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Determination of Selection Criteria for Spray Drift Reduction from Atomization Data

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ABSTRACT: In the testing and evaluation of drift reduction technologies, there are different metrics that can be used to determine whether a technology reduces drift relative to a reference system. These metrics can include a reduction in the percentage of fine drops, measured spray drift from a field trial, or computer modeling of spray drift based on the application system and the droplet spectrum resulting from the specified operational conditions. The percentage of the spray volume constituted by droplets with diameters of less than 141 μm provided the most consistent and robust separation of droplet sizes and drift potential across all the nozzle, adjuvant, and active ingredient combinations tested. This study illustrates that adjuvants alter the spray distribution in different ways for different spray nozzles. The oil concentrate in this study uniformly narrowed the entire spray distribution, whereas in contrast the polymers widened the spray distribution because there was a greater increase in the spray volume made up of large droplets and only a modest increase in the spray volume made up of smaller droplets. When evaluating different spray technologies, it is critical that one consider the

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overall spray distribution and use it as a comparative measure of multiple technologies, particularly with active formulations and spray solution modifiers.

KEYWORDS: drift reduction technologies, DRT, adjuvant, spray atomization

Introduction

Drift is the off-target movement of a pesticide to an unintended target. In 2009, the National Pesticide Information Center handled 86 drift inquiries [1], which is a significant increase from the 46 cases they handled in each of 2007 and 2008. With more inquiries being made about pesticide drift and off-target damage and injury from pesticide applications [2], there is growing concern among agricultural pesticide applicators and growers that over-regulation will result in unnecessary buffer zones, which would restrict their ability to adequately control crop-specific pests.

In 2004, the U.S. Environmental Protection Agency (EPA) recognized the need to develop a testing program for measuring drift reduction technologies (DRTs) [3]. DRTs can be spray nozzles, sprayer modifications, spray delivery assistance, spray solution property modifiers (adjuvants), and/or landscape modifications. The DRT Program is an EPA-led program 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]. As part of the EPA DRT Program, a set of protocols, standard operating procedures, and data quality assurance steps were developed and tested in order to ensure that the results were scientifically valid and repeatable while maintaining data quality and protection throughout the study [5]. Testing methods for quantifying spray drift reduction through the DRT Program include both wind tunnel [6,7] and field evaluations [8–10]. Although wind tunnel studies are less expensive and time consuming to complete, they require methodology for translating the droplet size data to downwind drift. Typically, when discussing spray drift as a function of droplet size, a number of spray fraction cutoffs have been considered, including 100 μm [11], 105 μm [12], 141 μm [13,14], 150 μm [15], and 200 μm [16,17]. Within the framework of a DRT program, if a single droplet size fraction is desired, the selection goal is to allow for the separation of different technologies tested based on the measured or estimated downwind spray drift. If a single droplet spectra indicator can consistently allow for the separation of treatments based on estimates of drift, it will allow for an easier, simpler means of comparing treatments.

The objective of this work was to determine which droplet size metric provided the most consistent and informative estimate of spray drift reduction using a large aerial and ground spray database. This metric will help to pinpoint a specific value that regulators and researchers can use to objectively make standardized assessments of current and future DRTs. The effects of different spray adjuvants were also explored to determine whether the same metrics could be used to separate treatment effects.

Materials and Methods

Seven spray nozzles and eight spray formulations (four adjuvants tested without a formulated active ingredient herbicide product, and four with) were evaluated for droplet size in a low speed wind tunnel. The results were examined to determine what measure of droplet size metric allowed for separation of the different treatments, as well as which provide a reliable estimate for comparison of relative spray drift between the treatments.

Spray Nozzles

The seven spray nozzles from Spraying Systems Inc. (Wheaton, IL) used in these studies were the following:

- TeeJet XR11002 @ 276 kPa (40 psi),
- TeeJet AIXR11002 @ 276 kPa (40 psi),
- TeeJet Turbo Tee Jet 11002 @ 276 kPa (40 psi),
- TeeJet AI11002 @ 276 kPa (40 psi),
- TeeJet Flat Fan 11003 @ 296 kPa (43 psi),
- TeeJet Flat Fan 11006 @ 200 kPa (29 psi), and
- TeeJet Flat Fan 8008 @ 248 kPa (36 psi).

