Pesticide Formulations and Delivery Systems: Innovating Legacy Products for New Uses
STP 1558, 2012
Available online at www.astm.org
DOI:10.1520/STP104403

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Wind Tunnel and Field Evaluation of Drift from Aerial Spray Applications with Multiple Spray Formulations

REFERENCE: Fritz, Bradley K., Clint Hoffmann, W., Wolf, Robert E., Bretthauer, Scott, and Bagley, W. E., "Wind Tunnel and Field Evaluation of Drift from Aerial Spray Applications with Multiple Spray Formulations," *Pesticide Formulations and Delivery Systems: Innovating Legacy Products for New Uses* on December 1–3, 2011 in Tampa, FL; STP 1558, M. Bernards, Guest Editors, pp. 1–18, doi:10.1520/STP104403, ASTM International, West Conshohocken, PA 2012.

ABSTRACT: The impact of tank mix adjuvants and a formulated fungicide on spray atomization and in-field movement under aerial application conditions was examined. High speed wind tunnel testing was conducted to determine droplet size resulting from treatments selected for evaluation in the field. These treatments included a "blank" (water plus a non-ionic surfactant) as well as five additional solutions with a formulated fungicide, four of which have an additional adjuvant. The wind tunnel testing measured droplet size using the flat fan nozzles and operational parameters (spray pressure, nozzle orientation, and airspeed) selected for field trials. These treatments were then evaluated in the field for both in-swath and downwind deposition, with a mass balance on the measured results used to compare each of the formulated product treatments to a reference treatment. Wind tunnel results showed the formulated product tank mixes resulted in significantly different droplet sizes than the water and non-ionic surfactant "blank" reference

Manuscript received October 7, 2011; accepted for publication May 30, 2012; published online September 2012.

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sprays. Additional adjuvants resulted in minimal changes in droplet size as compared to the formulated product mixture. However the polymer tested broadened the droplet size distribution. Drift modeling of the wind tunnel droplet size results demonstrated little difference between the formulated product and spray adjuvant spray mixtures. However, all treatment solutions significantly reduced modeled drift as compared to the reference treatment. While the field study results did highlight significant differences between treatments solutions, it also showed a great degree in data variability as a result of meteorological and sampling issues. These results have led the authors to conclude that field testing of potential drift reduction technologies under aerial application conditions will be cost prohibitive and likely would give highly variable results. Wind tunnel evaluations at certified laboratories offer a much quicker and inexpensive method for evaluating large numbers of nozzle and spray formulation treatments.

KEYWORDS: drift, drift reduction technology, spray droplet sizing, active ingredient, spray adjuvants

Introduction

Improving application efficiency and decreasing off-target movement of sprays from aerial sprays continues to be a major concern. Ongoing research and education efforts, new product developments, and adaption of existing methods continue within the industry to address these concerns. With the development of these new and alternative methods and technologies comes the need to evaluate their performance. There are several testing protocols and standards available that outline test methods for evaluating sprays from agricultural application systems in the lab [1–4], through modeling [5,6], or under field conditions [1,7]. These methods have been applied to document and establish a number of factors that influence the movement of applied sprays including droplet size [8], spray formulation [9], canopy effects [10], wind speed [11], and atmospheric stability [12]. All of these factors were also examined as part of a series of drift studies conducted using the Spray Drift Task Force [13]. Most of the dominant parameters impacting spray drift, including nozzle type and configuration, droplet size, and wind speed have been well studied and documented. Less studied and documented are the affects from adjuvants added to active ingredient formulations and their impact on droplet size and potential spray drift.

Spanoghe et al. [14] reviewed available literature regarding agricultural adjuvants and their impact on droplet size characteristics and concluded that while these products do have an influence on the solution physical properties and resulting droplet spectrum, that other changes such as spray pressure and nozzle type play a larger role. However, relative velocity differences between the spray jet and airstream, especially under aerial application conditions, were not mentioned. The relative difference in air and liquid velocities is recognized as one of the most significant influences on spray droplet size for aerial application spray systems [15]. Generally, studies examining the effects of adjuvants under aerial application conditions found only minor differences in droplet sizes among spray solutions containing formulated active products [16,17] but more significant differences when a formulated product was not included [18–20]. Sanderson et al. [16] showed only minor droplet size variations in a wind tunnel for three formulations of Propanil (an emulsifiable concentrate, a liquid flowable, and a water dispersable granule), with and without a non-ionic surfactant and a crop oil, sprayed in a 52 m/s (117 mph) airstream with a disc core nozzle. Although there were significant differences between formulation types, the addition of either adjuvant to a given formulation type generally showed little, or no, significant changes in droplet size and relative drift potential. Kirk [17] found that the adjuvant influence on atomization, when included in different Roundup tank mixes, could not be distinguished in wind tunnel atomization studies and field drift studies. Both Hall et al. [18] and Hoffmann et al. [19] did find differences in median droplet size amongst six different adjuvants but only tested the products in water solution. Lan et al. [20] found differences in deposited droplet sizes and concentrations for near-downwind deposition (<25 m) of aerial sprayed treatments between four adjuvants tested using a blank EC formulation, but did not report any wind tunnel measured droplet size data. While the few studies cited are somewhat inconsistent, there is a trend indicating that for aerial applications, where air shear is the dominant force driving atomization, adjuvant effects are only distinguishable when tested in "blank" (i.e., no formulated product) spray mixes.

