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Evaluation of Spray Drift Using Low-Speed Wind Tunnel Measurements and Dispersion Modeling

ABSTRACT: The EPA's proposed test plan for the validation testing of pesticide spray drift reduction technologies (DRTs) for row and field crops, focusing on the evaluation of ground application systems using the low-speed wind tunnel measurements and dispersion modeling, was evaluated. Relative drift reduction potential for a given DRT tested in a low-speed wind tunnel is derived from airborne droplet size measurements and airborne and deposited liquid volume measurements downwind from the spray nozzle. Measurements of droplet size and deposition data were made in a low-speed wind tunnel using standard reference nozzles. A blank emulsifiable concentration spray was applied at two different wind speeds. The wind tunnel dispersion (WTDISP) model was used to evaluate the drift potentials of each spray using the droplet size and spray flux measured in the wind tunnel. The specific objectives were (1) the evaluation of model accuracy by comparison of modeled downwind deposition to that measured in the wind tunnel, (2) the evaluation of drift reduction potential of the spray nozzles relative to a reference nozzle, and (3) the determination of low-speed wind tunnel data collection requirements for model input to optimize the evaluation process. The modeled deposition data did not compare well to the measured deposition data, but this was expected as the model was not meant to be used for this purpose. The tested nozzles were rated using the International Standards Organization drift classification standard. The drift ratings generally showed trends of larger droplet producing nozzles having greater drift reduction ratings. An examination of several scenarios using reduced model input requirements, which would decrease the low-speed wind tunnel data collection time, did not show any conclusive results. They suggest that further testing and refinement of the data collection process and the WTDISP model may support wider use of this system for the assessment of DRTs.

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

Introduction

Spray drift is defined 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]. Industry, research agencies, and applicators are making great efforts to identify and develop alternative materials, methods and equipment to reduce drift and minimize adverse effects on off-target entities. 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. Sayles et al. [2] proposed the development of a testing program for measuring drift reduction technologies (DRTs), with Kosusko et al. [3] providing details on additional program operational framework. The goal of this EPA-led initiative is 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 basic operational framework falls into three different testing regimes: 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. The development of a draft set of

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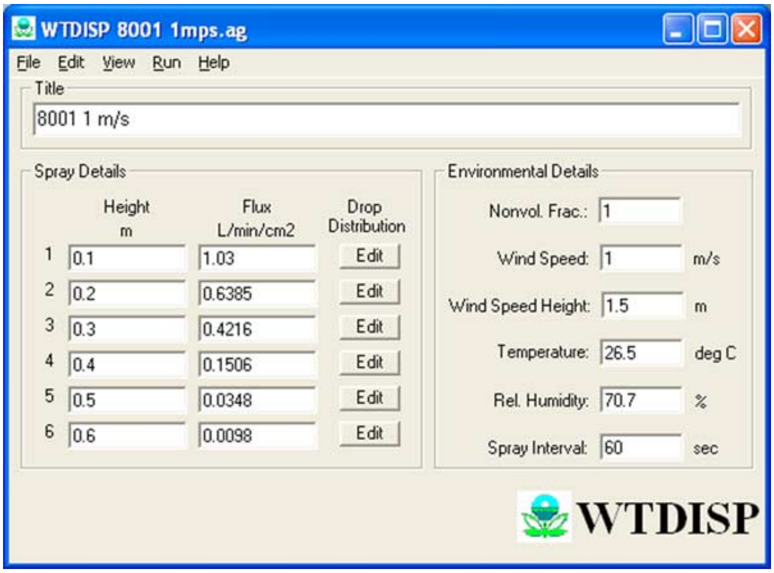

FIG. 1—*WTDISP input screen.*

protocols, standard operating procedures, and data quality assurance steps to ensure scientific validity and repeatability was completed for all three testing regimes [5]. Initial testing of both the high-speed and low-speed wind tunnel testing protocols was undertaken by Fritz et al. [6] and Hoffmann et al. [7]. Both of these studies focused on droplet sizing (for the low- and high-speed testings) and flux (for the low-speed testing) measurements across a set, or modified set, of American Society of Agricultural and Biological Engineers (ASABE) reference nozzles [8]. The high-speed tunnel testing showed a separation in spray droplet distribution of the nozzles corresponding to their associated droplet size classifications, with smaller droplets for the nozzles in the finer size classifications and larger droplets with increasingly coarse size classifications [7]. The low-speed tunnel testing measured spray concentration and droplet size at a location 2 m downwind of the spray nozzle, finding that droplet size and total spray flux 2 m downwind were generally greater for the coarser nozzles [6].

