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Using Glufosinate in Sequential Application Systems with Dicamba on Palmer Amaranth

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Authors' contributions

This work was carried out in collaboration between both authors. Author GFO collected data, performed the statistical analysis and wrote the first draft of the manuscript. Author PAD designed the study, wrote the protocol, and co-wrote the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: Determine the influence of sequential spray order and role of glufosinate when used in a system with dicamba to control Palmer amaranth at three different growth stages.
Study design: Randomized complete block design with four replications
Place and duration of Study: A fallow, non-crop field at the Texas A&M AgriLife Research and Extension Center, Lubbock, Texas, during the 2018-2019 growing seasons
Methodology: Herbicides were applied to < 10 cm, 10 to 20 cm, and > 30 cm Palmer amaranth with a handheld 1.93m CO_2-pressurized backpack calibrated to deliver 140 L ha^{-1} at 207 kPa. Palmer amaranth control was visually estimated on a scale of 0 (no control) to 100% (complete plant death) relative to the nontreated control. Palmer amaranth biomass and density were taken when all plots reached 50% or less control in 2019. Palmer amaranth control, biomass, and density were subjected to analysis of variance and means were separated using Fisher's Protected LSD at an alpha of 0.05.
Results: Palmer amaranth control decreased as Palmer amaranth size at initial application

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increased. A difference in efficacy based on herbicide order was observed for < 10 cm Palmer amaranth. Glufosinate followed by dicamba was less effective (76-83%) than dicamba followed by glufosinate (93-96%) at 2 of 4 rating dates following sequential applications in both years. Dicamba + acetochlor followed by glufosinate provided greater Palmer amaranth control than dicamba followed by dicamba at one or more rating dates across all weed sizes.

Conclusion: Glufosinate served as a complimentary partner in the dicamba-based system, and additional modes of action will be more effective to slow the development of resistance to group 4 herbicides when compared to repeated use of a group 4 herbicide used alone.

Keywords: Acetochlor; dicamba; glufosinate; Palmer amaranth; postemergence; sequential applications.

ABBREVIATIONS

AE : Acid Equivalent
AI : Active Ingredient
DAIA : Days After Initial Application
DASA : Days After Sequential Application

1. INTRODUCTION

Palmer amaranth (*Amaranthus palmeri* S. Watson) is challenging to control and has become a problem weed nationwide. Once easily controlled with glyphosate in the era of RoundUp Ready crops, management has evolved to be more complex since the first glyphosate-resistant Palmer amaranth was discovered in 2005. Glyphosate resistance has increased the cost of Palmer amaranth control by increasing herbicide use, cultivation frequency, and handweeding [1]. Palmer amaranth can reduce cotton yield up to 52% with densities of 10 plants per 9 m^{-1} and use twice as much water as cotton per day [2,3]. These characteristics make Palmer amaranth a competitive weed and indicate sustainable control options for this weed are imperative for the future of cotton production.

A new variety of cotton that is dicamba-tolerant was released in 2016. This variety allows for a unique application of dicamba that was not only previously unavailable for use postemergence in cotton, but could cause severe symptomology or complete crop loss if non-tolerant cotton is exposed to this herbicide [4,5]. Currently, incidence of dicamba-resistant Palmer amaranth are low [6], making it a reasonable choice for controlling glyphosate-resistant populations. Knowledge gained from the war on glyphosate resistance suggests that moving forward, any new herbicide technology must incorporate multiple modes of action in order to prevent accelerated development of herbicide resistance and keep the system sustainable.

Glufosinate may serve as a system partner when used in sequential applications with dicamba. With zero cases of confirmed glutamine-synthetase resistant Palmer amaranth on record as of April of 2021 [6], glufosinate is an ideal choice for managing herbicide resistant populations of Palmer amaranth. Volatility and off-target movement concerns surround dicamba [7-9], but glufosinate doesn't illicit the same concerns and presently is a widely used and accepted herbicide [10]. Although glufosinate has the potential to fortify dicamba systems, further research is needed to identify best use practices when using glufosinate and dicamba in sequential applications. Dicamba and glufosinate both offer the most control when Palmer amaranth is less than 10 cm [11,12]. However, timely applications are not always possible and Palmer amaranth has the ability to grow 2 cm per day in favorable conditions [13]. Thus, research is needed to determine the efficacy of the herbicide duo on various sizes of Palmer amaranth. Information on how sequential application order influences efficacy and potential soil residual herbicides, such as acetochlor, that may further fortify the herbicide system would be useful for producer implementation and could increase the acceptance rate of the dicamba-based system.

