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Glyphosate Spray Drift Management with Drift-Reducing Nozzles and Adjuvants[1]

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Abstract: Field experiments were conducted to evaluate the effect of five spray-nozzle types and three drift-control adjuvants (DCA) on glyphosate spray drift. The extended-range (XR) flat-fan nozzle at 280 kPa was used as the standard comparison. DCAs were evaluated for drift reduction with the use of the XR and air-induction (AI) nozzles. Wind speed ranged from 1.3 to 9.4 m/s (3 to 21 mph). Lethal drift (D_L) and injury drift (D_I) were determined by downwind visual observation of grain sorghum response. Drift distances were measured from the spray swath edge. The Turbo FloodJet and AI nozzles reduced D_L distance by 34%. All four drift-reducing (DR) nozzles reduced D_I distance by 22 to 32%. Reducing the pressure of the XR flat-fan nozzle from 280 to 140 kPa did not reduce D_L or D_I distance. When applied through AI nozzles, each DCA increased droplet volume diameter, one DCA reduced D_I distance and none reduced D_L distance when applied through XR tips. The DCAs did not affect D_L or D_I distance.
Nomenclature: Glyphosate; grain sorghum, *Sorghum bicolor* (L.) 'Topaz'.
Additional index words: Drift-control adjuvant, flat-fan nozzle, flood nozzle.
Abbreviations: AI, air induction; AMS, ammonium sulfate; DAP, days after planting; DAT, days after treatment; DCA, drift-control adjuvant; DG, preorifice flat fan; D_I, injury drift; D_L, lethal drift; DR, Combo-Jet; GR, glyphosate resistant; HRC, herbicide-resistant crops; TD, TurboDrop; TF, Turbo FloodJet; TT, Turbo TeeJet; VMD, volume median diameter; XR, extended range.

INTRODUCTION

The integration of herbicide resistant crops into United States agriculture has caused increased usage of nonselective herbicides over the past decade. Off-target herbicide movement due to drift is a concern because of injury or contamination risk to plants, wildlife, and surface water. Currently, the vast majority of soybean hectares (87%) and a growing number of corn hectares (17%) are planted to herbicide-resistant crops (HRC) nationwide (National Agricultural Statistics Service, 2005). Glyphosate is the predominant herbicide used in these cropping systems and is applied preemergence and postemergence, resulting in multiple opportunities for glyphosate off-target drift. Herbicide drift not only damages susceptible plants in adjacent areas, but may also reduce weed control in the target area.

Spray nozzles produce droplet sizes ranging from 10 to greater than 1,000 μm (Bouse et al. 1990). Driftable droplets are generally characterized as smaller than 150 μm in diameter (Yates et al. 1985). A droplet with a diameter of 100 μm can drift 7.5 times further than a 500 μm droplet in a 1.4 m/s wind (Bode 1987). Spray droplet size is the primary factor influencing spray drift that can be controlled through management techniques (Kirk 2003).

Nozzle design influences droplet size distribution pattern (Combellack et al. 1996). Larger spray droplets are produced with drift-reduction nozzles due to the nozzle's preorifice, which reduces liquid velocity and pressure at the exit orifice (Derksen et al. 1999; Lafferty et al. 2001). Drift-reducing nozzles increase the volume median diameter (VMD) of the spray mixture and reduce the percent of the spray volume consisting of droplets <200 μm (Mueller and Womac 1997). Drift Guard (DG) and Turbo TeeJet (TT) nozzles had greater VMDs and fewer droplets smaller than 100 μm than XR nozzles. With wind speeds ranging from 5 to 25 km/h, the resulting airborne drift with these two nozzles was reduced 50% compared to the XR nozzle (Grover et al. 1997). Droplets produced by XR flat-fan nozzles are more susceptible to drift than those of other nozzle types (Wolf and Frohberg 2002). Mueller and Womac (1997) ranked XR > DG > TT[3] nozzles as most to least drift prone, re-

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[3] TeeJet XR, Drift Guard, and Turbo TeeJet are trademarks of Spraying Systems Co., Wheaton, IL 60188.

