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ENGINEERING AND GINNING

Utility of Hooded Broadcast Sprayer in Reducing Herbicide Particle Drift in Cotton

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ABSTRACT

Use of hooded sprayers to mitigate spray particle drift during pesticide applications in cotton has not been investigated. Therefore, experiments were conducted in cotton fields in 2021 and 2022 to compare particle drift of dicamba applied with open and hooded broadcast sprayers at six different spray qualities: Fine (F), Medium (M), Coarse (C), Very Coarse (VC), Extremely Coarse (EC), and Ultra Coarse (UC). A fluorescent tracer dye was mixed and applied with the dicamba solution to measure drift deposition at different downwind distances up to 105 m from the target area. Results showed particle drift for F and M spray qualities applied with a hooded sprayer were reduced up to 94% and 77%, respectively, out to 10 m downwind from the application area compared to the open boom sprayer. Hooded sprayer decreased particle drift for C and VC spray qualities as well but only for short distances downwind (≤ 5 m). Sprayer type did not affect the particle drift for EC and UC spray qualities and it was also significantly lower than other spray qualities across both sprayer types. From 20 to 60 m downwind, dicamba applications with hooded sprayer exhibited as much as 42% less drift than open boom sprayer applications regardless of the spray quality. These data suggested that hooded sprayers are effective in reducing particle drift in cotton and thus can be utilized as a viable spray drift management technique for herbicide applications in cotton.

The introduction of auxin-resistant (AR) cotton (*Gossypium hirsutum* L.) cultivars have provided growers a valuable tool for effective post-emergence weed management in these crops (Legleiter et al. 2018). The adoption of AR technologies in the United States has steadily increased as more growers are planting cotton cultivars that are tolerant to auxin herbicides today. For example, more than 90% of the cotton acres in the United States in 2021 were planted in AR cultivars (USDA NASS, 2021). The improved control of glyphosate-resistant *Amaranthus* species with dicamba and 2,4-D (Meyer et al. 2015), is another motivation for growers to integrate these auxin herbicides in their cotton weed management programs. While the weed control benefits of AR technologies are undisputable, increased use of auxin herbicides have also raised concerns due to the increased potential of off-target movement and consequently the increase in number of herbicide drift complaints in recent years (EPA, 2017; 2021). Broadleaf plant species (not resistant to auxin herbicides) are highly sensitive to auxin herbicides and can exhibit significant damage and loss in yield even at very low rates (Egan et al. 2014; Kruger et al. 2012). Additionally, prolonged exposure to dicamba and 2,4-D through off-target movement have also been linked to reduced susceptibility and development of herbicide resistance in certain weed species (Manalil et al. 2011; Tehranchian et al. 2017).

Off-target movement of herbicides can occur in many different forms including volatilization, tank contamination, and particle drift (Cundiff et al. 2017; Steckel et al. 2010). Amongst these, spray particle drift is one of the most common mechanisms of off-target movement that involves physical movement of spray particles/droplets through the air at the time of application or later to any other place than the target area (Mathews et al. 2014). Over the years, numerous studies have investigated the influence of environmental, operational, and application factors on spray particle drift including wind speed and direction, ground speed, boom height, spray droplet size, and distance of susceptible vegetation from application area (Al Heidary et al. 2014; Alves et al. 2017; Maybank et al. 1978; Nordby and Skuterud, 1974; Thistle, 2004). Since spray quality is one of the influential parameters affecting herbicide drift, the main factors that affect spray quality including

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nozzle design, spray pressure, and physiochemical properties have also been thoroughly investigated by many researchers (Creech et al. 2015; Hewitt 2008; Hilz and Vermeer 2013, Schampheleire et al. 2009). Spray qualities with volume medium diameter (VMD) of 100 to 200 µm have high drift potential (Wolf et al. 1993), therefore the use of venturi nozzles with air-inclusion and pre-orifice components that create coarser spray droplets (VMD >385 µm) is one of the main strategies for spray drift management (Etheridge et al. 1999). In fact, the current pesticide labels for both dicamba and 2,4-D require that growers must utilize a combination of approved nozzle and pressure to attain coarser spray qualities to reduce spray particle drift during herbicide applications (Anonymous, 2022a, 2022b). Beside the above-mentioned considerations, informing best management practices for herbicide applications including proper nozzle selection, use of drift-reducing adjuvants (DRAs), and new pesticide formulations, through various educational and Extension efforts are also among the main strategies practiced to effectively manage spray drift (Bish and Bradley, 2017; Hewitt, 2008; Hilz and Vermeer, 2013).

