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PREEMERGENCE AND POSTEMERGENCE EFFICACY OF DICAMBA ON GLYPHOSATE RESISTANT PALMER AMARANTH (*Amaranthus palmeri* S. Wats.) AND OPTIMUM RATE FOR CONTROL

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EXECUTIVE SUMMARY

The extensive adoption of glyphosate-resistant (GR) technology from the 1990's through the mid 2000's led to a reduction in the use of herbicides other than glyphosate for weed control in soybeans.

Growers relying solely on glyphosate for weed control has led to the evolution of GR weed biotypes, which has reduced or eliminated the viability of glyphosate-only herbicide systems.

Dicamba, which has been used in row crops for many years, has provided control of many annual broadleaf weeds including *Amaranthus* species. Due to the evolution of GR weeds, interest in the utility of dicamba for an alternative control option is increasing.

In field studies, Valor SX (Flumioxazin) applied preemergence at 0.06 lb/acre provided 95% control of GR Palmer amaranth. Clarity (dicamba) applied at 1.0 and 0.50 lb/acre provided 85 and 75% control, respectively. Residual control from dicamba will not persist as long as that from Valor SX.

Residual activity and persistence of both Valor SX and Clarity applied preemergent was greatest at 14 days after treatment (DAT) and declined at 21 and 28 DAT.

Valor SX applied preemergence resulted in the greatest reduction in GR Palmer amaranth plant density and biomass at 28 DAT.

Dicamba applied postemergent at a 0.50 lb/acre rate controlled 5-cm-tall Palmer amaranth 81 and 90% at 14 and 28 DAT, respectively. When applied at a 1.0 lb/acre rate, control was 88 and 95% at 14 and 28 DAT, respectively. Addition of glyphosate to dicamba did not significantly improve control.

Dicamba applied postemergent at a rate of 0.50 lb/acre to 10- and 15-cm-tall Palmer amaranth provided only 70 and 75% and 60 and 68% control at 14 and 28 DAT, respectively.

Since dicamba applied postemergence did not provide 100% control of 5-cm-tall GR Palmer amaranth, it should not be relied on as a one-pass herbicide program for managing this weed.

Results from these field experiments and a companion greenhouse experiment indicate that postemergent applications of dicamba must be made to very small (~2 inches tall) GR Palmer amaranth to optimize weed control, especially at the expected use rate of 0.50 lb/acre.

BACKGROUND

The extensive adoption of glyphosate-resistant (GR) technology from the 1990's through the mid 2000's led to a reduction in the use of herbicides other than glyphosate (Young 2006; Whitaker et al. 2010). During that time many growers relied only on glyphosate for weed control (Foresman and Glasgow 2008; Gustafson 2008; Green 2009). This has led to evolution of GR biotypes, which has reduced or eliminated the viability of glyphosate-only herbicide systems (Whitaker et al. 2010). Of the weeds that have evolved to GR, Palmer amaranth (*Amaranthus pameri* S. Wats.) has become the most problematic weed in the southeastern United States (Steckel 2007). In addition, Palmer amaranth populations have also been confirmed to exhibit multiple-resistance to glycine and ALS-inhibiting herbicides in Mississippi and Georgia (Nandula et al. 2012; Sosnoskie et al. 2011).The development of dicamba resistance in soybean and cotton could provide an alternative mechanism-of-action (MOA) to GR cropping systems to control Palmer amaranth (Behrens et al. 2007; Subramanian et al. 1997).

Auxinic herbicides 2,4-D and MCPA were the first truly selective herbicides, and their discovery was revolutionary for agriculture (Coupland 1994). Dicamba, also an auxinic herbicide, was commercialized in the 1960's, and commercial formulations include Clarity® and Banvel® (BASF, Florham Park, NJ), which are labeled for use in soybean, cotton, and corn (Feng et al. 2010). Clarity®[1] may be applied preemergence 15 to 30 days prior to planting cotton and soybean at rates of 0.27 to 0.55 kg ae ha^{-1}, but after 2.5 cm of accumulated rainfall or irrigation. Similar rates of Clarity may be applied preemergence or early postemergence in corn.

Dicamba, which has been used in row crops for many years, has proved to provide control of many annual broadleaf weeds including *Amaranthus* species (WSSA 2007). Dicamba has been proven to control *Amaranthus* species, as evidenced by 97 to 100% control of GR Palmer amaranth at the six-leaf stage with dicamba applied at 0.28 kg ha^{-1} (Norsworthy et al. 2008).

Due to the evolution of GR weeds, interest in the utility of dicamba for an alternative control option is increasing. Dicamba has become a common herbicide for early preplant applications in the spring and has been shown to provide greater than 86% control of GR horseweed (*Conyza canadensis* L. Cronq.) (Owen et al. 2009). Another experiment by Eubank et al. (2008) found that the addition of 2,4-D and dicamba to paraquat improved control of GR horseweed (78 to 89%). However, crop injury can be expected on soybean if the dicamba label is not closely followed.

