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Reducing Herbicide Particle Drift: Effect of Hooded Sprayer and Spray Quality

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Research Article

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Abstract

A field study was conducted in 2015 and 2016 to compare particle drift of glyphosate using a fluorescent tracer dye applied with hooded and open sprayers at four spray qualities (Fine [F], Medium [M], Very-Coarse [VC], and Ultra-Coarse [UC]). F and M spray qualities exhibited up to 86% and 56% less drift, respectively, out to 31 m downwind with the hooded sprayer than with the open sprayer. Conversely, VC and UC spray qualities were not affected by sprayer type out to 31 m downwind. From 43 to 104 m downwind, hooded sprayer applications exhibited approximately 50% less drift than open sprayer applications, regardless of spray quality. From 43 to 89 m downwind, F spray qualities, regardless of sprayer type, exhibited higher drift than all other spray qualities. These data indicate that hooded sprayers considerably reduce drift of all spray qualities at short distances downwind. Additionally, at longer distances downwind, both larger spray qualities and sprayer hoods reduced drift independently.

Introduction

Transgenic crops engineered to have with herbicide resistance have revolutionized the agricultural industry. The recently introduced synthetic auxin-resistant (AR) crop varieties confer resistance to 2,4-D or dicamba in soybean [*Glycine max* (L.) Merr] and cotton (*Gossypium hirsutum* L.), which have been shown to provide increased control of glyphosate-resistant *Amaranthus* species when integrated into soybean and cotton herbicide programs (Meyer et al. 2015b; USDA APHIS 2014, 2015a, 2015b, 2015c). Despite the utility of AR technology, increased applications of 2,4-D and dicamba have caused growing concern for growers of auxin-susceptible crops. In 2017, high numbers of dicamba drift complaints were documented in the United States in dicamba-susceptible soybean and cotton as well as other high-value ornamental and horticultural crops due to increased dicamba use (EPA 2017). Soybean and cotton are extremely sensitive to dicamba and 2,4-D, respectively. As little as 0.01% of the labeled rate of dicamba often results in observable symptomology and yield reductions of up to 42% in soybean (Auch and Arnold 1978; Griffin et al. 2013; Sciumbato et al. 2004; Steckel et al. 2010; Wax et al. 1969). Likewise, as little as 0.5% of the labeled rate of 2,4-D has been shown to cause up to 60% injury and yield reductions of 45 to 100% in cotton depending on formulation and growth stage at time of exposure (Everitt and Keeling 2009; Marple et al. 2007). Aside from crop injury, off-target movement of herbicides has been linked to the evolution of herbicide resistance in weedy species by repeated exposure of sublethal rates (Londo et al. 2010; Manalil et al. 2011). This is particularly troubling with new AR technologies because Palmer amaranth (*Amaranthus palmeri* S. Watson), one of the species AR technology was developed for, has been shown to exhibit up to threefold reduced susceptibility to dicamba and 2,4-D after three generations of sublethal-dose exposure (Tehranchian et al. 2017). Consequently, herbicide drift could also pose risk to the usefulness and longevity of AR technologies for weed control.

Off-target herbicide movement has been studied for decades (Al-Khatib et al. 1993, 2003; Everitt and Keeling 2009; Greenshields and Putt 1958; Kaupke and Yates 1966; Maybank et al. 1974; Morgan et al. 1957; Schroeder et al. 1983; Smith et al. 2017; Staten 1946). Volatilization, tank contamination, and particle drift have been identified as common causes of off-target herbicide movement (Cundiff et al. 2017; Steckel et al. 2010). However, particle drift is the most preventable form of off-target movement because application methods can be adjusted to minimize drift potential.

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Environmental conditions, boom height, droplet size, and distance from susceptible vegetation are major factors affecting particle drift (Maybank et al. 1978; Nordby and Skuterud 1975; Thistle 2004; Wolf et al. 1993). Consideration of buffer distance between treated areas and susceptible vegetation is also imperative in minimizing particle drift. Marrs et al. (1993) suggested that 20 m buffer zones were adequate for protection of adjacent land from glyphosate under wind speeds of 7 to 11 kph. However, current labels for dicamba and 2,4-D require a 34 to 67 m and 9 m buffer, respectively, depending on herbicide rate (Anonymous 2016b; 2017).