This study examines best use practices of glufosinate as a sequential application partner in a dicamba-based herbicide system to manage Palmer amaranth. The objectives of this study were to 1) evaluate the efficacy of glufosinate when used sequentially with dicamba, 2) determine the influence of sequential spray order across three sizes of Palmer amaranth and 3) examine the use of acetochlor as a soil residual herbicide in a dicamba-based system.

2. MATERIAL AND METHODS

2.1 Study Location

This study was conducted in a non-crop setting near Lubbock, Texas (GPS Coordinates: Latitude

33.69357, Longitude -101.82485; Elevation of 979m above sea level) during the 2018 and 2019 growing seasons to evaluate Palmer amaranth control following sequential applications of glufosinate (Liberty 280 SL®, BASF Ag Products) and dicamba (XtendiMax® with VaporGrip® Technology, Bayer CropScience) with and without acetochlor (Warrant®, Bayer CropScience). The trial location was a fallow field with a dense population of Palmer amaranth (approximately 70 per m^2). Plot size was 4.05 m by 9.14 m. The soil was an Acuff Loam with 1% organic matter and a pH of 7.5 [14]. In-furrow irrigation was used to promote weed emergence, but no supplemental irrigation was used during the duration of the trial. Rainfall during the duration of the trial amounted to 100 mm from June 1 to August 31 in 2018 and 302 mm during this time period in 2019. Pendimethalin (Prowl H_2O®, 0.86 kg ai ha^{-1}, BASF) was applied preplant and incorporated twice to a depth of 5 to 8 cm using a rolling cultivator immediately after application on May 3, 2018 and April 25, 2019 to lessen Palmer amaranth density.

2.2 Treatments

Treatments consisted of 1.) non-treated weedy check, 2.) glufosinate followed by (fb) glufosinate, 3.) glufosinate fb dicamba,
4.) glufosinate + acetochlor fb glufosinate,
5.) glufosinate fb glufosinate + acetochlor,
6.) glufosinate + acetochlor fb dicamba,
7.) glufosinate fb dicamba + acetochlor,
8.) dicamba fb dicamba, 9.) dicamba fb glufosinate, 10.) dicamba + acetochlor fb glufosinate, 11.) dicamba + acetochlor fb dicamba, 12.) dicamba fb dicamba + acetochlor, and 13.) dicamba fb glufosinate + acetochlor. Treatments were applied to < 10 cm, 10 to 20 cm, and > 30 cm Palmer amaranth. Weed size was based on plant height at the time of the initial application. Treatments were arranged in a randomized complete block design within weed size and replicated three times.

Strategic irrigation within each weed size block allowed for all Palmer amaranth to be at desired heights simultaneously in 2018. Thus, treatments to all sizes of Palmer amaranth were applied on June 15 and sequential applications were made 10 days later on June 25. Strategic watering in 2019 was attempted but did not yield all plant heights at a given date; therefore, treatments were applied as Palmer amaranth reached desired height. Palmer amaranth < 10 cm were treated on July 1 fb the sequential application on July 12; Palmer amaranth 10 to 20 cm were treated on July 9 fb the sequential application on July 19; Palmer amaranth > 30 cm were treated on June 13 fb the sequential application on June 24. Weeds were hand-pulled or hoed in each size block to allow consistent population heights as necessary in both years.

Glufosinate rate was dependent on the time of sequential treatment order. When glufosinate was applied in sequence, the second application rate was 0.59 kg active ingredient (ai) ha^{-1} due to restrictions per the 2018 label [15]. Initial applications of glufosinate and those applied sequentially after dicamba or dicamba + acetochlor were applied at 0.88 kg ai ha^{-1}. Dicamba was applied at 0.56 kg acid equivalent (ae) ha^{-1} and acetochlor at 1.261 kg ai ha^1.