A study by Feng et al. (2010) evaluated injury of conventional soybean and dicamba-resistant soybean 28 days after a preemergence and postemergence application of dicamba at various rates; results from this particular study indicate complete death of conventional soybean treated with dicamba at 0.55 kg ha^{-1} with little to no injury on dicamba-resistant soybean, even at the highest rate observed (5.0 kg ha^{-1}). Thompson et al. (2007) reported soybean sensitivity to preemergence applications of dicamba applied within 14 days of planting. However, dicamba and other auxinic herbicides vary in soil persistence, depending on environmental conditions such as soil moisture (Cheng and Lehmann 1985). Other research by Altom and Stritzke (1973)

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[1] Clarity®, BASF Agricultural Products, Research Triangle Park, NC 27709.

indicates that dicamba is persistent and has a half-life that varies from 7 to 32 days in various soils.

Auxinic herbicides do not affect a single target site and they do not have long-term residual activity, which has led to the belief that these compounds are “low-risk” for resistance development (Coupland 1994). Despite commercialization of dicamba in agriculture over 50 years ago, the incidence of resistance has remained low compared to glyphosate usage and resistance issues since GR crops were introduced (Jasieniuk et al. 1995). According to Heap (2013), five weed species have been reported as dicamba-resistant in cropland: common hempnettle (*Galeopsis tetrahit* L.), kochia (*Kochia scoparia* L.), wild mustard (*Sinapis arvensis* L.), common lambsquarters (*Chenopodium album* L.) and prickly lettuce (*Lactuca serriola* L.).

Dicamba is more specifically classified as a synthetic auxin herbicide, which is readily absorbed by shoot and root uptake and is translocated through the plant’s system by both phloem and xylem pathways accumulating in areas of active growth (WSSA 2007; Ashton and Crafts 1981). The auxinic herbicides are structurally similar to plant hormones indole-3-acetic acid (IAA), often referred to as auxins. The plant hormone IAA is vital to regulate cell division and elongation along with long-range signaling for systemic communication among various plant organs (Mithila et al. 2011; Grossman 2010; Went 1926). These herbicides generally regulate the functions of IAA in vascular tissue and floral meristem differentiation, leaf initiation, phyllotaxy, senescence, apical dominance and root formation (Grossman 2010). Dicamba mimics the natural plant hormone IAA, resulting in epinastic response in broadleaf weed species, eventually leading to chlorosis and necrosis (WSSA 2007).

The auxin herbicides exhibit selectivity to various weeds and are often classified intro four groups, depending on structural and chemical properties: phenoxyalkanoic acids (e.g. 2,4-D), benzoic acids (e.g. dicamba), pyridines (e.g. picloram), and quinolinecarboxylic acids (e.g. quinclorac) (Mithila et al. 2005). Selectivity of these herbicides depends largely on the resemblance of their structure to endogenous auxins within the plant (Coupland 1994). Selectivity is due to decarboxylation, side chain degradation, and side chain elongation as a result of rapid conversion of parent molecules from aryl hydroxylation, and glycoside conjugate formation (Coupland 1994; Owen 1991; Hagin et al. 1970; Broadhurst et al. 1966).

A new technology in the pipeline for commercialization is dicamba-resistant soybean, which will be marketed as Genuity® Roundup Ready 2 Yield® Xtend (Monsanto Company, St. Louis, MO). Along with this new technology are new formulations of a traditional chemistry. Monsanto Company and BASF Corporation are collaborating together to bring the dicamba-resistant soybean technology to market with intentions to develop individual formulations of dicamba to be used for this cropping system. BASF will introduce BAS 18322H, a new low-volatile formulation of dicamba. The dicamba-resistant soybean system will allow producers the option of applying dicamba as an additional MOA in-season and prior to planting for control of GR Palmer amaranth along with other broadleaf weeds. Research is needed to evaluate the level of efficacy that can be obtained with new dicamba formulations.

The overall objective of this research is to determine the optimum utilization of dicamba-resistant soybean technology to manage troublesome weed species in Mississippi. The specific objectives include: (1) determining residual activity of field-applied dicamba on Palmer amaranth emergence; (2) use field experiments to evaluate various rates of dicamba to determine

the most efficacious rates and timings for the postemergence control of GR Palmer amaranth; and (3) use greenhouse experiments to evaluate and confirm the optimum rate for control of Palmer amaranth with the new BAS 18322H formulation of dicamba.

