DEVELOPMENT OF A CANOPY OPENER TO IMPROVE SPRAY DEPOSITION AND COVERAGE INSIDE SOYBEAN CANOPIES: PART 2. OPENER DESIGN WITH FIELD EXPERIMENTS


ABSTRACT. Conventional boom sprayers usually are not effective in delivering droplets to inner parts of dense target canopies, such as soybeans at growth stages from R3 to R5. An experimental mechanical canopy opener was developed with the assistance of mathematical models and attached to a conventional boom sprayer to increase spray deposition and coverage inside soybean canopies. The opener consisted of a 2.5 cm diameter metal pipe to push canopies forward, and a frame for connecting the pipe to the spray boom. Field experiments were conducted to determine the amount of spray deposition and percentage of spray coverage on artificial targets at the middle and lower portions of soybean canopies with three opener depths (7.5, 15, and 22.5 cm), three opener widths (15, 25, and 35 cm), and two different sizes of flat-fan nozzles. Additional field experiments were conducted to compare spray deposition and coverage inside soybean canopies among treatments using an air-assisted sprayer, the conventional boom sprayer with the opener, and the boom sprayer with a conventional flat-fan nozzle and a dual-pattern nozzle assembly without the opener. At the time of experiments, the soybean plants were at R5 growth stage with an average height of 1.06 m. An opener width of 25 cm or larger significantly increased the spray deposition and coverage inside the canopies. An opener depth from 7.5 to 15 cm had better spray coverage than the 22.5 cm opener depth. The boom sprayer with the opener produced no significant difference in spray deposition and coverage at the middle of canopies compared to the air-assisted sprayer, but it did produce significantly lower spray deposition and coverage at the lower portions of canopies than the air-assisted sprayer. With assistance from the opener to push the top of canopies, spray deposition and coverage on targets inside soybean canopies by the boom sprayer was improved.

Keywords. Air-assisted sprayer, Aphid, Boom sprayer, Disease, Insect, Mechanical bender, Pesticide, Soybean rust.

Generally, crop protection products (CPP) are effective if pesticides are applied at the right time and spray equipment is calibrated and operated properly to deliver the desired active ingredient rate to the intended target area. Among the CPP, the application of fungicides and insecticides realizes greater challenges than herbicides because diseases or insects may occur in hard-to-reach places inside canopies where spray droplets cannot be delivered easily and effectively. In contrast, weeds are usually not hidden in the canopy. For example, Asian soybean rust (Phakopsora pachyrhizi), a deadly disease that causes premature defoliation of soybeans, first shows its symptoms in the lower parts of the plant, and then spreads towards the top of the plant. White mold (Sclerotinia sclerotiorum), another serious soybean disease, initially starts from deep inside the canopy, near the stems where the blossoms are located. Aphids (Aphis glycines) are serious insect pests that also attack soybean plants in the lower parts of the canopy. The important factor affecting the control of diseases such as white mold and rust is to provide thorough coverage of soybean leaves with fungicide from the top to the bottom of the plants. Unfortunately, as mentioned previously, penetration of spray droplets into the lower parts of the soybean canopy using a conventional boom sprayer is rather difficult, especially under dense canopy conditions (Zhu et al., 2002, 2004; Ozkan et al., 2006; Hanna et al., 2007). Specially designed air-assisted sprayers are needed to improve penetration and deposition at the lower parts of dense canopies (Zhu et al., 2006).

Air-assisted sprayers can effectively deliver pest control agents inside dense canopies (Reichard et al., 1979; Fox et al., 1982; Salyani, 2000; Derksen et al., 2001; Mueller et al., 2002; Ozkan et al., 2006; Derksen et al., 2006). Sprayers equipped with advanced sensors have also been investigated to improve spray performance and reduce pesticide requirements (Molto et al., 2001; Salyani et al., 2006; Solanelles et al., 2006). However, growers of row crops such as soybeans are reluctant to buy these sprayers due to their relatively high cost and marginal benefit. These growers are looking for other application techniques that will enable them to spray fungicides and insecticides into lower parts of the canopy effectively with a much lower cost.

