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Evaluation of non-labeled herbicides in cotton production in Mississippi

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Weed resistance has decreased the number of herbicides that provide effective weed control in cotton. Studies were conducted to determine weed control efficacy and crop safety in cotton with herbicides not currently labeled for use in the crop. Herbicides were applied at two different timings near Starkville and Brooksville, MS. Cotton injury following application of ametryn, bentazon, florpyrauxifen-benzyl, topramezone and tolpyralate at the 3-5 or the 8-10 node growth stage ranged from 24 to 43% and 15 to 51%, respectively, up to 56 days after application. Except for bentazon, applying non-labeled herbicides to cotton at the 3-5 or 8-10 node growth stage decreased seedcotton yield 25 to 44%. Application of bentazon had no effect on yield when applied to cotton at both growth stages and may need to be further evaluated for use in cotton.

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CHAPTER I

COTTON (*GOSSIPYUM HIRSUTUM*) SENSITIVITY AND YIELD RESPONSE TO ON-LABELED HERBICIDES IN MISSISSIPPI

Abstract

Weed resistance has decreased the number of herbicides that provide effective weed control in cotton. Studies were conducted to determine weed control efficacy and crop safety in cotton with herbicides not currently labeled for use in the crop. Herbicides were applied at two different timings near Starkville and Brooksville, MS. Cotton injury following application of ametryn, bentazon, florpyrauxifen-benzyl, topramezone and tolpyralate at the 3-5 or the 8-10 node growth stage ranged from 24 to 43% and 15 to 51%, respectively, up to 56 days after application. Except for bentazon, applying non-labeled herbicides to cotton at the 3-5 or 8-10 node growth stage decreased seedcotton yield 25 to 44%. Application of bentazon had no effect on yield when applied to cotton at both growth stages and may need to be further evaluated for use in cotton.

Introduction

Cotton (*Gossypium hirsutum* L.) hectarage affected by herbicide-resistant weeds has increased since the introduction of RoundUp Ready (RR) technology (Young 2006; Gianessi 2008). Glyphosate resistant Palmer amaranth (*Amaranthus palmeri*) was identified in Georgia in 2004 (Culpepper 2006). Since that time, 10 additional weed species have been confirmed to be glyphosate-resistant (Heap 2021). Further complicating this in cotton is that many glyphosate-resistant weeds are also resistant to herbicides with alternative modes of action. For example, Palmer amaranth is resistant to eight herbicide groups including ALS inhibitors (Group 2), microtubule assembly (Group 3), synthetic auxins (Group 4), PS II inhibitors (Group 5), EPSP inhibitors (Group 9), PPO inhibitors (Group 14), very long chain fatty acid (Group 15), and HPPD inhibitors (Group 27) (Heap 2021).

The primary postemergence (POST) herbicide programs utilized for effective weed control in cotton are threatened by herbicide-resistant Palmer amaranth. Cotton resistant to both glyphosate and glufosinate, GlyTol® + LibertyLink® was introduced in 2011 (Reed 2012). A single application of glufosinate or glufosinate followed by another application of glufosinate to Palmer amaranth less than 10 cm in height provided > 93% control (Corbett et al., 2004; Barnett et al., 2013). However, glufosinate resistant Palmer amaranth was recently discovered in Arkansas (Norsworthy and Barber, Unpublished data 2020). Cotton resistant to glyphosate, dicamba and glufosinate (Bollgard II® XtendFlex™) was introduced in 2015 (ISAAA 2015; USDA-APHIS 2015; Anonymous 2015). Dicamba tank-mixed with glufosinate was 15-20% more effective than glufosinate alone, or 10-30% more effective than dicamba alone with regard to Palmer amaranth control (Cahoon et al., 2015b; Merchant et al., 2014). Dicamba resistant Palmer amaranth was identified in Kansas in 2018 (Peterson et al., 2019), and Tennessee in 2020 (Steckel unpublished data, 2020). Enlist™ cotton technology, which confers resistance to 2,4-D, glufosinate and glyphosate, was introduced in 2016 (Manuchehri, 2017). 2,4-D applied to Enlist™ cotton varieties provided up to 90% Palmer amaranth control (Manuchehri, 2017). However, 2,4-D resistant Palmer amaranth was identified in Kansas in 2015 (Kumar et al., 2019) and Tennessee in 2020 (Steckel, unpublished data 2020). To extend the effectiveness of glufosinate, dicamba and 2,4-D in cotton production systems, residual herbicides must be included in weed control programs (Meyer and Norsworthy 2019; Norsworthy 2012).