A handheld 1.93m CO_2-pressurized backpack calibrated to deliver 140 L ha^{-1} at 207 kPa^{-1} was used to apply all treatments. Application speed was 4.8 km $hour^{-1}$. Turbo TeeJet 11002 nozzles were used for all glufosinate treatments whereas 11002 Turbo TeeJet Induction nozzles were used for all dicamba treatments. All glufosinate treatments included ammonium sulfate at 2.86 kg ha^{-1}.

2.3 Data Collection and Analysis

Palmer amaranth control was evaluated 7 days after initial application (DAIA) and 7, 14, 21, and 30 days after sequential application (DASA). Control was estimated on a scale from 0% to 100%, with 0% indicating no control and 100% indicating complete necrosis [16]. The number of Palmer amaranth were recorded and harvested from one m^2 within each plot and placed in mesh bags once weed control was less than 50% for the majority of plots, and fresh weights were recorded in 2019. Palmer amaranth were harvested at 33 days after sequential application for Palmer amaranth < 10 cm at initial application, 62 days for 10 to 20 cm Palmer amaranth at initial application, and 37 days for Palmer amaranth > 30 cm at initial application. Mesh bags were dried in a plant dryer at 35°C for one to two weeks and dry weights were recorded.

Data were subjected to ANOVA using the PROC GLIMMIX procedure of SAS 9.1 (SAS Institute Inc., SAS Campus Drive, Cary, NC 27513). Means of treatment effects were separated by year, weed size, and using Fisher's Protected LSD at an alpha level of 0.05. Year by treatment and weed size by treatment interactions were observed; therefore, data were analyzed separately by year and by weed size.

3. RESULTS AND DISCUSSION

3.1 < 10 cm Palmer amaranth

Seven days after initial application (DAIA), glufosinate controlled < 10 cm Palmer amaranth 92 to 96%, which was greater than Palmer amaranth control following dicamba (69 to 73%) in 2018 (Table 1). When glufosinate was applied in the sequential application, at least 97% control was observed 7 days after sequential application (DASA) except for glufosinate fb glufosinate + acetochlor (92%) in 2018. Palmer amaranth was controlled 95% following both dicamba fb glufosinate + acetochlor and dicamba + acetochlor fb glufosinate 21 DASA. Palmer amaranth control ranged from 77 to 93% 30 DASA.

In 2019, glufosinate controlled < 10 cm Palmer amaranth 89 to 90% 7 DAIA, which was greater than Palmer amaranth control following dicamba (78 to 79%) (Table 2). All treatments provided at least 89% Palmer amaranth control 7 DASA. Treatments with glufosinate in the sequential application controlled Palmer amaranth better than treatments with dicamba in the sequential application 7 DASA. Twenty-one DASA, dicamba + acetochlor fb glufosinate or dicamba controlled Palmer amaranth 91%, which was greater than treatments with glufosinate in the initial application. Dicamba + acetochlor fb glufosinate or dicamba controlled Palmer amaranth 75% and 73%, respectively, 30 DASA.

Dicamba fb glufosinate provided as good or better control of < 10 cm Palmer amaranth as two applications of dicamba or glufosinate across all rating dates in both years. Glufosinate fb dicamba was not as effective as dicamba fb glufosinate 7 and 14 DASA in 2018 and 7 and 21 DASA in 2019. Reed [11] reported minimal control of Palmer amaranth of similar size with two or three sequential applications of glufosinate. In contrast, Corbett et al. [17] reported 100% control of 2 to 5 cm and 8 to 10 cm Palmer amaranth following sequential applications of glufosinate made 10 days apart at lower rates of glufosinate per hectare.

Less than 10 cm Palmer amaranth treated with dicamba + acetochlor fb glufosinate had 87% reduction in dry weight 33 DASA compared to the non-treated control (Table 3). Treatments of two applications of dicamba reduced dry weight by 70% when compared to the non-treated control. No difference in dry weight reduction was observed between treatments of dicamba fb glufosinate (57%) or glufosinate fb dicamba (55%). All treatments reduced dry weight of < 10 cm Palmer amaranth compared to the non-treated control.