Spray Solutions

Testing was conducted using glyphosate (Roundup PowerMAX, EPA Reg. No. 524–549, Monsanto Company, St. Louis, MO) as the active ingredient. This potassium glyphosate contains 540 g acid equivalent glyphosate per liter and is sprayed at 1.6 l/hectare (22 oz/acre), yielding a 1.7 % v/v dilution in the spray tank and simulating spraying at 93.6 l/hectare (10 gal/acre). Four spray adjuvants (A, C, D, and F (as designated by Elsik [18]) (Table 1) were tested in water only and in water plus the glyphosate. The specific polymers were chosen so as to create a range of solutions with and without an active ingredient; therefore, the random designation of adjuvants described by Elsik [18] was maintained in these tests. To evaluate the potential drift reduction of each nozzle and/or adjuvant

TABLE 1—*Spray adjuvant classifications and rates used.*

Solution	Adjuvant Class	Rate
A	Synthetic polymer	0.5 % v/v
C	Synthetic polymer	0.27 % v/v
D	Natural polymer	0.081 % w/w
F	Oil	0.313 % v/v

combination, a solution of water plus a 90 % non-ionic surfactant at 0.25 % v/v was evaluated and used as a reference spray. Background on this spray solution and its validity as a reference spray is further described in the literature [6,7].

Droplet Sizing in U.S. Department of Agriculture Testing Facility

The U.S. Department of Agriculture Agricultural Research Service low-speed wind tunnel testing facility is located in College Station, TX. The tunnel has a cross-sectional area of 1.2 m × 1.2 m (4 ft × 4 ft) and an overall length of 14.6 m (48 ft). Air speed can be varied from 0.2 m/s to 5.4 m/s through the tunnel. The tunnel has a flow straightener to produce relatively laminar flow through the tunnel. Each nozzle tested was mounted 3 m upwind of the tunnel exit on a traverse system allowing the nozzle to move vertically over a 1 m length. Each nozzle was set to spray horizontally so that the entire spray plume was traversed through the laser beam. The nozzle assembly was plumbed to a pressurized stainless steel spray vessel containing the spray solution with a pressure regulator to control spray pressure. Spray was activated using a ball valve. For the glyphosate spray solutions, a power-assisted scrubber/filtration system was positioned at the end of the tunnel to capture the exiting spray droplets.

A Sympatec HELOS laser diffraction droplet sizing system (Sympatec Inc., Clausthal, Germany) was used to measure the droplet size downwind of the tested nozzles and solutions. The Helos system utilizes a 623 nm He-Ne laser and was fitted with a lens (denoted by the manufacturer by R7) with a dynamic size range of 0.5 μm to 3500 μm 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 and located 0.6 m (24 in.) downwind from the nozzle.

Droplet Size Statistics

Droplet size measurements included the volume median diameter ($D_{V0.5}$), $D_{V0.1}$, and $D_{V0.9}$. $D_{V0.5}$ is the droplet diameter (in micrometers) at which 50 % of the spray volume is constituted by droplets of a lesser diameter. $D_{V0.1}$ and $D_{V0.9}$ values describe the proportion of the spray volume (10 % and 90 %, respectively) comprising droplets of a specified size or less. The relative span (RS), which is calculated as the difference between the 10 % and 90 % volumes over the 50 % volume, was also determined. Tests were performed within the guidelines provided by ASTM E1260-05 [19]. The laser analytical software was programmed to output volume fractions of spray comprising droplets less than 30, 50, 80, 100, 105, 141, 150, and 200 μm. The effectiveness of a solution and nozzle combination in terms of drift reduction was computed by evaluating the percent reduction in the volume of droplets less than a specific droplet size relative to a reference spray. For example, if 20 % of the spray volume of the reference spray was made up of droplets less than 200 μm (percentage < 200 μm) and a particular adjuvant and nozzle combination produced 10 % of the spray in the percentage < 200 μm, the corresponding percent reduction would be 50 %.

Downwind Deposition Modeling Assessments

In order to translate the droplet size data to an estimate of drift, AGDISP [20] modeling software was employed. Because the testing was done in a low speed tunnel that simulates ground applications, the ground model portion of AGDISP was used. All treatment model evaluations were conducted using the same spray system setup, with only the spray droplet size distribution changing for each treatment. All default conditions were used with the following changes: (1) released height = 1 m, (2) no evaporation, (3) 0 swath offset, and (4) no canopy. Droplet size data were entered using a parametric distribution, which fits a droplet size distribution using the input $D_{V0.5}$ and RS. After model execution was completed, the total downwind deposition as a fraction of the total applied volume was recorded.