In the mid-southern USA, diuron, fluometuron and prometryn are the primary soil applied residual herbicides used in cotton production systems. Applied alone, diuron, fluometuron, prometryn provided 70 to 91% Palmer amaranth control 3 weeks after application (Whitaker at al., 2011). Herbicides such as acetochlor, *S*-metolachlor and pyritiobac can be applied to prevent germination of Palmer amaranth during the season (Cahoon et al., 2015). *S*-metolachlor applied POST, does not provide effective Palmer amaranth control, but when tank mixed with glyphosate can increase effectiveness of glyphosate (Clewis et al., 2006). Acetochlor, *S*-metolachlor or pyritiobac sodium tank mixed with glufosinate resulted in 96 to 97%, 90 to 94%, and 95 to 96% Palmer amaranth control, respectively, 7 days after EPOST application (Cahoon et al., 2015). Tank mixing *S*-metolachlor with glyphosate, glufosinate, and dicamba resulted in 99% Palmer amaranth control (Mayer and Norsworthy, 2019). However, *S*-metolachlor resistant Palmer amaranth was identified in Arkansas in 2018 (Brabham et al., 2019).

Introducing herbicides not currently labeled for use in cotton could be a means to expand modes of action and products utilized in cotton production systems. Ametryn, bentazon, florpyrauxifen-benzyl, topramezone, and tolpyralate are not currently labeled for use in cotton but can control weeds that are problematic across the southern cotton belt. For example, topramezone is labeled for use in corn (*Zea mays* L.) and controls both grass and broadleaf weed species when applied POST (Arslan et al., 2016, Bollman et al., 2008). Tolpyralate applied POST controls several grass and broadleaf weed species including *Amaranthus* species, common ragweed (*Amrbosia artemisiifolia*), ladysthumb (*Persicaria maculosa*), wild mustard (*Sinapis* *arvensis*), green foxtail (*Setaria viridis*) and barnyardgrass (*Echinochloa crus-galli*), but residual activity is limited (Metzger at al., 2018; Kikugawa et al., 2015). Ametryn is effectively controls grass and broadleaf weed species and is labeled for use in corn, coffee (*Coffea arabica* L.), citrus, and ornamentals (Anonymous, 1970). Florpyrauxifen-benzyl is labeled in rice (*Oryza sativa*) as a POST herbicide and effectively controls some grass and broadleaf weed species (Miller and Norsworthy 2018). Additionally, florpyrauxifen-benzyl provides control of auxin-, PSII-, ACCase-, and ALS-resistant grass or broadleaf weed species (Epp et al., 2016). Bentazon is a POST herbicide labeled for use in soybean (*Glycine max* L.) to control broadleaf weed species and sedges. Bentazon controls several weed species such as common ragweed, common lambsquarters (*Chenopodium album*), velvetleaf (*Abutilon theophrasti*), jimsonweed (*Datura stramonium*), and common cocklebur (*Xanthium strumarium*) (Weed Science Society of America, 1994). Introduction of these herbicides into cotton production systems is predicated on them causing no adverse effect on cotton growth and development and effectively controlling Palmer amaranth. Therefore, studies were conducted to determine the effect of ametryn, bentazon, topramezone, florpyrauxifen-benzyl, and topyralate application on 3-5 node and 8-10 node cotton on cotton injury and yield.

Materials and Methods

Field studies were conducted in 2020 and 2021 at the R.R Foil Plant Science Research Center, near Starkville, MS and the Black Belt Branch Experiment Station in Brooksville, MS. An additional study was also conducted in 2020 at W.B. Andrews Agriculture System Research Farm, near Starkville, MS. Cotton variety DP 1646 B2XF (Delta Pine, Bayer Crop Science, St. Louis, MO) was seeded at 108,680 seeds ha^{-1} at the R.R. Foil Plant Science Research Center in 2020 and 2021 and at the W.B. Andrews Agriculture System Research Farm in 2020. Cotton variety NexGen 3729 B2XF (Americot Inc., Lubbock, TX) was seeded at 108,680 seeds ha^{-1} in 2020 at the Black Belt Branch Experiment Station. Planting and harvest dates as well as herbicide application dates are given in Table 1. Cotton at all locations was grown on raised beds with 96 cm row spacing. Plots at the R.R Foil Plant Science Research Center and Black Belt Branch Experiment Station consisted of three rows that were 9.14 m in length whereas plots at W.B. Andrews Agriculture System Research Farm in Starkville, MS consisted of three rows that were 6.1 m in length. Herbicide application was made to cotton at two growth stages: 3-5 and 8-10 nodes. Herbicides utilized in this experiment and application rates are given in Table 2. Treatments were arranged in a randomized complete block design with four replications. All treatments were applied with a CO_2-pressurized backpack sprayer utilizing a four-nozzle boom equipped with AIXR 11002 (Teejet Technologies, Wheaton, IL) nozzles with a 48 cm spacing between each nozzle. The sprayer was calibrated to deliver 140 L ha^{-1} at 276 kPa.