The objective of this work was to evaluate the effects of a formulated spray product with and without additional tank-mix adjuvants on spray atomization and modeled and field measured deposition and drift. Modeled and field measured results for the different spray treatment solutions were compared following proposed drift reduction technology testing protocols.

Methods

Field Testing

Six treatments (Table 1) were tested in a field of recently harvested wheat (stubble ∼ 10 cm tall) located near College Station, TX (30°33′09.83″N 96°27′17.52″W). Field testing was conducted on two days, June 21 (day 1) and July 10 (day 2), 2011. A reference treatment was made using the American Society of Agricultural and Biological Engineers (ASABE) Standard S572 [4] fine/medium boundary spray nozzle; a 110° flat fan nozzle with a number 3 orifice (Spraying Systems Co., Wheaton, IL) operating at 296 kPa (43 psi). The other five treatments consisted of 40° flat fan nozzles with number 12 orifices spraying

TABLE 1—*Atomization and field study treatment nozzle and airspeed operational parameters*.

					Spray Formulation (Water Carrier)	
Treatment	Nozzle and Orientation	Spray Pressure[a] (kPa (psi))	Airspeed (m/s (mph))	Number of Nozzles	Active Ingredient (Rate)	Adjuvant (Rate)
1-REF	11003 @ 0°	296 (43)	61.2 (137)	60	None	90% non-ionic surfactant (0.25% v/v)
2-HL	4012 @ 28°	262 (38)	61.2 (137)	36	Headline AMP™ (39.1 ml/L)	none
3-HL COC	4012 @ 28°	262 (38)	61.2 (137)	36	Headline AMP™ (39.1 ml/L)	crop oil concentrate 83/17% petroleum oil/surfactant (3% v/v)
4-HL HSOC	4012 @ 28°	262 (38)	61.2 (137)	36	Headline AMP™ (39.1 ml/L)	high surfactant oil concentrate 25% surfactant (0.5% v/v)
5-HL GP	4012 @ 28°	262 (38)	61.2 (137)	36	Headline AMP™ (39.1 ml/L)	guar gum polymer (240 g/L)
6-HL PP	4012 @ 28°	262 (38)	61.2 (137)	36	Headline AMP™ (39.1 ml/L)	petroleum polymer (15.6 ml/L)

[a]An additional set of wind tunnel testing was done for all treatments using 552 kPa (80 psi) to account for the incorrect pressure used on the first day of field testing.

different spray formulations all operating at 262 kPa (38 psi). The reference spray treatment required sixty, 11003 flat fan nozzles. The other treatments, treatments 2–6, required thirty-six, CP-11TT 4008 nozzles. Note that these five treatments consisted of the fungicide Headline AMP™ (BASF Corporation, Research Triangle Park, NC) with and without additional adjuvants. The selected 40° nozzle was a CP Products (CP Products, Tempe, AZ) 4012 flat fan tip held in a CP-11TT body attached to a CP-06 swivel. Nozzle operational parameters were established based on desired field application rates, product restrictions, and best management practices. An additional set of wind tunnel evaluations (as described later) were made for all six treatments but with all spray pressures set to 551.5 kPa (80 psi). This was due to a malfunction in the aircraft spray system used in the field studies that incorrectly forced spray pressures to 551.5 kPa during the first day of field evaluations. The nozzle settings, airspeeds, and spray formulations for the six treatments are given in Table 1. Each treatment is also assigned an acronym shorthand following the treatment number (Table 1) to facilitate easier discussion throughout the text.

