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Jessica A. Kelton, Andrew J. Price, Michael G. Patterson, C. Dale Monks, and Edzard van Santen*

Amaranthus control in cotton can be difficult with the loss of glyphosate efficacy, especially in conservation-tillage cropping systems. Research was conduction from 2006 to 2008 at EV Smith Research Center, Shorter, AL, to determine the level of glyphosate-susceptible *Amaranthus* control provided by four initial tillage and herbicide treatments, including 1) moldboard plowing followed by a single-pass disking and field cultivation plus pendimethalin at 1.2 kg ai ha^{-1} preplant incorporation (PPI), 2) two-pass disking followed by field cultivation plus pendimethalin at 1.2 kg ha^{-1} PPI, 3) no tillage including an application of pendimethalin at 1.2 kg ha^{-1} PRE, or 4) no tillage without pendimethalin in 2006. No further tillage practices or pendimethalin applications were utilized after study initiation. Initial tillage operations, including inversion with disking or disking twice, resulted in *Amaranthus* density of $\leq$ 4 plants m^{-2} and 47 to 82% control, whereas no-tillage treatments had $\geq$ 4 plants m^{-2} and 14 to 62% control. Subsequent applications of PRE herbicides included fluometuron at 1.68 kg ai ha^{-1} or prometryn at 1.12 kg ai ha^{-1} and provided 53 to 98% and 55 to 93% control, respectively, and reduced *Amaranthus* density compared to no PRE herbicide to $<$ 2 plants m^{-2}, regardless of tillage treatment. A POST application of glyphosate at 1.0 kg ae ha^{-1} improved control in conjunction with almost all treatments in each year. Results indicate that a one-time tillage operation followed by a return to reduced tillage may aid in the reduction of *Amaranthus* density when used with PRE-applied herbicides; however, this system will likely not provide adequate control when high population densities of glyphosate-resistant *Amaranthus* are present, thus highlighting the need for a highly efficacious POST herbicide system.
Nomenclature: Fluometuron; glyphosate; pendimethalin; prometryn; cotton, *Gossypium hirsutum* L.
Key words: Glyphosate, herbicide resistance, no tillage.

El control de *Amaranthus* en algodón puede ser difícil con la pérdida de eficacia de glyphosate, especialmente en sistemas de cultivos con labranza de conservación. Se realizaron investigaciones desde 2006 a 2008 en el Centro de Investigación EV Smith, en Shorter, Alabama, para determinar el nivel de control de *Amaranthus* susceptible a glyphosate provisto por cuatro tratamientos con labranza inicial y herbicidas, los cuales incluyeron 1) labranza con arado de vertedera seguida por un único pase de rastra de discos y un cultivador más pendimethalin a 1.2 kg ai ha^{-2} en pre-siembra incorporado (PPI), 2) dos pases de rastra de discos seguidos por un pase con cultivador más pendimethalin a 1.2 kg ha^{-1} PPI, 3) sin labranza incluyendo una aplicación de pendimethalin a 1.2 kg ha^{-1} PRE, o 4) sin labranza y sin pendimethalin en 2006. No se realizaron prácticas adicionales de labranza o aplicaciones de herbicidas después del inicio del estudio. Las operaciones de labranza iniciales que incluyeron inversión del suelo con el pase de discos una o dos veces resultaron en densidades de *Amaranthus* $\leq$4 plantas m^{-2} y 47 a 82% de control, mientras que los tratamientos sin labranza tuvieron $\geq$4 plantas m^{-2} y 14 a 62% de control. Las aplicaciones posteriores de herbicidas PRE incluyeron fluometuron a 1.68 kg ai ha^{-1} o prometryn a 1.12 kg ai ha^{-1} y brindaron 53 a 98% de control, respectivamente, y redujeron la densidad de *Amaranthus* en comparación con los tratamientos sin herbicidas PRE a $<$2 plantas m^{-2} sin importar el tratamiento de labranza. Una aplicación de glyphosate a 1.0 kg ae ha^{-1} mejoraron el control en combinación con casi todos los tratamientos en cada año. Los resultados indican que una operación de labranza seguida por labranza reducida podría ayudar en la reducción de la densidad de *Amaranthus* cuando se usó herbicidas aplicados PRE. Sin embargo, este sistema probablemente no brindará control adecuado cuando altas poblaciones de *Amaranthus* resistente a glyphosate están presentes, resaltando la necesidad de tener un sistema de herbicidas POST eficaz.