Weed and insect management in cotton were conducted following local recommendations (Crow et al 2021; Barber et al. 2021). Fluometuron (Cotoran, ADAMA, Raleigh, NC) and paraquat (Gramoxone SL 2.0, Syngenta Crop Protection, Greensboro, NC) were applied preemergence (PRE) at 1.68 kg ai ha^{-1} and 0.84 kg ai ha^{-1}, respectively, at all locations over both years. Glufosinate (Liberty 280 SL, BASF Corporation, Research Triangle, NC) and dimethenamid-P (Outlook, BASF Corporation, Research Triangle, NC) were applied at 0.59 kg ai ha^{-1} and 0.84 kg ai ha^{-1}, respectively, as an early post (EPOST) application at all locations over both years. Late post (LPOST) application included glyphosate (Roundup, Monsanto Company, St. Louis, MO) at 1.26 kg ae ha^{-1} and *S*-metolachlor (Dual Magnum, Syngenta Crop Protection, Greensboro, NC) at 1.39 kg ai ha^{-1} (Table 1). Plots were kept weed free using the aforementioned herbicide programs during the growing season to minimize weed competition effects which could confound data related to cotton sensitivity following application of non-labeled herbicides. All plots were treated with mepiquat chloride at 0.0246 kg ai ha^{-1} (Mepiquat, Loveland Products, Inc., Greeley, CO) 28 days after the second herbicide application timing. A total of 135 kg ha^{-1} of nitrogen was injected 5.0 cm into the soil in a split application with one-half applied pre-plant and one-half side-dressed at first bloom. Harvest aids including S, S, S-Tributyl phosphorotrithioate (Folex, AMVAC Chemical Corporation, Los Angeles, CA) at 1.26 kg ai ha^{-1}, ethephon (Boll Buster, Loveland Products, Inc., Greeley, CO) at 0.278 kg ai ha^{-1}, and carfentrazone (Aim, FMC Corporation, Philadelphia, PA) at 0.0263 g ai ha^{-1} were applied at 60% open boll at all locations over both years.

Data collection included visual evaluation of crop injury on a 0 to 100 scale at 7, 14, 28 and 56 days after each application. Plots were harvested using a spindle picker modified for small plot research. Cotton injury and yield data were analyzed using PROC GLIMMIX in SAS 9.4. Location and nested with location were considered random effects. All data were subjected to analysis of variance (ANOVA) and means were separated using Fisher's protected least significant difference (LSD) at α=0.05.

Results and Discussion

The primary hypothesis of this research was that application of non-labeled herbicides to cotton will have a negative effect on crop growth and development. Cotton injury following application of ametryn, bentazon, florpyrauxifen-benzyl, topramezone and tolpyralate at the 3-5 or 8-10 node growth stage ranged from 24 to 73% up to 56 days after application (Table 4).

At 7 and 14 DAT, application of ametryn and tolpyralate to 3-5 node cotton resulted in 54-60% visual injury (Table 4). However, application of topramezone, florpyrauxifen-benzyl, and bentazon to 3-5 node cotton resulted in less visual injury which ranged from 31 to 38% at 7 to 14 DAT. At 28 days after 3-5 node application, 27-32% visual injury was observed following application of bentazon, florpyrauxifen-benzyl, and topramezone to 3-5 node cotton. However, application of ametryn and tolpyralate to 3-5 node cotton resulted in greater visual injury (42-54%) (Table 4). At 56 days after application of flopyrauxifen-benzyl and topramezone to 3-5 node cotton, 23 and 24% visual injury, respectively, was observed. However, application of tolpyralate resulted in increased visual injury at 43% (Table 4).

At 7 DAT, application of ametryn, florpyrauxifen-benzyl, topramezone, and tolpyralate to 8-10 node cotton, 58-62% visual injury was observed (Table 4). However, application of bentazon to 8-10 node cotton resulted in reduced visual injury (32%). At 14 DAT, application of topramezone or tolpyralate to 8-10 node cotton visual injury ranged from 69-73%. However, application of florpyrauxifen-benzyl and bentazon to 8-10 node cotton resulted in 58 and 34% visual injury, respectively. At 28 DAT, application of topramezone and tolpyralate to 8-10 node cotton, resulted in 59 and 63% visual injury (Table 4). Application of florpyrauxifen-benzyl to 8-10 node cotton resulted in 43% visual injury and application of bentazon resulted in 20% visual injury. At 56 DAT, application of ametryn, topramezone, and tolpyralate to 8-10 node cotton, 51-54% visual injury was observed (Table 4). At the same evaluation period, application of florpyrauxifen-benzyl and bentazon resulted in 38% and 15% injury, respectively.

With the exception of bentazon, the evaluated herbicides caused severe visual injury and reduced seedcotton yield (Table 5). Application of tolpyralate and topramezone to 3- to 5-node cotton resulted in reduced seedcotton yield at 1,198 and 1,217 kg seed cotton ha^{-1}, respectively, compared to the untreated check (Table 5). Ametryn and florpyrauxifen-benzyl applied to 3- to 5-node cotton also reduced seedcotton yield compared to the untreated check. Topramezone, florpyrauxifen-benzyl, amentryn, and tolpyralate applied to 8- to 10-node cotton resulted in reduced seedcotton yield at 1,178, 1,106, 1,115, and 1,1285 kg seed cotton ha^{-1}, respectively. Seedcotton yield following application of bentazon to 8- to 10-node cotton was similar to the yield of the untreated check.

