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Spray Drift from Dicamba and Glyphosate Applications in a Wind Tunnel

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With the recent introductions of glyphosate- and dicamba-tolerant crops, such as soybean and cotton, there will be an increase in POST-applied tank-mixtures of these two herbicides. However, few studies have been conducted to evaluate drift from dicamba applications. This study aimed to evaluate the effects of dicamba with and without glyphosate sprayed through standard and air induction flat-fan nozzles on droplet spectrum and drift potential in a low-speed wind tunnel. Two standard (XR and TT) and two air induction (AIXR and TTI) 110015 nozzles were used. The applications were made at 276 kPa pressure in a 2.2 m s^{-1} wind speed. Herbicide treatments evaluated included dicamba alone at 560 g ae ha^{-1} and dicamba + glyphosate at 560 + 1,260 g ae ha^{-1}. The droplet spectrum was measured using a laser diffraction system. Artificial targets were used as drift collectors, positioned in a wind tunnel from 2 to 12 m downwind from the nozzle. Drift potential was determined using a fluorescent tracer added to solutions, quantified by fluorimetry. Dicamba droplet spectrum and drift depended on the association between herbicide solution and nozzle type. Dicamba alone produced coarser droplets than dicamba + glyphosate when sprayed through air induction nozzles. Drift decreased exponentially as downwind distance increased and it was reduced using air induction nozzles for both herbicide solutions.
Nomenclature: Dicamba; glyphosate; cotton, *Gossypium hirsutum* L.; soybean, *Glycine max* (L.) Merr.
Key words: Application technology, environmental contamination, herbicide, tank-mixture.

Herbicide application is an important activity in crop protection systems. It provides effective and economical weed management and is the primary method of weed control in agronomic crops (Heap 2014). The value of the worldwide herbicide market grew by 39% between 2002 and 2011 (Gianessi 2013), and in the United States alone, the use of herbicides increased 130% between 2002 and 2010 (Osteen and Fernandez-Cornejo 2013).

Recent introductions of soybean and cotton cultivars genetically modified with tolerance to the synthetic auxin herbicide dicamba will allow this compound to be used with greater flexibility. However, it may expose susceptible soybean and cotton cultivars to nontarget herbicide drift. Previous research has determined that soybean and cotton are highly sensitive to low doses of dicamba (Egan et al. 2014).

Spray drift is defined as the quantity of plant protection product carried out of the sprayed (treated) area by air currents during an application. It persists as one of the major problems in modern row-crop production agriculture (Nuyttens et al. 2011; Tsai et al. 2005). One way of reducing drift has been the use of air induction nozzles. During the past ten years, this type of nozzle has been recommended by many nozzle manufacturers and researchers to reduce spray drift, because it produces larger droplets and a smaller portion of drift-prone droplets than do standard hydraulic nozzles (Guler et al. 2007).

Different techniques have been used to study spray drift. Because weather conditions cannot be controlled, it is very difficult to perform spray drift measurements in the field with a high degree of repeatability (Miller and Butler Ellis 2000). The controlled conditions found in wind tunnels make

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them well suited for studies where relative drift values are required (Derksen et al. 1999; Hislop et al. 1993; Sidahmed et al. 2004). This information concerning wind tunnels has been used to classify equipment provided to the end user, so that appropriate spray equipment could be selected to minimize the risk of spray drift (Parkin et al. 1994).

Much research has been conducted to evaluate glyphosate drift (Deeds et al. 2006; Ellis and Griffin 2002; Koger et al. 2005; Schrübbers et al. 2014), but few studies have been developed to evaluate the drift of dicamba or dicamba co-applied with glyphosate. There is a great potential for use of these herbicides due to the development of crops that are resistant to them.

The objectives of this study were to evaluate the effects of dicamba sprayed through standard and air-induction flat-fan nozzles, with and without glyphosate, on droplet spectrum and drift in a low-speed wind tunnel.

Materials and Methods

Experiments were conducted at the Pesticide Application Technology Laboratory at the West Central Research and Extension Center of the University of Nebraska–Lincoln in North Platte, NE in 2015. The experimental design was a split plot arranged in a completely random design with four replications for all experiments. Main plot, subplot, and sub-subplot consisted of two herbicide treatments, four nozzle types, and seven downwind distances from the nozzle (2, 3, 4, 5, 6, 7, or 12 m), which were points where data were collected.

