Research Article

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Utility of roller wiper applications of dicamba for Palmer amaranth control in soybean

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Abstract

BACKGROUND: The commercialization of dicamba-resistant soybean has resulted in increased concern for off-target movement of dicamba onto sensitive vegetation. To mitigate the off-target movement through physical drift, one might consider use of rope wicks and other wiper applicators. Although wiper-type application methods have been efficacious in pasture settings, the utility of dicamba using wiper applicators in agronomic crops is not available in scientific literature. To determine the utility of roller wipers for dicamba applications in dicamba-resistant soybean, two separate experiments were conducted in the summer of 2020 and replicated in both Keiser and Fayetteville, AR, USA.

RESULTS: Utilizing opposing application directions and a 2:1:1 ratio of water: formulated glyphosate: formulated dicamba were the most efficacious practices for controlling Palmer amaranth. The high herbicide concentrations and wiping in opposing directions increased dicamba-resistant soybean injury when the wiper contacted the crop, but no yield loss was observed because of this injury. Broadcast applications resulted in greater Palmer amaranth mortality than roller wiper applications, and the most effective roller wiper treatments were when two sequential applications were made inside the crop canopy.

CONCLUSIONS: Dicamba applications require adequate coverage for optimum weed control. While efforts can be made to increase roller wiper efficacy by optimizing coverage and timing of applications, broadcast applications are superior to roller wiper applicators for weed control. Roller wiper applications did not reduce soybean yield, thus wiper-type applications may be safely used in dicamba-resistant soybean, albeit the likelihood for off-target damage caused by volatilization of these treatments would need to be investigated.

Keywords: herbicide application techniques; weed wiper; rope wick; wick applicator; spray drift management; resistance management

1 INTRODUCTION

Dicamba is a synthetic auxin herbicide (WSSA Group 4) that has been primarily used for broadleaf weed management. The use of dicamba in North America has been an integral aspect of weed management programs in corn (*Zea mays* L.), small grains, pasture, and rangeland for more than 50 years.[1–3] The evolution of herbicide-resistant weeds, such as Palmer amaranth, waterhemp [*Amaranthus tuberculatus* (Moq.) J. D. Sauer], and horseweed (*Conyza canadensis* L. Cronq.) in soybean, has forced producers to seek alternative options for broadleaf weed management in broadleaf crops, such as the addition of dicamba.[4–6] In response to the growing number of herbicide-resistant broadleaf weeds in cotton (*Gossypium hirsutum* L.) and soybean, Monsanto, now owned by Bayer Crop Sciences, developed crops that were resistant to both glyphosate and dicamba.[7] The commercialization of the herbicide Xtendimax® plus VaporGrip® and dicamba-resistant soybean branded as RoundupReady 2 Xtend Soybean® in 2016 enabled producers to apply dicamba in-crop for broadleaf weed control.

Combinations of glyphosate and dicamba controlled 90% to 100% of glyphosate-resistant waterhemp, Palmer amaranth, and horseweed.[8] Applications of dicamba in dicamba-resistant cotton controlled 88% to 90% of protoporphyrinogen oxidase (PPO)-resistant Palmer amaranth in Arkansas at 21 days after treatment (DAT).[9] Growers in Nebraska reported that the addition of dicamba to soybean herbicide programs resulted in improved weed control for 93% of growers surveyed.[10] Concurrent with the commercialization of dicamba for in-crop use over soybean in 2016, there was an increase in complaints for auxin damage on non-dicamba resistant soybean. The off-target movement of dicamba was deemed to be caused primarily by three factors, volatilization, physical spray drift, and tank contamination.[11,12]

In order to prevent off-target movement of dicamba onto sensitive crops and vegetation, producers and researchers began to seek alternative management practices that would mitigate physical spray drift and tank contamination. The use of growing

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physical barriers, such as corn[13] and the use of hooded sprayers,[14] to avert spray droplets from leaving the treated area have been shown to be viable options for mitigating physical, off-target herbicide movement. An additional method being considered by producers to reduce physical spray drift is the utilization of application technology that does not depend on broadcasting spray solution to control weeds. Rather than spraying droplets on weeds, wipers and wicks directly apply the herbicide onto the leaves of vegetation via contact with a saturated surface, such as a rope or fabric material.[15] By applying herbicide directly onto the target plants, the risk of off-target movement via physical drift from a broadcast spray is greatly decreased.[16]

Wiper type applicators, such as rope wicks, roller wipers, and rotary wipers, were initially utilized for applying auxin herbicides, such as 2,4-D, above broadleaf crops to selectively control broadleaf weeds that grew above the crop canopy.[17,18] Prior to the development of glyphosate-resistant crops, rope wicks and wipers were used to apply glyphosate above crop canopies to effectively control weeds, such as johnsongrass [*Sorghum halepense* (L.) Pers.], shattercane [*Sorghum bicolor* (L.) Moench spp.], and volunteer corn, as long as the target weed remained above the crop canopy.[19,20] However, to prevent potential crop injury, care had to be taken to prevent leaking or dripping of herbicide from pipes or improperly calibrated systems.[17,21,22] Previous extension research conducted in Arkansas during the onset of glyphosate-resistant Palmer amaranth in cotton investigated the utility of wiper type applicators, specifically roller wiper and rope wick applicators, for applications of paraquat and diuron to manage Palmer amaranth for rescue applications (Norsworthy, personal communication, 2019).

