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Weed Management and Economics in Dicamba-Tolerant Cotton

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Authors' contributions

This work was carried out in collaboration among all authors. Authors BMD, CDRW and JWK designed and conducted the study and performed the data analysis. Author BMD wrote the first draft of the manuscript. Authors CDRW, JWK and PAD prepared the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Increasing populations of glyphosate-resistant Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] have increased weed management costs for Texas High Plains cotton [*Gossypium hirsutum* (L.)] producers. The introduction of dicamba-tolerant cotton varieties and registration of dicamba formulations for postemergence use, combined with residual herbicides, can effectively control Palmer amaranth. Field studies were conducted in 2018 and 2019 near Lubbock, TX, USA to evaluate Palmer amaranth control and economics of weed management in dicamba-, glufosinate-, glyphosate-, and conventional cotton systems. The most consistent season-long Palmer amaranth control was achieved with the dicamba-tolerant system in both years. In 2018, greatest lint yields were achieved with dicamba-tolerant system when compared to the conventional and glufosinate-tolerant systems. In 2018, greatest gross margin above weed management costs were achieved with the dicamba-tolerant and glyphosate-tolerant systems. Greatest lint yield was achieved with the dicamba-tolerant and conventional systems in 2019 and greatest gross margins were achieved with the dicamba-tolerant system. Total variable costs were similar across all systems, with greater seed/technology and herbicide costs in dicamba-tolerant and glufosinate-tolerant systems, compared to higher tillage and hand hoeing costs in glyphosate-tolerant and conventional systems.

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1. INTRODUCTION

Upland cotton [*Gossypium hirsutum* (L.)] is an economically important agronomic crop in the United States. In 2019, the United States planted 5.6 million hectares, harvested 4.7 million hectares, and produced 20.1 million bales of cotton [1]. The value of the 2019 cotton crop in the United States was estimated to be $6 billion dollars [2]. In 2019, Texas cotton producers planted 2.8 million hectares, harvested 2.4 hectares, and produced an estimated 6.6 million bales of cotton, which was over 30% of the United States cotton production [3].

In Texas cotton production, Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] ranks number one among the most troublesome and common weeds [4]. Glyphosate-resistant Palmer amaranth was first identified in the Texas High Plains (THP) in 2011 according to the International Survey of Herbicide Resistant Weeds list [5]. Decreased glyphosate efficacy forced producers to use other methods of weed management such as cultivation, hand-hoeing, spot-spraying, and the use of residual herbicides [6]. This increase in weed management cost is due to additional herbicide and labor associated with herbicide-resistant weed control for producers on the THP.

Currently, chemical weed control with herbicides and cultivation are the main methods of weed management in the United States [7]. Chemical management is effective due to selectivity of herbicides with different modes of action that can be incorporated into a weed management system. Glyphosate-tolerant cotton cultivars were first commercially available in 2006, which gave producers the ability to broadcast glyphosate, a non-selective herbicide, postemergence (POST) due to genetic transformations in cotton [8]. This technology allowed producers to control grasses and broadleaf weeds POST without negatively affecting cotton [8]. Widespread acceptance of glyphosate-tolerant technology occurred by 2010, when 91% of cotton hectares across the United States were planted to glyphosate-tolerant cultivars [9]. Glyphosate and glyphosate-tolerant cultivars gave producers an economically viable way to successfully control many troublesome weeds.

Dicamba-tolerant cotton varieties were commercialized in 2016, and in 2017, the registration of new, lower volatility dicamba formulations for POST use in cotton gave producers another tool to manage glyphosate-resistant Palmer amaranth. Dicamba is a selective herbicide that can be applied POST for broadleaf weed control and can provide soil residual activity lasting up to two weeks [10]. To minimize future dicamba resistance issues observed with glyphosate, it is recommended to use residual herbicides preplant incorporated (PPI), preemergence (PRE), and POST with dicamba as part of an overall system to diversify modes of action and weed management approaches [11,12]. Several studies have been conducted to document the efficacy of dicamba in cotton, but more information is needed to address the economics of using dicamba in a weed management system compared to other technologies on the Texas High Plains. Therefore, the objectives of these studies were to: 1) compare postemergence options in different cotton technologies as part of an overall weed management system in cotton production, and 2) identify the most economically viable system of weed management and document the comparative value of dicamba technology to other systems.

