GREENHOUSE EVALUATION OF AIR-ASSIST DELIVERY PARAMETERS FOR MATURE POINSETTIAS

R. C. Derksen, C. M. Ranger, L. A. Cañas, H. Zhu, C. R. Krause

ABSTRACT. *Understanding the performance characteristics of application equipment is important for helping make the most efficacious applications. While handguns making high volume applications are common in greenhouse production, it is difficult to achieve uniform distribution of product in a timely manner. Broadcast applications made using air-assistance can help aid canopy penetration and the volume of carrier required to make applications. The objectives of this research were to determine how air-assist sprayer application parameters influence spray deposits on the undersides of leaves in a mature poinsettia canopy. Bench-top trials were conducted using a motorized boom inside a greenhouse to treat a mature and dense poinsettia canopy. Sprayer treatments applied a tank mix of water and fluorescent tracer. Nylon screen targets were secured to the underside surfaces of leaves in the upper and lower elevation of target plants. A five-port, air-assist nozzle with flat fan nozzle tips was used to make the applications. Three air outlet speeds, two travel speeds, and three nozzle flow rates were evaluated. Each treatment was replicated three times. Spray deposits were highly variable. Upper elevation spray deposits were significantly greater than lower elevation deposits. Individually, higher air outlet speed (36.0 m s^{-1}), slower travel speed (3.2 km h^{-1}), and higher nozzle flow rate (1.17 L min^{-1}) tended to produce higher sprayer deposits on the underside surfaces of leaves. The combination of travel speed and nozzle flow rate that produced the highest application rate (900 L ha^{-1}) also produced the highest deposits. There was a 500% increase in underside leaf surface deposits in the lower canopy area for a corresponding 500% increase in application rate. However, the main effects produced no significant differences in spray deposits in the lower canopy area. Further improvements in directing sprays or providing canopy turbulence are necessary to improve deposition and management of insect pests feeding on the underside of poinsettia leaves.*

Keywords. *Poinsettia, Sprayers, Droplet, Air-assisted sprayers, Greenhouse, Spray deposition.*

Poinsettias continue to generate the most sales in the United States among all potted flowering plants. In 2008, sales of poinsettias amounted to $154 million in wholesale sales (USDA, 2009). Insects feeding on the undersides of poinsettia leaves can significantly impact the quality and value or ornamental crops such as greenhouse grown poinsettias. As the poinsettia canopy matures, the underside of the nearly horizontal leaves become more difficult to treat with pesticides that require direct contact with insect pests.

Handguns are typically used by applicators to direct spray at greenhouse canopies. However, handguns require the operator direct the spray at each target to ensure deposition. It is difficult to maintain the angle of spray and speed of movement to ensure uniform spray delivery. Broadcast applications used in field crop applications can treat large swaths in a single pass to provide uniform spray delivery over a canopy. Knewitz et al. (2003) reported that a handheld boom using cone nozzles provided more uniform spray distribution in an ornamental canopy than a single-nozzle handgun. Langenakens et al. (2002) also reported that boom or broadcast applications provided more uniform spray distribution than a handgun application to greenhouse plants on the floor.

Growers find that they can visualize treated areas more easily using high volume, handgun treatments. Unfortunately, handgun applicators usually are directed at one side of a canopy only and such use can result in wide variations in deposit patterns. Evaluating handgun treatments, Derksen et al. (2008) found that spray canopy or target position was a significant factor in the fate of the spray. There was a 4x difference in the amount of material found on targets between upper and lower parts of the canopy. Derksen et al. (2008) also reported a 10x difference between the amount of spray deposit found on the front side of the plant facing the nozzle discharge compared to the backside of the plant. Comparing handgun delivery with broadcast delivery using a five-port, air-assist delivery system, Derksen et al. (2010) reported that both treatments resulted in high variability in abaxial surface deposits but that the air-assist treatment produced the highest mean deposits in the lower canopy area.