By using wiper-type applicators in crops resistant to herbicides, such as dicamba, the risk for crop injury would be reduced and would potentially allow for producers to use a wiper type application within the crop canopy. To effectively assess the utility and feasibility of dicamba applications using a wiper-type applicator in dicamba-resistant soybean, two separate studies were conducted in the summer of 2020. The objectives of these studies were to determine optimal practices for a roller-wiper application, evaluate application timing and coverage methods for maximizing Palmer amaranth control, evaluate crop safety from roller-wiper applications in dicamba-resistant soybean, and determine whether or not that roller wiper applications of dicamba would be viable options for Palmer amaranth control compared to broadcast applications in dicamba-resistant soybean.

2 MATERIALS AND METHODS

2.1 Experiment design and establishment

Two separate field experiments were both conducted in 2020 at the Northeast Research and Extension Center near Keiser, AR (35.68, −90.08) and at the Milo J. Shult Arkansas Agricultural Experiment Station at in Fayetteville, AR (36.09, −94.17). The purpose of these experiments was to investigate (i) the influence of weed height, herbicide concentration, and application direction on Palmer amaranth control in dicamba-resistant soybean (herbicide rate study) and (ii) the impact that application method and the use or non-use of sequential herbicide applications has on weed control in dicamba-resistant soybean (herbicide placement study). Dicamba-resistant soybean (Asgrow 46X6; Bayer CropScience, St Louis, MO, USA) was planted on May 20 at both Keiser and Fayetteville. These locations are more 375 km apart. Row spacings were 97 cm in Keiser and 91 cm in Fayetteville. Both locations were furrow-irrigated to supplement natural rainfall. The soil texture at Fayetteville was a Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudult) with a pH of 6.4. The soil texture at Keiser was a Steele loamy sand (sandy over clayey, mixed, superactive, non-acid, thermic Aquic Udifluvent) with a pH of 6.7.[24] Both sites had natural populations of glyphosate-resistant Palmer amaranth (Norsworthy, 2021 personal communication).

The herbicide rate experiment was designed as a randomized complete-block design using a three-factor factorial ($3 \times 2 \times 2$) treatment structure that included a non-treated control and an additional comparison treatment where plots were subjected to a typical postemergence dicamba-based broadcast spray application. The broadcast program consisted of dicamba at 560 g a.e. ha^{-1} (Xtendimax; Bayer Crop Science) plus glyphosate at 1260 g a.e. ha^{-1} (Roundup PowerMax II; Bayer Crop Sciences) plus pyroxasulfone at 120 g a.i. ha^{-1} (Zidua WDG; BASF, Research Triangle Park, NC, USA) followed by dicamba at 560 g ha^{-1} + glyphosate at 1260 g ha^{-1} + acetochlor at 1260 g a.i. ha^{-1} (Warrant; Bayer Crop Sciences). The three factors of the experiment were target weed height at application (20–30 cm, 40–50 cm, 60–70 cm), herbicide concentration [one part Xtendimax:one part Roundup PowerMax: six parts water (*v/v/v*) or one part Xtendimax:one part Roundup PowerMax:two parts water (*v/v/v*)], and application direction (one direction or two). Concentrations were based off of those specified in dicamba product labels.[25] Plots receiving applications from multiple directions were applied for the first time as the tractor moved down the rows and the second application was made in the opposite direction immediately after the tractor moved completely through the field and had turned to travel in the opposite direction. The plots measured 6.1 m in length and were two rows wide (1.8 m wide in Fayetteville and 1.9 m wide in Keiser) with a two-row non-treated running check on either side of the treated rows.

All plots excluding the non-treated control were treated with *S*-metolachlor at 562 g ha^{-1} (Dual Magnum; Syngenta Crop Protection, Greensboro, NC, USA) at planting using a carbon dioxide (CO_2)-pressurized backpack sprayer at 140 L ha^{-1} using AIXR 110015 nozzles (TeeJet Technologies, Wheaton, IL, USA) to slow emergence of Palmer amaranth. Roller wiper treatments were made when Palmer amaranth were the appropriate heights in plots. The comparative broadcast treatment was made as a salvage treatment when Palmer amaranth reached a 20- to 30-cm height, and a sequential application was made 14 days after final treatment (DAFT). At time of the initial postemergence application, ten Palmer amaranth plants were measured and marked with paint at the base of the plant to aid identification and location of targeted plants at a later date.[26–28] In the case where there were not ten Palmer amaranth plants in the plot, all Palmer amaranth in the plot were measured and marked. Palmer amaranth densities and heights were recorded at the time of the first postemergence application (Table 1). Temperature was recorded throughout the season using a Watch Dog 2000 Series permanent weather station (Spectrum Technologies Inc., Aurora, IL, USA) located on site (Fig. 1). Roller wiper applications were made using a Grassworks™ three-point tractor-mounted weed wiper (Grassworks USA LLC, Lincoln, AR, USA) (Fig. 2) where the wiper was wetted prior to entering the plot and was consistently rolling as the tractor moved through the plot. The roller wiper was selected over other types of wiper type applicators due to the ability to utilize the multiple tanks to carry the different herbicide concentration mixtures to the remote field location as well as due to the research laboratory already having possession of the roller wiper. The carpet on the wiper is wetted using spray nozzles

Table 1. Average Palmer amaranth height and density at the time of initial application for both the herbicide rate and herbicide placement experiments in Fayetteville and Keiser, AR, in 2020

Location	Experiment	Height average (range) (cm)	Density average (range) (plants m^{-2})
Fayetteville	Herbicide rate	—[a]	8 (1–16)
	Herbicide placement	44 (8–72)	8 (1–16)
Keiser	Herbicide rate	—	27 (20–52)
	Herbicide placement	50 (37–71)	22 (12–36)

[a] Herbicide rate experiments included target heights 20–30, 40–50, and 60–70 cm as factors.