Another spray drift reduction method studied by many researchers previously (Edwards and Ripper, 1953; Fehringer and Cavaletto, 1990; Smith, 1982; Wolf et al. 1993) which is gaining renewed interest again is the use of mechanical devices such as protective shields on sprayer booms. Protective shields across the boom, also known as "spray hoods", serves as a physical barrier around the spray boom and helps in reducing the amount of spray particles by minimizing the exposure to wind forces (Ozkan et al. 1997). Several studies have reported drift reduction of 40% to 90% by use of spray hoods compared to open boom sprayers (Edwards and Ripper, 1953; Fehringer and Cavaletto, 1990; Henry et al. 2014; Wolf et al. 1993). While most of these hooded sprayer studies have been conducted in non-cropped, fallow or grass fields, Foster et al. (2018) investigated spray drift in the fields planted in soybean (*Glycine max* Merr) (two out of three locations) and reported that spray drift can be reduced by approximately 50% by use of a hooded sprayer regardless of the nozzle type when compared to the conventional open boom sprayer. Findings from this study were instrumental in inclusion of a hooded sprayer as one of the spray drift management strategies on the current dicamba label (Anonymous, 2022a); however, it is only applicable to dicamba applications in soybean as this spray drift work was conducted in soybean. According to the current dicamba label, growers/applicators are required to leave a 73.1 m downwind buffer between the last treated row and the nearest downwind field edge. Despite some challenges associated with their use, including reduced access to nozzles and slower operating speeds (Virk and Prostko, 2022; Wolf et al. 1993), one of the major benefits of using a hooded sprayer in soybean is the reduction in the downwind buffer to 33.5 m. Currently, this incentive of reduced downwind buffer with use of a hooded sprayer is not available to cotton growers for dicamba applications. Consequently, the full length of the downwind buffer (73.1 m) means either less effective weed control or utilizing more expensive herbicide options in these areas of the field.

With pesticide application regulations becoming stricter along with the increased use of dicamba in cotton, it is important to investigate the potential of hooded sprayers as another possible drift reduction tool. Therefore, the objective of this study was to compare and evaluate spray drift from a hooded versus an open boom sprayer across different spray qualities and to determine the utility of a hooded sprayer in reducing spray particle drift during herbicide applications in cotton.

MATERIALS AND METHODS

Study Location and Treatments. Field experiments in this study were conducted at the Southeast Research and Educational Center in Midville, GA (32.880834°N, -82.205086°W) in 2021 and 2022. The predominant soil types in the fields are Tifton loamy sand (2 to 5% slope) and Dothan loamy sand (2 to 5% slope). Cotton cultivar ST 4990 BX3F (BASF, Florham Park, NJ) was planted with 91.4 cm row spacing during both years. The study treatments consisted of a factorial arrangement of sprayer type and spray quality with each combination of sprayer type and spray quality replicated three times. The treatments for sprayer type consisted of an open boom and a hooded boom sprayer (Fig. 1a and 1b, respectively) while the treatments for spray quality consisted of six different droplet spectrums as described by the American Society of Agricultural and Biological Engineers (ASABE) S572.1 (ASABE, 2009): Fine (F; 61-105 µm), Medium (M; 236-340 µm), Coarse (C; 341-403 µm), Very Coarse (VC; 404-502 µm), Extremely Coarse (EC; 503-665 µm) and Ultra Coarse (UC; >665 µm). Both the open and the hooded broadcast sprayers (642E three-point wheel boom broadcast sprayer and 642E three-point wheel boom broadcast Redball hooded sprayer, respectively, Wilmar Manufacturing LLC, Benson, MN) had a boom length of 7.1 m with nozzles spaced equidistant (0.51 m) on the boom. Each sprayer had a 568 L polyethylene tank and was operated using its own tractor. For the hooded sprayer, the hood was constructed of molded polymer plastic that surrounded the nozzles across the whole boom. The hood sections reached approximately 40.5 cm below the nozzle orifices and a plastic curtain further reached 27 cm below the backside of the plastic hood as shown in Fig. 1b. The boom height for both sprayers were set at 50.8 cm from the canopy and was maintained throughout the study using the sprayer guide wheels and the tractor's hydraulic hitch system. At the selected boom height, the plastic curtain on the hooded sprayer was approximately 10 cm below the crop canopy.

Figure 1. Redball broadcast (a) open boom sprayer and (b) hooded sprayer used for making herbicide applications in 2021 and 2022.

Different spray qualities were attained by varying nozzle size, nozzle type, or ground speed while keeping the same spray pressure (276 kPa) across all the treatments (Table 1). Different nozzle types (Table 1; XRC – extended range, TT – turbo teeJet, AIXR – air induction extended range, AI – air induction, and TTI – turbo teeJet induction) were used to apply spray quality treatments in this study and were manufactured by and acquired from TeeJet Technologies (Springfield, IL). Prior to testing, the sprayers were calibrated to deliver 140.3 L ha^{-1} of spray volume at 276 kPa and 9.7 km h^{-1} for a 03 nozzle, and at 276 kPa and 12.9 km h^{-1} for a 04 nozzle.

Table 1. Information on nozzle type, spray pressure and speed used to attain different spray qualities for both open and hooded sprayers in 2021 and 2022.

Sprayer	Nozzle	Pressure	Speed	Spray Quality[z]
		---- kPa ----	-- km h^{-1} --	
Open/ Hooded	XRC11003	276	9.7	F
	XRC11004	276	12.9	M
	TT11003	276	9.7	C
	AIXR11003	276	9.7	VC
	AI11003	276	9.7	EC
	TTI11003	276	9.7	UC

[z] Spray quality classifications according to ASABE Standard S572.1.

Spray Application and Data Collection. In both years of the study, an application area that measured 7.1 m wide (equal to the sprayer boom width) and 152.4 m in length was selected and marked off in the cotton field. This application area was selected considering the prevalent wind direction (S-SW) at the site and aligned accordingly so that the sprayer pass was perpendicular (±30°) to the wind direction. For data collection, a line of mylar cards (76 x 102 mm), were placed downwind at 1, 2, 3, 5, 10, 20, 30, 45, 60, 90 and 105 m from the edge of the application area and similar to the field layouts followed by Grover et al. (1978), Henry et al. (2014), and Foster et al. (2018). Similarly, a mylar card was placed 30 m upwind from the application area as a control for each treatment. All mylar cards were placed on stands, built using plant support stakes and card holders as shown in Fig. 2. The cardholders were adjusted to set mylar cards at the same height as the top of the cotton canopy. The application area and sampling points (downwind and upwind of the application area) were kept similar between all the treatments to mitigate any effect of landscape and other variables that could possibly cause variations in spray drift response beside the treatments.