Reports of evaluated herbicides on cotton growth and development are limited presumably because they are not labeled for use in the crop. In these experiments, ametryn applied to 3-5 or 8-10 node cotton resulted in 36 to 51% visual injury. Previous research reported that ametryn is very toxic to cotton (Eshel and Ilani, 1975), which is similar to data we observed. Florpyrauxifen-benzyl applied to 3-5 or 8-10 node cotton resulted in 23 to 38% visual injury. Previous research has shown that florpyrauxifen-benzyl applied at 3 g ai ha^{-1} resulted in 77% visual injury on cotton (Miller and Norsworthy, 2018). Unless an alternative delivery technique can be used that may reduce the adverse effects of these herbicides on cotton growth and development, it is unlikely that these chemistries have utility US cotton production systems.

Bentazon could potentially be incorporated into cotton production systems to help control problematic weed species. Bentazon applied at 3-5 and 8-10 node cotton resulted in 28 to 15% visual injury, respectively, but had no adverse effect on seedcotton yield were observed. Bentazon (PS II inhibitor, Group 6) could be introduced in weed management programs to control weed species of interest such as common ragweed, common lambsquater, velvetleaf, jimsonweed, and common cocklebur **(**Weed Science Society of America, 1994; Lycan and Hart, 1999). The limiting factor for bentazon use in cotton production could be lack of effectiveness on *Amaranthus* species (Buchanan et al., 1982; Grichar 1994; Wilcut et al., 1993).

Conclusion

This study was conducted to evaluate the feasibility of utilizing herbicides not currently labeled for use in cotton in order to broaden weed control options. Except for bentazon, applying non-labeled herbicides to cotton at the 3-5 or 8-10 node growth stage decreased seedcotton yield by 25 to 44%. Bentazon had no effect on yield when applied up to 8-10 node growth stage and may need to be further evaluated for use in cotton as a tool for weed resistance management.

Table 1.1 Planting dates, herbicide applications and harvest dates in Mississippi, 2020 and 2021.

City	Location	Year	Planting date	Herbicide application date: PRE	EPOST	LPOST	3-5 node	8-10 node	Harvest
Starkville	R.R Foil Plant Science Research Center	2020	22 May	22 May	05 June	14 August	15 June	01 August	21 October
Brooksville	Black Belt Experiment Station	2020	22 May	22 May	05 June	14 August	19 June	06 August	27 October
Starkville	Andrews Agriculture System Research Farm	2020	05 May	05 May	20 May	23 July	05 June	06 July	21 October
Starkville	R.R Foil Plant Science Research Center	2021	18 May	18 May	01 June	18 August	10 June	15 July	10 November
Brooksville	Black Belt Experiment Station	2021	07 June	07 June	22 June	18 August	15 July	10 August	15 November

Table 1.2 Weed management programs utilized in 2020 and 2021.

Application Timing	**Herbicide**	**Trade name**	**Rate (g ai or ae ha^{-1})**
PRE	fluometuron	Cotoran	1680
	paraquat	Gramoxone SL 2.0	840
EPOST	glufosinate	Liberty 280 SL	600
	dimethenamid-P	Outlook	840
LATE POST	glyphosate	RoundUp PowerMaxII	1260
	S-metolachlor	Dual Magnum	1390

PRE = Preemergence
EPOST = Early postemergence
LATE POST = Late postemergence

Table 1.3 Herbicides and adjuvants used in experiments in Mississippi in 2020 and 2021

Herbicide and adjuvants	Rate (g ai ae ha^{-1})	Trade Name	MOA	WSSA Group	Manufacture
topramezone	24.6	Impact	HPPD	27	AMVAC Chemical Corporation
crop oil conc.	1%	Agri-Dex			Helena Chemical Co.
florpyrauxifen-benzyl	29.5	Loyant	Synthetic auxin	4	Corteva Agriscience
methylated seed oil	0.5%	MSO			Helena Chemical Co.
bentazon	840	Broadloom	PS II	6	UPL, King of Prussia
crop oil conc.	1%	Agri-Dex			Helena Chemical Co.
ametryn	1800	Evik DF	PS I	5	Syngenta Crop Protection
tolpyralate	29.2	Shieldex			SummitAgro USA
crop oil conc.	1%	Agri-Dex	HPPD	27	Helena Chemical Co.

[a] Specimen labels for each product and mailing addresses and web site addresses of each manufacturer can be found at http://www.cdms.net

Table 1.4 Effect of non-labeled herbicide application on cotton injury 7, 14, 28 and 56 days after treatment (DAT) pooled across years and locations.[a]

	Crop injury (%) Application timings							
	3-5 node				**8-10 node**			
Herbicide	**7 DAT**	**14 DAT**	**28 DAT**	**56 DAT**	**7 DAT**	**14 DAT**	**28 DAT**	**56 DAT**
topramezone	34 b	31 b	27 c	24 b	59 a	69 ab	59 ab	51 a
florpyrauxifen-benzyl	36 b	37 b	27 c	23 b	59 a	58 c	43 c	38 b
bentazon	38 b	38 b	32 bc	28 ab	32 b	34 d	20 d	15 c
ametryn	55 a	54 a	42 ab	36 ab	58 a	65 bc	52 bc	51 a
tolpyralate	58 a	60 a	54 a	43 a	62 a	73 a	63 a	54 a

