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Wind Tunnel Evaluation of Drift Reduction Potential and Spray Characteristics with Drift Retardants at High Operating Pressure

ABSTRACT: Although considerable research has been done on effectiveness of drift retardants for many years, answers to some questions are still unclear to applicators. Laboratory tests were conducted to evaluate drift potentials associated with off-target ground and airborne spray deposits discharged with a hollow cone nozzle spraying three different drift retardants at a high operating pressure and various wind velocities in a wind tunnel. Droplet sizes and spray widths were also determined with a laser imaging system and a portable spray patternator. At 1655 kPa pressure and 4.65 L/m flow rate, the volume median diameters of droplets from the hollow cone nozzle discharging spray mixtures containing water only, polyvinyl polymer, nonionic colloidal polymer and polyacrylamide polymer drift retardants were 201, 222, 239, and 210 µm, respectively. The major spray pattern width was not changed after drift retardants were added into the spray carrier. For the wind velocity from 1 to 5 m/s in the wind tunnel, the polyacrylamide drift retardant produced the highest airborne deposit among the three drift retardants, followed by polyvinyl, and then nonionic colloidal. Also, the polyacrylamide drift retardant produced the highest ground drift potential, followed by nonionic colloidal and then polyvinyl. According to the results from this laboratory study, both nonionic colloidal and polyvinyl polymer drift retardants reduced the drift potential compared to the spray carrier containing water only.

KEYWORDS: pesticide, droplet size, droplet velocity, spray pattern, spray additives

Introduction

Spray drift is a serious problem in pesticide spray applications since it causes inefficient use of pesticide, damage to crops in adjacent fields, and air and water pollution [1]. There is no doubt that droplet size is one of the most important factors not only for obtaining better coverage and efficiency of spray tasks but also for minimizing drift potential to the nontargeted areas.

Several factors such as atomization methods, nozzle types, physical properties of tank mixtures, and weather conditions can affect droplet sizes during the spray application [2]. Since weather conditions are very difficult to control and vary greatly in the fields, changing physical properties of spray mixtures with drift retardants is a relatively easy way to control droplet sizes [3]. Water soluble synthetic polymers were generally effective in increasing spray droplet size and reducing the content of the droplets that are more prone to drift [4].

Many new drift retardant chemicals have been released in the market since past decades; however, some drift retardants lost their ability to produce larger droplets after recirculation through the pumps [5,6]. Zhu et al. [7] reported that the drift retardant with the active ingredient of xanthan gum maintained the greatest resistance to breakdown due to shear after the investigation of the shearing effect on physical
properties of various polymer compositions with a range of molecular weights, anionicities and concentrations.

Although considerable research has been done on effectiveness of drift retardants, these studies are mostly related to low operating pressures between 140 to 550 kPa. Information is needed on spray drift reduction potential by using drift retardants at high operating pressure conditions. In orchard spray applications, applicators normally use high pressure and high application rate to achieve successful application objectives. It is unclear to the applicators whether drift retardant chemicals can reduce spray drift under high operating pressure conditions in orchard and nursery applications. Therefore, the objective of this research was to evaluate spray characteristics and drift reduction potential with several drift retardants containing different active ingredients discharged at high operating pressure under the laboratory conditions.

**Materials and Methods**

**Nozzle and Drift Retardants**

Droplet sizes, spray pattern widths, and drift reduction potentials among three different commercially-available drift retardants at a high pressure were investigated under laboratory conditions. The active ingredients in the three drift retardants were polyvinyl polymer (PP), nonionic colloidal polymer (NCP), and polyacrylamide (PA). A spray mixture containing water only was also tested under the same conditions as a baseline for the comparison. A hollow cone nozzle (Ceramic D5-DC45, Spraying Systems Co., Wheaton, IL) was selected to discharge sprays for the test because hollow cone nozzles are commonly used in orchard and nursery air blast sprayers. The operating pressure of 1655 kPa and flow rate of 4.65 L/min was used for all the laboratory tests. Drift retardants and test conditions are given in Table 1.

