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Field Scale Evaluation of Spray Drift Reduction Technologies from Ground and Aerial Application Systems

ABSTRACT: The objective of this work is to evaluate a proposed test plan for the validation testing of pesticide spray drift reduction technologies (DRTs) for row and field crops, focusing on the testing of ground and aerial application systems under full-scale field evaluations. The measure of performance for a given DRT tested under field conditions is the downwind deposition as measured on horizontal fallout collectors. Ground and aerial application equipment were evaluated for in-swath and downwind deposition of sprays as applied by both a reference system and a drift reducing technology. For this study, the reference system was defined as a spray boom outfitted with the ASABE Fine/Medium boundary reference nozzles. For the ground system, the drift reducing system tested was a ground sprayer outfitted with an air-induction version of the reference nozzle. The aerial system DRT was a flat fan nozzle specifically designed for aerial application usage. Downwind deposition was measured from the edge of the swath out to 100 m downwind. Additionally, the airborne portion of the spray remaining suspended in the air at 50 m downwind was measured. There were a number of confounding issues with the measured data including poor recovery of deposits and non-ideal wind directions during specific replications. Even with these issues, the drift reduction between the reference and DRT system measured in the field for the aerial trials was similar to that estimated using the agricultural dispersion model. A number of additional improvements and checks are suggested prior to further field evaluations.

KEYWORDS: drift, DRT, drift reduction technology, spray droplet sizing

Introduction

The physical transport of applied agrochemical sprays through the air to any off-target site is considered spray drift [1]. The area of spray drift research is a well established one, with numerous studies examining the effects of droplet size [2], spray formulation [3], canopy effects [4], wind speed [5], atmospheric stability [6], as well as human exposure [7] and environmental effects [8] from spray drift. Large scale evaluations of drift from agricultural spray applications for ground, aerial, and orchard systems were conducted by the Spray Drift Task Force [9], which examined the effect of meteorology, as well as spray droplet size, tank mix formulation, and plant canopy. Through the basic understandings established by these and other studies, researchers and the industry have development new methods, equipment, and spray formulations with the intent of minimizing spray drift. With an increasing number of these new and alternative technologies, there is a growing need to determine if, and to what effect, they reduce spray drift, with several testing programs for measuring drift reduction technologies (DRTs) being proposed [10,11]. The U.S. EPA is making an effort to fill this need with a program designed to protect environmental and human health through the use of tested and approved DRTs [12].

The presently proposed framework addresses three testing methodologies, which include high-speed wind tunnel testing for aerial application technologies, low-speed wind tunnel testing for ground application technologies, and full-scale field testing for all types of application technologies. Protocols, standard operating procedures, and data quality assurance steps have been drafted for all three testing scenarios [13], with initial testing of both the high-speed and low-speed wind tunnel testing protocols being completed [14–17]. To date, the field testing portion of the draft protocol has not been evaluated.

The measure of performance for field tested DRTs will be directly determined from the deposition measured downwind of the application site [5]. The proposed field testing protocols follow recommenda-

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tions and guidance given by ASABE Standard S561.1, which established procedures for measuring drift from ground, orchard, and aerial sprayers [18]. Specifically, horizontal fallout collectors should be positioned from the edge of the spray swath to 61 m downwind to allow for the determination of the integrated downwind deposition out to 61 m and the point deposition at 30 m. The proposed protocol recommends three parallel downwind sampling lines with fallout collectors at 4, 8, 16, 30, and 61 m. The spray swath should be of sufficient length (200 m is recommended) such that spray material will reach the farthest collectors under the varying wind conditions of the study. Field-collected data can be input into spray dispersion models, such as agricultural dispersion (AGDISP), the model that is currently being used in the field of aerial application [19,20]. AGDISP is a near-wake model that "solves a Lagrangian system of equations for the position and position variance of spray material released from each nozzle on an aircraft" [21].

The objective of this work was to evaluate the proposed U.S. EPA Drift Reduction Technology field testing protocol by conducting a full-scale assessment for both aerial and ground spray application systems. The objective is not to determine the drift reduction ratings of the systems tested, but rather to determine the validity of the proposed protocols and to identify any potential issues that are not addressed within said protocols.