The two herbicide treatments evaluated were dicamba (Clarity®, BASF Corporation, Research Triangle Park, NC) alone and dicamba plus glyphosate (Roundup PowerMax®, Monsanto Company, St. Louis, MO) at 560 g ae ha^{-1} and 560+1,260 g ae ha^{-1}, respectively, applied at 200 L ha^{-1}. In addition, a 1,3,6,8-pyrenetetrasulfonic acid tetrasodium salt (PTSA) fluorescent tracer (Spectra Colors Corp., Kearny, NJ) was added to the solutions at 1 g L^{-1} to be detected by fluorimetry afterwards (Hoffmann et al. 2014). Nozzle types included Extended Range (XR), Turbo TeeJet® (TT), Air-Induction Extended Range (AIXR), and Turbo TeeJet® Induction (TTI) (Spraying Systems Co., Wheaton, IL). All nozzles were 110015 flat-fan nozzles evaluated at a pressure of 276 kPa. A digital manometer was fixed next to each nozzle to ensure that the pressure was the same for all nozzles. Each replication consisted of a continuous 10-second application, controlled by a digital auto shut-off timer switch (Intermatic Inc., EI 400C, Spring Grove, IL). Data for all distances were collected at the same time from a single spray, and each set was considered as one replication.

Droplet Spectrum. The droplet spectrum for each spray and nozzle combination was evaluated at 276 kPa pressure and analyzed using a Sympatec HELOS-VARIO K/R laser diffraction droplet sizing system (Sympatec Inc., Clausthal, Germany) set up with an R7 lens with a dynamic size range of 9 to 3700 µm. The distance from the nozzle tip to the laser was 0.3 m. This system was integrated into the wind tunnel, and the wind speed was maintained at 6.7 m s^{-1} during data acquisition following methodology proposed by Fritz et al. (2014). A minimum of three replicated measurements were made for each treatment, with each replication consisting of a complete vertical traverse of the spray plume. Spray parameters of interest were $D_{v0.1}$, $D_{v0.5}$, and $D_{v0.9}$, the droplet diameters (µm) for which 10%, 50%, and 90% of the total spray volume is contained in droplets of equal or lesser size, respectively. Relative span (RS) and volume percentage of droplets smaller than 100 µm (V_{100}) were also recorded. Relative span is a dimensionless parameter indicative of uniformity of droplet size distribution, calculated using Equation 1, while V_{100} is an indicator of the potential risk of drift.

$$RS = (D_{v0.9} - D_{v0.1})/D_{v0.5} \qquad [1]$$

Determination of Drift Potential. All treatments were applied in a low-speed wind tunnel with a working section 1.2 m wide, 1.2 m high, and 15 m long. This wind tunnel uses an axial fan (Hartzell Inc., Piqua, OH) to generate air flow and move air from the fan into an expansion chamber located in front of the tunnel. The wind speed was fixed at 2.2 m s^{-1} (8 km h^{-1}). Environmental conditions during applications were kept at 20 C (±2 C) and 60% to 70% relative humidity.

This study was conducted twice, separated temporally to represent two experimental runs. All conditions, such as treatments, wind tunnel set up, and procedures, were the same for both runs. Drift was determined according to the ISO/DIS 22856-1 Standard (ISO 22856 2008), with a few modifications. Prior to each application, artificial

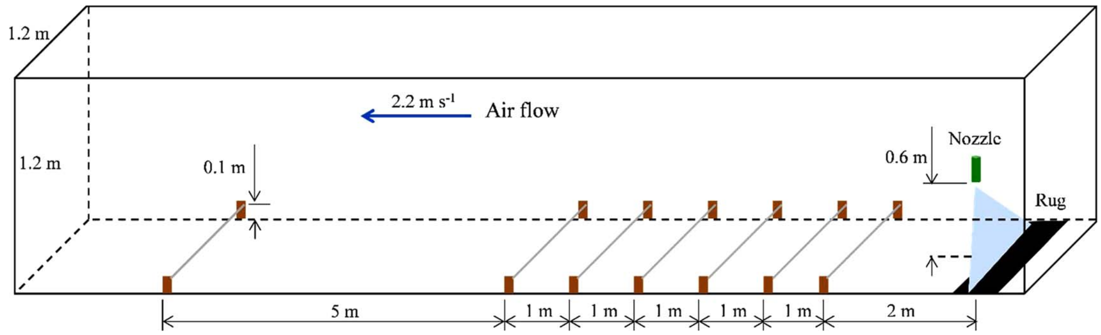

Figure 1. Schematic drawing detailing the positions of nozzle and drift collectors in a low-speed wind tunnel.