CONVERSION OF UNITS

0.07 kg/ha = 0.06 lb/acre
0.14 kg/ha = 0.125 lb/acre
0.28 kg/ha = 0.25 lb/acre
0.56 kg/ha = 0.50 lb/acre
0.75 kg/ha = 0.67 lb/acre
0.84 kg/ha = 0.75 lb/acre
1.1 kg/ha = 1.0 lb/acre
2.24 kg/ha = 2.0 lb/acre
140 L/ha = 15 gal/acre
248 kPa = 36 psi
262 kPa = 38 psi
400 kPa = 58 psi

FIELD EXPERIMENTS--CONDUCT

Locations and years:

2011 Location One: on-farm near Greenville, Mississippi (34°34'N, 90°46'W); Commerce very fine sandy loam soil with a pH of 5.9, an organic matter content of 0.96%, and a cation exchange capacity (CEC) of 9.6.

2011 Location Two: on-farm near Jonestown, Mississippi (33°35'N, 91°07'W); Dubbs and Dundee very fine sandy loam soil with a pH of 6.2, an organic matter content of 0.72%, and a CEC of 12.3.

2012 Location: on-farm at the same Greenville, Mississippi location.

Both locations were naturally infested with established populations of GR Palmer amaranth. These on-farm locations have been in row crop production for many years, with the Greenville location mostly devoted to GR soybean production and the Jonestown location having rotations of GR corn (*Zea mays* L.) in 2010 and GR cotton (*Gossypium hirsutum* L.) in 2009 prior to this research.

Experimental Design, Preemergence Experiment:

Factorial arrangement of treatments in a randomized complete block design.
Factor One: four rates of dicamba[2] at 0, 0.28, 0.56, and 1.1 kg ae ha^{-1}.
Factor Two: application timings of 30, 15, and 0 days prior to planting.

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[2] **Dicamba, Clarity®, BASF Agricultural Products, Research Triangle Park, NC 27709.**

Flumioxazin[3] at 0.07 kg ae ha^{-1} was applied as a comparison treatment of residual activity. All treatments contained paraquat[4] at 0.75 kg ae ha^{-1} and NIS[5] (non-ionic surfactant) at 0.25% v/v.

Treatment Application Method, Preemergence Experiment:

Greenville location: applied with a tractor-mounted sprayer calibrated to deliver 140 L ha^{-1} at a pressure of 248 kPa.

Jonestown location: applied with a CO_2 pressurized backpack sprayer which was also calibrated to deliver 140 L ha^{-1} at a pressure of 262 kPa. Tee Jet®[6] flat fan nozzles were used for all applications.

Treatment Application Dates, Preemergence Experiment:

2011: March 29, April 11, and April 21. Daytime temperatures during this time frame ranged from 16 to 27 C. Overall rainfall accumulations at both locations were sufficient for activation of residual activity.

2012: April 23, May 8, and May 23. Daytime temperatures in 2012 ranged from 21 to 32 C, which was slightly warmer than the prior year. Rainfall in 2012 was almost half the amount received in 2011, which did not provide residual activation at several application timings.

Data Collection, Preemergence Experiment:

Visual ratings at 7, 14, 21, and 28 days after treatment (DAT) based on a scale from 0 to 100%, with 0 representing no residual control and 100% representing no emergence of plants within a plot.

At 28 DAT, two 1-m^2 areas of each plot were hand-harvested to collect plant density counts and above-ground biomass for Palmer amaranth. Plant biomass samples were oven-dried for 7 days at 66 C. These two areas were averaged and plant density and biomass were calculated as a percent reduction based on the nontreated plot of each replication, where:

Percent Reduction = Plant density or biomass of nontreated minus plant density or biomass of treatment/plant density or biomass of nontreated x100 (*Equation 1*).

Data Analyses, Preemergence Experiment:

Data were analyzed in ANOVA, and means were separated using Fisher's protected LSD at $p \leq 0.05$ through SAS[7] PROC MIXED v.9.2. Locations were analyzed as site-years and were included as a random statement with DAT and herbicide treatment as main effects.

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[3] **Flumioxazin, Valor SX®, Valent U.S.A. Corporation, Walnut Creek, CA 94596.**
[4] **Paraquat, Gramoxone SL®, Syngenta, Greensboro, NC 24719.**
[5] Non-Ionic Sufactant, Induce®, Helena Chemical Company, Collierville, TN 38017
[6] Tee Jet®, Spraying Systems Co., Wheaton, IL 60189.
[7] SAS, Version 9.2, SAS Institute, Inc., SAS Campus Dr., Cary, NC 27513.

Experimental Design, Postemergence Experiment:

Factorial arrangement of treatments in a randomized complete block design.
Factor One: three rates of dicamba at 0.28, 0.56, and 1.1 kg ae ha^{-1}.
Factor Two: two rates of glyphosate[8] at 0 and 0.84 kg ae ha^{-1} .
Factor Three: plant heights at application of 5, 10, and 15–cm-tall Palmer amaranth.