Methods

Spray Treatment Setups

Field study tests compared four unique spray treatments; two from an aerial platform and two from a ground based sprayer. Both the aerial and ground based applications consisted of a reference spray system and DRT treatment. The details of each treatment setup are detailed in the following sections.

Aerial Spray Treatments—Aerial spray treatments were performed using an AirTractor (Air Tractor, Inc., Olney, TX) 402B aircraft. The reference spray treatment consisted of 40 11003 flat fan nozzles (Spraying Systems, Inc., Wheaton, IL) that were operated at 303 kPa (44 psi) oriented 0° (straight down, vertical to the plane of flight). The DRT treatment consisted of 15 CP11TT 4008 nozzles (CP Products, Inc., Tempe, AZ) operating at 276 kPa (40 psi) and 0° orientation. Both treatments were applied at an airspeed of 58 m/s (130 mph) at a 20 m (65 ft) total swath width at a height of 3 m (10 ft), which, with the given nozzle setups and operating pressures, resulted in application rates of 6.5 L/ha (0.7 GPa) for both treatments. The spray solution was water with SilGuard 309 (Wilbur-Ellis Co., San Francisco, CA) at 0.25 % v/v and caracid brilliant flavine FFS fluorescent dye (Carolina Color and Chemical Co., Charlotte, NC) at 24.7 g/ha (10 g/acre).

Ground Spray Treatments—Ground spray applications were made using a John Deere (Deere and Co., Moline, IL) 8250 sprayer. The reference spray treatment consisted of 30 11003 flat fan nozzles operated at 276 kPa (40 psi) while the DRT treatment was 30 Teejet (TeeJet Technologies, Wheaton, IL) AI11003 air induction nozzles operated at 276 kPa (40 psi). The nozzles for both treatments were positioned along the boom to deliver a 30 m (98 ft) effective swath width and at a height of 1.8 m (6 ft) above the ground surface. Both treatments were applied at a ground speed of 4.5 m/s (10 mph), resulting in an application rate of 43 L/ha (4.6 GPa). The spray solution for the ground applications was also water with SilGuard 309 at 0.25 % v/v and caracid brilliant flavine FFS fluorescent dye at 24.7 g/ha (10 g/acre).

Spray Droplet Sizing

Prior to field treatments, the spray nozzles selected for both the ground and aerial treatments were evaluated for droplet size under the specified operating conditions (spray pressure, nozzle orientation, and airspeed (for the aerial treatments)). This was a measure of the droplet size applied for all treatments at the nozzle. A Sympatec Helos laser diffraction droplet sizing system (Sympatec, Inc., Clausthal, Germany) was used, which utilizes a 623 nm He–Ne laser and lens with a dynamic size range of 0.5–3500 μm, which is divided across 32 sizing bins. All measurements were conducted at the USDA-ARS wind tunnel site in College Station, TX. Aerial nozzle droplet sizing was conducted in the high-speed wind tunnel while the ground nozzle droplet sizing was conducted in the low-speed wind tunnel. For the aerial droplet sizing work, the nozzles were positioned at the outlet of the high-speed wind tunnel and set up and operated as specified earlier. The Sympatec was positioned ~61 cm (24 in.) downwind of the spray nozzle outlet. With the ground droplet sizing work, the nozzles were positioned within the low-speed wind tunnel on a vertical traverse and were set up and operated at the specified pressures with the nozzle pointing such that the emitted spray was directed downwind in the tunnel. The tunnel was operated at an air velocity of 3 m/s (7 mph). The Sympatec was position ~61 cm (24 in) downwind of the nozzle outlet. Three replications were completed for the specified nozzle setup for each spray treatment. A replication comprised traversing the entire spray plume through the SympatecHelos laser beam nozzle. Tests were performed within the guidelines provided by ASTM E1260-03, Standard Test Method for Determining Liquid Drop Size Characteristics in a Spray Using Optical Nonimaging Light-Scattering Instruments [22].

For each treatment tested, the volume median diameter ($D_{V0.5}$), $D_{V0.1}$, and $D_{V0.9}$) were determined. $D_{V0.5}$ is the droplet diameter (μm) where 50 % of the spray volume consists of droplets of equal or lesser diameter. Similarly, the $D_{V0.1}$ and $D_{V0.9}$ values are the diameters such that 10 % and 90 %, respectively, of the spray volume consists of droplets of equal or lesser diameter. The percent volume less than 100 μm, which is an indicator of the "driftable" portion of a spray, was also determined.