Statistical Methods

Statistical means and percent volumes for each of the nozzle and spray solution combinations were calculated using SAS 9.2 for Windows software [21]. Percent mean reductions of spray volume were separated using Duncan's Multiple-Range Test in Proc GLM with $\alpha = 0.05$. To determine which droplet size statistics were significant predictors of the downwind deposition, as predicted by the AGDISP ground model, PROC GLM (GLM stands for "general linear model") was used. Initially, all droplet size variables ($D_{V0.1}$, $D_{V0.5}$, RS, and percentages of droplets less than 30, 100, 105, and 141 μm in size) were included in the model. Successive testing removed non-significant variables until only those significant at the $\alpha = 0.05$ level were included. The significant variables ($D_{V0.5}$, RS, and percentages of droplets less than 30 and 141 μm in size) were then used to develop a regression model to predict downwind deposition using PROC REG (REG stands for "regression") and a least squares regression fit.

Results

The complexity of the atomization process was revealed, as each combination of a nozzle and an adjuvant with/without glyphosate had a slightly different trend (Tables 2 and 3). For adjuvant A, the droplet spectra, which encompasses all the categories of droplet size measurements, increased in size when the formulated glyphosate was added when the flat fan nozzles were used, but the droplet spectra decreased with the other three nozzles. The average droplet size spectra increased across nozzles when adjuvant C was added to glyphosate, except with

TABLE 2—*Means of droplet size statistics and percent volumes for sprays with and without glyphosate and solutions A and C (synthetic polymers).*

Solution A						Percentage of Spray Volume Comprising Droplets with Diameters Less than:				
Nozzle	Active Ingredient	$D_{V0.1}$, μm	$D_{V0.5}$, μm	$D_{V0.9}$, μm	RS	30 μm	100 μm	105 μm	141 μm	200 μm
AI11002	No	370	734	1045	0.9	0.2	0.4	0.4	0.8	1.9
	Yes	296	619	939	1.0	0.2	0.4	0.5	1.4	4.0
TJ11002	No	197	453	700	1.1	0.0	2.0	2.3	4.8	10.3
	Yes	162	359	606	1.2	0.0	3.1	3.7	9.3	22.7
FF8008	No	194	541	939	1.4	0.0	2.3	2.6	5.3	10.6
	Yes	233	716	1556	1.8	0.0	1.8	2.0	3.9	7.7
FF11006	No	200	491	821	1.3	0.0	2.0	2.3	4.7	10.0
	Yes	233	716	1556	1.8	0.0	1.8	2.0	3.9	7.7
FF11003	No	131	339	604	1.4	0.1	5.2	5.9	11.8	23.1
	Yes	154	434	1162	2.3	0.1	3.6	4.2	9.2	20.4
XR11002	No	124	307	570	1.5	0.2	5.7	6.6	13.4	26.6
	Yes	126	306	667	1.8	0.1	5.5	6.7	16.3	34.9

Solution C						Percentage of Spray Volume Comprising Droplets with Diameters Less than:				
Nozzle	Active Ingredient	$D_{V0.1}$, μm	$D_{V0.5}$, μm	$D_{V0.9}$, μm	RS	30 μm	100 μm	105 μm	141 μm	200 μm
AI11002	No	563	1051	1379	0.8	0.0	0.0	0.0	0.2	0.6
	Yes	659	1247	1678	0.8	0.0	0.0	0.0	0.0	0.2
TJ11002	No	301	699	1118	1.2	0.0	0.6	0.8	1.8	4.1
	Yes	391	894	1412	1.1	0.0	0.2	0.2	0.7	1.9
FF8008	No	352	896	1407	1.2	0.0	0.8	0.9	1.8	3.5
	Yes	267	891	1508	1.4	0.1	2.1	2.3	3.9	6.7
FF11006	No	308	704	1076	1.1	0.0	0.6	0.7	1.6	3.8
	Yes	362	907	1427	1.2	0.0	0.6	0.7	1.4	3.0
FF11003	No	182	481	865	1.4	0.0	2.3	2.7	5.7	12.2
	Yes	243	716	1451	1.7	0.1	1.5	1.7	3.5	7.1
XR11002	No	465	716	1245	1.1	0.0	1.2	1.4	3.0	6.7
	Yes	223	621	1367	1.8	0.0	1.4	1.6	3.6	8.1
ASABE F/M Reference Nozzle										
FF11003	Water + NIS	100.56	232.22	561.92	2.0	0.95	9.85	11.2	21.77	40.58