All treatments were replicated once on day 1 will all spray pressures at 552 kPa (80 psi). The applied spray rates for the reference treatment (1-REF) on day 1 was 12.8 L/ha (1.4 gpa), while the spray rates for the other treatments (2–6) were 25.6 L/ha (2.7 gpa). Three replications of each treatment were completed on day 2 with pressures specified as listed in Table 1. The applied spray rate for 1-REF was 9.4 L/ha (1 gpa) while the spray rate for the remaining was 18.7 L/ha (2 gpa). Aerial spray treatments were performed using an AirTractor (Air Tractor, Inc., Olney, TX) 402B aircraft operated at 61.2 m/s (137 mph) with a spray swath of 20 m (67 ft) and a release height of 3 m (10 ft). Each

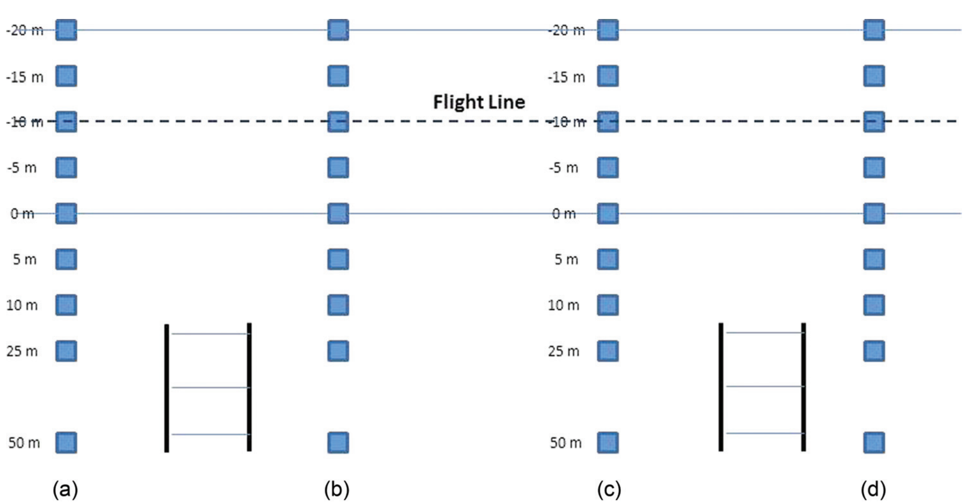

FIG. 1—*Field drift study layout.*

spray swath was applied along the flight line (Fig. 1) with the spray remaining active a minimum of 152 m (500 ft) to either side of the A and D sampling lines. Each spray treatment tank mix also included caracid brilliant flavine FFS fluorescent dye (Carolina Color & Chemical Co., Charlotte, NC) at a rate of 0.66 g/L. The aircraft was ferried from the field to the runway facilities between treatments where the booms and tank were emptied and rinsed prior to loading the next treatment's spray solution.

Four parallel sampling lines (A–D), 100 m (328 ft) apart, were deployed with five in-swath (−20 m, – 15 m, – 10 m, – 5 m, and 0 m, where 0 m is the downwind edge of the swath) and four downwind (5 m, 10 m, 25 m, and 50 m) sample stations per line (Fig. 1). Sampling lines were deployed such that they were parallel to the observed wind direction in the field. All in-swath and downwind deposition samplers consisted of clean 10 cm × 10 cm Mylar cards held in place on metal plates of the same dimensions using metal clips. The Mylar card and metal plate assemblies were positioned on 0.3 m × 0.3 m (1 ft × 1 ft) plywood squares to ensure the cards were horizontal to the ground surface and free from interference or contamination by plant foliage. Prior to each treatment replication spray pass, new Mylar cards were deployed. At the completion of each replication, Mylar cards were collected into individually labeled zip-top bags. All sample bags were labeled with unique identifiers that included treatment, replication number, sample type, location in the field, and serial number.

Sample Processing and Recovery Analysis

The labeled plastic bags containing the collected Mylar cards were transported to the laboratory for processing. Sample processing followed methods detailed in Ref [21] to obtain dye deposition per area. The calculated deposition rates were then adjusted for dye recovery rates. Recovery rates were determined for each spray solution by spiking six Mylar cards, each with 10 μl of solution. The spiked samples were then processed for deposition, which was then compared to the known spiked volume to determine recovery. Recovery percentages were 99 %, 97 %, 95 %, 95 %, 93 %, and 96 % for Treatments 1–6, respectively. Additionally, tank mix samples were collected and analyzed following methods described in Ref [21] to determine actual dye concentration rates. These data were then used calculate the spray volume deposition values. Deposition data were further calculated to determine the total in-swath deposition and total downwind (5–50 m) deposition as a fraction of the total applied spray [22] using the calculated spray rates. Deposition concentrations were also adjusted for wind direction (actual versus sampling line) [23,24]. Averages, standard deviations, and mean separations (Tukey's honestly significant difference (HSD) at $\alpha = 0.5$) were calculated using SYSTAT (Version 13, Systat Software, Inc., Chicago, IL).