Field Testing Protocol

Downwind Sampling

The field sampling setup was adopted from previously reported studies [22–24] and from the Draft Generic Verification Protocol from the U.S. EPA for the evaluation of DRTs [5]. The field location selected for the study was located ~7 miles southwest of College Station, TX (30.542241°, −96.419044°) in a field of recently planted cotton (cotton plants at the four to six leaf stage and ~20 cm tall). The treatment and sampling layout was structured such that a 100 m long application swath was perpendicular to downwind sampling lines that extended 100 m. The length of the application swath was restricted in length by the terrain of the available application site. The application swath followed a heading of 75° such that the ideal crosswind to move material perpendicularly downwind would be 165°. The downwind edge of the application line was defined as the 0 m mark with in-swath and upwind sampling locations defined as negative (−) distances and the downwind sampling positions defined as positive (+). Two parallel sampling lines (labeled A and B) were established with mylar fallout cards (10×10 cm) positioned horizontally on the ground upwind (−40 m), in-swath (−20, −15, −10, −5, and 0 m), and downwind (1, 2, 5, 10, 20, 50, and 100 m) (Fig. 1). Only two parallel downwind sampling lines, 10 m apart, were used in this study, as compared to the three recommended in the DRT protocol, in order to accommodate a greater number of sampling locations with more locations near the downwind edge of the application swath. Additionally, two towers (positioned 10 m apart and parallel to the spray swath) were positioned with a monofilament line (0.457 mm diameter) suspended between them at 50 m downwind to measure the portion of spray that remained airborne with monofilament lines suspended at 1, 5, and 10 m.

Prior to each treatment replication, mylar cards and monofilament lines were deployed at the specified sampling locations. Mylar cards were mounted on metal plates (10×10 cm) (held in place with a clip on the upwind side) that were placed onto plywood plates (30×30 cm) that were positioned at each sampling location. The plywood plates ensured that the mylar/metal plate samples were horizontal to the ground surface and free from interference or contamination by plant foliage. The metal plates holding the mylar samples were sized to the mylar sheets used in order to provide a clean mounting spot for the new mylar samples that were deployed with each new treatment replication. Monofilament lines were deployed using fishing reels that were attached to one of the towers at each location. The line was stretched from one tower to the other. The fishing reel drags were set to allow the line to be pulled out by hand while maintaining tension on the line. The lines were attached to the second tower via a loop tied into one end that was attached to a clip on the tower. The fishing reels shielded the line inside from being contaminated during a given treatment replication, allowing for rapid deployment of the line between replications.

At the completion of each replication, mylar samplers were collected into individually labeled zip-top bags that were stored in closed ice-chests. Monofilament lines were collected using a cordless drill holding a tapioca straw onto which the exposed line was rolled. Once the exposed line was collected onto the straw, it was cut and both the straw and the line were placed into individually labeled zip-top bags that