[a] Means within column followed by the same letter are not significantly different ($\alpha \leq 0.05$)

Table 1.5 Effect of herbicide application on cotton yield pooled over years and locations.[a]

	Seedcotton Yield (kg/ha)	
Herbicide treatment	**3-5 node**	**8-10 node**
topramezone	1217 c	1178 b
florpyrauxifen-benzyl	1603 b	1106 b
bentazon	2146 a	1781 a
ametryn	1449 bc	1115 b
tolpyralate	1198 c	1285 b
UTC*	2137 a	1959 a

*UTC = untreated check

[a] Means within column followed by the same letter are not significantly different ($\alpha \leq 0.05$).

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CHAPTER II

POTENTIAL TO INTEGRATE NON-LABELED HERBICIDES INTO MIDSOUTHERN USA COTTON WEED CONTROL PROGRAMS

Abstract

The prevalence of herbicide-resistant weed populations has reduced the number of herbicides that effectively control troublesome weed species in cotton. This study was conducted to determine if common weed species in Mississippi cotton production systems can be controlled by herbicides currently not labeled for use in the crop. Ametryn, bentazon, florpyrauxifen-benzyl, topramezone and tolpyralate efficacy on Palmer amaranth, prickly sida, common ragweed, johnsongrass, and Texas panicum was investigated under greenhouse conditions. Common ragweed control, regardless of herbicide, exceeded 97% by 21 DAT. Similarly, with the exception of bentazon, the evaluated herbicides provided greater than 95% Palmer amaranth control at 21 DAT. Florpyrauxifen-benzyl and ametryn provided >95% prickly sida control up to 21 DAT. Conversely, regardless of herbicide or evaluation timing, grass weed control never exceeded 71%. The evaluated herbicides provided >95% control of the evaluated broadleaf weed species and should be evaluated for crop injury and potential cotton herbicide programs.

Introduction

Herbicide resistance is a natural response to novel agricultural activities (Norwsorthy et al., 2012). Continuous application of a single herbicide or herbicides with same mode of action can lead to increased selection pressure, and herbicide resistance (Norsworthy et al., 2012).

Glyphosate-resistant cotton (*Gossypium hirsutum* L.) cultivars were introduced in 1997 (Young 2006). The first glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) population was reported in Georgia cotton in 2004 (Culpepper et al., 2006). Subsequently, 10 weed species that are problematic in USA cotton production have been reported to be glyphosate-resistant (Heap 2021).

Herbicide resistance in cotton is compounded by the fact that many glyphosate-resistant weeds are also resistant to herbicides with alternative modes of action. For example, Palmer amaranth is resistant to eight herbicide groups including ALS inhibitors (Group 2), microtubule assembly (Group 3), synthetic auxins (Group 4), PS II inhibitors (Group 5), EPSP inhibitors (Group 9), PPO inhibitors (Group 14), very long chain fatty acid (Group 15), and HPPD inhibitors (Group 27) (Heap 2021). EPSP inhibitor (Group 9) resistant common ragweed (*Ambrosia artemisiifolia*) biotypes were reported in Missouri in 2004 (Pollard 2007; Heap 2017), which was followed by 15 other states reporting GR common ragweed biotypes (Heap 2017). Johnsongrass (*Sorghum halepense*) resistance to EPSP inhibitor (Group 9), ACCase- (Group 1) and ALS inhibitors (Group 2) (Burke et al., 2006; Heap 2013; Smeda et al., 1997) has also been reported. The ability of problematic weed species to develop resistance to multiple modes of action is placing stress on effective, economical weed control programs in cotton production systems.

Due to the genetic flexibility of problematic weed species, novel postemergence (POST) herbicide programs are failing almost immediately upon introduction in the market. For example, glufosinate applied alone or followed by a second application of glufosinate provided >93% control of 10 cm tall Palmer amaranth (Corbett et al., 2004; Barnett et al., 2013; Mayer and Norsworthy, 2019). However, glufosinate resistant Palmer amaranth biotypes have been reported in Arkansas (Norsworthy and Barber, unpublished data 2020). Similarly, dicamba applied alone or followed by glufosinate plus dicamba provided 93% Palmer amaranth control (Vann et al., 2017). However, dicamba resistant Palmer amaranth biotypes were recently reported in Kansas (Peterson et al., 2019) and Tennessee (Steckel 2020, unpublished data). A single application of 2,4-D provided 89% Palmer amaranth control and 2,4-D tank mixed with glufosinate increased Palmer amaranth control to 97% (Meyer and Norsworthy, 2019). 2,4-D resistant Palmer amaranth biotypes were recently reported in Kansas (Kumar et al., 2019) and Tennessee (Steckel 2020, unpublished data). To prolong the life of currently effective herbicide options, residual herbicides must be included in weed management programs (Mayer and Norsworthy, 2019).