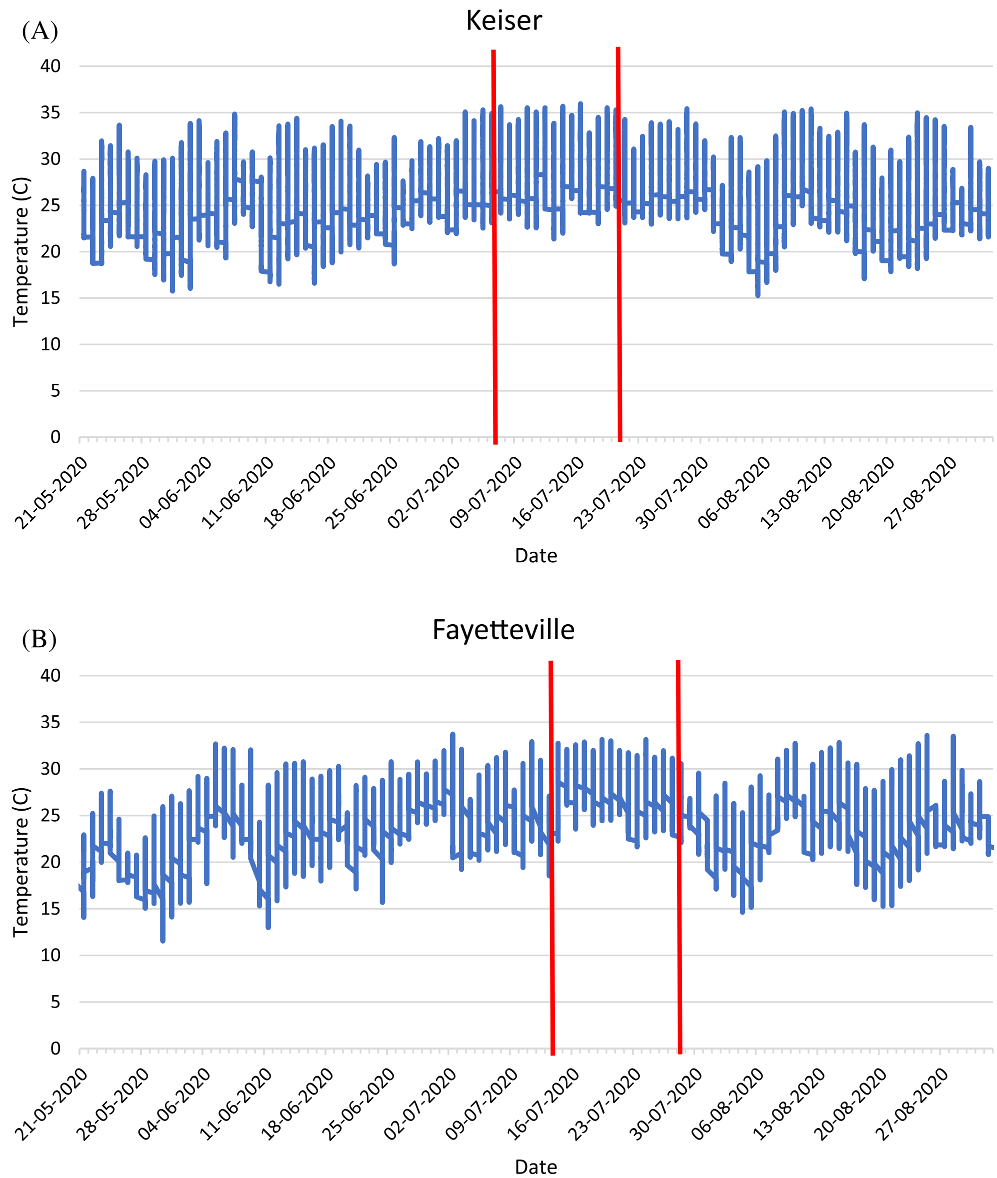

Figure 1. Air temperature in degrees Celsius during the growing season at (A) Keiser and (B) Fayetteville, AR. Vertical red lines indicate herbicide application dates.

inside of closed system that prevents herbicide physical drift. The wiper was placed 10 cm into the crop canopy and was moved through the plot at a speed of 8.5 kph. Treatments were wiped in succession as the tractor traveled down the rows, lowering the wiper into the canopy for plots receiving treatments and raising the wiper above the canopy to avoid treating plots not receiving treatments. Between different treatments, plots were allowed to dry in order to mitigate contamination of the tractor as the applicator moved through the field to apply different treatments.

The herbicide placement experiment was designed as a three factor (3 × 2 × 2) factorial with the first factor being the