Air-assisted spraying is used to a lesser degree to treat field crops with broadcast sprayers than in tree and vine crops. An air stream helps provide energy to carry spray droplets to the target and may provide turbulence that can aid in greater deposition on more target surfaces. Manor and Gal (2002) demonstrated the benefits in deposition provided by several turbulent air-jets directed at a grape canopy. Field

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trials examining delivery by air-assisted techniques compared to conventional delivery through non-air-assisted techniques reported that, at the same carrier rate, air-assisted delivery improves canopy penetration and the amount of spray deposited on canopy targets (Womac et al., 1992; Piché et al., 2000; Derksen et al., 2001; Mueller et al., 2002; Derksen et al., 2008). Manor et al. (1989) found improvements in overall droplet coverage and defoliation in a dense, lapped cotton crop when treated with an air-assisted sprayer. Derksen et al. (2007) achieved higher spray coverage on abaxial surfaces of bell pepper leaves using air-assisted delivery with single fan nozzles than when using conventional delivery with either twin-fan and air induction nozzles. In greenhouse studies with potted herb crops, Gamliel et al. (2000) found that air-assisted delivery of aerosol sprays (cold fogger, 5 L ha^{-1}) produced higher abaxial deposits than low volume, air-assisted delivery (50 L ha^{-1}) and high volume, handgun application (200 L ha^{-1})

While ornamental producers are encouraged to use so-called 'soft' pesticides, these generally rely on contact with the pest and require delivery to specific target areas of plants. The objective of this research was to evaluate selected spray delivery parameters comprised of air outlet speed, travel speed, and nozzle flow rate for deposition of spray material on the underside of leaves in the upper and lower elevations of a mature poinsettia canopy. The intent is to better define delivery parameters for treating greenhouses ornamentals that will maximize spray deposits for managing insect pests feeding on the underside of leaves.

Materials and Methods

Experimental Plot

Freedom Red poinsettia cuttings received from Paul Ecke Ranch were transplanted on 2 April 2007. The cuttings were stuck in 15-cm pots at the greenhouse facility of the Department of Entomology at the Ohio Agricultural Research and Development Center in Wooster, Ohio. Figure 1 illustrates the layout for each replicate for each treatment. The positions of the target plants were constant for each equipment pass. Poinsettias were spaced 27 cm on center on the bench. The target plants were replaced between each test application and border plants remained in place.

Treatments

The trial consisted of 18 different treatments. Treatments included combinations of three different air outlet speeds (AOS), three different nozzle flow rates (NFR), and two different travel speeds (TS). Table 1 describes the various combinations of sprayer delivery parameters used in these trials. The order of applications was not randomized but was based on minimizing the number of changes between tests. Each of the treatments was replicated three times producing a total of 54 runs for these trials. All treatments applied the same spray mixture containing water and brilliant sulfaflavine (BSF) (MP Biomedicals, Inc., Aurora, Ohio) at a concentration of 3 g L^{-1}.

The air-assist, five-port nozzle manifold used to make the applications is pictured in figure 2. The five-port nozzle consisted of an air manifold with five ports (Montana Industrials, Dal Negro, Brazil; distributed by Pickin' Patch, Inc., Plymouth, Ind.) and five nozzles for liquid discharge. The internal geometric construction of the five-port air manifold is described by Zhu et al. (2006). The manifold was cast with five ports at 15° radial separation, each with an inside diameter of 3.6 cm. The liquid dischargers were flat fan nozzle inserts modified to fit in the outlets of the air manifold. Sets of five each of TeeJet XR11001, XR11002, and XR11003 (Spraying Systems Co., Wheaton, Ill.) tips

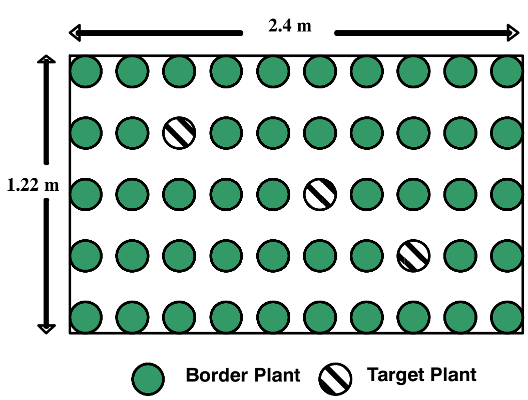

Figure 1. Experimental layout for each replicate.

