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Evaluation of Italian ryegrass and Palmer amaranth control in Mississippi

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Italian ryegrass is a problematic weed in Mississippi corn production due to the development and proliferation of glyphosate resistance. Studies were conducted to assess Italian ryegrass control prior to planting using herbicides. Effects of fall and spring applied burndown herbicide applications for Italian ryegrass control and subsequent corn grain yield were investigated at the R.R. Foil PSRC in Starkville, MS, at the Coastal Plain Experiment Station in Newton, MS, and the Black Belt Experiment Station in Brooksville, MS on soil textures ranging from sandy loam to silt clay loam. A fall preemergence (PRE) application of *S*-metolachlor + metribuzin followed by paraquat in the spring provided 99% Italian ryegrass control 28 days after paraquat application. Four spring burndown treatments provided Italian ryegrass control similar to that observed following application of the fall PRE application followed by paraquat in the spring. Applications clethodim + glufosinate + paraquat + dimethenamid-P; clethodim + glufosinate + paraquat + *S*-metolachlor; clethodim + paraquat + dimethenamid-P; and clethodim + oxyfluorfen + paraquat + *S*-metolachlor resulted in similar levels of Italian ryegrass control at 96%, 98%, 94%, and 99%, respectively. Corn yield following the fall PRE followed by spring paraquat application was 10,687 kg ha^{-1}. Corn yield following clethodim + paraquat + dimethenamid-P as well as clethodim + oxyfluorfen + paraquat + *S*-metolachlor applied in the

spring resulted in similar corn grain yield to that following the fall PRE followed by spring paraquat application at 9,649 kg ha^{-1} and 9,567 kg ha^{-1}, respectively. Spring burndown herbicide treatments could be used to control Italian ryegrass while producing similar corn yield to the standard fall herbicide followed by paraquat application in the spring.

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CHAPTER I

EVALUATION SPRING BURNDOWN APPLICATIONS TO MAXIMIZE ITALIAN RYEGRASS [*LOLIUM PERENNE SSP. MULTIFLORUM* (LAM.)] CONTROL IN MISSISSIPPI CORN

Abstract

Italian ryegrass is a problematic weed in Mississippi corn production due to the development and proliferation of glyphosate resistance. Studies were conducted to assess Italian ryegrass control prior to planting using herbicides. Effects of fall and spring applied burndown herbicide applications for Italian ryegrass control and subsequent corn grain yield were investigated at the R.R. Foil PSRC in Starkville, MS, at the Coastal Plain Experiment Station in Newton, MS, and the Black Belt Experiment Station in Brooksville, MS on soil textures ranging from sandy loam to silt clay loam. A fall preemergence (PRE) application of *S*-metolachlor + metribuzin followed by paraquat in the spring provided 99% Italian ryegrass control 28 days after paraquat application. Four spring burndown treatments provided Italian ryegrass control similar to that observed following application of the fall PRE application followed by paraquat in the spring. Applications clethodim + glufosinate + paraquat + dimethenamid-P; clethodim + glufosinate + paraquat + *S*-metolachlor; clethodim + paraquat + dimethenamid-P; and clethodim + oxyfluorfen + paraquat + *S*-metolachlor resulted in similar levels of Italian ryegrass control at 96%, 98%, 94%, and 99%, respectively. Corn yield following the fall PRE followed by spring paraquat application was 10,687 kg ha^{-1}. Corn yield following clethodim + paraquat +

dimethenamid-P as well as clethodim + oxyfluorfen + paraquat + *S*-metolachlor applied in the spring resulted in similar corn grain yield to that following the fall PRE followed by spring paraquat application at 9,649 kg ha^{-1} and 9,567 kg ha^{-1}, respectively. Spring burndown herbicide treatments could be used to control Italian ryegrass while producing similar corn yield to the standard fall herbicide followed by paraquat application in the spring.

Introduction

Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.)] (IR) is a problematic weed for Mississippi corn [*Zea mays* (L.)] producers that often results in reduced yields. Italian ryegrass is abundant in the mid-southern United States and uncontrolled IR can increase seed deposition in the soil seed bank. Continued lack of control coupled with selection pressure could lead to evolving complex patterns of herbicide resistance (Bararpour et al., 2020). Previous research has shown that applying a preemergence (PRE) herbicide in the fall followed by a postemergence (POST) application in early spring resulted in greatest IR control and corn yield (Wesley 2019).

Italian ryegrass is a winter annual bunchgrass that can grow from 30 to 90 cm tall (Bond et al. 2014; Hannaway et al. 1999) and germinates from September to November with vigorous growth from Dec. to Feb (Nandula et al., 2009). Italian ryegrass establishes dominance early and quickly becomes a competitor for nutrients, sunlight, and water (Bond et al. 2014). Italian ryegrass grows well in a variety of soil textures, especially where pH levels range from 5 to 7.9 (Bond et al. 2014; Hannaway et al. 1999) and disrupts successful crop establishment when proper control is not achieved (Bond et al. 2014). Italian ryegrass decreases corn yield across Mississippi and further yield reduction may continue without proper control (Bond 2018).

With the introduction of glyphosate-tolerant corn, widespread use of glyphosate for PRE and POST weed management has become a standard practice (Chahal et al., 2016). Combined with the adoption of different tillage practices, such as reduced tillage and no-till cropping systems, glyphosate-resistant IR has become problematic. The first report of glyphosate-resistant IR in Mississippi row crop production occurred in 2005 (Nandula et al., 2007). In response, producers have turned to other herbicides such as spring applied clethodim for control (Bond 2018). Clethodim has been proven to be effective for control of glyphosate-resistant IR; however, there are several reports of IR developing resistance to clethodim around the world (Heap 2022; Nandula et al., 2020).

Currently, the recommendation for control of glyphosate-resistant IR in Mississippi is a fall PRE application of *S*-metolachlor +metribuzin (Boundary® 6.5 EC) followed by a POST application of paraquat (Gramoxone® 2.0 SL) 28 days before planting (Bond et al. 2014, Wesley 2019). However, relying on the current recommendation has proven difficult over the past several growing seasons due to increased autumn rainfall. Additionally, increased rainfall during the winter months may lead to soil erosion and decreased integrity of beds formed following fall ridge till operations as a result of less vegetative growth following application of a fall PRE. Finding alternative options to a fall PRE followed by paraquat in the spring may allow producers increased flexibility for glyphosate-resistant IR control as well as potentially minimizing soil erosion due to lack of vegetative cover during winter months. Therefore, the primary objective of this study was to identify effective herbicide control options applied as a spring burndown application for the control of glyphosate-resistant IR in corn production systems. In addition, corn grain yield following spring burndown applications was measured to determine if spring burndown applications are comparable to fall PRE applications followed by paraquat in the spring.