Aside from environmental conditions, spray quality is the most influential factor affecting particle drift (Creech et al. 2015). Spray qualities with droplet volume median diameter (VMD) of 100 to 200 µm or less are considered to have extremely high drift potential (Wolf et al. 1993). Operating pressure, orifice size, nozzle type, and tank solution primarily determine spray quality (Henry et al. 2016; Ramsdale and Messersmith 2001). Operating pressure is inversely related to VMD; higher pressures generally decrease VMD (Maybank et al. 1978). In some cases, lower VMD spray qualities are desirable to maximize coverage for increased efficacy of contact herbicides; however, systemic herbicides such as glyphosate, dicamba, and 2,4-D do not require maximized coverage and can be applied with higher VMD spray quality–producing nozzles (Henry et al. 2014; Meyer et al. 2015a). In fact, product labels for 2,4-D and dicamba require that specific nozzle and pressure combinations be used so that VC to UC spray qualities are produced to reduce particle drift (Anonymous 2016a, 2017).

Sprayer hoods are an additional drift reduction tool that is often not considered. Traditionally, hooded sprayers were designed with multiple hoods consisting of 1 to 2 nozzles per hood for interrow post-directed applications of nonselective herbicides such as glyphosate before the advent of glyphosate-resistant crops (Dill et al. 2008). Currently, most hooded sprayers are used for similar applications in specialty crops such as sweet corn (*Zea mays* L.) and sugarcane (*Saccharum officinarum* L.) to reduce crop injury (Griffin et al. 2012; Kleppe and Harvey 1991). However, hooded sprayers designed for broadcast applications are currently available and have a continuous shield over the entire spray boom to aid in drift reduction (Figure 1). Regardless of hood design or material, hooded sprayers generally reduce particle drift by minimizing spray exposure to wind forces (Ozkan et al. 1997). Drift reductions of 1.8 to 2.8 fold have been reported by use of hooded sprayers compared with open sprayers (Fehringer and Cavaletto 1990).

A review of the literature revealed that many studies investigating particle drift as affected by sprayer type or spray quality either conducted studies under wind tunnel conditions or did not test a wide range of spray qualities in a factorial comparison with sprayer type (Alves et al. 2017a, 2017b; Ozkan et al. 1997; Sidahmed et al. 2004; Wolf et al. 1993). The hooded sprayers used in some studies are often designed for interrow post-directed applications and would not be suited for broadcast treatments (Roten et al. 2014).

Aside from risk for damage to neighboring crops, herbicide drift also poses multiple threats to ecological communities (Egan et al. 2014; Relyea 2005). Moreover, excessive particle drift of any herbicide can present risk of product registration becoming more restrictive or terminated at state or federal levels (Mortensen and Egan 2012). Consequently, the objective of this research was to examine four spray qualities applied with or without sprayer hoods to determine the most effective application technique for reducing particle drift from broadcast applications.

Figure 1. Broadcast Redball hooded sprayer with a continuous shield (top) and broadcast Redball open sprayer (bottom) (Wilmar Manufacturing LLC, Benson, MN).

Materials and Methods

Site and Materials

A study was conducted twice in 2015 and 2016 at the West Central Research and Extension Center in North Platte, NE (41° 05′10.0″N, 100°46′33.9″W and 41°05′23.3″N, 100°45′45.4″W) and in 2016 at the Black Belt Experiment Station in Brooksville, MS (33°15'24.5"N, 88°33'24.4"W), thus providing three site-years for analysis. Nebraska and Mississippi soil types were Cozad silt loam (coarse-silty, mixed, superactive, mesic, Typic Haplustolls) with 2% organic matter (OM) and Brooksville silty clay (fine, smectitic, thermic Aquic Hapluderts) with 1.6% OM, respectively. Soybean ('Asgrow 4632', Monsanto Company, St. Louis, MO) was planted with 96 cm row spacing for both years and at all locations, except for in 2016 at Nebraska, which was conducted under fallow conditions. The study was a randomized complete block

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design with four replications and a factorial arrangement of treatments. Factors were spray quality and sprayer type. Treatments were blocked by time, utilizing the same application and collection areas for each treatment to mitigate landscape effects. Spray quality consisted of four levels or droplet size spectrums: Fine (F; 106–235 µm), Medium (M; 236–340 µm), Very-Coarse (VC; 404-502 µm), and Ultra-Coarse (UC; >665 µm) (ASABE 2009). Sprayer type consisted of two levels: open and hooded (Figure 1).