Table 1. Spray equipment parameters.

Travel Speed (km h^{-1})	Nozzle Pressure (kPa)	Single Nozzle Flow Rate (L min^{-1})	Application Rate (L ha^{-1})
3.2	289.4	0.39	300
6.4	289.4	0.39	150
3.2	296.3	0.78	600
6.4	296.3	0.78	300
3.2	289.4	1.17	900
6.4	289.4	1.17	450

Figure 2. Five-port, air-assist sprayer manifold.

were used to achieve the three different delivery rates. Nozzle tips were mounted at the centerline of each port of the five-port air manifold.

The air-assist, five-port nozzle was mounted on an 5.2-m tower irrigation boom supported on the ends by rails with a Common Sense Controller (Greenhouse Technology, Inc., Richmond, Ky.) which could be set to operate at different travel speeds over the treatment area (fig. 3). The air supply was provided by a Black & Decker Model BV4000 leaf blower/vacuum (Towson, Md.) mounted on the irrigation boom. The five-port manifold was operated at 30° forward of vertical with the center of the manifold 35.6 cm above the canopy (fig. 2). Air velocity measurements of the modified five-port spray nozzle were made using a TSI Model 8386A VelociCalc air velocity meter (Shoreview, Minn.). The air velocity at the five outlets was measured directly at each nozzle outlet. The air velocity measurements were offset from the spray tips, which were mounted in the center of the spray nozzles and interfered with measures directly at the outlet. The three air outlet speed treatment settings produced an average outlet speed of 36.0, 27.4, and 18.3 m s^{-1}.

Monofilament nylon screen (Filter Fabrics, Inc., Goshen, Ind.) attached to the undersides of leaves with double-sided tape prior to treatment were used as targets to simulate leaves to collect foliar spray deposits within the poinsettia canopy. Each screen size was 3.8 × 3.8 cm. The screen had a nominal porosity of approximately 56% or fiber frontal area percentage of 44%. Individual screens were attached to the undersides of two leaves from each of the upper and lower elevations resulting in four total targets per plant. Target leaves were chosen at random at each elevation but were selected to be larger than the targets.

Droplet Sizing and Velocity Measurement

Droplet size distributions and for test nozzles were determined using a particle/droplet laser image analysis system (Oxford Lasers VisiSizer and PIV, Oxfordshire, UK) described by Güler et al. (2007). During the tests, the laser image analysis system setting was lens option 3 at magnification setting 1. At this setting, the system could measure droplets from 42.8 to 1023.7 µm. At least 10,000 droplets were counted for the size measurements. Droplet samples were taken 50 cm below the center nozzle orifice and across centerline along the long axis of the spray pattern by scanning within 30 cm on either side of the centerline of the spray patterns. The measurement for each condition was replicated three times.

Tracer Extraction

Following treatment, target plants from the locations identified in figure 1 were removed from the treatment area and replaced with three untreated plants and new targets. After a drying time of approximately 10 min, the screens from the treated plants were removed. The two screens from each elevation on an individual plant were collected and placed in 125-mL glass bottles.

Spray deposits were extracted from the targets by rinsing with 30 mL of purified water (prepared with Mega-pure System, model MP-12A, Barnstead International, Dubuque, Iowa). A 4-mL sample rinsate solution was then placed in a cuvette for determination of peak fluorescent intensity with a luminescence spectrometer (model LS 50B, Perkin-Elmer, Ltd., Beaconsfield, U.K.) at an excitation wavelength of 460 nm. The limit of detection for the fluorometer is 1 ppb. If a sample concentration fell above the calibration range, it was further diluted and measured again. Quantification of dye deposition was achieved using a standard concentration curve prepared with serially diluted samples of known concentration. The mass of tracer found on the targets was converted to spray volume using the concentration of tracer in the tank mix because not all treatments applied the same rate of tank mix.