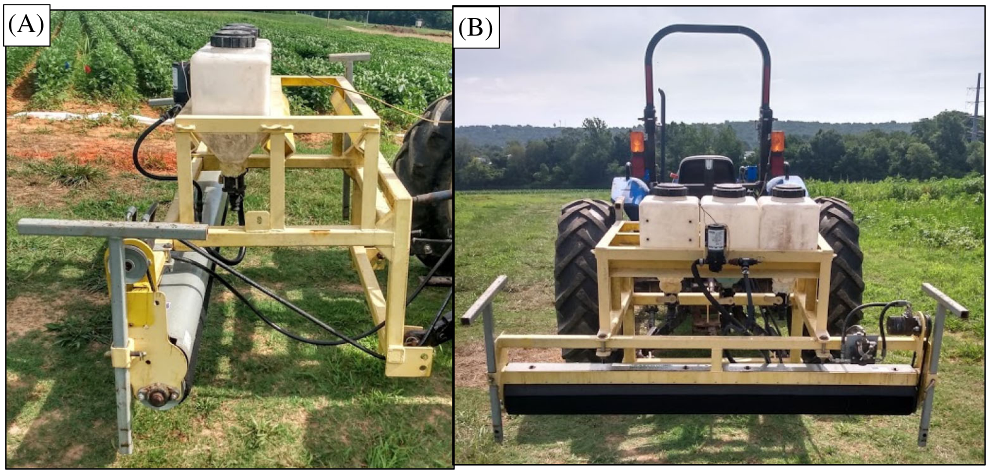

Figure 2. Side (A) and rear (B) view of the two-row Grassworks® roller wiper used for both studies.

placement of the application (over the top broadcast, at canopy roller wiper, and roller wiper 10 cm inside the soybean canopy), the second factor being the preemergence herbicide used [S-metolachlor at 534 g a.i. ha^{-1} (Dual Magnum; Syngenta Crop Protection) and a combination of flumioxazin at 35 g a.i. ha^{-1} and pyroxasulfone at 45 g a.i. ha^{-1} (Fierce; Valent, Walnut Creek, CA, USA)], and the third factor being the presence or absence of a sequential application 14 days following the initial application. At time of initial postemergence application, ten Palmer amaranth plants were measured, marked, and counted as described for the previous experiment. Palmer amaranth densities and heights were recorded at the time of the first postemergence application (Table 1) and temperature was recorded throughout the season using a Watch Dog 2000 Series permanent weather station (Spectrum Technologies Inc.) located on site (Fig. 1).

Preemergence and broadcast applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 276 kPa. Preemergence applications were made using TeeJet AIXR 110015 nozzles and broadcast postemergence applications were made using TeeJet TTI 110015 nozzles. Roller wiper applications were made as previously described using the Grassworks™ weed wiper. The wiper was placed 10 cm into the crop canopy for the in-canopy treatments and touching the crop canopy (0–2 cm within the crop canopy) for the canopy treatments. Ground speed of the tractor was 8.5 kph. Initial applications were made when Palmer amaranth measured 40–50 cm in height (Table 1) and soybean measured 50 cm in height.

2.2 Data collection

For both studies, visible estimates of Palmer amaranth control were rated at 7, 14, 21, and 28 DAFT on a scale of 0 to 100, where 0 represents no plant symptomology and 100 represents plant death. At 28 DAFT, marked Palmer amaranth plants were individually evaluated for mortality (dead or alive) and the total number of deceased Palmer amaranth were divided by the number of marked plants to provide mortality proportion for each plot.[26–28] Visible soybean injury was rated at 7, 14, and 21 DAFT in the herbicide placement study and at 14 and 21 DAFT in the herbicide rate study on a similar scale to that used for Palmer amaranth control. Soybean grain from the two treated rows of each plot was harvested at maturity using an ALMACO© SPC40 (ALMACO, Nevada, IA, USA) and adjusted to 13% moisture.

2.3 Data analysis

Data for both trials were analyzed in R version 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria). Data were evaluated for normality using Shapiro–Wilks tests and equal variance was determined by plotting the residuals of the model prior to final model selection.[29] Variables which met both normality and homogeneity of variance assumptions were evaluated with linear models using base functions. Those models that did not satisfy the assumptions of equal variance or normal distribution were analyzed using a non-parametric factorial model using the rankFD package.[30,31] Initially, models were tested with site as a factor to test for interactions between site and other factors. Exploratory model testing of Palmer amaranth data for the herbicide placement study resulted in site by factor interaction for all variables. As a result, data were analyzed separately by site. Conversely, exploratory model testing found only two site by factor interactions for the herbicide rate study. As a result, the herbicide placement study data were pooled over site. One-way analysis of variance (ANOVA) analyses were conducted using data from the herbicide rate study to compare results from the roller wiper treatments to a broadcast comparison. Data in the herbicide placement study were subjected to Type I ANOVA, and means were separated using least significant differences with Tukey's adjustment at $\alpha = 0.05$. Data in the herbicide rate study were subjected to Type III ANOVA using Palmer amaranth height relative to the height of the roller wiper at time of application as a covariate, and means were separated using least significant differences with Tukey's adjustment at $\alpha = 0.05$.

3 RESULTS AND DISCUSSION

3.1 Herbicide rate study

Generally, there were differences between the two sites, primarily as it related to Palmer amaranth control, but there were no significant interactions between site and any other factor, except between site and target height for Palmer amaranth control and mortality at 28 DAFT (Table 2). As a result, data were pooled across sites rather than analyzing the data separately.

