Wide-swath Spray Application in Ornamental Nurseries with Cannon Air Jet Sprayer

Heping Zhu, Agricultural Engineer, USDA/ARS, ATRU, Wooster, OH. heping.zhu@ars.usda.gov
Yang Yu, Visiting Associate Professor, FABE, OARDC/The Ohio State University, Wooster, OH.
Richard C. Derksen, Agricultural Engineer, USDA/ARS, ATRU, Wooster, OH.
H. Erdal Ozkan, Professor, FABE, The Ohio State University, Columbus, OH.
Charles R. Krause, Plant Pathologist, USDA/ARS, ATRU, Wooster, OH.

Written for presentation at the 2007 ASABE Annual International Meeting
Sponsored by ASABE
Minneapolis Convention Center
Minneapolis, Minnesota
17 - 20 June 2007

Abstract. Pesticide spray applications in nurseries are usually implemented in the very early morning to avoid chemical exposures to regular workers and to prevent potential drift to nearby residential areas. Conventional sprayers cannot efficiently apply pesticides to many container ornamental crops due to the special planting circumstance. A cannon air jet sprayer was investigated in an effort to use optimal spray techniques to effectively control pest insects or diseases for container ornamental crops. Air velocity, spray deposition, spray coverage and spray spot density on artificial targets inside and outside hydrangea plants at two heights across the spray swath were evaluated and correlated. Treatments included three flow rates, three travel speeds, and two different nozzle settings. Under the calm weather conditions, the cannon air jet sprayer could provide fairly uniform spray distributions across the 24 m spray swath.

Keywords. Floral crop, Pesticide, Spray deposition, Spray coverage, Air velocity.
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.

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 and field crops with conventional spraying systems. 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. 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.

In recent years, the spray techniques for field trees in nursery production have been studied (Krause et al., 2004; Zhu et al., 1997, 2005). Groszkiewicz et al (1991) evaluated spray techniques for Christmas trees. Derksen et al. (2004) investigated canopy deposits, spray coverage and downwind ground deposits from an air curtain sprayer in a nursery field with red maple trees, and found adjustments were necessary to sprayer settings used for orchard applications to obtain uniform spray deposits in nursery applications. Zhu et al. (2006) developed and investigated a customer-designed five-port air assisted sprayer to control pests for dense nursery crops. However, little research has been done for the spray techniques used for ornamental container production.

Ornamentals are usually grown in containers. The layouts of the plants are arranged in many different patterns for easy transportation, storage and production management. The size of fields varies widely with varieties. In many cases, these container-grown crops are managed in plastic-covered greenhouses (polyhouses). The plastic covers are used in winter time while they are removed during the growing season when it is warm.

The greenhouses are placed side by side with metal frames remained on the top of each production plot during the growing season (Figure 1). Due to the complexity of ornamental production circumstance, it is very difficult to use conventional boom sprayers and air blast sprayers to treat the plants for insect or disease control.

Figure 1. A field view of container-grown ornamentals in a commercial nursery.
The cannon sprayer has an advantage to obtain a very wide spray swath without long arms used in conventional boom sprayers. The air from the sprayer can carry small droplets inside canopies for extensive distances. Compared to the conventional boom sprayers and airblast sprayers, the cannon sprayer is small in size for easy transportation and storage, requires a small spray path for application. However, there is little information on how uniform of spray deposition and coverage across the spray swath that the cannon sprayer can provide, and how far the plants can be effectively covered by the sprays.

The objective of this research was to evaluate the uniformity of spray deposition, coverage and air velocity distribution across the spray swath from the cannon sprayer, and to determine the maximum spray range that plants can be adequately treated. Potential benefits from this study would assist nursery growers to identify optimal spray techniques to effectively control pest insects or diseases for container nursery production.

Materials and Methods

Measurement of Spray Deposition and Coverage

A Model J400 cannon air jet sprayer (Jacto Inc., Brazil) was used for the spray tests. The sprayer offers 24 m spray swath, a 400 L capacity tank, and four flow rate selections. The recommended tractor to carry the sprayer required 50 hp and above. The sprayer also provided an option to choose either hydraulic nozzles or spinning disks for two small air jets to treat targets close to the sprayer.

Spray deposition and coverage were measured at 16 locations between 1.5 m and 24 m from the sprayer in a flat field without plants (Figure 2) and in another field containing hydrangea plants (Figure 3). The locations of targets to measure spray deposition and coverage with or without plants were shown in Figure 4. The distance between each two locations was 1.5 m. Table 1 lists the treatments to determine spray deposits and coverage at different distances from the sprayer with and without plants. Tests #1 to 6 were conducted on a flat ground without plants, and test #7 was conducted in a commercial field with hydrangea plants. A spray mixture containing water and Brilliant Sulfaflavine (MP Biomedicals, Inc., Aurora, OH) at a concentration of 2 g/L was used for all treatments. Each treatment repeated three times.