Statistical Analyses

Deposition data were converted into volume of spray solution found on the targets. Potential outliers in the deposition data for each BSF delivery method were identified as extreme Studentized residual values (PROC GLM, SAS

Figure 3. Watering boom with five-port, air-assist sprayer and blower.

Institute Inc., Cary, N.C.). If an outlier could not be explained, it was removed to avoid violating assumptions of equal normality and variance. The three subsamples associated with each spray replicate were then averaged. The model fit distribution was examined along with residual plots and Box-&-whisker plots. A four-factor mixed effects repeated measures ANOVA (analysis of variance) was conducted on the fixed effects factors of AOS, TS, and NFR with repeated measures on ELEV (PROC GLM, SAS Institute Inc., Cary, N.C.). Random effects were PASS and Plant (AOS*TS*NFR).

Results and Discussion

The atomization characteristics of the five treatments are shown in table 2. The tests revealed that not running the blower for air-assistances produced the smallest droplet spectrum for each of the three nozzle treatments. Droplet size differences between the 18.3 and 36 m s^{-1} air outlet speeds (AOS) were smaller than those between AOS of 0 and 18.3 m s^{-1}. The smallest nozzle tip, XR11001, produced the smallest droplet spectrum at all blower settings and the XR11003 produced the largest droplet spectrum.

The ANOVA table for the four-factor mixed effects analysis showed a significant AOS*TS*NFR*ELEV interaction ($p = 0.0012$). Because of the complexity of examining the four-way interaction and the significance level of the main effect ELEV ($p < 0.0001$), two three-factor ANOVAs were conducted examining the effects of AOS, TS, and NFR at each level of ELEV (one for upper elevation and one for lower elevation).

Four outliers occurred in the upper elevation group and were removed from further analysis. The results for the upper elevation three-factor ANOVA evaluation showed a significant AOS*TS*NFR interaction ($p = 0.0008$) (table 3). Even though all main effects (AOS, TS, and NFR) and one two-factor interaction (TS*NFR) were significant ($p < 0.05$) in the upper elevation evaluation, these are not easily explained since the three-way interaction is significant. Pairwise differences were examined using the differences of least squares means with a Bonferroni adjustment to correct for the number of interaction comparisons (table 4). Mean separation was based on differences of least squares means at $p \leq 0.05$ with a Bonferroni adjustment.

The treatment combination with the highest AOS (36.0 m s^{-1}), the slowest travel speed (3.2 km h^{-1}), and the highest NFR (1.17 L min^{-1}) produced significantly higher underside leaf deposits in the upper elevation than all other treatment combinations except for AOS = 36.0, TS = 6.4, and NFR = 0.78. The treatment combinations using the lowest NFR (0.39 L min^{-1}) and the highest TS (6.4 km h^{-1}) tended to produce the lowest underside leaf deposits in the upper elevation.

One data point outlier was removed from the lower elevation group prior to further analysis. The results for the upper elevation three-factor ANOVA evaluation for the lower elevation showed no significant interactions or main effects for AOS, TS, and NFR (table 5). No means separation testing was performed on the lower elevation data since no significant effects were observed despite a six times difference in the application rate.

The effect that AOS had on underside leaf deposits in both the upper and lower elevations is illustrated in figure 4. As AOS increased from 18.3 to 36.0 m s^{-1}, underside leaf spray deposits in the upper elevation tended to increase across all treatment combinations. AOS appeared to have a much smaller affect on underside leaf spray deposits in the lower elevation.

Figure 5 illustrates the effect that TS had on deposits on the underside of leaves at both the upper and lower elevations. Underside leaf spray deposits were higher in the upper elevation compared to the lower elevation. Across all treatment combinations, deposits were lower at the higher TS. Lower application rates were associated with higher TS. The decrease in deposits at the higher TS was more significant in the upper elevation than the lower elevation.

Table 3. Type 3 tests of fixed effects for upper elevation.

Effect	Numerator Degrees of Freedom	Denominator Degrees of Freedom	F Value	Pr > F
AOS	2	140	4.85	0.0092
TS	1	140	7.14	0.0084
AOS*TS	2	140	2.56	0.0811
NFR	2	140	20.73	<.0001
AOS*NFR	4	140	0.51	0.7269
TS*NFR	2	140	5.14	0.0070
AOS*TS*NFR	4	140	5.03	0.0008

Table 2. Treatments and droplet sizing.