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The technique of using Dropleg extension pipes (Micron Sprayers, Ltd., Herefordshire, U.K.) has been effectively used with conventional sprayers to treat targets from the bottom up, providing much better coverage on the lower parts of the targets. However, this technique requires canopies that are planted in rows with a minimum clearance of 30 cm between rows. Unfortunately, today most soybeans are solid-seeded, resulting in denser plantings with a row spacing of 13 to 20 cm. For this reason, it is difficult for Dropleg pipes to travel inside soybeans to apply chemicals at the lower parts of canopies.

Using conventional sprayers with an attachment to open the canopy as the sprayer travels may be an economic and effective way for growers to adapt current equipment and achieve adequate spray penetration into the lower parts of soybean plants. For widespread adoption of this technique, it is also important that the “opener” should be simple in design, so that growers can build it themselves and integrate it into their conventional boom sprayers.

In part 1 of this research, mathematical models were developed to determine two critical design parameters: optimum width and depth of an effective opener (Zhu et al., 2008). However, the models simplified the crop growing conditions, horizontally on the bars. With this design, the opener depth and opener width, could be adjusted by moving the holders by changing positions of the screws on the holders. The horizontal bars were used to support the two holders, and the two horizontal square bars, and two brackets. The two holders were spaced 0.45 m apart. The boom height could be adjusted from 1.10 to 1.70 m above the ground.

In addition to the measurement of spray deposition and coverage, the maximal horizontal deflection at the top of the canopies was measured for the three opener depths. The deflection was measured with a tape measure at the time when the sprayer stopped after traveling 3 m in the soybean field.

**MATERIALS AND METHODS**

**Opener Development**

In part 1 of this research, mathematical models were developed to estimate the opener depth and width that would most effectively open a mature soybean canopy for increasing spray deposition in the lower soybean canopy (Zhu et al., 2008). The model predicted that a depth of 18 cm or smaller and a width between 5 and 54 cm were required for XR8002 flat-fan nozzles mounted on a conventional boom sprayer using a boom height of 33 cm above 1.06 m tall soybean plants. With the same sprayer and soybean plants and using XR8004 nozzles, the opener depth was 14 cm or smaller and the opener width ranged between 4 and 47 cm.

The canopy opener was fabricated with a frame consisting of a straight metal pipe, two vertical metal holders, two horizontal square bars, and two brackets. The two holders were used to tightly hold two ends of the metal pipe, the two horizontal bars were used to support the two holders, and the two brackets were used to mount the bars on the spray boom. The metal pipe was 3.6 m long and 2.5 cm diameter. The height of the pipe, which defined the opener depth, could be adjusted by changing positions of the screws on the holders. The horizontal distance between the pipe and nozzles, which defined the opener width, could be adjusted by moving the holders horizontally on the bars. With this design, the opener depth and width could be adjusted as needed to match predictions by the mathematical models. Originally, the two ends of the metal pipe were loosely mounted on the holders for free rotation. The pipe was assumed to perform as a roller when it was pushing plants. When the pipe impacted plants, it would rotate freely to dampen the impact force on the plants. However, the holders could not hold the long pipe because a large deformation occurred to the two vertical holders after the opener impacted plants. A PVC pipe was also originally selected for the opener design, but it did not work as well as the metal pipe because the PVC pipe was too flexible and bowed toward the ground after its two ends were attached to the two vertical holders. In the final design, the two ends of the metal pipe were attached to the vertical holders with lock nuts.

The canopy opener was mounted on a three-point-hitch boom sprayer that also included a gasoline engine-driven diaphragm pump, a 200 L water tank and a 3 m long boom on the right side. The opener was attached to the boom, which was equipped with seven nozzles (fig. 1). The first nozzle was 0.50 m away from the rear tire of the tractor, and the nozzles were spaced 0.45 m apart. The boom height could be adjusted from 1.10 to 1.70 m above the ground.

**EXPERIMENT 1: COMPARE OPENER DESIGNS**

Spray deposition and coverage experiments were conducted in a field with drilled bean canopies planted at an 18 cm row spacing. The variety of the soybean was Pioneer Roundup-resistant 93M11 (Pioneer Hi-Bred International, Inc., Des Moines, Iowa). At the time of the tests, the plants were at R5 growth stage with an average height and weight of 1.06 m and 109 g, respectively.