For both locations, the treated area was 9.1 m wide and 183 m long in 2015 and 168 m long in 2016. Treatments were applied as one pass on the upwind side of the experimental area, perpendicular to wind direction and a collection line of mylar cards (Grafix Plastics, Cleveland, OH) placed downwind from the center of the treated area similar to the field layouts of Wolf et al. (1993) and Grover et al. (1978). Average soybean stage and canopy height at the time of application were: R5 and 60 cm (Nebraska 2015) and R4 and 50 cm (Mississippi 2016) (Fehr and Caviness 1977). Small mylar cards (52 by 72 mm) were placed at sample points 2, 4, 6, 14, 30, 43, and 59 m downwind from the treated area and perpendicular to the spray pass. Likewise, large mylar cards (104 by 144 mm) were placed at 73, 89, and 104 m downwind. A small mylar card was placed 9 m upwind of the treated area as a control for each treatment. Mylar cards were placed on adjustable card holders set at the top of the soybean canopy or 30 cm above the ground at the fallow site.

Treatment Application

Air-Induction (AI) 11002 and Extended Range (XR) 11002 and 11003 nozzles (TeeJet Technologies, Springfield, IL) were used to apply treatments. Treatments were applied with either a tractor-mounted hooded sprayer (642E Three-Point Wheel Boom Broadcast Redball Hooded Sprayer, Wilmar Manufacturing LLC, Benson, MN) (Figure 1), or an open sprayer (642E Three-Point Wheel Boom Broadcast Sprayer, Wilmar Manufacturing LLC, Benson, MN) both with 9.1 m boom length, calibrated to deliver 140 L ha^{-1} at 207, 414, and 300 kPa and 8, 11, and 13 kph, respectively (Table 1). Nozzle, pressure, and speed were adjusted as shown in Table 1 to produce spray qualities representing F, M, VC, and UC droplet distributions as described by ANSI/ASAE 572.1 standard (ASABE 2009). Applications were made on August 12, 2016 in Mississippi and on August 3, 2015 and August 9, 2016 in Nebraska. A 51 cm nozzle spacing and 51 cm boom height above target were utilized for all applications. Treatment solutions consisted of glyphosate (Roundup PowerMax, Monsanto Company, St. Louis, MO) at 1.26 kg ae ha^{-1}. Additionally, rhodamine WT dye (Cole-Parmer, Vernon Hills, IL) at 0.2% v v^{-1} for the Mississippi location, and 1,3,6,8-pyrene tetra sulfonic acid tetra sodium salt (PTSA) fluorescent tracer dye (Spectra Colors Corp., Kearny, NJ) at 1,321 mg L^{-1} for both years at the Nebraska location were included for fluorimetry analysis (Hoffmann et al. 2014).

Table 1. Application parameters for treatments investigating the effect of sprayer type and spray quality on particle drift.

Sprayer type	Nozzle	Pressure	Sprayer speed	Spray quality[a]
		kPa	kph	
Open	XR11002	414	11	F
Open	XR11003	300	13	M
Open	AI11002	414	11	VC
Open	AI11002	207	8	UC
Hooded	XR11002	414	11	F
Hooded	XR11003	300	13	M
Hooded	AI11002	414	11	VC
Hooded	AI11002	207	8	UC

[a]Spray quality classifications and associated droplet size spectrum as defined by American Society of Agricultural and Biological Engineers S572.1: Fine (F; 106–235 µm), Medium (M; 236–340 µm), Very-Coarse (VC; 404–502 µm), and Ultra-Coarse (UC; > 665 µm).

Data Collection

Meteorological conditions were recorded on 30-s intervals during applications by an onsite weather station (WatchDog 2000 Series Weather Station, Spectrum Technologies, Aurora, IL) and a handheld anemometer (Kestrel 3000 Pocket Weather, Kestrel Meters, Minneapolis, MN) (Table 2). To allow sufficient time for deposition of small droplets, mylar cards remained in the field for 2 min after each application. Following the 2-min waiting period, mylar cards were collected in order of lowest to highest concentration, moving from the furthest distance downwind to the treated area, changing gloves between each card to prevent cross-contamination. Furthermore, at the time of collection, each mylar card was placed into separate plastic bags and placed into a dark cooler until transported to a lab freezer and stored for 1 wk at –20 C until extraction and fluorimetry analysis.