The stated measure of drift reduction for both testing protocols is derived from the modeled downwind deposition from 0 to 60 m. Agricultural dispersion (AGDISP) [9] is the preferred model for use with the high-speed wind tunnel data, while both AGDISP and wind tunnel dispersion (WTDISP) models are mentioned in the low-speed wind tunnel protocol as potential models to translate the measured droplet size and flux data into downwind deposition estimates. However, AGDISP is primarily an aerial application model and is not currently structured to use this type of data. Hewitt [10] and Connell et al. [11] explored the development and use of WTDISP to estimate downwind deposition using spray droplet size and flux data measured in a low-speed wind tunnel from a series of nozzles, and they found good relative comparison between WTDISP modeled results and those measured during field studies using the same nozzles.

The objective of this work is to evaluate a WTDISP model for predicting downwind spray movement from droplet size and spray flux data measured in a low-speed wind tunnel under multiple wind speed conditions. This deposition predicted by the WTDISP model will be compared to the reported [6] in-tunnel deposition (2–5 m downwind of the spray nozzle) and used to compare the tested nozzles using a drift reduction rating scheme.

Methods

WTDISP is a dispersion model designed to integrate spray flux measurements made in a wind tunnel and then predict downwind deposition and drift that would be expected in a field application using the equipment tested in the wind tunnel. By using the model, it is hoped that researchers can limit the number of field trials, which can be very expensive to conduct. Downwind deposition values were modeled using WTDISP following the input procedures and guidelines outlined in the user manual and on-screen menus. The input screen (Fig. 1) shows all of the inputs required by the model to predict downwind drift. The specific inputs required are spray flux and droplet size measured 2 m downwind from the spray technology

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

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

being tested (i.e., nozzle, adjuvant, etc.). The spray flux and droplet size measured 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7 m above the wind tunnel floor. The environmental conditions such as temperature, wind speed, and relative humidity must also be input into WTDISP. The procedure for determining and measuring these input values is discussed in the sections that follow.

Wind Tunnel Dispersion Modeling Inputs

Spray flux and droplet size at 2 m downwind of the nozzle spray flux data inputs were based on the data set collected by Fritz et al. [6]. This data set included droplet size and monofilament deposition ($\mu L/cm^2$) of spray at 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7 m for a selection of nozzles that represent a modified version of the ASABE S572.1 [8] reference nozzles. WTDISP requires flux in units of $L/min/cm^2$ and only has input capacity for six heights. The 0.7 m height from the Fritz [6] data set was dropped for this work as the measured monofilament concentrations at this height were minimal. The treatment of the time component of the required flux input will be discussed later. The measured monofilament deposition values reported by Fritz et al. [6] were corrected for the collection efficiency of the monofilament sampler following the method reported by Fritz and Hoffmann [12] using the measured droplet size distributions and reported airspeeds and environmental conditions. The measured data were also corrected for recovery losses. The percent recovery was determined by spiking ten clean samples of monofilament with a known volume of spray material. The samples were then processed following the study [6] protocols. The measured amount of spray material was then compared to the amount used to spike the samples. The average recovery rate was 90 %. Collection efficiencies and measured and adjusted string concentration data for the 1 and 2.5 m/s airspeed trials are reported in Tables 10 and 11 in the Appendix, respectively. The droplet sizes at each of the heights under the two airspeeds as reported by Fritz et al. [6] are shown in Tables 12 and 13 in the Appendix.

The WTDISP droplet size input interface allows a user to either import (from a text file) the droplet size data or to input the data bin by bin. The data from Fritz et al. [6] were not in a form for importing, and the bin by bin option was found to be very time consuming given the number of modeling runs that were required. To more efficiently enter this data, the AGDISP droplet size entry interface was used as a further exploration of simplified and extended data input options in this study. The AGDISP model droplet size input interface has a user-defined option that allows for parametric droplet size entry using only the $D_{V0.5}$ and the relative span (RS) ($D_{V0.9}-D_{V0.1}/D_{V0.5}$, where $D_{V0.X}$ represents the droplet diameter at which 0.X faction of the spray is contained in smaller droplets), which are used to interpolate the full droplet spectrum based on typical distributions for flat fan agricultural nozzles with Newtonian tank mixes. While this procedure does slightly modify the measured droplet spectrum curve, the cumulative impact on the overall downwind deposition is minimal. The calculated RS values for the Fritz et al. [6] data set (Tables 12 and 13 in the Appendix) and the reported $D_{V0.5}$ values were used to generate the required droplet size distributions using this interface. The distribution data were then copied (in text form) directly from the AGDISP input file to the WTDISP input file in the appropriate location for each height, which could then be read and opened by WTDISP.

Environmental Data

The environmental conditions (temperature, wind speed, and relative humidity) were input based on the values measured and reported by Fritz et al. [6] and as shown in Tables 1 and 2. The non-volatile fraction

TABLE 2—*Airspeed, temperature, and relative humidity means and standard deviations for flux and deposition measurements at 2.5 m/s airspeed.*

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

was set to one in order to remove the effects of evaporation and looking solely at the drift as related to droplet size of the spray as generated by the nozzles.