spectively. Wolf (2005) showed that the XR flat-fan nozzle produced greater drift than Combo-Jet (DR) flat-fan or air-induction (AI) nozzles, and TT nozzles were intermediate. Increasing the application volume (47 L/ha to 94 L/ha) did not reduce spray drift with TT, AI, or DR nozzles as compared to the XR nozzle (Wolf 2005). The VMD of a nozzle can be misleading because it does not indicate the range of droplet sizes produced. Current drift-reducing nozzles have shifted the droplet spectrum, yet the uniformity of spray droplets has not increased (Lafferty and Tian 2001).

Adjuvants are products tank-mixed into spray solution to modify solution characteristics, and can be used in combination with drift-reducing nozzles to control drift. Utility adjuvants are primarily used to adjust the spray solution to possess certain characteristics deemed desirable by the operator, not to increase herbicide efficacy. Drift-control adjuvants (DCA), sometimes referred to as *antidrift adjuvants* or *drift retardants*, are characterized by their VMD and driftable fraction (McMullan 2000). The viscoelastic properties are altered in DCAs by including polymers that increase the initial extensional viscosity and decrease shear viscosity. Adjusting these viscosity properties produces a coarser spray with a higher VMD and lower driftable fraction (McMullan 2000; Zhu et al. 1997). Main components in these DCAs are polyacrylamides, polyethylene oxides, or polysaccharides (Kirk 2003), although the active ingredients are proprietary to each manufacturer. Bouse et al. (1988) showed that by increasing polymer concentration from 0.00 to 0.05% in a spray mixture, the VMD increased from 365 to 495 μm and the percentage of droplets less than 204 μm decreased from 4.8 to 2.4% of the total. Zhu et al. (1997) found the VMD to variably increase, from 120 to 200%, based on the polymers used, that is, polyethylene oxide, polyacrylamide, or polysaccharide (xanthum).

Droplet density (drops/cm^2) was reduced when DCAs were added to the spray mixture with XR, DG, and TT nozzles (Fietsam et al. 2004). Although DCAs have been beneficial in controlling drift in some instances, the magnitude of drift reduction is likely to be greater through selection of specific nozzle types (Bouse et al. 1988). For example, spray volume output with AI nozzles was not influenced by DCAs, but the AI nozzle possessed the lowest droplet density of any nozzle tested regardless of DCA presence (Fietsam et al. 2004).

Glyphosate resistance (GR) in major crop species has been achieved through insertion of an insensitive EPSPS (5-enolpyruvylshikimate-3-phosphate synthase) enzyme enabling GR crops to tolerate glyphosate exposure (Padgette et al. 1995). Glyphosate-resistant crops can withstand glyphosate applied postemergence, yet the shikimate pathway is disrupted in susceptible plants, thereby inhibiting aromatic amino acid biosynthesis (Hernandez et al. 1999; Jensen 1986). Limiting off-target movement of glyphosate is important, because even limited exposure to the herbicide can induce plant injury. Hua Liu et al. (1996) reported that glyphosate absorption and translocation is determined more by the concentration of glyphosate in spray droplets than droplet number or droplet size.

The first objective of this research was to determine whether drift-reducing nozzles reduce glyphosate spray drift compared to a standard XR flat-fan nozzle. Second, three DCAs were evaluated with the XR and AI nozzles for effectiveness in reducing drift. Because plant death and injury are important distinctions, drift data are presented as lethal drift (D_L) distance and injury drift (D_I) distance.

