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Evaluation of the EPA Drift Reduction Technology (DRT) Low-Speed Wind Tunnel Protocol

ABSTRACT: The EPA's proposed Drift Reduction Technology (DRT) low-speed wind tunnel evaluation protocol was tested across a series of modified ASAE reference nozzles. Both droplet size and deposition and flux volume measurements were made downwind from the nozzles operating in the tunnel at airspeeds of 1 m/s and 2.5 m/s, following the prescribed protocol. Overall, the data followed anticipated trends with a few unanticipated results observed, which could be addressed in future iterations of the protocol. There were some difficulties meeting the proposed protocol data quality requirements. Refined quality requirements would address this with no detrimental effect to the overall data set. Major concerns, at this point, are the feasibility of the overall protocol as well as the applicability of the final collected data. The protocol was tailored such that the collected data would directly input into a dispersion model (most likely WTDISP). However, not having access to such a model puts into question the validity and practicality of the protocol in its present form. Given the time requirements, which require approximately nine times that of the high speed protocol (90 min versus 10 min, unpublished data), there is a definite need to modify the existing protocol to insure equitable implementation of the overall DRT program.

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

Introduction

Spray drift has always been one of the major concerns in the application industry. EPA defines spray drift as "…the physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter from the target site to any non- or off-target site" [1]. Given the potential plant and human health issues, concerted efforts by industry, research agencies, and applicators have been made to find new materials, methods, and equipment that reduce drift. With new products and methods continually developed, there is growing concern and interest as to whether these products work and to what level they reduce drift. The proposed development of a testing program for measuring drift reduction technologies (DRTs) by Sayles et al. [2] was recognized by the EPA. A further operational framework for a DRT evaluation program was provided by Kosusko et al. [3]. The DRT Program, as it stands now, is an EPA-led initiative with the stated goal to "achieve improved environmental and human health protection through drift reduction by accelerating the acceptance and use of improved and cost-effective application technologies." [4] The first step in this process is the development of a set of protocols, standard operating procedures, and data quality assurance steps to ensure scientific validity and repeatability [5].

The measure of performance for low-speed wind tunnel testing is modeled downwind deposition (0 to 60 m) based on the droplet size and flux data measured for a given technology operating under the proposed low-speed wind tunnel protocols. The draft protocol states that the collected data will be used with a dispersion model such as AGDISP or WTDISP that is capable of translating the droplet size and spray flux data to an estimate of downwind deposition. AGDISP is an aerial application model that is not set up to use this data; therefore, the authors conclude that WTDISP was the model targeted by the proposed protocol. At the time this study and manuscript were prepared, WTDISP was not available for public or private use or evaluation [6]. Based on this, and based on the authors' estimate of the time required to complete this testing, additional samples were included that will later be discussed as alternative measures of performance.

The methodologies and results described here are as given in the unpublished draft "Test/QA Plan for the Validation Testing of Pesticide Spray Drift Reduction Technologies for Row and Field Crops for

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TABLE 1—*Droplet size data in static air, flowrate, and operational pressures for the ASABE reference nozzles and nozzles used in study.*

Nozzle	Pressure, kPa	Flowrate, L/min	$D_{V0.1}\pm$s.d., μm	$D_{V0.5}\pm$s.d., μm	$D_{V0.9}\pm$s.d., μm	% Vol<100 ±s.d., μm
11001	450	0.48	54.2±0.4	106.7±1.4	196.9±3.0	45.0±1.0
8001	450	0.47	53.9±1.4	105.1±0.5	205.4±6.7	46.5±0.4
11003	300	1.2	75.7±0.7	186.6±6.1	364.3±5.5	19.1±0.6
8003	300	1.2	80.7±1.1	210.9±4.1	391.3±2.6	16.5±0.5
11006	200	1.9	97.7±0.8	268.1±3.3	488.8±3.2	10.6±0.2
8006	200	1.8	109.4±1.0	316.7±8.5	577.5±10.4	8.0±0.1
8008	250	2.7	137.0±1.4	366.6±1.6	653.3±5.2	5.1±0.1
6510	200	3.0	175.8±3.5	484.2±2.9	873.7±8.4	3.6±0.7

Protocol Verification." This test plan is in the developmental stage with RTI (Research Triangle Institute) International and USDA-ARS. The goal of this work is to evaluate the proposed protocol and to provide some insight on usability and practicality, and provide some comparison to the high-speed wind tunnel testing protocol.

Methods

The following sections describe the different components of the proposed protocol. These are not as detailed as given in the unpublished draft protocol, but contain sufficient information to document the protocol tested.