To extract fluorescent dye from mylar cards, 40 or 60 ml of 10:90 isopropyl alcohol:distilled water solution was added to water-tight sealable plastic bags containing one small or large mylar card, respectively. Bags were then vigorously shaken by hand for 30 s to wash dye from mylar cards, similar to the methods of previous drift experiments (Alves et al. 2017a, 2017b; Vieira et al. 2018). A 1-ml aliquot was then taken from each bag and placed in a glass cuvette for fluorimetry analysis (Model T200, Turner Designs, San Jose, CA). Spray solution samples were used to create a baseline value; thus, fluorimeter readings were given as relative fluorescence units (RFU). It was hypothesized that F spray quality originating from an open sprayer would have the greatest propensity to drift. Therefore, to normalize data among site-years and dye types, RFU values for the F spray quality applications originating from the open sprayer treatment at the 2-m sampling site were set to 100% for each replication and data were expressed as a percentage of this RFU value, similar to Henry et al. (2014).

Statistical Analysis

Statistical analyses were conducted using R software (version 0.98.1091, RStudio Inc, Boston, MA) under the *agricolae*, *graphics*, *investr*, *nlme*, and *stats* packages. To test for main effects of spray quality and sprayer type and interactions, data were subjected to ANOVA. Where significant effects were detected, means were separated using Fisher's protected LSD ($\alpha = 0.05$).

Additionally, data were grouped by treatment and fitted to an asymptotic nonlinear regression model (Figure 2). Normalized RFU data were regressed over sampling site distance downwind. The asymptotic model used was

$$Y = Y_{asym}\left[1 - \exp\left(-aI / Y_{asym}\right)\right] \quad [1]$$

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Table 2. Meteorological conditions during applications comparing particle drift from Nebraska (NE) and Mississippi (MS) field trials.[a,b]

Sprayer type	Spray quality[c]	Site-year	Wind speed	Temperature	RH
			kph	C	%
Open	F	NE 2015	10.8	30	46
		NE 2016	12.8	31	46
		MS 2016	12.7	34	51
Open	M	NE 2015	17.7	30	46
		NE 2016	13.5	32	46
		MS 2016	14.8	35	50
Open	VC	NE 2015	16.4	31	50
		NE 2016	14.5	30	46
		MS 2016	13	36	48
Open	UC	NE 2015	18.8	30	49
		NE 2016	12.5	31	46
		MS 2016	12	36	48
Hooded	F	NE 2015	13.1	30	49
		NE 2016	13.5	29	46
		MS 2016	13	36	49
Hooded	M	NE 2015	16.7	29	49
		NE 2016	13	31	46
		MS 2016	14.3	37	51
Hooded	VC	NE 2015	14.9	30	50
		NE 2016	14.1	30	45
		MS 2016	13.8	36	50
Hooded	UC	NE 2015	17.7	31	50
		NE 2016	12.5	35	50
		MS 2016	15.6	31	44

[a]Meteorological conditions were recorded on 30-s intervals during applications.
[b]Abbreviation: RH, relative humidity.
[c]Spray quality classifications and associated droplet size spectrum as defined by American Society of Agricultural and Biological Engineers S572.1: Fine (F; 106–235 µm), Medium (M; 236–340 µm), Very-Coarse (VC; 404–502 µm), and Ultra-Coarse (UC; >665 µm).

where Y was the response variable (expressed as percent of the RFU of the F/open sprayer treatment at 2 m), Y_{asym} was the asymptotic Y value (fitted Y value where slope approaches 0), I was the explanatory variable (distance from the boom), and a was the logarithmic rate constant (LRC). Additionally, a lack-of-fit test was conducted at the 95% level to determine the appropriateness of fit of the regression model (Ritz and Streibig 2005). Regression parameters were compared using 95% confidence intervals. Also, the regression model was used to estimate intercepts (Y at $I = 0$) and the distance downwind at which 5% or 10% RFU were detected [detection distance (DD_x)], expressed as DD_5 and DD_{10}, respectively.

Results and Discussion

Interactions between site-years and main effects were not detected ($P > 0.17$); therefore, data were pooled across site-years. Interactions between main effects (sprayer type and spray quality) were detected at sampling sites closest to the sprayer (2, 4, 6, 14, and 31 m). At sampling sites beyond 31 m (43, 59, 73, 89, and 104 m), interactions between main effects were not significant; however, both main effects (spray quality and sprayer type) were significant. Consequently, data are presented as the interaction between main effects for sampling sites 2 to 31 m (Table 3) and as separate main effects for sampling sites 43 to 104 m (Tables 4 and 5).