For the tests in the field without plants (figure 2), nylon screens with 5 by 5 cm size were used as samplers to collect spray deposits, and water sensitive papers (WSP) with 5 by 7.5 cm size were used to measure spray coverage. At each location, spray deposits were measured at 20 cm (bottom target) and 40 cm (top target) above the ground, and each height had one screen. The spray coverage was measured by a WSP at 20 cm above the ground for each location.
For the tests in the commercial field containing hydrangea plants, sheet metal plates with 2.5 by 7.5 cm size were used as samplers to collect spray deposits inside canopies. Screens were not used here because they were too soft to resist the deformation caused by interruptions from canopies. WSPs with 5 by 7.5 cm size were used to measure spray coverage. Each hydrangea plant was grown in a nominal 11.3 L container. The container was 24 cm high and 28 cm in diameter. The average plant height was 46 cm above the container, and the average plant width was 63.5 cm. Plants were placed side by side with little gaps as usually practiced in commercial productions (figure 3). The sheet metal plates were placed inside canopies at 20 cm and 40 cm above the container. Each height had one plate. At 20 cm above the container inside canopies, a WSP was placed adjacent to the metal plate to determine spray coverage inside canopies.

All samples were collected 10 minutes after spraying. Deposition targets were stored in 120 mL glass bottles and WSPs were stored in paper bags. For deposition sample analysis with fluorescence, a given amount of distilled water was added in each bottle to wash tracer from sample surfaces and bottles were shaken approximately for 3 minutes. After completing the washing process, approximately 4 mL of washing liquid was transferred to a clear cuvette. The fluorescence

### Table 1. Treatments of spray deposition and coverage measurement across spray swath between 1.5 and 24 m from the cannon air jet sprayer.

<table>
<thead>
<tr>
<th>Test order</th>
<th>Travel speed (km/h)</th>
<th>Flow rate (L/m)</th>
<th>Field condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.2</td>
<td>6.2</td>
<td>Flat field without plants</td>
</tr>
<tr>
<td>2</td>
<td>3.2</td>
<td>17.8</td>
<td>Flat field without plants</td>
</tr>
<tr>
<td>3</td>
<td>3.2</td>
<td>37.5</td>
<td>Flat field without plants</td>
</tr>
<tr>
<td>4</td>
<td>6.4</td>
<td>6.2</td>
<td>Flat field without plants</td>
</tr>
<tr>
<td>5</td>
<td>6.4</td>
<td>17.8</td>
<td>Flat field without plants</td>
</tr>
<tr>
<td>6</td>
<td>6.4</td>
<td>37.5</td>
<td>Flat field without plants</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>17.8</td>
<td>Commercial field with hydrangea plants</td>
</tr>
</tbody>
</table>

Figure 4. Schematic of spray deposition, coverage and air velocity measurement at different distances from the sprayer.
intensity of each sample was then determined with the Model LS 50B luminescence spectrometer (Perkin-Elmer Limited, Beaconsfield, Buckinghamshire, England) at an excitation wavelength of 460 nm. The amount of spray deposited on each target was then converted to the volume of spray per square centimeter, or mL/cm².

The total spray spot area on a WSP was analyzed with a computer imaging system. The system included a desktop computer, a Model Scanjet 5530 photo-smart scanner (Hewlett-Packard Company, Palo Alto, CA), and an image analyzing software (Image Tool 3.0, The University of Texas Health Science Center, San Antonio, TX). The spray coverage was the percentage of total spray spot area divided by the WSP area.

**Measurement of Dynamic Air Velocity**

Air velocities discharged from the cannon sprayer were measured at 16 locations between 1.5 m and 24 m downstream from the sprayer for the fields without plants and with plants in the same fields as indicated above for the spray deposition and coverage tests. For the air velocity measurement without plants (figure 2), the air velocity probe was placed 20 cm above the ground (figure 4), and the sprayer travel speed was 3.2, 4.8 and 6.4 km/h, respectively. For the air velocity measurement with plants (figure 3), the air velocity probe was placed inside the plant and was 20 cm above the container. The sprayer travel speed for the condition with plants was 3.2 km/h. Air velocities near three nozzle outlets were also measured when the sprayer was not moving. The air velocity measurement for each travel speed was repeated three times.