Spray deposits and coverage inside soybean canopies were compared for the boom sprayer with and without the opener. With the opener (fig. 1), tests were conducted with 18 different treatments including three opener depths, three opener widths, and two sizes of flat-fan pattern nozzles. Without the opener, tests were conducted with the two flat-fan nozzles only. The two nozzles were XR8002VS and XR8004VS flat-fan nozzles (Spraying Systems, Inc., Wheaton, Ill.). Flow rate was 0.77 L/min for the XR8002 nozzle operated at 276 kPa and 1.33 L/min for the XR8004 nozzle operated at 208 kPa.

As defined in part 1 of this study, the opener depth was the depth of the opener inside the soybean canopy, and the opener width was the horizontal distance between the nozzles and the opener. Corresponding with the mathematical model predictions mentioned above, opener depths of 7.5, 15, and 22.5 cm and opener widths of 15, 25, and 35 cm were selected for the test. The 22.5 cm depth was greater than the maximal depth predicted by the models, and this value was used to verify effectiveness of model predictions.

The spray boom was set at 33 cm above the canopies. Application rate for all treatments was adjusted to 145 L/ha by adjusting the sprayer travel speed. Travel speed was 6.4 km/h for the spray with the XR8002VS nozzle and 11.2 km/h for the spray with the XR8004VS nozzle.

In addition to the measurement of spray deposition and coverage, the maximal horizontal deflection at the top of the canopies was measured for the three opener depths. The deflection was measured with a tape measure at the time when the sprayer stopped after traveling 3 m in the soybean field.
EXPERIMENT 2: COMPARE OPENER WITH OTHER SPRAY METHODS

Another set of tests was conducted to compare spray deposition and coverage inside soybean canopies using an air-assisted sprayer and the conventional boom sprayer with and without the opener as described in experiment 1 above. The air-assisted sprayer was an Advance 3000 pull-type sprayer manufactured by Jacto, Inc. (Pompeia, Brazil). It had an 18.3 m long air bag along the entire length of the boom. The nozzles were located just ahead of the narrow air outlet, which ran the entire length of the boom. The air jet was delivered at a 58° angle (from horizontal) toward the liquid spray pattern, which had a vertical direction toward the soybean canopy. Nozzles were hollow-cone JA3 nozzles (Jacto, Inc., Pompeia, Brazil) mounted 10 cm behind the air jet outlet. Only seven nozzles (0.50 m apart) covering a 3.5 m spray swath adjacent to the sprayer were used, and each nozzle had a flow rate of 1.33 L/min operated at 1030 kPa pressure.

The boom sprayer and the opener previously described in experiment 1 were used in experiment 2. Flat-fan XR8004 nozzles were chosen for the test with the canopy opener. Based on test results from experiment 1, an opener depth of 15 cm and an opener width of 25 cm were chosen for experiment 2. For the conventional boom sprayer treatments without the opener, XR8004 and a dual nozzle containing two pre-orifice Turbo-TeeJet flat-fan tips (Turbo-Duo QJ90-2XTT11002, Spraying Systems, Inc., Wheaton, Ill.) were used for comparison. The Turbo-Duo nozzle produced two fan patterns from two tips with a 90° angle of separation between them. One pattern was angled 45° forward and the other was 45° backward from the travel direction. The operating pressure both for the XR8004 and the Turbo-Duo nozzles was 208 kPa, with each nozzle discharging 1.33 L/min.

Similar to experiment 1, the nozzle height was 33 cm above the canopy, travel speed was 11.2 km/h, and application rate was 145 L/ha for all treatments in experiment 2. Detailed information on the experimental design for experiment 2 was reported by Ozkan et al. (2006).

SAMPLE COLLECTION AND ANALYSIS

Both experiments 1 and 2 were conducted in the same field with R5 growth stage soybeans. Two sides of the field were surrounded by tall trees planted as wind barriers. Four separate rectangular plots were selected in the field for each treatment, and each plot was cut into a 46 m long × 4.6 m wide area. Treatments were organized in a randomized block design for plots with four replications. A spray mixture containing water and Brilliant Sulfaflavine (BSF, MP Biomedicals, Inc., Aurora, Ohio), a fluorescent tracer at a concentration of 2 g/L, was used to determine the volume of spray deposits on artificial targets.