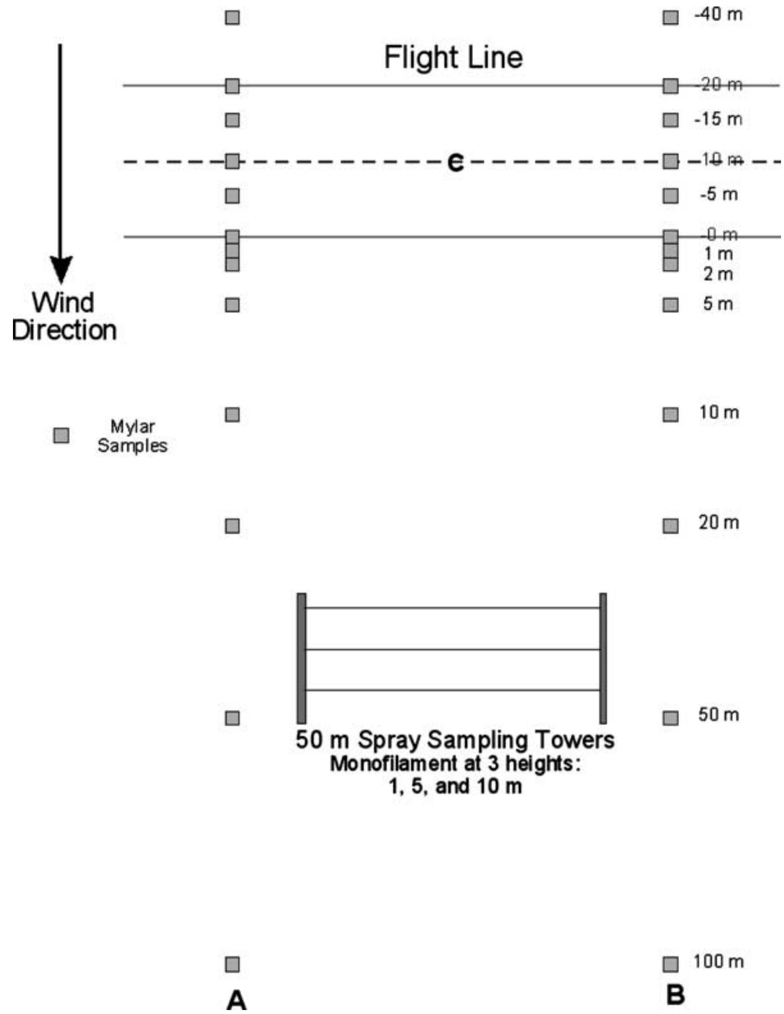

FIG. 1—*Field sampling layout.*

were also stored in closed ice-chests. 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 monofilament line and mylar samples were transported to the laboratory for processing. 40 ml of ethanol was pipetted into each bag, the bags were agitated by hand for ~15 s, and 6 mL of the effluent was poured into a cuvette. The cuvettes were then placed into a spectrofluorophotometer (Shimadzu, Model RF5000U, Kyoto, Japan) with an excitation wavelength of 423 nm and an emission at 489 nm. The fluorometric readings were converted to $\mu L/cm^2$ using a projected area of the sampler (100 cm^2 for the mylar cards and 45.7 cm^2 for the monofilament) and by comparisons to standards generated using the actual spray solution used. The minimum detection level for the dye and sampling technique was 0.07 ng/cm^2.

All deposition data was expressed as a mass of dye per area ($\mu g/cm^2$). The calculated values were adjusted based on dye recovery rates, which were determined by spiking both mylar and monofilament string samples with 10 μL of spray solution collected from both the ground and aerial spray hoppers. The spiked samples were then processed following the described methods above and the results, in the form of total volume (μL) of material deposited, were compared to the known spiked volume. For the mylar samples, recovery rates were 14.4 % and 26.7 % for the ground and aerial treatments, respectively. For the monofilament, recovery rates were 63.7 % and 74 % for the ground and aerial treatments, respectively. These recovery rates where much lower than those previously reported for the same sampling materials and methods [23]. The authors conjecture that the use of SilGuard, a silicone polymer, resulted in spray material and dye binding to the surfaces of the mylar and monofilament samplers and that different rates

TABLE 1—*Distance ranges and areas used in integration of in-swath mylar deposition data.*

	Ground Treatments		Aerial Treatments	
Mylar Sample	In-Swath Range Applied (m)	Total Area Applied to Sampler Measured Concentration (for 10 cm Distance) (cm^2)	In-Swath Range Applied (m)	Total Area Applied to Sampler Measured Concentration (for 10 cm Distance) (cm^2)
−20	−17.5 to −30	12,500	−17.5 to −20	2500
−15	−12.5 to −17.5	5000	−12.5 to −17.5	5000
−10	−7.5 to −12.5	5000	−7.5 to −12.5	5000
−5	−2.5 to −7.5	5000	−2.5 to −7.5	5000
0	0 to −2.5	2500	0 to −2.5	2500

used for ground and aerial treatments could have created the differences in recovery between them. While the field collected data was adjusted based on these recovery rates, the fact that the recovery rates were so low, particularly for the mylar samplers, created issues with recovering data from the slides as in-swath dye deposition rates on the order of 0.1 μg/cm² (0.1 ppm), were anticipated. The effective minimum deposition rate that can effectively be detected using the described fluorometric methods was 0.001 ppm.