Framework of the Proposed Low-Speed Wind Tunnel Testing Protocol

As stated earlier, the measure of performance for low-speed wind tunnel tested DRTs relies on droplet size and spray flux measurements downwind of a nozzle. The general experimental design measures this data 2 m downwind from a given DRT system operating at a specified pressure, position, nozzle height, and airspeed. The recorded ambient conditions (i.e., temperature, relative humidity, airspeed) define the bounds for which any tested system is verified. Specifically, this means that a given DRT must be tested at all airspeeds for which a drift reduction rating is desired and can be applied. In addition to the droplet size and flux measurements 2 m downwind from the nozzle, the protocol requires deposition measurements be made at the same time for comparison to modeled results as a measurement of model accuracy.

The proposed protocol also specifies Data Quality Objectives (DQOs) that should be met. To meet these DQOs, the protocol requires that each set of measurements (droplet sizing and flux measurements) be replicated three times for each nozzle at each operating condition and measurement location. Specific DQOs require volume median diameter $D_{V0.5}$, $D_{V0.1}$, and $D_{V0.9}$ (the droplet diameter bounding the upper and lower 10 percent fractions of the spray) to vary by less than ±3 %.

The measured data for DRT systems tested are to be compared to a reference system tested under the same conditions as a measure of drift reduction. At this time, no reference system has been defined, though it will likely consist of one or more of the ASABE S572 [7] reference nozzles.

Nozzles

For this work, a modified set of the five ASABE S572 reference nozzles were tested. For the first three categories, the 110° nozzles were replaced with 80° nozzles, because the 110° nozzles resulted in spray mixture hitting the sides of the tunnel walls. Droplet sizing in static air with the 80° nozzles operating at the same pressure as the 110° nozzles showed very similar droplet sizes as well as the same flowrates (Table 1). All droplet sizing in this study was conducted using the Sympatec Helos laser diffraction droplet sizing system (Sympatec Inc., Clausthal, Germany). The Helos system uses a 623 nm He–Ne laser and was fitted with an R5 lens, which resulted in a dynamic size range of 0.5 μm to 875 μm in 32 sizing bins. Tests were performed within the guidelines provided by ASTM Standard E1260: "Standard Test Method for Determining Liquid Drop Size Characteristics in a Spray Using Optical Nonimaging Light-Scattering

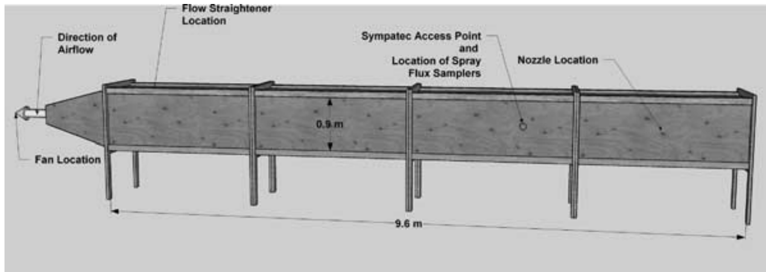

FIG. 1—*Operational setup of USDA-ARS wind tunnel for DRT protocol evaluation.*

Instruments" [8]. Droplet sizing data measured included volume median diameter ($D_{V0.5}$), the 10 % and 90 % diameters ($D_{V0.1}$ and $D_{V0.9}$), and the percent volume less than 100 μm as defined by ASTM Standard E1620 [9]. The five nozzles tested were flat fan nozzles 8001, 8003, 8006, 8008, and 6510 produced by Spraying System, Inc. (Wheaton, IL).

Spray Solution

The spray solution used in all testing was an emulsifiable concentrate (EC) blank material which consisted of 9.2 % v/v Aromatic 200 (Exxon Mobil Corporation, Irving, TX), 0.35 % v/v Toximul 3473 (Stepan Company, Northfield, IL), and 0.45 % v/v Toximul 3474 (Stepan Company, Northfield, IL). Additionally, Caracid Brilliant Flavine FFN, a fluorometric tracer dye (0.264 g/L), was added for deposition analysis. The dynamic surface tension and viscosity were measured. Dynamic surface tension was measured with a SensaDyne Surface Tensiometer 6000 (Chem-Dyne Research Corp., Mesa, AZ) using the maximum bubble pressure method. The gas flowrate settings were varied until surface age values were found on either side of the target time of 0.02 s. These values were then used to interpolate the value at 0.02 s. Then, a table of percent flow rate settings was built in 5 % increments to include the previous settings. This table was calibrated using 200 proof ethanol and pure water. The probes were lowered into the sample and the dynamic surface tension, bubble rate, bubble age, and temperature were measured at each setting in the table. The dynamic surface tension at 20 ms was linearly interpolated from the results. The tests were replicated three times. Viscosity was measured with a Brookfield Synchro-Lectric Viscometer (Model LVT, Brookfield Engineering, Middleboro, MA) using a UL adapter 0.1–100 cps range. The spindle was inserted into the sample. The motor was started and run until the dial reading stabilized and the reading was recorded. The dynamic surface tension was 39.6 mN/m at 20 ms and the viscosity was 1.6 cP at 20°C.