collectors composed of colorless, round strings of 2-mm diameter and 1.0-m length (Blount Inc., Magnum Gatorline™, Portland, OR) were positioned at each distance, parallel to the tunnel floor and perpendicular to its length.

The nozzle was placed 0.6 m above the tunnel floor in the longitudinal center of the wind tunnel. Collectors were placed 0.1 m above the tunnel floor. A 1.2 m by 0.5 m rug with polyethylene blades 1 cm tall (GrassWorx LLC., St. Louis, MO) was positioned on the sprayed area to absorb droplets, simulating a leaf surface (Figure 1). After the application was performed, the strings were collected and placed individually into prelabeled plastic bags and then placed in a dark container to prevent photodegradation of the tracer. Samples were kept in the dark until fluorimetric analysis could be conducted.

In the laboratory, a total of 50 mL of 10:90 (v:v) isopropyl alcohol:distilled water solution was added to each plastic bag using a bottle top dispenser (LabSciences Inc., 60000-BTR, Reno, NV). Samples were then swirled and shaken to release the fluorescent material. After the tracer was suspended in the liquid, a 1.5 mL aliquot was drawn from each sample bag to fill a glass cuvette. The cuvette was placed in a PTSA module inside a fluorimeter (Turner Designs, Trilogy 7200.000, Sunnyvale, CA) that uses ultraviolet light to collect fluorescence data. The fluorimeter was initially calibrated in relative fluorescence units (RFUs), and the data was then converted into milligrams per liter using a calibration curve for the tracer. Finally, the percentage drift for each distance was calculated using Equations 2 and 3:

$$\beta_{dep} = \frac{(\rho_{sample} - \rho_{blank}) \times f_{flow} \times f_{conc} \times V_{dil}}{\rho_{spray}}, \text{ and} \quad [2]$$

$$\%\,\text{Drift} = \frac{\beta_{dep} \times C_{length}}{C_{diameter} \times A_{time} \times R_{flow}} \times 6, \quad [3]$$

where β_{dep} is the spray drift deposited (mL), ρ_{sample} is the fluorimeter reading of the sample (mg L^{-1}), ρ_{blank} is the fluorimeter reading of the blanks (collector + extractor solution) (mg L^{-1}), ρ_{spray} is the concentration of the solution (g L^{-1}), f_{flow} is an adjustment factor for flow rate (dimensionless), f_{conc} is an adjustment factor for tracer concentration from spray (dimensionless), V_{dil} is the volume of dilution liquid used to extract the tracer from the collector (L), C_{length} is the drift collector length (mm), $C_{diameter}$ is the drift collector diameter (mm), A_{time} is the application time (s), and R_{flow} is the flow rate of the nozzle (L min^{-1}).

Statistical Analysis. Normality of residuals and homogeneity of variance of droplet spectrum data were analyzed using Shapiro Wilk and Levene's tests, respectively. If necessary, $D_{v0.1}$, $D_{v0.5}$, $D_{v0.9}$, and RS data were transformed by $(x + 0.5)^{0.5}$ and V_{100} data were transformed by arc sine $[(x/100)^{0.5}]$. Volume percentage of droplets smaller than 100 µm (V_{100}) and RS data were subjected to analysis of variance using Sisvar Statistical Software, version 5.6 (Ferreira 2011), and averages were compared using Tukey's test at $\alpha = 0.05$. A confidence interval of 95% was used for $D_{v0.1}$, $D_{v0.5}$, and $D_{v0.9}$ comparisons using SigmaPlot, version 11.0 (Systat Software Inc., Chicago, IL). This analysis was performed to produce a graphical representation of cumulative volume fraction.