Nozzle Tip	Nozzle Pressure (kPa)	Air Outlet Speed (m s^{-1})	Droplet Spectrum Characteristics			
			$D_{V.10}$ (μm)	$D_{V.50}$ (μm)	$D_{V.90}$ (μm)	Maximum (μm)
XR11003	289.4	36.0	111.8	249.0	427.0	606.7
XR11003	289.4	27.4	121.9	270.4	435.5	651.3
XR11003	289.4	18.3	117.4	258.6	411.1	577.5
XR11003	289.4	off	94.8	176.6	376.4	645.4
XR11002	296.3	36.0	95.8	201.9	363.8	527.0
XR11002	296.3	27.4	98.9	205.0	348.5	464.4
XR11002	296.3	18.3	96.0	200.5	337.2	507.7
XR11002	296.3	off	83.9	149.4	284.4	435.1
XR11001	289.4	36.0	86.5	163.2	265.7	466.0
XR11001	289.4	27.4	89.7	160.5	254.1	382.3
XR11001	289.4	18.3	88.7	155.7	254.2	405.6
XR11001	289.4	off	78.5	137.7	204.6	325.5

Table 4. Mean deposits upper elevation deposits by treatment.

Air Outlet Speed (m s^{-1})	Travel Speed (km h-^{1})	Single Nozzle Flow Rate (L min^{-1})	Mean Spray Volume Deposit (μL cm^{-2})	Standard Deviation
18.3	3.2	0.39	0.0141 b c[a]	0.0089
18.3	3.2	0.78	0.0264 b c	0.0208
18.3	3.2	1.17	0.0339 b c	0.0133
18.3	6.4	0.39	0.0098 c	0.0089
18.3	6.4	0.78	0.0266 b c	0.0163
18.3	6.4	1.17	0.0344 b c	0.0141
27.4	3.2	0.39	0.0256 b c	0.0191
27.4	3.2	0.78	0.0316 b c	0.0225
27.4	3.2	1.17	0.0338 b c	0.0164
27.4	6.4	0.39	0.0093 c	0.0095
27.4	6.4	0.78	0.0322 b c	0.0167
27.4	6.4	1.17	0.0339 b c	0.0211
36.0	3.2	0.39	0.0255 b c	0.0168
36.0	3.2	0.78	0.0316 b c	0.0215
36.0	3.2	1.17	0.0745 a	0.0077
36.0	6.4	0.39	0.0130 c	0.0096
36.0	6.4	0.78	0.0459 a b	0.0431
36.0	6.4	1.17	0.0214 b c	0.0091

[a] Means followed by the same letter are not significantly different.

Table 5. Type 3 tests of fixed effects for lower elevation.

Effect	Numerator Degrees of Freedom	Denominator Degrees of Freedom	F Value	Pr > F
AOS	2	143	0.05	0.9503
TS	1	143	0.81	0.3699
AOS*TS	2	143	0.59	0.5547
NFR	2	143	2.08	0.1285
AOS*NFR	4	143	0.77	0.5454
TS*NFR	2	143	0.26	0.7676
AOS*TS*NFR	4	143	0.93	0.4499

The effect of the NFR main effect on spray deposits across all treatment combinations is illustrated in figure 6. While the two-way interaction of NFR was not significant at either elevation (tables 3 and 4), higher NFR tended to result in higher underside leaf spray deposits in both the upper and lower elevation. The effect of increasing NFR produced a greater change in spray deposits on leaves in the lower elevation than the upper elevation. The resulting 125% increase in foliar spray volume deposits in the upper canopy was not consistent with the 200% increase in nozzle output. Increasing NFR from 0.39 to 1.17 L min^{-1} resulted in a 170% increase in spray volume deposits in the lower canopy area. The effect of increasing NFR from 0.39 to 0.78 L min^{-1} appears to have had a greater affect on foliar spray volume deposit than the increase from 0.78 to 1.17 L min^{-1}. It is not clear from these results if the increase in droplet size measured with greater nozzle output (table 2) may have contributed to changes in canopy penetration and deposits on the underside of leaf surfaces.