Low-Speed Tunnel

All testing was conducted in the USDA-ARS low-speed wind tunnel [10]. The tunnel has a cross-sectional area of 0.9 by 0.9 m^2 and an overall length of 9.6 m. Airspeed can be varied from 0.2 m/s to 5.4 m/s through use of an inline gate value. The tunnel is outfitted with a flow straightener (5 by 5 cm^2 gridded square section 0.75 m in length) downwind of the working sections. The tunnel floor was covered with artificial turf and a shallow catch pan with drain under the nozzle. Air velocity and spray dispersion characteristics are detailed by Fritz and Hoffmann [10]. Each nozzle tested was mounted in the nozzle assembly that was mounted 1 m from the tunnel opening (Fig. 1) at a height of 0.6 m above the tunnel floor and was set to spray straight down into the catch basin with the spray fan oriented perpendicular to the airflow direction. The nozzle assembly was plumbed to a pressurized pot containing the spray solution with a pressure regulator to control spray pressure. Spray was turned on and off using a ball valve. Spray was emitted for 10 s for all replications on all nozzles. Airspeed, temperature, and relative humidity were measured using a FlowKinetics (FlowKinetics, LLC, Bryan, TX) FKT Series Flow Measurement System. Data were recorded for each replication conducted.

Droplet Sizing Measurements

Droplet sizing was conducted 2 m downwind from the nozzle at seven heights (10, 12, 30, 40, 50, 60, and 70 cm above floor surface). At the access point 2 m downwind from the nozzle, a slot was cut in the tunnel

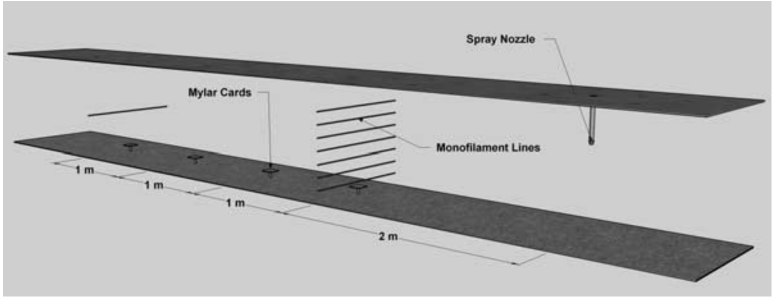

FIG. 2—*Deposition and flux sampling locations.*

wall (on each side of the tunnel) that was 6 cm wide and ran from the tunnel floor to the tunnel ceiling. This allowed access for droplet sizing and spray flux measurements. The Sympatec was mounted on a frame specifically constructed to insure appropriate instrument alignment. This was critical as the Sympatec consists of two components: a laser unit and a lens and detector unit between which a spray being measured must pass. The mount maintained the alignment while using a forklift to raise and lower the instrument to each measurement height. For each nozzle/airspeed combination, the Sympatec was positioned such that the laser beam was located at one of the required heights. At that height, three replicated droplet size measurements were made with the tunnel operating at a given airspeed with the nozzle spraying for 10 s. After the three replicate measurements were completed, the Sympatec was positioned at the next height, and another three replicated measurements made. This was continued until all heights were measured. Once droplet sizing was complete, the Sympatec was moved away from the 2 m access slot to allow for setup and positioning of spray flux measurement equipment.

Spray Flux and Deposition Measurements

Spray flux was also measured 2 m downwind from the spray nozzle at the same six heights using monofilament line (0.46 mm diameter by 0.9 m; total area of 4.2 cm^2) (Fig. 2). Additionally, a monofilament line was set at 5 m downwind at a height of 40 cm above the floor. This 5 m line is not included in the DRT protocol, but was included by the authors as a potential measurable drift reduction indicator. On one side of the tunnel, fishing reels with the monofilament line were secured on the outside of the tunnel wall at each height. On the other side of the tunnel, a series of clips were secured outside the tunnel at each height to hold the monofilament in place. After each spray replication, the monofilament at each height was collected by winding onto plastic straws (1.3 cm diameter by 15 cm long) using a friction fit rod mounted in a cordless drill. Prior to spooling, the monofilament line was marked with a permanent marker at the location where in exits the reel. The line was then spooled onto the straw until the mark was reached. The straw with the line was removed from the rod and placed in a labeled plastic bag. The process of collecting the exposed monofilament also served to spool new line from the reel into the tunnel, which was then secured on the other end with the clips.