Meteorological Data

The original meteorological monitoring equipment deployed during the field studies malfunctioned. Meteorological data were obtained from the United States Department of Agriculture, Agricultural Research Service, Areawide Pest Management Unit's (USDA ARS APMRU) Minilab Weather Station (http://apmru.usda.gov/weather/), which was located approximately four miles from the field site used in the study. Temperature and relative humidity (Campbell Modified Vaisala Probe, Campbell Scientific Inc., Logan, UT), and wind speed and direction (Met-One 034B Anemometer, Met One Instruments, Grant Pass, OR) were collected for each day. This station records the data on an hourly basis so individual replication data for each treatment were not available.

High Speed Wind Tunnel Testing

Droplet size measurements were made for the six spray treatments that were evaluated under field conditions. Atomization testing was conducted in the United States Department of Agriculture, Agricultural Research Service (USDA ARS) Aerial Application Technology high speed wind tunnel facility. The tunnel has an outlet section of 0.3 m × 0.3 m (1 ft × 1 ft) with a plumbed spray section mounted on a vertical linear traverse (Fig. 2). The tunnel's operational airspeed is from 6.7 m/s to 98 m/s (15 mph to 220 mph). Spray nozzles are mounted on the boom similar to how they would be configured on the aircraft. The boom is plumbed to a pressurized spray container from which the spray pressure is adjusted and maintained. During testing, the boom section

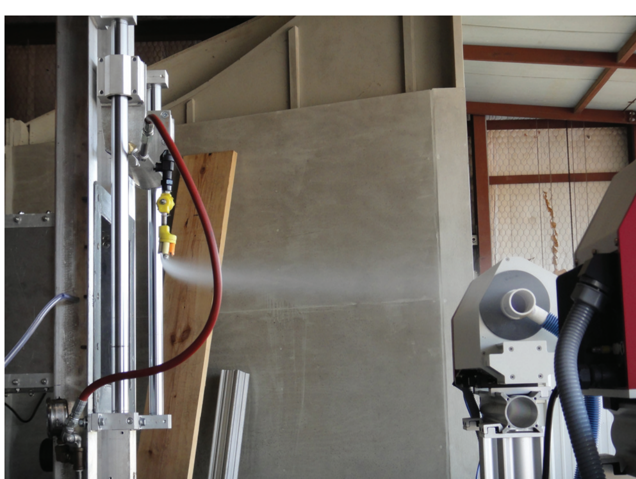

FIG. 2—*Wind tunnel outlet, mounted nozzle traverse and Sympatec position.*

and nozzle are traversed vertically such that the entire spray plume travels through the measurement plane of the laser diffraction system.

Droplet size measurements were made using a Sympatec HELOS laser diffraction droplet sizing system (Sympatec Inc., Clausthal, Germany) which was positioned approximately 1.2 m downstream of the spray nozzle outlet to insure full atomization of the spray [25]. The HELOS system was set up with a lens (manufacturer labeled as R7) with a dynamic size range of 0.5–3500 μm divided across 32 sizing bins. The two components of the system, an emitter and receiver, were mounted across from each other downstream of the nozzle outlet and position such that the laser was centered on the tunnel outlet. Vibration from the wind tunnel required suppressing the largest droplet size bin channel, but for all treatments tested the largest droplet size measured was a minimum of four bins from this channel. A minimum of three replicated measurements were made for each treatment. Each replication consisted of a complete vertical traverse of the spray plume. After the replicated measurements for each treatment were completed, droplet size statistics were determined for the $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$, which are the droplet diameters (μm) for which 10 %, 50 %, and 90 %, respectively, of the total spray volume is contained in droplets of equal or lesser size. Further, the percentage spray volume contained in spray droplets of 100 μm or less ($\% < 100\ \mu$m), which is an indicator of the fraction of the total spray volume likely to drift, was reported. Averages, standard deviations, and mean separations (Tukey's HSD at $\alpha = 0.5$) were calculated using SYSTAT.

AGDISP Modeling

Using the results from the high speed wind tunnel testing, the Agricultural Dispersion (AGDISP version 8.24) model was used to predict the transport and fate of the sprays resulting from the six treatments in Table 1. AGDISP allows users to input a unique droplet size distribution that is then used to drive the dispersion and deposition calculations based on that spray being released under user specified aircraft operation conditions, meteorological conditions, and field characteristics. The simulations run for this study were setup to mirror, as close as possible, aircraft operational conditions and field characteristics that were present during the field testing portion of the study. This included specifying the aircraft as an AirTractor (Air Tractor, Inc., Olney, TX) AT-402B operating at an airspeed of 61.2 m/s (137 mph) and an application height of 3 m (10 ft). The boom setup included 60 nozzles, evenly spaced using 65 % of the boom length, for treatment 1, and 36 nozzles, evenly spaced using 65 % of the boom length, for treatments 2–6. Spray rates were set at 9.4 L/ha (1 gpa) for treatment 1 and 18.7 L/ha (2 gpa) for treatments 2–6. Droplet size distributions were input using the results from the high speed wind tunnel testing. It should be noted that two simulations were performed for each treatment; one at the droplet size measured using a spray pressure of 552 kPa (80 psi) (which will be designated as day 1 results) and the other using droplet size measured using the correct spray pressure as designated in Table 1 (which will be designated as day 2 results). Air temperature was set at 25°C (77°F) and relative humidity at 70 %. Wind direction was assumed to be perpendicular to the swath. Three wind speed conditions were modeled; 0.9 m/s, 1.8 m/s, and 3.6 m/s (2 mph, 4 mph, and 8 mph). A canopy roughness of 0.762 cm (0.3 in) was specified. All simulations were run with no evaporative losses and no swath offset (AGDISP defaults a one-half swath offset).