For analysis of drift potential, Kolmogorov-Smirnov and Levene's tests were applied to analyze normality of residuals and homogeneity of variance,

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respectively, using SPSS Statistical Software, version 17.0 (SPSS Inc., Chicago, IL). In cases where the assumptions were significant at $\alpha = 0.01$, the data were transformed by arc sine $[(x/100)^{0.5}]$ and subjected to a new analysis. Data (original and transformed) were subjected to analysis of variance (ANOVA) using Sisvar Statistical Software, version 5.6 (Ferreira 2011). When significant differences were observed, herbicide solutions and nozzles were compared to each other for each distance using Tukey's multiple comparison test. Regression analysis was performed for all distances at $\alpha = 0.05$.

Results and Discussion

Normality of residuals and homogenity of variance assumptions from the original V_{100} and drift data were not reached at $\alpha = 0.01$; therefore, data were transformed for all comparisons between treatments to improve the analysis. Data transformation was applicable to both runs. For the other variables, ANOVA was conducted using the original data.

Droplet Spectrum. Droplet size spectrum was significantly affected by spray composition for AIXR and TTI nozzles (Figure 2), producing smaller droplets when dicamba was combined with glyphosate. For this solution, there was a reduction in $D_{v0.5}$ values (also known as volumetric median diameter) of approximately 8.9% and 6.8% for TTI (absolute value 704 µm) and AIXR (absolute value 347 µm), respectively.

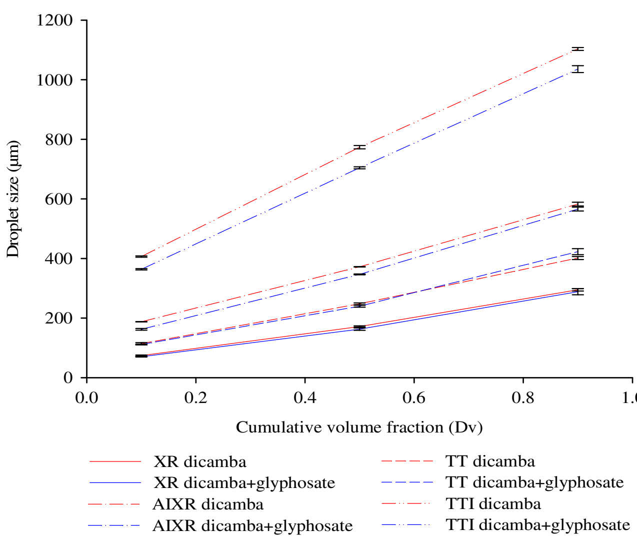

Figure 2. Droplet diameter for the cumulative volume fraction ($D_{v0.1}$, $D_{v0.5}$, $D_{v0.9}$) of two herbicide solutions sprayed with four different nozzle types. $D_{v0.1}$, $D_{v0.5}$, and $D_{v0.9}$ are the droplet diameters (µm) for which 10%, 50%, and 90% of the total spray volume is contained in droplets of equal or lesser size, respectively.

Meyer et al. (2015) evaluated the droplet spectrum of dicamba, glyphosate, and glufosinate sprayed through three nozzles at 141 L ha^{-1} carrier volume and 276 kPa pressure. They did not observed differences in $D_{v0.5}$ between dicamba and dicamba plus glyphosate for TT, AIXR, or TTI nozzles. However, it is important to recognize that the authors used a different dicamba formulation and lower carrier volume, which may explain differences in results.

When sprayed through extended range nozzles (XR and AIXR), the droplet spectrum produced by dicamba alone had a lower V_{100} than did the spectrum produced by dicamba plus glyphosate (Figure 3). In contrast, when sprayed through a TTI nozzle, dicamba alone produced a higher V_{100} (0.33%) than did dicamba plus glyphosate (0.02%). The highest and lowest potential risks of drift were observed for XR and TTI nozzles, respectively, for both herbicide solutions. The XR nozzle produced much smaller droplets than did the TTI nozzle, whose droplets were on average four times larger than those produced by XR, which means that the V_{100} increased as the droplet size decreased.