Meteorological Monitoring

Meteorological data was monitored throughout with a meteorological monitoring station positioned ~30 m upwind of the spray swath. The meteorological tower measured sampled data every second and logged 1 min averages of wind speed and direction (RM Young model 05701 Wind Monitor-RE, RM Young Co., Traverse City, MI), temperature (RM Young model 43347VC Temperature Probe in a model 43408 aspirated radiation shield), and relative humidity (RM Young model 71372) at 2.5 m. All data was logged to a datalogger (Model CR 21X, Campbell Scientific, Logan, UT). After the completion of the study, the data was averaged over a 3 min period corresponding to the minute during and the 2 min following the time of application. Additionally, the wind direction difference from the ideal direction (165°) was determined.

Data Analysis

The in-swath, downwind, upwind, and 50 m drift towers deposition data was expressed as a percent of the total material applied. To determine the total material applied, both the ground and aerial tank mixes were analyzed for actual dye mixing rates and were found to be 315 and 2050 μg/mL, respectively. The ground and aerial application rates (43 and 6.5 L/ha, respectively) were multiplied by the dye mixing rates to determine the dye per area rates (0.135 and 0.144 μg/cm², respectively). To express the mylar (10 × 10 cm cards) data as a fraction of applied, the total amount applied in-swath over a 10 cm travel distance was calculated for both the ground and aerial treatments. The ground applications were made over a 30 m swath, which, coupled with the 10 cm travel distance, results in an application area of 30 000 cm². The aerial applications were made over a 19.8 m swath, which, following the same calculation, results in an application area of 19 800 cm². These results coupled with the dye per area rates return total dye application values of 4050 and 2851 μg for ground and aerial treatments, respectively, over the given areas.

To express the in-swath mylar data as a percent of applied, the adjusted data (based on recovery) was integrated over the in-swath distance. Prior to integration, both in-swath and downwind mylar samples from lines A and B were averaged for corresponding distances within each replication. Ground applications were centered over the −15 m location, resulting in the −20 m sample being overly weighted in the integration. For the ground and aerial application in-swath data, each mylar sample was applied across an area range with the entire swath width then being integrated. These area ranges with the total area applied to each sample (with respect to the 10 cm distance) for both the ground and aerial treatments are shown in Table 1. To perform the integration, the adjusted in-swath deposition data (μg dye/cm²) at each sampling location was multiplied by the corresponding area applied (shown in Table 1) to return to mass of dye sampled (μg). These values were then summed over the entire in-swath set of samples to return a total

TABLE 2—*Distance ranges and areas used in integration of downwind mylar deposition data.*

Mylar Sample	Downwind Range Applied (m)	Total Area Applied to Sampler Measured Concentration (for 10 cm Distance) (cm^2)
1	0–1.5	1500
2	1.5–3.5	2000
5	3.5–7.5	4000
10	7.5–15	7500
20	15–20	5000

mass of dye depositing in-swath. This value was then divided by the total mass applied, as presented earlier, to express the total in-swath deposition as a percent of the total applied material.

Similarly for the downwind deposition data, the mylar deposition data was adjusted for recovery and then integrated using the areas and distances shown in Table 2. For the downwind data, the area ranges and total areas used for the integration were the same for both the ground and aerial treatments. Note that the 50 and 100 m downwind deposition data is not included for either ground or aerial treatment since no deposition was measured, which was the result of low overall deposition coupled with low recovery. Following the same procedures as the in-swath data, the downwind data was integrated, summed, divided by the total material applied, and expressed as a percent of applied.

The 50 m monofilament tower data was also expressed as a percent of applied. Like the mylar samples, all monofilament data was adjusted for recovery using the values presented earlier. To determine the total amount of material applied to adjust the monofilament data, the distance of the line (10 m) had to be accounted for. The calculations are identical to those discussed for the mylar data, except 10 m is substituted for the 10 cm, returning total applied values of 405 000 and 285 120 μg for the ground and aerial treatments, respectively. The monofilament data was integrated over the total sampling height and line width and then compared to the total applied. The height ranges and total areas applied to monofilament samples at each height for the 50 m monofilament towers are shown in Table 3. Following the procedures mentioned earlier, the monofilament data was integrated over the total height, summed, and then compared to the total applied to express that data as a percent of applied.