Less than 10 cm Palmer amaranth treated with dicamba + acetochlor fb glufosinate had 3 Palmer amaranth per m^2 33 DASA (Table 4). The reverse of this treatment, glufosinate fb dicamba + acetochlor, had 42 Palmer amaranth per m^2, where the greatest Palmer amaranth density out of all herbicide treatments was observed. Acetochlor applied in the initial application was able to control newly emerging Palmer amaranth seedlings, while the sequential application 10 days later likely occurred when Palmer amaranth were greater than 3 cm in height. This delay in application timing resulted in less effective Palmer amaranth control. Thus, including acetochlor in the initial application would create a more effective, sustainable herbicide system than including it in the sequential application or not at all. Treatments of two applications of dicamba had 28 Palmer amaranth per m^2. All treatments reduced the number of Palmer amaranth per m^2 compared to the non-treated control.

3.2 10 to 20 cm Palmer amaranth.

In 2018, glufosinate controlled Palmer amaranth 81 to 83% 7 DAIA, which was greater than Palmer amaranth control following dicamba (64 to 66%). All treatments controlled Palmer amaranth greater than 90% 7 DASA except for treatments with two applications of dicamba (80-86%) (Table 1). Dicamba + acetochlor fb glufosinate controlled Palmer amaranth 91% 14 DASA, which was greater than Palmer amaranth control following dicamba fb dicamba (85%). Glufosinate + acetochlor fb dicamba controlled Palmer amaranth 75% 30 DASA, which was similar to dicamba fb dicamba (74%).

In 2019, glufosinate controlled Palmer amaranth 90 to 92%, which was greater than Palmer amaranth control following dicamba (82 to 83%) 7 DAIA (Table 2). Similar to 2018, dicamba + acetochlor fb glufosinate controlled Palmer amaranth 85%, which was greater than Palmer amaranth control following dicamba fb dicamba (76%) 14 DASA. Palmer amaranth control ranged from 70 to 83% 21 DASA. Vann et al. [18] found 16 to 23 cm Palmer amaranth were controlled 79% by two applications of glufosinate and 81% by two applications of dicamba 14 DASA. Sequential order of dicamba and glufosinate affected control of 10 to 20 cm Palmer amaranth at only one rating event in one out of two years: dicamba fb glufosinate + acetochlor controlled Palmer amaranth 98% 7 DASA, which was better than glufosinate + acetochlor fb dicamba (91%). For all other treatments and rating dates across 2018 and 2019, sequential order did not influence 10 to 20 cm Palmer amaranth control.

Dry weight of Palmer amaranth that were 10 to 20 cm in height at initial application were reduced 86% 62 DASA from the dicamba fb dicamba treatment when compared to the non-treated control, which was similar to dicamba fb glufosinate (65%) (Table 3). Two applications of dicamba with acetochlor at either timing reduced dry weight 80 to 82% compared to the non-treated control. All treatments reduced Palmer amaranth dry weight compared to the non-treated control. No differences in Palmer amaranth density were observed 62 DASA (Table 4).

3.3 > 30 cm Palmer amaranth

In 2018, glufosinate controlled Palmer amaranth 51 to 57% 7 DAIA, which was greater than Palmer amaranth control following dicamba (39 to 43%) (Table 1). Dicamba + acetochlor fb glufosinate controlled Palmer amaranth 72% 7 DASA, which was greater than two applications of dicamba (50%) or glufosinate (60%). Twenty-one DASA, glufosinate fb dicamba controlled Palmer amaranth 55%, which was similar to dicamba + acetochlor fb glufosinate (54%) and greater than all treatments with dicamba alone in the initial application (50%). Palmer amaranth control ranged from 44 to 57% 30 DASA in 2018.