Wind Tunnel Dispersion Modeling of Fritz et al. [6] Data

Using the previously discussed results, all appropriate data were input into WTDISP for each nozzle and airspeed combination tested. There were several adjustments that were made to make WTDISP accommodate the measured data formats.

As discussed earlier, WTDISP looks for a flux at 2 m downwind of the nozzle in units of $L/cm^2/min$ as well as a spray interval in seconds. The model multiplies the entered flux by the spray interval (converted to minutes) to calculate a total flux value in L/cm^2. The values measured in the 2008 study [6] were in units of $\mu L/cm^2$ and corresponded to a spray interval of 10 s. To return modeled estimates of downwind deposition that are representative of the actual spray interval and measured spray plume characteristics, the measured monofilament deposition data were entered for each height (in units of $\mu L/cm^2$) and the spray interval was entered as 60 s. This results in the monofilament concentrations being multiplied by 1 (1 min=60 s). Output results are converted to the spray flux data in units of $\mu L/cm^2$ using a factor of 1×10^{-6} (convert from litre to microlitre).

The modeled deposition estimates are relative in position to the input flux locations. The flux locations measured during the low-speed wind tunnel data collection trials were 2 m downwind of the spray nozzle. The mylar fallout deposition measurements were made at 2, 3, 4, and 5 m downwind of the spray nozzles. The 2 m flux locations and the 2 m downwind deposition locations coincided in the Fritz et al. study [6]. When the spray flux and droplet size data were input into WTDISP, the model was designed so that these data represented the spray cloud profile that was leaving the edge of a field boundary. Therefore, the modeled deposition at 0 m would correspond to that measured at 2 m downwind from the actual spray nozzle, and likewise the modeled deposition at 3 m would correspond to that measured at 5 m.

Optimization of the Number of Flux Entries Required

As reported by Fritz et al. [6], the low speed wind tunnel collection requirements for droplet size and flux data required for WTDISP modeling assessment were an intensive process requiring, under the present sampling protocols, ten times greater time requirement compared to the high-speed wind tunnel testing protocols [7]. Given this difference, one of the objectives of this work was to explore the possibility of reducing the required number of heights at which droplet sizing and flux measurements must be collected while maintaining the relative downwind deposition and drift reduction ratings between the different nozzles and wind speeds.

Initially, the monofilament deposition data measured at each height for each nozzle operating in each airspeed were plotted to examine the spray plume pattern with the height in the tunnel (Figs. 2 and 3 for 1 and 2.5 m/s airspeeds, respectively). Note that the plots are of the measured data and the measured data corrected for sampler collection efficiency as the plots are to give a general indication of the plume profile. While the monofilament deposition for all nozzles at both airspeeds tended to be similar at the top location, there tended to be more separation between nozzles in the middle and lower locations with increased flux from the smaller droplet producing nozzles toward the bottom of the tunnel. It is expected that measuring the droplet size and flux at the middle height only will likely not show a separation between the treatments (nozzles), and this was tested. For this work, three alternative scenarios and the full data set were compared. The first, referred to as Scenario 1 (S1), used only the 0.1, 0.3, and 0.6 m droplet size and

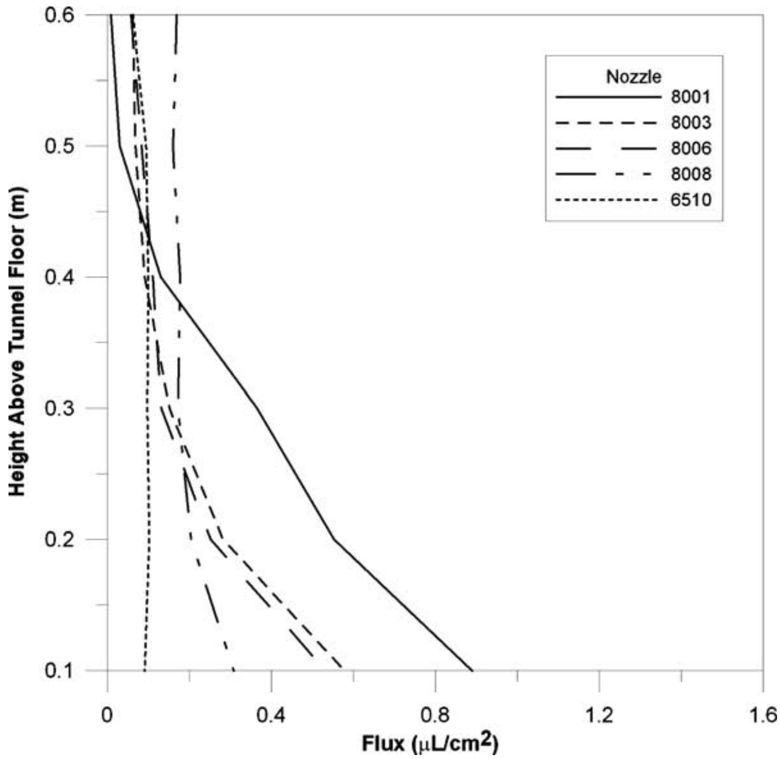

FIG. 2—*Flux data by height of tunnel floor for each nozzle operated in a 1 m/s airstream.*