Visible Palmer amaranth control and mortality were influenced by the interaction between target weed height and site at 28 DAFT

Table 2. The *P*-values from analysis of covariance for soybean injury at 14 and 21 days after final treatment (DAFT), soybean yield, Palmer amaranth control at 14, 21, and 28 DAFT, and Palmer amaranth mortality 28 DAFT from 2020 in Fayetteville and Keiser, AR

	Soybean injury ($P > F$)		Soybean	Palmer amaranth control ($P > F$)			Palmer amaranth
Source	14 DAFT	21 DAFT	yield ($P > F$)	14 DAFT	21 DAFT	28 DAFT	mortality ($P > F$)
Height	0.1972	0.1930	0.8512	0.0661	0.9787	0.7689	0.2487
Rate	**0.0009**	**0.0018**	0.6108	0.3293	0.7141	0.0634	**0.0008**
Direction	0.6314	**0.0119**	0.5511	**0.0016**	**0.0449**	**0.0338**	**0.0047**
Site	0.9054	0.3324	**0.0001**	**<0.0001**	**<0.001**	**<0.0001**	**<0.0001**
Height:Rate	0.0935	0.0775	0.6215	0.5186	0.9505	0.7941	0.4521
Height:Direction	0.3833	0.9527	0.6443	0.9437	0.7320	0.9681	0.5824
Rate:Direction	0.2441	0.6960	0.8724	**0.0213**	0.4388	0.9948	0.4995
Height:Site	0.2539	0.9150	0.4447	0.4701	0.1162	**0.0131**	**0.0001**
Rate:Site	0.1356	0.1390	0.4908	0.6028	0.3820	0.4206	0.4258
Direction:Site	0.2966	0.6043	0.8684	0.2399	0.3952	0.0634	0.1577
Height:Rate:Direction	0.8165	0.7720	0.5331	0.7260	0.9915	0.5655	0.8378
Height:Rate:Site	0.8426	0.4404	0.5635	0.2627	0.6632	0.4289	0.9588
Height:Direction:Site	0.2488	0.6243	0.9084	0.0681	0.5000	0.5928	0.5151
Rate:Direction:Site	0.1265	0.6043	0.9840	0.2399	0.6077	0.3724	0.4272
Height:Rate:Direction:Site	0.2210	0.3079	0.5968	0.3964	0.8611	0.7697	0.4034

Bolded values indicate statistical significance at $\alpha = 0.05$.

Table 3. Palmer amaranth control at 28 days after final treatment (DAFT) and Palmer amaranth mortality at 28 DAFT by interactions location by Palmer amaranth height at time of application in 2020 at Fayetteville and Keiser, AR

Treatment		Palmer amaranth control (%)	28 DAFT	Palmer amaranth mortality (%)
Location × Palmer amaranth height				
Site	Palmer amaranth height			
Fayetteville	20–30 cm	81 a		53 ab
	40–50 cm	80 a		60 a
	60–70 cm	72 ab		31 c
Keiser	20–30 cm	59 b		17 c
	40–50 cm	58 b		24 c
	60–70 cm	72 ab		38 bc

Means followed by the same letter are not statistically different based on Tukey's ($\alpha = 0.05$).

(Table 2). Palmer amaranth control at 28 DAFT for the two smallest target heights in Fayetteville were similar, resulting in 81% and 80% control for the 20–30 cm and 40–50 cm target heights respectively (Table 3). These levels of control were greater than those at Keiser for the same target heights, where 59% and 58% Palmer amaranth control occurred following treatment at the 20–30 cm and 40–50 cm target heights respectively. At the tallest target weed height, Palmer amaranth control was 72% at both Keiser and Fayetteville, although the control was not different from that of the smaller target weed heights (Table 3).

Palmer amaranth mortality followed a similar trend to Palmer amaranth control at 28 DAFT. An improvement in mortality occurred in Fayetteville for the two smallest target heights with 53% and 60% mortality for the 20–30 and 40–50 cm target heights compared to the 60–70 cm target height where only 31% mortality was achieved. At Keiser, mortality did not vary among the three target heights (Table 3). These discrepancies in control between the two locations may be attributed to differences in weed density (Table 1). The reduced density in Fayetteville would have allowed for greater contact between the wiper and individual weeds instead of some weeds being shielded from the wiper by other weeds in a denser population, such as in Keiser.[23]

Soybean manifested chlorosis and necrosis following roller wiper applications (Fig. 3). Slight differences were ascertained between the two herbicide concentrations at 14 and 21 DAFT (Table 2), resulting in soybean injury that was <10% at any evaluation timing but there were no more than a 3% difference in the injury that resulted from the different herbicide concentrations. (Table 4). Greater phytotoxicity could be expected at higher concentrations due to the increased adjuvant load from the glyphosate formulation used, as at high concentrations, adjuvants may illicit plant injury.[32] Chlorosis may have also been the result of increased aminomethylphosphonic acid (AMPA) concentrations, a byproduct of the metabolism of glyphosate by glyphosate-resistant soybean, that may have been caused by the increased concentration of glyphosate by the roller wiper.[33] Soybean injury at 21 DAFT was also slightly influenced by the number of directions of the herbicide applications (Table 2). Applications from two directions resulted in 5% injury, whereas those with a single application direction resulted in 4% injury (Table 4). Although the injury could be associated with adjuvant burn, the difference in injury can be attributed to differences in coverage that resulted from applying herbicide to both sides of the plant. Injury was low and appeared to be transient and had no effect on soybean yield.

When compared to a typical broadcast herbicide application, the roller wiper provided inferior Palmer amaranth control and mortality (Table 5). At 14, 21, and 28 DAFT, broadcast applications controlled Palmer amaranth 86–94% compared to 70–72% control with the roller wiper applications. Greater Palmer amaranth mortality resulted from the broadcast application (83%) than from the roller wiper applications (37%) (Table 5). Deviations in mortality may be attributed to differences in herbicide coverage, where the broadcast applications were able to evenly distribute herbicide throughout the crop canopy while the roller wiper applications were only able to place herbicide at the point of contact and not place any herbicide on weeds below the height of the roller wiper. Similar results have been observed in studies investigating the effects of different droplet sizes from broadcast applications where less uniform distribution of herbicide reduced weed control.[26,34,35,37] Soybean visible injury, although so low as to have no significant effect on yield, was slightly higher with the broadcast application than the roller wiper applications (Table 5). Other research[32,33,38] also suggests that the degree of injury in this study would not affect soybean yield.