The effect of application rate on underside leaf spray deposits can be illustrated by examining the various combinations of TS and NFR across all treatment (fig. 7). The application rates used in this study ranged from 150 to 900 L ha^{-1}. There are two sets of data points at the 300 L ha^{-1} application rate since two different combinations of TS and NFR (TS = 3.2 km h^{-1} + NFR = 0.39 L min^{-1} and TS = 6.4 km h^{-1} + NFR = 0.78 L min^{-1}) resulted in the same application rate. With an average difference in $D_{v.50}$ of approximately 42 μm, the faster moving treatment (TS = 6.4 km h^{-1} + NFR = 0.78 L min^{-1}) producing the larger spectrum produced higher underside leaf surface deposits at both canopy elevations than the slower travel speed treatment (TS = 3.2 km h^{-1} + NFR = 0.39 L min^{-1}) with its smaller droplet

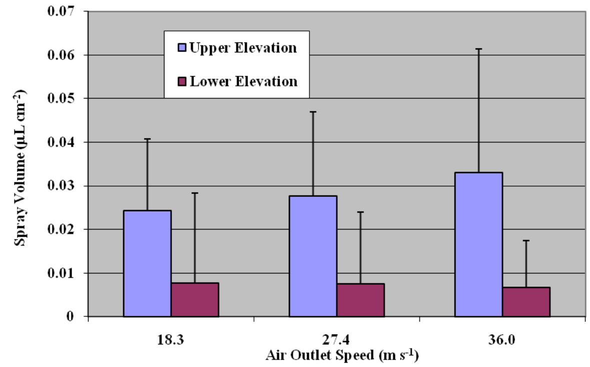

Figure 4. Mean spray volume deposit and standard error bars by air outlet speed across all nozzle flow rates and travel speeds.

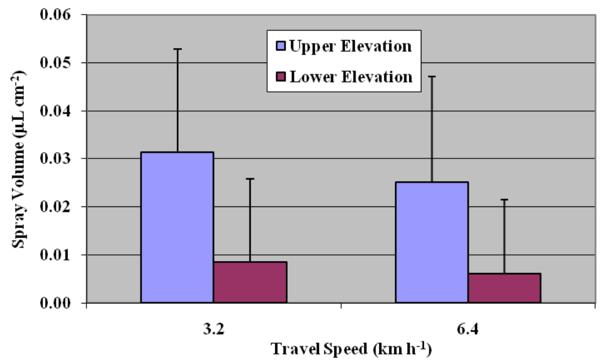

Figure 5. Mean spray volume deposit and standard error bars by travel speed across all nozzle flow rates and air outlet speeds.

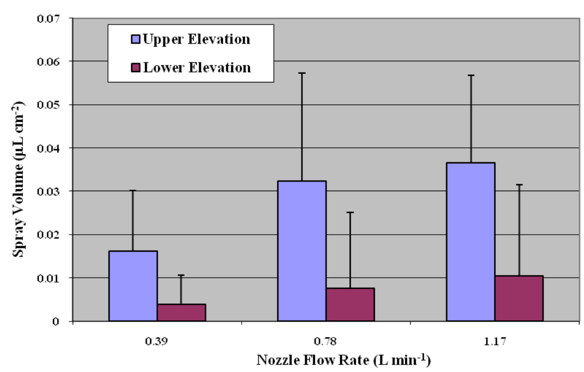

Figure 6. Mean spray volume deposit and standard error bars by individual nozzle flow rate for a single nozzle across all air outlet and travel speeds.