2. MATERIALS AND METHODS

2.1 Experimental Design and Management Systems

Field trials were conducted in 2018 and 2019 at the Texas A&M AgriLife Research and Extension Center near Lubbock, TX (33.68816, -101.83171) to evaluate the control of Palmer amaranth using different weed management systems. The cost of each management system was also assessed to determine the economic profitability. Plots were arranged in a randomized complete block design with four replications. Plots were 8 rows by 13.7 m in length. The soil texture is an Acuff loam (Fine-loamy, mixed thermic Aridic Paleustolls) with less than 1% organic matter and a pH of 7.9 [13]. For these experiments, DeltaPine® 1522 B2XF was planted on 102 cm row spacing, at a depth of 3.8 cm, and a seeding rate of 11.6 kg ha^{-1} (128,440 seeds ha^{-1}). Cotton was planted on 4 May 2018 and 13 May 2019. Rainfall in 2018 totaled 304 mm and 576 mm in 2019. Plots received 254 mm of supplemental furrow irrigation in 2018 and 152 mm in 2019.

Weed management systems included a dicamba-tolerant, glufosinate-tolerant, glyphosate-tolerant, conventional, and dicamba PRE only system (Table 1). For all systems, conventional tillage practices were used for land preparation; including a preplant herbicide application and incorporation, listing to form beds, and rod-weeding prior to planting to control emerged weeds. Cultivation and hand-hoeing were used in addition to glyphosate to remove escaped/resistant Palmer amaranth. A tractor mounted row crop cultivator was used for in-season cultivation. The conventional system utilized cultivation and hand-hoeing to control Palmer amaranth escapes. Within the dicamba PRE only system, dicamba was applied PRE and glyphosate was used for POST Palmer amaranth control. POST applications were made when Palmer amaranth plants were 5-10 cm in height.

2.2 Herbicides and Application

Herbicides used in this trial included trifluralin at a 1.12 kg ai ha^{-1} rate and incorporated to a depth of 5.0-7.5 cm, prometryn at a 1.12 kg ai ha^{-1} rate, dicamba at a 0.56 kg ae ha^{-1} rate, glufosinate at a 0.88 kg ai ha^{-1} rate, glyphosate at a 1.26 kg ai ha^{-1} rate, and acetochlor at a 1.26 kg ai ha^{-1} rate (Table 2). All systems received trifluralin PPI, prometryn PRE (except for the dicamba PRE only), and acetochlor with mid-postemergence (MPOST) applications for residual weed control.

Preplant incorporated and preemergence herbicide applications were made using a compressed-air tractor mounted sprayer, and all POST applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 220 kPa. Sprayers were equipped with TurboTeeJet 11002 nozzles (Spraying Systems Co., North Avenue and Schmale Roade, Wheaton, IL 60188) for non-dicamba applications and TurboTeeJet Induction 11002 nozzles for dicamba applications. All applications were made at 4.8 km hr^{-1} at 207 kPa.

2.3 Weed Control, Harvest, and Loan Value

Palmer amaranth control was estimated 14 days after treatment (DAT) following each application, and tillage and hand-hoeing were performed at this time. Palmer amaranth control was estimated using a scale of 0 to 100 percent with 0 representing no control and 100 representing complete control, represented by plant death [14]. The middle two rows of each plot were

Table 1. Weed management systems for palmer amaranth management in cotton in 2018 and 2019

System	PPI	PRE	EPOST	MPOST
Dicamba-tolerant	trifluralin	prometryn	dicamba + glyphosate	dicamba + glyphosate + acetochlor
Glufosinate-tolerant	trifluralin	prometryn	glufosinate	glufosinate + acetochlor
Glyphosate-tolerant	trifluralin	prometryn	glyphosate	glyphosate + acetochlor
Conventional	trifluralin	prometryn	--	acetochlor
Dicamba PRE only	trifluralin	dicamba + glyphosate	glyphosate	glyphosate + acetochlor
Untreated	trifluralin	--	--	--

