Effect of Air Support and Spray Angle on Coarse Droplet Sprays in Ivy Pot Plants

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Abstract. Due to the decreasing availability of authorized plant protection products, adequate pest control becomes more difficult in many ornamentals. Although much attention is given to predator-pest interactions in integrated control, almost no research is available about the optimization of spray application techniques in ornamentals. Yet, spray boom systems - instead of the still predominantly used spray guns – might improve crop protection management in greenhouses considerably. Spray application technique will influence the spray deposition and as such its efficiency. In this study, the effect of air support and spray angle (-30°, 0°, 30°) on spray deposition in Ivy pot plants was tested using a coarse droplet spray nozzle (Lechler ID 90 02 at 6.0 bar). Spray deposition was measured using a quantitative method (mineral chelates). Spray coverage was assessed by the hand of a visual method using water sensitive paper. All applications were performed in the laboratory with a fully automated spray system. Spray deposits were measured at three plant levels on the top and on the bottom side of the leaves, together with off-target depositions. The use of air support improved crop penetration and deposition on the bottom side of the leaves and reduced spray deposition in the top layer at the top side of the leaves, resulting in a more uniform spray distribution over the crop canopy. The effect of air support on crop penetration was most pronounced with the standard 0° spray angle. Without air support, spray angling improved crop penetration but not the deposition at the bottom side of the leaves.

Keywords. Spray application, air support, ornamentals, pot plants, spray deposition, spray nozzle, crop protection.
Introduction

In 2004 a survey amongst Flemish ornamental plant growers revealed that they predominantly use knapsack sprayers and lances for their crop protection purposes (Goossens et al., 2004; Braekman and Sonck, 2008). When these techniques are compared with spray boom equipment, they are often found to be less effective, even though they mostly result in a higher application rate (450 to 6650 L ha⁻¹) (Langenakens et al., 2002; Nuyttens et al., 2004, 2009a). Furthermore, these techniques are known for their heavy workload and their high operator exposure risks. Additionally, since frequent spraying with a less than optimal technique could lead to resistance, better application techniques and equipment could contribute to a sustainable use of the available plant protection products. For these reasons, a research project concerning the optimization of spraying equipment and technology used in ornamental horticulture was started in 2006. For most growers, the optimal settings for spray boom equipment remain unclear due to the tremendous diversity of ornamental plants and production systems present in Flanders (Braekman and Sonck, 2007). That is why one of the main objectives of this project is to study the effect of nozzle type, spray pressure, droplet characteristics, spray angle, application rate and air support on spray deposition and biological efficacy of boom applications with a focus on a good penetration in the crop and a uniform distribution of spray liquid on the plant.

A first series of experiments reported by Foqué and Nuyttens (2010 a & b) mainly focussed on the effect of nozzle type, spray pressure and droplet characteristics on the spray distribution in Ivy pot plants. Additionally, the effect of spray angle was studied for the standard flat fan TeeJet XR 80 03 nozzle. The experiments showed a significant and important variation of deposition and coverage. Spray deposition on and coverage of the bottom side of the leaves was generally low, but could be improved with a factor 3.0 to 4.9 using the appropriate application technique. The hollow cone, the air inclusion flat fan and the standard flat fan nozzle with an inclined spray angle performed best because of the effect of, respectively the swirling droplets, the droplets with a high momentum and the droplet direction. From these tests the air inclusion nozzle and the standard flat fan nozzle were selected for further studies.

Present study examined the potential effect of spray angle and air support on the deposition on and coverage of the bottom side of the leaves, the penetration of the spray liquid in the crop and the uniformity of liquid distribution in Ivy pot plants using an air inclusion nozzle.