Dicamba plus glyphosate generated a more heterogeneous droplet spectrum than did dicamba alone for all nozzles tested. The greater RS of dicamba plus glyphosate compared to that of dicamba alone (Figure 4) indicates that the inclusion

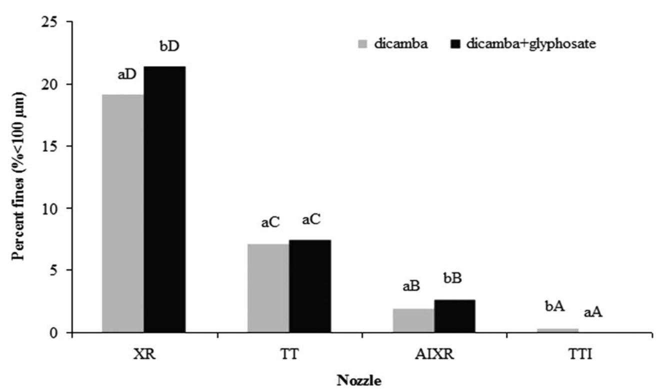

Figure 3. Volume percentage of droplets smaller than 100 µm produced by two herbicide solutions sprayed with four different nozzle types. Comparisons between solutions for each nozzle type are shown with lowercase letters, and comparisons between nozzles for each solution are shown with uppercase letters. $F_{nozzle \times solution} = 27.7^{**}$, significant at $\alpha = 0.01$.

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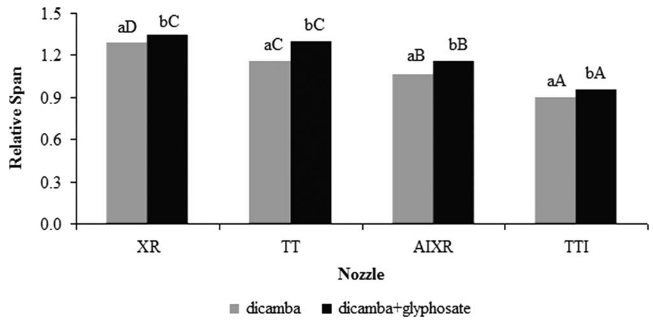

Figure 4. Relative span of droplet sizes produced by two herbicide solutions sprayed with four different nozzle types. Comparisons between solutions for each nozzle type are shown with lowercase letters, and comparisons between nozzles for each solution are shown with uppercase letters. $F_{nozzle \times solution} = 7.3^{**}$, significant at $\alpha = 0.01$.

of glyphosate widened the droplet spectrum of dicamba. Similarly, V_{100} values from XR and AIXR nozzles were higher for dicamba plus glyphosate than they were for dicamba alone. A more heterogeneous droplet spectrum tends to produce a higher percentage of fine droplets. However, this can vary with nozzle type, as was observed for the TTI nozzle, which produced a lower V_{100} and greater RS with dicamba plus glyphosate than it did with dicamba alone. It is well known that different nozzle types respond differently to changes in fluid physical properties (Butler Ellis et al. 2001), and flat-fan and air induction nozzles both produce a wide spectrum of droplet sizes (Matthews 2000).

When comparing nozzles within each solution, greater RSs were associated with smaller droplet sizes. The TTI nozzle produced the most homogeneous droplets, followed by the AIXR, TT, and XR nozzles. Similar results were observed for V_{100}, meaning this variable may be correlated with RS as well.

Determination of Drift Potential. In run 1, the highest percentage of drift was observed for the XR nozzle at all distances and with both solutions, except at 12 m for dicamba alone, where drift from this nozzle was similar to drift produced by the TT nozzle (Table 1). The highest and lowest percentages of drift were 65.9% at 2 m and 0.1% at 12 m, produced by XR and TTI nozzles, respectively. These results were expected due to differences in droplet size between the two nozzles. Butler Ellis et al. (2002) evaluated spray characteristics and drift performance of air induction nozzles and concluded that spray drift was largely influenced by droplet size, with larger $D_{v0.5}$ resulting in less drift.

Dicamba plus glyphosate resulted in less drift than did dicamba alone when sprayed through XR and AIXR nozzles, whereas the opposite was observed for the TTI nozzle. Miller and Butler Ellis (2000) reported that physicochemical properties of solutions, including those conferred by adjuvants, produce inconsistent results between nozzles, especially for air induction nozzles. They found many cases of interactions between nozzle type and spray solution similar to those observed in this study.