The probe to measure air velocity at each location was a Model 1210-60, 0.15-mm cylindrical, hot-film, constant temperature anemometer (CTA) sensors (TSI Incorporated, St. Paul, MN) controlled by a Model 1050B anemometer (TSI Incorporated, St. Paul, MN). Each CTA sensor was enclosed in a screen guard to protect it from damage by moving foliage. Output signals from the anemometer were recorded with a 14-channel, Model 3500, magnetic tape recorder (Sangamo Electric Company, Springfield, IL). The sensors were calibrated with a Model 1125 calibrator (TSI Inc., Shoreview, MN). After air-velocity signals were recorded on a magnetic tape in the field, a Keithley Model KPCI-3108 data acquisition board (Keithley Instruments, Inc. Cleveland, OH) was used in the laboratory to convert analog velocity

![Figure 5. Air velocity profiles without plants at 7.6, 9.1, 10.7, and 12.2 m (or 25, 30, 35, and 40 ft) from the sprayer when travel speed was 3.2 km/h (or 2 mph).](image)

![Figure 6. Air velocity profiles inside hydrangea plants at 7.6, 9.1, 10.7, and 12.2 m (or 25, 30, 35, and 40 ft) from the sprayer when travel speed was 3.2 km/h (or 2 mph).](image)
signals from the magnetic tape to digital format, acquired and stored at a rate of 2,000 samples per second. The air velocity profile at each location was then obtained during the short period of time when the sprayer was passing the sprayed line (figures 5 and 6).

All deposition, coverage and air velocity tests were conducted in very early mornings when the wind was calm. The wind speed and direction at 2.5 m above the ground and 10 m upstream from the sprayer were measured with a portable weather station. Wind speed was below 1.8 m/s and wind direction was parallel to the spray direction for all tests.

**Measurement of Leaf Area Index (LAI)**

The leaf area index of hydrangea canopies 16 locations from 1.5 to 24 m from the sprayer was determined using an LAI-2000 plant canopy analyzer (LI-COR®, Inc., Lincoln, Nebraska) with two sensor modes. The upper sensor was set about 1.2 m above the ground. Both sensors were leveled. At each location, LAI at four orientations in a square shape were measured to provide a mean value for that location. The measurement was repeated twice at each location. The sky was fully covered by clouds at the moment of measurement. The LAI sensor was also calibrated under fully-cloudy conditions.

**Results and Discussion**

**Without Plants**

Without plants, the peak air velocity gradually decreased as the distance from the sprayer increased (figure 7). The air between 7.6 and 24 m from the sprayer was discharged from the main air jet, and the air between 1.5 and 6.1 m was mainly from the two small jets. Between 1.5 and 6.1 m from the sprayer, the air velocity decreased dramatically because of low volume of air discharged from the two small jets. For the 3.2 km/h travel speed, the peak air velocity decreased from 17.7 to 2.3 m/s when the distance from the sprayer increased from 1.5 to 6.1 m. For the same travel speed, the peak air velocity decreased from 7.9 to 3.1 m/s when the distance from the sprayer increased from 7.6 to 24 m.

Because of the air drag force, the sprayer travel speed influenced the peak air velocity across the spray swath. The peak air velocity slightly decreased as the travel speed increased under the condition of no plants (figure 7).

Spray deposits on both top and bottom targets without plants increased as flow rate increased, and increased as the travel speed decreased (figures 8 and 9, Table 2). Higher travel speed and higher flow rate had higher variations in spray deposition across 24 m spray swath than lower travel speed (Table 2). For the 3.2 km/h travel speed, the coefficient of variation on
the average spray deposits across the 24 m spray swath for all three flow rates were less than 80%.

Table 2. Average spray deposit and its variation on top and bottom targets without plants across the spray swath between 1.5 and 24 m from the cannon sprayer at 3.2 and 6.4 km/h travel speeds and three different flow rates

<table>
<thead>
<tr>
<th>Flow Rate (L/m)</th>
<th>Top Targets 3.2 km/h</th>
<th>6.4 km/h</th>
<th>Bottom Targets 3.2 km/h</th>
<th>6.4 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deposit (µL/cm²) CV†</td>
<td></td>
<td>Deposit (µL/cm²) CV</td>
<td></td>
</tr>
<tr>
<td>6.2</td>
<td>0.110 49</td>
<td>0.027 98</td>
<td>0.082 45</td>
<td>0.030 79</td>
</tr>
<tr>
<td>17.8</td>
<td>0.181 54</td>
<td>0.085 135</td>
<td>0.145 56</td>
<td>0.049 129</td>
</tr>
<tr>
<td>37.5</td>
<td>0.347 70</td>
<td>0.183 160</td>
<td>0.265 76</td>
<td>0.141 145</td>
</tr>
</tbody>
</table>

†CV – coefficient of variation on the average deposit across the 24 m spray swath.