MATERIALS AND METHODS

A field experiment was conducted six times during 2000 and 2001 at the University of Nebraska Agronomy Research Farm in Lincoln, NE. The plots were located on Sharpsburg silty clay loam (fine, smectitic, mesic Typic Arguidolls) with 6.7 pH and 3.1% OM. Fields were tilled prior to planting to prepare the seedbed. The bioassay species to determine spray drift was Asgrow[4] 'Topaz' grain sorghum, which was drilled in rows spaced 18 cm apart and seeded at a high rate of 750,000 seeds/ha. Plots were 9 by 15 m in size with no buffer areas between plots. Glyphosate[5] was applied at 840 g ae/ha plus ammonium sulfate (AMS) at 2.0% wt/wt in water at 94 L/ha except 67 L/ha at 140 kPa with the 11004 XR nozzle. The TeeJet 11004 XR flat-fan nozzle at 280 kPa was regarded as the standard treatment and was compared with the Air-Induction 11004 TeeJet (AI),[6] 11004 Turbo TeeJet (TT),[6] TF-2 Turbo FloodJet (TF),[6] and TD04 TurboDrop (TD)[7] all at 280 kPa, as well as the 11004 XR TeeJet at 140 kPa.

Drift-control adjuvants were added to the spray solution according to the product labels as follows: Array 1,081 g/100 L spray solution, B, i.e., Border order 75 g and 50 g/100 L spray solution for the XR and AI noz-

[4] Asgrow Seed; Monsanto Co., St. Louis, MO 63167.

[5] Roundup Ultra; Monsanto Co., St. Louis, MO 63167.

[6] AI TeeJet, Turbo TeeJet, and Turbo FloodJet; Spraying Systems Co., Wheaton, IL 60189.

[7] TurboDrop; Greenleaf Technologies, Covington, LA 70434.

Table 1. Establishment, evaluation, and environmental conditions associated with glyphosate drift injury on grain sorghum.

Experiment no.	Planting date	Spray date	Crop height	Air temperature	Humidity	Wind speed	Time	Evaluation date
		DAP[a]	cm	°C	%	m/s		DAT[b]
1	May 16, 2000	23	10–20	33	55	3.7–7.4	2:00–7:30 P.M.	15
2	May 30, 2000	39	80–90	32	63	1.3–3.6	2:00–4:00 P.M.	14
3	June 30, 2000	24	50–60	27	48	1.3–5.0	12:00–2:00 P.M.	21
4	May 8, 2001	34	15–20	32	50	3.3–9.4	1:00–5:00 P.M.	10
5	May 14, 2001	35	15–25	33	36	4.1–8.7	2:00–4:30 P.M.	14
6	May 23, 2001	33	25–30	32	31	2.9–8.9	1:00–4:00 P.M.	10

[a] DAP = days after planting.
[b] DAT = days after treatment.

zles, respectively, and Placement 66 ml/L of formulated glyphosate. The solutions were applied through both the XR and AI nozzles. Array is a blend of organic elasto polymers dry bonded to AMS. Because Array contains AMS, the amount of AMS was adjusted to ensure all treatments contained 2% AMS. Border EG 250 is a blend of nonionic, water-soluble polymers. Array and Border EG 250 contain DR2000, a polysaccharide-based DCA that has been found to increase spray retention (Hall et al. 1998). Placement is a herbicide encapsulator composed of petroleum distillates and fatty acids.

Treatments were applied east to west with a tractor-mounted, 3-m-wide spray boom in a south crosswind. The south 3 m of each plot was the spray swath, and spray drifted northward onto the remaining 12 m of the plot. Although temperature inversions can affect drift, inversion conditions did not occur during applications. A boom height of 60 cm above the sorghum canopy and nozzle spacing of 76 cm provided 100% spray overlap for all nozzles except the Turbo FloodJet. The boom height was decreased to 45 cm above canopy with the TF nozzle treatment to provide 100% spray overlap. Treatments were made with a tractor-mounted CO_2 sprayer operated at 12.9 km/h.

Wind speed was measured 120 cm above ground level with a Kestrel 3000[8] wind meter for each plot. Wind gusts were avoided by visually observing crop movement upwind. The upwind fetch (distance upwind free of disturbance) was always greater than 400 m. Environmental conditions are presented in Table 1 for each experiment.