**Droplet Size and Velocity Measurement**

Droplet size spectra and droplet velocities were determined using particle/droplet image analysis system (Oxford Lasers VisiSizer and PIV, Oxfordshire, UK). During the tests lens option 3 was selected at the magnification setting 2. At this setting, the system was able to measure droplets from 21.2 to 1732.0 μm. Droplet sizes for water and drift retardants were measured at the pressure and flow rate given in Table 1. Droplet samples were taken 50 cm below the nozzle orifice and across the centerline of the spray pattern with a 5 cm interval within a 60 cm range. Because of the hollow cone spray pattern, droplet percentiles were measured 20, 25, and 30 cm distances from the centerline of the nozzle on both sides of the spray cone. At least 10,000 droplets were sampled at each point. The particle image velocimetry (PIV) software and 2-D settings of the laser system were used to measure average droplet velocities within the 10 × 10 cm area 50 cm below the nozzle orifice. Schematic views of the particle/droplet image analysis system for droplet size and PIV velocity measurements are given in Fig. 1(a) and 1(b), respectively.

Droplet sizes of spray mixtures containing different drift retardants were then classified according to the ASAE Standard No. S572 AUG99 [11]. To determine threshold values, XR-11001, XR-11003, XR-11006, and Teejet 8008 flat fan pattern nozzles were used as reference nozzles at the working pressure of 450, 300, 200, and 250 kPa, respectively [12]. These nozzles provided all necessary criteria described in ASAE-S572.
Spray Pattern Width Measurement

Spray distribution patterns discharged from the nozzle for different spray mixtures were determined with a portable spray pattern analyzing system. During the tests, the nozzle height was 50 cm above the table of the pattern analyzing system. Each measurement was repeated three times.

Wind Tunnel Tests

Spray drift reduction potentials for spray mixtures with different drift retardants were evaluated in a wind tunnel containing a 3.7-m long, 0.61-m wide, and 0.91-m high test section. The evaluation was conducted at three wind velocities: 1, 2.5, and 5 m/s. The wind velocity was measured with Model 8386, 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). Details of the structure of the wind tunnel and measurement of wind velocity were given in a publication by Reichard et al. [13]. A single nozzle was used and mounted in the test section of the wind tunnel at 0.67 m above the wind tunnel floor, midway across the width of the tunnel, and 2.5 m upwind from the downstream end of the test section. The nozzle was oriented to discharge spray downward toward the wind tunnel floor. Dimensions and positions of the nozzle, wind velocity probe and spray deposit sampling targets are given in Fig. 2.

A 5-cm thick sponge panel was mounted on each sidewall of the wind tunnel to prevent droplets rebounding from the sidewall to the test section. Nozzle flow was controlled with a solenoid valve. A timer was used to operate the valve for five seconds during each test. Liquid was delivered to the nozzle from a diaphragm pump, and the bypass liquid was recirculated back to the reservoir.

Except for the three drift retardants and water, the spray mixtures used in the tests were additionally
mixed with 3 g of fluorescent tracer Brilliant Sulfaflavine (BSF) (MP Biomedicals, Inc., Aurora, OH) per litre of water for quantification of ground and airborne spray deposits in the wind tunnel.

During experiments two different types of collectors were used for collecting horizontal ground spray deposits and vertical airborne deposits. The horizontal collector was a combination of 1.70-m long and 0.10-m wide strips of a muslin fabric and plastic. The strip was evenly cut into 17 pieces of 10×10 cm and was attached on the upper surface of the plywood collectors. To prevent tracer contamination from muslin fabrics to plywood surface, plastic film pieces were placed between the plywood and muslin fabrics [14]. The plywood was supported horizontally with its upper surface 0.17 m above the wind tunnel floor to avoid collecting any droplets rebounding from the floor. The target was placed in the center of the wind tunnel and with its long axis parallel to the wind direction. The upwind side of the target was placed 0.40 m downstream from the nozzle to avoid collecting unusually large droplets during the brief period of starting or stopping spray.