Materials and Methods

Studies were conducted across multiple sites in Mississippi in 2020 and 2021 to evaluate Italian ryegrass control from spring burndown applications without a previous application of herbicide in the fall in comparison to that from fall applied burndown applications followed by a spring burndown application of paraquat. Studies were conducted at CPBES in Newton, MS in 2020 and at the R.R. Foil PSRC in Starkville, MS, the CPBES in Newton, MS, and the BBBES in Brooksville, MS in 2021. Treatments were arranged in a randomized complete block design with four replications. Plots at the CPBES consisted of six 76-cm rows whereas plots at the R.R. Foil PSRC and the BBBES consisted of four 97-cm rows. Plots at all locations were 9.14 m in length. Corn hybrid 'DKC 70-27' was seeded at 69,200 seed ha^{-1} at all locations and years. Crop management practices including fertilization, irrigation, and pest management (other than weed control) were performed according to Mississippi State extension recommendations. Planting and harvest dates, herbicide application dates, and other agronomic information is given in Table 1.1.

Herbicide treatments were applied using a CO_2-pressurized backpack sprayer equipped with a four-nozzle spray boom with nozzles spaced 48 cm apart. The sprayer was calibrated to deliver 140 L ha^{-1} of spray solution at 276 kPa using AIXR 11002 nozzles (Teejet Technologies, Wheaton, IL). Oregon Grown brand, 'Gulf' Italian ryegrass, was drilled at each location using a no-till drill (Great Plains Manufacturing Incorporated, 1525 E. North Street, Salina, KS) on 19 cm row spacings at 112 kg ha^{-1} during the first week of November of each year. Herbicide treatments included two separate application timings described in Table 1.1. The first application was made within 7 days of ryegrass seeding and the second application was made the following spring approximately 28 days prior to corn planting (Wesley 2019).

Herbicides evaluated (spring applied unless otherwise indicated) included (all rates in g ai ha^{-1} and rate for each product initially listed was used in all treatments): *S*-metolachlor + metribuzin (Boundary® 6.5 SC) at 3,400 fall applied followed by paraquat (Gramoxone® 2.0 SL) at 1,120 the following spring; acetochlor + mesotrione + clopyralid (Resicore®) at 2,300 + glufosinate (Liberty® 280 SL) at 657 + oxyfluorfen (Goal® 2XL) at 560; quizalofop (Assure® II) at 93 + glufosinate + *S*- metolachlor (EverpreX®) at + paraquat at 1,120; clethodim (Select Max®) at 136 + glufosinate + paraquat + dimethenamid-P (Outlook®) at 1,100; clethodim + glufosinate + paraquat + *S*- metolachlor; clethodim + paraquat + dimethenamid-P; and clethodim + oxyfluorfen + paraquat + *S*- metolachlor. All applications included crop oil concentrate (Agri-Dex, Helena Chemical Company,225 Schilling Boulevard, Suite 300, Collierville, TN 38017) at 1% v v^{-1}.

Data collection consisted of visual evaluations of IR control on a scale from zero to 100% (complete plant death) taken at 7, 14, 21 and 28 days after spring applications are made. Also, corn heights were taken at all locations at the tassel stage. Corn was harvested using a Kincaid 8-XP plot combine (Kincaid Equipment Manufacturing, Haven, KS) at all locations. Seed corn weights from each plot were collected, corrected to 15% moisture and converted to kg ha^{-1}. Data were subjected to ANOVA using the Proc GLIMMIX procedure in SAS 9.4 (SAS Institute Inc., Cary, NC) and means were separated using Fisher's protected least significant difference (LSD) at α=0.05 where random effects were year and location.

Results and Discussion

The primary hypothesis of this study was that spring burndown applications would effectively control IR. The secondary hypothesis was that corn grain yield following spring burndown applications would be similar to those following the fall PRE followed by spring paraquat application. The fall PRE application of *S*-metolachlor + metribuzin followed by paraquat in the spring resulted in 96% to 99% IR control at 7, 14, 21, and 28 days after the spring paraquat application (Table 2.1) and these data are consistent with Bond et al. (2014) and Wesley (2019). Treatments that did not include paraquat or clethodim in the spring burndown application provided less IR control at all rating periods than other treatments (Table 1.2). In addition, corn grain yield was reduced when paraquat and either clethodim or quizalofop was not included in the spring burndown application (Table 1.2). Similar results were observed by Bond et al. 2014.

Italian ryegrass control 7 days after spring burndown application ranged from 72% to 96% (Table 1.2). The greatest level of control (96%) was observed following a fall application of S-metolcahlor + metribuzin followed by a spring paraquat application. Application of clethodim + glufosinate + paraquat + dimethenamid-p; clethodim + glufosinate + paraquat + *S*-metolachlor; and clethodim + oxyfluorfen + paraquat + *S*-metolachlor resulted in 86% to 90% IR control. The lowest level of control 7 days after spring burndown was observed following application of acetochlor + mesotrione + clopyralid + glufosinate + oxyfluorfen at 72%.

Similar results with respect to IR control were observed 14 days after spring burndown application in that the greatest level of control (98%) was observed following a fall application of S-metolcahlor + metribuzin followed by a spring paraquat application (Table 1.2). A spring burndown application of clethodim + oxyfluorfen + paraquat + *S*-metolachlor as well as clethodim + glufosinate + paraquat + *S*-metolachlor resulted in similar levels of IR control at

96% and 92%, respectively. Reduced IR control was observed following spring application of quizalofop + glufosinate + *S*-metolachlor + paraquat which provided 82% control. The lowest level of control 14 days after spring burndown was observed following application of acetochlor + mesotrione + clopyralid + glufosinate + oxyfluorfen at 65%.

By 21 days after spring burndown application, several treatments provided IR control similar to that observed following a fall application of *S*-metolachlor + metribuzin followed by a spring application of paraquat (99%) (Table 1.2). A spring burndown application of clethodim + glufosinate + paraquat + dimethenamid-P; clethodim + oxyfluorfen + paraquat + *S*-metolachlor as well as clethodim + glufosinate + paraquat + *S*-metolachlor resulted in similar levels of IR control at 93%, 98%, and 94%, respectively. Application of clethodim + paraquat + dimethenamid-P provided similar control (90%) at 21 days after spring burndown to that observed following application of clethodim + glufosinate + paraquat + dimethenamid-P (93%) and clethodim + glufosinate + paraquat + *S*-metolachlor (94%). Reduced IR control was observed following spring application of quizalofop + glufosinate + *S*-metolachlor + paraquat which provided 82% control. The lowest level of control 21 days after spring burndown was observed following application of acetochlor + mesotrione + clopyralid + glufosinate + oxyfluorfen at 62%.