Grain sorghum was visually assessed 10 to 21 d after treatment (DAT) to determine lethal and injury response. Herbicide drift that induced sorghum death (brown growing point), is termed *lethal drift* (D_L). Herbicide drift that caused visible foliar injury symptoms of chlorosis and necrosis is termed *injury drift* (D_I). Lethal-drift (D_L) distance was the distance from the downwind edge of the spray boom to the furthest dead grain sorghum plant. Injury-drift (D_I) distance was the distance from the downwind edge of the spray boom to the farthest injured grain sorghum plant. Injury-drift distance inherently includes the D_L distance, because plant death will occur closer to the treated area.

A water-sensitive card (wsc)[9] was placed on the soil surface directly under the spray path in each 2001 experiment. The wsc (2.5 by 7.6 cm) permanently changes color upon contact with water droplets. Cards were collected immediately, placed in individual plastic bags, and analyzed at Kansas State University with the use of DropletScan™[10] software. DropletScan™ measures volume median diameter ($D_{V0.5}$) of the spray spectrum as well as $D_{V0.1}$ and $D_{V0.9}$; $D_{V0.1}$ is reported herein. $D_{V0.1}$ is the droplet diameter below which 10% of the spray volume occurs.

The experimental design was a randomized complete block with four replicates. Data were subjected to analysis of variance with the use of the SAS Proc GLM[11] program. Wind was included as a covariant in the drift analysis. Means were separated with a pairwise T test ($P = 0.05$). No significant year or date interactions existed for any of the drift or droplet statistics measured. The six trials were pooled so each treatment mean represents 24 replicates.

RESULTS AND DISCUSSION

The TF, AI, and TD nozzles reduced D_L distance by 0.5 m (34%), compared to the XR nozzle at 280 kPa (Table 2); whereas, the TT nozzle did not reduce D_L distance compared to the XR nozzle. All four drift-reducing nozzles reduced D_I distance by 1.8 to 2.6 m (22

[8] Kestrel 3000; Nielsen-Kellerman Co., Chester, PA 19013.

[9] Water-sensitive cards; Novartis Corporation, East Hanover, NJ 07936.

[10] DropletScan™ (WRK of Arkansas, Lonoke, AR and WRK of Oklahoma, Stillwater, OK); Devore Systems, Inc., Manhattan, KS.

[11] SAS Proc GLM; SAS Institute Inc., Cary, NC 27513.

Table 2. Volume diameter (0.1), lethal drift distance, and injury drift distance of glyphosate spray as affected by nozzle type. Sorghum was the drift indicator species.

Nozzle type	Spray pressure	Volume diameter[a,b]	Lethal drift distance[b]	Injury drift distance[b]
	kPa	microns	meter	
Turbo FloodJet	280	261 bc	1.1 a	5.5 a
TeeJet Al	280	284 a	1.1 a	5.7 a
Turbo Drop	280	267 ab	1.1 a	6.3 a
Turbo TeeJet	280	250 cd	1.3 ab	6.2 a
XR TeeJet	280	240 de	1.6 b	8.1 b
XR TeeJet	140	222 ef	1.7 b	8.0 b

[a] The volume diameter (0.1) is the droplet diameter below which 10% of the spray volume occurs.

[b] Means within a column followed by the same letter do not differ (p = 0.05) with the use of a pairwise T test.

Table 3. Volume diameter (0.1),[a] lethal drift distance, and injury drift distance of glyphosate spray as affected by three drift-control agents within two nozzle types. Sorghum was the drift indicator species.

Nozzle type	Drift agent	Volume diameter[a,b]	Lethal drift distance[b]	Injury drift distance[b]
		microns	meter	
XR TeeJet	None	240 AB	1.8 A	8.6 A
	Array	256 A	1.7 A	7.7 A
	Border	240 AB	1.7 A	7.2 A
	Placement	232 B	1.6 A	8.2 A
TeeJet AI	None	285 b	1.1 ab	6.2 b
	Array	303 a	0.9 ab	5.8 b
	Border	302 a	0.8 a	4.8 a
	Placement	308 a	1.4 b	6.0 b

[a] The volume diameter (0.1) is the droplet diameter below which 10% of the spray volume occurs.

