$, $D_{V.5}$, and $D_{V.9}$, respectively.

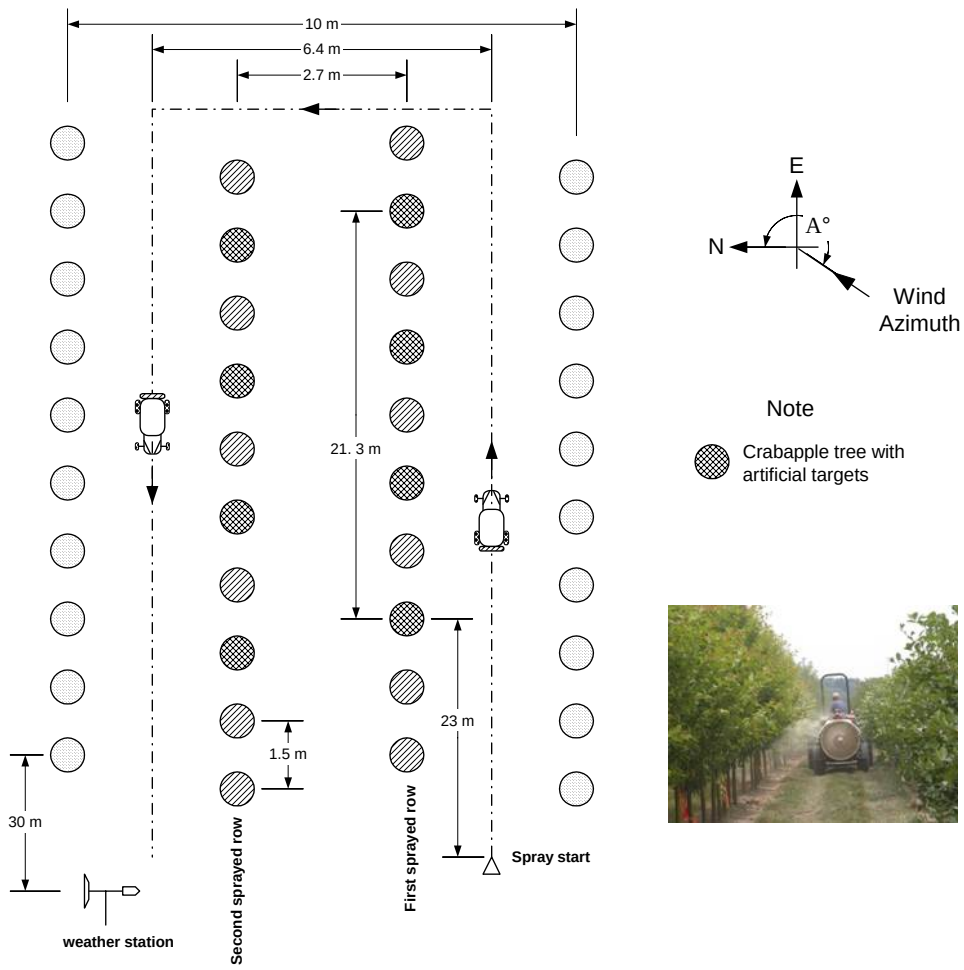

Fig. 1. Schematic and photo of spray site in Experiment 1 (drawing was not to scale).

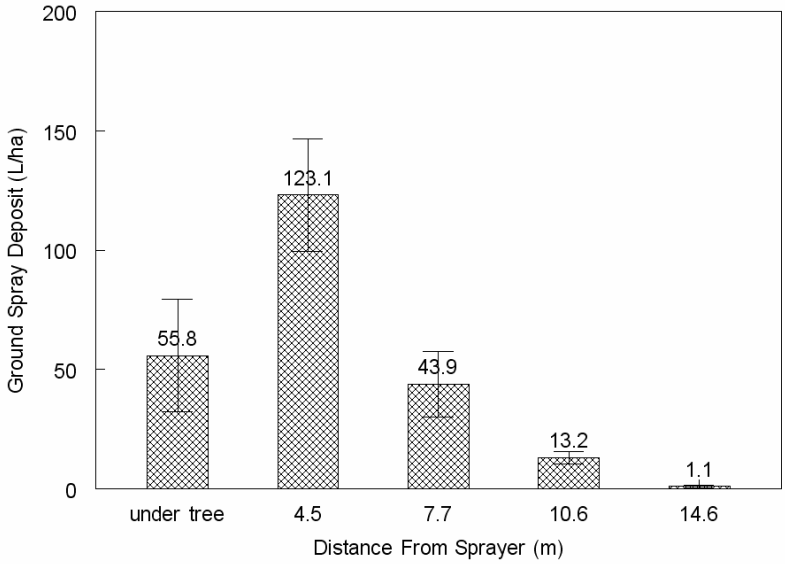

Fig. 2. Spray deposits at different distances downstream from the sprayer at 700 L/ha (73 GPA) application rate in Experiment 2.