Deposition was measured at 2, 3, 4, and 5 m downwind (Fig. 2) using Mylar® plates (10 by 10 cm^2; total area 100 cm^2) placed on holders held 3 cm above the floor. After each spray replication, the Mylar cards were collected into labeled plastic bags. The Mylar card holders were rinsed in clean water and dried between each replication and prior to new mylar being placed on them.

Testing Schedule

Each nozzle was tested at two wind speeds: 1 m/s and 2.5 m/s. These airspeeds were chosen to be representative of ambient air conditions. A 5 m/s wind speed was to be included in place of the 2.5 m/s, but initial testing saw the Mylar® cards at 2 and 3 m being overloaded with deposited spray material from the 8001 and 8003 nozzles, even at a reduced spray interval of 5 s. Each nozzle/wind speed combination required 24 replications to complete all measurements. Flux and deposition measurements were made over three replications, with a blank being conducted after the third replication. To perform droplet size measurements, the monofilament mounting system had to be removed from the tunnel to allow laser access. Droplet size measurements required three replications per measurement height. To minimize change-over setup time between the droplet sizing and the flux measurements, the order was alternated for each nozzle

TABLE 2—*Airspeed, temperature, and relative humidity means and standard deviations for flux and deposition measurements at 1 m/s airspeeds.*

Nozzle	Airspeed ± s.d., m/s	Temperature ± s.d., °C	Relative Humidity ± s.d., %
8001	1.0 ± 0.06	26.5 ± 0.29	70.7 ± 0.58
8003	1.1 ± 0.06	28.0 ± 0.29	68.7 ± 2.52
8006	1.1 ± 0.06	29.6 ± 0.66	63.0 ± 2.00
8008	1.1 ± 0.06	26.3 ± 0.00	68.3 ± 1.53
6510	1.1 ± 0.06	26.6 ± 0.29	68.7 ± 1.53

such that droplet sizing and spray flux/deposition measurements were conducted back-to-back between nozzles. The monofilament system was put into place and flux and deposition sampling conducted. A partial testing schedule for one airspeed is shown below.

8001 nozzle
- 3 replications flux and deposition
- 21 replications droplet sizing

8003 nozzle
- 21 replications droplet sizing
- 3 replications flux and deposition

8006 nozzle
- 3 replications flux and deposition
- 21 reps droplet sizing

Sample Processing and Data Analysis

All droplet size data was averaged over the three replications made at each measurement location for each nozzle/wind speed combination. Standard deviations were also calculated. The labeled plastic bags containing the collected monofilament and Mylar® card samples were transported to the laboratory for processing. Thirty millilitres of ethanol were pipetted into each bag, the bags were agitated, 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 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. Blank samples were processed following the same protocols. All flux and deposition measurements were converted from units of $\mu L/cm^2$ to a fraction of the total spray volume applied by dividing by the total volume applied from each nozzle during the 10 s interval. For clarity the fractional deposition values were expressed as millionths (monofilament flux measurements) or ten-thousandths (Mylar deposition measurements). There were no significant contamination issues for either the monofilament or the Mylar blanks.

Results

Airspeed, Temperature, and Relative Humidity Data

Airspeed, temperature, and relative humidity averages and standard deviations measured for each nozzle over the three replications measuring flux and deposition are given in Table 2 (1 m/s airspeeds) and Table 3 (2.5 m/s airspeeds).

Droplet Size Data

The measured droplet sizes for all five nozzles at the seven heights are shown for 1 m/s airspeed (Table 4) and the 2.5 m/s airspeed (Table 5). The measured droplet sizes for a given nozzle at a given wind speed generally decreased as height from the floor increased. Overall droplet sizes also tended to increase as the nozzle orifice size increased with the exception of the 6510 nozzle, which tended to have smaller droplet sizes than most of the other nozzles. Droplet sizes for given nozzles also tended to be larger at the higher

TABLE 3—*Airspeed, temperature, and relative humidity means and standard deviations for flux and deposition measurements at 2.5 m/s airspeeds.*

Nozzle	Airspeed ± s.d., m/s	Temperature ± s.d., °C	Relative Humidity ± s.d., %
8001	2.4 ± 0.15	27.9 ± 1.55	66.0 ± 1.00
8003	2.5 ± 0.15	26.4 ± 0.17	66.0 ± 0.00
8006	2.4 ± 0.10	26.6 ± 0.29	66.0 ± 0.00
8008	2.4 ± 0.10	28.5 ± 0.29	64.7 ± 1.53
6510	2.4 ± 0.21	29.9 ± 0.29	60.7 ± 0.58

airspeed. The standard deviations tended to be greater at the higher measurement heights from the floor. This is likely due to much lower droplet concentrations at these heights (as will be shown by the flux measurements) resulting in much lower optical concentrations and smaller sample sizes.