Figure 3. Image of chlorotic soybean injury 14 days after final treatment as a result of roller wiper application of dicamba.

3.2 Herbicide placement study

Results for the herbicide placement study varied between locations, partially because of differences in weed population densities (Table 1) and climate (Fig. 1) between the two locations. At Keiser, Palmer amaranth populations were 22 plants m^{-2} compared to the 8 plants m^{-2} in Fayetteville (Table 1). Keiser was also generally warmer than Fayetteville throughout the growing season (Fig. 1), resulting in greater Palmer amaranth growth during the season.[39] As a result, several site by treatment factor interactions emerged (data not shown); thus, the two locations were analyzed separately to better understand the results from the study (Table 6).

At Keiser, Palmer amaranth control was influenced by two factors, herbicide placement and the number of applications at 14, 21, and 28 DAFT (Table 6). At 28 DAFT, the broadcast treatment resulted in greater control compared to the at-canopy treatment only, while the inside-canopy treatment was similar to both other placements at 28 DAFT (Table 7). The lower Palmer amaranth control by the roller wiper treatments can be attributed to inferior herbicide coverage of all weeds in the plot. The roller wiper applications were limited by the relative height of the applicator, whereas the broadcast applications were made to all weed sizes. The lack of uniformity of coverage onto weeds and the inability to reach weeds below the canopy has been a shortfall of wiper-based applications as previously reported by Moyo *et al.*[37] With the wiper-based applications, the herbicides were primarily applied to the top leaves of the Palmer amaranth.

Previous research has found that dicamba typically translocates only to the nutrient sinks of the plant,[41–43] which at the time of application was limited to the upper Palmer amaranth leaves and inflorescence. As a result, dicamba, does not typically translocate to the lower parts of the plant, resulting in symptomology being primarily concentrated near the area of application for the roller wiper applications. Conversely, the broadcast applications

Table 4. Soybean injury at 14 and 21 days after final treatment (DAFT), soybean yield, Palmer amaranth control at 28 DAFT, and Palmer amaranth mortality at 28 DAFT by rate, direction, and location in Keiser and Fayetteville, AR in 2020

Treatment	Soybean injury 14 DAFT (%)	Soybean injury 21 DAFT (%)	Yield (kg ha^{-1})	Palmer amaranth control 28 DAFT (%)	Mortality (%)
Rate					
High	9 a	6 a	2844	73	44 a
Low	6 b	4 b	3052	67	30 b
Direction					
One	7	4 b	2973	66 b	31 a
Two	8	5 a	2923	74 a	43 b
Site					
Fayetteville	8	5	2760 b	77	48
Keiser	7	4	3136 a	63	26

Means followed by the same letter are not statistically different based on Tukey's ($\alpha = 0.05$).

Table 5. Palmer amaranth mortality, visual control at 28 days after application, visible soybean injury 14 and 21 days after application and soybean yield for contrast analyses comparing broadcast applications of dicamba to roller wiper applications of dicamba at Fayetteville and Keiser, AR in 2020

		Palmer amaranth control (%)	Soybean injury (%)		
Broadcast *versus* wiper	Palmer amaranth mortality (%)	28 DAFT	14 DAFT	21 DAFT	Soybean yield (kg ha^{-1})
Broadcast	82.5 a	94 a	2 b	2 b	2900
Wiper	37.1 b	70 b	7 a	5 a	3100
P-Value	**0.0002**	**<0.0001**	**0.0004**	0.0135	0.6786

Means followed by the same letter are not statistically different based on Tukey's ($\alpha = 0.05$).
Bolded values indicate statistical significance at $\alpha = 0.05$.

Table 6. The *P*-values from analysis of variance for soybean injury at 7, 14 and 21 days after final treatment (DAFT), soybean yield, Palmer amaranth control at 14, 21, and 28 DAFT, and Palmer amaranth mortality 28 DAFT from 2020 in Fayetteville and Keiser, AR

	Palmer amaranth control ($P > F$)			Palmer amaranth mortality ($P > F$)	Soybean injury ($P > F$)			Soybean yield ($P > F$)
Source	14 DAFT	21 DAFT	28 DAFT		7 DAFT	14 DAFT	21 DAFT	
Keiser								
PRE	0.0762	0.4984	0.7633	0.3009	0.7084	0.2831	0.3246	0.4435
Placement	**0.0013**	**0.0130**	**0.0109**	**0.0075**	**0.0006**	0.8086	0.3788	0.1745
Num.app	**0.0017**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0043**	0.3246	0.8269
PRE:Placement	0.8565	0.7820	0.3346	0.6909	0.7680	0.7415	0.3788	0.0878
PRE:Num.app	0.0732	0.1868	0.7534	0.6227	0.7084	0.7607	0.3246	0.4004
Placement:Num.app	0.0880	0.5451	0.1587	**0.0343**	**0.0006**	0.7398	0.3788	0.3380
PRE:Placement:Num.app-value	0.2244	0.1015	0.9686	0.9512	0.7680	0.2201	0.3788	0.1461
Fayetteville								
PRE	0.1416	0.1932	**0.0270**	**0.0041**	0.8136	0.5701	0.9999	0.3418
Placement	0.0727	**0.0070**	**0.0038**	**0.0008**	**0.0019**	0.1120	0.0879	0.4420
Num.app	**0.0077**	**0.0105**	0.0826	**0.0157**	0.2044	0.4802	**0.0109**	0.4894
PRE:Placement	0.3636	0.0595	**0.0078**	**0.0046**	0.3117	0.4867	0.3569	0.6384
PRE:Num.app	0.3593	0.4540	0.3698	0.4421	0.1492	0.3373	0.8277	0.1121
Placement:Num.app	0.0881	**0.0222**	**0.0287**	**0.0209**	0.3362	0.3335	0.4294	0.4898
PRE:Placement:Num.app-value	0.9063	0.3207	0.1043	0.2492	0.8943	0.8098	0.1058	0.2269