Abbreviations: PPI, preplant incorporated; PRE, preemergence; EPOST, early-postemergence; MPOST, mid-postemergence

Table 2. Herbicide information for all products used in experiments

Herbicide common name	Herbicide trade name	Rate Giorgio ha^{-1}	Cost \$ ha^{-1}	Manufacturer
Trifluralin	Trifluralin 4 EC	1.12	11.73	
Prometryn	Caparol 4L	1.12	19.14	Syngenta
Dicamba	XtendiMax	0.56	23.37	Bayer Crop Science
Glyphosate	Roundup PowerMax	1.26	12.35	Bayer Crop Science
Glufosinate	Liberty 280SL	0.88	48.14	Bayer Crop Science
Acetochlor	Warrant	1.26	25.02	Bayer Crop Science
In-season cultivation	--	--	19.76	--
Hand-hoeing	--	--	$7.50/hr	--

Table 3. Input dates for palmer amaranth systems in 2018 and 2019

	2018			
Timing	**Application**	**Cultivation**	**Hoeing**	**Irrigation**
PPI	April 4	--	--	--
PRE	May 4	--	--	May 5
EPOST	June 7	June 22	June 22	June 27
MPOST	July 12	July 12	July 12	July 23
	2019			
	Application	**Cultivation**	**Hoeing**	**Irrigation**
PPI	Feb 12	--	--	--
PRE	May 13	--	--	--
EPOST	June 18	June 19	June 19	July 3
MPOST	July 5	July 12 & Aug 12	July 12 & Aug 14	July 29

Abbreviations: PPI, preplant incorporated; PRE, preemergence; EPOST, early-postemergence; MPOST, mid-postemergence

Table 4. Application description for Palmer amaranth systems in 2018 and 2019

	2018			2019		
	PRE	**EPOST**	**MPOST**	**PRE**	**EPOST**	**MPOST**
Application Date	**May 4**	**Jun 7**	**Jul 12**	**May 15**	**Jun 18**	**Jul 5**
Air Temperature (^{0} C)	20	35	26	25	26	27
Relative Humidity (%)	35	29	59	42	60	40
Wind Speed (kph)	11	11	11	10	8	10
Surface Soil Temperature (^{0} C)	19	32	27	22	29	29
Cloud Cover (%)	0	65	80	10	0	25
Weed Height at Application (cm)		5 - 10	5 - 10		5 - 10	5 - 10
Crop stage at Application		3 to 4 leaf	8 to 10 leaf		3 to 4 leaf	8 to 10 leaf

Abbreviations: PRE, preemergence; EPOST, early-postemergence; MPOST, mid-postemergence

mechanically harvested with a John Deere 7445 two-row cotton stripper equipped with an on-board scale to record seed cotton weight. Grab samples from each plot were obtained for ginning. Seed cotton samples were weighed and ginned, and lint weights were recorded to determine percent turnout. Fiber samples were obtained after ginning from each plot, sent to the Fiber and Biopolymer Research Institute (FBRI) in Lubbock, TX and subjected to High Volume Instrument (HVI) testing to determine fiber micronaire, color, staple, strength, length, and uniformity. This information was used to determine loan value (Cotton Incorporated Loan Calculator) for each sample and to estimate a dollar per hectare return for each plot. In 2019, the glyphosate-tolerant and dicamba PRE only systems were not harvested due to early-season rainfall, weed pressure, and low efficacy using glyphosate POST.

2.4 Economic and Statistical Analysis

An economic analysis was conducted to assess the profitability and to create a partial budget for each weed management system. Weed management economic budgets were estimated by calculating crop revenue and expenses. Total revenue was calculated by multiplying lint yield with the loan rate from each system, which did not include revenue from seed. Variable costs were defined as expenses for weed control including seed/technology, herbicides, cultivation, and hand-hoeing. Total margin was used as the measure of profitability and was calculated by subtracting variable cost from the total revenue in each system. Since this is a partial budget for weed management, total margin will be referred to as, “total margin above weed management cost.”

For these experiments, data were subjected to analysis of variance (ANOVA) and means separated by Fischer's Protected LSD at the 5% confidence level (PROC GLIMMIX, SAS 9.4). Means within a column followed by the same letter are not different in tables according to Fisher's Protected LSD test at α < 0.05.