At 28 days after spring burndown application, several treatments provided IR control similar to that observed following a fall application of *S*-metolachlor + metribuzin followed by a spring application of paraquat (99%) (Table 1.2). Bond et al. (2014) and Wesley (2019) observed similar levels of IR control with a fall application followed by a spring application of paraquat. A spring burndown application of clethodim + glufosinate + paraquat + dimethenamid-P; clethodim + glufosinate + paraquat + *S*-metolachlor; clethodim + paraquat +

dimethenamid-P; + clethodim + oxyfluorfen + paraquat + *S*-metolachlor resulted in similar levels of IR control at 96%, 98%, 94%, and 99%, respectively. Similar to results observed at 14, and 21 days after spring burndown, reduced IR control 28 days after spring burndown was observed following application of quizalofop + glufosinate + *S*-metolachlor + paraquat. Additionally, the lowest level of IR control observed at all rating periods, including 28 DAT, was observed following application of acetochlor + mesotrione + clopyralid + glufosinate + oxyfluorfen.

Corn grown following the fall PRE application of *S*-metolachlor + metribuzin followed by paraquat yielded 10,687 kg ha^{-1} (Table 1.3). In addition, corn grown following spring application of clethodim + paraquat + dimethenamid-P as well as clethodim + oxyfluorfen + paraquat + *S*-metolachlor had similar yield to that of the fall PRE at 9,649 kg ha^{-1} and 9,567 kg ha^{-1}, respectively. Spring application of acetochlor + mesotrione + clopyralid + glufosinate + oxyfluorfen; quizalofop + glufosinate + *S*-metolachlor + paraquat; clethodim + glufosinate + paraquat + dimethenamid-P; and clethodim + glufosinate + paraquat + *S*-metolachlor had 14 to 26% lower yield than that of the fall PRE at 7,933 kg $ha^{-1,}$. 8,915 kg ha^{-1}, 9,235 kg ha^{-1}, and 9,035 kg ha^{-1}, respectively. While similar levels of IR control were observed at all rating periods, treatments that included glufosinate had lower corn grain yield when compared to the fall PRE (Gardner et al. 2005; Meyer et al. 2021). In addition, these data indicate that for IR control prior to planting and to maximize corn grain yield, clethodim should be incorporated for control compared to the standard (Bond 2018). Also, clethodim out performed quizalofop with respect to IR control as treatments that included quizalofop instead of clethodim resulted in 9% to 18% less IR control.

Conclusion

The primary objective of this study was to identify effective spring burndown options for the control of IR prior to corn planting. An additional objective was to assess corn grain yield following spring burndown applications compared to the fall PRE + spring paraquat applications for IR control was investigated. The fall PRE application of *S*-metolachlor + metribuzin followed by paraquat in the spring resulted in 99% control of IR 28 DAT (Bond et al. 2014, Wesley 2019). A number of treatments were found to provide similar IR control to that following a fall application of *S*-metolachlor + metribuzin followed by paraquat in the spring. However, only clethodim + paraquat + dimethenamid-P and clethodim + oxyfluorfen + paraquat + *S*-metolachlor applied in the spring produced mean grain yield and IR control at 28 DAT similar to the fall burndown treatment followed by paraquat in the spring. In addition, quizalofop included in a tank mix was less effective for IR control compared to clethodim. Effective spring burndown options exist for IR control and optimal grain yield. However, increased cost per treatment may hinder utilization by growers. A fall applied PRE application followed by paraquat in the spring continues to be an effective option for IR control. If fall residual applications cannot be made or do not work with a given producers system, spring applied options for IR control exist albeit they are likely less cost effective.

Tables

Table 1 Year, location, latitude, longitude, soil texture, planting date, harvest date, fall application date, and spring application date for all locations in the study evaluating spring burndown applications to maximize Italian ryegrass [*Lolium perenne ssp. multiflorum* (Lam.)] control in Mississippi corn (*Zea Mays L*.).

Year	Location	Latitude	Longitude	Soil texture	Planting Date	Harvest Date	Fall Application Date	Spring Application Date
2020	CPBES	32.3342	-89.0821	sandy loam	2 Apr 2020	Sep-14-2020	Nov-4-2019	Feb-24-2020
2021	R.R. Foil PSRC	33.4654	-88.7635	silt clay loam	6 Apr 2021	Aug 24 2021	Nov-6-2020	Feb-26-2021
	BBBES	33.2569	-88.5555	silty clay	20 Apr 2021	Aug 23 2021	Nov-18-2020	Feb-27-2021
	CPBES	32.3341	-89.0810	sandy loam	6 Apr 2021	Aug 23 2021	Nov-6-2020	Feb-27-2021

Table 2 Italian ryegrass [*Lolium perenne ssp. multiflorum* (Lam.)] control using spring burndown applications at the R.R. Foil PSRC, Mississippi State, MS, Black Belt Experiment Research Station Brooksville, MS and the Coastal Plain Branch Experiment Station Newton, MS in 2020 and 2021.

Treatment	**Italian ryegrass control**[c]			
	7 DAT	**14 DAT**	**21 DAT**	**28 DAT**
	--------------------------% Visual Control------------------------			
S-metolachlor + metribuzin[a] fb paraquat[b]	96 a	98 a	99 a	99 a
acetochlor + mesotrione + clopyralid glufosinate oxyfluorfen[b]	72 e	65 e	62 d	55 c
quizalofop glufosinate *S*-metolachlor paraquat[b]	79 d	82 d	82 c	80 b
clethodim glufosinate paraquat dimethenamid-P[b]	86 bc	91 bc	93 ab	96 a
clethodim glufosinate paraquat *S*-metolachlor[b]	88 b	92 abc	94 ab	98 a
clethodim paraquat dimethenamid-P[b]	81 cd	87 cd	90 b	94 a
clethodim oxyfluorfen paraquat *S*-metolachlor[b]	90 b	96 ab	98 a	99 a
P-value	<.0001	<.0001	<.0001	<.0001

[a]Fall preemergence application
[b]Spring burndown applications
[c]Means within each column with the same letter are not statistically different (α=0.05).