The airborne deposit collector was 7 pieces of 10×10 cm nylon screens. They were vertically mounted in an array strip at the downstream end of the plywood to collect airborne droplets above the downstream end of the fabric strip. Detailed information about collection efficiency of nylon screens was given by Fox et al. [15].

After each spray run, the dried combination of each 10×10 cm fabric and plastic sample was placed into a clean glass bottle and each screen sample was placed in another clean bottle. For fluorescence analysis, 30 mL distilled water was added in each bottle to wash tracer from sample surfaces and bottles were shaken for 3 min. After completing the washing process, approximately 4 mL of washing liquid was transferred to a clear cuvette. The fluorescence intensity of each sample was then determined with the Model LS 50B luminescence spectrometer.

Each wind tunnel run was replicated three times. Data were averaged from the three replications for each test condition. The fluorescence tracer recovery rate from the muslin fabrics was also determined prior to the wind tunnel tests. The recovery rate of BSF from muslin fabric with distilled water was above 92%.

Test data were analyzed with the analysis of variance based on a completely randomized design. Differences among means were determined with Duncan’s New Multiple-Range Test using ProStat version 3.8 (Poly Software International, Inc., Pearl River, NY) at the 0.05 level of significance.

Results and Discussion

Droplet Size and Velocity

Table 2 shows droplet size distributions and average droplet velocities 50 cm below the nozzle orifice with three drift retardants and water only. Treatments with PP and NCP produced larger droplets and higher droplet velocity than the treatment with water only while the treatment with PA had droplet size and velocity very close to the treatment with water only. Among spray mixtures containing three different drift retardants, the NCP treatment provided the least portion of volume of droplets smaller than 200 μm.
According to the previous study [16], droplets smaller than 200 μm are more prone to drift. If %volume < 200 μm from the treatment with water only is used as a reference, the drift potential may be reduced 32, 26, and 17% after the spray mixture is added with the NCP, PP, and PA drift retardants, respectively. Therefore, treatments with all three drift retardants reduced drift potential according to the droplet size measurement.

The volume median diameters of the droplets with water-only treatment and PA drift retardant were very close to the fine classification range (Fig. 3). The classification chart was prepared according to the ASAE Standard No: S572 AUG99. After water was mixed with either PP or NCP drift retardant, the volume median diameter of droplets changed to the medium classification range (Fig. 3).

Because of the increase in average droplet sizes, treatments with all three drift retardants slightly increased droplet velocities 50 cm below the nozzle orifice (Table 2).

### Spray Pattern Width

Table 3 shows the spray pattern width within 95% volume range associated with spray mixtures containing drift retardants and water only. There was little difference in the pattern width among treatments for spray mixtures with water only and with three drift retardants.

### Ground and Airborne Deposits in Wind Tunnel

Figure 4 shows ground spray deposits on the targets between 0.4 and 2.1 m downwind from the nozzle discharging spray mixtures with water only and with three drift retardants at wind velocities of 1, 2.5, and 5 m/s in the wind tunnel.

At 1 m/s wind velocity, the treatments with PP and NCP have slightly lower ground deposits than the treatment with water only while the treatment with PA had the ground deposits similar to the water-only

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**TABLE 2—Droplet percentiles and vertical velocities.**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>$D_{V0.1}$ (μm)</th>
<th>$D_{V0.5}$ (μm)</th>
<th>$D_{V0.9}$ (μm)</th>
<th>Relative Span$^a$</th>
<th>% Volume $&lt;200\mu m$</th>
<th>Average Droplet Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water only</td>
<td>150.0</td>
<td>201.4</td>
<td>292.3</td>
<td>0.71</td>
<td>48.1%$^b$</td>
<td>2.2</td>
</tr>
<tr>
<td>PP</td>
<td>156.2</td>
<td>222.0</td>
<td>338.0</td>
<td>0.82</td>
<td>35.59%</td>
<td>3.2</td>
</tr>
<tr>
<td>NCP</td>
<td>162.5</td>
<td>239.4</td>
<td>361.1</td>
<td>0.83</td>
<td>32.87%</td>
<td>3.1</td>
</tr>
<tr>
<td>PA</td>
<td>151.2</td>
<td>210.0</td>
<td>310.4</td>
<td>0.76</td>
<td>40.08%</td>
<td>2.5</td>
</tr>
</tbody>
</table>