Artificial targets used to collect spray deposits inside canopies were 2.5 × 7.5 cm sheet metal plates. A second set of artificial targets consisting of 5.0 × 7.5 cm water-sensitive papers was used to determine spray coverage inside the canopies. Three stakes holding artificial targets were placed 17, 23, and 29 m from the beginning edge of each plot. The artificial targets were horizontally positioned 30 and 60 cm above the ground (fig. 2), representing the lower and middle parts of the canopy, respectively. At each height, two metal plates and two water-sensitive papers were attached to the target holder. Each set of water-sensitive paper and metal plate targets was positioned at a 180° angle from each other. The arti-
The artificial targets were mounted horizontally with their longer axis normal to the stake and with 90° radial separation from each other at each height. The midpoint of each plate was 11 cm away from the stake. The artificial targets were oriented to avoid overlapping between two heights.

The artificial targets were collected 5 minutes after spraying. The two plates at each height were stored in a 125 mL wide-mouth glass bottle in non-transparent boxes. The water-sensitive papers were stored in plastic sandwich bags.

After the metal targets were brought to the laboratory, they were washed with 20 mL of purified water (prepared with the Barnstead Mega-Pure system, model MP-12A) to dissolve the BSF. Then, a 4 mL sample solution was 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. If a sample concentration fell above the calibration range, it was further diluted and measured again. The amount of spray deposits on plates was calculated from the peak fluorescent intensity, and then converted to the volume of spray liquid per square centimeter (L/cm²).

Percentage of the spray deposit area on the total area of each water-sensitive paper was determined with a computer imaging system that included a desktop computer, an HP Scanjet 5530 photo-smart scanner with a resolution of 600 dpi, and imaging software (Imaging Tool Windows, version 3.00, The University of Texas Health Science Center, San Antonio, Tex.). The upper threshold for the image scanning process was set between 140 and 180 depending on the background color on each water-sensitive paper. The lower threshold was always set as zero. Spray coverage was defined as the percent spray deposit area on the water-sensitive paper area.

During the tests, a portable weather station was used to measure ambient air temperature, relative humidity, and wind velocity. The wind velocity was below 1.8 m/s for both experiments. From the beginning to the end of experiment 1, the ambient temperature changed from 24°C to 26°C and relative humidity changed from 69% to 57%. From the beginning to the end of experiment 2, the ambient temperature changed from 30°C to 32°C and relative humidity changed from 59% to 51%.

Droplet sizes from nozzles used in the tests were measured with the Oxford Lasers VisiSizer particle/droplet image analysis system. Droplet size distributions were determined 0.3 m below the nozzle orifice across the centerline of the spray pattern width. A minimum 10,000 droplets were counted at each sampling position for the droplet size distribution analysis.

Data were first analyzed by one-way ANOVA to test the null hypothesis that all treatments had equal means with Duncan’s methods using ProStat version 3.8 (Poly Software International, Inc., Pearl River, N.Y.). 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.

**RESULTS AND DISCUSSION**

**EXPERIMENT 1**

Nearly all treatments with any combinations of opener depth and width for both the XR8002 and XR8004 nozzles had significantly higher spray deposition and coverage at the middle and lower levels of the soybean canopies than the conventional boom sprayer treatments without the opener (figs. 3 through 6). For the XR8002 nozzle, there was no significant difference in spray deposits at the middle of canopies for all three different opener depths between the 25 and 35 cm opener widths (fig. 3a). This result was also true for the deposits on the lower canopies (fig. 3b). The three opener depths had similar average spray deposits at either middle or lower canopies for both the XR8002 and XR8004 nozzles, while deposits at the middle canopy were about 3 times the deposits shown in the lower canopy (table 1). For all three opener depths, spray deposits at the middle of canopies with the 15 cm opener width were significantly lower than those with the 25 and 35 cm opener widths (fig. 3a). At the lower canopy, the 35 cm opener width produced significantly higher deposits than the 15 cm opener width (fig. 3b).