Table 3 Corn (*Zea Mays L.*) yield for all locations in the study evaluating spring burndown applications to maximize Italian ryegrass [*Lolium perenne ssp. multiflorum* (Lam.)] control in Mississippi corn.

Treatment	**[c]Yield**
	---------------------------- kg ha^{-1} ----------------------------
S-metolachlor + metribuzin[a] fb paraquat[b]	10,687 a
acetochlor + mesotrione + clopyralid glufosinate oxyfluorfen[b]	7,933 c
quizalofop glufosinate *S*-metolachlor Paraquat[b]	8,915 bc
clethodim glufosinate paraquat dimethenamid-P[b]	9,235 b
clethodim glufosinate paraquat *S*-metolachlor[b]	9,035 bc
clethodim paraquat dimethenamid-P[b]	9,649 ab
clethodim oxyfluorfen paraquat *S*-metolachlor[b]	9,567 ab
P value	<.0001

[a]Fall preemergence application
[b]Spring burndown applications
[c]Means within each column with the same letter are not statistically different (α=0.05).

Literature Cited

Alessi, J, Power, JF (1971). Corn emergence in relation to soil temperature and seeding depth Agronomy J. 63(5):717-719.

Bararpour, T, Bond, JA, Singh, G, Hale, RR, Edwards, M, and Lawrence, BH. (2020). Glyphosate-resistant Italian ryegrass (*Lolium perenne L. spp. multiflorum*) control and seed suppression in Mississippi. Agronomy. 10(2):162.

Bararpour, MT, JK Norsworthy, NR Burgos, NE Korres, EE Gbur (2017) Identification and biological characteristics of Ryegrass (lolium spp.) accessions in Arkansas. Weed Sci. 65:350–360

Bond J, Eubank W, Bond RC, Golden BR, Edwards HM (2014) Glyphosate-resistant Italian ryegrass (*Lolium perenne* ssp. *multiflorum*) control with fall-applied residual herbicides. Weed Technol. 28:361-370.

Bruns, HA, Abbas, HK (2006). Planting date effects on Bt and non-Bt corn in the Mid-South USA. Agron. J. 98(1), 100-106.

Chahal, PS, Jhala, AJ (2016). Factors affecting germination and emergence of glyphosate-resistant hybrid corn (Zea mays L.) and its progeny. Canadian J. Plant Sci. 96(4), 613-620.

Clark A (2012) Managing Cover Crops Profitably. 4th edn. College Park, MD: Sustainable Agriculture Research and Education program. Pp 74-75.

Cox, WJ, and Cherney, JH. (2015). Field-Scale Studies Show Site-Specific Corn Population and Yield Responses to Seeding Depths. Agron. J. 107(6), 2475-2481.

Gardner, AP, York, AC, Jordan, DL, & Monks, DW. (2006). Glufosinate antagonizes postemergence graminicides applied to annual grasses and johnsongrass. J. Cot. Sci, 10: 319-327.

Hannaway, DB, Fransen, S, Cropper, JB, Teel, M, Chaney, M, Griggs, T, Halse, R, Hart, J, Cheeke, P, Hansen, D, Klinger, R, Lane, W, 35(1), 12-21.

Nandula VK (2014) Italian ryegrass (*Lolium perenne* ssp. *multiflorum*) and corn (*Zea mays*) competition. American J. Plant Sci. 5:3914-3924

Nandula, VK, Giacomini, DA, Lawrence, BH, Molin, WT, Bond, JA. (2020). Resistance to clethodim in Italian ryegrass (*Lolium perenne* ssp. *multiflorum*) from Mississippi and North Carolina. Pest Manag. Sci. 76(4), 1378-1385.

Nandula VK, Poston DH, Eubank TW, Koger CH and Reddy KN. (2007). Differential response to glyphosate in Italian ryegrass (*Lolium multiflorum*) populations from Mississippi. *We*ed Technol. 21:477– 482.

Nandula, VK, Poston, DH, Reddy, KN. (2009). Seed germination differences between glyphosate-resistant and-susceptible Italian ryegrass populations. Seed Technol. 123-133.

Webster, TM, RL Nichols (2012). Changes in the prevalence of weed species in the major agronomic crops of the Southern United States: 1994/1995 to 2008/2009. Weed Sci. 60:145–157.

Wechsler, SJ, & Fernandez-Cornejo, J. (2016). US Corn and Soybean Farmers Apply a Wide Variety of Glyphosate Resistance Management Practices. *Amber Waves*, 24.

Wesley, MT (2019). Italian ryegrass (*Lolium perenne* L. *ssp. multiflorum*) control in Mississippi corn (*Zea mays L*.) production [Unpublished Master's thesis] Mississippi State University.

[USDA] United States Department of Agriculture, Natural Resources Conservation Service (2002) Plant fact sheet, Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot). Washington, DC: United States Department of Agriculture, p 1.

CHAPTER II

ASSESSING RESIDUAL PALMER AMARANTH (AMARANTHUS PALMERI) CONTROL USING PREEMERGENCE HERBICIDE APPLICATIONS IN COTTON [GOSSYPIUM HIRSUTUM (L.)]

Abstract

Palmer amaranth is one of the most problematic weeds in modern cotton production in the United States. Studies were conducted to evaluate residual Palmer amaranth control in cotton using commonly applied herbicides. Effects of preemergence herbicide applications for Palmer amaranth control were investigated at the R.R. Foil PSRC in Starkville, MS; at the Black Belt Experiment Station in Brooksville, MS; and at a grower field in Dundee, MS. Eleven different herbicides representing six Weed Science Society of America Mode of Action Groups were evaluated in this experiment. All residual herbicide treatments provided at least 88% Palmer amaranth control at 7, 14, and 21 days after treatment (DAT). No difference in Palmer amaranth control was present between residual herbicide at 7, 14, or 21 DAT. By 28 DAT, acetochlor, *S*-metolachlor, fomesafen, norflurazon, fluridone + *S*-metolachor, and fluridone + fluometuron had greater than 87% Palmer amaranth control. Control declined at 35, 42, 49, and 56 DAT. Less than 89%, 82%, 60%, and 50% Palmer amaranth control was observed at 35, 42, 49, and 56 DAT, respectively. Several options exist that provide excellent Palmer amaranth control. However, control began to decline at 28 DAT. Growers should be aware of potential length of residual control from at-planting application of the residual herbicide of choice and plan a

diverse and efficacious postemergence weed management program that is initiated when residual control begins to be ineffective.