Note: NIS = Non-ionic surfactant.

the extended range (XR) 11002 nozzle. There was no consistent trend between glyphosate and non-glyphosate treatments with adjuvant D. Values in all droplet spectra categories decreased when glyphosate was combined with adjuvant F. The reference nozzle at the bottom of each of the tables is shown because these

TABLE 3—*Means of droplet size statistics and percent volumes for solutions D (natural polymer) and F (oil).*

Solution D						Percentage of Spray Volume Comprising Droplets with Diameters Less than:				
Nozzle	Active Ingredient	$D_{V0.1}$, μm	$D_{V0.5}$, μm	$D_{V0.9}$, μm	RS	30 μm	100 μm	105 μm	141 μm	200 μm
AI11002	No	325	678	1037	1.0	0.0	0.2	0.3	0.9	2.7
	Yes	286	582	952	1.1	0.0	0.6	0.7	1.6	4.2
TJ11002	No	186	430	685	1.2	0.0	2.2	2.6	5.4	11.7
	Yes	169	396	659	1.2	0.0	2.2	2.6	6.3	15.0
FF8008	No	170	424	738	1.3	0.0	2.4	2.8	6.4	14.3
	Yes	158	412	778	1.5	0.0	2.9	3.4	7.6	16.6
FF11006	No	149	349	652	1.4	0.0	3.3	3.8	8.7	19.7
	Yes	154	392	806	1.7	0.0	3.1	3.6	8.1	18.2
FF11003	No	113	256	483	1.4	0.4	7.0	8.2	17.3	34.6
	Yes	116	285	586	1.7	0.6	6.7	7.7	16.0	31.2
XR11002	No	95	204	408	1.5	0.7	11.4	13.2	26.6	48.5
	Yes	98	225	499	1.8	1.0	10.4	11.9	23.6	43.0
Solution F						Percentage of Spray Volume Comprising Droplets with Diameters Less than:				
Nozzle	Active Ingredient	$D_{V0.1}$, μm	$D_{V0.5}$, μm	$D_{V0.9}$, μm	RS	30 μm	100 μm	105 μm	141 μm	200 μm
AI11002	No	257	501	711	0.9	0.0	0.6	0.7	1.9	5.2
	Yes	228	462	704	1.0	0.0	1.1	1.2	2.9	7.2
TJ11002	No	130	247	406	1.1	0.0	4.2	5.0	12.8	32.5
	Yes	129	245	413	1.2	0.0	4.3	5.2	13.2	33.2
FF8008	No	237	469	734	1.1	0.0	0.7	0.8	2.2	6.3
	Yes	205	402	653	1.1	0.0	1.0	1.1	3.1	9.4
FF11006	No	193	376	592	1.1	0.0	1.1	1.3	3.7	11.1
	Yes	175	343	560	1.1	0.0	1.3	1.7	4.8	15.0
FF11003	No	136	255	400	1.0	0.0	3.7	4.5	11.2	29.2
	Yes	126	238	390	1.1	0.0	4.5	5.5	14.2	35.2
XR11002	No	112	201	329	1.1	0.0	6.2	7.8	21.5	49.5
	Yes	109	198	322	1.1	0.1	7.1	8.8	22.9	51.1
ASABE F/M Reference Nozzle										
FF11003	Water + NIS	100.56	232.22	561.92	2.0	0.95	9.85	11.2	21.77	40.58

Note: NIS = Non-ionic surfactant.

values are used to calculate the percent reductions for each nozzle, pesticide, and adjuvant combination (see Appendix, Tables 5–8).

Some consistent trends among adjuvant and nozzle type combinations exist. With the flat fan nozzles, droplet size increased when the glyphosate was added to the synthetic polymer solution. The changes or increases in $D_{V0.1}$ tended to be less significant, whereas changes in $D_{V0.9}$ tended to show proportionally larger increases than did changes in $D_{V0.5}$ and $D_{V0.1}$. This is reflected in the increased relative spans. This trend is similar, though not as severe, with the natural polymer (adjuvant D). However, when looking at the nozzle and oil concentrate interaction, the addition of the active product results in a uniform (i.e., values of all droplet size parameters decrease proportionately as reflected by few if any changes in the RS) decrease in droplet spectra (Table 3).