The XR8004 nozzle had slightly different deposition results from the XR8002 nozzle (figs. 4a and 4b). At the 15 cm opener depth with the XR8004 nozzle, the amount of spray deposit at the lower canopy was 0.035, 0.070, and 0.058 μL/cm² when the opener width was 15, 25, and 35 cm, respectively. The average spray deposit at lower canopies for the three opener depths from the XR8004 nozzle was 0.039, 0.056, and 0.060 μL/cm² when the opener width was 15, 25,
Figure 3. Spray deposits at the middle and lower soybean canopies from the XR8002 nozzles with and without the canopy opener at three different opener depths and three different opener widths. Spray deposits with the same letters are not significantly different at the 0.05 level.

Figure 4. Spray deposits at the middle and lower soybean canopies from XR8004 nozzles with and without the canopy opener at three different opener depths and three different opener widths. Spray deposits with the same letters are not significantly different at the 0.05 level.

Figure 5. Spray coverage at the middle and lower soybean canopies from XR8002 nozzles with and without the canopy opener at three different opener depths and three different opener widths. Spray coverages with the same letters are not significantly different at the 0.05 level.
and 35 cm, respectively (table 2). Under the same conditions, the average spray deposit in the middle of canopies was 0.121, 0.197, and 0.202 μL/cm², respectively. With the same opener width, there was no significant difference in spray deposits at lower canopies among the three opener depths (fig. 4b).

For both nozzles, an opener width 25 cm or greater produced higher spray deposits at middle and lower canopies than the 15 cm opener width, but opener depths ranging from 7.5 to 22.5 cm had little difference in the deposits regardless of the opener width. One explanation for this result is that with a narrower opener width, the canopies might return to their upright position before droplets had enough time to reach the lower canopies. The 25 cm opener width was about the middle point of the opener width range estimated by the mathematical models. In the models, the opener width range was determined by the droplet travel times from the nozzles to the tops and then the bottoms of plant canopies. With the 25 cm opener width, droplets reached the middle of the canopies when plants rebounded to an upright position. In the field, soybean leaves were located mostly at the apical portions of plants, and this favored unimpeded droplet deposition at the basal portions after droplets passed the middle of canopies. Consequently, higher deposition occurred at the middle and lower parts of canopies with a larger opener width.

The mathematical model in part 1 of this study had indicated that the plant return time would not be affected by the opener depth, and the maximal opener depth would be about 14 cm for the XR8004 nozzle and 18 cm for the XR8002 nozzle. When the opener depth was 7.5, 15, and 22.5 cm, the measured average maximal horizontal deflection at the top of canopies was 0.32, 0.44, and 0.56 m, respectively. For the same conditions, the mathematical model predicted that the deflection for a 1.06 m soybean plant would be 0.35, 0.49, and 0.60 m, respectively. The deflections measured were slightly lower than the deflections predicted by the model because the top portion of the plants was mainly formed by soft leaves.

In contrast with deposition results, the percent spray coverage at the middle and lower canopies varied with the opener width for both the XR8002 nozzles (figs. 5a and 5b) and the XR8004 nozzles (figs. 6a and 6b). Among the three opener depths and three opener widths with the XR8002 nozzle, the highest spray coverage at the middle canopies occurred with the 25 cm opener width and 15 cm opener depth (fig. 5a), and the highest spray coverage at the lower canopies occurred with the 35 cm opener width and 15 cm opener depth (fig. 5b).

### Table 1. Average spray deposit and coverage among three opener widths at middle and lower soybean canopies for XR8002 and XR8004 nozzles with three different opener depths from experiment 1.

<table>
<thead>
<tr>
<th>Opener Depth (cm)</th>
<th>Spray Deposit (μL/cm²)</th>
<th>Spray Coverage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At Middle Canopy</td>
<td>At Lower Canopy</td>
</tr>
<tr>
<td></td>
<td>XR8002</td>
<td>XR8004</td>
</tr>
<tr>
<td>7.5</td>
<td>0.144</td>
<td>0.161</td>
</tr>
<tr>
<td>15</td>
<td>0.165</td>
<td>0.170</td>
</tr>
<tr>
<td>22.5</td>
<td>0.152</td>
<td>0.189</td>
</tr>
</tbody>
</table>

### Table 2. Average spray deposit and coverage among three opener depths at middle and lower soybean canopies for XR8002 and XR8004 nozzles with three different opener widths from experiment 1.