monofilament deposition data. The second, Scenario 2 (S2), used only the 0.2 and 0.5 m droplet size and monofilament deposition data. The third and final, Scenario 3 (S3), used only the 0.3 m droplet size and flux data. The full data set using all six heights of measured droplet size and monofilament deposition data is referred to as full protocol (FP).

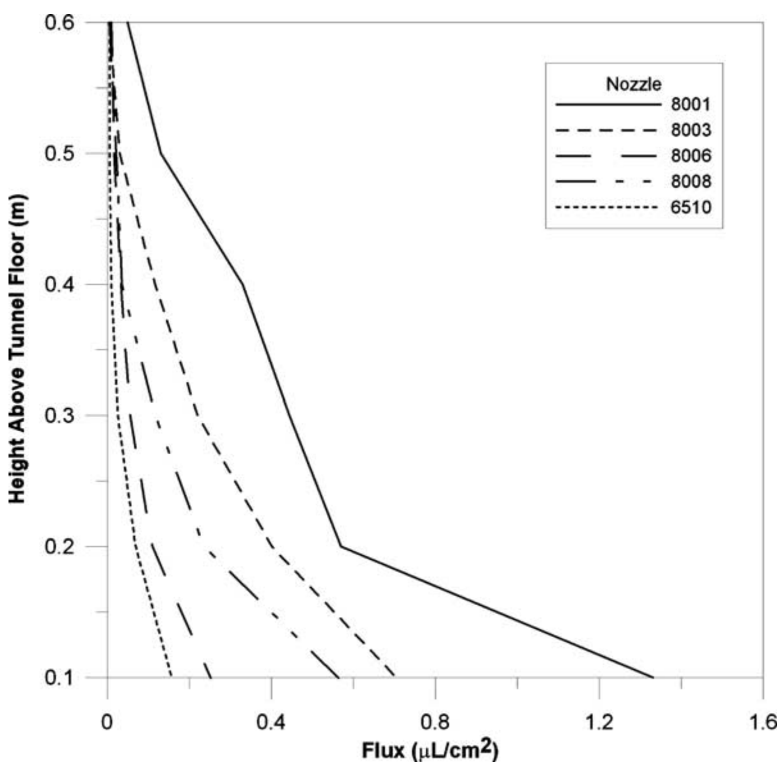

FIG. 3—*Flux data by height of tunnel floor for each nozzle operated in a 2.5 m/s airstream.*

TABLE 3—*Wind tunnel measured versus WTDISP modeled deposition for airspeed of 1 m/s.*

Nozzle	Distance (m)	Deposition (μL/cm^2)	
		Measured	WTDISP Modeled
8001	2	0.819	0.028
	3	0.589	0.173
	4	0.262	0.032
	5	0.090	0.006
8003	2	0.711	0.026
	3	0.389	0.018
	4	0.183	0.0046
	5	0.063	0.0002
8006	2	0.539	0.019
	3	0.192	0.074
	4	0.130	0.019
	5	0.025	0.005
8008	2	0.381	0.019
	3	0.075	0.126
	4	0.123	0.021
	5	0.029	0.004
6510	2	0.261	0.002
	3	0.063	0.048
	4	0.123	0.006
	5	0.031	0.001

Using a data file that incorporates all six measurement heights (FP), new files were made and modified to represent each indicated scenario. This was accomplished by entering a zero value for both height and flux for the locations in each scenario that were not being used and saving the data file under a new name. For example, for S1 for the 8001 nozzle at 1 m/s, the FP input data were modified by changing the spray flux and the height values at 0.2, 0.4, and 0.5 to zero. All modeling scenarios were run, and the results were compared.

Drift Reduction Ratings

According to the proposed DRT evaluation protocols, the measure of performance for a given DRT is based on modeled deposition from 0 to 61 m (0–200 ft) downwind. The measurements for each technology evaluated are compared to similar data collected for a reference system operating under the same conditions. The reference system for this work was defined as the nozzle, which defines the fine/medium boundary in the ASABE spray nozzle classification standard [8]. This nozzle is the 11003 flat fan, which as discussed by Fritz et al. [6] was replaced with the 80° version of this nozzle, or the 8003 flat fan nozzle, which has a similar droplet spectrum and flowrate as the 11003 [6]. The nozzles selected were not meant to enhance the current standard or form the basis for a standard but were rather selected using the standard such that the nozzles would separate in terms of droplet size produced and therefore drift values measured and modeled. Based on the modeled data, a drift reduction rating in the form of a percent reduction from the reference system was calculated based on data corresponding to a deposition of 10 m downwind and total integrated deposition from 0 to 61 m downwind. While the integrated deposition will likely be more consistent than the single point source data, the 10 m distance data are included as an exploratory measure and for possible comparison with future field collected data.

