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Management of Palmer Amaranth (*Amaranthus palmeri*) in Second-Generation Glyphosate-Resistant Cotton

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ABSTRACT

Field experiments were conducted in 2005 and 2006 to evaluate glyphosate timings and use of residual herbicides to control Palmer amaranth (*Amaranthus palmeri* S. Wats.) in second-generation glyphosate-resistant cotton (*Gossypium hirsutum* L.). Glyphosate treatments based on timing were used, in addition to preplant incorporated and postemergence-topical residual herbicides, to determine effective Palmer amaranth management systems. In 2005, complete control (100%) of Palmer amaranth was achieved across all glyphosate postemergence-topical systems. Less than complete control (94 to 98%) was observed with postemergence-directed glyphosate-resistant systems either with or without trifluralin preplant incorporated compared to second-generation glyphosate-resistant postemergence-topical systems. In 2006, similar Palmer amaranth control (95 to 99%) was observed across all second-generation glyphosate-resistant systems following trifluralin preplant incorporated and no benefit was observed from pyrithiobac or *S*-metolachlor tank-mixed with glyphosate. When trifluralin was not used, pyrithiobac or *S*-metolachlor tank-mixed with glyphosate early postemergence-topical followed by glyphosate improved control compared to glyphosate alone. Delaying early-season glyphosate applications did not reduce cotton lint yield; however, when no glyphosate was used cotton yields were reduced.

KEY WORDS: *Amaranthus palmeri* S. Wats., glyphosate, *Gossypium hirsutum* L., palmer amaranth, residual herbicides, roundup ready flex cotton, weed management systems

Abbreviations: ASN, as-needed; DAT, days after treatment; EPOST, early postemergence-topical; fb, followed by; GR, glyphosate-resistant; MPOST, mid postemergence-topical; PDIR, postemergence-directed; POST, postemergence-topical; PPI, preplant incorporated.

INTRODUCTION

The introduction of glyphosate-resistant (GR) cotton cultivars in the late 1990's allowed producers to effectively control many weeds season-long (Goldmon et al., 1996; Welch et al., 1997). Glyphosate applications in first generation GR cotton are restricted to postemergence-topical (POST) through the four-leaf growth stage of cotton, and glyphosate applied after this stage must be postemergence-directed (PDIR) to reduce the risk of yield loss in first generation GR cotton (Light et al., 2003; Welch et al., 1997). Producers have been successful at controlling early-season weed flushes; however, season-long Palmer amaranth control in first generation GR cotton has been limited on the Texas Southern High Plains due to the small POST application window, weed size, semi-arid conditions, and repeated weed flushes during the growing season.

Second-generation GR cotton was introduced in 2006 and offers cotton cultivars with season-long tolerance to glyphosate POST. Additional benefits of second-generation GR cotton systems are convenience, production flexibility, economic feasibility and promotion of conservation tillage, all while obtaining superior weed control (Dill 2005). In 2008, 77% of the Texas High Plain's cotton acres were planted to second-generation GR cotton cultivars, which has increased from 13% in 2006 (Anonymous, 2009).

Second-generation GR systems also provide the ability to use other herbicide modes of action as needed for weed management or the management of resistant biotypes (Clewis et al., 2006a). Residual herbicides applied preplant incorporated (PPI) and preemergence are successful in managing early-season annual weeds such as Palmer amaranth (Keeling et al., 1997). Residual herbicides used in conjunction with glyphosate provide excellent weed control, high yields and at the same time reduce the number of glyphosate POST applications (Askew et al., 2002; Isgett et al., 1997; Keeling et al., 2006; Keeton and Murdock 1997).

The wide use and acceptance of this new technology suggests that there will be a continued increase in second-generation GR cotton production as producers seek more flexible application windows. Therefore, research was conducted to evaluate Palmer amaranth management in second-generation GR cotton with different glyphosate POST application timings in combination with PPI and POST residual herbicides.

MATERIALS AND METHODS

Field experiments were conducted in 2005 and 2006 at the Texas *Agri*LIFE Research and Extension Center near Lubbock. The soil type was an Acuff clay loam [Fine-loamy, mixed, thermic Aridic Paleustolls, (41% sand, 25% silt, 34% clay)] with <1% organic matter and pH of 7.6. Stoneville 4554 B2RF cotton was planted on 40 in. rows at a depth of 2 in. using a seeding rate of 15 lb/A. Planting dates were May 18, 2005 and May 8, 2006. During October and November of 2004, 8.9 in. of rainfall was received which benefited the 2005 crop. Little rainfall was received prior to planting in 2006. Rainfall received from April 1 to August 31 totaled 8.8 and 4.8 in. in 2005 and 2006, respectively, and an additional 6 in. of water by furrow irrigation was applied in 2005 and 12 in. in 2006.

