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An Overview of Spray Drift Reduction Testing of Spray Nozzles

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Abstract. *The importance of the development and testing of drift reduction technologies (DRTs) is increasing. Common spray drift reduction technologies include spray nozzles and spray adjuvants. Following draft procedures developed for a DRT program, three spray nozzles were tested under high air speed conditions (i.e.45-65 m/sec (100-140 mph)), which are relevant to the aerial application of crop production and protection materials. The spray nozzles were evaluated in the USDA-ARS High Speed Wind Tunnel facility. Droplet size of each of the nozzles with different airspeeds, spray pressures, and orientation were measured with a Sympatec Helos laser diffraction*

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instrument. The measured droplet size spectra for each test was input in a spray dispersion model (AGDISP) to calculate the downwind drift expected from a typical aerial application scenario. The three spray nozzles reduced spray drift by 70-84% as compared to a reference nozzle. The nozzles generated spray droplets with volume median diameters 60-80 µm larger than the reference nozzle. One of the aerial application industry's Best Management Practices (BMP) is the use of a swath offset at the downwind most edge of a spray block. The spray swath near this edge is moved upwind (i.e. offset) by ½ to 1 swath width. When this BMP was combined with the drift reductions from the spray nozzles, the amount of drift reduction was slightly increased to 93-96%. These results demonstrate the possibility of combining multiple drift reduction techniques and technologies to greatly reduce spray drift.

Keywords. *drift, DRT, drift reduction technology, droplet sizing, spray droplet size.*

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Introduction

The development and testing of drift reduction technologies have come to the forefront of application research in the past few years in the United States. EPA recognized the need for testing DRTs, such as spray nozzles, sprayer modifications, spray delivery assistance, spray property modifiers (adjuvants), and/or landscape modifications. The DRT Program is an EPA-led initiative to "achieve improved environmental and human health protection through drift reduction by accelerating the acceptance and use of improved and cost-effective application technologies" (EPA, 2006). The first step in implementing the DRT program is to develop a set of protocols, standard operating procedures, and data quality assurance steps so that the results from any trials or research conducted are scientifically valid and repeatable; data quality and protection must also be maintained throughout the study (EPA, 2002 and Kosusko, 2006).

Best Management Practices (BMP) are common industry practices that are used to apply agrochemicals to optimizes in swath deposition while minimizing off-target movement. For aerial applications, common BMPs are identification of sensitive areas around a field to be sprayed, modifying spray applications to account for changes in wind speed and direction, proper equipment setup to optimize agrochemical delivery (DuPont Crop Protect, 1996), and other professional practices all directed at making the most effective spray application. One common BMP is the use of a swath offset to minimize off-target deposition when an application is made near a downwind field edge. This practice involves moving a spray swath some distance upwind of a downwind field edge while spraying in a crosswind (Dow AgroSciences, 2009).

The objective of this work is to evaluate the DRT testing program for aerial applications under high airspeeds (i.e. >60 mph). The measure of performance for the DRTs (nozzles) from high speed wind tunnel measurements will be derived from droplet size distribution measurements which are used, along with dispersion modeling, to obtain an estimate of downwind deposition from 0 to 10 m.

Material and Methods

Three test nozzles and a reference nozzle were tested. The three test nozzles were a ULD 120-04 nozzle (Hypro, New Brighton, MN), an AI-11003 VS nozzle (Teejet Technologies, Wheaton, IL) and a CP11TT 40^0 Flat Fan nozzle with a #08 orifice (CP Products Inc., Mesa, AZ). The nozzle used to define the Fine/Medium boundary in the ASABE Standard was selected as the reference nozzle. Specifically, this reference nozzle was a Spraying Systems 110^0 Flat fan nozzle with a #03 orifice operated at 300 kPa (43psi). The testing nomenclature for the nozzles tested were:

N1: Hypro ULD 120-04;

N2: Teejet AI 11003 VS;

N3: CP11TT 4008.