Similar to the spray deposition results, spray coverage on targets without plants also increased as the flow rate increased, and increased as the travel speed decreased (figure 10). For the three different flow rates at 6.4 km/h travel speed, the spray spot density on targets without plants was generally greater than 100 spots/cm² while at 3.2 km/h travel speed the most portion of water sensitive papers were covered by sprays (figure 11). The coefficient of variation on spray coverage on targets across 24 m spray swath increased with the travel speed, but decreased with the flow rate (table 3).
Figure 10. Spray coverage on WSPs across the spray swath from the cannon sprayer at three travel speeds (3.2 and 6.4 km/h) and three flow rates (F0=6.2, F2=17.8, and F4=37.5 L/m) in the field without plants. The sprayer used hydraulic nozzles for the two small jets. Coverage readings of 45% and above indicated WSPs were too wet to be accurately measured.

Figure 11. Density of spray spots on 1 cm² WSPs across the spray swath from the cannon sprayer at three travel speeds (3.2 and 6.4 km/h) and three flow rates (F0=6.2, F2=17.8, and F4=37.5 L/m) in the field without plants. The sprayer used hydraulic nozzles for the two small jets. WSPs with 400 spots/cm² and above were too wet to count number of spots.

Table 3. Average spray coverage and its variation on targets without plants across the spray swath between 1.5 and 24 m from the cannon sprayer at 3.2 and 6.4 km/h travel speeds and three different flow rates

<table>
<thead>
<tr>
<th>Flow Rate (L/m)</th>
<th>3.2 km/h</th>
<th>6.4 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coverage (%)</td>
<td>CV† (%)</td>
</tr>
<tr>
<td>6.2</td>
<td>32</td>
<td>71</td>
</tr>
<tr>
<td>17.8</td>
<td>64</td>
<td>41</td>
</tr>
<tr>
<td>37.5</td>
<td>76</td>
<td>30</td>
</tr>
</tbody>
</table>

†CV – coefficient of variation on the average spray coverage across the 24 m spray swath.

Figures 12 and 13 show the combined spray deposits at top and bottom targets without plants for different peak air velocities at 3.2 and 6.4 km/h travel speeds, respectively. The spray deposits increased as the peak air velocity increased except for the 6.2 L/m flow rate at the 6.4 km/h travel speed. With the 3.2 km/h travel speed when the peak air velocity increased from 3 to 9 m/s, the estimated spray deposition increased from 0.146 to 0.219 µL/cm² for 6.2 L/m flow rate, from 0.257 to 0.369 µL/cm² for 17.8 L/m, and from 0.540 to 0.693 µL/cm² for 37.5 L/m,
respectively. For a given travel speed even without plant conditions, there was no linear translation from the flow rate to spray deposits. That is, the spray deposits on targets were not linearly increased by increasing flow rate.

Figure 12. Effect of peak air velocity on spray deposition on targets 20 and 40 cm above the ground without plants for the flow rate of 6.2, 17.8 and 37.5 L/m, respectively. Travel speed was 3.2 km/h.

Figure 13. Effect of peak air velocity on spray deposition on targets 20 and 40 cm above the ground without plants for the flow rate of 6.2, 17.8 and 37.5 L/m, respectively. Travel speed was 6.4 km/h.

With Hydrangea Plants

The average LAI of canopies at 16 locations was 5.2 with a standard deviation of 0.7. The value of LAI indicated that the foliage of hydrangea plants was very dense. With such high LAI, the peak air velocity inside hydrangea canopies was greatly reduced. The highest peak air velocity inside canopies measured across the 24 m spray swath was less than 6 m/s (figure 14). Also, the peak air velocity at locations between 6.1 and 24 m from the sprayer had more fluctuation than the situation without canopies. For example, between 6.1 and 24 m from the sprayer and at 3.2 km/h travel speed, the peak air velocity inside hydrangea canopies was in the range between 0.5 and 4.2 m/s while without canopies it was in the range between 3.3 and 7.9 m/s.

Hydrangea is one of the densest ornamental plants in nurseries. In most cases, hydrangea requires the top portion of canopies to be treated well. The cannon sprayer could deliver sprays to the top portion of targets 24 m away from the sprayer (figure 15). The spray deposit at lower portion of the canopy did not
receive the same quantity of spray deposits as at the top portion of canopies across the 24 m spray swath (figure 16).