Measurements, Postemergence Experiment:

Visual ratings were taken 7, 14, 21, and 28 DAT. Visual ratings were made on a scale from 0 to 100%, with 100% being completely controlled and 0% representing no visual effects. Plant density counts and above-ground biomass for Palmer amaranth were collected 28 DAT and were recorded as the average of two 1-m^2 areas of each plot. Plant biomass samples were oven-dried for 7 days at 66 C. Plant biomass were calculated as a percent reduction based on the nontreated plot of each replication (Equation 1).

Data Analyses, Postemergence Experiment:

Data were analyzed in ANOVA, and means were separated using Fisher's protected LSD at $p \leq 0.05$ through SAS PROC GLIMMIX v.9.2. Locations were analyzed as site-years and were included as a random statement with plant height, biomass, and herbicide treatment as main effects.

GREENHOUSE EXPERIMENT--CONDUCT

Conducted in 2012 at the R.R. Foil Research Center in Starkville, Mississippi for confirmation of the optimum rate of dicamba for control of GR Palmer amaranth.

Experimental Design:

Factorial arrangement of treatments in a randomized complete block design.
Factor One: five rates of dicamba (BAS 18322H) at 0.14, 0.28, 0.56, 1.1, and 2.24 kg ae ha^{-1}.
Factor Two: plant heights of 5, 10, and 15–cm-tall Palmer amaranth.

Confirmed GR Palmer amaranth seed was collected from prior field experiment plots and grown in flats to be transplanted at the seedling stage into individual 10 by 10 cm pots. Each pot was filled with a commercial potting mix[9] and contained one plant. Plants were fertilized and sub-irrigated as needed. Treatments were made in a spray chamber calibrated to deliver 140 L ha^{-1} with a Tee Jet® flat fan spray tip at 400 kPa.

Measurements:

Visual ratings were made at 7, 14, 21 and 28 DAT. Visual ratings were based on a scale from 0 to 100%, with 0% representing no visual effects and 100% representing complete control. At 28

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[8] **Glyphosate, Roundup PowerMax®, Monsanto Company, St. Louis, MO 63167.**
[9] Metro-Mix 360, Sun Gro Horticulture, Vancouver, British Columbia.

DAT, Palmer amaranth plants were hand-harvested to collect plant density and above-ground biomass. Plant biomass was calculated as a percent reduction based on the nontreated plot of each replication (Equation 1).

Data Analyses:

Data were analyzed in ANOVA, and means were separated using Fisher's protected LSD at $p \leq 0.05$ through SAS PROC GLIMMIX v.9.2. Trials were repeated in time and included as a random statement with plant height, biomass, and herbicide treatment as main effects.

Results and Discussion--Preemergence Field Experiment

There were no interactions between rating intervals and herbicide treatments; however, they were independently significant ($p \leq 0.05$). Application timings effects were not significant; thus, data were pooled across the three timings. Data will be discussed as herbicide treatments pooled across rating intervals and also as rating intervals pooled across all herbicide treatments.

- Flumioxazin controlled Palmer amaranth 95% and was similar to control from the 0.56 and 1.1 kg ha^{-1} rates of dicamba at 75 and 85%, respectively. The lowest rate of dicamba, 0.28 kg ha^{-1}, resulted in only 66% control (Table 1).

Table 1 Preemergence control of Palmer amaranth with dicamba and flumioxazin. Data are pooled over rating intervals and application timings.

Herbicide	Rate	Control[a]
	kg ae ha^{-1}	—%—
Dicamba	0.28	66 b
Dicamba	0.56	75 ab
Dicamba	1.1	85 ab
Flumioxazin	0.07	95 a

[a] Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD at $p \leq 0.05$.

- 87% control at 14 DAT was the greatest of the three rating dates. All treatments at the 21 and 28 DAT significantly declined in their control (Table 2).

Table 2. Preemergence control of Palmer amaranth based on rating intervals after initial treatment. Data are pooled over herbicide treatments and application timings.

Rating interval[a]	Control[b]
	—%—
14 DAT	87 a
21 DAT	81 b
28 DAT	72 c

[a] Abbreviations: DAT, days after treatment.
[b] Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD at $p \leq 0.05$.

There was no significant interaction between herbicide rate and application timing for plant density and biomass reductions of Palmer amaranth. Therefore, data were pooled over application timings and are discussed according to herbicide treatments. The below results are based on data in Table 3.

- Flumioxazin reduced Palmer amaranth plant density by 88%, which was greater than 0.28 kg ha^{-1} dicamba which reduced plant density 16% compared to the nontreated.

- Dicamba at 0.56 and 1.1 kg ha^{-1} and flumioxazin reduced plant biomass of Palmer amaranth between 73 and 92%.

- Dicamba at 0.28 kg ha^{-1} only reduced plant biomass 25%.

Table 3. Percent reduction of Palmer amaranth density and biomass 28 DAT with dicamba and flumioxazin applied preemergence[a]. Data were calculated as a percent reduction of the nontreated check.