Spray Solutions

All nozzle evaluations were made using a spray solution containing water with 0.25% volume/volume (v/v) of a 90% nonionic surfactant (NIS) (R-11, Wilbur-Ellis Company, San Antonio, TX). The water plus NIS solution was used because it is a good simulant of most water-based insecticide sprays and allows the sprayers to be tested without exposing the personnel involved with this study to insecticides.

Droplet Size Measurements

A Sympatec Helos laser diffraction droplet sizing system (Sympatec Inc., Clausthal, Germany) was used to measure the droplet size downwind of the tested nozzles. The Helos system utilizes a 623 nm He-Ne laser and was fitted with a lens (denoted by manufacturer as R7) with a dynamic size range of 0.5 µm to 3500 µm which is divided across 32 sizing bins. The laser system has two components, the emitter and the receiver, which were positioned across from each other and outside of the wind tunnel. The laser was horizontally positioned so that the beam was in the center of the wind tunnel outlet.

Droplet size measurements included volume median diameter (DV0.5), and DV0.1 and DV0.9. DV0.5 is the droplet diameter (µm) where 50% of the spray volume or mass is contained in droplets of lesser diameter. DV0.1 and DV0.9 values describe the proportion of the spray volume (10% and 90%, respectively) contained in droplets of the specified size or less. The percent volume less than 200 µm, which is an indicator of the "driftable" portion of a spray, was also computed along with the Relative Span (RS) (Eq. 1), which is a dimensionless measure of the spread of the droplet sizes in the spray.

$$RS = \frac{D_{V0.9} - D_{V0.1}}{D_{V0.5}} \quad (1)$$

All measurements were conducted at the USDA-ARS wind tunnel site in College Station. Three replications were conducted for each combination of air speed, spray nozzle, spray solution, and/or nozzle orientation. A replication comprised of traversing the entire spray plume through the Sympatec Helos laser beam nozzle at a distance of 24 in from the laser beam of the droplet measurement system.

AGDISP Model Setup and Inputs

AGDISP Ver. 8.21 was used in the modeling scenarios with the following inputs standard across all scenarios reported in this manuscript:

- Aircraft: Air Tractor AT-401 with 66 ft swath width;
- Application Scenario: 11.5 ft release height with 10 spray applications moving upwind;
- Meteorological Conditions: Wind Speed: 5 mph @ 90^0 (crosswind), Temperature: 80^0F, Relative Humidity: 70%.

Based on the droplet size measurements from each of the nozzle evaluations, the corresponding droplet size data was input into the model and a simulation run was made with the AGDISP model. One of the default settings in the AGDISP model is a swath offset of 0. The effects of changing this offset from 0 to a 1/2 swath offset were modeled.

Drift Reduction Ratings from ISO and LERAP Standards

The two most commonly used drift reduction classification systems are the Local Environmental Risk Assessment for Pesticide (LERAP) and the International Standards Organization (ISO)

systems. The LERAP system (Gilbert, 2000) uses a system of stars (No stars to ***) to denote the level of drift reduction that a given technology provides as compared to a reference system. These ratings are used to determine the size of the spray buffer mitigation the applicator can use with a given spray technology. The ISO drift reduction standard (ISO, 2006) defines the six drift reduction classes ranked alphabetically (A-F) with the A class having the greatest percentage reduction and the F class the least (Table 1). The ISO classification is also used as a method to mitigate the size of a no-spray buffer area. Unlike the ISO classification system, the LERAP method groups systems with a 75% reduction or greater into a single classification group.

TABLE 1. Drift reduction classification for the LERAP and ISO system based on percentage reduction of candidate system as compared to reference system.