Distances 2 to 31 m

In the F and M spray qualities, particle drift was reduced by 6% to 86% and 3% to 56%, respectively, with the use of a hooded sprayer for sampling distances up to 31 m (Table 3). Particle drift from VC and UC spray qualities was not reduced by using a hooded sprayer except for the UC application at the 14-m sampling site. Both F and M spray qualities originating from an open sprayer consistently exhibited the highest drift. Interestingly, the use of a hooded sprayer in combination with F or M spray qualities resulted in particle drift similar to VC or UC applications. Similarly, Henry et al. (2014) reported hooded sprayers reduced particle drift out to 32 m when finer quality–producing XR or AIXR nozzles were used; however, no effect of sprayer type was found when coarser quality–producing Turbo TeeJet Induction (TTI) nozzles were used. Additionally, Ford (1986) reported drift reductions of approximately 85% out to 32 m downwind with the addition of porous shields behind spray nozzles; however, standard flat fan nozzles were used and the experiment was conducted under an average wind speed of 16 km h^{-1} compared to approximately 14 km h^{-1} in the present study (Table 2).

Distances 43 to 104 m

When averaged across spray qualities, particle drift from the hooded sprayer was consistently 1 to 2% lower than the open sprayer at sampling sites 43, 59, 73, 89, and 104 m downwind (Table 4). While these drift reductions appear to be minimal, in terms of relative deposition at longer distances downwind, hooded sprayers proportionally exhibit one third to half as much drift as open sprayers. Similarly, Sidahmed et al. (2004) reported consistent reductions in drift from 48% to 61% using different shielded sprayer types when compared to an open sprayer across six nozzle and pressure combinations under wind tunnel conditions.

Averaged across sprayer types, F spray qualities produced 2% higher deposition than UC spray qualities at the 43-m sampling site (Table 5). Deposition of F spray qualities was 1.3% and 1.5% higher, respectively, than VC and UC spray qualities at 59 m. Likewise, deposition of F spray qualities was 1.4% higher than UC spray qualities at 89 m. No differences were observed between spray quality deposition amounts at 73 and 104 m. No differences between M, VC, and UC spray qualities were observed at 43, 59, 73, and 104 m, suggesting that there was not enough power to detect differences in M, VC, and UC spray qualities at the resolution from the techniques used. Also, these data suggest that there may not be a way to contain long-distance transport of spray droplets from any pesticide applications using hydraulic nozzle systems.