Materials and Methods

Spray application techniques

The self-propelled aluminium spray unit with a horizontal spray boom, described by Foque and Nuyttens (2010 a & b), was equipped with an air support system simulating the Hardi Twin air support system (Nuyttens et al., 2007a). Six different spray application techniques were tested to evaluate the effect of spray angle (0°, -30° and 30°) and air support (with and without) on a coarse droplet application (Table 1). All sprayings were performed with a Lechler ID 90 02 air inclusion nozzle (Lechler GmbH, Metzingen, Germany) at 6.0 bar with a nominal flow rate of 1.11 L min⁻¹, a volume median diameter of 402.3 ± 0.2 µm and an average one dimensional droplet velocity of 2.09 m s⁻¹. Droplet characteristics were measured at 0.5 m below the spray nozzle as described by Nuyttens et al. (2007b, 2009b). As in agreement with Foqué and Nuyttens (2010a, b), sprayings were performed with a nozzle distance of 0.25 m, a boom height of 0.45 m and an intended speed of about 2.7 km h⁻¹, resulting in an application volume of about 1000 L ha⁻¹.
Table 1. Spray application parameters for the application techniques tested (mean ± sd).

<table>
<thead>
<tr>
<th>Techniquea</th>
<th>Spray angle (°)b</th>
<th>Air support</th>
<th>Speed (km h⁻¹)</th>
<th>Application rate (L ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID 90 02 (0°)</td>
<td>0</td>
<td>No</td>
<td>2.48 ± 0.01</td>
<td>1057 ± 5</td>
</tr>
<tr>
<td>ID 90 02 (30°)</td>
<td>30</td>
<td>No</td>
<td>2.46 ± 0.01</td>
<td>1069 ± 3</td>
</tr>
<tr>
<td>ID 90 02 (-30)</td>
<td>-30</td>
<td>No</td>
<td>2.50 ± 0.01</td>
<td>1049 ± 2</td>
</tr>
<tr>
<td>ID 90 02 (0°) + Air</td>
<td>0</td>
<td>Yes</td>
<td>2.48 ± 0.03</td>
<td>1058 ± 12</td>
</tr>
<tr>
<td>ID 90 02 (30°) + Air</td>
<td>30</td>
<td>Yes</td>
<td>2.48 ± 0.03</td>
<td>1057 ± 15</td>
</tr>
<tr>
<td>ID 90 02 (-30°) + Air</td>
<td>-30</td>
<td>Yes</td>
<td>2.49 ± 0.02</td>
<td>1056 ± 8</td>
</tr>
</tbody>
</table>

a All sprayings with Lechler ID 90 02 air inclusion nozzle at 6.0 bar

b Spray angle relative to the movement of the spray boom: forward (30°), downward (0°) or backward (-30°)

Experimental setup

The experimental setup was very similar to the one described by Foqué and Nuyttens (2010a & b). Ivy pot plants (Hedera algeriensis var. Montgomery) were used to evaluate the effect of application technique on crop deposition and coverage. The plants were placed on a rolling bench (2.00 m x 3.50 m) in three rows of six plant pallets (0.53 m x 0.31 m) (Figure 1). Each pallet contained six ivy pot plants. Plant density was 32.6 plants per square meter. Because of the design of the tray, plant distances were 16 cm within the same pallet in the spray direction, 19 cm perpendicular to the spray direction and 21.5 cm for the distance between the first and the last plant of two consecutive pallets in the spray direction. Plant characteristics and setup resulted in a closed and dense canopy with an average height of 18.9 ± 2.4 cm. Based on a visual assessment, the canopy was more dense than the one used by Foqué and Nuyttens (2010 a & b).

Spray deposition and coverage

Before each test, filter paper collectors (FPC, 5.7 cm x 2.6 cm) were attached to six collector plants to measure spray deposition. Spray coverage was assessed by the use of water sensitive papers (WSP, 2.6 cm x 3.8 cm) attached to three collector plants (Figure 1).

For each sampled plant, six collectors were equally distributed between three crop zones, i.e. the uppermost foliage layer, the zone between the middle of the plant and the soil and the soil area. In the first two crop zones one collector was positioned at the upper side of a leaf, the other one was attached at the bottom side of another leaf. For the collectors at the soil area, one was placed on a small Petri dish, horizontally to the soil, while the other was attached to the plants stem without touching the soil. The latter two collectors gave an indication of crop penetration and possible differences in run-off. The height of each collector was measured during the experimental setup. The collector plants were randomly distributed between the other ivy plants.