Since the introduction of glyphosate-resistant cotton, adoption of this technology has reached 78% of cotton grown in the United States partially because of the effective weed control afforded to producers (Givens et al. 2009; Owen 2010; Steckel et al. 2008). There has been a concomitant increase in reduced-tillage cotton hectares in the southeastern United States since the commercial release of glyphosate-resistant cotton in 1997 (Frisvold et al. 2010; Roberts et al. 2006). Utilization of glyphosate-resistant cotton in conjunction with reduced-tillage practices has provided producers an economical and effective means for cotton production.

Reduced tillage has long been proven to provide many environmental benefits, primarily, reducing soil erosion and water runoff (Baumhardt and Lascano 1996; Reeves 1994, 1997). Moreover, reducing tillage intensity has been shown to increase soil organic matter, improve water infiltration, increase soil water holding capacity, and increase quantity and diversity of soil organisms such as earthworms (Bruce et al. 1992; Heisler 1998; Kemper and Derpsch 1981; Reeves 1994, 1997; Truman et al. 2003). In addition to environmental benefits achieved through reduced-tillage practices, economic incentives from decreased production costs have

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made reduced tillage an important alternative to conventional tillage practices. Prior to the availability of glyphosate-resistant cotton, weed control could be difficult to achieve without the inclusion of tillage practices. Since its release, however, growers have become increasingly dependent on glyphosate as the only herbicide utilized in reduced-tillage cotton.

The dependence on glyphosate as a single means of weed control has resulted in the appearance of several glyphosate-resistant weed species in cotton production in the southern United States, including horseweed [*Conyza canadensis* (L.) Cronq.], Palmer amaranth (*Amaranthus palmeri* S. Wats.), and giant ragweed (*Ambrosia trifida* L.) (Culpepper et al. 2004; Heap 2012; Koger et al. 2004; Norsworthy et al. 2010; Powles 2008). The high seed production, rapid growth, shallow germination, and shade tolerance of Palmer amaranth has enabled this species to be a successful competitor in row crop productions, particularly in conservation-tillage practices where minimal soil disruption favors germination of weed seed in the upper soil layer (Grichar et al. 2004; Price et al. 2011; Steckel et al. 2004). The evolution of glyphosate resistance in Palmer amaranth has increased the severity of Palmer amaranth in reduced-tillage settings that rely on POST applications of glyphosate to achieve adequate levels of suppression (Price et al. 2011). In addition, glyphosate resistance has been reported in other *Amaranthus* species, such as tall waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] and spiny amaranth (*Amaranthus spinosus* L.), in several U.S. states (Heap 2012).

Herbicide resistance in weed species has been reported for several decades. Since the first documented case of triazine-resistant common groundsel (*Senecio vulgaris* L.), reported cases of resistant weed species have grown to over 200 worldwide, affecting nearly all of the herbicide groups (Appleby 2005; Heap 2012). The appearance of herbicide-resistant weeds can greatly affect weed management strategies as well as costs associated with control practices. Although resistance may spur the adoption of integrated weed management practices, lack of effective weed control may force growers to utilize more expensive tactics that degrade soil quality to achieve some management of a resistant weed (Price et al. 2011). Such was the case with glyphosate-resistant horseweed. Appearance of resistant horseweed in soybean in areas of the southeast forced many conservation-tillage growers to abandon reduced-tillage practices to gain control over the weed until more effective herbicide practices were established (Steckel and Culpepper 2006; Steckel et al. 2011).

Few highly effective control options for *Amaranthus* remain in cotton systems where glyphosate resistance has been confirmed, and utilization of intensive tillage practices has been suggested for heavy infestations (Culpepper et al. 2008). Inversion tillage has been shown to reduce *Amaranthus* germination through seed burial, as well as to facilitate incorporation of residual preplant incorporated (PPI) herbicides effective against the extended germination period of Palmer amaranth (Culpepper et al. 2009). Tillage, as a long-term solution, comes at a high price both economically and environmentally and threatens the continuation of conservation tillage (Price et al. 2011).