Drift Reduction (%)[1]	25 ≤ 50	50 ≤ 75	75 ≤ 90	90 ≤ 95	95 ≤ 99	≥ 99
LERAP Drift Classification	*	**	***	***	***	***
ISO Drift Classification	F	E	D	C	B	A

1 Drift reduction is the percentage of drift reduction achieved by a technology as compared to a standard reference.

Results

The droplet size measurements for the Reference and three test nozzles are shown in Table 2. As expected, the droplet size decreased for each of the nozzles as the airspeed in the wind tunnel increased from 120 to 140 mph. The droplet sizes also increased with N1 and N2 when the spray pressure was increased from 30 to 60 psi. These data were used in all of the subsequent AGDISP modeling work.

TABLE 2. Droplet size data from nozzle evaluation tests.

Nozzle	Airspeed mph	Spray Pressure psi	$D_{V0.5}$[1] (µm)	Relative Span[2]	%<200µm[3]
Reference	120	42	210.7	1.13	45.6
	140	42	183.5	1.13	57.9
N1	120	30	276.7	1.06	25.9
	120	60	290.1	1.04	22.3
	140	30	214.5	1.13	44.1
	140	60	228.6	1.11	39.0
N2	120	30	275.9	1.07	26.5
	120	60	291.0	1.07	23.1
	140	30	223.2	1.12	40.9
	140	60	234.2	1.10	37.1

N3	120	40	308.5	1.03	21.1
	140	40	261.1	1.10	30.2

1 DV0.5 = Volume Median Diameter
2 Relative Span = [DV0.9 - DV0.1]/ DV0.5
3 %<200µm = Percentage of Spray Volume Comprised of Droplets Less Than 200 µm in diameter.

Modeling Application Efficiency

After running AGDISP using the droplet size measurements for the different testing scenarios (nozzle, pressure, airspeed), the modeling outputs were recorded. Application efficiency is the amount of spray material, expressed as a percentage of spray released from the simulated aircraft that deposits in the field or targeted area. For all of the simulations, downwind deposition out to 10 m was modeled. This is representative of the spray deposition from the edge of the swath to a distance 10 m downwind. The airborne drift at 10 m represents the portion of the spray volume that remains in the air at this distance.

The modeled outputs for all four nozzles for airspeed tests of 120 and 140 mph are presented in Tables 3 and 4, respectively. The Reference nozzle generated an application efficiency of 86.7% with 1.5% of the spray in the air 10 m from the field boundary in the 120 mph modeling runs. The three nozzles (N1, N2, and N3) tested all had improved application efficiencies and large decreases in airborne drift as compared to the reference nozzle. In the 140 mph tests, the Reference nozzle had an application efficiency of 84.6% and 2.45% of the spray was still airborne at 10 m. The three nozzles tested all had improved application efficiencies and decreases in airborne drift.

TABLE 3. Modeled Application Efficiency, Downwind Deposition, and Airborne Drift from the Six Nozzle Tests at Airspeeds of 120 mph.

Nozzle	Pressure psi	Application Efficiency (% of Applied)	Downwind Deposition (%)	Airborne Drift (%)
Reference	43	86.74	11.75	1.51
N1	30	90.34	9.34	0.33
	60	90.76	8.97	0.27
N2	30	90.21	9.35	0.45
	60	90.67	9.03	0.30
N3	40	91.16	8.61	0.24

TABLE 4. Modeled Application Efficiency, Downwind Deposition, and Airborne Drift from the Four Nozzle Tests at Airspeeds of 140 mph Airstream.

Nozzle	Pressure psi	Application Efficiency (% of Applied)	Downwind Deposition (%)	Airborne Drift (%)

Reference	43	84.63	12.91	2.45
N1	30	87.19	11.36	1.45
	60	88.13	10.70	1.18
N2	30	87.84	10.85	1.32
	60	88.58	10.47	0.952
N3	40	89.7	9.67	0.629

Drift Reduction from Nozzles

Drift reduction is defined as the reduction in the airborne portion of the spray as compared to a reference (ISO Standard). The test nozzles reduced airborne spray drift by 70-84% in the 120 mph airstreams and from 41-74% in the 140 mph airstream tests (Table 5). At lower airspeed, the tested nozzles received E and D ratings based on the ISO drift classification scheme and ** and *** based on the LERAP scheme (Table 5). At 140 mph, the test nozzles received F and E ratings based on the ISO drift classification scheme and * and ** based on the LERAP scheme.