The outputs from AGDISP included application efficiency (the percentage of applied spray material that deposits in-swath) and the downwind deposition (the percentage of applied spray material that deposits downwind of the intended swath). Comparisons were made between treatments 2–6 by calculating the percentage difference in both application efficiency and downwind deposition as compared to the reference (1-REF). Similar results will be used when analyzing potential drift reduction technologies (DRTs) such as the Environmental Protection Agency (EPA) DRT [1] testing program.

Results

Field Study

The observed meteorological data for each day are given in Table 2 and the order and time each treatment was tested, along with the flight line heading, for each day is given in Table 3. The flight line on Day 2 was adjusted as a result

TABLE 2—*Meteorological data for both study days.*

Hour	Average T (°C)	Average Relative Humidity (%)	Average Wind Speed (m/s)	Average Wind Direction (° coming from)	Wind Direction Standard Deviation (°)
Day 1—June 21, 2011					
8	27.4	91	2.7	178	14.2
9	28.4	85	4.1	200	12.6
10	29.3	79	3.9	203	13.2
11	30.8	72	4.2	200	13.9
12	31.9	67	4.0	212	15.7
Day 2—July 10, 2011					
8	25.1	97	1.4	143	10.2
9	27.4	90	1.6	168	28.9
10	29.1	83	2.1	197	29.4
11	30.4	76	1.5	201	58.3
12	31.9	69	1.5	189	55.9

TABLE 3—*Treatment times and flight heading for each day's treatments.*

Treatment	Time	Flight Line Heading (°)
	Day 1	
2-HL	9:30 am	270
3-HL COC	9:51 am	270
4-HL HSOC	10:16 am	270
1-REF	10:37 am	270
5-HL GP	10:58 am	270
6-HL PP	11:20 am	270
	Day 2	
6-HL PP	9:38 am	220
5-HL GP	10:01 am	270
1-REF	10:28 am	270
4-HL HSOC	10:48 am	270
3-HL COC	11:17 am	270
2-HL	11:35 am	270

of the observed shifting wind direction. While wind speeds were consistent during day 2 treatments, the first hour of day 1 treatments was over 1 m/s lower than that present in the rest of that day's trials. Day 1 wind speeds were also more than double that of day 2. The treatments were arranged both days such that the reference treatment (1-REF) was the middle treatment in an effort to have the meteorological conditions of the other treatments as similar as possible to the reference. Approximately 20 mins were required to complete the single replication on day 1 for each treatment and approximately 20–25 mins to complete all three replications for each treatment on day 2.

The mean in-swath deposition and downwind deposition, as a fraction of the total applied spray volume, are given in Table 4. For day 1, the data from sampling lines A–D for the single replication completed were averaged. For day 2, the data from sampling lines A–D for all three reps completed were averaged. The overall in-swath and downwind deposition rates, as compared to the total applied, were fairly low on day 2. During the second day's testing, the winds were light and variable and resulted in the sampling and flight lines being reoriented after the first two treatments. However the light and variable winds still resulted in very low deposition rates. While the wind direction on day 1 was more consistent, the variation present was coupled with the higher wind speeds. These issues resulted in a significant degree of variability in the field data, as indicated by the standard deviations seen across both the in-swath and downwind deposition data (Table 4). Consequently, this level of variability resulted in few significant differences between treatment means, particularly in downwind deposition, for both days (Table 4). The use of a spray nozzle designed for the aerial platform (the 40° flat fan nozzle held

TABLE 4—*Deposition data for all treatments across both days and all replications.*