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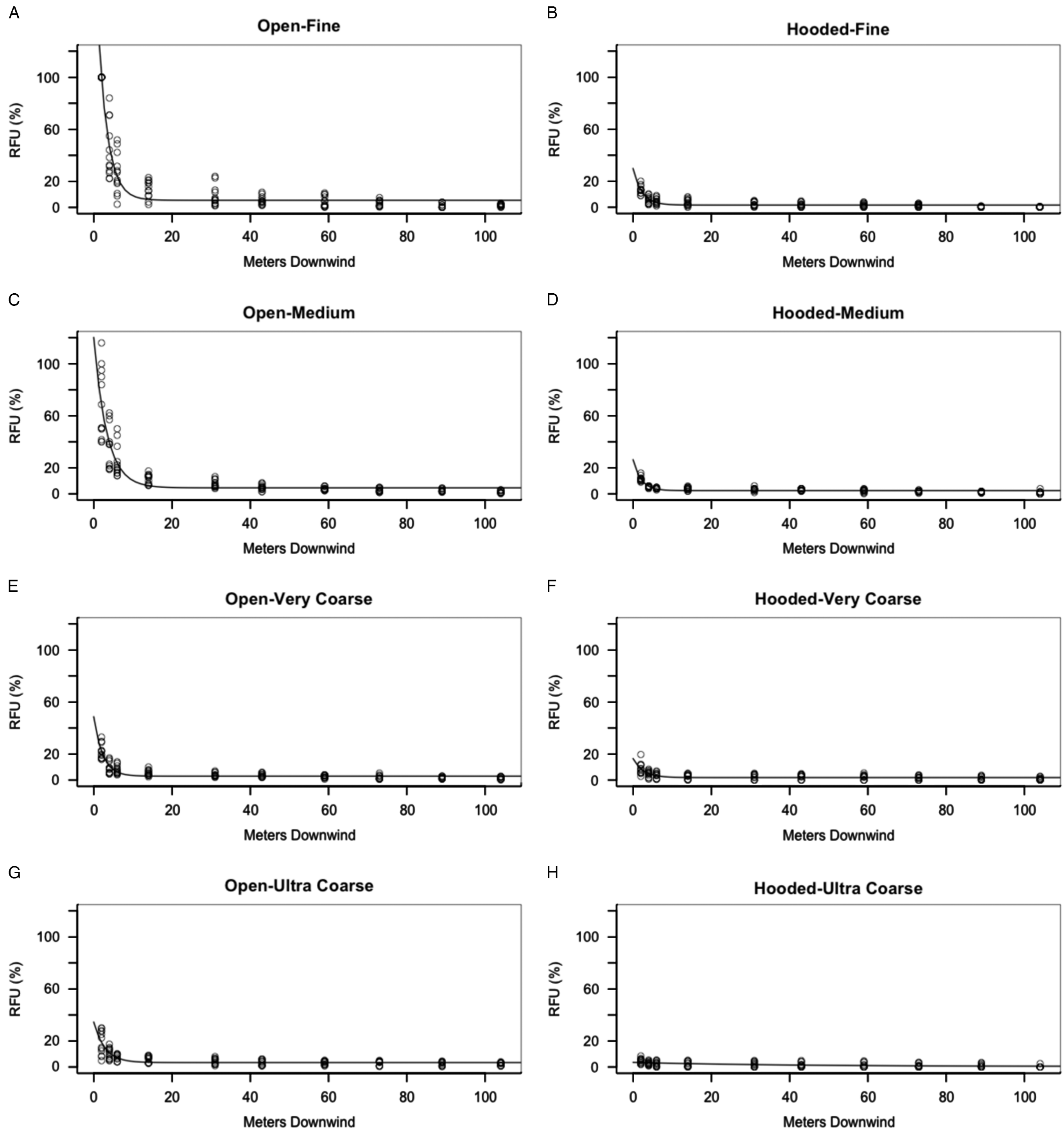

Figure 2. Nonlinear asymptotic regression model[a] fitted over data from the current study, which investigated the effect of spray quality and sprayer type on particle drift. [a]Regression model $Y = Y_{asym}[1\text{–}\exp(-aI/Y_{asym})]$, where Y is the response variable (% relative fluorescence [RFU]), Y_{asym} is the Y asymptote, I is the explanatory variable (distance from the boom), and a is the initial slope at low I values.

Regression Analysis

To further characterize particle drift of treatments, deposition data were regressed over downwind distance for each treatment using the regression model shown in Equation 1 (Figure 2). Lack-of-fit tests for data were not significant at the 95% level, confirming that the model selection was appropriate (Ritz and Streibig 2005). An observation of the graphs in Figure 2 revealed that the same spray quality applied from a hooded sprayer exhibited considerably lower particle drift compared to the open sprayer. Likewise, it is evident that coarser spray qualities are less susceptible to particle drift (Figure 2).

The asymptote estimate from regression analysis represented the fitted Y value at which the slope approaches 0. A higher asymptote implies that overall, droplets traveled a longer distance than a model with a lower asymptote. Asymptotes generally decreased as spray quality VMD increased (Table 6). The F spray

Table 3. Particle drift deposition of fluorescent tracer dye from 2 to 31 m downwind as influenced by spray quality and sprayer type.[a]

Spray quality[b]	Sprayer type	Distance downwind (m)				
		2	4	6	14	31
		%RFU of Open Fine^{-1} at 2 m				
F	Hooded	14 cd[c]	7 b	5 b	4 cd	3 c
	Open	100 a	44 a	26 a	15 a	9 a
M	Hooded	12 cd	8 b	7 b	6 c	5 b
	Open	68 b	37 a	25 a	11 b	8 a
VC	Hooded	9 cd	5 b	4 b	3 cd	3 c
	Open	22 cd	9 b	8 b	5 c	4 bc
UC	Hooded	5 d	3 b	2 b	2 d	2 c
	Open	19 cd	10 b	7 b	6 c	4 bc

[a]Abbreviation: RFU, relative fluorescence units.
[b]Spray quality classifications and associated droplet size spectrum as defined by American Society of Agricultural and Biological Engineers S572.1: Fine (F; 106–235 µm), Medium (M; 236–340 µm), Very-Coarse (VC; 404–502 µm), and Ultra-Coarse (UC; >665 µm).
[c]Means followed by the same letter in each column are not different according to Fisher's LSD test at α = 0.05.