Several studies have shown that droplets smaller than 100 μm are more prone to drift (Antuniassi et al. 2014; Murphy et al. 2000; Nuyttens et al. 2007; Wolf 2000). However, greater drift is not necessarily observed in cases with higher volume percentage of fine droplets. In order to accurately predict drift based on droplet size, it is important to consider the full droplet spectrum. Even though the TTI nozzle produced a higher V_{100} with dicamba alone than it did with dicamba plus glyphosate, larger droplets were produced, and in turn, it had a lower percentage of drift than did dicamba plus glyphosate.

Unlike the results of run 1, in run 2 dicamba alone and dicamba plus glyphosate sprayed through the TT, AIXR, and TTI nozzles produced a similar percentage of drift (Table 1). At 12 m, TT and AIXR nozzles generated similar drift for dicamba alone. However, for dicamba plus glyphosate, AIXR produced less drift than did TT, and no differences were observed between the two standard nozzles or between the two air induction nozzles. The TTI nozzle produced approximately 95% less drift than did the XR nozzle.

This shows that the use of air induction nozzles is an excellent option for reducing environmental contamination. Stainier et al. (2006) evaluated potential drift of two phenmedipham formulations associated with different adjuvants using standard and air induction flat-fan nozzles, and found that the air induction nozzles reduced the potential drift by 83% compared to standard nozzles. Taylor et al. (1999) also reported reductions in fallout deposits using air induction nozzles that varied from 89% to 91% depending on the orifice size of the nozzle. However, the use of air induction nozzles cannot be broadly recommended for all pesticide applications because of herbicide efficacy considerations. Some

Table 1. Drift percentage from herbicide applications using four different nozzle types in a wind tunnel, in two experimental runs. Measurements were taken from 2 to 12 m downwind.[a]

Distance	Herbicide solution	Nozzle (Run 1)[b]				Nozzle (Run 2)[c]			
m		XR[d]	TT	AIXR	TTI	XR	TT	AIXR	TTI
		%							
2	Dicamba	65.9 dB	40.1 cA	15.6 bB	4.5 aA	56.1 dB	35.8 cA	14.7 bA	3.3 aA
	Dicamba + glyphosate	56.3 dA	40.9 cA	14.2 bA	6.9 aB	49.5 dA	37.6 cA	13.2 bA	5.4 aB
3	Dicamba	40.8 dB	23.3 cA	8.1 bB	1.8 aA	31.7 dB	18.8 cA	6.7 bA	1.2 aA
	Dicamba + glyphosate	33.5 dA	23.5 cA	6.9 bA	2.9 aB	28.0 dA	20.4 cA	5.8 bA	2.2 aA
4	Dicamba	25.3 dB	14.0 cA	4.8 bB	0.8 aA	19.3 dB	10.7 cA	3.7 bA	0.8 aA
	Dicamba + glyphosate	20.5 dA	13.4 cA	3.7 bA	1.7 aB	17.1 dA	11.7 cA	3.1 bA	1.2 aA
5	Dicamba	16.6 dB	9.6 cB	3.6 bB	0.5 aA	13.0 dB	6.6 cA	2.4 bA	0.5 aA
	Dicamba + glyphosate	13.1 dA	7.8 cA	2.3 bA	1.1 aB	10.9 dA	7.3 cA	1.9 bA	0.8 aA
6	Dicamba	12.1 dB	6.9 cB	2.9 bB	0.3 aA	9.3 dB	4.3 cA	1.5 bA	0.4 aA
	Dicamba + glyphosate	8.6 dA	5.3 cA	1.7 bA	0.9 aB	7.6 dA	4.9 cA	1.3 bA	0.4 aA
7	Dicamba	8.9 dB	5.3 cB	2.6 bB	0.2 aA	6.5 dB	3.3 cA	1.2 bA	0.4 aA
	Dicamba + glyphosate	6.2 dA	3.5 cA	1.4 bA	0.8 aB	5.0 cA	3.4 bA	1.0 aA	0.6 aA
12	Dicamba	3.0 cB	2.7 cB	1.9 bB	0.1 aA	2.0 cA	0.9 bA	0.4 bA	0.1 aA
	Dicamba + glyphosate	1.9 cA	1.1 bA	0.8 abA	0.6 aB	1.7 bA	0.9 bA	0.3 aA	0.1 aA

[a] Averages followed by the same lower case letter in each row or upper case letter in each column, within each distance and run, do not differ using Tukey's test at $\alpha = 0.05$.