In 2019, glufosinate alone provided similar Palmer amaranth control to glufosinate + acetochlor and dicamba + acetochlor, and greater control than dicamba alone (57%) 7 DAIA (Table 2). Palmer amaranth control following dicamba fb dicamba (66%) was similar to glufosinate + acetochlor fb dicamba (61%) 7 DASA. Two applications of glufosinate with or without acetochlor controlled Palmer amaranth 20% 21 DASA, while dicamba fb dicamba provided 79% control. Dicamba fb glufosinate provided similar control (67%) to two applications of dicamba (79%) 21 DASA. Palmer amaranth was controlled < 69% following all treatments from 21 to 30 DASA except dicamba + acetochlor fb dicamba, which maintained control above 70%. The challenge of reduced control of Palmer amaranth greater than 10 cm in size is well-documented. Reed [11] reported applications of glufosinate alone controlled 5 to 10 cm Palmer amaranth greater than 15 to 20 cm Palmer amaranth 14 and 21 days after treatment. Whitaker et al. [19] reported that although a second application of glufosinate initially improved Palmer amaranth control, many weeds survived and grew to heights too large to be controlled by a layby application when Palmer amaranth size at initial application was 5 to 8 cm. Thus, Palmer amaranth are best controlled before reaching 30 cm in height and later applications will not be effective.

Treatments that included two applications of glufosinate did not reduce Palmer amaranth dry weight compared to the non-treated control (Table 3). Additionally, dicamba fb glufosinate + acetochlor did not reduce Palmer amaranth dry weight compared to the non-treated control. Glufosinate fb dicamba + acetochlor reduced Palmer amaranth dry weight by 60% compared to the non-treated control, which was similar to dicamba fb dicamba (72%).

Acetochlor proved to impact the control of > 30 cm Palmer amaranth. Treatments that included acetochlor reduced subsequent weed flushes after application, reducing Palmer amaranth density 37 DASA compared to the non-treated control, except for treatments of dicamba fb dicamba + acetochlor and glufosinate + acetochlor fb dicamba (Table 4). The initial population of Palmer amaranth were relatively large and could have shaded out and out-competed emerging Palmer amaranth. Once treatments were applied and the canopy of Palmer amaranth was less dense, the shading and competition effect lessened and plots that were not treated with acetochlor could have experienced a new flush of Palmer amaranth. No efficacy difference was noted between the early postemergence or mid-postemergence application of acetochlor. The height of the Palmer amaranth likely plays a role in the importance of the addition of acetochlor to the herbicide system.

Table 1. Palmer amaranth control following initial and sequential applications of glufosinate and dicamba in 2018

		Palmer amaranth size at application														
		< 10 cm					10 to 20 cm					> 30 cm				
		Days after application[a]														
		EPOST[b]	MPOST				EPOST	MPOST				EPOST	MPOST			
Initial application	Sequential application	7[c]	7	14	21	30	7	7	14	21	30	7	7	14	21	30
		%														
Glufosinate		92 b					83 a					57 a				
	Glufosinate		98 a	92 abcd	86 c	86 c		97 ab	82 d	69 bc	62 d		60 bcd	59 abc	52 ab	47 bc
	Glufosinate + acetochlor		92 d	83 e	76 d	77 d		96 ab	83 cd	66 c	62 d		67 ab	55 bc	47 c	44 c
	Dicamba		92 d	88 de	88 bc	87 bc		93 abc	86 abcd	74 ab	72 abc		65 ab	62 ab	55 a	53 a
	Dicamba + acetochlor		94 cd	92 abcd	92 abc	89 abc		95 abc	90 ab	74 ab	73 abc		63 bc	64 a	54 ab	53 a
Dicamba		69 c					66 b					39 c				
	Glufosinate		98 a	96 ab	93 ab	91 abc		95 abc	87 abcd	69 bc	71 abc		67 ab	60 abc	50 bc	50 ab
	Glufosinate + acetochlor		99 a	97 a	95 a	92 ab		98 a	88 abc	72 abc	70 bc		67 ab	61 ab	50 bc	57 bc
	Dicamba		90 e	93 abc	92 abc	92 ab		80 e	85 bcd	71 abc	74 ab		50 e	55 bc	50 bc	51 a
	Dicamba + acetochlor		93 d	91 cd	94 ab	93 a		90 cd	87 abcd	73 abc	73 ab		53 de	57 abc	50 bc	51 a
Glufosinate + acetochlor		96 a					81 a					51 b				
	Glufosinate		99 a	94 abc	91 abc	92 ab		98 a	90 a	72 abc	67 cd		57 cde	53 c	47 c	46 c
	Dicamba		96 b	94 abc	93 ab	90 abc		91 bcd	86 abcd	73 abc	75 ab		60 bcd	58 abc	51 ab	51 a
Dicamba + acetochlor		73 c					64 b					43 c				
	Glufosinate		98 a	96 ab	95 a	91 abc		98 a	91 a	78 a	71 abc		72 a	63 a	54 a	51 a
	Dicamba		95 cd	93 abc	94 ab	93 a		86 de	86 abcd	73 abc	77 a		55 de	57 abc	50 bc	50 ab

