Weed Management and Crop Response with Glyphosate, *S*-Metolachlor, Trifloxysulfuron, Prometryn, and MSMA in Glyphosate-Resistant Cotton

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Field studies were conducted in five states at six locations from 2002 through 2003 to evaluate weed control and cotton response to early POST (EPOST), POST/POST-directed spray (PDS), and late POST-directed (LAYBY) systems using glyphosate-trimethylsulfonium salt (TM), *s*-metolachlor, trifloxysulfuron, prometryn, and MSMA. Early POST applications were made from mid May through mid June; POST/PDS applications were made from early June through mid July; and LAYBY applications were made from early July through mid August. Early season cotton injury and discoloration was minimal ($<$ 1%) with all treatments; mid- and late-season injury was minimal ($<$ 2%) except for trifloxysulfuron POST (11 and 9%, respectively). Annual grasses evaluated included barnyardgrass, broadleaf signalgrass, goosegrass, and large crabgrass. Broadleaf weeds evaluated included entireleaf morningglory, pitted morningglory, sicklepod, and smooth pigweed. For the EPOST, POST/PDS, and LAYBY applications, weeds were at cotyledon to 10 leaf, 1 to 25 leaf, and 2 to 25 leaf stage, respectively. Annual broadleaf and grass control was increased with the addition of *s*-metolachlor to glyphosate-TM EPOST systems (85 to 98% control) compared with glyphosate-TM EPOST alone (65 to 91% control), except for sicklepod control where equivalent control was observed. Annual grass control was greater with glyphosate-TM plus trifloxysulfuron PDS than with trifloxysulfuron POST or PDS, or trifloxysulfuron plus MSMA PDS (90 to 94% vs. 75 to 83% control). With few exceptions, broadleaf weed control was equivalent for trifloxysulfuron applied POST alone or PDS alone or in combination with glyphosate-TM PDS or MSMA PDS herbicide treatments (81 to 99% control). The addition of a LAYBY herbicide treatment increased broadleaf weed control by 11 to 36 percentage points compared with systems without a LAYBY. Cotton lint yield increased 420 kg/ha with the addition of *s*-metolachlor to glyphosate-TM EPOST treatments compared with systems without *s*-metolachlor EPOST. Cotton lint yield was increased 330 to 910 kg/ha with the addition of a POST herbicide treatment compared with systems without a POST/PDS treatment. The addition of a LAYBY herbicide treatment increased cotton lint yield by 440 kg/ha compared with systems without a LAYBY.

Nomenclature: Glyphosate-TM; MSMA; prometryn; *s*-metolachlor; trifloxysulfuron; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv. ECHCG; broadleaf signalgrass, *Brachiaria platyphylla* (Griseb.) Nash. BRAPP; entireleaf morningglory, *Ipomoea hederacea* var. *integriuscula* Gray. IPOHG; goosegrass, *Eleusine indica* (L.) Gaertn. ELEIN; large crabgrass, *Digitaria sanguinalis* (L.) Scop. DIGSA; pitted morningglory, *Ipomoea lacunosa* L. IPOLA; sicklepod, *Cassia obtusifolia* L. CASOB; smooth pigweed, *Amaranthus hybridus* L. AMACH; cotton, *Gossypium hirsutum* L. 'DP 458 RR/BG', 'DP 555 RR/BG', 'FM 989 RR/BG', 'PM 2344 RR/BG', 'ST 4793 RR'.
Key words: Trimethylsulfonium salt, weed management.

Glyphosate-resistant (GR) cotton offers many benefits to growers including broad-spectrum control of annual and perennial grass, sedge and broadleaf weeds (Clewis et al. 2006; Franz et al. 1997; Tharp and Kells 1999; VanGessel et al. 2000), potential to eliminate soil-applied herbicides, ease of POST application (Culpepper and York 1999), low cost, and a favorable environmental profile (Culpepper and York 1999; Shaner 2000). The wider application window of glyphosate application timing in GR cotton, i.e., POST up to four leaves and POST-directed spray (PDS) from five to eight leaves, increases the flexibility of POST weed management decisions. However, these advances in biotechnology have shifted weed management programs from traditional multiple herbicide-application approach to relying on total POST herbicide systems, which include PDS and late POST-directed (LAYBY) applications (Askew and Wilcut 1999; Culpepper and York 1999; Culpepper et al. 2000; Thomas et al. 2006).