With the air induction (AI) and XR nozzles, the interaction of the synthetic polymers and the active ingredient resulted in a decrease in droplet size for adjuvant A and an increase for adjuvant C in droplet spectra. With the XR nozzle, adjuvant C also showed less uniform RS values, resulting from greater decreases in $D_{V0.1}$ and increases in $D_{V0.9}$.

Metrics for Discrimination of Different Potential Drift Reduction Technologies

The different nozzles were selected so as to reflect a range of droplet sizes and droplet spectra characteristics that were different not only in magnitude but also in the relative span of the droplet size distribution. This created a number of scenarios that could be compared in order to determine whether statistical separation between nozzles with known characteristics exists. For example, the nozzles were chosen based on past experience so as to create a range of different droplet sizes; therefore, if the selection metric would properly classify these nozzles, the method may then be applied to future DRTs for which the differences are not known.

Within each unique spray formulation (adjuvant only and adjuvant plus glyphosate), the shaded lines in Tables 5–8 (Appendix) represent the minimum droplet size for which the optimal statistical separation in treatments (in this case, nozzles) is present. For the purposes of this work, "optimal" is defined as the smallest droplet size fraction for which the most statistically separate groupings could be determined. In Tables 5–8, the mean percent reduction for each specified volume fraction for each nozzle–spray formulation combination from the corresponding reference nozzle volume fraction is shown, and statistical significance was tested by row. For adjuvant A, the minimum droplet size fraction that provided four degrees of means separation was 80 μm with glyphosate and 105 μm without glyphosate. For adjuvants C and D, the minimum diameters that met the optimal separation criteria were 80 and 100 μm, respectively, irrespective of the absence or presence of the formulated glyphosate. For adjuvant F, minimum diameters of 105 and 141 μm, with and without glyphosate, respectively, were the optimal sizes at which the separation criteria were met. Because the objective was to select a criteria metric that fit across all testing conditions and combinations, the percentage of spray volume comprising droplets less than 141 μm in size resulted in the most consistent separation of treatments.

Use of Droplet Size Characteristics to Predict Downwind Drift Levels

Table 4 shows the downwind deposition estimates generated from the measured droplet size data (Tables 2 and 3) using AGDISP [22,23]. The ground portion of the AGDISP model is a statistical model based on a database of measured data to which regression curves are fit. The downwind deposition is a prediction of the percentage of spray applied to a field that would be expected to be deposited downwind of the treated field. Although the deposition results are not based on a physical model, they do provide a relative comparison

TABLE 4—*Results from AGDISP modeling using measured droplet size data.*

		Downwind Deposition (Percentage of Total Applied), %	
Solution	Nozzle	Without Active	With Active
A	AI11002	0.00	0.01
	TJ11002	0.07	0.25
	FF8008	0.24	0.58
	FF11006	0.21	0.57
	FF11003	0.64	1.87
	XR11002	0.22	1.65
C	AI11002	0.00	0.00
	TJ11002	0.04	0.01
	FF8008	0.14	0.14
	FF11006	0.04	0.04
	FF11003	0.31	0.46
	XR11002	0.04	0.71
D	AI11002	0.01	0.05
	TJ11002	0.15	0.20
	FF8008	0.30	0.60
	FF11006	0.60	1.00
	FF11003	1.10	1.60
	XR11002	2.10	2.70
F	AI11002	0.00	0.04
	TJ11002	0.50	0.72
	FF8008	0.06	0.10
	FF11006	0.13	0.16
	FF11003	0.30	0.56
	XR11002	0.94	0.99
NIS only	FF11003	3.15	na

Note: NIS = Non-ionic surfactant.

between the treatments based on changes in droplet size characteristics. For example, it is clear that the addition of the active ingredient increased the downwind deposition of the spray for nearly all the nozzle and adjuvant combinations. Furthermore, these data can be used to evaluate the significant droplet size metrics that are good predictors of the downwind movement of sprays.

The impact of different droplet size related metrics on the drift potential was evaluated. Only RS ($P \leq 0.000$), the percent volume < 30 μm ($P \leq 0.000$), the percent volume < 141 μm ($P \leq 0.000$), and $D_{V0.1}$ ($P = 0.0236$) were predictors of the total downwind deposition. The percent volumes less than 80, 100, and 105 μm allow for significant means separations of the measured nozzles droplet sizes, but they do not serve as significant indicators of the drift potential compared to the percent spray volumes less than 30 and 141 μm.