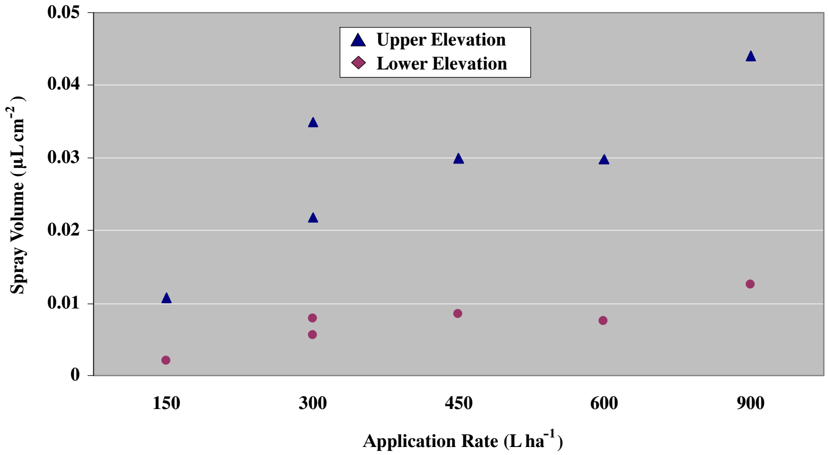

Figure 7. Spray volume deposit by application rate across all air outlet speeds.

spectrum. Averaged across all Air Outlet Speed combinations, the greatest effect application rate had on the spray deposit was between 150 and 300 L ha^{-1} and 600 and 900 L ha^{-1}. Figure 7 shows that despite doubling the output from 300 to 600 L ha^{-1}, there was little change in underside leaf spray deposits. Overall, the 900 L ha^{-1} application rate tended to produce the highest spray deposits on the underside of leaves in both the upper and lower elevations. Between 150 and 900 L ha^{-1}, the 312% increase in spray deposit for spray deposits in the upper canopy area did not match the 500% increase in the application rate. However, there was approximately a 500% increase in deposits in the lower canopy area between the 150 and 900 L ha^{-1} treatment application rates.

Summary and Conclusions

The threat to crop quality from insect pests such as aphids and whiteflies feeding on the undersides of leaves is crucial to the ornamental industry. A study was designed to look at a range of air-assist application parameters that could affect spray deposition on the underside of leaves in a mature poinsettia canopy. A five-port, air-assist nozzle with flat fan spray tip inserts was used as the delivery device. There was considerable variability in the results. Average spray deposit on the underside of leaves in the lower elevation of the poinsettia canopy were not statistically different between the 18 different application treatments. However, there was a significant three-way interaction in the upper elevation canopy between air outlet speed, travel speed, and nozzle flow rate. Pairwise comparisons showed that the highest nozzle flow rate (1.17 L min^{-1}) and slowest travel speed (3.2 km h^{-1}) tended to produce the highest spray deposits in the upper elevation. The lowest nozzle flow rate (0.39 L min^{-1}) and the highest travel speed (6.4 km h^{-1}) tended to produce the lowest underside leaf spray deposits. Higher deposits at the slower travel speed were likely due to the increased air velocity and turbulence in the canopy. There were indications that spray deposits on the undersides of leaves increased with increasing air outlet speed which also likely increased turbulence in the canopy. However, air outlet speed appeared to be a more significant factor in the upper elevation than the lower elevation. The dense nature of the mature poinsettia canopy and relatively large leaves likely dissipated the energy of the air and significantly reduced the amount of turbulence deeper in the canopy. Across all air outlet speeds, for the range of application rates evaluated, spray deposits tended to increase with increasing application rate. However, the influence of droplet size was not specifically evaluated as an independent factor and could also play a role in deposition.

In previous work, air-assisted applications have been shown to help improve canopy penetration and in particular, can help move smaller droplets down into a canopy. Still, as these trials demonstrated, getting spray to deposit on the underside surfaces of poinsettia leaves, even with air-assistance, is a formidable challenge. Turbulence within the canopy is necessary to increase underside leaf surface deposits. This study focused on using a 30° angle for the air/spray stream. While this angle of attack appeared to successfully turn over a few leaves at the top of the plant, the effect was minimal deeper in the canopy. Further work is necessary to determine the influence of the angle of the air/spray stream. Since air-assistance is more effective at moving smaller droplets, it may be useful to evaluate the impact of spray quality on spray deposition with an air-assist sprayer in the poinsettia canopy. However, it is important to note that the amount of spray deposit does not necessarily translate into efficacy. Spray coverage may be critical for good efficacy in some situations and was not evaluated in these trials. However, these trials illustrate the difficulty treating the undersides of leaves and the importance of evaluating the role of pesticides with systemic activity in pest control programs.