	In-Swath Deposition (−20 m to 0 m) (% of Total Applied)							
	Day 1				Day 2			
Treatment	Mean[a]		±	Standard Deviation	Mean[a]		±	Standard Deviation
1-REF	16.9	a	±	4.2	5.8	a	±	1.6
2-HL	51.9	b	±	13.3	22.6	b	±	5.9
3-HL COC	30.7	ab	±	12.5	37.0	c	±	13.2
4-HL HSOC	34.5	abc	±	14.0	22.1	b	±	7.9
5-HL GP	58.2	c	±	10.5	33.4	bc	±	13.0
6-HL PP	56.1	c	±	4.3	29.4	bc	±	9.6
	Downwind Deposition (5 m to 50 m) (% of Total Applied)							
	Day 1				Day 2			
Treatment	Mean[a]		±	Standard Deviation	Mean[a]		±	Standard Deviation
1-REF	3.7	a	±	0.6	7.3	b	±	4.7
2-HL	8.3	b	±	3.2	4.9	ab	±	2.4
3-HL COC	2.8	a	±	1.1	7.4	b	±	4.2
4-HL HSOC	2.2	a	±	0.8	6.6	ab	±	2.4
5-HL GP	3.3	a	±	2.8	5.1	ab	±	4.0
6-HL PP	4.1	ab	±	0.8	2.8	a	±	0.9

[a]Means followed by the same letter(s) within each day's in-swath deposition and integrated deposition data are not significantly different. Determined using Tukey's HSD at $\alpha = 0.05$ level.

with the CP Products nozzle body) results in significantly improved in-swath deposition and decreased downwind deposition, as compared to the reference treatment (1-REF). The use of spray tank adjuvants did not show consistent increase in in-swath deposition nor decrease in downwind deposition, as compared to the formulated product treatment (2-HL). However, there is some indication that the polymers to increase the in-swath deposition; as a result of an increase in the number of larger spray droplets created (discussed in the following section). However, consistent significant decrease in downwind deposition is not seen with the use of additional adjuvants across both days tested (Table 4).

Spray Droplet Sizing

Droplet sizes for the five solutions containing active ingredient were very different from those of the water and 90 % non-ionic surfactant solution (Table 5). Overall volume median diameters (VMDs) ranged from 168 μm to 299 μm, for all treatments across both spray pressures. The percentage of spray volume

TABLE 5—*Atomization results for treatment tests in high speed wind tunnel studies.*

Day 1																
	$D_{V0.1}$				$D_{V0.5}$				$D_{V0.9}$				%<100 μm			
Treatment	Mean[a]		Standard Deviation		Mean[a]		Standard Deviation		Mean[a]		Standard Deviation		Mean[a]		Standard Deviation	
1-REF	80.5	c	±	1.9	179.5	c	±	2.3	308.6	c	±	3.4	16.3	a	±	0.2
2-HL	123.5	a	±	1.1	274.5	b	±	1.9	451.7	b	±	3.8	6.5	d	±	0.1
3-HL COC	123.8	a	±	1.0	282.7	b	±	1.1	462.7	b	±	1.3	6.5	d	±	0.2
4-HL HSOC	120.2	a	±	2.1	273.2	b	±	1.5	445.8	b	±	1.4	6.9	d	±	0.3
5-HL GP	96	ab	±	1.4	299.1	a	±	2.1	557.6	a	±	3.0	10.7	c	±	0.3
6-HL PP	80.7	b	±	1.2	280	b	±	4.2	587.9	a	±	3.4	14.3	b	±	0.3
Day 2																
1-REF	65.5	e	±	0.9	167.9	d	±	0.6	297.4	e	±	4.4	21.7	a	±	0.6
2-HL	100.2	b	±	1.2	255.7	bc	±	1.0	434.3	c	±	0.9	10.0	d	±	0.2
3-HL COC	105.3	a	±	1.2	244.3	c	±	1.8	393.1	d	±	3.1	9.0	ef	±	0.2
4-HL HSOC	107.7	a	±	3.0	254.3	bc	±	11.2	409.4	cd	±	16.0	8.6	f	±	0.5
5-HL GP	90.7	c	±	1.1	293.9	a	±	2.2	547.9	b	±	3.7	11.7	c	±	0.2
6-HL PP	78.1	d	±	1.5	265.3	b	±	8.7	661.0	a	±	26.6	15.5	b	±	0.6

[a]Means followed by the same letter(s) within each day's droplet size data are not significantly different. Determined using Tukey's HSD at $\alpha = 0.05$ level.