Conclusions

The results of this work demonstrate the complex interactions that occur between spray nozzle and spray formulation and further demonstrate the complex relationship between spray adjuvants and active products. With the imminent launch of the EPA's DRT Program, there are potentially hundreds of spray adjuvants that could be presented as candidates for testing. This study illustrates that adjuvants potentially will not have behave the same with all nozzles, but the percentage of the spray volume made up of droplets less than 141 μm in size was a consistent metric for discriminating between different DRTs and as a predictor of downwind drift. $D_{V0.1}$ and percent volumes less than 80, 100, and 105 μm were also valuable metrics in discriminating among potential DRTs. The different types of adjuvants tend to alter the spray distribution in different ways. The oil concentrate in this study uniformly reduced the entire spray distribution, whereas in contrast the polymers tend to show greater increases in the portion of the spray made up of larger diameter droplets but less of an increase in the smallest diameter droplets of the spray, effectively widening the overall spray distribution. However, the DRT program and applicators should not dismiss the value of those products in spray solutions, and care must be taken to ensure that they can continue to be used in appropriate situations despite the fact that they could lead to increased drift.

The different distribution characteristics complicate comparisons among multiple treatments, especially where drift is concerned. The adjuvants that widen the distribution might reduce the volume of spray made up of droplets below some specified diameter, such as 100 or 200 μm, but they sometimes increase the finest portion of the spray. This makes measuring the relative effectiveness of a candidate DRT difficult if only one spray indicator, such as the percent volume less than 141 μm, is used with no regard for the remaining distribution characteristics. As the results of this study have shown, even though a particular single spray distribution indicator allows for easy separation and comparison of spray treatments, it does not necessarily serve as a valid indicator of the actual drift potential of the resulting spray and warrants further study and refinement. When evaluating different spray technologies, it is critical that the overall spray distribution be considered and used as a comparative measure of multiple technologies, particularly where active formulations and spray solution modifiers are concerned.

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APPENDIX

TABLE 5—*Percent reduction of spray volume fraction for solution A (synthetic polymer) with and without active ingredient for each of the nozzles tested.*

		Percent Reduction of Volume Fraction as Compared to Reference Nozzle					
Active Ingredient	Spray Volume Fraction Upper Boundary, μm	AI11002	TJ11002	FF8008	FF11006	FF11003	XR11002
No	30	76 A	100 A	97 A	100 A	92 A	82 A
	50	89 A	89 A	87 A	89 A	63 B	57 B
	80	96 A	81 B	79B	82 B	49 C	44 C
	100	96 A	80 B	77 B	80 B	47 C	42 C
	105	**96 A**	**80 B**	**77 B**	**80 B**	**48 C**	**41 D**
	141	96 A	78 B	76 B	79 B	46 C	38 D
	150	96 A	78 B	76 B	78 B	46 C	38 D
	200	95 A	75 B	74 B	75 B	43 C	35 D
Yes	30	84 A	98 A	98 A	97 A	93 A	91 A
	50	93 A	86 AB	87 AB	92 A	75 AB	73 B
	80	**96 A**	**73 BC**	**82 B**	**86 AB**	**64 CD**	**56 D**
	100	96 A	69 BC	82 AB	85 A	61 C	44 D
	105	95 A	67 BC	82 AB	85 A	60 C	40 D
	141	94 A	54 C	82 AB	84 AB	54 C	25 D
	150	94 A	56 BC	82 ABC	84 AB	53 C	23 D
	200	90 A	44 BC	81 AB	83 AB	44 BC	14 C

Note: Means within a given row followed by the same letter are not significantly different as determined by Duncan's Multiple-Range Test ($\alpha = 0.5$).

TABLE 6—*Percent reduction of spray volume fraction for solution C (synthetic polymer) with and without active ingredient for each of the nozzles tested.*