Monofilament Flux Data

Measured monofilament fluxes for each nozzle at each measurement location are given for the 1 m/s airspeed and the 2.5 m/s airspeed (Table 6). The measured fluxes tended to decrease as height increased.

TABLE 4—*Droplet size data (means ± standard deviations) 2 m downwind of nozzle at 1 m/s airspeed.*

Nozzle	Height, cm	$D_{V0.1}$ ± s.d., μm	$D_{V0.5}$ ± s.d., μm	$D_{V0.9}$ ± s.d., μm
	70	43.5 ± 1.2	74.6 ± 2.0	106.3 ± 4.0
	60	45.3 ± 1.2	71.5 ± 5.6	108.7 ± 9.0
	50	49.3 ± 3.7	77.2 ± 4.4	115.5 ± 4.4
8001	40	53.1 ± 1.9	81.9 ± 2.7	124.4 ± 6.9
	30	50.3 ± 2.1	79.4 ± 4.7	120.2 ± 10.0
	20	52.8 ± 0.6	80.4 ± 0.4	118.4 ± 1.0
	10	55.9 ± 0.9	84.2 ± 1.2	123.0 ± 3.5
	70	38.6 ± 0.7	78.7 ± 1.0	129.4 ± 0.6
	60	39.1 ± 1.4	81.3 ± 0.9	138.0 ± 3.0
	50	38.6 ± 0.9	88.9 ± 4.5	142.9 ± 5.4
8003	40	39.6 ± 0.6	83.6 ± 0.8	138.6 ± 1.9
	30	43.5 ± 1.0	86.0 ± 2.1	140.4 ± 1.1
	20	45.3 ± 1.3	85.0 ± 0.9	143.3 ± 2.2
	10	50.6 ± 0.9	86.3 ± 1.7	145.8 ± 2.3
	70	45.3 ± 4.9	88.8 ± 9.5	133.1 ± 13.9
	60	41.9 ± 3.6	84.7 ± 11.9	132.2 ± 17.8
	50	49.4 ± 3.9	97.8 ± 3.1	142.7 ± 3.8
8006	40	48.5 ± 1.0	89.7 ± 2.6	139.1 ± 1.3
	30	48.3 ± 0.8	88.5 ± 1.0	134.3 ± 1.7
	20	47.7 ± 1.3	79.5 ± 0.6	126.3 ± 2.9
	10	51.1 ± 1.5	91.4 ± 1.0	137.2 ± 2.5
	70	37.9 ± 5.3	78.9 ± 13.8	131.3 ± 23.8
	60	48.7 ± 7.7	103.6 ± 12.2	161.2 ± 12.7
	50	52.6 ± 0.9	108.9 ± 3.8	168.5 ± 4.2
8008	40	55.0 ± 1.2	110.2 ± 2.4	163.6 ± 3.0
	30	53.1 ± 3.3	105.4 ± 3.7	159.3 ± 4.2
	20	54.6 ± 3.9	106.0 ± 5.8	158.4 ± 5.6
	10	53.3 ± 2.4	105.3 ± 4.1	158.3 ± 7.2
	70	37.0 ± 4.5	77.8 ± 7.4	133.6 ± 7.6
	60	44.3 ± 1.0	95.8 ± 0.9	159.9 ± 1.4
	50	42.7 ± 7.8	92.3 ± 16.2	157.8 ± 20.9
6510	40	42.5 ± 2.9	95.2 ± 10.8	167.5 ± 19.2
	30	41.1 ± 2.5	91.8 ± 4.4	166.1 ± 5.2
	20	40.6 ± 0.9	88.2 ± 2.6	148.0 ± 5.0
	10	45.0 ± 3.0	92.9 ± 8.5	146.2 ± 13.3

TABLE 5—*Droplet size data (means ± standard deviations) 2 m downwind of nozzle at 2.5 m/s airspeed.*