Postemergence-topical (POST) and preplant incorporated (PPI) herbicide applications were made using a tractor-mounted compressed-air sprayer or a CO_2 pressurized backpack sprayer both calibrated to deliver 10 gal/A with TurboTeeJet 110015VS nozzles spaced at 20 in. Preplant herbicides were incorporated 2 to 3 in. immediately after application using a spring-tooth harrow.

Herbicides included trifluralin PPI at 0.75 lb ai/A, *S*-metolachlor at 1.0 lb ai/A tank-mixed with glyphosate early-postemergence (EPOST) or mid-postemergence (MPOST), pyrithiobac at 0.03 lb ai/A tank-mixed with glyphosate EPOST or MPOST, and glyphosate at 0.75 lb ae/A applied EPOST, MPOST and as-needed (ASN). A GR herbicide program was also evaluated consisting of glyphosate EPOST followed by postemergence-directed (PDIR) applications of glyphosate both at 0.75 lb/A.

Percent weed control was estimated 14 and 28 days after each glyphosate application followed by an end of season evaluation using a scale from 0 (no control) to 100% (complete control). Yield was determined by harvesting the middle two rows using a two row plot stripper on October 18, 2005 and October 20, 2006. Samples were collected from each plot for ginning to determine the percent turnout of cotton lint used to calculate lint yields.

The experiments were arranged in a randomized complete block design with three replications. Plots were four rows wide by 30 ft in length and a natural infestation of Palmer amaranth was present at approximately 1 plant/ft^2. Arcsine square root transformation was performed on Palmer amaranth control data but did not affect conclusions; therefore, non-transformed means are presented. Data were subjected to analysis of variance (SAS 9.1) and means were separated using Fisher's Protected LSD test at the 5% level of probability.

RESULTS AND DISCUSSION

Palmer Amaranth Control. A year by treatment interaction was observed; therefore, Palmer amaranth control data was analyzed by year. In 2005, early-season Palmer amaranth control 14 days after treatment (DAT) ranged from 95 to 100% (Table 1). Trifluralin preplant incorporated (PPI) controlled Palmer amaranth 96% while glyphosate applied early postemergence-topical (EPOST) achieved 100% control. Glyphosate systems applied mid postemergence-topical (MPOST) controlled Palmer amaranth 95 to 99%, with similar control achieved with glyphosate alone or glyphosate plus either *S*-metolachlor or pyrithiobac. At 28 DAT, Palmer amaranth was controlled 83% with trifluralin PPI alone. Control was similar between glyphosate applied either EPOST or MPOST and control ranged from 85 to 98%; however, there was a trend towards increased control with the use of *S*-metolachlor or pyrithiobac tank-mixed with glyphosate compared to glyphosate applied alone. At the end of the season (120 DAT), trifluralin PPI alone did not control Palmer amaranth at least 70% (Table 1).

After all second-generation GR systems received a sequential glyphosate application, complete Palmer amaranth control was achieved, corroborating similar results from Main et al. (2007). In those studies, Palmer amaranth control was nearly complete with any treatment containing multiple glyphosate applications. Less than complete Palmer amaranth control (98 and 94%) was observed with first generation GR systems comprised of glyphosate EPOST followed by (fb) glyphosate PDIR either with or without trifluralin PPI, respectively. In 2005, timely rainfall throughout the growing season allowed for optimum crop growth, reducing the amount of in-season irrigation needed, and subsequently less weed germination throughout the growing season. A glyphosate POST only system controlled Palmer amaranth 100%; therefore, no benefit from PPI or tank-mixed POST residual herbicides was observed.

In 2006, early-season Palmer amaranth control ranged from 92 to 100%, with trifluralin PPI controlling Palmer amaranth 82% (Table 1). Glyphosate following trifluralin PPI controlled Palmer amaranth 98 to 100%, with similar control for both EPOST and MPOST timings. When no PPI was used, Palmer amaranth control ranged from 92 to 98%, with a trend towards improved control when glyphosate applications were delayed from EPOST to

Table 1. Palmer amaranth (*Amaranthus palmeri*) management in second-generation GR cotton systems in 2005 and 2006[a].