Table 5. Drift reductions from three spray nozzles as compared to a reference nozzle with corresponding ISO and LERAP Drift Reduction Ratings.

Nozzle	Pressure psi	Drift Reduction (%)	ISO Drift Ratings	LERAP Drift Ratings
120 mph Airspeed				
N1	30	78.4	D	***
	60	82.3	D	***
N2	30	70.3	E	**
	60	80.3	D	***
N3	40	84.3	D	***
140 mph Airspeed				
N1	30	40.8	F	*
	60	51.8	E	**
N2	30	46.1	F	*
	60	61.1	E	**
N3	40	74.3	E	**

Effects of Swath Offset on Application Efficiency and Drift Reduction

All of the scenarios that were modeled to produce the results in Tables 3 and 4 were rerun with a ½ swath offset except the Reference nozzle settings. A ½ swath offset was the equivalent of

making a spray application 10 m further upwind from the field edge. For both of the airspeeds, the three nozzles combined with a ½ swath offset resulted in application efficiencies between 93-97% (Tables 6 and 7) and only minor changes in the airborne drift percentages. The offset results in more material depositing in the field, which is why aerial applicators have adopted this practice. After running the same drift reduction calculations with the swath offset included, the only scenario that resulted in a change in drift classification was N3 at 120 mph, which improved from an E to a D on the ISO drift classification system, but did not change under the LERAP scheme.

TABLE 6. Modeled application efficiency, downwind deposition, and airborne drift from five nozzle tests in a 120 mph airstream combined with a ½ swath offset.

Nozzle	Pressure psi	Application Efficiency (% of Applied)	Downwind Deposition (%)	Airborne Drift (%)
Reference [1]	43	86.74	11.75	1.51
N1	30	96.14	3.54	0.322
	60	96.57	3.17	0.261
N2	30	96.02	3.55	0.437
	60	96.47	3.24	0.293
N3	40	96.95	2.82	0.227

[1] Reference modeling results were not run with a swath offset

TABLE 7. Modeled application efficiency, downwind deposition, and airborne drift from five nozzle tests in a 140 mph airstream combined with a ½ swath offset.

Nozzle	Pressure psi	Application Efficiency (% of Applied)	Downwind Deposition (%)	Airborne Drift (%)
Reference	43	84.63	12.91	2.45
N1	30	93	5.59	1.41
	60	93.95	4.9	1.14
N2	30	93.66	5.06	1.28
	60	94.41	4.66	0.93
N3	40	95.56	3.84	0.60

Conclusion

This work examined a drift reduction testing protocol comparing three different nozzles to a reference nozzle. Additionally, an industry Best Management Practice (BMP) of offsetting near

field edge spray swaths was examined. The techniques and procedures for determining the nozzle effects on spray droplet size under high-speed air-sheer showed distinct differences between the nozzles tested and the reference nozzle. Using the AGDISP model, these droplet size results were translated to estimates of downwind deposition and airborne drift as a means of comparing the relative efficiencies of each nozzle as compared to the reference nozzle under different airspeeds and pressures. When compared to the reference nozzle, the results showed that:

- The three spray nozzles reduced spray drift by 40-84% (i.e. VMDs 30-80 μm larger than the reference nozzle);

- After modeling the aerial application industry's Best Management Practices (BMP) of ½ swath offset, the results showed further increases in drift reduction and large increases application efficiency which ranged from 93-97%;

- The combination of multiple drift reduction techniques/technologies can greatly reduce spray drift.

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