In the mid-southern USA, diuron, fluometuron and prometryn are the primary soil applied residual herbicides in cotton production systems. Applied alone, diuron, fluometuron, prometryn resulted in 70 to 91% Palmer amaranth control 3 weeks after application (Whitaker et al., 2011). Herbicides such as acetochlor, *S*-metolachlor and pyritiobac can be applied to prevent germination of Palmer amaranth during the season (Cahoon et al., 2015). *S*-metolachlor applied POST, does not provide effective Palmer amaranth control (Whitaker et al., 2011), but when tank mixed with glyphosate, control was increased 47% (Clewis et al., 2006). Tank mixing acetochlor, *S*-metolahclor, and pyritiobac sodium with glufosinate, resulted in 96 to 97%, 90 to 94%, and 95 to 96% Palmer amaranth control, respectively, 7 days after EPOST application (Cahoon et al., 2015). Tank mixing *S*-metolachlor with glyphosate, glufosinate, and dicamba resulted in 99% Palmer amaranth control (Mayer and Norsworthy, 2019). However, *S*-metolachlor resistant Palmer amaranth was identified in Arkansas in 2018 (Brabham et al., 2019).

Introducing herbicides not currently labeled for use in cotton could be a means to expand modes of action utilized in cotton production systems. Ametryn, bentazon, florpyrauxifen-benzyl, topramezone, and tolpyralate are not currently labeled for use in cotton but can control problematic weeds across the southern cotton belt. For example, topramezone is labeled for use in corn (*Zea mays* L.) and controls both grass and broadleaf weed species including Palmer amaranth, tall waterhemp (*Amaranthus tuberculatus*), common ragweed, prickly sida (*Sida spinosa*), barnyardgrass (*Echinochloa crus-galli*), giant foxtail (*Setaria faberi*) when applied POST (Arslan et al., 2016, Bollman et al., 2008). Tolpyralate applied POST controls several grass and broadleaf weed species including *Amaranthus* species, common ragweed, ladysthumb (*Persicaria maculosa*), wild mustard (*Sinapis arvensis*), green foxtail (*Setaria viridis*) and barnyardgrass, but residual activity is limited (Metzger at al., 2018; Kikugawa et al., 2015). Ametryn is a selective herbicide which effectively controls grass and broadleaf weed species such as barnyardgrass, Texas panicum (*Urochloa texana*), morningglory (*Ipomoea* spp.), and *Amaranthus* species, and is labeled for use in corn, coffee (*Coffea arabica* L.), citrus, and ornamentals (Anonymous, 1970). Florpyrauxifen benzyl is labeled in rice (*Oryza sativa*) as a POST herbicide and effectively controls barnyardgrass, junglerice (*Echinochloa colona*) and broadleaf weed species such as Palmer amaranth, common ragweed, redroot pigweed (*Amaranthus retroflexus*) (Miller and Norsworthy 2018). Additionally, florpyrauxifen benzyl provides control of auxin-, PSII-, ACCase-, and ALS-resistant barnyardgrass or Palmer amaranth (Epp et al., 2016, Sanders et al., 2020). Bentazon is a POST herbicide labeled for use in soybean (*Glycine max* L.) to control broadleaf weed species and sedges. Bentazon controls several weed species such as common ragweed, common lambsquarters (*Chenopodium album*), velvetleaf (*Abutilon theophrasti*), jimsonweed (*Datura stramonium*), and common cocklebur (*Xanthium* *strumarium*) (Weed Science Society of America, 1994). Introduction of these herbicides into cotton production systems is predicated on them causing no adverse effect on cotton growth and development and effectively control Palmer amaranth and other troublesome weed species. Therefore, this study was conducted to determine the effect of ametryn, bentazon, florpyrauxifen-benzyl, topramezone, and tolpyralate on five weed species that are troublesome in Mississippi cotton.

Materials and Methods

Greenhouse studies were conducted in 2020 and 2021 at R.R. Foil Plant Science Research Center near Starkville, MS to evaluate control of five weed species common to cotton production using five herbicides not labeled for use in cotton. Weed seeds were planted into 10x10 cm square pots (The HC Companies, Twinsburg, OH) filled with Ferti-lome potting mix (Lambert Peatmoss Inc., Quebec, Canada). Plants were overhead watered two times per day until soil saturation was achived. Daytime temperature was kept at 25± 2 C and a nighttime temperature was kept at 18± 3 C, with a relative humidity of 75%. Sodium halide lamps were used as an additional light source and day length was set at 16 h of daylight and 8 h of dark. Multiple weed seeds were planted in each pot and thinned after emergence to one plant per pot. Treatments were arranged in randomized complete block design with four replications. Herbicides, application rates, adjuvants utilized are listed in Table 1. Weed species evaluated included Palmer amaranth, prickly sida, common ragweed, johnsongrass and Texas panicum. Herbicide applications were made when all weed species reached 10 cm in height. All treatments were applied using a two-nozzle, Generation III Research Track Sprayer (DeVries Manufacturing, Hollandale, MN 56045) calibrated to deliver 140 L ha^{-1} at 276 kPa, with AIXR 110015 (Teejet Technologies, Wheaton, IL) nozzles, a speed of 4.8 km h^{-1}, and nozzle height 50 cm above each plant. Plants were immediately returned to the greenhouse after herbicide application. Visual injury was assessed at 7, 14, 21 days after treatment (DAT) and ranged from zero (no injury) to 100 (complete control) percent. Visual injury data were analyzed using PROC GLIMIX in SAS 9.4. All data were subject to analysis of variance (ANOVA) and means were separated using Fisher's protected least significant difference (LSD) at α=0.05.