		Percent Reduction of Volume Fraction as Compared to Reference Nozzle					
Active Ingredient	Spray Volume Fraction Upper Boundary, μm	AI11002	TJ11002	FF8008	FF11006	FF11003	XR11002
No	30	100 A	100 A	97 B	99 AB	97 AB	98 AB
	50	100 A	100 A	95 A	100 A	83 B	93 A
	80	100 A	95 A	92 A	95 A	77 B	89 A
	100	**100 A**	**94 A**	**92 A**	**94 A**	**76 B**	**88 AB**
	105	100 A	93 A	92 A	94 A	76 B	88 AB
	141	100 A	92 A	92 A	93 A	74 B	86 AB
	150	99 A	92 A	92 A	93 A	74 B	86 AB
	200	98 A	90 A	91 A	91 A	70 B	84 AB
Yes	30	100 A	100 A	87 D	97 B	94 C	96 B
	50	100 A	100 A	74 B	98 AB	88 C	95 B
	80	100 A	99 A	76 E	94 B	85 D	88 C
	100	**100 A**	**98 B**	**79 E**	**94 C**	**85 D**	**86 D**
	105	100 A	98 B	79 E	94 C	85 D	86 D
	141	100 A	97 B	82 E	94 C	84 D	83 D
	150	100 A	97 B	82 E	94 C	84 D	83 DE
	200	100 A	95 B	83 D	93 C	83 D	80 E

Note: Means within a given row followed by the same letter are not significantly different as determined by Duncan's Multiple-Range Test ($\alpha = 0.5$).

TABLE 7—*Percent reduction of spray volume fraction for solution D (natural polymer) with and without active ingredient for each of the nozzles tested.*

		Percent Reduction of Volume Fraction as Compared to Reference Nozzle					
Active Ingredient	Spray Volume Fraction Upper Boundary, μm	AI11002	TJ11002	FF8008	FF11006	FF11003	XR11002
No	30	100 A	98 A	96 A	97 A	60 AB	30 B
	50	100 A	87 A	89 A	80 A	45 B	9 C
	80	**99 A**	**79 B**	**79 B**	**70 C**	**34 D**	**−8 E**
	100	98 A	78 B	76 B	67 C	29 D	−16 E
	105	98 A	77 B	75 B	66 C	27 D	−17 E
	141	96 A	75 B	70 C	60 D	21 E	−22 F
	150	95 A	75 B	70 C	60 D	20 E	−23 F
	200	94 A	71 B	65 C	51 D	15 E	−19 F
Yes	30	100 A	100 A	100 A	99 A	33 B	−2 C
	50	100 A	92 AB	83 B	81 B	39 C	2 D
	80	**95 A**	**81 B**	**74 C**	**72 C**	**36 D**	**−2 E**
	100	94 A	78 B	71 C	70 C	32 D	−6 E
	105	94 A	77 B	70 C	68 C	31 D	−6 E
	141	93 A	71 B	65 C	63 D	26 E	−8 F
	150	92 A	70 B	64 C	62 D	26 E	−8 F
	200	90 A	63 B	60 C	55 D	23 E	−6 F

Note: Means within a given row followed by the same letter are not significantly different as determined by Duncan's Multiple-Range Test ($\alpha = 0.5$).

TABLE 8—*Percent reduction of spray volume fraction for solution F (oil) with and without active ingredient for each of the nozzles tested.*

		Percent Reduction of Volume Fraction as Compared to Reference Nozzle					
Active Ingredient	Spray Volume Fraction Upper Boundary, μm	AI11002	TJ11002	FF8008	FF11006	FF11003	XR11002
No	30	100 A	100 A	100 A	100 A	100 A	98 A
	50	100 A	80 B	100 A	99 A	82 B	84 B
	80	95 A	64 B	95 A	92 A	67 B	60 B
	100	94 A	57 B	93 A	90 A	62 B	38 C
	105	**94 A**	**55 D**	**92 A**	**88 B**	**61 C**	**31 E**
	141	91 A	41 D	90 A	83 B	49 C	1 E
	150	91 A	39 D	89 A	82 B	47 C	−3 E
	200	88 A	20 D	85 A	73 B	28 C	−22 E
Yes	30	100 A	100 A	100 A	100 A	98 A	89 B
	50	94 AB	81 ABC	98 A	97 A	78 BC	73 C
	80	90 A	64 B	92 A	89 A	63 B	49 B
	100	90 A	57 B	90 A	86 A	54 B	28 C
	105	89 A	54 B	90 A	85 A	51 B	22 C
	141	**87 A**	**39 C**	**86 A**	**78 B**	**35 C**	**−5 D**
	150	87 A	37 C	85 A	76 B	32 C	−9 D
	200	82 A	18 D	77 B	63 C	13 E	−26 F

Note: Means within a given row followed by the same letter are not significantly different as determined by Duncan's Multiple-Range Test ($\alpha = 0.5$).

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