To measure off-target spray deposition, six filter paper collectors were placed outside the crop and six others were placed within the crop between the pots (three in a dense crop zone and three in a less dense crop zone) (Figure 1).
Figure 1. Layout of a typical experimental set-up with the position of the plants provided with filter paper collectors (1-6) and water sensitive paper collectors (1-3) and the position of off-target collectors in ((HttpStatus) 1-6 (OT_{in})) and out of the crop (HttpStatus 1-6 (OT_{out})).
While the WSP were replaced for every spraying, the same filter paper collectors were used for a set of six different application techniques using a different mineral chelate (Chelal®, BMS Micro-Nutrients NV, Bornem, Belgium) to obtain a direct comparison between the different techniques as described by Braekman et al. (2009 and 2010) and Nuyttens et al. (2004 and 2009 b). The crop and collectors were allowed to dry completely between two successive sprayings. After spraying with all six techniques, the FPC were gathered and analyzed using Inductively Coupled Plasma (ICP) analysis. For a comparative assessment of the different techniques, the results were normalised to an application rate of 1000 L ha⁻¹ and a tank concentration of 1.0 g L⁻¹. After each application, the WSP were gathered and digitised at 600 dpi. An image analysis system developed by Jeroen Baert using a Halcon 8.0 software (MVTec Software GmbH, München, Germany) was used to calculate spray coverage.

Each spray application was repeated three times.

**Statistical analysis**

Statistica 7.1 was used for all statistical analysis. A P-value < 0.05 was considered to be statistically significant. Deposition and coverage data were analysed using a non parametrical Kruskal-Wallis test because no adequate way was found to transform the data into a normally distributed data set.

**Results**

**Spray application parameters and environmental conditions**

Average application rate and speed of the spray boom varied respectively from 2.48 to 2.50 km h⁻¹ and from 1049 to 1069 L ha⁻¹ for the different techniques (Table 1). Average measured nozzle flow rate was 1.092 ± 0.001 L min⁻¹. No significant differences in application rate and driving speed were found. With a boom height of 0.45 m and a downward spray angle, a coefficient of variation (CV) of 8.4% was found using a spray distribution bench (ISO 5682-1) in the ILVO Spray Tech Lab. This value fulfils the European standard EN 12761-2 (CV < 9%).

During the experiments, the ambient temperature (20.3 ± 1.8°C) and relative humidity (53.6 ± 7.6%) were relatively constant.
Figure 2. Spray deposition (L ha⁻¹) at different collector positions (mean ± SE) with a natural (A) and a logarithmic (B) scale of the Y-axis. 1: upper layer, upper side of leaves; 2: upper layer, bottom side of leaves; 3: middle layer, upper side of leaves; 4: middle layer, bottom side of leaves; 5: ground level, attached to stem; 6: ground level, horizontal to soil. Bars carrying the same label are not statistically different.
**Spray deposition**

No significant differences in spray deposition were found at collector position 1 (upper layer, upper side of the leaf), position 3 (middle layer, upper side of the leaves) and position 5 (ground level, attached to the stem) (Figure 2). Significant differences were found at the other collector positions. Spraying with an angle of 30° or -30° without air support resulted in a lower deposition at the bottom side of the leaves in the upper layer, compared with the deposition after spraying with air support at an angle of -30°. The same result was obtained at the bottom side of the leaves in the middle layer. At ground level, a significant higher deposition was found with a spray angle of 0° combined with air support, compared with spraying at an angle of 30° or -30° without air support.

The off-target depositions were evaluated as above and presented in Figure 3. Off-target positions between plant pots (OT$_{in}$) were found to capture a significantly lower amount of spraying liquid than collectors placed outside of the crop (OT$_{out}$). Inside the crop, there was no statistically significant difference in off-target deposition between the dense and the less dense crop zone for the same technique although there is again a tendency for an increased deposition in the less dense zone. Off-target deposition in the crop was significantly lower with a spray angle of 0° without air support, than with a spray angle of 30° with air support. There were no significant differences between the other techniques. In general, there is a tendency for an increased off-target deposition using air support, although difference were not always significant.