		Reduction[b]			
Herbicide	**Rate**	**Plant density**		**Plant biomass**	
	kg ae ha^{-1}	%			
Dicamba	0.28	16	c	25	b
Dicamba	0.56	54	ab	75	a
Dicamba	1.1	40	bc	73	a
Flumioxazin	0.07	88	a	92	a

[a] Abbreviation: DAT, days after treatment.
[b] Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD at $p \leq 0.05$.

Over the length of this study, application timings between March 29 and May 23 did not affect residual activity and persistence of dicamba or flumioxazin on Palmer amaranth. Residual activity of herbicide treatments on Palmer amaranth was greatest at the 14 DAT rating and declined at each rating time thereafter. These results indicate that dicamba applied preemergence at 0.56 kg ha^{-1} or higher offers residual control of Palmer amaranth comparable to that of flumioxazin, the standard residual herbicide used in this experiment. However, residual control of dicamba will not persist as long as flumioxazin, as seen during the wet conditions in 2011. In drier years, as in 2012, dicamba can be very persistent in the soil (Altom and Stritzke 1973). Dicamba should be evaluated in combination with residual herbicides such as flumioxazin to provide consistent residual control of Palmer amaranth. The improved residual control of dicamba during dry conditions or environments is only a benefit of dicamba persistence and should not be solely relied on for preemergence control of Palmer amaranth. Future research should include various rates of dicamba in combination with residual herbicides to determine if dicamba provides additional control.

Results and Discussion—Postemergence Field Experiment

At 14 and 28 DAT, significant interaction was present between herbicide treatments and plant height. For the purpose of this paper, only the 14 and 28 DAT efficacy ratings will be discussed. The below results are taken from the data in Table 4.

- Glyphosate alone at 0.84 kg ha^{-1} provided 39 and 30% control of 5-cm-tall Palmer amaranth at 14 and 28 DAT, respectively.

- All treatments containing dicamba, regardless of rate, improved control of 5-cm-tall Palmer amaranth over glyphosate alone at both 14 and 28 DAT.

- Dicamba alone at 0.56 and 1.1 kg ha^{-1} were comparable to each other, and controlled 5-cm-tall Palmer amaranth between 81 and 88% at14 DAT and between 90 and 95% 28 DAT.

- The lowest rate of dicamba, at 0.28 kg ha^{-1}, controlled 5- cm-tall Palmer amaranth between 76 and 82% at 14 and 28 DAT, respectively.

- The addition of glyphosate to dicamba did not significantly improve control of 5-cm-tall Palmer amaranth over the dicamba-alone treatments at 14 and 28 DAT.

- As weed height increased to 10 cm, glyphosate alone controlled Palmer amaranth only 28 and 17% at 14 and 28 DAT, respectively.

- Dicamba alone at 0.28, 0.56, and 1.1 kg ha^{-1} controlled 10-cm-tall Palmer amaranth 60, 70, and 80%, respectively, at 14 DAT.

- Dicamba alone at 0.28, 0.56, and 1.1 kg ha^{-1} controlled 10-cm-tall Palmer amaranth 61, 75, and 87%, respectively, at 28 DAT.

- At 14 DAT, glyphosate used in combination with dicamba at 0.56 kg ha^{-1} slightly but significantly improved control of 10-cm-tall Palmer amaranth. When used with1.1 kg ha^{-1} dicamba, it did not. Glyphosate used in combination with all rates of dicamba did not improve control of 10-cm-tall Palmer amaranth compared to control using dicamba alone at 28 DAT.

- Glyphosate controlled 15-cm-tall Palmer amaranth only 11% at 14 and 28 DAT. Dicamba alone at 0.56 and 1.1 kg ha^{-1} controlled 15-cm-tall Palmer amaranth 60 and 71% at 14 DAT and 68 and 79% at 28 DAT, respectively.

- The addition of glyphosate to 0.56 kg ha^{-1} dicamba improved control of 15-cm-tall Palmer amaranth to 67% compared to only 60% control with dicamba alone at 14 DAT.

- When glyphosate was used in combination with 0.56 and 1.1 kg ha^{-1} dicamba, no significant increase in control of 15- cm-tall Palmer amaranth was provided at 28 DAT. However, the addition of glyphosate applied in combination with the lowest rate of 0.28 kg ha^{-1} dicamba increased control of 15-cm-tall Palmer amaranth at 28 DAT but not at 14 DAT.

- Dicamba alone at 0.28 kg ha^{-1} controlled 15-cm-tall Palmer amaranth only 52% compared to the combination of 0.28 kg ha^{-1} dicamba plus glyphosate, which controlled 60% at 28 DAT.

- Dicamba applied alone at 0.56 kg ha^{-1} controlled 5-, 10-, and 15-cm-tall Palmer amaranth 90, 75, and 68% at 28 DAT, respectively.