Results and Discussion

The primary hypothesis of this research was that non-labeled herbicides will effectively control troublesome weed species in cotton. Weed control following application of ametryn, bentazon, florpyrauxifen-benzyl, topramezone and topyralate on Palmer amaranth, prickly sida, and common ragweed ranged from 11 to 98% up to 21 DAT. Contrary to our hypothesis, bentazon did not provide effective Palmer amaranth control (2%), while topramezone and topyralate were ineffective on prickly sida (12 to 14%) (Table 2).

With the exception of bentazon, the evaluated herbicides provided >95% Palmer amaranth control up to 21 DAT. All non-labeled herbicides provided effective common ragweed control (>97%) up to 21 DAT. Control of prickly sida ranged from 93 to 95% following application of bentazon, ametryn and florpyrauxifen-benzyl up to 21 DAT. Topramezone and topyralate did not effectively control prickly sida (12 to 14%) up to 21 DAT (Table 2).

Palmer amaranth

Ametryn provided 94% to 96% Palmer amaranth control up to 21 DAT. Florpyrauxifen-benzyl, topramezone and tolpyralate provided 95% to 98% Palmer amaranth control at 14 and 21 DAT. Bentazon provided no Palmer amaranth control, at any rating period.

Previous reports regarding herbicides evaluated on weed control in cotton are limited because these herbicides are not currently labeled in cotton. Previous research demonstrated ametryn applied LAYBY at 1120 g ai ha^{-1} provided 88% Palmer amaranth control in corn (Burke et al., 2008). Florpyrauxifen-benzyl applied at 30 g ai ha^{-1} provided >95% Palmer amaranth control up to 4 weeks after application. These data are similar to our observations (Wright et. al, 2020, Sanders et al., 2019, Miller and Norsworthy 2017). Tolpyralate applied at 40 g ai ha^{-1} resulted in 95% Palmer amaranth control up to 21 DAT (Kohrt and Sprague 2017). Tolpyralate applied at 30 g ai ha^{-1} resulted in 92% Palmer amaranth control 4 weeks after application (Metzger et al., 2018). Topramezone applied at 18 g ai ha^{-1} provided 88 to 96 % Palmer amaranth control up to 14 DAT (Kohrt and Sprague 2017). Bentazon lacked effectiveness on *Amaranthus* species in several previous studies (Buchanan et al., 1982; Grichar 1994; Wilcut et al., 1993), which is similar to data we observed.

Previous research documented that flourpyrauxifen-benzyl can effectively control Palmer amaranth (Miller and Norsworthy 2017), However, Miller and Norsworthy (2018) observed that simulated drift of florpyrauxifen-benzyl resulted in significant injury on cotton. Ametryn provided effective Palmer amaranth control, but according to previous research (Ugljic et al., unpublished data) ametryn is very injurious on cotton. Topramezone and tolpyralate provided effective Palmer amaranth (>95%) control; however, high levels of crop injury are a limiting factor for these herbicides in cotton production systems (Ugljic et al., unpublished data). Reduced herbicide rates, or different herbicide placement techniques should be considered for further research due to significant injury caused by broadcast applications.

Common ragweed

At 7 DAT, bentazon and ametryn provided 93-94% common ragweed control (Table 2). Reduced control following application of flourpyrauxifen-benzyl, topramezone and tolpyralate was observed 7 DAT at 86%, 76%, and 67% control, respectively. At 14 and 21 DAT, no difference in common ragweed control was observed between herbicides evaluated, with control ranging from 97-98% (Table 2).

Previous research in soybean demonstrated 99% common ragweed control when bentazon was applied at 950 g ai ha^{-1} (Ganie and Jhala 2017). These data are similar with our observations. Topramezone applied at 18.4 g ai ha^{-1} provided 96% common ragweed control up to 3 weeks after application in corn production (Ganie and Jhala 2017). Tolpyralate applied at 30 g ai ha^{-1} provided 97% common ragweed control up to 4 weeks after application (Metzger et al., 2018), which is similar with data we observed. Limited to no published literature exists on common ragweed control following application of ametryn and florpyrauxifen-benzyl.

The evaluated herbicides provided effective common ragweed (> 97%) control. Previous research (Ugljic et al., unpublished data) indicates that these herbicides could be considered as a possible weed control option in cotton production system. However, further research regarding crop tolerance to these herbicides is need.