Figure 2. Illustration of mylar cards placed on stands for drift data collection during spray drift assessment.

Herbicide applications were made on 30 July 2021 and 22 July 2022 when the cotton was at six to eight leaf stage and approximately 40 cm in height. The herbicide solution consisted of dicamba (XtendiMax, Bayer CropScience, St. Louis, MO) at 1.54 kg ai ha^{-1} and glyphosate (Roundup PowerMAX 3, Bayer CropScience, St. Louis, MO) at 2.1 kg ai ha^{-1}. Additionally, rhodamine WT dye (Cole-Parmer, Vernon Hills, IL) at 0.5% v v^{-1} was mixed in the solution and used during both years to aid in fluorimetry analysis (Hoffmann, et al. 2014). During testing, each sprayer pass represented a treatment combination of a sprayer type and spray quality, with mylars cards placed at the pre-determined distances from the application area. An onsite weather station (Vantage Pro2, Davis Instruments, Hayward, CA) was erected 30-m from the application area and measured meteorological conditions including wind speed, temperature, and relative humidity on 1-min intervals during applications. The meteorological data, averaged across replications, by sprayer type and spray quality for both years is presented in Table 2.

After each application, mylar cards were carefully collected by two different teams – each consisting of two to three people – to avoid contamination between the upwind and downwind samples. The downwind mylar cards were collected by one team starting from the furthest distance downwind from the application area and moving inwards while changing gloves between each card to prevent cross-contamination. A separate team collected the upwind sample after each sprayer application. During collection, each mylar card was placed into a separate plastic bag and placed in a dark cooler over dry ice until transported to the lab for extraction and fluorimetry analysis.

Table 2. Meteorological conditions (averaged across sprayer type and spray quality) during spray drift data collection in 2021 and 2022.

Sprayer Type	Spray Quality[z]	Temperature		Wind Speed		Relative Humidity	
		2021	2022	2021	2022	2021	2022
		°C		km h^{-1}		%	
Open	F	32.5	33.3	11.3	10.1	68.3	61.3
	M	33.4	31.1	12.9	11.3	62.3	73.0
	C	32.4	32.0	10.8	12.4	68.7	68.0
	VC	33.0	32.2	10.9	10.2	65.0	65.3
	EC	34.4	31.5	11.3	14.5	59.3	66.0
	UC	32.9	30.2	10.9	12.9	65.0	68.3
Hooded	F	34.6	30.2	17.2	16.1	57.7	73.3
	M	34.4	32.6	19.8	13.2	56.3	67.0
	C	34.4	30.6	15.6	10.6	58.0	71.7
	VC	34.4	33.9	14.0	12.7	59.3	64.7
	EC	34.4	31.3	17.2	16.3	58.3	69.7
	UC	34.4	32.2	16.1	10.9	58.3	68.3

[z] **Spray quality classifications according to ASABE S572.1.**

Fluorimetry and Statistical Analysis. A solution of 10:90 isopropyl alcohol to distilled water was prepared and used to extract fluorescent dye from the mylar cards. Forty milliliters of this solution was added to each water-tight sealed plastic bag containing the mylar card, and then the bag was vigorously shaken by hand for 30 s to wash dye from the mylar cards, similar to the methods used in the previous drift experiments (Alves et al. 2017; Vieira et al. 2018). Further, a 1-ml sub-sample of the solution was pipetted into a glass cuvette and placed in the fluorometer (Trilogy Laboratory Fluorometer, Turner Designs, San Jose, CA) for analysis. The pipette and glass cuvette were rinsed after each sample to prevent cross-contamination. The fluorometer provided readings as raw fluorescence units (RFU) for each sample based on the amount of the dye detected in the solution. It was hypothesized that F spray quality from an open boom sprayer at 1 m would have the highest propensity for spray drift, thus the RFU values for the F spray quality from the open sprayer at 1 m downwind distance was set to 100% for each replication and all other data were expressed as a percentage of this RFU value, similar to Foster et al. (2018).

All statistical analysis were conducted using SAS 9.4 (SAS Institute, Cary, NC). Year by treatment interactions were not significant ($p > 0.23$); therefore, data were pooled across both years. A two-way ANOVA analysis was conducted to test the main and interaction effects of sprayer type and spray quality on particle drift. For effects that were significant, means were separated using Fisher's protected LSD test ($\alpha = 0.05$). Additionally, different nonlinear regression models including asymptotic logistic and exponential were fitted to the spray drift data and were compared using lack-of-fit tests ($p < 0.05$) and Akaike's information criterion (AIC) values (Archontoulis and Miquez, 2015). The asymptotic nonlinear exponential regression model that provided the best fit and the lowest AIC was

$$Y = a + b.Exp\left(-c.X\right)$$

where Y is the response variable (expressed as percent of the RFU of the F/open sprayer at 1 m), a is the asymptote (fitted Y value as b approaches zero), b is the scaling parameter, c is the growth rate constant and X is the explanatory variable (downwind distance from the boom). Normalized RFU data – grouped by each treatment combination of sprayer type and spray quality – were regressed over sampling site distance downward using the selected nonlinear regression model and regression parameters for each combination of sprayer type and spray quality were estimated and compared amongst each other. The regression parameters were also used to estimate the intercepts (Y at X=0) and the downwind distance at which 10% RFU were detected, expressed as DD_{10}.