Nozzle	Height, cm	$D_{V0.1}$ ± s.d., μm	$D_{V0.5}$ ± s.d., μm	$D_{V0.9}$ ± s.d., μm
	70	37.77 ± 1.52	64.47 ± 3.79	89.77 ± 4.66
	60	42.33 ± 1.16	71.67 ± 2.15	99.63 ± 2.12
	50	39.23 ± 1.27	64.93 ± 1.75	88.33 ± 1.17
8001	40	50.77 ± 2.30	86.63 ± 5.62	121.30 ± 5.43
	30	51.40 ± 3.53	85.00 ± 2.71	121.00 ± 6.61
	20	52.97 ± 2.27	86.10 ± 3.22	119.13 ± 1.66
	10	62.93 ± 4.41	95.93 ± 3.13	127.60 ± 3.50
	70	40.60 ± 0.46	75.17 ± 1.63	106.07 ± 1.36
	60	40.77 ± 0.90	73.83 ± 2.93	102.00 ± 2.26
	50	47.20 ± 0.78	83.23 ± 4.53	114.87 ± 7.16
8003	40	48.67 ± 3.93	84.60 ± 9.53	119.20 ± 10.62
	30	51.27 ± 0.90	84.03 ± 1.45	117.87 ± 1.32
	20	56.40 ± 0.87	93.83 ± 2.06	128.67 ± 4.41
	10	65.47 ± 2.70	103.67 ± 1.33	139.13 ± 4.76
	70	30.83 ± 0.31	58.20 ± 0.26	86.67 ± 0.35
	60	34.57 ± 0.55	62.43 ± 0.31	95.93 ± 0.15
	50	44.37 ± 8.66	80.33 ± 11.89	115.57 ± 12.69
8006	40	45.40 ± 7.70	82.63 ± 12.09	124.27 ± 18.89
	30	44.00 ± 5.16	81.03 ± 4.51	125.23 ± 8.74
	20	57.07 ± 7.68	95.03 ± 9.85	135.00 ± 11.23
	10	56.17 ± 1.00	101.53 ± 4.05	153.60 ± 15.48
	70	41.20 ± 2.26	71.80 ± 2.56	104.27 ± 3.15
	60	50.07 ± 1.32	80.90 ± 0.60	118.40 ± 2.99
	50	45.10 ± 5.07	77.03 ± 6.35	112.57 ± 12.87
8008	40	52.63 ± 5.35	91.37 ± 12.19	136.60 ± 24.84
	30	52.03 ± 6.29	91.17 ± 5.17	127.73 ± 8.19
	20	55.87 ± 4.79	88.47 ± 6.59	122.50 ± 6.07
	10	66.13 ± 5.13	112.30 ± 11.39	152.63 ± 13.82
	70	41.77 ± 1.32	72.47 ± 3.15	102.23 ± 3.04
	60	44.37 ± 0.59	78.57 ± 1.14	108.77 ± 1.79
	50	45.70 ± 1.05	79.33 ± 1.01	114.90 ± 8.93
6510	40	46.67 ± 0.80	85.87 ± 2.45	121.30 ± 5.26
	30	43.07 ± 4.05	81.47 ± 3.65	121.37 ± 3.04
	20	42.00 ± 3.70	83.53 ± 3.54	121.40 ± 2.26
	10	46.87 ± 1.67	79.63 ± 17.47	133.30 ± 0.89

For the 8001 and 8003 nozzles, the flux increased as the airspeed increased, but decreased as airspeed increased for the remaining nozzles. The total flux at 2 m (integrated over all sampling heights) is given for 1 m/s and 2.5 m/s airspeeds (Table 7). These show the same trends in overall flux per nozzle with respect to airspeed. The measured flux at the 5 m location at a height of 40 cm is shown for each nozzle for airspeeds of 1 m/s and 2.5 m/s (Table 8). The 5 m flux data generally saw decreasing flux as the orifice size increased, with the exception of the 8008 nozzle, and higher fluxes at the lower airspeeds. This follows the same trends seen in the total integrated flux measurements at 2 m.

Mylar Deposition Data

Measured Mylar® deposition values are shown for each nozzle at each distance for airspeeds of 1 m/s and 2.5 m/s (Table 9). Generally deposition decreased as distance from the nozzle increased at both airspeeds and as nozzle orifice size increased. Overall deposition also increased as the airspeed increased.

TABLE 6—*Monofilament flux data measured at 2 m downwind from nozzle at seven heights expressed as millionths of total applied spray volume at 1 and 2.5 m/s airspeeds.*