$^a$Relative Span = ($D_{V0.9}$ - $D_{V0.1}$) / $D_{V0.5}$.

$^b$Numbers in a column followed by the same letter are not significantly different at the 0.05 level.
treatment (Fig. 4(a)). The PP treatment produced the lowest total amount of ground deposits across the targets from 1.0 to 2.1 m downwind from the nozzle, followed by the NCP treatment (Table 4). However, the PA treatment produced slightly higher total ground deposit than water-only treatment (Table 4). The most portion of spray volume was expected to deposit on the floor within 0.4 m downwind from the nozzle.

When the wind velocity increased from 1 to 2.5 m/s, the amount of ground deposits for all treatments also increased (Fig. 4(a) and 4(b)). The 2.5 m/s wind velocity resulted in nearly 21, 23, 16, and 17 times higher total ground deposits for water-only, PP, NCP, and PA treatments than the treatments at 1 m/s wind velocity, respectively. Similarly, at 2.5 m/s wind velocity the PP treatment produced the lowest total amount of ground deposits across the targets from 1.0 to 2.1 m downwind from the nozzle, followed by the NCP treatment (Table 4). At this wind velocity, the PA treatment produced slightly lower total ground deposit than water-only treatment (Table 4). The total amount of ground deposits from the PP or NCP treatment were nearly 40 % less than the amount produced by water-only or PA treatment (Table 4).

In contrast, when wind velocity increased from 2.5 to 5 m/s, the total amount of ground deposits for all treatments decreased (Fig. 4(b) and 4(c)). This was because a large portion of spray droplets deposited beyond the ground target area due to higher wind velocity. Still, at 5 m/s wind velocity, the PP treatment produced the lowest total amount of ground deposits across the targets from 1.0 to 2.1 m downwind from the nozzle, followed by the NCP treatment (Table 4). However, the PA treatment produced slightly higher total ground deposit than the water-only treatment (Table 4).

Although the total amount of ground deposits from the PP treatment was lower than the NCP treatment for all wind velocities, the difference between the two treatments at the same wind velocity was not significant. Similarly, the difference in total amount of spray deposits between water-only and PA treatments was not significant. However, the difference in the total amount of ground deposits between the PP or NCP treatment and the water-only or PA treatment was significant. A higher portion of ground deposits occurred on the first half of the ground target than the second half of the ground target at all three wind velocities (Fig. 4).

Figure 5 shows airborne spray deposits on the vertical targets 2.1 m downwind from the nozzle discharging spray mixtures with water only and with three drift retardants at wind velocities of 1, 2.5, and 5 m/s in the wind tunnel. At all three wind velocities, the NCP treatment produced the lowest airborne deposits among all treatments, followed by the PP treatment (Fig. 5 and Table 4) without any significant