Results

Wind Tunnel Measured versus Modeled Deposition Results

WTDISP is not appropriate for comparison of modeled and measured ground deposition as stated by the developer [13] and as evidenced by the results shown in Tables 3 and 4. However, Hewitt [10] and Connell

TABLE 4—*Wind tunnel measured versus WTDISP modeled deposition for airspeed of 2.5 m/s.*

Nozzle	Distance (m)	Deposition ($\mu L/cm^2$) Measured	WTDISP Modeled
8001	2	0.908	0.0004
	3	0.439	0.444
	4	0.260	0.072
	5	0.173	0.010
8003	2	0.472	0.0001
	3	0.210	0.244
	4	0.197	0.047
	5	0.101	0.007
8006	2	0.248	0.0001
	3	0.068	0.068
	4	0.037	0.019
	5	0.018	0.005
8008	2	0.333	0.000
	3	0.118	0.005
	4	0.083	0.0007
	5	0.038	0.0001
6510	2	0.078	0.000
	3	0.029	0.0001
	4	0.006	0.0004
	5	0.002	0.0001

et al. [11] suggested and continued to research options for the use of WTDISP for absolute rather than relative performance data through additional description of the spray source and sprayer speed using laser measurements of flux in wind tunnels. The measured deposition values for the present study have been adjusted for the recovery of 93 % following the methods listed previously.

The modeled and measured results at 3 m tend to be similar, while the modeled results tended to be much lower than those measured at the other distance. WTDISP models the flux movement as if it were in an open ambient environment, and the measured data correspond to an enclosed tunnel environment within which the plume dispersion is limited to the enclosed area.

Wind Tunnel Dispersion Modeling Results

The numerical deposition data, as modeled by WTDISP, for each nozzle operating under each airspeed and for each input scenario are shown in Table 5.

TABLE 5—*Modeled deposition at 10 m downwind and integrated from 0 to 60 m downwind for each scenario for each nozzle operating under 1 and 2.5 m/s airspeeds.*

		Deposition @ 10 m ($\mu L/cm^2$)				Integrated Deposition 0–60 m ($\mu L/cm^2$)			
	Nozzle	FP	S1	S2	S3	FP	S1	S2	S3
1 m/s	8001	3.0×10^{-04}	1.5×10^{-04}	4.7×10^{-04}	1.9×10^{-03}	0.017 00	0.018 00	0.017 40	0.009 40
	8003	1.0×10^{-05}	6.6×10^{-04}	9.1×10^{-04}	1.1×10^{-03}	0.008 70	0.012 90	0.009 80	0.003 90
	8006	2.5×10^{-04}	3.1×10^{-04}	3.5×10^{-04}	5.1×10^{-04}	0.011 00	0.009 00	0.009 90	0.005 00
	8008	2.7×10^{-04}	2.5×10^{-04}	9.7×10^{-06}	3.0×10^{-05}	0.006 60	0.006 00	0.008 80	0.006 00
	6510	8.0×10^{-05}	8.7×10^{-05}	5.4×10^{-04}	6.5×10^{-04}	0.005 20	0.005 30	0.003 20	0.003 40
2.5 m/s	8001	4.1×10^{-04}	7.6×10^{-04}	2.6×10^{-03}	3.4×10^{-03}	0.024 00	0.028 30	0.011 00	0.007 80
	8003	4.2×10^{-04}	3.1×10^{-04}	8.4×10^{-04}	2.0×10^{-03}	0.014 00	0.012 90	0.009 80	0.003 90
	8006	6.3×10^{-04}	3.1×10^{-04}	3.5×10^{-04}	5.1×10^{-04}	0.004 70	0.005 20	0.002 20	0.001 00
	8008	4.7×10^{-06}	3.8×10^{-07}	9.7×10^{-06}	3.0×10^{-05}	0.012 00	0.013 90	0.004 90	0.002 20
	6510	1.8×10^{-05}	8.7×10^{-06}	3.9×10^{-06}	7.1×10^{-06}	0.002 80	0.003 20	0.001 40	0.000 50

TABLE 6—*Modeled deposition at 10 m downwind and integrated from 0 to 60 m downwind for each scenario for each nozzle operating under 1 and 2.5 m/s airspeed expressed as millionths percentages of applied.*