less than 100 μm in diameter, a potential indicator of the portion of spray (smaller droplets) most prone to drift, ranged from 6.5 % to 21.7 %. The droplet size for day 1 were generally larger than those from day two as a result of the increased spray pressured on day 1 (551.5 kPa versus 296 kPa). This increased pressure has the effect of increasing droplet velocities, as compared to the lower pressure, resulting in lower velocity gradients between the droplets and the surrounding high speed air. This will decrease atomization resulting in larger droplet sizes [25]. The smallest overall droplet size resulted from the reference nozzle treatment (1-REF) at both pressures. All formulated product and formulated product plus adjuvant solutions (2–6) showed significant increases in the overall droplet spectrum ($D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$) as well as a significant reduction in the number of fine droplets (% < 100 μm). The addition of both the crop (3-HL COC) and high surfactant oil (4-HL HSOC) concentrates showed few significant changes in overall droplet spectrum, as compared to the formulated product alone (2-HL) for both Day 1 and 2 treatments. The addition of the guar gum polymer (5-HL GP) resulted in significant increases in the 50 % and 90 % droplet diameters but significantly decreased the 10 % volume diameter and significantly increased the volume of spray containing droplets 100 μm or less. Similarly the addition of the petroleum polymer (6-HL PP) significantly increased the 90 % volume diameter but also significantly decreased the

TABLE 6—*AGDISP results for application efficiency and downwind deposition for the seven treatments selected for field evaluation.*

		Application Efficiency (% appl.) at Windspeeds Shown (m/s)			Downwind Deposition (% appl.) at Windspeeds Shown (m/s)		
Day	Treatment	0.9	1.8	3.6	0.9	1.8	3.6
1[a]	1-REF	83.5	74.9	55.6	16.5	25.0	44.2
	2-HL	90.8	85.8	72.5	9.1	14.2	27.4
	3-HL COC	91.2	86.3	73.5	8.8	13.7	26.4
	4-HL HSOC	90.8	85.7	72.4	9.2	14.3	27.6
	5-HL GP	90.4	85.3	72.7	9.6	14.5	26.9
	6-HL PP	88.4	81.8	68.6	11.6	17.4	30.2
2	1-REF	81.7	72.3	52.2	18.3	27.4	47.3
	2-HL	89.4	83.6	69.3	10.6	16.3	30.6
	3-HL COC	89.2	83.4	68.4	10.8	16.6	31.5
	4-HL HSOC	90.0	84.4	70.4	10.4	15.6	29.6
	5-HL GP	89.8	84.2	71.5	10.2	15.5	27.9
	6-HL PP	86.5	78.2	64.9	13.5	19.6	31.8

[a]Day 1 spray pressures were at 551.5 kPa versus 296 kPa (T1) and 296 kPa (T2–6) kPa used on Day 2.

TABLE 7—*AGDISP modeled application efficiencies and downwind depositions for each treatment expressed as a percent change using Treatment 1 as a reference.*

		Application Efficiency (%) Compared with T1 at Windspeeds Shown (m/s)			Downwind Deposition (%) Compared with T1 at Windspeeds Shown (m/s)		
Day	Treatment	0.9	1.8	3.6	0.9	1.8	3.6
1[a]	1-REF						
	2-HL	8.7	14.6	30.4	−44.8	−43.2	−38.0
	3-HL COC	9.2	15.2	32.2	−46.7	−45.2	−40.3
	4-HL HSOC	8.7	14.4	30.2	−44.2	−42.8	−37.6
	5-HL GP	8.3	13.9	30.8	−41.8	−42.0	−39.1
	6-HL PP	5.9	9.2	23.4	−29.7	−30.4	−31.7
2	1-REF						
	2-HL	9.4	15.6	32.8	−42.1	−40.5	−35.3
	3-HL COC	9.2	15.4	31.0	−41.0	−39.4	−33.4
	4-HL HSOC	10.2	16.7	34.9	−43.2	−43.1	−37.4
	5-HL GP	9.9	16.5	37.0	−44.3	−43.4	−41.0
	6-HL PP	5.9	8.2	24.3	−26.2	−28.5	−32.8

[a]Day 1 spray pressures were at 551.5 kPa versus 296 kPa (T1) and 296 kPa (T2–6) used on Day 2.

TABLE 8—*AGDISP modeled application efficiencies and downwind depositions for each treatment expressed as a percent change using Treatment 2 as a reference.*

		Application Efficiency Compared with T2 at Windspeeds Shown (m/s)			Downwind Deposition Compared with T2 at Windspeeds Shown (m/s)		
Day	Treatment	0.9	1.8	3.6	0.9	1.8	3.6
1[a]	2-HL						
	3-HL COC	0.4	0.6	1.4	−3.3	−3.5	−3.6
	4-HL HSOC	0.0	−0.1	−0.1	1.1	0.7	0.7
	5-HL GP	−0.4	−0.6	0.3	5.5	2.1	−1.8
	6-HL PP	−2.6	−4.7	−5.4	27.5	22.5	10.2
2	2-HL						
	3-HL COC	−0.2	−0.2	−1.3	1.9	1.8	2.9
	4-HL HSOC	0.7	1.0	1.6	−1.9	−4.3	−3.3
	5-HL GP	0.4	0.7	3.2	−3.8	−4.9	−8.8
	6-HL PP	−3.2	−6.5	−6.3	27.4	20.2	3.9

[a]Day 1 spray pressures were at 551.5 kPa versus 296 kPa (T1) and 296 kPa (T2–6) used on Day 2.