In fields with extreme infestations of glyphosate-resistant *Amaranthus*, it has been suggested that one soil-inversion operation, followed by a return to no tillage in subsequent years, would provide effective *Amaranthus* suppression while preserving future viability of conservation-tillage practices (Shaw et al. 2012). Employing 1 yr of inversion-tillage operations together with PRE herbicides may reduce *Amaranthus* germination in the first year, and decrease *Amaranthus* populations in following years. The re-establishment of reduced-tillage practices would minimize the risk of returning potentially glyphosate-resistant *Amaranthus* to the surface in following years.

Research is needed to evaluate the efficacy of this approach for *Amaranthus* control in cotton. The objective of this research was to determine the effects on weed control and cotton yield from the utilization of tillage followed by a return to less intensive tillage practices. In addition, the efficacy of herbicide treatments, particularly soil-applied residual herbicides alone or in conjunction with glyphosate, under tillage treatments was evaluated.

Materials and Methods

Field trials were conducted at the EV Smith Research Center near Shorter, AL, in 2006, 2007, and 2008. The experimental area contained an *Amaranthus* complex consisting of Palmer amaranth, spiny amaranth, and smooth pigweed (*Amaranthus hybridus* L.). Soil at this location was a Norfolk sandy loam (fine-loamy, siliceous thermic Typic Kandiudults) with 1% organic matter and pH 6.1. The experiment was a split-plot design with four main management plots and three replications. Prior to planting in 2006, the four management treatments included 1) moldboard plowing followed by a single-pass disking and field cultivation plus pendimethalin (Prowl® H_2O, BASF Corporation, Research Triangle Park, NC) at 1.2 kg ai ha^{-1} PPI, 2) two-pass disking followed by field cultivation plus pendimethalin at 1.2 kg ha^{-1} PPI, 3) a no-till treatment with an application of pendimethalin at 1.2 kg ha^{-1} PRE (NONE A), and 4) a no-till treatment without pendimethalin (NONE B). No additional tillage operations were utilized in subsequent years of the experiment, nor was pendimethalin applied after 2006. The cotton variety DP 143 B2RF (Deltapine®, Monsanto Company, St. Louis, MO) (2006 and 2007) and DP 141 B2RF (2008) was planted the first week of May of each year in four-row plots (91-cm row spacing). Fertilizer applications were made according to Alabama Cooperative Extension System recommendations.

Subsequent herbicide applications in 2007 and 2008 included fluometuron (Cotoran® 4L, Makhteshim Agan of North America, Raleigh, NC) at 1.68 kg ai ha^{-1} or prometryn (Caparol® 4L, Syngenta Crop Protection, Greensboro, NC) at 1.12 kg ai ha^{-1} applied alone or followed by (fb) a POST application of glyphosate (Roundup Weathermax®, Monsanto Company, St. Louis, MO) at 1.0 kg ae ha^{-1} between the two- to three-leaf cotton stage and weeds were between 0.5 and 5 cm tall (Table 1). Herbicide treatments were applied with a tractor-mounted sprayer calibrated to 140 L ha^{-1} at 165 kPa.

Table 1. Tillage, herbicide treatments, and rates.

Initial management practice[a]	Herbicide applications each year	Rate
		kg ai or ae ha^{-1}
Invert, disk, cultivation	Fluometuron fb[b] glyphosate	1.68; 1.0
	Fluometuron only	1.68
	Prometryn fb glyphosate	1.12; 1.0
	Prometryn only	1.12
	Glyphosate only	1.0
	None	–
Disk 2×, cultivation	Fluometuron fb glyphosate	1.68; 1.0
	plus fluometuron only	1.68
	Prometryn fb glyphosate	1.12; 1.0
	Prometryn only	1.12
	Glyphosate only	1.0
	None	–
None A[c]	Fluometuron fb glyphosate	1.68; 1.0
	Fluometuron only	1.68
	Prometryn fb glyphosate	1.12; 1.0
	Prometryn only	1.12
	Glyphosate only	1.0
	None	–
None B[d]	Fluometuron fb glyphosate	1.68; 1.0
	Fluometuron only	1.68
	Prometryn fb glyphosate	1.12; 1.0
	Prometryn only	1.12
	Glyphosate	1
	None	–

[a] As part of the initial management practice, pendimethalin was applied at 1.2 kg ha^{-1} preplant incorporated in conventional tillage systems or applied PRE with reduced tillage.