Using all data collected, a mass balance was performed for each replicated treatment by summing the percent collected in all sampling areas. The summed total was defined as accounted while the difference was defined as unaccounted. DRT ratings were calculated only for aerial treatments as a result of little or no downwind data for the ground treatments (discussed in greater detail later). The treatments were compared using both the integrated downwind deposition data (integrated from 0 to 20 m) and the integrated 50 m tower data for the aerial reference and the aerial DRT treatments. The comparisons were made on a rep by rep basis as each corresponding replication was performed very close, time wise and meteorologically, to each other with corresponding replication being compared (e.g., R1 Reference to R1 DRT, R2 Reference to R2 DRT, etc.). The DRT treatment's effective reduction was calculated using Eq 1. An averaged DRT reduction was determined by averaging the reductions determined for each replication.

$$DRT_{reduction} = \frac{(\text{Reference} - \text{DRT})}{\text{Reference}} 100 \tag{1}$$

where:

$DRT_{reduction}$ = percent reduction in downwind spray movement of DRT treatment as compared to the Reference treatment,

TABLE 3—*Height ranges and areas used in integration of 50 m monofilament drift tower data.*

Monofilament Sample Height (m)	Height Range Applied (m)	Total Area Applied to Sampler Measured Concentration (for 10 m Width) (cm^2)
1	0–2.5	250 000
5	2.5–7.5	500 000
10	7.5–12.5	500 000

TABLE 4—*Droplet size data for selected treatments at specified operating conditions.*

Treatment	Droplet Size Parameters (μm) D_{V10}	D_{V50}	D_{V90}	Percent Less than 100 μm	Droplet Size Classification
Aerial reference	43.6	108.7	182.8	43.9	Fine/medium
Aerial DRT	166.1	335.3	520.1	3.0	Medium
Ground reference	84.1	194.7	320.2	14.2	Fine/medium
Ground DRT	157.2	385.6	638.8	3.8	Very coarse

Reference = downwind spray movement from Reference treatment expressed as either integrated downwind deposition from 0 to 50 m or integrated vertical spray deposition at 50 m, and

DRT = downwind spray movement from DRT treatment expressed as either integrated downwind deposition from 0 to 50 m or integrated vertical spray deposition at 50 m.

AGDISP Modeling

In addition to the field measured drift data collected for the aerial treatments, the droplet size data, aircraft operational parameters, and meteorological conditions were used to model the drift and airborne fraction of spray from each treatment. Model inputs included the nozzle layout on the booms as used in the field study and aircraft operational parameters reported earlier. The average wind speed, temperature, and relative humidity conditions (1.3 m/s, 28.5°C, and 81 %, respectively) were input for both aerial treatments. The wind direction was set as perpendicular to the flight line when modeling both treatments, even though this was not the case in the field. The surface roughness was set to 0.008 m with no crop canopy. Modeling outputs recorded were total downwind deposition and airborne drift, both expressed as a percentage of the total material applied. DRT reductions for both the downwind deposition and airborne drift data were determined using Eq 1.

Results

Droplet Size

The droplet size statistics measured for each of the treatments tested are given in Table 4.

Meteorological Data

The meteorological data recorded during each replication of each treatment is given in Table 5.

Deposition Data

The in-swath, downwind, and 50 m drift tower deposition data, as well as the mass balance results for both the aerial and ground treatments, are given for each treatment replication combination in Tables 6 and 7, respectively.

Both the aerial and ground treatment replications show very poor accountability for all replications and treatments. As a result of the ground treatments' poor mass accountability and, except for the first three replications of the ground reference treatment, with no downwind deposition being measured, comparisons of DRT and reference treatments were conducted only for the aerial treatments. For both aerial treatments, replications 1 and 5 were dropped as a result of wind direction variations exceeding the recommended 30° [18]. While the aerial reference treatment replication 2 slightly exceeded the 30° point (Table 5), given that the aerial DRT treatment was acceptable, this replication was kept due to the low number of acceptable replications. The averages and standard deviations in Table 8 are based only on the data from the second, third, and fourth replications.