RESULTS AND DISCUSSION

Spray Particle Drift – 1 to 10 m. A significant interaction ($p > 0.05$) between the main effects of sprayer type and spray quality existed at the sampling sites closest to the application area i.e. 1, 2, 3, 5 and 10 m. Both F and M spray qualities from an open boom sprayer exhibited the highest particle drift while UC spray quality showed the lowest drift (Table 3). Up to the sampling distance of 10 m, the hooded sprayer reduced the particle drift by 61% to 94% and 45% to 77% for the F and M spray qualities, respectively, when compared to drift from the open boom sprayer. For C and VC spray qualities, the drift reduction with a hooded sprayer was only observed up to the 1 and 3 m sampling sites, respectively whereas the particle drift was similar for both open and hooded sprayers beyond those downwind distances for these spray qualities. In the EC and UC spray qualities, there were no significant differences in particle drift between the open and hooded sprayer across all the sampling sites up to 10 m. These results attained for sprayer type and spray quality were mostly similar to the findings of other spray drift studies (Foster et al. 2018; Henry et al. 2014; Vieira et al. 2022), conducted in the presence of other crop canopies in the field. In their study, Henry et al. (2014) reported that hooded sprayers reduced the particle drift for XR nozzles (producing finer/medium droplets) up to 32 m in the trials conducted in the presence of approximately 20 cm tall wheat stubble and soybean canopy in 2012 and 2013, respectively. Similarly, particle drift reductions of 6% to 86% and 3% to 65% were observed for F and M spray qualities, respectively, by Foster et al. (2018), with use of a hooded sprayer for sampling distances up to 31 m during herbicide applications in soybean at R4-R5 stage and approximately 50 – 60 cm tall. Both of these studies also indicated no effect of sprayer type on particle drift for the TTI and AI nozzles (producing coarser spray qualities) at most of the sampling sites downwind, similar to the results attained for UC spray quality in the present study. These findings differed slightly from a recent study conducted by Vieira et al. (2022), where the authors reported reduced drift potential from use of a hooded sprayer across both AIXR and TTI nozzles (VC and UC spray quality, respectively) when used with and without the addition of a drift reducing adjuvant (DRA).

Though the influence of spray type and spray quality was mostly similar between the previous drift studies mentioned above and the present study, the distance up to which the particle drift was detected varied among the studies. These variations in particle drift distance are common, and also completely unavoidable as it is affected by numerous variables including wind speed and direction, field slope, sprayer setup and operation, and pesticide formulation (Gil et al. 2015; Grella et al. 2017; Nuyttens, 2007; Van de Zande et al. 2005). Amongst these, wind speed is one of the most influential factors affecting particle drift distance. The experiments in the present study were conducted under an average wind speed of 12.6 km h^{-1} compared to approximately 14 km h^{-1} wind speed in the study by Foster et al. (2018), which could be one of the reasons for difference in particle drift distances between the two studies. An increase in downwind distance of spray drift with increase in wind speed was also reported by Alves et al. (2017) across four different nozzles types (XR, TT, AIXR, and TTI) in a wind tunnel study.

Another factor that can influence the amount and distance of particle drift is crop canopy and height. However, research studies investigating the effect of crop canopy at different stages or heights, especially in row crops, on spray particle drift are limited. Such studies are also difficult to implement due to the challenges associated with crop canopy assessments and multiple spray drift data collections at different times during the growing season while trying to keep the field and environmental conditions similar across the testing period. Thus, spray drift studies in specific crop(s) of interest, similar to the study presented here in cotton, are common but also important to investigate spray drift in that particular crop/field conditions. These crop-specific studies also help in better understanding of spray drift from boom sprayers in different crops and in varying field and environmental conditions.

Spray Particle Drift – 20 to 105 m. At sampling sites beyond 10 m, the main effects of sprayer type and spray quality were significant (p > 0.05) for particle drift at sampling sites of 20, 30, 45, and 60 m downwind from the application areas while none of the main effects or their interaction were significant beyond the downwind distance of 60 m. In comparison among the sprayer types, while the particle drift (%RFU) values between the open and hooded sprayer differed only by less than 1.2%, the

Table 3. Influence of spray type and spray quality on herbicide particle drift from 1 to 10 m downwind from the application area.

Spray Quality[z]	Sprayer Type	Downwind Distance (m) 1	2	3	5	10
		%RFU[y,x] of Open Fine at 1 m				
F	Open	100 a	36 a	25 a	18 a	12 a
	Hooded	6 d	5 d	5 c	4 c	5 b
M	Open	63 b	31 ab	28 a	12 ab	12 a
	Hooded	14 cd	8 cd	8 c	7 c	7 b
C	Open	37 c	12 cd	10 bc	8 c	4 b
	Hooded	5 d	5 d	5 c	6 c	4 b
VC	Open	42 bc	25 bc	16 ab	9 bc	7 b
	Hooded	7 d	7 d	6 c	6 c	4 b
EC	Open	21 cd	13 cd	8 c	7 c	6 b
	Hooded	6 d	4 d	5 c	5 c	7 b
UC	Open	9 d	8 cd	8 c	7 c	6 b
	Hooded	4 d	3 d	5 c	5 c	4 b

[z] Spray quality classifications according to ASABE S572.1.