![Figure 3. Off target spray deposition (L ha$^{-1}$) at 0.225 m from the edge of the crop (OT$_{out}$), within the crop in a dense crop zone (OT$_{in}$ dense) and in a less dense crop zone (OT$_{in}$ less dense). Bars carrying the same label are not statistically different.](image-url)
Figure 4. Spray coverage (%) at different collector positions (mean ± SE) with a natural (A) and a logarithmic (B) scale of the Y-axis. 1: upper layer, upper side of leaves; 2: upper layer, bottom side of leaves; 3: middle layer, upper side of leaves; 4: middle layer, bottom side of leaves; 5: ground level, attached to stem; 6: ground level, horizontal to soil. Bars carrying the same label are not statistically different.
Spray coverage

No significant differences in spray coverage were found at position 2 (upper layer, bottom side of the leaves) and 4 (middle layer, bottom side of leaves) (Figure 4). Significant differences were found at the other collector positions. In general, there is a good correspondence between spray deposition and coverage results although there are some differences as discussed below. The WSP were significantly more covered at the upper side of the leaves in the upper layer after spraying with angle of 0° without air support, compared with spraying with air support and an angle of 0 and 30°. The WSP in the middle layer, attached at the upper side of the leaves, were significantly more covered after spraying at an angle of 0° with air support than after spraying with an angle of 30° without air support. On the ground level, spray coverage was significantly higher on the horizontal WSP after spraying with air support with an angle of 0°, compared with the coverage obtained after spraying without air support and an angle of 30°.

Crop characteristics

During the experiments each collector's height was measured. Average heights of collector position 1, 2, 3, 4, 5 and 6 were, respectively 19.2 ± 2.8 cm, 18.7 ± 2.1 cm, 7.6 ± 1.8 cm, 7.6 ± 2.0 cm, 2.6 ± 0.6 cm and 1.1 ± 0.4 cm. The ivy crop can be described as a dense canopy with many shielded features caused by frequently overlapping foliage from different plants and the more or less horizontal position of the leaves (Foqué and Nuyttens, 2010 a & b).

Discussion

The experiments show a significant effect of sampling position on deposition and coverage. In general, the highest values are found at the upper side of the leaves in the upper layer (from 207 to 383 L ha⁻¹, from 42 to 79% coverage), followed by the upper side of the leaves in the middle layer (from 50 to 122 L ha⁻¹, from 7 to 34% coverage) and the bottom side of the leaves in the upper layer. The lowest coverage and deposition is measured at the bottom side of the leaves in the middle layer and at ground level attached to the stem (from 5.3 to 16.7 L ha⁻¹ and from 0.2 to 7.6% coverage). At ground level, values range from 2.3 to 17.5% coverage and from 8.6 to 42.5 L ha⁻¹ and are very comparable with the off target deposits in the dense crop zone. The variation in plant architecture, spray distribution and positioning of the collectors explains the important variability of the deposits measured at each sampling point for one and the same application technique.

Besides sampling position, spray application technique also affects spray deposition and coverage. On the upper side of the leaves in the top layer (position 1) no significant effect of application technique on deposition could be found mainly because of the important variability in measuring results as mentioned above. Although not statistically significant, an interesting trend was observed. With the standard 0° spray angle, using air support reduced spray deposition and spray coverage on the top of the crop canopy with a factor of 1.8, respectively, from 383 L ha⁻¹ to 207 L ha⁻¹ and from 79% to 43%. This might be an indication of an improved crop penetration. This effect of air support for the 0° configuration was significant for the spray coverage (Figure 4). Although less pronounced, a similar effect of air support on coverage and deposition was observed for the 30° and -30° applications, except for the spray deposition with -30° configuration. Without air support, highest deposition and coverage is obtained with the 0° configuration; with air support, the -30° configuration results in the highest deposition and coverage. In general, spray deposition and coverage is high in this plant layer and potentially high enough for an adequate pest control irrespective of spray application technique.
For deposition and coverage on the upper side of the leaves in the middle layer (position 3) of the canopy, a clear positive effect of air support on crop penetration is found with the 0° spray angle although not statistically significant. This effect was much less pronounced or even absent with the -30° and 30° spray angles. With the standard 0° spray angle, the use of air support results in an increase of spray deposition and coverage, probably because of the increase in the momentum of the droplets and their capacity to penetrate the crop canopy. Moreover, we assume that the air stream tends to open the canopy and helps the spray particles to penetrate deeper into the plant canopy. The opposite effect of air support on the top layer (decrease in spray deposition) and the middle layer (increase in spray deposition) with the standard spray angle results in a more uniform spray distribution over the crop canopy. Without air support the highest crop penetration can be obtained with the -30° spray angle. With air support, the standard 0° spray angle results in the highest crop penetration.