[b] fb, followed by.

[c] Pendimethalin was applied PRE without incorporation.

[d] No pendimethalin was applied at study initiation.

Control ratings of the *Amaranthus* complex were taken at three intervals: early, mid, and late season, on a 0 to 100% scale where 0 is no control and 100 is complete control. Late-season *Amaranthus* density per 1 m^2 at 60 d after application (DAA), percent cotton injury at 30 DAA, and seed cotton yield were also determined. The center two rows of each plot were harvested once for lint and seed with a spindle picker modified for small-plot harvesting.

Data were subjected to ANOVA with the GLIMMIX procedure in SAS (Version 9.2, SAS Institute, Inc., Cary, NC). *Amaranthus* plant counts and cotton-yield data met assumptions of normality and homogeneity of variance; however, weed control ratings were arcsine transformed prior to analysis. Results are backtransformed for presentation. The LSMEANS option with a Dunnett's test adjustment was utilized for comparison to nontreated plots with significance at $P \leq 0.05$.

Results and Discussion

Weed Control. Weed control ratings had significant interactions for the following: year × initial management × PRE herbicide, year × initial management × POST herbicide, as well as year × PRE herbicide × POST herbicide. Interactions were similar and significant for both early- and late-season ratings; therefore, late-season interactions are presented.

In 2006, late-season *Amaranthus* control was generally most effective with fluometuron applications, regardless of initial tillage and herbicide treatment, with 74 to 98% control over no PRE application (Table 2). In 2007 and 2008, both prometryn and fluometuron increased *Amaranthus* control within initial management treatments compared to no PRE herbicide applications. Fluometuron provided good control for initial management treatments that included a pendimethalin application at experiment initiation (94 to 96%) in 2007. In 2008, prometryn provided control equivalent to that observed for fluometuron the previous year, with 91 to 93% control in treatments with an initial application of pendimethalin.

Table 2. Late-season *Amaranthus* control by year, management treatment, and PRE herbicide application at EV Smith Research Center.

		None[b]				Prometryn					Fluometuron				
Year	Initial management practice[a]	Control	LL[c]	UL[d]	Rank	Control	LL	UL	Rank	P value vs. none[e]	Control	LL	UL	Rank	P value vs. none
		%				%					%				
2006	None B[f]	48	34	62	4	62	48	76	4	0.2469	74	60	85	3	0.0161
2006	None A	61	47	75	2	74	61	86	3	0.2854	74	60	85	4	0.3276
2006	Disk 2×, cultivation	61	46	74	3	81	69	91	2	0.0483	88	77	95	2	0.0046
2006	Invert, disk, cultivation	78	65	88	1	87	76	95	1	0.3427	98	92	100	1	0.0019
2007	None B	18	9	31	4	55	41	69	4	0.0004	53	39	67	4	0.0007
2007	None A	48	34	63	3	83	71	92	3	0.0006	94	86	99	2	< 0.0001
2007	Disk 2×, cultivation	58	44	72	2	85	73	94	2	0.0074	94	85	99	3	0.0001
2007	Invert, disk, cultivation	84	72	93	1	88	77	95	1	0.8016	96	89	100	1	0.0509
2008	None B	31	18	44	4	70	56	82	4	0.0002	85	73	94	4	< 0.0001
2008	None A	68	54	81	3	93	83	98	1	0.0039	87	76	95	2	0.0481
2008	Disk 2×, cultivation	72	58	84	2	91	81	98	3	0.0265	85	74	94	3	0.1888
2008	Invert, disk, cultivation	84	72	93	1	92	82	98	2	0.3855	94	86	99	1	0.1721

[a] As part of the initial management practice, pendimethalin was applied preplant incorporated with tillage or PRE with no tillage.