[y] RFU represents relative fluorescence units.

[x] Means followed by the same letter within each column are not significantly different at (p > 0.05).

drift reduction from a hooded sprayer was still considerable ranging from 22% to 42% at the sampling sites of 20 to 60 m (Table 4). These results were again similar to the findings of Henry et al. (2014) and Foster et al. (2018). Compared to an open sprayer, Henry et al. (2014) reported the effectiveness of a hooded sprayer in reducing particle drift across XR and AIXR nozzles up to 100% from 32 to 45 m downwind from the application area whereas Foster et al. (2018) indicated drift reductions as much as 50% with a hooded sprayer at downwind distances of 43 to 104 m.

Upon comparison between different spray qualities, the particle drift for F and M spray qualities was greater by 1.3% to 2.4% (RFU) from EC and UC spray qualities at the 20 and 30 m sampling sites (Table 5). Similarly, particle drift for F spray quality was greater by 1.6% to 2.7% and 1.1% to 1.9% than C, VC, EC, and UC spray qualities at sampling sites within 45 and 60 m, respectively. These results were attributed to the presence of greater number of finer spray particles (VMD ≤ 235µm) in F spray quality and their potential to travel farther than coarser spray qualities (VC, EC ,and UC; VMD ≥ 502 µm) during pesticide applications (Al Heidary et al., 2014). Differences in particle drift between M, C, VC, EC, and UC spray qualities were not observed beyond the 45 m sampling distance. Foster et al. (2018) shared similar results where no differences existed between the M, VC, and UC spray qualities at 43, 59, 73, and 104 m. The authors also attributed this to the lack of power and resolution in the fluorescent dye analysis techniques in detecting small differences in drift depositions. Among other factors, this can also be influenced by the accuracy and resolution of the fluorometer used for analysis. Contrarily, it should be noted that highly accurate fluorescent extraction instruments and analysis methods are expensive, and sometimes can also be impractical to utilize in large field scale spray drift studies.

Nonlinear Regression Analysis. The asymptotic nonlinear regression models fitted to the particle drift deposition data at different downwind distances for open and hooded sprayer are presented in Figs. 3 and 4, respectively. An observation of the graphs in Figs. 3 and 4 revealed that the same spray quality applied with a hooded sprayer exhibited considerably lower particle drift (< 40% RFU) compared to the open sprayer (≤ 100% RFU). Similarly, a comparison among spray qualities revealed that F and M spray qualities for both open and hooded sprayer (Figs. 3 and 4, respectively) are more susceptible to particle drift than EC and UC spray qualities. Additionally, the highest particle drift occurred mostly at sampling distances closest (≤ 10 m) to the application area for both sprayers.

Table 4. Influence of spray type on herbicide particle drift from 20 to 105 m downwind from the application area.

Sprayer Type	Distance Downwind (m)						
	20	30	45	60	75	90	105
	%RFU[z,y] of Open Fine at 1 m						
Open	5.3 a	4.7 a	3.9 a	3.7 a	2.3 a	1.4 a	1.0 a
Hooded	4.2 b	3.8 b	3.1 b	2.6 b	2.0 a	1.2 a	0.9 a

[z] RFU represents relative fluorescence units.

[y] Means followed by the same letter within each column are not significantly different at ($p > 0.05$).

Table 5. Influence of spray quality on herbicide particle drift from 20 to 105 m downwind from the application area.

Spray Quality[z]	Distance Downwind (m)						
	20	30	45	60	75	90	105
	%RFU[y,x] of Open Fine at 1 m						
F	6.1 a	5.8 a	5.1 a	4.2 a	3.6 a	2.0 a	1.5 a
M	5.6 a	4.7 a	4.2 ab	3.6 ab	3.3 a	1.7 a	1.0 a
C	5.1 b	4.3 ab	3.5 b	3.1 b	2.9 a	1.9 a	1.1 a
VC	4.3 bc	3.5 b	3.2 b	2.9 b	2.1 a	1.2 a	1.3 a
EC	3.7 c	3.6 b	2.9 b	2.7 b	2.7 a	1.7 a	1.3 a
UC	3.7 c	3.4 b	2.4 b	2.3 b	2.6 a	1.7 a	1.2 a

[z] Spray quality classifications according to ASABE S572.1.

[y] RFU represents relative fluorescence units.

[x] Means followed by the same letter within each column are not significantly different at ($p > 0.05$).

Asymptote estimates from regression analysis represent Y values at which the slope of the curve approaches zero (Table 6). A higher asymptote value indicates that spray particles travelled a longer distance than a model with a lower asymptote and vice-versa. The asymptote for F spray quality (7.5 %RFU) was the highest among all the treatments indicating the potential of finer spray particles to travel longer distances from the application area. Besides F spray quality, the asymptotes for all other spray qualities for both open and hooded sprayer were comparable to each other when considering the standard error associated with these values. Since the asymptote values represent particle drift at longer distances from the application area, these data validated the ANOVA results which suggested that the difference in particle drift between F spray quality and other spray qualities, and among the spray types was noticed only up to 60 m, and no difference in particle drift deposition within the spray qualities and sprayer type existed beyond that sampling distance. The scale parameter represents the variability present in the distribution which means higher values indicate wider range in particle drift deposition and lower values represent small variation in particle drift deposition. The scale decreases with increase in spray quality VMD due to large variability in particle deposition for the finer spray qualities and relatively small variability for coarser spray qualities (Table 6). Lower scale values for UC spray quality for the open sprayer and all spray qualities for the hooded sprayer also indicated small variability in particle drift deposition amounts across the sampling distances. These data also suggest that both coarser spray qualities and hooded sprayer consistently reduce variability in particle drift.