- Dicamba applied at the highest rate of 1.1 kg ha^{-1} controlled 5-, 10-, and 15-cm-tall Palmer amaranth 95, 87, and 79% at 28 DAT, respectively. A greenhouse study by Norsworthy et al. (2008) conflicts with the findings of this study in that the control of six-leaf (5-10 cm tall) Palmer amaranth with 0.28 kg ha^{-1} dicamba was less than 97 to 100% control.

Table 4. Postemergence control of 5-, 10-, and 15-cm-tall Palmer amaranth with dicamba and glyphosate combinations.

			Control[a, b]			
Application timing	**Herbicide**	**Rate**	**14 DAT**		**28 DAT**	
		kg ae ha^{-1}	*%*			
5 cm	Glyphosate	0.84	39	c	30	d
	Dicamba	0.28	76	b	82	c
	Dicamba	0.56	81	ab	90	abc
	Dicamba	1.1	88	a	95	ab
	Dicamba + Glyphosate	0.28 + .84	81	ab	84	bc
	Dicamba + Glyphosate	0.56 + .84	85	ab	90	abc
	Dicamba + Glyphosate	1.1 + .84	90	a	96	a
10 cm	Glyphosate	0.84	28	d	17	d
	Dicamba	0.28	60	c	61	c
	Dicamba	0.56	70	b	75	b
	Dicamba	1.1	80	a	87	a
	Dicamba + Glyphosate	0.28 + .84	70	b	67	c
	Dicamba + Glyphosate	0.56 + .84	78	a	78	b
	Dicamba + Glyphosate	1.1 + .84	83	a	87	a
15 cm	Glyphosate	0.84	11	e	11	e
	Dicamba	0.28	51	d	52	d
	Dicamba	0.56	60	c	68	bc
	Dicamba	1.1	71	ab	79	a
	Dicamba + Glyphosate	0.28 + .84	58	cd	60	c
	Dicamba + Glyphosate	0.56 + .84	67	b	71	b
	Dicamba + Glyphosate	1.1 + .84	78	a	85	a

[a] Abbreviation: DAT, days after treatment.
[b] Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD at $p \leq 0.05$.

The below results are taken from the data in Table 5.

- A significant interaction between herbicide treatment and plant height occurred for plant density at the 5- and 15-cm-tall timings, but not at the 10-cm-tall timing. Glyphosate alone only reduced plant density of 5-cm-tall Palmer amaranth by 24%.

- Plant density of 5-cm-tall Palmer amaranth was reduced with all dicamba treatments compared to glyphosate alone or the nontreated.

- All treatments containing dicamba reduced 5-cm-tall plant density from 55 to 82% compared to the nontreated.

- At the 10-cm-tall timing, a reduction in plant density only occurred with dicamba alone at 0.56 kg ha^{-1}, and with dicamba at 0.56 and 1.1 kg ha^{-1} in combination with 0.84 kg ha^{-1} glyphosate; this reduction was not different from other treatments including glyphosate alone. The result of increased plant density at the 10-cm-tall timing is likely due to rainfall following the application, which promoted Palmer amaranth emergence and decreased residual activity of dicamba.

- Glyphosate applied alone at 0.84 kg ha^{-1} on 15-cm-tall Palmer amaranth increased plant density above the nontreated check by 6%, which is likely a result of reduced plant competition allowing emergence of Palmer amaranth. At the 15 cm timing, all treatments containing dicamba reduced plant density compared to glyphosate alone and the nontreated.

A significant interaction between herbicide treatment and plant biomass occurred at each application timing.

- Glyphosate applied alone reduced plant biomass of 5-cm-tall Palmer amaranth only 4% compared to the nontreated.

- All dicamba treatments reduced 5-cm-tall Palmer amaranth plant biomass compared to glyphosate alone and the nontreated.

- Dicamba applied at 1.1 kg ha^{-1} with and without glyphosate reduced 5-cm-tall plant biomass between 89 and 92%. However, these treatments only reduced plant biomass more than glyphosate applied alone and dicamba applied at 0.28 kg ha^{-1} with 0.84 kg ha^{-1} glyphosate.

- Glyphosate applied alone reduced 10-cm-tall plant biomass by only 11% compared to the nontreated.

- All dicamba treatments, excluding dicamba at the lowest rate of 0.28 kg ha^{-1}, applied at the 10-cm-tall timing reduced plant biomass from 64 to 89%.

- Glyphosate applied alone at the 15-cm-tall timing had no effect on plant biomass.

- All dicamba treatments reduced plant biomass at the 15-cm-tall timing.

- Dicamba at 1.1 kg ha^{-1} applied alone or in combination with 0.84 kg ha^{-1} glyphosate reduced plant biomass from 83 to 87%, which was greater than the 63% reduction with 0.28 kg ha^{-1} dicamba.