[b] Means within a nozzle type and a column followed by the same letter do not differ (p = 0.05) when compared with the standard nozzle used alone, with the use of a pairwise T test.

to 32%), compared to the XR nozzle (Table 2). Although Wolf (2005) showed no drift-reduction advantage with TT nozzles as compared to XR nozzles, spray drift was only measured out to 4 m and differences may have been masked. Fietsam et al. (2004) found that, with glyphosate, the XR nozzle had greater drift compared to DG and AI nozzles, but not more than TT nozzle.

Decreasing spray pressure by 50% with the XR nozzle did not affect D_L and D_I distances (Table 2), which matches findings by Mueller and Womac (1997) and Wolf and Frohberg (2002). Reducing the pressure was not an effective way to reduce spray drift when using the XR nozzle. Although less water was applied at 140 kPa, this did not change D_I or D_L distances.

Higher $D_{V0.1}$ values indicate a lower proportion of drift-prone droplets. The AI, TD, and TF nozzles increased $D_{V0.1}$ compared to the XR flat-fan standard (Table 2). These three nozzles reduced the percentage of driftable particles, which resulted in lower D_L and D_I distances. The XR nozzle at 140 kPa did not differ in $D_{V0.1}$ from the XR nozzle at 280 kPa. This lack of change in $D_{V0.1}$ values is probably the reason there was no difference in D_L or D_I distances for the two pressures. Although detectable drift would have been greater if the water-sensitive cards had been placed above the soil surface (Vangessel and Johnson 2005), the relative differences among nozzles are not expected to have been different.

The XR and AI nozzles were also evaluated with and without drift-control adjuvants. When applied through the XR nozzles, Array, Border, or Placement did not reduce D_L distance (Table 3). When applied with the AI nozzle, D_L distances associated with DCA applications were similar to applications without DCA, but the D_L distance associated with Placement was 0.6 m greater than that of Border.

Drift-control adjuvants did not reduce D_I distance when applied with the XR nozzle (Table 3). D_I distance was reduced 1.5 m (24%) when Border was applied with the AI nozzle compared to the AI nozzle alone. Array and Placement had no effect on D_I distance with the AI nozzle. Overall the DCAs did not reduce D_L or D_I distance, except for Border when applied with the AI nozzle.

Fietsam et al. (2004) found that a polyacrylamide- and polysaccharide-based DCA reduced total drift by 13% and 18%, respectively. Similar to our findings, Vangessel et al. (2005) found that the addition of DCAs to flood or flat-fan nozzles did not reduce spray drift or injury to sorghum.

The effect of DCAs on $D_{V0.1}$ differed between XR and AI nozzles (Table 3). When applied with the XR nozzle, the $D_{V0.1}$ associated with the DCA's did not differ from the application without a DCA; however, the $D_{V0.1}$ was greater for Array than Placement. When applied with the AI nozzle, Array, Border, and Placement increased the $D_{V0.1}$ by 17 to 23 μm. Although each DCA reduced driftable droplets when applied with the AI nozzle, this reduction did not translate to in-field differences of D_L or D_I distance, except with Border. Ramsdale and Messersmith (2001) found no differences in control of three bioassay species among DG, TT, AI, TD, and conventional TP nozzles, despite differences in the spray coverage on water-sensitive cards.

The use of XR nozzles is discouraged in high-wind environmental conditions, as greater drift is expected to occur than with TT, AI, TD, or TF nozzles. Drift-reduction nozzles (TT, AI, TD, or TF) reduced D_L and D_I distances compared to the XR nozzle. The D_L distance was reduced up to 0.6 m with these nozzles compared to the XR nozzle. The D_I distance was reduced up to 2.6 m. The only drift reduction for a DCA was D_L distance with Border using the AI nozzle. Based on this research, reduction of off-target glyphosate movement will be accomplished more frequently with drift-reducing nozzles than DCAs. The use of drift-reducing nozzles to control drift is less expensive than including a DCA with each spray application.

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