On the bottom side of the leaves in the upper layer (position 2), the use of air support increases spray deposition with a factor of 4.1, 2.2 and 2.0 respectively, for the 30°, -30° and 0° spray angle. Differences were not always statistically significant. Same trends were found based on the spray coverage except for the 0° spray angle. At this position, the application with air support and a 30° spray angle produces the highest deposition as well as coverage.

Looking to the spray deposits in the middle layer on the bottom side of the leaves (position 4), the same positive effect of air support on spray deposition was observed for the 30° and -30° configuration with increases in spray deposition with a factor of, respectively 1.7 and 6.9. With the standard spray angle of 0°, the use of air support did not improve spray deposition on the bottom side of the leaves in the middle layer while deposition on the upper side increased with a factor of 2.1. The positive effect of air support on spray deposition on the bottom side of the leaves was not confirmed by the spray coverage results. There was a trend for a decreased coverage using air support for the three spray angles. The discrepancy between deposition and coverage is mainly caused by droplet size effects. With air support, larger spray droplets reach the bottom side of the leaves compared with the techniques without air support. For the same spray deposition, smaller droplets produce the highest coverage (Wolf et al., 2009). Without air support, highest deposition on the bottom side of the leaves in the middle crop layer is reached with the standard 0° spray angle. With air support the highest deposition is reached with the -30° spray angle.

Considering the bottom sides of the leaves, there is a factor of 5.0 (upper layer) and 4.4 (middle layer) difference in deposition and of 3.1 (upper layer) and 37.1 (middle layer) difference in coverage between the best and the worst application technique. This demonstrates the important effect of the application technique on the deposition on the bottom side of the leaves. Turner and Matthews (2001) also reported low coverage on the bottom side of leaves after spraying with several types of hydraulic nozzles. We have to notice that the highest deposition obtained on the bottom surface is still low due to the effect of shielding. However, as several growers emphasised the importance of reaching the lower side of the leaves, even the limited improvement could lead to an improved biological efficacy. Although there is sometimes a concern that the larger droplets produced by air injection nozzles may decrease the efficacy (Hoffman et al., 1998), different studies demonstrated that they provide at least a similar performance compared with conventional sprays (Ebert et al., 1999; Shaw et al., 2000; Frießleben, 2004).

Deposition and coverage results at the base of the plant (position 6) confirm the increased penetration capacity using air support. Spray coverage at the base of the plant increased with a factor of 3.2, 3.4 and 7.2 using air support, respectively, for spray angles of 30°, -30° and 0°. Without air support, highest penetration capacity was found with the 30° spray angle. With this spray angle, the use of air support did not improve spray deposition at the base of the plant.
With the 0 and -30° spray angle using air support, spray deposits increased with a factor of, respectively, 4.0 and 3.4. With air support, highest penetration capacity was found with the standard 0° spray angle which is in agreement with the results on the upper side of the leaves in the middle layer. Although not statistically significant, the same effect of spray angle and air support were found at the collector position attached to the stem at ground level (position 5).

Conclusions

The experiments showed a significant and important variation of deposition and coverage in the dense crop. Spray application technique has an important effect on deposits on the bottom side of the leaf, crop penetration and the uniformity of liquid distribution on the crop. The use of air support generally improves crop penetration and deposition on the bottom side of the leaves and reduces spray deposition in the top layer at the top side of the leaves, resulting in a more uniform spray distribution over the crop canopy. The effect of air support on crop penetration was most pronounced with the standard 0° spray angle. Without air support, spray angling can also improve crop penetration, but not the deposition at the bottom side of the leaves.

In future, the effect of spray volume (500, 1000 and 2000 L ha⁻¹) and air support will be investigated with a standard flat fan nozzle to further improve crop penetration and deposition. Bio-efficacy trials will be carried out to link deposition results with the bio-efficacy of non-systemic plant protection products. The effect of plant architecture will also be investigated.

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References