[b] Late-season control ratings for no PRE herbicide (NONE) included both treatments without an herbicide application as well as POST-only glyphosate treatments.

[c] LL, lower 95% confidence limits.

[d] UL, upper 95% confidence limits.

[e] P value significant at $P \leq 0.05$.

[f] Treatment did not include an initial application of pendimethalin.

Table 3. Late-season *Amaranthus* control by year, management treatment, and POST herbicide application at EV Smith Research Center.

Year	Initial management practice[a]	None				Glyphosate				
		Control	LL[b]	UL[c]	Rank	Control	LL	UL	Rank	P value vs. none[d]
		—%				—%				
2006	None B	24	14	35	4	93	86	97	4	< 0.0001
2006	None A	35	24	48	3	95	89	99	3	< 0.0001
2006	Disk 2×, cultivation	47	34	60	2	97	92	100	2	< 0.0001
2006	Invert, disk, cultivation	74	62	84	1	98	94	100	1	< 0.0001
2007	None B	14	6	23	4	73	63	82	4	< 0.0001
2007	None A	56	43	68	3	94	88	98	2	< 0.0001
2007	Disk 2×, cultivation	76	65	86	2	85	77	92	3	0.1751
2007	Invert, disk, cultivation	79	68	89	1	97	92	100	1	0.0004
2008	None B	38	26	51	4	84	76	91	4	< 0.0001
2008	None A	62	49	74	3	97	93	100	1	< 0.0001
2008	Disk 2×, cultivation	64	52	76	2	96	91	99	3	< 0.0001
2008	Invert, disk, cultivation	82	71	90	1	96	91	99	2	0.0025

[a] As part of the initial management practice, pendimethalin was applied preplant incorporated with tillage or PRE with no tillage except for treatment labeled None B.
[b] LL, lower 95% confidence limits.
[c] UL, upper 95% confidence limits
[d] P value significant at $P \leq 0.05$.

Generally, glyphosate increased *Amaranthus* control in each year of the study regardless of tillage (Table 3) or PRE herbicide treatment (Table 4). Control with inversion tillage and glyphosate applications ranged from 96 to 98% during the experiment. No-tillage treatments that included a PRE (fluometuron or prometryn) application followed by (fb) glyphosate provided similar control for the duration of the study, with 94 to 97% control. Without glyphosate applications, inversion tillage provided greater control than other tillage treatments, with 74 to 82% control. Prometryn and fluometuron provided 88 to 97% control throughout the study when used in conjunction with glyphosate applications (Table 4). Without glyphosate, control provided by either PRE application was reduced to 46 to 78%. In cases of glyphosate resistance, the utilization of inversion tillage followed by a return to conservation tillage may aid in reducing *Amaranthus* density, but additional control strategies beyond PRE herbicide use would be necessary to further reduce populations.

Amaranthus density (plants m^{-2}) analysis showed year × POST herbicide and initial management practice × POST herbicide interactions occurred. Glyphosate applications reduced amaranth density compared to no POST application, regardless of initial tillage/herbicide treatments, by 1 to 4 plants m^{-2} (Figure 1). These findings reaffirm the importance of a postemergent herbicide for season-long control (Grichar et al. 2004). Without a glyphosate application, tillage operations reduced *Amaranthus* density over no-tillage treatments; however, with glyphosate treatments, density was similar in no-tillage treatments with PRE herbicides compared to increased tillage treatments. In areas that have high levels of glyphosate resistance and where glyphosate is not an effective option, tillage may reduce *Amaranthus* density compared to no tillage; however, dependence on continuous tillage for suppression of *Amaranthus* could perpetuate glyphosate-resistant populations by burying and distributing resistance genetics (seed) throughout the soil profile. With cotton lint yields having previously been shown to be reduced by 6 to 13% with one *Amaranthus* plant per row (9 to 10 m),

Table 4. Late-season *Amaranthus* control by year, PRE herbicide application, and POST herbicide application at EV Smith Research Center.