Introduction

The introduction of RoundUp® Ready cotton (*Gossypium hirsutum* L.) in 1997 allowed growers to enhance weed management programs (Young 2006). However, relying too heavily on chemical control for management of problematic weeds contributed to herbicide resistance (Young 2006). Herbicide resistance can occur after continued application of a specific herbicide or herbicides with the same mode of action (Norsworthy et al. 2012). Glyphosate-resistant Palmer amaranth [*Amaranthus palmeri* (S. Wats.)] was first documented in Georgia in 2004 along with 16 other weed species in subsequent years (Culpepper 2006; Heap 2021). Palmer amaranth is a summer annual broadleaf and one of the most common and problematic weeds for cotton growers in Mississippi and across the Southeast (Chahal et al. 2015; Southern Weed Science Society 2022; Whitaker et al. 2011). Palmer amaranth disrupts crop growth and starves competing plants for nutrients ultimately resulting in yield loss (Beiermann et al. 2022). Germination over an extended period of time, drought tolerance, and adaptability to shading make Palmer amaranth extremely competitive and difficult to control (Beiermann et al. 2022; Whitaker et al. 2011).

Palmer amaranth resistance is not limited to glyphosate. 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). In cotton, Palmer amaranth resistant to ALS-inhibitors has become common over the years. Palmer amaranth resistant to the ALS-inhibiting herbicide, pyrithiobac, was reported in Mississippi (Nandula et al., 2012). Furthermore, *Amaranthus* ssp. tall waterhemp (*Amaranthus tuberculatus*) and redroot pigweed (*Amaranthus* retroflexus) resistance to imazaquin was documented in Mississippi (Nandula et al., 2020). Palmer amaranth resistance has also been reported in South Carolina to microtubule inhibiting herbicides, such as pendimethalin (Gossett et al. 1998; Heap 2021). In addition, Palmer amaranth resistance to the PPO-inhibiting herbicide fomesafen has been identified in Arkansas (Salas et al., 2016). Recently, Palmer amaranth resistant to *S*-metolachlor was confirmed as well in Arkansas (Brahbam et al., 2019).

Prior to the commercialization of glyphosate-tolerant cotton, 50 and 25% of the herbicide used for weed control, across cotton hectares applied with herbicide, from 1992 to 1999 was accounted for by trifluralin and fluometuron, respectively (Young 2006). However, Palmer amaranth control from broadcast applied, postemergence (POST) applications was limited prior to the introduction of glyphosate-tolerant cotton (Culpepper and York 1998). The introduction of glyphosate-tolerant cotton allowed for 2-3 POST applications of glyphosate over-the-top of the crop with a use rate of 840 g ai ha^{-1}. Growing reliance on glyphosate for broad spectrum weed control heightened the risk of weeds becoming less sensitive to glyphosate (Burke et al. 2005; Askew and Wilcut 1999). Development of glyphosate-resistant Palmer amaranth populations resulted in limited options available for POST control of Palmer amaranth (Cahoon et al. 2015a). In 2011, technology providing cotton tolerance to glyphosate and glufosinate, GlyTol® + LibertyLink®, was introduced (Reed 2012). A single application of glufosinate to Palmer amaranth followed by another application of glufosinate when plants were less than 10 cm in height resulted in >93% control (Barnett et al. 2013; Corbett et al. 2004). In 2015, cotton tolerant to glyphosate, glufosinate, and dicamba, (Bollgard II® XtendFlex™), was introduced. (ISAAA 2015; USDA-APHIS 2015; Anonymous 2015). Palmer amaranth control of 93% from application of dicamba + glufosinate was observed compared to 80% control from treatments with only glufosinate (Cahoon et al. 2015b). In 2016, cotton tolerant to glyphosate, glufosinate, and 2,4-D known as Enlist™ was introduced (Manuchehri 2017). For all systems that included 2,4-D, Palmer amaranth control following POST applications ranged from 96 to 98%. These three technologies account for more than 91% of cotton hectarage in the United States (USDA-NASS 2020). However, since introduction of these technologies, Palmer amaranth resistance to glufosinate, dicamba, and 2,4-D have been confirmed. A glufosinate resistant Palmer amaranth population was reported in Arkansas in 2022 (Carvalho-Moore et al. 2022). In 2018, dicamba resistant Palmer amaranth was reported in Kansas and Tennessee (Peterson et al. 2019)(Steckel,2020). Palmer amaranth resistant to 2,4-D was reported as well in Kansas in 2015 and Tennessee in 2020 (Kumar et al. 2019)(Steckel,2020). To prolong the effectiveness of Xtend® and Enlist® cotton technologies, residual preemergence (PRE) herbicide applications are critical (Chahal et al. 2015; Culpepper and York, 1998; Toler et al. 2002; Whitaker et al. 2011).

Soil applied herbicides with residual activity are a fundamental component to full season Palmer amaranth control in cotton production. Acetochlor, *S*-metolachlor, pendimethalin, fomesafen, diuron, fluometuron, norfluorazon, pyrithiobac, prometryn, and fluridone are herbicide options for PRE application that provide residual Palmer amaranth control (Whitaker et al. 2011; Young 2006). *S*-Metolachlor and acetochlor do not provide control of emerged Palmer amaranth, but have residual activity when applied PRE (Whitaker et al. 2011). Pendimethalin can be used as a soil-applied PRE providing suitable control of grasses and some broadleaf weed species (Cahoon et al. 2015c). However, pendimethalin does not provide effective control of Palmer amaranth (Whitaker et al. 2011). Although concerns exist with regard to development of

PPO resistant Palmer amaranth, fomesafen provides effective Palmer amaranth control (Cahoon et al. 2015a). Diuron and fluometuron can be applied PRE for residual Palmer amaranth control (Chahal et al. 2015). However, fomesafen has been shown to be more effective (Whitaker et al. 2011). Norflurazon provides effective control of broadleaf weeds such as morningglory (*Ipomoea ssp.*) and sicklepod (*Senna obtusifolia*); however, the label indicates amaranth species will only be suppressed following application (Anonymous 2009; Wilcut et al. 1997). Pyrithiobac can be soil applied for residual control or applied early POST in cotton for broadleaf weed control although it is not effective for control of some broadleaf weeds and grasses (Culpepper and York 1997; 1998). Populations of Palmer amaranth that are cross-resistant to ALS-inhibiting herbicides are of concern (Chahal et al. 2015). Prometryn is an option for cotton when applied PRE for Palmer amaranth control (Foster et al. 2020). Fluridone, when sufficient rainfall occurs after application, is also a viable option for control of Palmer amaranth and several other grass and broadleaf weeds (Hill et al. 2016). Weed management practices that incorporate resistance management begin with a proper foundation for Palmer amaranth control in cotton production. The use of PRE applied herbicides which offer residual control reduce Palmer amaranth pressure throughout the growing season (Thompson 2020). However, few studies exist that directly compare length of residual control from all available PRE applied, residual herbicides for Palmer amaranth control in cotton. Therefore, studies were conducted to determine residual length of Palmer amaranth control in cotton following PRE herbicide application.