		Deposition @ 10 m (Millionth Percent of Applied)				Integrated Deposition 0–60 m (Millionth Percent of Applied)			
	Nozzle	FP	S1	S2	S3	FP	S1	S2	S3
1 m/s	8001	0.3830	0.1946	0.6004	2.4835	21.7022	22.9788	22.2129	12.0001
	8003	0.0050	0.3279	0.4526	0.5605	4.3500	6.4500	4.9000	1.9500
	8006	0.0833	0.1022	0.1177	0.1688	3.6667	3.0000	3.3000	1.6667
	8008	0.0600	0.0560	0.0022	0.0066	1.4667	1.3333	1.9556	1.3333
	6510	0.0160	0.0173	0.1072	0.1291	1.0400	1.0600	0.6400	0.6800
2.5 m/s	8001	0.5281	0.9676	3.3273	4.3447	30.6384	36.1278	14.0426	9.9575
	8003	0.2079	0.1563	0.4183	0.9773	7.0000	6.4500	4.9000	1.9500
	8006	0.2116	0.1022	0.1177	0.1688	1.5667	1.7333	0.7333	0.3333
	8008	0.0010	0.0001	0.0022	0.0066	2.6667	3.0889	1.0889	0.4889
	6510	0.0036	0.0017	0.0008	0.0014	0.5600	0.6400	0.2800	0.1000

These data were then converted to a percentage of the total volume applied (Table 6). The total volume applied was calculated based on a 10 s spray time and the measured nozzle flowrate (0.47, 1.2, 1.8, 2.7, and 3.0 L/min for the 8001, 8003, 8006, 8008, and 6510 nozzles, respectively [6]). As the calculated percentages were numerically small, the data were expressed as millionth percentages of applied.

Using these data, a percent reduction in drift from that modeled for the 8003 reference nozzle was determined (Table 7). Note that the modeled deposition values using the flux and droplet size data at all six heights for the 8003 nozzle (for both the 10 and the 0–60 m integrated values) did not follow expected trends as seen in the other nozzles (i.e., the values would be expected to fall between the 8001 and the 8006 values). However, when looking at the modeled results using the alternative scenarios (S1–S3), these trends did hold. The modeling inputs and results were analyzed a number of times for the 8003 FP data, but no discernable reason for this inconsistency was found. As this data represent the reference point, the determined reductions and ratings are affected. The percent reduction within each scenario, wind speed, and deposition data sets was determined by comparison to the corresponding data for the 8003 nozzle. For example, the percent reduction in modeled deposition at 10 m using all six flux heights for the 8006 nozzle operating in a 1 m/s airstream was calculated based on the modeled deposition at 10 m using all six flux heights for the 8003 nozzle under the same airspeed. There was also no consistency in the drift reduction percentages for either the 10 or the 0–60 m integrated deposition data in terms of reductions at the three scenarios versus the FP data. Overall, these data were more consistent, in terms of maintaining similar reduction levels across the different flux measurements scenarios, at the 2.5 m/s wind speed.

The reduction percentages were then used to provide each nozzle/airspeed combination with a DRT rating. One potential method for ranking the effectiveness of these nozzles in reducing drift as compared to the reference nozzle is a drift classification scheme developed by the International Standards Organi-

TABLE 7—*Drift reduction percentages for each nozzle operating under each airspeed as compared to the 8003 reference nozzle results.*

		Percent Reduction in Drift Compared to 8003 Reference Nozzle							
		Deposition @ 10 m				Integrated Deposition 0–60 m			
	Nozzle	FP	S1	S2	S3	FP	S1	S2	S3
1 m/s	8001	−7559.6	40.6	−32.7	−343.0	−398.9	−256.3	−353.3	−515.4
	8003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8006	−1566.7	68.8	74.0	69.9	15.7	53.5	32.7	14.5
	8008	−1100.0	82.9	99.5	98.8	66.3	79.3	60.1	31.6
	6510	−220.0	94.7	76.3	77.0	76.1	83.6	86.9	65.1
2.5 m/s	8001	−154.0	−519.0	−695.4	−344.6	−337.7	−460.1	−186.6	−410.6
	8003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8006	−1.8	34.6	71.9	82.7	77.6	73.1	85.0	82.9
	8008	99.5	99.9	99.5	99.3	61.9	52.1	77.8	74.9
	6510	98.3	98.9	99.8	99.9	92.0	90.1	94.3	94.9

TABLE 8—*ISO 22369-1:2006(E) drift reduction classes based on percentage reduction of candidate system as compared to reference system.*

	Class					
	F	E	D	C	B	A
Drift reduction (%)	25≤50	50≤75	75≤90	90≤95	95≤99	≥99

zation (ISO) standard [14]. This standard defines the six classes ranked alphabetically (A–F), with the A class having the greatest percentage reduction and the F class the least (Table 8). Reduction levels that did not fall into this scheme or nozzles that showed increases compared to the reference nozzle were assigned a "no rating" or "nr." This scheme, which is used in this work to show the potential rating for the different nozzles tested, does not imply that this will be the final drift rating system used within the DRT program.