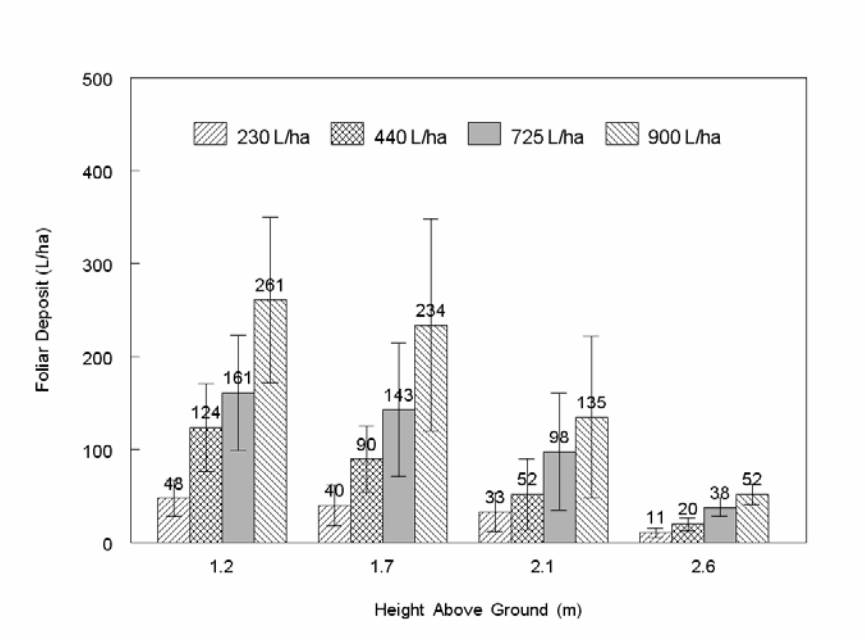

Fig. 3. Spray deposits at four heights [1.2 m (3.9 ft), 1.7 m (5.6 ft), 2.1 m (6.9 ft), and 2.6 m (8.5 ft)] inside crabapple canopies and four different application rates [230 L/ha (24 GPA), 440 L/ha (46 GPA), 725 L/ha (76 GPA), and 900 L/ha (94 GPA)] in Experiment 1.

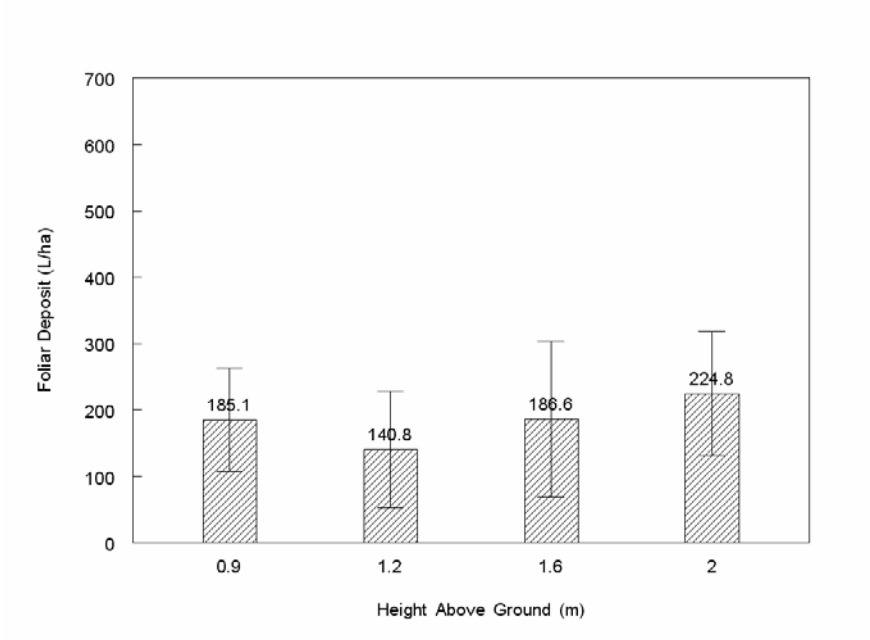

Fig. 4. Spray deposits at four different heights [0.9 m (3.3 ft), 1.2 m (3.9 ft), 1.6 m (5.2 ft), and 2 m (6.6 ft)] inside crabapple canopies applied at 700 L/ha (73 GPA) application rate in Experiment 2.

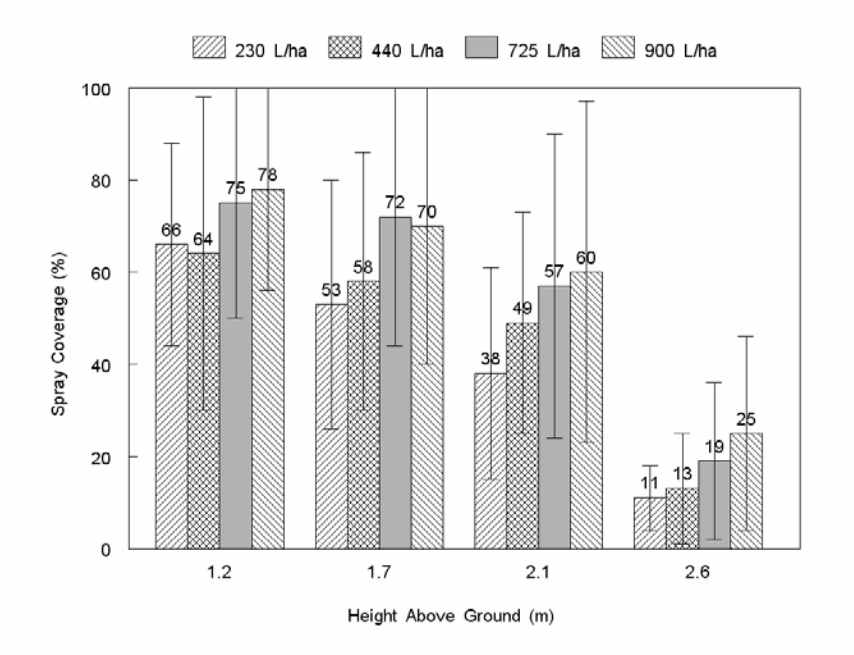

Fig. 5. Spray coverage at four heights [1.2 m (3.9 ft), 1.7 m (5.6 ft), 2.1 m (6.9 ft), and 2.6 m (8.5 ft)] inside crabapple canopies and four different application rates [230 L/ha (24 GPA), 440 L/ha (46 GPA), 725 L/ha (76 GPA), and 900 L/ha (94 GPA)] in Experiment 1. Error bars represent standard deviations from means.