Weed management system[b]		Application timing[c]	2005			2006		
			14DAT[d]	28DAT	120DAT	14DAT	28DAT	120DAT
			-----% control-----					
trifluralin alone		PPI	96bc	83d	66d	82g	47h	30d
trifluralin fb								
	gly fb gly	EPOST	100a	91bcd	100a	98bc	94def	97ab
	gly+pyr fb gly	EPOST	100a	95abc	100a	100a	98abc	99a
	gly+*S*-met fb gly	EPOST	100a	98a	100a	100a	99ab	99a
	gly fb gly	MPOST	100a	92abcd	100a	99ab	99ab	96ab
	gly+pyr fb gly	MPOST	96bc	95abc	100a	100a	99ab	96ab
	gly+*S*-met fb gly	MPOST	99abc	97ab	100a	100a	98abc	95ab
	GR: gly fb gly	PDIR	99abc	94abcd	98b	100a	99ab	86c
no trifluralin								
	gly fb gly	EPOST	100a	85cd	100a	92f	75g	85c
	gly+pyr fb gly	EPOST	100a	95abcd	100a	98bc	89f	95ab
	gly+*S*-met fb gly	EPOST	100a	95abcd	100a	95e	91ef	92b
	gly fb gly	MPOST	97abc	88bcd	100a	97cd	100a	96ab
	gly+pyr fb gly	MPOST	98abc	94abcd	100a	97cd	99ab	94ab
	gly+*S*-met fb gly	MPOST	95c	93abcd	100a	97cd	100a	93b
	GR: gly fb gly	PDIR	98abc	88bcd	94c	100a	96cde	87c

[a] Abbreviations: DAT, days after treatment; EPOST, early-postemergence; fb, followed-by; gly, glyphosate; GR, glyphosate-resistant;
MPOST, mid-postemergence; PDIR, postemergence-directed; PPI, preplant incorporated; pyr, pyrithiobac; *S*-met, *S*-metolachlor.
[b] Herbicide rate = 0.75 lb ai/A, trifluralin; 0.75 lb ae/A, glyphosate; 0.03 lb ai/A, pyrithiobac; 1.0 lb ai/A, *S*-metolachlor.
[c] Application timings reflect the first glyphosate application. However, GR systems had an initial glyphosate application made EPOST followed by glyphosate PDIR. In 2006, two PDIR applications of glyphosate were needed.
[d] Evaluations reflect days after the first glyphosate application.

MPOST. Culpepper and York (1999) found improved control of large crabgrass [*Digitaria sanguinalis* (L.) Scop.], when glyphosate applications were delayed in a weed management program with pendimethalin plus fluometuron. Tharp and Kells (1999) reported that control of many weed species improved by delaying herbicide applications in glufosinate- and glyphosate-resistant corn (*Zea mays* L.). Delaying glyphosate applications to MPOST allowed for more weed seeds to germinate before the application, and weed seed germination after the application was minimal due to dryer soil conditions. VanGessel et al. (2000) found that delaying glyphosate applications past the four-trifoliate stage in glyphosate-resistant soybean [*Glycine max* (L.) Merr.] provided inconsistent weed control.

When evaluated 28 DAT, trifluralin PPI controlled Palmer amaranth 47%, whereas trifluralin fb glyphosate EPOST resulted in 94% control (Table 1). Pyrithiobac or *S*-metolachlor tank-mixed with glyphosate EPOST improved control to at least 98%. Glyphosate EPOST without a PPI controlled Palmer amaranth 75%, and the addition of pyrithiobac or *S*-metolachlor to glyphosate EPOST improved control to 89 and 91%, respectively. Similarly, Clewis et al. (2006b) found improved Palmer amaranth control when S-metolachlor was tank-mixed with glyphosate. Glyphosate MPOST controlled Palmer amaranth 98 to 100%; however, no benefit was observed from trifluralin PPI or tank-mixes of *S*-metolachlor or pyrithiobac with glyphosate MPOST. Askew and Wilcut (1999) reported that soil applied herbicides were not necessary in many studies when repeated glyphosate application were used in cotton. At the end of the season, trifluralin PPI controlled Palmer amaranth 30%. Similar control (95 to 99%) was observed across all glyphosate-based Roundup Ready Flex systems following trifluralin PPI, with no benefit from pyrithiobac or *S*-metolachlor tank-mixed with glyphosate. When no PPI was used, pyrithiobac or *S*-metolachlor tank-mixed with glyphosate EPOST fb glyphosate controlled Palmer amaranth 95 and 92%, respectively. Palmer amaranth control was controlled 85% following glyphosate EPOST fb glyphosate.