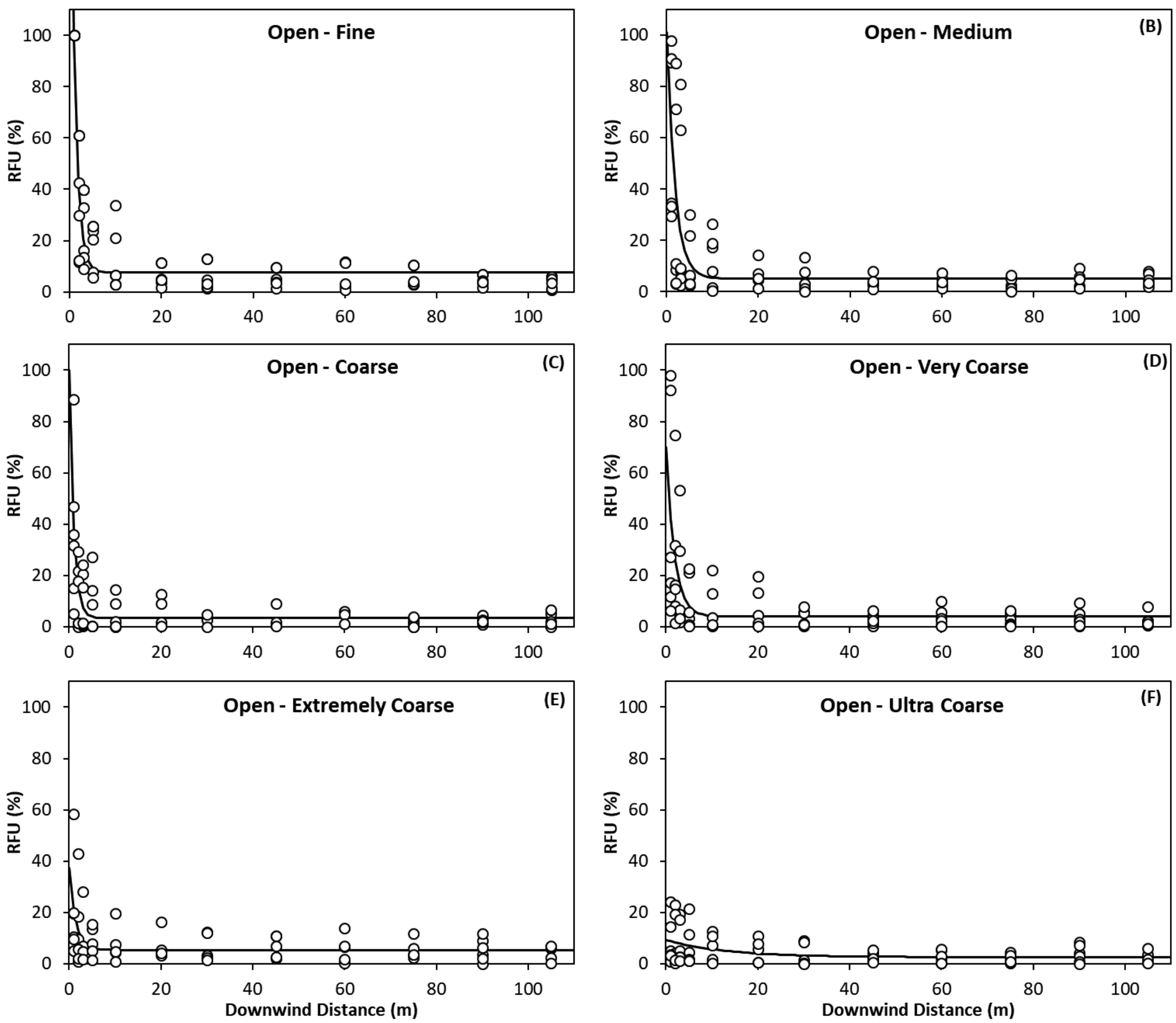

Figure 3. Particle drift recorded at different downwind distances for dicamba applied with different spray qualities with open boom sprayer. The dark solid line in each graph represents the nonlinear regression model fitted to the drift data.