3. RESULTS AND DISCUSSION

In 2018, the most consistent season-long Palmer amaranth control was achieved with the dicamba-tolerant system and did not require any cultivation or hoeing (Table 5). Cahoon et al. found that two POST applications of dicamba + glyphosate-controlled Palmer amaranth by 99% at the end of the season [15]. Everman et al. found that one EPOST application of glufosinate alone controlled Palmer amaranth by 89% and glufosinate applied with prometryn controlled Palmer amaranth by 93% at the end of the season [16]. Glyphosate-tolerant and dicamba PRE only weed control systems were not different after cultivation and hand-hoeing to remove Palmer amaranth that escaped glyphosate applications [16]. Sosnoskie and Culpepper found that increased populations of glyphosate-resistant Palmer amaranth forced the use of residual herbicides, cultivation, and hand-weeding to successfully control glyphosate-resistant Palmer amaranth [17]. This led to an increase in weed management variable cost using a glyphosate-based system (Table 7). Season-long Palmer amaranth control was least effective with the conventional system. In-season irrigation, lack of herbicide use, and escaped weeds from cultivation and hand-hoeing could have contributed to decreased Palmer amaranth control.

There were no differences in the dicamba-tolerant, glyphosate-tolerant, and the dicamba PRE only systems, there was a trend towards higher lint yields with the dicamba-tolerant system in 2018. Lint yield and total revenues for the glyphosate-tolerant, glufosinate-tolerant, and dicamba PRE only, and conventional systems were not different (Table 7). Additional costs related to cultivation and hoeing increased the total variable costs of the dicamba PRE only system when compared to the other treatments. Dicamba-, glufosinate-, glyphosate-tolerant, and conventional systems had total variable costs that were not different. Total margin above weed management costs were not different across these systems. The dicamba- and glufosinate-tolerant systems have higher seed/technology and herbicide cost compared to the glyphosate-tolerant and conventional systems that have lower seed/technology and herbicide cost, but additional cultivation and hand-hoeing costs. Except for the dicamba PRE only, there were no differences in total/gross margin across all other systems in 2018. However, the dicamba-tolerant system trended towards higher total/gross margin above weed management costs.

In 2019, the most consistent season-long Palmer amaranth control was achieved with the dicamba-tolerant system with 97-100% control (Table 8). Norsworthy et al. found that dicamba controlled three glyphosate-resistant Palmer amaranth biotypes 97-100% 28 DAT [18]. The dicamba-tolerant system did not require any cultivation or hand-hoeing, while the conventional system relied on tillage and hand-hoeing combined with residual herbicides PPI, PRE, and mid-season to control Palmer amaranth. The glufosinate-tolerant system required rescue

Table 5. Palmer amaranth control in cotton production in 2018

	Treatments[a]		EPOST		MPOST
System	**EPOST[b]**	**MPOST**	**14 DAT**	**28 DAT**	**14 DAT**
			------------------%------------------		
Dicamba-tolerant	glyphosate + dicamba	glyphosate + dicamba + acetochlor	99 a	100 a	100 a
Glufosinate-tolerant	glufosinate	glufosinate + acetochlor	99 a	93 b	95 b
Glyphosate-tolerant	glyphosate	glyphosate + acetochlor	85 b	96 ab	94 b
Conventional	-	acetochlor	85 b	86 c	83 c
Dicamba PRE only	glyphosate	glyphosate + acetochlor	87 b	95 ab	96 b

[a]Herbicide rates listed in Table 2

[b]Abbreviations: EPOST, early-postemergence; MPOST, mid-postemergence

[c]Means withing a column followed by the same letter are not different according to Fisher's Protected LSD test at α < 0.05

Table 6. Weed management input costs for 2018

System	Seed/Technology	Herbicides	Cultivation	Hand-hoeing
	----------------------------- $ ha^{-1}-----------------------------			
Dicamba-tolerant	158	151	-	-
Glufosinate-tolerant	158	176	-	-
Glyphosate-tolerant	91	104	40	68 c
Conventional	62	55	40	151 a
Dicamba PRE only	158	140	40	90 b

Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $\alpha < 0.05$

Table 7. Lint yield, total revenue, total variable cost, and gross margin over weed management cost for 2018

System	Lint Yield	Total Revenue	Total Variable Cost	Gross Margin
	kg ha^{-1}	----------------------------- $ ha^{-1}-----------------------------		
Dicamba-tolerant	915 a	1031 a	309 b	722 a
Glufosinate-tolerant	755 b	851 a	334 b	527 bc
Glyphosate-tolerant	822 ab	927 a	303 b	624 ab
Conventional	691 b	799 a	308 b	491 c
Dicamba PRE only	793 ab	916 a	403 a	513 bc

Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $\alpha < 0.05$

Table 8. Palmer amaranth control in cotton production in 2019

	Treatments[a]		EPOST		MPOST
System	EPOST[b]	MPOST	14 DAT	28 DAT	14 DAT
			------------------%------------------		
Dicamba-tolerant	glyphosate + dicamba	glyphosate + dicamba + acetochlor	98 ac	97 a	100 a
Glufosinate-tolerant	glufosinate	glufosinate + acetochlor	92 b	68 c	91 a
Glyphosate-tolerant	glyphosate	glyphosate + acetochlor	95 ab	59 c	58 b
Conventional	-	acetochlor	94 ab	89 b	94 a
Dicamba PRE only	glyphosate	glyphosate + acetochlor	93 b	76 bc	45 b

[a]Herbicide rates listed in Table 2
[b]Abbreviations: EPOST, early-postemergence; MPOST, mid-postemergence
[c]Means withing a column followed by the same letter are not different according to Fisher's Protected LSD test at $\alpha < 0.05$

cultivation and hand-hoeing to remove Palmer amaranth that escaped glufosinate applications in 2019. The least effective season-long Palmer amaranth control was with the glyphosate-tolerant and dicamba PRE only systems.

Lint yields were not different and highest total revenues were achieved with the dicamba-tolerant and conventional systems during the 2019 season. The glyphosate-tolerant and dicamba PRE only systems were not harvestable in 2019 due to early-season rainfall, weed pressure, and low glyphosate efficacy POST which contributed to Palmer amaranth competition with cotton plants in these systems. Total variable costs were highest with the glufosinate-tolerant system due to rescue cultivation and hand-hoeing needed.

Total variable costs for the dicamba-tolerant and conventional systems were not different (Table 10). However, the dicamba-tolerant system had greater seed/technology and herbicide costs compared to the conventional systems which had lower seed/technology and herbicide costs but included the addition of cultivation and hand-hoeing costs. The addition of cultivation and hand-hoeing also significantly increased the weed management variable costs for the glufosinate-tolerant system. Greatest gross

Table 9. Weed management input costs for 2019

System	Seed/Technology	Herbicides	Cultivation	Hand-hoeing
	----------------------------- $ ha^{-1}-----------------------------			
Dicamba-tolerant	158	151	-	-
Glufosinate-tolerant	158	176	40	195 a
Glyphosate-tolerant	91	-	-	-
Conventional	62	55	59	189 a
Dicamba PRE only	158	-	-	-

Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at α < 0.05

Table 10. Lint yield, total revenue, total variable cost, and gross margin over weed management cost for 2019

System	Lint Yield	Total Revenue	Total Variable Cost	Gross Margin
	kg ha^{-1}	----------------------------- $ ha^{-1}-----------------------------		
Dicamba-tolerant	459 a	503 a	309 b	351 a
Glufosinate-tolerant	288 b	319 b	569 a	-250 c
Glyphosate-tolerant	-	-	-	-
Conventional	410 ab	437 a	365 b	72 b
Dicamba PRE only	-	-	-	-

Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at α < 0.05

margin above weed management cost was achieved with the dicamba-tolerant system in 2019.

4. CONCLUSION

Dicamba-tolerant systems effectively controlled Palmer amaranth in both 2018 and 2019 when compared to other weed management systems. Dicamba-tolerant systems also increased gross margin above weed management cost. These results demonstrate the efficacy of dicamba systems as a method to control glyphosate-resistant Palmer amaranth without reliance on tillage or hand labor.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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