Using this rating system, the drift reduction values in Table 7 were converted to ISO drift classes (Table 9). The ratings follow expected trends, with the larger droplet producing nozzles having higher star ratings as a result of higher drift reduction values when compared to the reference system. A comparison of the drift reductions (Table 7) and the drift ratings (Table 9) shows no consistent results in terms of the different modeling scenarios (S1, S2, and S3) as compared to the results from using the FP data. While none of the scenarios provide a perfect matching to the FP derived drift rating values, the S1 data set is generally closest, in terms of modeled downwind deposition, to the full data set.

Conclusions

Data collected in the process of evaluating the EPA's proposed DRT protocol were used to conduct modeling assessments to determine relative drift reductions between nozzle and airspeed combinations. Prior to the experimental modeling runs, a series of test cases was conducted to determine specific operating characteristics of the WTDISP model. Using ISO-developed drift reduction classes, the modeled data generally showed that the larger droplet producing nozzles had reduced drift levels, as compared to the selected standard, but the results were not consistent. Tests examining potential decreased data input schemes did not show promise. Given the limited testing and review that the WTDISP model has received in referenced literature and based on the results of this work, there is a need for further testing and development of this model prior to its integration into a regulatory framework. Most importantly, there needs to be an assurance that this model is representative of the changes in spray drift levels that would result in the field with the appropriate equipment modifications in order to fairly credit applicators with potential drift reductions.

TABLE 9—*ISO drift reduction class rating for the different nozzle and airspeed combinations and the different modeling scenarios.*

		ISO Drift Reduction Rating Using the 8003 as the Reference Nozzle							
		Deposition @ 10 m				Integrated Deposition 0–60 m			
	Nozzle	FP	S1	S2	S3	FP	S1	S2	S3
1 m/s	8001	nr	nr	nr	nr	nr	E	nr	nr
	8003								
	8006	nr	E	E	E	nr	E	F	nr
	8008	nr	D	A	B	E	D	E	F
	6510	nr	C	D	D	D	D	D	E
2.5 m/s	8001	nr	nr	nr	nr	nr	nr	nr	nr
	8003								
	8006	nr	nr	E	D	D	E	D	D
	8008	A	A	A	A	E	E	D	D
	6510	B	B	A	A	C	C	C	B

Note: An nr rating corresponds to no drift class rating.

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Appendix: Monofilament Concentration Corrected for Collection Efficiency and Droplet Size Data for Nozzles Tested in Low Speed Wind Tunnel

See Tables 10–13.

TABLE 10—*Collection efficiencies and measured and adjusted monofilament concentrations measured by Fritz et al. [6] at 1 m/s.*

Nozzle	Height (cm)	Calculated Collection Efficiency (%)	Measured Monofilament Concentration ($\mu L/cm^2$)	Adjusted Monofilament Concentration ($\mu L/cm^2$)
8001	60	86.7	0.0085	0.0098
	50	86.6	0.0301	0.0348
	40	86.6	0.1304	0.1506
	30	86.6	0.3651	0.4216
	20	86.6	0.5529	0.6385
	10	86.5	0.8890	1.0277
8003	60	85.7	0.0614	0.0716
	50	86.0	0.0682	0.0793
	40	86.5	0.0910	0.1052
	30	86.0	0.1513	0.1759
	20	86.7	0.2822	0.3255
	10	86.0	0.5778	0.6719
8006	60	86.0	0.0574	0.0667
	50	85.9	0.0835	0.0972
	40	86.1	0.1107	0.1286
	30	85.5	0.1316	0.1539
	20	86.4	0.2515	0.4459
	10	86.2	0.5320	0.6172
8008	60	85.5	0.1692	0.1979
	50	84.9	0.1599	0.1883
	40	85.5	0.1773	0.2074
	30	85.4	0.1727	0.2022
	20	85.6	0.2040	0.2383
	10	85.8	0.3083	0.3593
6510	60	84.9	0.0626	0.0737
	50	84.7	0.0945	0.1116
	40	83.7	0.0997	0.1191
	30	83.8	0.0974	0.1162
	20	85.9	0.1020	0.1187
	10	85.9	0.0910	0.1059

TABLE 11—*Collection efficiencies and measured and adjusted monofilament concentrations measured by Fritz et al. [6] at 2.5 m/s.*