The GR systems comprised of glyphosate EPOST fb two PDIR glyphosate applications either with or without trifluralin PPI controlled Palmer amaranth 86 and 87%. Similar second-generation GR systems required fewer glyphosate applications throughout the growing season to achieve similar or greater Palmer amaranth control (85 and 97%). In 2006, four in-season furrow irrigations were needed, which resulted in continuous weed seed germination throughout the growing season (authors personal observations). Therefore, overall Palmer amaranth control was less effective in 2006 compared to the 2005 growing season.

Yield. A year by treatment interaction was observed and data was analyzed by year. All glyphosate-based weed management systems produced greater yields than the trifluralin alone and non-treated control in both years; however, the benefit from the use of a residual herbicide with glyphosate was not always apparent. When glyphosate EPOST or MPOST followed trifluralin PPI, yield increased from 500 to up to 1035 lb/A (52% increase) in 2005 (Table 2). Delaying early-season glyphosate applications from EPOST to MPOST (seven days) did not reduce cotton lint yield. In 2006, lint produced in the trifluralin alone system was 223 lb/A, which was 76 to 78% less than the weed management systems that contained trifluralin followed by glyphosate alone applied EPOST (919 lb/A) or MPOST (1000 lb/A). Similar to 2005, no reductions in cotton lint yield was observed when early-season glyphosate applications were delayed from EPOST to MPOST (13 days) and the benefit of the residual herbicide with glyphosate was not always apparent Greater end of season weed control in the glyphosate-based weed management systems compared to the trifluralin alone systems was reflected in yield produced.

CONCLUSION

In one of two years, residual herbicides improved Palmer amaranth control in second-generation glyphosate-resistant cotton. In addition, residual herbicides are effective tools to reduce the risk of the development of glyphosate-resistant Palmer amaranth.

Table 2. Effects of Palmer amaranth control on second-generation GR cotton lint yield in 2005 and 2006[a].

Weed management system[b]	Application timing [c]		2005	2006
			-----------lb/A---------	
trifluralin				
	glyphosate fb glyphosate	EPOST	919 c-f [d]	910 b
	glyphosate+pyrithiobac fb glyphosate	EPOST	1,000 b-f	901 b
	glyphosate+*S*-metolachlor fb glyphosate	EPOST	982 b-f	1,214 a
	glyphosate fb glyphosate	MPOST	892 f	1,062 ab
	glyphosate+pyrithiobac fb glyphosate	MPOST	1,187 a	910 b
	glyphosate+*S*-metolachlor fb glyphosate	MPOST	1,026 bc	875 b
	GR: glyphosate fb glyphosate	PDIR	910 def	1,053 ab
no trifluralin				
	glyphosate fb glyphosate	EPOST	973 b-f	919 b
	glyphosate+pyrithiobac fb glyphosate	EPOST	1,017 bcd	1,071 ab
	glyphosate+*S*-metolachlor fb glyphosate	EPOST	1,008 b-e	1,080 ab
	glyphosate fb glyphosate	MPOST	1,035 b	1,000 ab
	glyphosate+pyrithiobac fb glyphosate	MPOST	1,000 b-f	1,116 ab
	glyphosate+*S*-metolachlor fb glyphosate	MPOST	1,071 b	1,053 ab
	GR: glyphosate fb glyphosate	PDIR	901 ef	1,089 ab
trifluralin alone		PPI	500 g	223 c
non-treated		NA	357 h	80 c .

[a] Abbreviations: EPOST, early-postemergence; fb, followed-by; GR, glyphosate-resistant; MPOST, mid-postemergence;
NA, not applicable; PDIR, postemergence-directed; PPI, preplant incorporated.

[b] Herbicide rate=0.75 lb ai/A, trifluralin; 0.75 lb ae/A, glyphosate; 0.03 lb ai/A, pyrithiobac; 1.0 lb ai/A, *S*-metolachlor.

[c] Application timings reflect the first glyphosate application. However, GR systems had an initial glyphosate application made EPOST followed by glyphosate PDIR. In 2006, two PDIR applications of glyphosate were needed.

[d] Yield means followed by the same lower case letter are not significantly different (P = 0.05) using Fisher's protected LSD.

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