[b] Original data: $F_{Levene} = 3.860$**; K-S = 0.191**. Transformed data: $F_{Levene} = 2.851$**; K-S =0.108**. $F_{sol \times noz \times dist}$: 9.8**. F_{Levene} and Kolmogorov-Smirnov's (K-S) test values of the F statistics. Data transformed by arc sine $[(\times/100)^{0.5}]$. $F_{sol \times noz \times dist}$: Calculated F-value for interaction between herbicide solution, nozzle, and distance. **Significant at $\alpha = 0.01$

[c] Original data: $F_{Levene} = 5.735$**; K-S = 0.243**. Transformed data: $F_{Levene} = 3.829$**; K-S = 0.156**. $F_{sol \times noz \times dist}$: 2.9**. F_{Levene} and Kolmogorov-Smirnov's (K-S) test values of the F statistics. Data transformed by arc sine $[(\times/100)^{0.5}]$. $F_{sol \times noz \times dist}$: Calculated F-value for interaction between herbicide solution, nozzle, and distance. **Significant at $\alpha = 0.01$.

[d] Teejet Technologies, Spraying Systems Co., Wheaton, IL 62703.

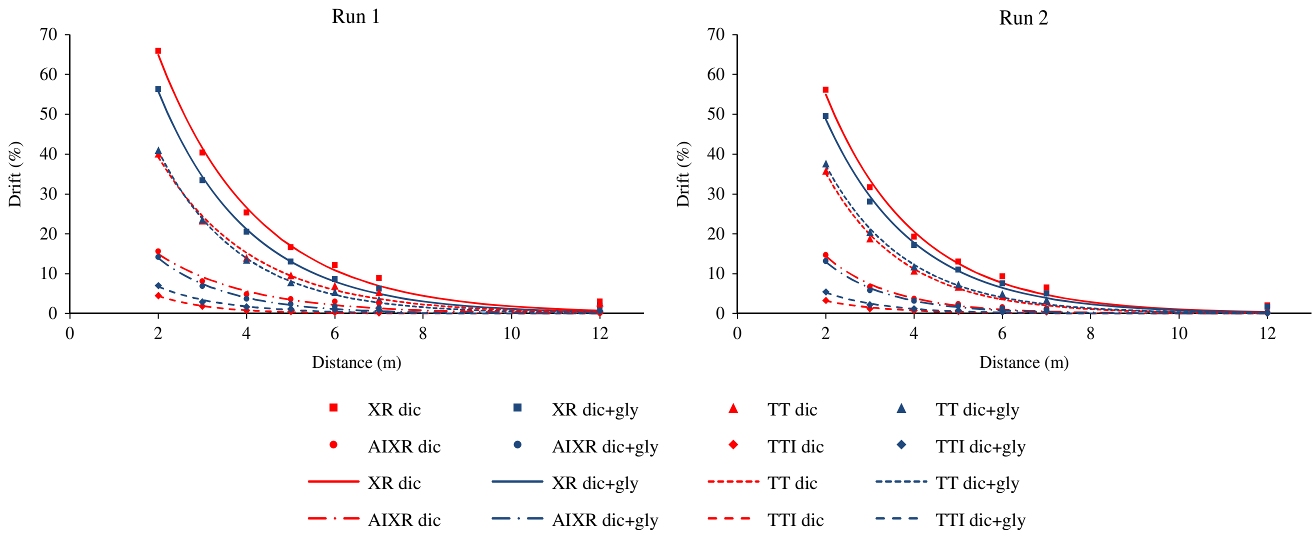

Figure 5. Percent drift in dicamba (dic) and dicamba plus glyphosate (dic + gly) applications made using four different nozzle types in two experimental runs.

herbicides have shown increased efficacy when sprayed using an air induction nozzle, while for others the opposite is true. According to Meyer et al. (2015), efficacy of the application is not the only factor that will determine nozzle selection. When spraying dicamba, nozzle selection requirements will primarily be based on the ability to minimize drift (have a high $D_{v0.5}$ and low V_{100}).