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Wind Velocity (m/s)</th>
<th>Ground Deposit (mL)</th>
<th>Airborne Deposit (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water only</td>
<td>1</td>
<td>0.332bc</td>
<td>0.186b</td>
</tr>
<tr>
<td>Water only</td>
<td>2.5</td>
<td>6.887e</td>
<td>1.803e</td>
</tr>
<tr>
<td>Water only</td>
<td>5</td>
<td>3.234g</td>
<td>5.039h</td>
</tr>
<tr>
<td>PP</td>
<td>1</td>
<td>0.179a</td>
<td>0.110a</td>
</tr>
<tr>
<td>PP</td>
<td>2.5</td>
<td>4.033d</td>
<td>1.709de</td>
</tr>
<tr>
<td>PP</td>
<td>5</td>
<td>2.427f</td>
<td>4.150g</td>
</tr>
<tr>
<td>NCP</td>
<td>1</td>
<td>0.270ab</td>
<td>0.108a</td>
</tr>
<tr>
<td>NCP</td>
<td>2.5</td>
<td>4.387d</td>
<td>1.333d</td>
</tr>
<tr>
<td>NCP</td>
<td>5</td>
<td>2.725f</td>
<td>3.932g</td>
</tr>
<tr>
<td>PA</td>
<td>1</td>
<td>0.419c</td>
<td>0.158c</td>
</tr>
<tr>
<td>PA</td>
<td>2.5</td>
<td>7.058e</td>
<td>3.111f</td>
</tr>
<tr>
<td>PA</td>
<td>5</td>
<td>3.699h</td>
<td>5.397i</td>
</tr>
</tbody>
</table>

Values in the same column followed by the same letter are not significantly different at the 0.05 level.
difference. Except for 1 m/s wind velocity, the PA treatment produced significantly higher airborne deposits than the water-only treatment at the other two wind velocities. The NCP treatment had 42, 26, and 22% less total airborne deposits than the water-only treatment when wind velocity was 1, 2.5, and 5 m/s, respectively.

At 1 and 2.5 m/s wind velocities, the airborne deposit decreased as the target height increased for all treatments (Fig. 5(a) and 5(b)). For example, at 2.5 m/s wind velocity when the target height increased from 0.05 to 0.65 m above the ground targets, the airborne deposit decreased from $9.24 \times 10^{-4}$ to $0.067 \times 10^{-4}$ mL/cm² for the water treatment, and decreased from $64.223 \times 10^{-4}$ to $0.825 \times 10^{-4}$ mL/cm² for the NCP treatment. However, at 5 m/s wind velocity, the highest airborne deposit occurred at 0.25 m above the ground targets. Therefore, the airborne drift was greatly influenced by changes in wind velocity.

In general, for all treatments, the airborne deposits at different heights greatly increased as wind velocity increased. For example, for the water-only treatment, the total amount of airborne deposit at 2.5 and 5 m/s wind velocities was 10 and 27 times higher than the deposits at 1 m/s wind velocity (Table 4). Similarly, for the NCP treatment, the total amount of airborne deposit at 2.5 and 5 m/s wind velocities was 12 and 36 times higher than the deposits at 1 m/s wind velocity.
Conclusions

Based on the experiments conducted in this study, conclusions are highlighted as:

- For the hollow cone nozzle D5-DC45 at 1655 kPa pressure, the spray mixtures containing all three drift retardants reduced the portion of droplets smaller than 200 μm. The treatment with NCP provided the largest volume median diameter and the least percent volume of droplets smaller than 200 μm.
- Droplet velocities were slightly increased but the spray pattern width was not changed after drift retardants were added into the spray solution containing water only.
- For wind velocities of 1, 2.5, and 5 m/s, the spray mixture containing PP drift retardant at 1655 kPa operating pressure had the lowest ground spray deposit while the spray mixture containing NCP drift retardant had the lowest airborne deposit among all the treatments in the wind tunnel.
- Compared to water only, the spray mixture containing PA drift retardant did not decrease both ground and airborne spray deposits in the wind tunnel at all three wind velocities.

![FIG. 5—Airborne spray deposits across the vertical screens for treatments with water only and with drift retardants at three wind velocities. (a) Wind velocity = 1 m/s, (b) Wind velocity = 2.5 m/s, (c) Wind velocity = 5 m/s.](image-url)
• For spray mixtures with drift retardants, the total airborne deposits increased as wind velocity increased while the total amount of ground deposits beyond 1 m downwind from the nozzle increased as wind velocity increased from 1 to 2.5 m/s but decreased as wind velocity increased from 2.5 to 5 m/s.

• Laboratory results should be validated in field conditions in the future.

References