Materials and Methods

A study investigating residual Palmer amaranth control following application of PRE herbicide treatments was conducted in 2020. Research was conducted at the R.R. Foil PSRC near Starkville, MS; at BBBES in Brooksville, MS; and at an on-farm location in Dundee, MS. At each location, the experimental design was a randomized complete block with four replications. Plots at each location consisted of four 97 cm rows that were 9.1 m in length. Cotton variety 'DP 1646 B2XF' (Delta Pine, Bayer Crop Science, St. Louis, MO) was seeded at 108,680 seeds ha^{-1} which was planted on raised beds. Treatments were applied PRE immediately after planting. All residual herbicide treatments included paraquat (Gramoxone® 2.0 SL) at 840 g ha^{-1} and paraquat alone was used as the control. Treatments consisted of: paraquat (Gramoxone® 2.0 SL) at 840 g ha^{-1}, acetochlor (Warrant®) at 1,350 g ha^{-1}, diuron (Direx®4L) at 1,120 g ha^{-1}, fluometuron (Cotoran® 4L) at 1,680 g ha^{-1}, fluridone (Brake®) at 220 g ha^{-1}, fluridone + fluometuron (Cotoran® 4L) at 1,680 g ha^{-1}, fluridone + *S*-metolachlor (EverpreX®) at 1,420 g ha^{-1}, fomesafen (Reflex®) at 420 g ha^{-1}, norflurazon (Solicam®DF) at 2,200 g ha^{-1}, pendimethalin (Prowl® H2O) at 1,060 g ha^{-1}, prometryn (Caparol® 4L) at 2,700 g ha^{-1}, pyrithiobac (Staple® LX) at 60 g ha^{-1}, and *S*-metolachlor at 1,420 g ha^{-1}. Treatments were applied to the center two rows of each experimental unit using a CO_2-pressurized backpack sprayer equipped with a four nozzle, 48 cm nozzle spacing boom calibrated to deliver 140 L ha^{-1} of spray solution at 276 kPa using AIXR 110015 (Teejet®, 1801 Business Park Dr, Springfield, IL 62703) nozzles. All treatments included 1% v/v crop oil concentrate (Agri-Dex, Helena Chemical Company,225 Schilling Boulevard, Suite 300, Collierville, TN 38017) as required by paraquat label.

Data collection consisted of visual evaluation of Palmer amaranth control at 7, 14, 21, 28, 35, 42, 49, and 56-days following PRE applications. Evaluations were made on a scale of zero to

100 where zero equates to no control and 100 equates to complete control. Data were subjected to ANOVA using the GLIMMIX procedure in SAS 9.4 (SAS Institute Inc., Cary, NC) where location and replication were treated as random effects. Means were separated using Tukeys's protected least significant difference (α=0.05) where random effects were replication and location.

Results and Discussion

The primary objective of this research was to determine length of Palmer amaranth control in cotton PRE herbicide application. Palmer amaranth control 7 DAT ranged from 90% to 99% with no differences due to herbicide application were observed at 7 DAT (Table 1). In addition, similar levels of Palmer amaranth control following paraquat application were observed 7 DAT by Hay (2017). Hay (2017) observed that treatments that included paraquat increased Palmer amaranth control two weeks after application. At 14 and 21 DAT, reduced Palmer amaranth control following application of paraquat alone was observed (57% and 29%, respectively) compared to all other herbicides (85% to 99%). These results were expected due to the lack of residual control following paraquat application. No difference in Palmer amaranth control was observed at 14 and 21 DAT between any herbicide that provided residual control. Previous research demonstrated similar Palmer amaranth control following applications of *S*-metolachlor, fomesafen, pendimethalin, prometryn and diuron at 20 DAT (Whitaker et al., 2011).

By 28 DAT, differences in Palmer amaranth control following herbicide application were observed (Table 1). Paraquat alone provided 29% control whereas all other herbicide provided at least 66% control. The greatest Palmer amaranth control (87% to 98%) 28 DAT was observed following application of acetochlor, *S*-metolachlor, fomesafen, norflurazon, fluridone + *S*-metolachlor, and fluridone + fluometuron. With the exception of paraquat, the lowest control 28

DAT was observed following application of fluometuron, pyrithiobac, and fluridone. The addition of *S*-metolachlor and fluometuron to fluridone increased Palmer amaranth control by 15% and 13%, respectively.

At 35 DAT, differences in Palmer amaranth control following herbicide application were also observed (Table 1). Paraquat alone provided 12% control whereas all other herbicide provided at least 59% control. The greatest Palmer amaranth control (71% to 89%) 35 DAT was observed following application of acetochlor, *S*-metolachlor, fomesafen, norflurazon, fluridone + *S*-metolachlor, and fluridone + fluometuron.

At 42 DAT, differences in Palmer amaranth control following herbicide application were present (Table 1). Paraquat alone provided 9% control whereas all other herbicide provided at least 56% control. The greatest Palmer amaranth control (65% to 82%) 42 DAT was observed following application of acetochlor, *S*-metolachlor, fomesafen, prometryn, fluridone + *S*-metolachlor, and fluridone + fluometuron. Previous research demonstrated similar Palmer amaranth control following applications of *S*-metolachlor, fomesafen, prometryn (>65%) while also demonstrating similar control following applications of pendimethalin and diuron (<65%) at 40 DAT (Whitaker et al., 2011). Palmer amaranth control in our experiment following application of pyrithiobac does not agree with these data.