AGDISP Results

AGDISP results for downwind deposition and airborne drift from both aerial treatments are shown in Table 9. Similar to the field measured data, reduction values are determined for both the downwind deposition and the airborne fraction remaining by comparing the results from the reference system to the DRT system.

TABLE 5—*Meteorological data recorded for each treatment/replication combination.*

Treatment	Replication	Wind Speed (m/s)	Wind Direction	Angle off Ideal 165° (Absolute Value)	Temperature (°C)	Relative Humidity
Aerial reference	1	0.15	53.1	111.9	25.7	92.5
	2	1.43	198.2	33.2	27	87.3
	3	0.85	157.4	7.6	28.2	82.2
	4	1.61	187.7	22.7	29.7	76.3
	5	1.61	199.2	34.2	30.6	70.3
Aerial DRT	1	0.18	319.4	154.4	27.4	86.1
	2	1.21	172.1	7.1	27.4	85.3
	3	1.30	183.7	18.7	29	79.8
	4	1.21	184.4	19.4	29.7	75
	5	1.70	213.1	48.1	30.6	68.9
Ground reference	1	0.46	107.7	57.3	25.9	93.9
	2	0.94	175.4	10.4	27.1	86.7
	3	1.21	165.7	0.7	28.3	81.4
	4	1.03	192.5	27.5	28.9	78.6
	5	1.03	199.1	34.1	30.1	73
Ground DRT	1	0.58	140	25	26.8	88.9
	2	0.63	246.3	81.3	27.9	83.1
	3	0.94	199.8	34.8	29.3	77.1
	4	1.43	165.6	0.6	29.9	71.9
	5	0.67	161.2	3.8	30.3	67.6

TABLE 6—*Deposition and mass balance results for aerial reference and DRT treatments.*

		Field Deposition Data and Mass Balance (Percent of Applied)				
Treatment	Rep	In-Swath	Downwind	50 m Drift Tower	Accounted	Unaccounted
Aerial reference	1	42.7	5.9	9.1	57.7	42.3
	2	22.9	18.2	20.7	61.8	38.2
	3	16.4	5.7	8.9	31	69
	4	15.7	4.2	8.8	28.7	71.3
	5	10.3	2.2	2.8	15.3	84.7
Aerial DRT	1	27.5	1.8	1.3	30.6	69.4
	2	34.8	1.7	0.8	37.3	62.7
	3	29.0	4.0	3.6	36.6	63.4
	4	31.1	2.1	2.4	35.6	64.4
	5	24.3	3.0	2.2	29.5	70.5

TABLE 7—*Deposition and mass balance results for ground reference and DRT treatments.*

		Field Deposition Data and Mass Balance (Percent of Applied)				
Treatment	Rep	In-Swath	Downwind	50 m Drift Tower	Accounted	Unaccounted
Ground reference	1	3.6	0.08	0.3	4.0	96.0
	2	1.7	0.05	0.7	2.5	97.5
	3	1.8	0.08	0.1	2.0	98.0
	4	1.7	0.0	0.3	2.0	98.0
	5	2.0	0.0	0.1	2.1	97.9
Ground DRT	1	3.4	0.0	0.1	3.5	96.5
	2	1.9	0.0	1.5	3.4	96.6
	3	1.2	0.0	0.6	1.8	98.2
	4	1.9	0.0	0.3	2.2	97.8
	5	2.4	0.0	0.0	2.4	97.6

TABLE 8—*DRT reduction values based on downwind deposition and 50 m tower data for aerial treatments.*

	Downwind Deposition		50 m Drift Tower	
Replication	$DRT_{reduction}$ (%)	Average ± St. Dev. Reduction (%)	$DRT_{reduction}$ (%)	Average ± St. Dev. Reduction (%)
1	69.5[a]		85.7[a]	
2	90.7		96.1	
3	29.8	56.8[a]±31.0[a]	59.6	76.1[a]±18.5[a]
4	50.0		72.7	
5	−36.4[a]		21.4[a]	

[a]Replications 1 and 5 were not included in the average and standard deviation calculations due to wind direction variations that exceeded acceptable levels.