- Plant density and biomass were reduced with all dicamba treatments at the 5- and 10-cm timings compared to glyphosate alone and the nontreated.

- At the 10-cm-tall timing, no significant reductions in plant density were measured among all dicamba and glyphosate treatments compared to the nontreated. This is likely the result of wet conditions which promoted Palmer amaranth emergence and decreased the residual activity of dicamba at the 10-cm-tall timing.

Table 5. Percent reduction of Palmer amaranth density and biomass 28 DAT with dicamba and glyphosate combinations applied postemergence[a].

Application timing	Herbicide	Rate	Reduction[b]			
			Plant density		Plant biomass	
		kg ae ha^{-1}	*%*			
5 cm	Glyphosate	0.84	24	d	4	c
	Dicamba	0.28	55	bc	67	ab
	Dicamba	0.56	66	ab	73	ab
	Dicamba	1.1	82	a	92	a
	Dicamba + Glyphosate	0.28 + .84	49	c	61	b
	Dicamba + Glyphosate	0.56 + .84	68	ab	81	ab
	Dicamba + Glyphosate	1.1 + .84	75	a	89	a
10 cm	Glyphosate	0.84	-29	b	11	c
	Dicamba	0.28	-15	ab	44	bc
	Dicamba	0.56	-4	ab	69	ab
	Dicamba	1.1	55	a	89	a
	Dicamba + Glyphosate	0.28 + .84	-20	b	64	ab
	Dicamba + Glyphosate	0.56 + .84	10	ab	78	ab
	Dicamba + Glyphosate	1.1 + .84	41	ab	84	a
15 cm	Glyphosate	0.84	-6	c	0	c
	Dicamba	0.28	49	b	63	b
	Dicamba	0.56	61	ab	75	ab
	Dicamba	1.1	75	ab	83	a
	Dicamba + Glyphosate	0.28 + .84	49	ab	59	b
	Dicamba + Glyphosate	0.56 + .84	50	ab	74	ab
	Dicamba + Glyphosate	1.1 + .84	80	a	87	a

[a] Abbreviation: DAT, days after treatment.
[b] Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD at $p \leq 0.05$.

Results from this two year postemergence experiment indicate that dicamba, even at the highest rate of 1.1 kg ha^{-1}, did not control 5-cm-tall Palmer amaranth 100%. These experiments were conducted at locations with very high populations of naturally occurring GR Palmer amaranth

(up to 1120 plant m^2), which may contribute to the measured level of efficacy. Dicamba provided a viable option for managing GR Palmer amaranth; however, it could not be used as a one-pass herbicide program for GR Palmer amaranth control. Dicamba will be a fundamental component of herbicide programs to manage GR Palmer amaranth in soybean and other crops, but sequential applications or tank mixtures with other herbicides will be required to achieve acceptable levels of control.

Results and Discussion—Greenhouse Experiment

At 14 and 28 DAT, a significant interaction was present between dicamba rate and plant height and findings will be reported as herbicide treatments for each application timing at 14 and 28 DAT. The following results are based on data in Table 6.

- All rates of dicamba controlled 5-cm-tall Palmer amaranth more than 86% at 14 DAT and 91% at 28 DAT.

- Dicamba at 1.1 and 2.2 kg ha^{-1} both controlled 5-cm-tall Palmer amaranth 99% at 28 DAT.

- Dicamba rates of 0.14, 0.28, and 0.56 kg ha^{-1} controlled 10-cm-tall Palmer amaranth 30, 44, and 51% at 14 DAT, respectively. By 28 DAT, dicamba at these rates controlled 10-cm-tall Palmer amaranth 66, 78, and 87%, respectively.

- Higher rates of dicamba at 1.1 and 2.2 kg ha^{-1} controlled 10-cm-tall Palmer amaranth between 68 and 71% at 14 DAT and between 96 and 98% at 28 DAT.

- Dicamba rates of 0.14, 0.28, and 0.56 kg ha^{-1} controlled 15-cm-tall Palmer amaranth only 25, 39, and 41% at 14 DAT, respectively. By 28 DAT, efficacy increased and dicamba at these rates controlled 15-cm-tall Palmer amaranth 54, 64, and 74%, respectively.

- Dicamba at higher rates of 1.1 and 2.2 kg ha^{-1} controlled 15-cm-tall Palmer amaranth between 45 and 51% at 14 DAT and 84 and 91% at 28 DAT.

- Dicamba applied at 1.1 kg ha^{-1} controlled 5-, 10-, and 15-cm-tall Palmer amaranth 99, 96, and 84%, respectively. However, the expected use rate will be 0.5 kg ha^{-1} of dicamba, which controlled 5-, 10-, and 15-cm-tall Palmer amaranth 97, 87, and 74%, respectively.