Figure 5 and Table 2 represent regressions for each combination of herbicide solution and nozzle. All functions were adjusted by two-parameter exponential equations, with R-squares over 94% in run 1 and over 96% in run 2. Thus, for all studied conditions, drift decreased exponentially as downwind distance from the nozzle increased. Drift distributions have been based on a potential function by Alves and Cunha (2014), Ganzelmeier et al. (1995), and Meli et al. (2003); on a four-parameter exponential decay function by Holterman and van de Zande (2003); and on a logistic function by Koger et al. (2005). One type of function cannot be generalized for all conditions, as seen in the drift data shown here, which are variable and dependent on the physicochemical properties of the spray solution, nozzle type

Table 2. Functions, R^2, and F_c generated by regression analysis of data on two different herbicide solutions sprayed through four nozzle types in two experimental runs.

		Run 1			Run 2		
Solution[a]	Nozzle[b]	Function ($\hat{y}$ =)	R^2	F_c[c]	Function ($\hat{y}$ =)	R^2	F_c
			%			%	
Dic	XR	$158.4830e^{-0.4461x}$	99.5	5,116.2	$146.9621e^{-0.4918x}$	99.3	1,716.5**
	TT	$101.1994e^{-0.4732x}$	98.8	1,827.8	$111.1452e^{-0.5741x}$	99.5	733.1**
	AIXR	$39.4825e^{-0.4856x}$	94.5	238.0	$53.8996e^{-0.6609x}$	98.8	121.0**
	TTI	$23.6336e^{-0.8369x}$	99.6	26.3	$13.3743e^{-0.7188x}$	96.4	5.7**
Dic + gly	XR	$146.6673e^{-0.4838x}$	99.7	3,899.7	$133.9633e^{-0.5051x}$	99.6	1,374.8**
	TT	$119.9544e^{-0.5394x}$	99.8	2,148.6	$112.4245e^{-0.5539x}$	99.6	812.0**
	AIXR	$48.2039e^{-0.6226x}$	98.4	236.2	$52.5060e^{-0.7002x}$	98.9	99.2**
	TTI	$25.6242e^{-0.6673x}$	95.3	51.9	$23.5360e^{-0.7463x}$	98.2	16.4**

[a] Abbreviations: Dic, dicamba; gly, glyphosate.
[b] Teejet Technologies, Spraying Systems Co., Wheaton, IL 62703.
[c] F_c: Calculated F-value.
** Significant at $\alpha = 0.01$.

and orifice size, wind speed, and location of the study (wind tunnel, bench or field).

As mentioned by Gil and Sinfort (2005), drift models cannot substitute for field determination, but rather are a powerful complement that aids understanding of the phenomenon. Indeed, field studies should be conducted to ensure that the results from this study apply in the field. It is also important to mention that differing results between the two runs may be explained by the small number of replications. Four replications are often considered an acceptable number for experiments with many treatments. However, because drift studies produce variable results, they should involve a larger number of replications whenever possible.

In conclusion, dicamba droplet spectrum and drift depend on the association between herbicide solution and nozzle type. These factors should be taken into consideration when making herbicide application decisions in order to reduce product losses and minimize environmental contamination. Dicamba alone produced coarser droplets than did dicamba plus glyphosate when sprayed through air induction nozzles. In addition, dicamba plus glyphosate generated a higher volume percentage of droplets smaller than 100 µm than did dicamba alone when sprayed through extended range nozzles. Lastly, for dicamba alone a more homogeneous droplet spectrum was observed as droplet size increased.

Drift decreased exponentially as downwind distance increased and was reduced by the use of air induction nozzles for both herbicide solutions. When sprayed through AIXR nozzles, Dicamba alone produced greater drift than did dicamba plus glyphosate, whereas the opposite was observed for TTI nozzles in run 1. However, in run 2, both herbicide solutions produced similar drift when sprayed through the same nozzle.

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