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References

Derksen, R. C., S. A. Miller, H. E. Ozkan, and R. D. Fox. 2001. Spray deposition characteristics on tomatoes and disease management as influenced by droplet size, spray volume, and air-assistance. ASAE Paper No. 011120. St. Joseph, Mich.: ASAE.

Derksen, R. C., S. Vitanza, C. Welty, S. Miller, M. Bennett, and H. Zhu. 2007. Field evaluation of application variables and plant density for bell pepper pest management. *Trans. ASABE* 50(6): 1945-1953.

Derksen, R. C., H. Zhu, H. E. Ozkan, R. B. Hammond, A. E. Dorrance, and C. R. Krause. 2008. Determining the influence of spray quality, nozzle type, spray volume, and air-assisted application strategies on deposition of pesticides in a soybean canopy. *Trans. ASABE* 51(5): 1529-1537.

Derksen, R. C., C. M. Ranger, L. A. Canas, J. C. Locke, H. Zhu, and C. R. Krause. 2010. Evaluation of handgun and broadcast spray systems for spray deposition in greenhouse poinsettia canopies. *Trans. ASABE* 53(1): 5-12.

Gamliel, A., M. Austerweil, and V. Zilberg. 1999. Improved application to reduce pesticide residues in herb crops. *Aspects of Applied Biology* 57: 273-278.

Güler, H., H. Zhu, H. E. Ozkan, R. C. Derksen, Y. Yu, and C. R. Krause, C.R. 2007. Spray characteristics and drift reduction potential with air induction and conventional flan fan nozzles. *Trans ASABE* 50(3):745-754.

Knewitz, H., H. Koch, and F. Lehn. 2003. Einsatz eines Düsenverbandes und flächenbezogene Dosierung bei der Anwendung von Pflanzenschutzmitteln im Gewächshaus. *Gesunde Pflanzen* 55(3): 70-76.

Langenakens, J., G. Vergauwe, and A. De Moor. 2002. Comparing handheld spray guns and spray booms in lettuce crops in a greenhouse. *Aspects of Applied Biology* 66: 123-128.

Manor, G., A. Hofner, R. Or, G. Phishler, Y. Epstein, T. Nakash, and M. Jacobi. 1989. Air stream facilitated application of cotton foliage treatments. *Trans. ASAE* 32(1): 37-40.

Manor, G., and Y. Gal. 2002. An improved vineyard sprayer. ASAE Paper No. 021003. St. Joseph, Mich.: ASAE.

Mueller, D. S., A. E. Dorrance, R. C. Derksen, E. Ozkan, J. E. Kurle, C. R. Grau, J. M. Gaska, G. L. Hartman, C. A. Bradley, and W. L. Pedersen. 2002. Efficacy of fungicides on Sclerotinia sclerotiorum and their potential for control of Sclerotinia stem rot soybean. *Plant Dis.* 86: 26-31

Piché, M., B. Panneton, and R. Thériault. 2000. Field evaluation of air-assisted boom spraying on broccoli and potato. *Trans. ASAE* 43(4): 793-799

USDA. 2009. *Floriculture and Nursery Crops Yearbook.* FLO-2008. Washington, D.C.: USDA Economic Research Service, Market and Trade Economics Division.

Womac, A. R., J. E. Mulrooney, and W. P. Scott. 1992. Characteristics of air-assisted and drop-nozzle sprays in cotton. *Trans. ASAE* 35(5): 1369-1376.

Zhu, H., R. D. Brazee, R. C. Derksen, R. D. Fox, C. R. Krause, H. E. Ozkan, and K. Losely. 2006. A specially designed air-assisted sprayer to improve spray penetration and air jet velocity distribution inside dense nursery crops. *Trans. ASABE* 49(5): 1285-1294.