<table>
<thead>
<tr>
<th>Opener Width (cm)</th>
<th>Spray Deposit (μL/cm²)</th>
<th>Spray Coverage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At Middle Canopy</td>
<td>At Lower Canopy</td>
</tr>
<tr>
<td></td>
<td>XR8002</td>
<td>XR8004</td>
</tr>
<tr>
<td>15</td>
<td>0.112</td>
<td>0.121</td>
</tr>
<tr>
<td>25</td>
<td>0.176</td>
<td>0.197</td>
</tr>
<tr>
<td>35</td>
<td>0.175</td>
<td>0.202</td>
</tr>
</tbody>
</table>
EXPERIMENT 2

With the XR8004 nozzle at the 25 cm opener width, spray coverage at the lower canopy varied from 3.3% to 3.9% when the opener depth changed from 7.5 to 22.5 cm.

Among the three opener widths for the XR8004 nozzle, the highest spray deposition at the middle of canopies was produced by the 35 cm opener width for the 7.5 cm opener depth, and by the 25 cm opener width for the 15 cm and 22.5 cm opener depths (fig. 6a). Among the three opener widths for the XR8004 nozzle, the highest spray deposition at the lower canopies was produced by the 35 cm opener width for the 7.5 cm and 15 cm opener depths, and by the 25 cm opener width for the 22.5 cm opener depth (fig. 6b).

Table 1 summarizes the average spray deposits and coverage among three different opener depths for each opener width, and table 2 summarizes the average spray deposits and coverage among three different opener widths for each opener depth. Statistical comparisons are not shown in tables 1 and 2 because they are included in figures 3 through 6. The average spray coverage of the three opener widths at the middle canopy did not vary greatly with the opener depth, while the average coverage at the lower canopy with the 22.5 cm opener depth was the lowest among the three depths (table 1). The 22.5 cm opener depth was greater than the depth range predicted by the mathematical models. The 25 cm opener width produced higher average spray coverage at the middle and lower canopies than the other two opener widths (table 2).

At the same target position inside canopies, the XR8002 and XR8004 nozzles had very little difference in the average amounts of spray deposits and average percentage of spray coverage when the opener was used (tables 1 and 2). This is not surprising because the application rates for the XR8002 and XR8004 nozzles were the same. Although the XR8002 nozzle produced smaller droplet sizes than the XR8004 nozzle (table 3), the number of droplets from the XR8002 nozzle was greater than the XR8004 nozzle. However, to produce an equal application rate, the XR8004 nozzle had a higher travel speed, resulting in less application time than the XR8002 nozzle.

Because of uneven field surfaces and plant heights, the opener might not have been able to reach some shorter plants if the opener depth was too shallow. Plants might have also provided sufficient load to resist deflection if the opener was too deep inside the canopy. Therefore, the opener depth between 7.5 cm and 15 cm would be an optimal range for the opener design.

EXPERIMENT 2

Figure 7 shows the comparison of spray deposits at the middle and lower canopies among the treatments of the air-assisted sprayer, the boom sprayer with opener, and the boom sprayer with either the XR8004 nozzle or the Turbo-Duo nozzle without the opener. Spray deposits with the same letters are not significantly different at the 0.05 level.

Table 3. Droplet size distribution from nozzles used in experiments 1 and 2.

<table>
<thead>
<tr>
<th>Nozzle</th>
<th>DV0.1 (μm)</th>
<th>DV0.5 (μm)</th>
<th>DV0.9 (μm)</th>
<th>Relative Span[^a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jacto JA3</td>
<td>82</td>
<td>118</td>
<td>182</td>
<td>0.85</td>
</tr>
<tr>
<td>XR8004</td>
<td>122</td>
<td>321</td>
<td>549</td>
<td>1.33</td>
</tr>
<tr>
<td>XR8002</td>
<td>89</td>
<td>180</td>
<td>349</td>
<td>1.44</td>
</tr>
<tr>
<td>Turbo-Duo</td>
<td>182</td>
<td>376</td>
<td>698</td>
<td>1.37</td>
</tr>
</tbody>
</table>

[^a] Relative span = (DV0.9 - DV0.1)/DV0.5.