At 49 and 56 DAT, differences in Palmer amaranth control following herbicide application were observed and similar trends of control were present (Table 1). Control following all herbicide applications showed less than 60% control while paraquat alone provided 0% control. The greatest Palmer amaranth control (42% to 60%) 49 DAT and 33% to 50% at 56 DAT was observed following application of *S*-metolachlor, pendimethalin, norflurazon, fluridone, fluridone + *S*-metolachlor, and fluridone + fluometuron. Previous research demonstrated similar Palmer amaranth control following application of pendimethalin and prometryn at 60 DAT (<50%), although control of palmer amaranth following application of *S*-metolachlor, fomesafen, diuron, and pyrithiobac at 60 DAT (>50%) in these experiments differ with respect to existing literature (Whitaker et al., 2011).

Under the conditions of this experiment, no herbicide application resulted in the control of Palmer amaranth >95% at 35, 42, 49, and 56 DAT. The decrease in Palmer amaranth control following application of acetochlor, *S*-metolachlor, fomesafen, norflurazon, fluridone + *S*-metolachlor, and fluridone + fluometuron from 28 DAT to 35 DAT suggests that residual control, even with recommended herbicides, will begin to degrade over time and subsequent postemergence herbicide programs should be initiated to ensure season long control.

Conclusion

The primary objective of this research was to determine residual length control of Palmer amaranth in cotton following PRE herbicide application. Palmer amaranth control following the application of acetochlor, *S*-metolachlor, fomesafen, norflurazon, fluridone + *S*-metolachlor and fluridone + fluometuron, all tank mixed with paraquat, resulted in the greatest residual Palmer amaranth control up to 28 DAT. Adequate Palmer amaranth control can be attained up to 28 DAT; however, POST herbicide programs should be initiated at that time to ensure season long Palmer amaranth control and minimal contribution to the soil seedbank.

Tables

Table 4 Herbicides used in experiments at the R.R. Foil PSRC Starkville, MS; at BBBES in Brooksville, MS; and at an on-farm location in Dundee, MS.in 2020.[a]

Herbicide	Rate (g ai ae ha^{-1})	Trade Name	MOA	WSSA Group	Manufacture
paraquat	840	Gramoxone® 2.0 SL	PS I	2	Syngenta Crop Protection
acetolchlor	1350	Warrant®	VLCFA Synthesis	15	Bayer Crop Science
S-metolachlor	1420	EverpreX®	VLCFA Synthesis	15	Corteva Agriscience
pendimethalin	1060	Prowl® H2O	Microtubule Assembly	3	BASF
fomesafen	420	Reflex®	PPO	14	Syngenta Crop Protection
diuron	1120	Karmex® DF	PS II	5	ADAMA
fluometuron	1680	Cotoran® 4L	PS II	5	ADAMA
norflurazon	2200	Solicam® DF	PDS	12	NovaSource
pyrithiobac	60	Staple® LX	ALS	2	DuPont
prometryn	2700	Caparol® 4L	PS II	5	Syngenta Crop Protection
fluridone	220	Brake®	PDS	12	SePRO Corporation

[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 5 Effect of preemergence herbicide application on Palmer amaranth control 7, 14, 21, 28, 35, 42, 49, 56 days after treatment (DAT) at the R.R. Foil PSRC near Starkville, MS; at BBBES in Brooksville, MS; and at an on-farm location in Dundee, MS. in 2020[a]

Herbicide	7 DAT		14 DAT		21 DAT		28 DAT		35 DAT		42 DAT		49 DAT		56 DAT	
Paraquat	90	a	57	b	29	b	29	f	12	e	9	d	0	c	0	e
Acetochlor[b]	98	a	99	a	95	a	87	a-d	71	a-d	66	abc	35	b	28	cd
S-metolachlor[b]	98	a	98	a	94	a	88	abc	74	a-d	65	abc	42	ab	33	a-d
pendimethalin[b]	95	a	98	a	92	a	70	cde	65	bcd	63	bc	57	a	48	ab
Fomesafen[b]	99	a	99	a	98	a	98	a	89	a	82	a	26	b	19	d
Diuron[b]	97	a	98	a	92	a	71	cde	62	d	54	c	27	b	20	d
Fluometuron[b]	96	a	95	a	89	a	66	e	62	d	57	bc	34	b	29	bc
Norflurazon[b]	99	a	99	a	96	a	90	ab	81	abc	62	bc	57	a	45	abc
Pyrithiobac[b]	99	a	95	a	85	a	69	de	59	d	56	bc	25	b	17	de
Prometryn[b]	98	a	96	a	88	a	70	cde	65	cd	65	abc	27	b	14	d
Fluridone[b]	97	a	96	a	92	a	77	b-e	60	d	56	bc	42	ab	34	a-d

Table 5 (continued)

fluridone + *S*-metolachlor[b]	99	a	98	a	96	a	92	ab	86	a	73	ab	58	a	48	a
fluridone + fluometuron[b]	99	a	98	a	95	a	90	ab	84	ab	74	ab	60	a	50	a

[a] Means within column followed by the same letter are not significantly different ($\alpha \leq 0.05$)
[b] Tank-mixed with paraquat

Literature Cited

ISAAA] International Service for the Acquisition of Agri-Biotech Applications (2015) Event Name: MON88913 x MON15985. http://www.isaaa.org/gmapprovaldatabase/event/default.asp? EventID=62 Accessed 7 April 2022.

Anonymous (2009) *Solicam ® herbicide product label. Syngenta Publication No. SCP 849A-L2E 1008 289881*. Greensboro, NC Syngenta. 50pp.

Anonymous (2015) – Cotton Grower – Bollgard II XtendFlex Cotton Poised for Limited Introduction – https://www.cottongrower.com/cotton-news/bollgard-ii-xtendflex-cotton-poised-for-limited-introduction/. Accessed April 12 2022.

Askew SD, Wilcut JW (1999) Cost and weed management with herbicide programs in glyphosate-resistant cotton (Gossypium hirsutum). Weed Technol 13:308-313

Barnett KA, Culpepper AS, York AC, Steckel LE (2013) Palmer amaranth (*Amaranthus palmeri*) control by glufosinate plus fluometuron applied postemergence to WideStrike® cotton. Weed Technology 27:291–297.

Beiermann CW, Creech CF, Knezevic SZ, Jhala AJ, Harveson R, Lawrence NC (2022) Influence of planting date and herbicide program on Amaranthus palmeri control in dry bean. Weed Technology doi: 10.1017/wet.2021.96

Brabham C, Norsworthy JK, Houston MM, Varanasi VK, Barber T (2019) Confirmation of S-metolachlor resistance in Palmer amaranth (Amaranthus palmeri). Weed Technology, 33:720-726.