qualities from the open sprayer produced an asymptote (5.5% RFU) higher than all hooded sprayer treatments, regardless of spray quality, indicating the highest drift of all treatments. Asymptotes for VC/open sprayer (3% RFU) and UC/open sprayer (3.4% RFU) treatments were both higher than the F/hooded sprayer asymptote (1.7% RFU), suggesting that the hooded sprayer, even with F spray quality, resulted in less drift than an open sprayer with high VMD spray qualities.

Differences were also detected between intercepts (Table 6). In the regression model, the intercept (Y at $I = 0$) is a predicted value that reflects the nature of Y at low X values. Therefore, higher intercepts simply imply higher particle drift at short distances. Consequently, the F/open sprayer and M/open sprayer treatments produced the highest (218.9% RFU) and second highest (120.3% RFU) intercepts among all treatments, respectively. Likewise, the M/open sprayer treatment produced a higher intercept (120.3% RFU) than all other treatments except the F/open sprayer. These two treatments with the highest intercepts also displayed the highest particle drift out to 31 m, suggesting that the trends present in the regression analysis mirrored those of the discrete sampling site analysis (Table 3). Overall, intercepts decreased as

Table 4. Particle drift deposition of fluorescent tracer dye from 42 to 104 m downwind influenced by sprayer type averaged across four spray qualities.[a,b]

Sprayer type	Distance downwind (m)				
	43	59	73	89	104
	%RFU of Open Fine^{-1} at 2 m				
Hooded	3 b[c]	2 b	2 b	1 b	1 b
Open	5 a	4 a	3 a	2 a	2 a

[a]Spray quality classifications and associated droplet size spectrum as defined by American Society of Agricultural and Biological Engineers S572.1: Fine (F; 106–235 µm), Medium (M; 236–340 µm), Very-Coarse (VC; 404–502 µm), and Ultra-Coarse (UC; >665 µm).
[b]Abbreviation: RFU, relative fluorescence units.
[c]Means followed by the same letter in each column are not different according to Fisher's LSD test at α = 0.05.

Table 5. Particle drift deposition of fluorescent tracer dye from 43 to 104 m downwind as influenced by spray quality averaged across hooded and open sprayer types.[a]

Spray quality[b]	Distance downwind (m)				
	43	59	73	89	104
	%RFU of Open Fine^{-1} at 2 m				
F	4.6 a[c]	3.8 a	2.8 a	2.4 a	1.6 a
M	3.9 ab	3.1 ab	2.2 a	1.7 ab	1.4 a
VC	3.1 ab	2.5 b	1.9 a	1.5 ab	1.2 a
UC	2.6 b	2.3 b	1.8 a	1.0 b	0.8 a

[a]Abbreviation: Relative fluorescence units.
[b]Spray quality classifications and associated droplet size spectrum as defined by American Society of Agricultural and Biological Engineers S572.1: Fine (F; 106–235 µm), Medium (M; 236–340 µm), Very-Coarse (VC; 404–502 µm), and Ultra-Coarse (UC; >665 µm).
[c]Means followed by the same letter in each column are not different according to Fisher's LSD test at α = 0.05.

spray quality VMD increased and in treatments applied with a hooded sprayer.

Logarithmic rate constants were also compared (Table 6). Logarithmic rate constants are essentially an inverse slope value. Therefore, more negative LRC values indicate low changes in Y for an increase in I while less negative LRC values indicate large changes in Y for an increase in I. The UC/hooded sprayer LRC (−3.7 %RFU m^{-1}) was lower than the LRCs of all other treatments, indicating that deposition was fairly similar across all sample sites. The M/open sprayer LRC (−1.19 %RFU m^{-1}) was lower than the M/hooded sprayer (−0.71%RFU m^{-1}), indicating that the use of a hooded sprayer profoundly reduced particle drift across the length of the experimental areas.