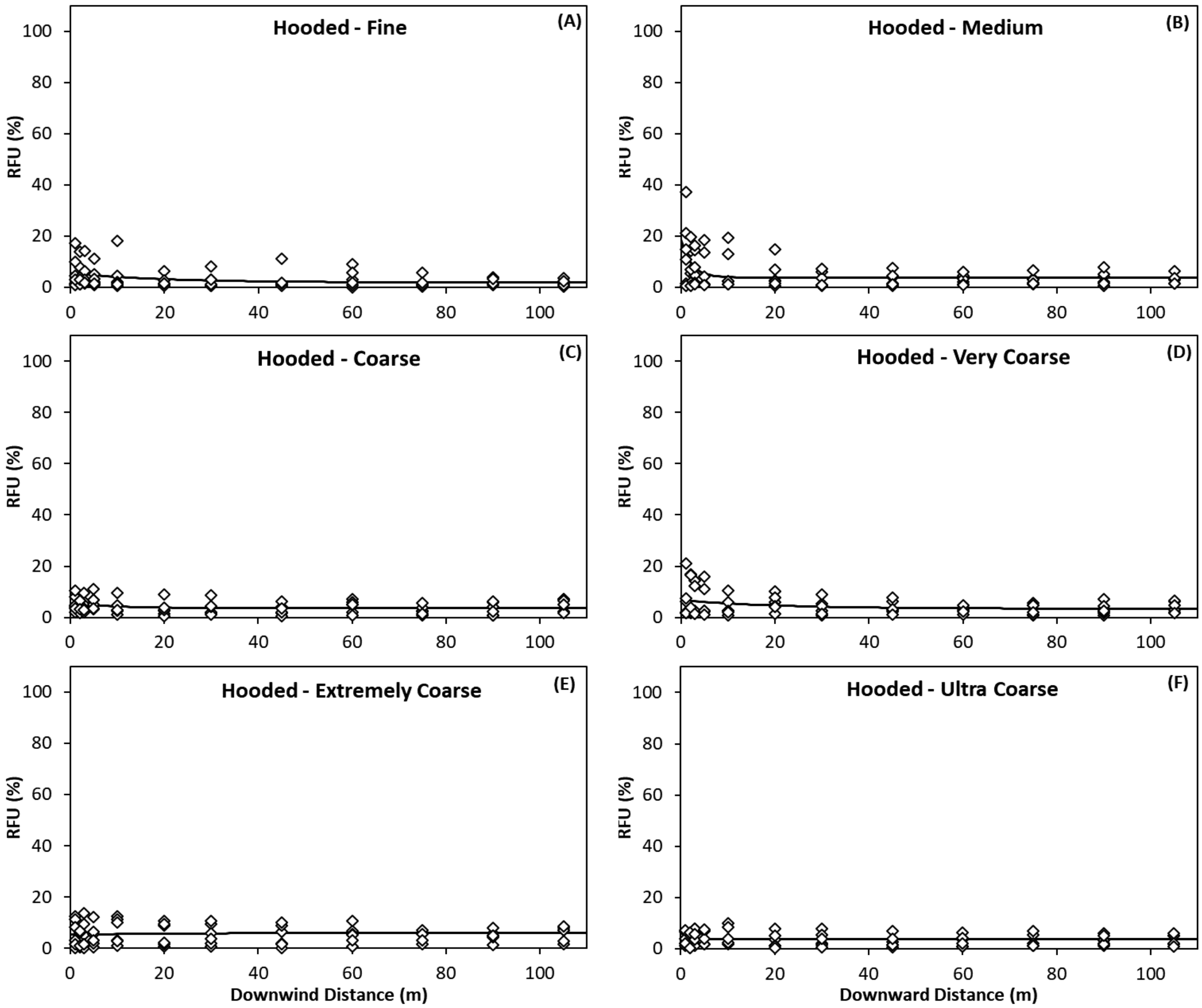

Figure 4. Particle drift recorded at different downwind distances for dicamba applied with different spray qualities with hooded boom sprayer. The dark solid line in each graph represents the nonlinear regression model fitted to the drift data.

Table 6. Parameter estimates for the nonlinear regression models fitted to the spray drift data and downward distance where 10% RFU were detected (DD_{10}) for sprayer type and spray quality.

Sprayer Type	Spray Quality[z]	Asymptote	Scale	Rate Constant	Intercept	DD_{10}
		------ %RFU[y] ------	------- %RFU -------	---- %RFU m^{-1} ----	------- %RFU -------	---- m ----
Open	F	7.5 (±1.3)	242.1 (±29.1)	0.98 (±0.10)	249.9 (±30.4)	9.3*
	M	5.1 (±2.1)	95.9 (±22.9)	0.54 (±0.16)	101.0 (±24.5)	11.5*
	C	4.1 (±1.4)	96.5 (±34.6)	1.03 (±0.32)	99.9 ± (36.1)	3.1
	VC	4.0 (±2.2)	66.0 (±20.5)	0.56 (±0.21)	70.1 (±22.6)	4.0
	EC	5.3 (±1.2)	31.9 (±16.1)	0.73 (±0.39)	37.3 (±17.3)	5.3
	UC	2.5 (±1.1)	6.7 (±1.9)	0.08 (±0.06)	9.2 (±2.9)	3.8
Hooded	F	1.9 (±0.9)	3.7 (±1.2)	0.05 (±0.05)	5.6 (±2.2)	3.3
	M	3.8 (±0.9)	14.9 (±6.3)	0.44 (±0.16)	18.7 (±7.1)	3.8
	C	3.6 (±0.5)	2.0 (±1.0)	0.11 (±0.04)	5.6 (±1.4)	3.8
	VC	3.4 (±0.9)	3.5 (±1.7)	0.06 (±0.27)	6.9 (±2.2)	4.4
	EC	3.2 (±0.8)	0.3 (±0.1)	0.02 (±0.01)	5.5 (±2.5)	3.4
	UC	3.0 (±0.7)	1.3 (±0.8)	0.04 (±0.02)	4.3 (±1.6)	3.5