Nozzle	Height, cm	Fraction of Applied ± s.d., millionths	
		Airspeed of 1 m/s	Airspeed of 2.5 m/s
8001	70	0.15 ± 0.10	0.14 ± 0.16
	60	0.11 ± 0.03	0.63 ± 0.66
	50	0.38 ± 0.17	1.66 ± 1.10
	40	1.66 ± 0.47	4.20 ± 1.60
	30	4.66 ± 0.92	5.66 ± 0.62
	20	7.06 ± 1.81	7.28 ± 2.46
	10	11.35 ± 4.09	17.01 ± 7.31
8003	70	0.24 ± 0.26	0.04 ± 0.00
	60	0.78 ± 1.19	0.06 ± 0.02
	50	0.87 ± 1.17	0.38 ± 0.27
	40	1.16 ± 1.26	1.49 ± 0.63
	30	1.93 ± 1.24	2.81 ± 1.51
	20	3.60 ± 0.98	5.13 ± 0.39
	10	7.38 ± 0.84	9.00 ± 0.51
8006	70	0.29 ± 0.19	0.05 ± 0.02
	60	0.73 ± 0.88	0.12 ± 0.09
	50	1.07 ± 1.12	0.21 ± 0.10
	40	1.41 ± 0.60	0.42 ± 0.15
	30	1.68 ± 0.79	0.71 ± 0.12
	20	3.21 ± 0.55	1.40 ± 0.36
	10	6.79 ± 2.77	3.22 ± 0.72
8008	70	1.98 ± 1.19	0.05 ± 0.00
	60	2.16 ± 0.36	0.06 ± 0.03
	50	2.04 ± 0.32	0.28 ± 0.43
	40	2.26 ± 0.63	0.45 ± 0.50
	30	2.20 ± 0.32	1.49 ± 0.86
	20	2.60 ± 0.27	3.01 ± 1.27
	10	3.94 ± 0.50	7.18 ± 1.07
6510	70	0.33 ± 0.14	0.07 ± 0.01
	60	0.80 ± 0.38	0.07 ± 0.02
	50	1.21 ± 0.19	0.07 ± 0.02
	40	1.27 ± 0.08	0.12 ± 0.05
	30	1.24 ± 0.12	0.33 ± 0.20
	20	1.30 ± 0.07	0.88 ± 0.56
	10	1.16 ± 0.06	2.00 ± 0.31

TABLE 7—*Total flux at 2 m downwind from nozzle integrated over total cross-sectional area of tunnel expressed as thousandths fraction of total applied spray material at 1 m/s and 2.5 m/s airspeed.*

Nozzle	Total Integrated Flux Volume, thousandths fraction of applied	
	Airspeed of 1 m/s	Airspeed of 2.5 m/s
8001	28.5	41.2
8003	18.2	21.3
8006	17.3	7.1
8008	20.3	14.7
6510	7.7	4.2

TABLE 8—*Measured flux data 5 m downwind from spray nozzle at 40 cm height expressed as millionths of fraction of total applied material at airspeed of 1 m/s and 2.5 m/s.*

	Fraction of Applied ± s.d., millionths	
Nozzle	Airspeed of 1 m/s	Airspeed of 2.5 m/s
8001	0.69 ± 0.20	0.82 ± 0.33
8003	0.76 ± 0.24	0.27 ± 0.04
8006	0.86 ± 0.22	0.20 ± 0.08
8008	0.97 ± 0.23	0.29 ± 0.02
6510	0.48 ± 0.16	0.17 ± 0.06

Discussion

Droplet Size, Spray Flux, and Deposition Results

There were a number of unanticipated results. The lower airspeed tests saw larger droplet sizes at higher sampling heights from the tunnel floor than at the higher airspeeds, though the higher airspeeds showed larger droplets at the lower sampling heights. If the standard deviation data is considered alongside the mean data for a given nozzle, the droplet sizes at each height did not vary much between airspeeds. The other interesting result was the smaller droplet sizes were with the 6510 nozzle. This potentially is a result of the different performance of the 65° angle compared to the 80° angle nozzles.

There were also some unexpected results in the monofilament flux data. At first pass, the greater flux values at the lower airspeed is not what one would anticipate, but if the standard deviations are considered, these differences become minor. For example, for the 8006 nozzle the average flux at 10 cm at 1 m/s is 6.8 millionths of applied (m.o.a.) while only 3.2 m.o.a. at 2.5 m/s. But at 1 m/s airspeed, the standard deviation is 2.8 and is 0.7 at 2.5 m/s. A simple means comparison of ±2 or even 1 standard deviation shows little difference in these values. While this does not apply to the entire data set, it is more common than not. This means that there is little separation in the flux values across the two airspeeds, which is not too surprising given that the airspeeds are not much separated.

Another issue observed was the greater fluxes at the 5 m location at the lower airspeed as compared to the higher airspeed. The authors initially include this data point as a potential point in a condensed

TABLE 9—*Deposition 2, 3, 4, and 5 m downwind of spray nozzle (expressed as millionth fraction of total applied spray volume) at 2.5 m/s.*