10 % and 50 % volume diameters and increased the number of fine droplet in the spray volume.

AGDISP *Modeling*

The results from the AGDISP modeling (Table 6) show that the nozzle/solution combination with the smallest droplet size (1-REF; smallest 10, 50 and 90% volume diameters as well as greatest % volume less the 100 μm) resulted in the lowest modeled application efficiency and highest downwind deposition. The addition of the oil concentrates (3-HL COC and 4-HL HSOC) as well as the guar polymer (5-HL GP) did not change modeled application efficiencies and downwind deposition values as compared to the formulated product alone (2-HL). The addition of the petroleum polymer (6-HL PP) resulted in reduced application efficiencies and increased downwind deposition, as compared to all other Headline treatments, again as a result of the corresponding increase in the overall volume of spray comprised of finer droplets. Additionally, these results show that performance of a drift reduction technology is highly influenced by the wind speed under which they are used.

Evaluation of any technology that may potentially reduce drift requires comparison to some reference treatment technology as a baseline [1]. Taking treatments 2–6 as potential drift reduction technologies (DRTs), they can be compared to the reference treatment (1-REF) for change in application efficiency and downwind deposition (Table 7). Application efficiencies increased (positive percentage) as a result of the use of the aerial nozzle and the addition of the Headline and adjuvants. This is directly related to the increase in droplet size of the sprays (Table 5). Application efficiency of treatments 2–6, relative to the reference, increased by a factor of 3 to 4 as the wind speed increased from 0.9 m/s to 3.6 m/s, as a function of increased swath offset and downwind deposition as a result of the increased movement of the spray. Similarly, modeled downwind deposition values were 30 % to 40 % lower for treatments 2–6 as compared with the reference treatment (1-REF).

To evaluate the effect of the adjuvants (treatments 3–6), the formulated product only treatment (2-HL) was used as a baseline for comparison. The addition of both the oil concentrations and guar polymer resulted in little change in application efficiency and downwind deposition (Table 8). Although there was a decrease in application efficiency and increase in downwind deposition with the petroleum polymer (6-HL PP), it was minor. None of the adjuvants, when added to the water plus Headline spray mixture (2-HL), served as a significant drift reduction technology.

Discussion and Conclusions

The objective of this work was to evaluate how the addition of a formulated spray product, with and without additional tank-mix adjuvants, changed both spray atomization at the nozzle as well as spray movement under aerial application conditions. Wind tunnel testing showed that in the presence of the formulated product (Headline) crop oils tend to have little impact on spray atomization while the polymers tended increase both the number of larger and smaller droplets in the spray. Testing of these adjuvants in the presence of a formulated product (this work and Refs [16,17]) tends to lessen the effect seen when testing in water alone [19]. The modeling results translated the droplet size results into estimates for in-swath and downwind deposition and showed little difference between the formulated product spray (2-HL) and spray treatment with additional adjuvants (3–6), with the exception of the petroleum polymer (6-HL PP). However, all treatments showed reductions in estimated drift levels as compared to the reference treatment (1-REF). The modeling results also demonstrated that the relative drift reduction levels are highly dependent on the wind speed under which the applications take place with approximately 10 % increases in drift as the wind speed increased from 0.9 m/s to 3.6 m/s.

Field evaluations showed a few significant differences between treatments, but overall resulted in highly variable data as a result of variability in meteorology over the testing periods. The field trial conducted with a reference treatment, as detailed in ASABE S561 [7], however it was not sprayed at the same exact time as the other treatments as this would have required two aircraft or a specialized spray system. ASABE Standard 561 states that if a reference system cannot be sprayed at the exact time, 25 or more replications of each treatment should be made, which would have resulted in a minimum of 150 spray runs for this study. This makes field testing large numbers of potential DRTs under aerial application conditions cost prohibitive. Wind tunnel evaluations offer a quick and inexpensive method for evaluating large numbers of nozzle and spray formulation treatments, without issues of meteorological, application, and sampling variability seen under field conditions. There is further need to investigate the interaction of active ingredient spray formulations and spray tank modifiers under high speed air shear atomization conditions to better understand the potential role and benefit that adjuvants play in aerial applications.

Acknowledgments

This study was supported in part by a grant from the Deployed War-Fighter Protection (DWFP) Research Program, funded by the U.S. Department of Defense through the Armed Forces Pest Management Board (AFPMB). Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

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