Prickly sida

Application of bentazon and ametryn provided 71-95% prickly sida control at 7 DAT (Table 2). Application of florpyrauxifen-benzyl, topramezone, and tolpyralate resulted in 49%, 19%, and 11% control, respectively, at 7 DAT. Prickly sida control at 14 and 21 DAT following application of florpyrauxifen-benzyl, bentazon, ametryn ranged from 93-95%. Reduced prickly sida control (12-14%) 14 and 21 DAT was observed following application of tolpyralate and topramezone (Table 2). Limited to no published literature exist on prickly sida control following application of evaluated herbicides. Further research is needed due to high potential for crop injury when these herbicides are applied via broadcast application.

Johnsongrass and Texas panicum

Ametryn provided 5% johnsongrass control, and 37% Texas panicum control up to 21 DAT. Tolpyralate provided 20% johnsongrass control, and 71% Texas panicum control up to 21 DAT (Table 2). Bentazon, topramezone, and florpyrauxifen-benzyl failed to provide control of grass species evaluated. Tolpyralate provided the greater level of johnsongrass and Texas panicum control at all rating periods (Table 2).

Conclusion

This study was conducted to determine the feasibility of controlling weeds in cotton with herbicides not currently labeled for use in the crop. Ametryn, bentazon, florpyrauxifen-benzyl, topramezone and tolpyralate efficacy on Palmer amaranth, prickly sida, common ragweed, johnsongrass and Texas panicum was investigated under greenhouse conditions. Common ragweed control, regardless of herbicide, exceeded 97% by 21 DAT. Similarly, with the exception of bentazon, the evaluated herbicides provided greater than 95% Palmer amaranth control at 21 DAT. Florpyrauxifen-benzyl and ametryn provided >95% prickly sida control up to 21 DAT. Conversely, regardless of herbicide or evaluation timing, grass weed control never exceeded 71%. The evaluated herbicides provided >95% control of the evaluated broadleaf weed species and should be evaluated for crop injury and potential for use in cotton herbicide programs.

Table 2.1 Herbicides and adjuvants used in greenhouse experiments in Mississippi in 2020 and 2021. [a]

Herbicide and adjuvants	Rate (g ai ae ha^{-1})	Trade Name	MOA	WSSA Group	Manufacture
topramezone	24.6	Impact	HPPD	27	AMVAC Chemical Corporation
crop oil conc.	1%	Agri-Dex			Helena Chemical Co.
florpyrauxifen-benzyl	29.5	Loyant®	Synthetic auxin	4	Corteva Agriscience
methylated seed oil	0.5%	MSO			Helena Chemical Co.
bentazon	840	Broadloom™	PS II	6	UPL, King of Prussia
crop oil conc.	1%	Agri-Dex			Helena Chemical Co.
ametryn	1800	Evik DF®	PS I	5	Syngenta Crop Protection
tolpyralate	29.2	Shieldex®			SummitAgro USA
crop oil conc.	1%	Agri-Dex	HPPD	27	Helena Chemical Co.

[a] Specimen labels for each product and mailing addresses and web site addresses of each manufacturer can be found at http://www.cdms.net

Table 2.2 Effect of non-labeled herbicides application on broadleaf weed species (common ragweed, Palmer amaranth, prickly sida) control 7, 14, 21 days after treatment (DAT) in 2020 and 2021. [a]

		Palmer amaranth			**Common ragweed**			**Prickly sida**		
Herbicide	**Rate** (g ai or ae ha^{-1})	**7 dat**	**14 dat**	**21 dat**	**7 dat**	**14 dat**	**21 dat**	**7 dat**	**14 dat**	**21 dat**
topramezone	24.6	87 b	95 a	98 a	76 c	98 a	98 a	11 c	14 b	12 b
florpyrauxifen-benzyl	29.5	85 b	96 a	98 a	86 b	98 a	98 a	49 b	95 a	95 a
bentazon	840	2 c	2 b	0 c	93 a	97 a	97 a	71 a	93 a	93 a
ametryn	1800	94 a	95 a	96 ab	94 a	97 a	97 a	72 a	95 a	95 a
tolpyralate	29.2	86 b	95 a	95 b	67 d	97 a	97 a	19 c	14 a	14 b

[a] Means within column followed by the same latter are not significantly different ($\alpha \leq 0.05$).

Table 2.3 Effect of non-labeled herbicides application on grass weed species control 7, 14, 21 days after treatment (DAT) in 2020 and 2021.[a]

		Johnsongrass			Texas panicum		
Herbicide	**Rate** (g ai or ae ha^{-1})	**7 dat**	**14 dat**	**21 dat**	**7 dat**	**14 dat**	**21 dat**
topramezone	24.6	0 c	1 c	1 c	4 c	2 d	2 d
florpyrauxifen - benzyl	29.5	0 c	2 c	2 c	6 c	14 c	9 c
bentazon	840	0 c	0 c	0 c	0 c	0 d	0 d
ametryn	1800	5 b	16 b	14 b	37 b	37 b	37 b
tolpyralate	29.2	20 a	56 a	56 a	71 a	57 a	57 a

[a] Means within column followed by the same latter are not significantly different ($\alpha \leq 0.05$).

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