Table 6. Confirmation of the optimum rate of dicamba (BAS 18322 H) for postemergence control of 5, 10, and 15-cm-tall Palmer amaranth.

Application timing	Herbicide	Rate	Control[a, b] 14 DAT		Control[a, b] 28 DAT	
		kg ae ha^{-1}	*%*			
5 cm timing	Dicamba	0.14	86	b	94	ab
	Dicamba	0.28	91	ab	91	b
	Dicamba	0.56	87	b	97	ab
	Dicamba	1.1	94	ab	99	a
	Dicamba	2.2	98	a	99	a
10 cm timing	Dicamba	0.14	30	c	66	d
	Dicamba	0.28	44	b	78	c
	Dicamba	0.56	51	b	87	b
	Dicamba	1.1	71	a	96	a
	Dicamba	2.2	68	a	98	a
15 cm timing	Dicamba	0.14	25	c	54	d
	Dicamba	0.28	39	b	64	c
	Dicamba	0.56	41	b	74	b
	Dicamba	1.1	45	ab	84	a
	Dicamba	2.2	51	a	91	a

[a] Abbreviation: DAT, days after treatment.
[b] Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD at $p \leq 0.05$.

A significant interaction occurred between dicamba rate and plant height when analyzing percent plant biomass reductions. However, when data were analyzed by plant height, there was no interaction among dicamba treatments at the 5-cm-tall timing, unlike at the 10- and 15-cm-tall timings where treatment interactions did occur. The following results are based on data in Table 7.

- All dicamba treatments provided a significant reduction of plant biomass for 5-, 10-, and 15-cm-tall Palmer amaranth compared to the nontreated.

- All rates of dicamba resulted in plant biomass reductions of between 86 and 94% for 5-cm-tall Palmer amaranth, but no differences were observed among rates used.

- Dicamba at 0.14 and 0.28 kg ha^{-1} both reduced 10-cm-tall Palmer amaranth plant biomass by 51%.

- Dicamba at 0.56 and 1.1 kg ha^{-1} reduced 10-cm-tall plant biomass by 72 and 81%, respectively. The 81% reduction from the 1.1 kg ha^{-1} rate was statistically similar to the 84% reduction from using the 2.2 kg ha^{-1} rate.

- Dicamba applied at 0.14 and 0.28 kg ha^{-1} reduced 15-cm-tall Palmer amaranth plant biomass by 39 and 41%, respectively. Dicamba applied at 0.56 and 1.1 kg ha^{-1} reduced

15-cm-tall plant biomass by 58 and 66%, respectively. The 78% reduction from using the 2.2 kg ha^{-1} rate was statistically similar to that from using the 1.1 kg ha^{-1} rate.

Table 7. Plant biomass reductions calculated as a percent reduction of biomass based on the nontreated check from 5, 10, and 15-cm-tall Palmer amaranth 28 DAT with various rates of dicamba applied postemergence[a].

Application timing	Herbicide	Rate	Reduction[b] Plant biomass	
		kg ae ha^{-1}	*%*	
5 cm timing	Dicamba	0.14	86	a
	Dicamba	0.28	87	a
	Dicamba	0.56	91	a
	Dicamba	1.1	95	a
	Dicamba	2.2	94	a
10 cm timing	Dicamba	0.14	51	c
	Dicamba	0.28	51	c
	Dicamba	0.56	72	b
	Dicamba	1.1	81	ab
	Dicamba	2.2	84	a
15 cm timing	Dicamba	0.14	39	c
	Dicamba	0.28	41	c
	Dicamba	0.56	58	b
	Dicamba	1.1	66	ab
	Dicamba	2.2	78	a

[a] Abbreviation: DAT, days after treatment.
[b] Means within a column followed by the same letter are not significantly different based on Fisher's protected LSD at $p \leq 0.05$.

Results from this greenhouse experiment indicate that smaller weed size is imperative when optimizing control of Palmer amaranth with dicamba, especially at rates lower than 1.1 kg ha^{-1}. Efficacy of dicamba at all rates was greater for the greenhouse experiment compared to the same treatments in the field experiment. This increase in control is likely the result of a controlled environment and not directly associated with the difference in formulations of dicamba. However, field research should be conducted to confirm if differences in control of Palmer amaranth exist with BAS 18322H compared to other formulations of dicamba.

All rates of dicamba resulted in a reduction of plant biomass for 5-, 10-, and 15-cm-tall Palmer amaranth. No significant differences occurred between dicamba rates for the reduction of plant biomass of 5-cm-tall Palmer amaranth. However, dicamba treatments at 1.1 and 2.2 kg ha^{-1} provided the greatest reduction in plant biomass of 10- and 15-cm-tall Palmer amaranth. These data suggest there is no benefit to applying dicamba at 2.2 kg ha^{-1} as opposed to 1.1 kg ha^{-1} for the control of 5-, 10-, and 15-cm-tall Palmer amaranth.

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