Nozzle	Height (cm)	Calculated Collection Efficiency (%)	Measured Monofilament Concentration ($\mu L/cm^2$)	Adjusted Monofilament Concentration ($\mu L/cm^2$)
8001	60	86.0	0.0494	0.0574
	50	86.3	0.1300	0.1506
	40	85.5	0.3293	0.3851
	30	85.5	0.4437	0.5189
	20	85.5	0.5702	0.6669
	10	85.1	1.3327	1.5660
8003	60	85.9	0.0047	0.0055
	50	85.6	0.0299	0.0349
	40	85.5	0.1165	0.1363
	30	85.5	0.2202	0.2575
	20	85.2	0.4016	0.4714
	10	84.8	0.7047	0.8310
8006	60	86.4	0.0096	0.0111
	50	85.7	0.0166	0.0194
	40	85.4	0.0330	0.0386
	30	85.5	0.0556	0.0650
	20	85.1	0.1095	0.1287
	10	84.5	0.2521	0.2983
8008	60	85.7	0.0050	0.0058
	50	85.8	0.0220	0.0256
	40	85.0	0.0354	0.0416
	30	85.3	0.1171	0.1373
	20	85.4	0.2359	0.2762
	10	84.6	0.5621	0.6644
6510	60	85.4	0.0055	0.0064
	50	85.4	0.0053	0.0062
	40	85.5	0.0095	0.0111
	30	84.9	0.0255	0.0300
	20	85.5	0.0690	0.0807
	10	85.3	0.1571	0.1842

Note: Spray droplet size 2 m downwind of the nozzle; droplet size data was measured and reported by Fritz et al. [6], as shown in Tables 3 and 4.

TABLE 12—*Droplet size data measured at each height 2 m downwind of spray nozzle at an airspeed of 1 m/s.*

Nozzle	Height (cm)	$D_{V0.1}$ (μm)	$D_{V0.9}$ (μm)	$D_{V0.5}$ (μm)	RS
8001	60	45.3	108.7	71.5	0.92
	50	49.3	115.5	77.2	0.86
	40	54.2	123.8	82.8	0.84
	30	50.3	120.2	79.4	0.88
	20	52.8	118.4	80.4	0.82
	10	55.9	123.0	84.2	0.80
8003	60	25.3	85.6	50.5	1.19
	50	30.9	98.3	58.9	1.16
	40	39.6	134.7	81.2	1.17
	30	46.1	149.5	94.9	1.10
	20	74.0	144.0	101.5	0.70
	10	75.5	144.9	103.2	0.67
8006	60	41.9	132.2	84.7	1.07
	50	49.4	142.7	97.8	0.95
	40	48.0	137.7	87.3	1.03
	30	82.4	164.3	113.9	0.72
	20	46.3	122.9	78.9	0.97
	10	63.1	138.5	93.7	0.81
8008	60	48.7	161.2	103.6	1.09
	50	52.6	168.5	108.9	1.06
	40	55.0	163.6	110.2	0.98
	30	53.1	159.3	105.4	1.01
	20	54.6	158.4	106.0	0.98
	10	53.3	158.3	105.3	1.00
6510	60	44.3	159.9	95.8	1.21
	50	42.7	157.8	92.3	1.25
	40	42.5	167.5	95.2	1.31
	30	41.1	166.1	91.8	1.36
	20	40.6	148.0	88.2	1.22
	10	45.0	146.2	92.9	1.09

TABLE 13—*Droplet size data measured at each height 2 m downwind of spray nozzle at an airspeed of 2.5 m/s.*

Nozzle	Height (cm)	$D_{V0.1}$ (μm)	$D_{V0.9}$ (μm)	$D_{V0.5}$ (μm)	RS
8001	60	42.3	99.63	71.7	0.80
	50	39.2	88.33	64.9	0.76
	40	50.8	121.3	86.6	0.81
	30	51.4	121.0	85.0	0.82
	20	53.0	119.1	86.1	0.77
	10	63.0	127.6	95.9	0.67
8003	60	40.8	102.0	73.8	0.83
	50	47.2	114.9	83.2	0.81
	40	48.7	119.2	84.6	0.83
	30	51.3	117.9	84.0	0.79
	20	56.4	128.7	93.8	0.77
	10	65.5	139.1	103.7	0.71
8006	60	34.6	95.9	62.7	0.98
	50	44.4	115.6	80.3	0.89
	40	45.4	124.3	82.6	0.95
	30	44.0	125.2	81.0	1.00
	20	57.1	135.0	95.0	0.82
	10	56.2	153.6	101.5	0.96
8008	60	51.5	115.0	81.5	0.78
	50	45.1	112.6	77.0	0.88
	40	52.6	136.6	91.4	0.92
	30	52.0	127.7	91.2	0.83
	20	55.9	122.5	88.5	0.75
	10	66.1	152.6	112.3	0.77
6510	60	45.2	85.2	130.3	1.0
	50	47.9	131.3	86.5	0.96
	40	46.7	121.3	85.9	0.87
	30	43.1	121.4	81.5	0.96
	20	42.0	121.4	83.5	0.95
	10	46.9	133.3	79.6	1.09

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