Abbreviations: PRE = preemergence herbicide option, Place = herbicide placement, Num.app = number of herbicide applications.
Bolded values indicate statistical significance at $\alpha = 0.05$.

provided a more uniform distribution of herbicide on the plant, thus increasing the amount of the plant that was exposed to dicamba and resulting in more uniform dicamba uptake and Palmer amaranth control, as reported by Cuvaca *et al.*[37]; Butts *et al.*[26]; and Meyer *et al.*[34,36]

Palmer amaranth control in Keiser was also influenced by the number of herbicide applications (with or without the sequential treatment) (Table 6). Averaged over all other factors, the addition of a second application resulted in 83% Palmer amaranth control at 28 DAFT (Table 7). Control with only the single application of dicamba was lower (63%). These results are similar to those by Priess *et al.*[44] in which a single application of dicamba resulted in 50% Palmer amaranth control and a sequential application increased control to 95% when a 14-day interval was implemented on 18-cm Palmer amaranth.

At 28 DAFT at Fayetteville, Palmer amaranth was controlled 85% and 89% with a single application of dicamba if it was applied with the roller wiper inside the canopy or if it was broadcast, respectively. However, control with two roller wiper applications did not differ between placement at canopy and inside the canopy. Mortality data were somewhat variable, but two applications placed at canopy increased control over one application (Table 7). Although not different from most other application placements, dicamba applied in two broadcast applications was numerically higher than other treatments.

The reduced control and mortality from the single at-canopy treatment may stem from the height of the roller wiper placement at which the herbicide only reached weeds that would be at or above the canopy, whereas, the in-canopy placement would reach weeds just below the crop canopy, and the broadcast placement could make contact with all weeds in the crop canopy. The lack of a significant difference between the single and sequential applications with the in-canopy placement as opposed to at-canopy placement may be a function of Palmer amaranth growth patterns following dicamba applications. Following the first application, the shorter plants that had not contacted the wiper potentially grew taller. As a result, a greater number of Palmer amaranth may have come in contact with the wiper as it moved through the plots. Meanwhile the plants that had been wiped with the previous application may have

Table 7. Visible Palmer amaranth control at 28 days after final treatment (DAFT), Palmer amaranth mortality, visible soybean injury at 7, 14, and 21 DAFT and soybean grain yield from Fayetteville and Keiser AR in 2020

Treatment		Palmer amaranth control (%)	Palmer amaranth mortality	Soybean injury (%)			Soybean yield (kg ha^{-1})
		28 DAFT		7 DAFT	14 DAFT	21 DAFT	
Fayetteville							
Herbicide placement							
At-canopy		76	47	4b	3	1	2500
Inside canopy		82	48	8a	4	2	2400
Broadcast		92	80	4b	2	1	2700
Premergence option							
S-Metolachlor		89	70	5	3	1	2500
Flumioxazin + pyroxasulfone		77	47	6	3	1	2600
Number of applications							
One		80	49	5	3	1 b	2600
Two		86	68	6	4	2 a	2500
Placement × number of applications							
Number of application	Herbicide placement						
One	At canopy	65 c	23 c	5	3	1	2600
	Inside canopy	87 ab	50 abc	6	3	3	2600
	Broadcast	88 ab	74 ab	4	3	2	2600
Two	At canopy	87 ab	71 ab	3	3	0	2500
	Inside canopy	77 bc	46 bc	10	6	1	2300
	Broadcast	95 a	86 a	4	2	0	2700
Preemergence × herbicide placement							
Preemergence option	Herbicide placement						
S-Metolachlor	At canopy	85 a	59 ab	4	4	1	2300
	Inside canopy	94 a	75 a	8	5	2	2400
	Broadcast	89 a	75 a	3	2	1	2700
Flumioxazin	At canopy	67 b	34 b	5	2	0	2700
+ pyroxosulfone	Inside canopy	70 b	22 b	8	4	2	2500
	Broadcast	95 a	86 a	5	3	2	2700
Keiser							
Herbicide placement							
At-canopy		66 b	19	3	1	0	3800
Inside canopy		69 ab	21	3	1	0	3900
Broadcast		83 a	43	0	1	0	4100
Number of applications							
One		63 b	12	4	2 a	0	3900
Two		83 a	43	0	0 b	0	3900
Placement × number of applications							
Number of application	Herbicide placement						
One	At canopy	50	6 b	5 a	0	1	3700
	Inside canopy	64	14 b	5 a	0	0	4100
	Broadcast	75	15 b	0 b	0	0	4100
Two	At canopy	83	32 b	0 b	2	0	3800
	Inside canopy	74	28 b	0 b	2	0	3700
	Broadcast	92	70 a	0 b	1	0	4200

Means followed by the same letter within a factor or for multiple factors are not statistically different based on Tukey's ($\alpha = 0.05$).

grown downwards as the result of epinasty from the prior dicamba application.[45] With the second application taking place at a greater height from the ground due to the continued growth of the soybean crop, the plants that had previously been wiped did not receive a second in-canopy application. Conversely, with the at-canopy application, the wiper was able to contact more weeds that had grown taller because fewer weeds were treated with the first application as a result of their uninterrupted growth.