![Figure 15](image1.png)  
**Figure 15.** Spray deposits on top targets inside canopies across the spray swath from the cannon sprayer at 3.2 km/h travel speed and 17.8 L/m flow rate in the field with hydrangea plants. The sprayer used hydraulic nozzles for the two small jets.

![Figure 16](image2.png)  
**Figure 16.** Spray deposits on bottom targets inside canopies across the spray swath from the cannon sprayer at 3.2 km/h travel speed and 17.8 L/m flow rate in the field with hydrangea plants. The sprayer used hydraulic nozzles for the two small jets.

The existence of plants affected the amount of spray deposits on the targets. The top targets with the hydrangea plants received more deposits than the top targets without plants while the bottom targets with the hydrangea plants received much less deposits than that without plants. For example, with hydrangea plants when the flow rate was 17.8 L/m and travel speed was 3.2 km/h, the average deposit across the 24 m spray swath was 0.268 µL/cm² with 77% CV at the top of the canopy, and was 0.014 µL/cm² with 146% CV at the bottom of the canopy. For the same conditions without plants, the average deposit was 0.181 µL/cm² with 54% CV at the top targets, and was 0.145 µL/cm² with 56% CV at the bottom targets.

Spray coverage and spray spot density inside canopies was much lower than the condition without plants (figures 17 and 18). Across 24 m spray swath and 25 cm below the canopies, the average spray coverage was 2.0% with 109% CV, and the average density of spray spots was 41 spots/cm² with 94% CV. The recommended droplet density in the target area was from 20 to 30 droplets per square centimeter for spraying insecticides and 50 to 70 droplets per square centimeter for spraying fungicides (Anonymous, 2004). Therefore, at 3.2 km/h travel speed and 17.8 L/m flow rate, the cannon sprayer could provide enough droplets to control insects inside hydrangea plants, but might not provide enough droplets for fungus control inside hydrangea plants. The application rate was 136 L/ha (14.5 gallon per acre) when the operation condition was 3.2 km/h travel speed, 17.8 L/m total flow rate and 24 m spray width. Currently, growers usually apply over 1000 L/ha rate with high pressure hand gun sprayers to treat hydrangea plants.
Figure 17. Spray coverage on WSPs across the spray swath from the cannon sprayer at 3.2 km/h travel speed and 17.8 L/m flow rate in the commercial field with hydrangea plants. The sprayer used hydraulic nozzles for the two small jets.

Figure 18. Density of spray spots on 1 cm² WSPs across the spray swath from the cannon sprayer at 3.2 km/h travel speed and 17.8 L/m flow rate in the commercial field with hydrangea plants. The sprayer used hydraulic nozzles for the two small jets.

Figure 19 shows the relationship between the peak air velocity and the combined spray deposits on top and bottom targets inside canopies at 3.2 km/h travel speed and 17.8 L/m flow rate. The spray deposits inside hydrangea canopies increased as the peak air velocity increased. When the peak air velocity increased from 0.5 to 4.5 m/s, the estimated spray deposits increased from 0.195 to 0.563 µL/cm². The deposition increase rate inside canopies was much higher than that without canopies (figures 12 and 19).

The spray deposition and coverage across the spray swath from the cannon sprayer might be sensitive to winds. The spray deposition and coverage would be greatly increased when the application had the same direction as the wind direction. Nursery growers usually spray pesticides in the very early morning. To avoid pesticide exposure to workers, they would like to complete the spray application before the workers go to the field. They also would not like to minimize spray drift because many nursery fields are small and close to residential areas. In the very early morning before the sunrise, the weather is usually very calm. Therefore, the cannon sprayers should have a great advantage to be used for nursery container crop productions.

Conclusion

Under the calm weather conditions, the cannon sprayer delivered acceptably uniform spray deposition and spray coverage across the 24 m spray swath in the fields with and without plants.
Travel speed greatly influenced the spray deposition without plants across the spray swath. With the same flow rate, lower travel speed produced higher spray deposits and coverage across the spray swath. Doubling both travel speed and flow rate would not produce the same deposition on targets as expected.

The peak air velocity tended to decrease as the distance from the sprayer increased. However, even at 24 m from the sprayer, the peak air velocity was higher than 3 m/s at 20 cm above the ground in the field without plants, and was about 1.2 m/s inside canopies in the field with hydrangea plants. Spray deposition on targets inside canopies or without plants increased as the peak air velocities near the targets increased.

Acknowledgements

Technical assistance was provided by A. Clark, L. Morris, B. Nudd and K. Williams. The authors also acknowledge Jacto Inc. for providing the sprayer, and Willoway Nurseries Inc. for the cooperation in providing the field space and plants.

References