[a] Abbreviations: EPOST, early postemergence application; MPOST, mid-postemergence application; [b] EPOST timing applied June 15, 2018; rating dates are given as days after initial application (DAIA). MPOST timing applied June 25, 2018; rating dates are given as days after sequential application (DASA);[c] Means within a column followed by a common letter were similar according to Fishers Protected LSD in SAS at P < 0.05.

Table 2. Palmer amaranth control following initial and sequential applications of glufosinate and dicamba in 2019

		Palmer amaranth size at initial application														
		< 10 cm					10- 20 cm					> 30 cm				
		Days after application[a]														
		EPOST[b]	MPOST				EPOST	MPOST				EPOST	MPOST			
Initial application	Sequential application	7 [c]	7	14	21	30	7	7	14	21	30	7	7	14	21	30
		%														
Glufosinate		90 a					90 a					67 a				
	Glufosinate		99 a	-	69 c	47 c		-	91 a	77 ab	63 bcde		56 de	42 ab	20 e	10 e
	Glufosinate + acetochlor		97 a	-	71 c	52 bc		-	78 bcd	70 b	51 e		58 bcde	33 b	20 e	13 e
	Dicamba		91 bc	-	57 d	48 c		-	81 bcd	76 ab	64 abcde		55 de	45 ab	64 bcd	50 c
	Dicamba + acetochlor		89 bc	-	57 d	50 c		-	85 ab	82 a	68 abcde		18 f	52 ab	70 abc	57 b
Dicamba		79 b					83 b					57 b				
	Glufosinate		98 a	-	83 b	58 bc		-	85 ab	80 a	67 abcde		59 bcde	42 ab	67 abcd	37 d
	Glufosinate + acetochlor		99 a	-	85 ab	64 ab		-	84 abc	74 ab	58 cde		57 cde	50 ab	58 cd	35 d
	Dicamba		91 bc	-	69 c	55 bc		-	76 cd	82 a	80 ab		66 a	55 a	79 a	69 a
	Dicamba + acetochlor		89 bc	-	74 c	58 bc		-	78 bcd	83 a	81 a		64 ab	54 a	70 abc	69 a
Glufosinate + acetochlor		89 a					92 a					63 ab				
	Glufosinate		98 a	-	83 b	59 bc		-	90 a	81 a	71 abcd		55 e	38 ab	20 e	10 e
	Dicamba		89 bc	-	70 c	55 bc		-	86 ab	82 a	75 abc		61 abcd	48 ab	56 d	48 c
Dicamba + acetochlor		78 b					82 b					58 ab				
	Glufosinate		98 a	-	91 a	75 a		-	85 ab	78 ab	57 de		58 bcde	43 ab	62 bcd	40 d
	Dicamba		92 b	-	91 a	73 a		-	75 d	83 a	80 ab		63 abc	53 a	74 ab	72 a

[a] Abbreviations: EPOST, early postemergence application; MPOST, mid-postemergence application ;[b] EPOST timing applied July 1, July 9, and June 13 to Palmer amaranth < 10 cm, 10 to 20 cm, and > 30 cm in height at initial application, respectively; rating dates are given as days after initial application (DAIA). MPOST timing applied July 12, July 19, and June 24 to Palmer amaranth < 10 cm, 10 to 20 cm, and >30 cm in height at initial application, respectively; rating dates are given as days after sequential application (DASA);[c] Means within a column followed by a common letter were similar according to Fishers Protected LSD in SAS at P < 0.05

Table 3. Palmer amaranth dry weight 33 to 62 days after sequential applications of glufosinate and dicamba in 2019