The downwind distances at which 5% or 10% dye concentrations were detected (DD_5 and DD_{10}, respectively) were estimated from the regression model (Table 6). However, no differences between DD_5 or DD_{10} values were observed. Additionally, DD_5 values for F/open sprayer and UC/hooded sprayer treatments were unable to be predicted. This was because >5% dye was found at all sampling sites for the F/open sprayer treatment and retrieval of a DD_5 value was not in the scope of the data as the asymptote was 5.5 (Tables 3 and 6). Likewise, the UC/hooded sprayer treatment only detected 5% dye at the 2-m sampling site and therefore the DD_5 value was not able to be predicted because the intercept was 3.6 (Table 6). Though prediction of DD_{10} gave a value for F/open sprayer, DD_{10} values for VC/hooded sprayer and UC/hooded sprayer could not be predicted because 10% dye was not in the scope of the dataset collected.

Overall, these data suggest that sprayer hoods can serve as additional particle drift reduction equipment. Additionally, the VC and UC spray qualities did not differ in their performance, regardless of the distance evaluated. These data would indicate that particle drift can still be reduced with higher VMD spray qualities and sprayer hoods beyond the 34-m buffer requirement for dicamba use in dicamba-tolerant crops (Anonymous 2016b). The 9-m buffer requirement for 2,4-D use in 2,4-D-resistant crops is probably not sufficient with lower VMD spray qualities applied with open sprayers (Anonymous 2017). The authors acknowledge that recommending new equipment or practices to applicators is often met with resistance. For example, Wolf et al. (1993) indicated that shields that cover the entire boom reduce

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Table 6. Regression model[a] parameters from analysis of the effect of sprayer type and spray quality on particle drift.[b]

		Regression parameters				
		Asymptote	Intercept	LRC	DD_5	DD_{10}
Sprayer type	Spray quality[c]	%RFU		%RFU m^{-1}	m	
Open	F	5.5 (±2.1)[d]	218.9 (±30.8)	−0.89 (±0.14)	NA[e]	9.4
Open	M	4.6 (±2.4)	120.3 (±23.5)	−1.19 (±0.24)	19.1	10.2
Open	VC	3.0 (±0.6)	48.7 (±11.2)	−0.80 (±0.22)	7.0	4.2
Open	UC	3.4 (±0.8)	34.6 (±9.8)	−1.03 (±0.33)	8.3	4.3
Hooded	F	1.7 (±0.5)	29.9 (±8.3)	−0.80 (±0.27)	4.8	2.7
Hooded	M	2.5 (±0.3)	26.3 (±6.1)	−0.71 (±0.22)	4.6	2.3
Hooded	VC	1.9 (±0.5)	16.5 (±6.6)	−0.96 (±0.45)	4.1	NA[f]
Hooded	UC	0.4 (±1.4)	3.6 (±0.7)	−3.7 (±1.2)	NA	NA

[a]Regression model $Y = Y_{asym}[1 - \exp(-aI/Y_{asym})]$, where Y was the response variable (% RFU), Y_{asym} was the Y asymptote, I was the explanatory variable (distance from the boom), and a was the initial slope at low I values.
[b]Abbreviations: LRC, logarithmic rate constant; DD_5, detection distance of 5% RFU; DD_{10}, detection distance of 10% RFU; RFU, relative fluorescence units of Open $Fine^{-1}$ at 2 m.
[c]Spray quality classifications and associated droplet size spectrum as defined by American Society of Agricultural and Biological EngineersS572.1: Fine (F; 106–235 µm), Medium (M; 236–340 µm), Very-Coarse (VC; 404–502 µm), and Ultra-Coarse (UC; >665 µm).
[d]95% confidence intervals are given in parentheses. Values within columns not followed by parentheses are not statistically different.
[e]5% tracer dye was not detected.
[f]10% tracer dye was not detected.

visibility and access to nozzles, as well as possible contamination of susceptible crops by wiping herbicide residue left on the hood (Figure 1). However, contamination of herbicide residues can be mitigated through proper cleaning of the spray equipment before and after application.

It is important that applicators take close note of the nozzle types used because spray quality distributions and drift potential vary greatly among nozzles (Alves et al. 2017a). No single drift reduction practice is a substitute for other application considerations. Training and educating applicators in proper application techniques, environmental conditions, and good judgment should also be incorporated to ensure particle drift is minimized (Bish and Bradley 2017). These data may help to expand current herbicide product labels in the areas of drift mitigation. The authors do acknowledge that these experiments were conducted under relatively similar environmental conditions and future research should be conducted under other environmental conditions such as higher wind speeds, temperatures, and lower humidity to gain a more robust confidence in the range in which hooded sprayers will contribute to drift reduction.

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