Burke IC, Troxler SC, Askew SD, Wilcut JW, Smith WD (2005) Weed Management Systems in Glyphosate-Resistant Cotton (Gossypium hirsutum). Weed Technology 19:422-429

Cahoon CW, York AC, Jordan DL, Everman WJ, Seagroves RW, Culpepper AS, Eure PM (2015a) Palmer amaranth (*Amaranthus palmeri*) management in dicamba-resistant cotton. Weed Technol. 29:758–770.

Cahoon CW, York AC, Jordan DL, Seagroves RW, Everman WJ, Jennings KM (2015b) Sequential and co-applications of glyphosate and glufosinate in cotton. J Cot Sci. 19:337–350.

Cahoon CW, York AC, Jordan DL, Everman WJ, Seagroves RW, Braswell LR, & Jennings KM (2015c) Weed Control in Cotton by Combinations of Microencapsulated Acetochlor and Various Residual Herbicides Applied Preemergence. Weed Technology, *29*(4), 740–750.

Carvalho-Moore, P, JK Norsworthy, F González-Torralva, J-I Hwang, JD Patel, LT Barber, TR Butts, JS McElroy (2022) Unraveling the mechanism of resistance in a glufosinate-resistant Palmer amaranth (Amaranthus palmeri) accession. Weed Science 70:370–379.

Corbett JL, Askew SD, Thomas WE, Wilcut JW (2004) Weed efficacy evaluations for bromoxynil, glufosinate, glyphosate, pyrithiobac, and sulfosate. Weed Technol. 18:443–453.

Culpepper AS, and York AC (1997) Weed management in no-tillage bromoxynil-tolerant cotton (*Gossypium hirsutum*). Weed Technol. 11:335–345.

Culpepper AS, and York AC (1998) Weed management in glyphosate-tolerant cotton. J. Cotton Sci. 2:174–185.

Culpepper AS, TL Grey, WK Vencill, JM Kichler, TM Webster, SM Brown, AC York, JW Davis, and WW Hanna (2006) Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) confirmed in Georgia. Weed Sci. 54:620–626.

Foster DC, Steckel L, McClure A (2020) Controlling auxin-resistant Palmer Amaranth in Tennessee https://extension.tennessee.edu/publications/Documents/W1008.pdf. Accessed April 12, 2022

Gossett BJ, Murdock EC, Toler JE. (1992) Resistance of Palmer amaranth (Amaranthus palmeri) to the dinitroaniline herbicides. Weed Technol;6:587–591

Hay, MM (2017) Control of Palmer Amaranth (*Amaranthus palmeri*) and common waterhemp (*Amaranthus rudis*) in double crop soybean and with very long chain fatty acid inhibitor herbicides. Thesis

Hill ZT, JK Norsworthy, LT Barber, E Gbur (2016) Residual weed control in cotton with Fluridone. https://www.cotton.org/journal/2016-20/1/upload/JCS20-076.pdf. Accessed March 29, 2022 Heap I (2020) The International Survey of Herbicide Resistant Weeds. Available at http://www.weedscience.org (verified 10 Sept 2020).

Manuchehri, MR, PA Dotray, JW Keeling, GD Morgan, SA Byrd (2020) Non–2,4-D–resistant cotton response to glyphosate plus 2,4-D choline tank contamination. Weed Technology 34:82–88

Nandula, VK, DA Giacomini, JD Ray (2020) Resistance to acetolactate synthase inhibitors is due to a W 574 to L amino acid substitution in the ALS gene of Redroot Pigweed and Tall Waterhemp. PLoS ONE 15.

Nandula VK, Reddy KN, Koger CH, Poston DH, Rimando AM, Duke SO, Bond JA, Ribeiro, DN (2012). Multiple Resistance to Glyphosate and Pyrithiobac in Palmer Amaranth (Amaranthus palmeri) from Mississippi and Response to Flumiclorac. Weed Sci. 60:179-188.

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, & Barrett, M (2012) Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci. 60:31-62.

Peterson D, Jugulam M, Shyam C, Borgato E (2019). Palmer amaranth resistance to 2, 4-D and dicamba confirmed in Kansas. *Kansas State Agronomy eUpdates* https://webapp.agron.ksu.edu/agr_social/m_eu_article.throck?article_id=2110 Accessed 5 April 2022.

Reed J (2012) Palmer amaranth and ivyleaf morningglory management in GlyTol® + LibertyLink® cotton resulting from glyphosate-resistant crops. Weed Technol. 20:301–307.

Sprague CL, Stoller EW, Wax LM, Horak MJ. (1997). Palmer amaranth (Amaranthus palmeri) and common waterhemp (Amaranthus rudis) resistance to selected ALS-inhibiting herbicides. Weed Sci;45:192–197

Steckel LE (2020)Dicamba-Resistant Palmer Amaranth in Tennessee: Stewardship Even More Important https://news.utcrops.com/2020/07/dicamba-resistant-palmer-amaranth-in-tennessee-stewardship-even-more-important/ Accessed 28 March 2022.

Steckel LE (2020) Palmer amaranth Escaping Auxin Herbicides as well as Follow Up Liberty Application https://news.utcrops.com/2021/07/palmer-amaranth-escaping-auxin-herbicides-as-well-as-follow-up-liberty-application/ Accessed 28 March 2022.

Thompson, C (2020) Systems approach key to controlling Palmer Amaranth. https://southeastagnet.com/2020/09/15/systems-approach-palmer-amaranth-culpepper/. Accessed April 12, 2022

Toler JE, Murdock EC, and Keeton A. (2002) Weed management systems for cotton (*Gossypium hirsutum*) with reduced tillage. Weed Technol. 16:773–780.

[USDA-NASS] US Department of Agriculture, National Agricultural Statistics Service (2020) Quick Stats. http://quickstats.nass.usda.gov/. Accessed: April 4, 2022Weed surveys (n.d.). Southern Weed Science Society. https://www.swss.ws/publications/weed-surveys/. Accessed October 13, 2022.

Wilcut JW, Jordan DL, Vencill WK, and Richburg III JS (1997) Weed Management in Cotton (*Gossypium hirsutum*) with Soil-Applied and Post-Directed Herbicides. Weed Technology, 11(2), 221–226.

Whitaker JR, York AC, Jordan DL, Culpepper AS, and Sosnoskie LM (2011) Residual herbicides for Palmer amaranth control. J Cot Sci. 15(1):89-99.

Young BG (2006) Changes in herbicide use patterns and production practices resulting from glyphosate-resistant crops. Weed Technol. 20:301-307.