	Distance,	Fraction of Applied ± s.d., millionths	
Nozzle	m	Airspeed of 1 m/s	Airspeed of 2.5 m/s
8001	2	9.72 ± 0.80	10.77 ± 1.60
	3	6.99 ± 1.63	5.21 ± 1.94
	4	3.12 ± 1.59	3.09 ± 0.82
	5	1.08 ± 0.45	2.06 ± 0.55
8003	2	1.77 ± 0.48	2.19 ± 0.83
	3	0.35 ± 0.06	0.97 ± 0.30
	4	0.57 ± 0.49	0.92 ± 0.51
	5	0.14 ± 0.15	0.47 ± 0.21
8006	2	0.29 ± 0.11	0.77 ± 0.43
	3	0.11 ± 0.03	0.21 ± 0.17
	4	0.19 ± 0.16	0.11 ± 0.12
	5	0.11 ± 0.08	0.06 ± 0.06
8008	2	0.20 ± 0.15	0.69 ± 0.15
	3	0.04 ± 0.02	0.24 ± 0.09
	4	0.06 ± 0.01	0.17 ± 0.12
	5	0.09 ± 0.02	0.08 ± 0.04
6510	2	0.03 ± 0.02	0.15 ± 0.11
	3	0.01 ± 0.01	0.05 ± 0.03
	4	0.07 ± 0.02	0.01 ± 0.01
	5	0.05 ± 0.00	0.00 ± 0.00

low-speed DRT protocol, assuming the data lent itself to that application. It was anticipated, based on experience, that greater fluxes would occur at the higher airspeeds, but even with the standard deviations considered, other than the 8001 nozzle, the fluxes were considerably less at 2.5 m/s. The authors believe that this could be a result of the placement of the monofilament. The spray plume profile at 5 m downwind of the nozzle may have been different between the two airspeeds such that the selected sampling height of 40 cm did not provide a fair comparison between the two (i.e., at 1 m/s the 40 cm flux may have been 60 % of the maximum flux concentration while only 30 % of maximum at 2.5 m/s). A better approach may be to use a vertical line which would permit sampling through the entire spray plume profile.

Time Requirements for Testing

One of the most significant findings of this work, relative to the implementation of this program, is the time required for completion. The actual wind tunnel testing component of this work (droplet sizing, flux, and deposition measurements) was performed by one person. Ideally, two or three would be preferred, but the additional personnel were not available for this work. The monofilament flux and mylar deposition sampling required, on average, approximately 10 min per replicated measure to spray, collect and change samples, and be prepared for the next replication. The droplet sizing measurements averaged approximately 15 min to complete three replicated measures at each of the seven sampling heights. Additional time was required for changing over from flux/deposition sampling to droplet sizing as well as sample placement and collection for the blanks. All told, testing of the five reference nozzles at two airspeeds with one spray formulation required three mornings of testing and an elapsed time of approximately 10 h. In addition to the wind tunnel testing component, collected samples had to be processed in the laboratory, which involved washing the samples and recording and converting the spectrofluorometric readings to concentrations. This process averaged about one minute per sample. Each nozzle/airspeed combination required 21 monofilament samples (three replications by seven sampling height at 2 m) and 12 Mylar® samples (three replications by four sampling locations) equaling a total of 33 samples. Overall time for washing and reading samples was approximately 5 h. Therefore each nozzle/airspeed combination testing required approximately 1.5 h to complete. By way of comparison, testing a single nozzle at a single airspeed under the high-speed DRT protocols, would require approximately 10 min. The high-speed DRT protocol requires only droplet size measurements be taken over three replications at each airspeed, following the same DQOs, where each measurement replication requires two to three measurements. This means that the low-speed testing protocol requires approximately ten times the amount of time to complete as the high-speed testing protocol.

Droplet Size Data Quality Objectives

The stated DQOs require standard deviations in the droplet sizing measurements be no more than ± 3 % of the mean for the $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$. Therefore, additional testing would be required for any set of replicated measurements if any of the $D_{V0.X}$ values exceeds 3 % of the mean values. Examining the measured data presented in Tables 4 and 5, at the 3 % variance limit, 73 % of the nozzle/airspeed/height measurement sets would require additional measurements. Reducing this variance restriction to 5 % reduces the number of sets requiring additional measurements to 54 %, likewise at 10 % variance restriction further reduces the number of sets to 26 %. There are no variance restrictions on the flux or deposition measurements.

Conclusions

The EPA's proposed Drift Reduction Technology evaluation protocol was tested across a series of modified ASABE reference nozzles. Both droplet size and deposition and flux volume measurements were made downwind from the nozzles at airspeeds of 1 m/s and 2.5 m/s. There were some unexpected results in the observed data, but all could be addressed in future iterations of the protocol. The major concern, at this point, is the applicability of the final collected data. The protocol was tailored so that the collected data could be directly inputed into a dispersion model (most likely WTDISP) but, not having access to this model puts into question the validity and practicality of the protocol in its present form. Given the time requirements, which require approximately nine times that of the high-speed protocol (90 min versus

10 min, unpublished data), there is a definite need to modify the existing protocol to ensure equitable implementation of the overall DRT program.

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