Discussions and Conclusions

The overall deposition results from the study are much lower than seen in typical studies conducted by the authors [23,24]. The consistently poor total accountancy of the total material spray, particularly in the case of the ground applications, even after accounting for the low recovery rate in the sample processing, was problematic. A number of areas were explored in an effort to determine the cause of the low overall deposition results. Upon initial setup of both the aerial and ground treatment, all nozzles were double-checked for appropriate settings as well as having the booms flow-rated to ensure proper operation. Tank samples collected from both the aerial and ground spray systems were analyzed for dye concentrations and determined that the appropriate mix rates were present. All sample processing and fluorescent measurement methods were double-checked but no significant errors were revealed. Monitoring of the spray systems during the times of application by the pilot and ground rig operator did not reveal any inconsistencies in applications. While ultraviolet degradation of the dye using blank samples was not measured in the field, exposed samples were collected within a 10 min period after each individual application, which previous unpublished studies have demonstrated to result in less than 10 % degradation loss. The analysis of the actual tank samples showed that the adjuvant did not mask fluorescence, as the tank samples diluted to specified dye concentration levels resulted in fluorescent levels corresponding to standard dye concentration samples with no adjuvant present. The authors conjecture that the adjuvant used in the study resulted in the binding of the fluorescent tracer to the sampling media (which reduced recovery to a greater degree than what was determined in the recovery analysis).

There were several points not addressed, or only briefly mentioned, within the DRT draft protocol that the results of this study demonstrate need to be considered in further studies of this type. The first is the inclusion of a limited number of water sensitive or kromekote cards both in-swath and downwind. These provide immediate visual feedback during the study as to the level of spray deposition. A visual record taken during future studies (spots on cards) could be used to confirm or deny the validity of fluorescent deposition measurements providing a second check on the results. The other critical point is the need to address the recovery of deposited material (i.e., tracer recovery). The draft protocol and the ASABE standard [18] both specify the need to test recovery using spike samples with tank mix solutions used but state that recovery should be between 80 % and 120 % of the spiked amount. Neither the draft protocol nor the ASABE standard, however, recommends that deposition data be corrected for recovery. Based on the results here, there is evidence that the use of different adjuvants and/or surfactants will likely result in different recovery rates as compared to spray solutions without or with different adjuvants and/or surfactants. Determining and correcting for the different recovery rates is critical to providing relevant comparisons between different technologies.

As with previous protocol evaluations [14,16], the issue of the time requirement is also important. The field evaluation portion of this study required ~5 h to complete. This does not include the time involved

TABLE 9—*AGDISP modeling results and $DRT_{reduction}$ values for the aerial reference and aerial DRT treatments.*

	Treatment		
AGDISP Modeled Data	Aerial Reference (Fraction of Applied)	Aerial DRT (Fraction of Applied)	$DRT_{reduction}$ (%)
Downwind deposition	35.4	8.9	74.9
Airborne drift	2.96	0.02	99.3

in setting up and calibrating the spray systems, mixing and loading of the spray solution, or preparation of sampling and sample collection equipment and field layout and setup. In addition to the time required for field evaluations, the collected samples required processing and analysis, which required ~6 h (sample washing and fluorescent analysis). Therefore, for a given platform, aerial or ground, field testing and sample processing of a single DRT at a single wind speed along with the reference system required 5.5 h. This is in comparison to the low-speed wind tunnel testing protocols that would require ~3 h for equivalent testing for ground DRT systems [14] or the high-speed wind tunnel testing protocols that would require ~20 min for equivalent testing for aerial DRT systems [16].

With potential increases in the usage and contaminant transport of crop protection and production products [25], there is a growing need to identify technologies that will reduce off-target movement of sprays and to quantify the reduction levels for improved risk assessment. To that end, the U.S. EPA is focusing on the development and continual improvement of a program for testing DRT products. This work was designed to fill the gap in the validation process by evaluating the field trial portion. While the field testing protocols are obviously much more labor and resource intensive, they do offer the benefit of a direct measure of downwind deposition from candidate systems as well as offer a method for testing systems that do not readily fit either the low- or high-speed testing protocols. As the results of this study show, though, field testing does have the potential to result in data that has a much larger degree of variability and error as a result of the natural variability resulting from meteorological conditions, inherent variability in the application systems, and variability resulting from sampling.

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