Year	PRE Herbicide	None				Glyphosate				
		Control	LL[a]	UL[b]	Rank	Control	LL	UL	Rank	P value vs. none[c]
		—%				—%				
2006	None	23	14	33	3	94	88	98	3	< 0.0001
2006	Prometryn	46	35	57	2	97	93	99	1	< 0.0001
2006	Fluometuron	67	56	77	1	97	93	99	2	< 0.0001
2007	None	25	16	36	3	79	70	86	3	< 0.0001
2007	Prometryn	67	56	77	2	88	82	94	2	0.0003
2007	Fluometuron	75	65	84	1	96	92	99	1	< 0.0001
2008	None	29	20	40	3	93	87	97	3	< 0.0001
2008	Prometryn	78	68	87	1	94	89	98	2	0.0009
2008	Fluometuron	76	66	85	2	96	92	99	1	< 0.0001

[a] LL, lower 95% confidence limits.
[a] UL, upper 95% confidence limits.
[c] P value significant at $P \leq 0.05$.

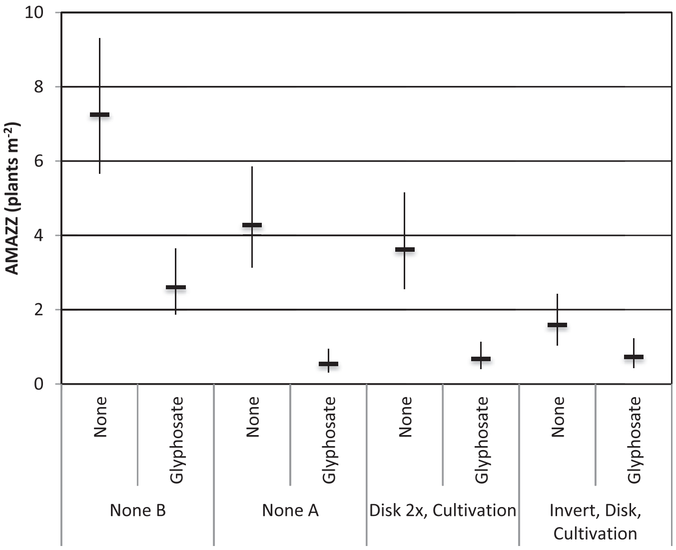

Figure 1. Mean *Amaranthus* (AMAZZ) density (plants m^{-2}) with upper and lower confidence limits under four initial management treatments with a POST herbicide application of glyphosate or no POST herbicide. Management treatments included a pendimethalin application at initiation except for treatment labeled None B.

Amaranthus densities observed under increased tillage treatments without a POST treatment (2 to 4 plants m^{-2} in this study) should negatively affect cotton yield (Morgan et al. 2001; Rowland et al. 1999). Moreover, inversion and disking did not increase *Amaranthus* control to levels exceeding 99%, which has been suggested as necessary for some infestations (Norsworthy et al. 2008), particularly if populations are to be prevented from replenishing the seedbank.

In 2006 and 2008, *Amaranthus* density was reduced with POST applications of glyphosate by 6 and 5 plants m^{-2}, respectively, over no POST applications; 2007 density revealed no difference between treatments (Figure 2). The PRE herbicide treatment main effect was also significant with both fluometuron ($P = 0.0010$) and prometryn ($P = 0.0021$) herbicides reducing *Amaranthus* density over no PRE applications (Figure 3). Research and current management

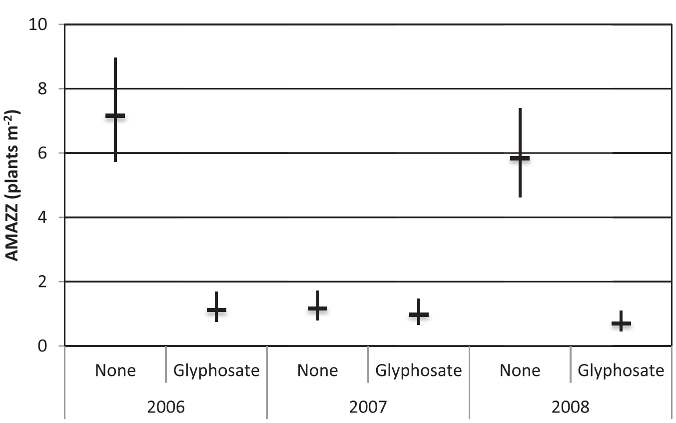

Figure 2. Mean *Amaranthus* (AMAZZ) density (plants m^{-2}) with upper and lower confidence limits by year for POST glyphosate applications or no POST herbicide.