		Dry weight[ab]		
		Palmer amaranth size at application		
Initial application	**Sequential application**	**< 10 cm**	**10 to 20 cm**	**> 30 cm**
		----g per m²----		
Non-treated control		679 a	685 a	547 a
Glufosinate				
	Glufosinate	275 bcd	307 b	520 a
	Glufosinate + acetochlor	188 de	278 bcd	544 a
	Dicamba	312 bc	292 bc	290 bcd
	Dicamba + acetochlor	357 b	220 bcde	220 cd
Dicamba				
	Glufosinate	293 bcd	241 bcde	323 bcd
	Glufosinate + acetochlor	205 cde	360 b	396 abc
	Dicamba	210 bcde	96 e	154 d
	Dicamba + acetochlor	160 de	134 cde	167 d
Glufosinate + acetochlor				
	Glufosinate	209 bcde	221 bcde	414 ab
	Dicamba	248 bcd	219 bcde	280 bcd
Dicamba + acetochlor				
	Glufosinate	90 e	317 b	315 bcd
	Dicamba	95 e	126 de	210 d

[a] Means within a column followed by a common letter were similar according to Fishers Protected LSD in SAS at P < 0.05; [b] Palmer amaranth harvested 33 days after sequential application for Palmer amaranth <10 cm at initial application, 62 days after sequential application for Palmer amaranth 10 to 20 cm at initial application, and 37 days for Palmer amaranth >30 cm at initial application.

Table 4. Palmer amaranth density 33 to 62 days after sequential applications of glufosinate and dicamba in 2019

		Palmer amaranth size at initial application[a]		
Initial application	**Sequential application**	**< 10 cm[b]**	**10 to 20 cm**	**> 30 cm**
		---No. per m^2---		
Non-treated control		69 a	50 a	24 a
Glufosinate				
	Glufosinate	18 cdef	4 b	16 ab
	Glufosinate + acetochlor	13 def	8 b	9 b
	Dicamba	32 bc	14 b	20 ab
	Dicamba + acetochlor	42 b	13 b	8 b
Dicamba				
	Glufosinate	12 def	10 b	15 ab
	Glufosinate + acetochlor	8 ef	8 b	11 b
	Dicamba	28 bcd	4 b	20 ab
	Dicamba + acetochlor	20 cde	5 b	12 ab
Glufosinate + acetochlor				
	Glufosinate	3 f	3 b	10 b
	Dicamba	15 def	9 b	12 ab
Dicamba + acetochlor				
	Glufosinate	3 f	12 b	11 b
	Dicamba	8 ef	6 b	7 b

[a] Means within a column followed by a common letter were similar according to Fishers Protected LSD in SAS at $P < 0.05$;[b] Palmer amaranth counted 33 days after sequential application for Palmer amaranth <10 cm at initial application, 62 days after sequential application for Palmer amaranth 10 to 20 cm at initial application, and 37 days for Palmer amaranth >30 cm at initial application

4. CONCLUSION

This research suggests Palmer amaranth < 10 cm in height at initial application were best managed with dicamba + acetochlor fb glufosinate, while Palmer amaranth > 10 cm can be controlled or suppressed with the same set of herbicides in either sequential order. Dicamba + acetochlor fb glufosinate controlled Palmer amaranth better than dicamba fb dicamba during at least one rating event across all weed sizes. Two applications of glufosinate provided minimal Palmer amaranth control. Two applications of dicamba may provide effective Palmer amaranth control but does not provide enough herbicide mode of action diversity to prevent against the development of herbicide resistant weeds [20]. The results of this study reinforce the need to manage Palmer amaranth at or before it reaches 10 cm in height and gives additional insight into management options that may suppress Palmer amaranth when timely applications are not possible. Our results demonstrated acetochlor should be included in the initial application to optimize reduction of weed emergence, particularly for applications made to < 10 cm Palmer amaranth. Glufosinate successfully served as a complimentary sequential application partner in a dicamba-based system and, with the addition of acetochlor, this herbicide trio could control Palmer amaranth while preventing rapid development of herbicide resistance to dicamba. Further research in a cotton setting is needed to fully ensure crop safety. Additionally, research evaluating other soil residual herbicides that are compatible with this system across multiple soil textures may be helpful for cotton producers in other areas.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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