Figure 8 shows the comparison of percent spray coverage at the middle and lower canopies among the treatments of the air-assisted sprayer, the boom sprayer with opener, and the boom sprayer with either the XR8004 nozzle or the Turbo-Duo nozzle without the opener. Spray coverages with the same letters are not significantly different at the 0.05 level.

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the canopy using the air-assisted sprayer and the opener was not significantly different, but they had significantly higher spray coverage than the XR8004 and Turbo-Duo nozzles without the opener. At the lower canopies, the air-assisted sprayer had significantly higher spray coverage than the opener, and sprayer with the opener had significantly higher spray coverage than the sprayer with either the XR8004 or Turbo-Duo nozzle without the opener. With the opener, small droplets could deposit on targets inside canopies easily, as small droplets had very low volume compared to large droplets. Because of this reason, with the opener the increase in the amount of spray deposits on targets inside canopies was not as significant as it was for the sprayer coverage.

The air-assisted sprayer had the highest spray deposition and coverage inside canopies because of the influence by the air curtain, which disturbed canopies and carried the small droplets inside. Droplets from the air-assisted sprayer were smaller than other treatments (table 3), which also helped to increase deposition and coverage. However, the air-assisted sprayer is usually more expensive and requires higher energy to operate than the conventional boom sprayer with a simple mechanical opener. In addition, the air-assisted sprayer has more maintenance and installation requirements than a conventional boom sprayer.

The Turbo-Duo nozzle had the lowest spray deposition and coverage among all treatments as a result of producing the largest droplets (table 3) with least vertical droplet velocities among all nozzles. A large portion of the droplet velocity from the Turbo-Duo nozzle was split horizontally, greatly weakening the droplet capability to penetrate the canopy. Most spray droplets from the Turbo-Duo nozzle would be intercepted by the top portion of canopies because of the wide release angle and high horizontal velocity component. Without assistance from air or an opener, boom sprayers require high vertical droplet velocity to increase the spray penetration into dense canopies.

The opener improved the spray performances of the conventional sprayer. However, there could be some potential problems associated with the use of openers on conventional sprayers with long booms. The opener weight and plant resistance might cause excessive stress to long booms. In addition, the depth of the opener inside canopies might have greater fluctuation because a long boom might bounce more frequently than a shorter boom. On the other hand, the opener might be a useful tool to increase the amount of spray deposits on targets inside canopies for short row crops.

**Summary**

Field experiments verified that the mathematical models presented in part 1 of this research (Zhu et al., 2008) were useful tools to assist in defining the opener depth and width ranges during the canopy opener developmental process. The opener depths within the predicted range produced greater spray coverage at lower canopies than the 22.5 cm opener depth, which was beyond the predicted range.

The amount of spray deposition and percentage of spray coverage at the lower and middle areas inside canopies were not significantly influenced by opener depth when depths were between 7.5 and 15 cm. However, quantity of spray deposition and coverage was influenced by the opener width. The 25 cm or wider opener width had much higher spray deposition and coverage in the lower portion of the canopy than the 7.5 cm width.

The opener design demonstrated that improved deposition and coverage inside soybean canopies could be achieved by opening and disturbing the top of canopies as compared to an air-assisted sprayer and conventional boom sprayers without the opener. With the opener, small droplets could easily reach the middle and lower canopies, resulting in increased spray coverage. Field experiments concluded that for the 1.06 m soybean plants the optimal opener depth range would be from 7.5 to 15 cm and the optimal width would be 25 cm, which fell within the range predicted by mathematical models.

Without the opener, the Turbo-Duo fan pattern nozzle produced the lowest spray deposition and coverage at the middle and lower canopies among all treatments. The horizontal velocity component of droplets discharged from the Turbo-Duo nozzle might have weakened the spray penetration into the tall soybean canopy.

The mechanical canopy opener was simple in design, and growers could build it themselves and integrate it into their conventional boom sprayers with short booms. The oscillation of the boom suspension must be smaller than the opener depth to prevent losing constant contact with plants that are deflected by the opener.

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**References**