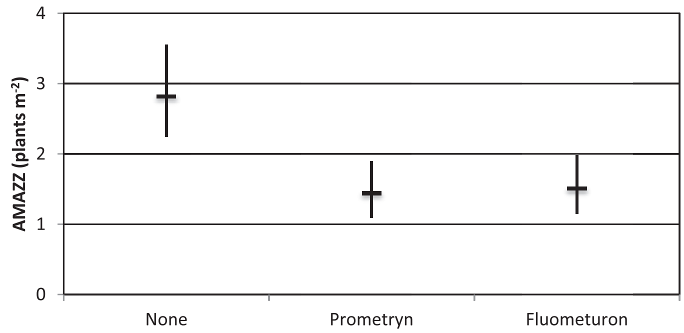

Figure 3. Mean *Amaranthus* (AMAZZ) density (plants m^{-2}) with upper and lower confidence limits in PRE herbicide treatments, fluometuron and prometryn, in comparison to no PRE herbicide application.

programs have noted the requirement of PRE applications for good *Amaranthus* control (Culpepper et al. 2011; Price et al. 2011). Reduced late-season *Amaranthus* density with PRE herbicides in this study underscore the need for residual herbicide applications for season-long control.

Cotton Injury and Seed Cotton Yield. Cotton injury was minimal each year of the study and no differences were detected among treatments ($P = 0.5557$, data not shown). Seed cotton yield differed significantly among years ($P < 0.0001$); therefore, data are presented by year. Initial management practice × herbicide, both PRE and POST, interactions were also detected. In 2006 and 2007, highest yields were achieved with tillage that included inversion, disking, and an initial pendimethalin application regardless of additional PRE applications producing 1,230 to 1,640 kg ha^{-1} more seed cotton than no-tillage treatments (Table 5). For these 2 yr, the 2× disking operations and no tillage fb PRE had similar yields yet were lower than inversion treatments. In 2006, the addition of either prometryn or fluometuron increased yields in each tillage treatment compared to no additional PRE herbicide with a 670 to 1,740 kg ha^{-1} increase in yields; this increase in yield was likely enhanced due to the increased weed control resulting from the pendimethalin application made prior to planting in 2006. Fluometuron application increased yield over prometryn by 420 to 840 kg ha^{-1} regardless of tillage operations. Cotton yields in 2007 were increased with the addition of either prometryn or fluometuron in no-tillage or 2× disk treatments with pendimethalin; however, only fluometuron increased yield for inversion-tillage treatments. Again, fluometuron increased cotton yield over prometryn treatments, particularly in 2× disk and inversion treatments, which had 450 and 300 kg ha^{-1} respective increases with fluometuron application.

Generally, 2008 cotton yield was lower compared to 2006 and 2007. In 2008, the EV Smith Research Center received 26.3 cm of rainfall in August, whereas only 5 cm was received September 1 through October 21; thus, boll rot on the lower branches combined with poor upper boll development likely reduced yield. The yield increases noted for inversion/disk and 2× disk-tillage treatments over no-tillage in previous years were not observed in 2008 (Table 5). Management treatments that included PREs had higher yields over plots without PRE

Table 5. Effect of tillage treatment and PRE herbicide application by year on cotton yield at EV Smith Research Center.