[z] **Spray quality classifications according to ASABE S572.1.**

[y] **RFU represents relative fluorescence units.**

* **Indicates values that were significantly different from other DD_{10} values within the same column at ($p < 0.05$).**

Rate constants (RC) for the regression models were also compared (Table 6). RC in an exponential nonlinear regression model represents a rate (growth or decay) at which the *Y* value changes with an increase in *X* values. In the present study, higher RC values mean large changes in particle drift deposition with increase in downwind distance and low RC values mean small changes in particle drift deposition with increase in downwind distance. Low RC values (<0.1% RFU m^{-1}) for F, VC, EC, and UC spray qualities for the hooded sprayer and UC spray quality for the open sprayer showed that particle drift deposition was fairly uniform across the sampling distance as compared to the other spray qualities for both hooded and open sprayer. Additionally, the hooded sprayer RC values (0.02 – 0.44 % RFU m^{-1}) were lower than the open sprayer (0.08 – 1.03 % RFU m^{-1}) for the same spray quality indicating the effectiveness of a hooded sprayer in reducing the particle drift deposition across the length of the downwind distance from the application area.

Intercepts for regression models were also calculated and compared among the treatments (Table 6). The intercept of the regression model is an expected mean value of *Y* when *X* = 0. Therefore, a high intercept value in the present study simply implies higher particle drift immediately next to the application area. Consequently, intercepts for the F, M, and C spray qualities for the open sprayer were highest (249.5, 101.0, and 99.9 % RFU, respectively) among all treatments implying highest drift deposition (closest to the application area) associated with these spray qualities. The intercept values, in general, decreased with an increase in spray quality VMD, again indicating the high drift potential linked with finer spray qualities. Similar to other regression parameters, the intercepts for the hooded sprayer (4.3 – 18.7%) were overall lower than the open sprayer (9.2 – 249.9%) regardless of the spray quality suggesting a reduction in particle drift at sampling sites closer to the application area. These findings also validated the ANOVA results, where the sampling sites closest to the application area (1, 2, and 3 m) had the highest particle drift for F, M, and C spray qualities, and hooded sprayer exhibited reduced particle drift compared to the open sprayer across all spray qualities. The downwind distance values at which 10% of the dye concentration was detected (DD_{10}, computed from the regression model) by sprayer type and spray quality are also presented in Table 6. The DD_{10} values for F and M spray quality for the open sprayer were 9.3 and 11.5 m, respectively, while the DD_{10} values for all other spray qualities ranged between 3.1 and 5.3 m for both sprayers and were not significantly different among the spray qualities and sprayer types.

Though the nonlinear regression models used by Foster et al. (2018) and in the present study differed; however, the results from interpretation of similar regression parameters (asymptote, rate constant, and intercept) were analogous to each other. The highest drift for F spray quality at different sampling sites - both closest (intercept) and at longer distances downwind (asymptote) – was observed in both studies. Likewise, similar trends in rate constants and the length of the intercepts in both studies indicated efficacy of hooded sprayer in reducing particle drift for F, M, and C spray qualities.

CONCLUSIONS

Hooded sprayers are getting renewed attention lately due to incentives associated with reduced downwind buffer zone requirements in certain crops such as soybean. Use of a hooded sprayer as one of the drift management strategies and subsequently the reduction of a downwind buffer for dicamba use in soybean is an option currently due to the research efforts of Henry et al. (2014) and Foster et al. (2018) in this area. The authors demonstrated the effectiveness of hooded sprayers in significantly reducing particle drift for herbicide applications in soybean. Similar results were attained in the present study where hooded sprayer effectively reduced particle drift by as much as 94% for the F spray quality and as much as 77% for the M spray quality within the downwind distances of 1 to 10 m from the application area as compared to dicamba applications with an open sprayer in cotton. Additionally, the drift reductions with hooded sprayer ranged from 22% to 42% from 20 to 60 m downwind distance from the application area when averaged across all spray qualities. Overall, these data suggest that hooded sprayers can serve as a viable drift reduction technique for dicamba applications in cotton.

The results from the study also showed that particle drift for VC, EC, and UC spray qualities, beyond 5 m downwind of the application area, was significantly lower than other spray qualities regardless of the sprayer type indicating the effectiveness of higher VMD spray qualities in reducing spray drift. From these data, it can be concluded that a hooded sprayer especially in conjunction with higher VMD spray qualities can be effectively used to reduce particle drift, and consequently the downwind buffer to 33.5 m (from 73.1 m) for dicamba use in cotton, similar to the current reduced downwind buffer for dicamba use in soybean (Anonymous, 2022b). Though this study demonstrated the utility of hooded sprayers for spray drift management in cotton, it is important to emphasize that effective drift mitigation strategies involves more than utilizing a single practice or piece of technology but more or so adopting best management practices during pesticide applications including proper nozzle selection, optimal sprayer settings and operation within recommended speeds, and consideration towards environmental conditions and surrounding fields/crops. The findings from this study may help to expand hooded sprayer use for drift mitigation in cotton and possibly in other crops in the future. To gain more confidence in performance of hooded sprayer and expand their utility across wider range of application conditions, future research efforts should include evaluating the impact of varying environmental conditions such as higher wind speeds and/or temperature as well as the influence of varying ground speeds on drift reduction and pesticide efficacy with hooded sprayers.

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