The same interaction was observed for Palmer amaranth mortality in Keiser, where there were no differences among the different placements following a single application (Table 7). There was, however, a difference between the broadcast herbicide placement and the two roller wiper placements following two postemergence applications; the at-canopy and in-canopy applications resulted in reduced mortality compared to the broadcast treatment (Table 7). Due to dense weed populations at Keiser, the benefits of the broadcast placement may not have been completely materialized following a single application, possibly due to a great number of larger Palmer amaranth that protected smaller Palmer amaranth beneath the canopy. This taller overgrowth may have allowed for those plants underneath to survive the single application. With the addition of the second application, those larger Palmer amaranth plants that were initially treated by the broadcast would have significantly reduced their surface area after 14 days following the dicamba application[46] allowing for the second application to contact the weeds that had previously been shielded.

Palmer amaranth control at 28 DAFT and mortality in Fayetteville were influenced by an interaction between herbicide placement and the preemergence option (Table 6). Broadcast treatments of flumioxazin + pyroxasulfone preemergence controlled Palmer amaranth 95%, which was similar to control with *S*-metolachlor preemergence followed by at-canopy, in-canopy, and broadcast postemergence placements (Table 7). Both roller wiper treatments, at-canopy and in-canopy, that followed flumioxazin + pyroxasulfone preemergence resulted in lower Palmer amaranth control than the broadcast applications. The differences between the two application methods (roller wiper *versus* broadcast) as influenced by the preemergence option and the mortality of the Palmer amaranth may be attributed to the differences in efficacy of the preemergence options. The premix of flumioxazin + pyroxasulfone may have provided a longer residual compared to *S*-metolachlor; pyroxasulfone has a half-life of 71 days compared to a half-life of 27 days for *S*-metolachlor.[47] Residual activity may have delayed growth of Palmer amaranth in the plots treated with flumioxazin + pyroxasulfone preemergence. Furthermore, the use of two separate, effective herbicides with the use of flumioxazin + pyroxasulfone compared to the single herbicide used with the treatments utilizing *S*-metolachlor would also explain the increase in Palmer amaranth suppression by those plots treated with flumioxazin + pyrixasulfone.[48] Therefore, for the roller wiper applications, weeds may have been shorter at application following flumioxazin + pyroxasulfone compared to Palmer amaranth following *S*-metolachlor, resulting in reduced contact by the roller wiper and decreased Palmer amaranth control.

Visible soybean injury at Fayetteville was influenced by herbicide placement at 7 DAFT (Table 6). The at-canopy and broadcast treatments both resulted in 4% injury while the in-canopy treatments resulted in 8% injury (Table 7). The increased injury from the in-canopy treatments may be attributed to the increased contact by the roller wiper in these plots as the wiper was placed deeper into the soybean canopy than the other treatments. Soybean injury was once again significant at 21 DAFT as a function of the number of herbicide applications (Table 6), where 2% soybean injury was recorded following the single application while there was only 1% injury following the second application, potentially due to higher temperatures following the first application (Fig. 1) these greater temperatures may have contributed to greater adjuvant injury as opposed to the cooler temperatures that followed the second application in Fayetteville.[32] Conversely, at 14 DAFT in Keiser, there was 2% soybean injury following the use of two applications where there was no injury following the use of a single application. Warmer temperatures in Keiser (Fig. 1) following the first application, relative to the second application, may have allowed for the soybean to recover and grow faster.[45] At 7 DAFT in Keiser, visible soybean injury was dependent on an interaction between application placement and the number of herbicide applications (Table 6). Following the single application, both roller wiper placements resulted in 5% injury while no injury was observed in the broadcast treatment (Table 7). The presence of injury as the result of the roller wiper applications may be attributed to physical contact and abrasion from the roller wiper and small sized tractor moving through the plots coupled with the increased concentrations of adjuvants from higher concentrations of formulated product that may have caused most of the injury (chlorotic or necrotic leaves).[32] There was no visible injury at 21 DAFT in Keiser and no differences in soybean grain yield were observed in both studies (Table 6). These results infer that any injury observed at 7 days after application was cosmetic and did not impact the grain production of the soybean. These results are not unlike previous works that have shown that low levels of injury from labeled applications do not correlate to yield loss.[49,50]

4 CONCLUSIONS

These studies suggest that the use of roller wiper applicators for weed control are not as effective as broadcast applications of dicamba. If roller wiper applicators are to be used, it is recommended that these applications be done in a way that maximizes herbicide coverage onto target weed species. The use of multidirectional applications with increased herbicide concentrations as well as sequential applications may be necessary for adequate control and to deliver a lethal rate in an attempt to curb herbicide resistance development through sub-lethal doses of dicamba.[51,53,54] During these studies, many of the weeds were above labeled heights according to current labels for dicamba herbicides. Further research may need to be conducted to investigate if applications may be optimized earlier in the season when both soybean and Palmer amaranth are smaller than 20 cm. At this point, broadcast applications of residual herbicides at the same time as the roller wiper applications should be utilized to prevent any further weed emergence before canopy closure by the soybean.[51,55] The use of roller wipers was found to be relatively safe for soybean production systems as yields were not reduced because of roller wiper applications.

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CONFLICT OF INTEREST

No conflicts of interest have been declared.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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