Year	Initial management practice[a]	PRE herbicide: None[b] Yield	None[b] Rank	Prometryn Yield	Prometryn Rank	Prometryn P value vs. none[c]	Fluometuron Yield	Fluometuron Rank	Fluometuron P value vs. none
		kg ha^{-1}		kg ha^{-1}			kg ha^{-1}		
2006	None B	737	4	1,640	4	0.0180	2,479	4	0.0001
2006	None A	1,764	2	2,254	3	0.2650	2,666	3	0.0180
2006	Disk 2×, cultivation	1,597	3	2,325	2	0.0653	3,011	2	0.0001
2006	Invert, disk, cultivation	2,374	1	3,046	1	0.0944	3,705	1	0.0003
	SE	281		281			281		
2007	None B	1,742	4	1,612	4	0.7931	1,940	4	0.5934
2007	None A	2,089	2	2,517	2	0.1123	2,616	3	0.0415
2007	Disk 2×, cultivation	1,909	3	2,293	3	0.1667	2,742	2	0.0007
2007	Invert, disk, cultivation	2635	1	2,548	1	0.8994	2,852	1	0.5361
	SE	214		214			214		
2008	None B	939	4	1,128	4	0.2434	1,669	4	0.0001
2008	None A	1,628	3	1,995	1	0.0090	1,947	1	0.0261
2008	Disk 2×, cultivation	1,738	1	1,961	2	0.1482	1,852	2	0.5800
2008	Invert, disk, cultivation	1,704	2	1,829	3	0.5142	1,838	3	0.4703
	SE	167		167			167		

[a] As part of the initial management practice, pendimethalin was applied preplant, incorporated with tillage or PRE with no tillage except for treatment labeled None B.

[b] Column includes treatments that received no herbicide application or a POST-only glyphosate application.

[c] P value significant at $P \leq 0.05$.

applications regardless of the additional PRE herbicide; however, these treatments produced similar yields when compared to each other with the no tillage or PRE herbicide providing increased control over other treatments.

In all 3 yr of the study, POST glyphosate applications resulted in increased yields ranging from 200 kg ha^{-1} to 1,960 kg ha^{-1} over no POST depending on the tillage (Table 6). In most instances, inversion-tillage treatments produced greater yields than other treatments, both with glyphosate (240 to 970 kg ha^{-1}) and without glyphosate (470 to 1,880 kg ha^{-1}), during 2006 and 2007. In 2008, however, tillage operations with pendimethalin applications did not differ with or without a glyphosate application. No-tillage with a PRE application resulted in slightly increased yield (by 301 kg ha^{-1}) when glyphosate was applied. The moderate increase in cotton yield observed with glyphosate use is consistent with reduced *Amaranthus* density observed for no-tillage treatments with a PRE application in 2006 that received glyphosate applications (Figure 1).

Results of this research indicate that inversion tillage followed by a return to less intensive tillage practices may aid in reducing *Amaranthus* populations in cotton; however, the addition of effective POST applications was still necessary for optimal control and is in agreement with recent literature evaluating control in glyphosate and glufosinate-based systems (Aulakh et al. 2012a,b; Riar et al. 2011; Whitaker et al. 2011). The use of PRE herbicides, particularly fluometuron, resulted in reduced *Amaranthus* density but did not provide season-

Table 6. Effect of initial management treatment and POST herbicide application by year on cotton yield at EV Smith Research Center.

Year	Initial management practice[a]	None Yield	None Rank	Glyphosate Yield	Glyphosate Rank	P value vs. none[b]
		kg ha^{-1}		kg ha^{-1}		
2006	None B	638	4	2,598	4	0.0001
2006	None A	1,343	3	3,112	3	0.0001
2006	Disk 2×, cultivation	1,487	2	3,135	2	0.0001
2006	Invert, disk, cultivation	2,517	1	3,565	1	0.0001
	SE	223		223		
2007	None B	947	4	2,582	4	0.0001
2007	None A	1,993	2	2,821	2	0.0001
2007	Disk 2×, cultivation	1,971	3	2,657	3	0.0001
2007	Invert, disk, cultivation	2,462	1	2,895	1	0.0110
	SE	172		172		
2008	None B	888	4	1,602	4	0.0001
2008	None A	1,706	2	2,007	1	0.0407
2008	Disk 2×, cultivation	1,744	1	1,956	2	0.1467
2008	Invert, disk, cultivation	1,691	3	1,888	3	0.1782
	SE	162		162		

[a] Initial management practices included an initial application of pendimethalin except in treatment labeled None B.

[b] P value significant at $P \leq 0.05$.

long control without an additional POST herbicide application. Additional research is necessary to evaluate the long-term effects of one-time tillage practices on *Amaranthus* seed bank dynamics. Research is also needed to determine alternative POST herbicide options in reduced-tillage cotton when glyphosate efficacy is lost.

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