A recent survey conducted by six universities and Marketing Horizons, Inc., showed that a third of 1,195 growers of cotton, corn (*Zea mays* L.), and soybean [*Glycine max* (L.) Merr.] surveyed (representing six agricultural states) relied solely on glyphosate for weed management (Clewis et al. 2007). It is estimated that $>$ 95% of all cotton currently grown in Mississippi and North Carolina is GR (A. C. York and D. R. Shaw, personal communication). Glyphosate drawbacks include lack of residual weed control necessitating multiple applications (Askew et al. 2002), marginal control of Florida pusley (*Richardia scabra* L.) and yellow (*Cyperus esculentus* L.) and purple nutsedge (*Cyperus rotundus* L.), and the requirement of timely applications for control of annual morningglories (Faircloth et al. 2001). Another more recent concern with glyphosate use is resistance development in weeds, such as horseweed [*Conyza canadensis* (L.) Cronq.] (Koger et al. 2004; Mueller et al. 2003; VanGessel 2001),

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Table 1. Cotton planting and herbicide application information for the six locations across five states.[a]

Year	Kinston, NC 2002	Kinston, NC 2003	St. Joseph, LA 2003	Vernon, TX 2003	Stoneville, MS 2003	Headland, AL 2003
Cotton variety	FM 989 RR/BG	FM 989 RR/BG	DP 458 RR/BG	PM 2344 RR/BG	ST 4793 RR	DP 555 RR/BG
Row spacing	96.5 cm	96.5 cm	101. 6 cm	101. 6 cm	101. 6 cm	91.4 cm
Plot size	3.9 × 9.1 m	3.9 × 9.1 m	4.1 × 12.2 m	4.1 × 6.1 m	4.1 × 6.7 m	3.9 × 9.1 m
Seedling rate	13.1 seed/m	13.1 seed/m	13.1 seed/m	13.1 seed/m	13.1 seed/m	13.1 seed/m
Soil type	Norfolk loamy	Norfolk loamy	Mhoon silt loam	Acuff clay loam	Dundee sandy loam	Dothan fine sandy loam
pH	5.9	5.9	6.8	7.1	6.7	6.5
OM (%)	2.2	1.2	0.5	0.3	1.1	0.4
Planting date	May 6	May 6	April 28	April 27	May 9	May 6
EPOST application date	May 29	June 12	May 12	June 17	May 20	June 6
POST application date	June 10	June 23	June 2	July 9	June 10	June 24
PDS application date	June 10	June 23	June 2	July 9	June 17	July 15
LAYBY application date	June 19	July 10	July 1	August 14	June 24	August 5
Spray volume	15 GPA	15 GPA	15 GPA	15 GPA	20 GPA	15 GPA
Spray tip	11002VS	11002VS	11003AI	11002XR	8004VS	11002VS
Spray pressure	30 psi	30 psi	32 psi	31 psi	28 psi	30 psi

[a] Abbreviations: OM, organic material; EPOST, early POST; PDS, POST-directed spray; LAYBY, late POST-directed; GPA, gallons per acre; psi, pounds per square inch.

common waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] (Patzoldt et al. 2004; Zelaya and Owen 2002), giant ragweed (*Ambrosia trifida* L.) (Heap 2007), Italian ryegrass (*Lolium multiflorum* Lam.) (Perez-Jones et al. 2005), Palmer amaranth (*Amaranthus palmeri* S. Wats.) (Culpepper et al. 2006), and common ragweed (*Ambrosia artemisiifolia* L.) (Brewer et al. 2006).

Fundamentals for successful weed management in all crop production systems incorporate timely application, proper herbicide selection, and use of multiple sites of action (Wilcut and Askew 1999). The registration of trifloxysulfuron provided growers with another POST option for broadleaf weed control in cotton. Trifloxysulfuron is a sulfonylurea herbicide that inhibits the acetolactate synthase enzyme (ALS, EC 4.1.3.18) primarily and is used for broadleaf and perennial sedge control (Porterfield et al. 2002b; Richardson et al. 2007). Trifloxysulfuron has low toxicological properties, a favorable environmental profile, and low use rates (Anonymous 2007). Previous research has shown that trifloxysulfuron POST controls common lambsquarters (*Chenopodium album* L.), common ragweed, entireleaf morningglory, pitted morningglory, smooth pigweed, Palmer amaranth, sicklepod, tall morningglory [*Ipomoea purpurea* (L.) Roth.], and yellow nutsedge (Burke and Wilcut 2004; Porterfield et al. 2002b, 2003; Richardson et al. 2007). However, trifloxysulfuron will not control jimsonweed (*Datura stramonium* L.), prickly sida (*Sida spinosa* L.), spurred anoda [*Anoda cristata* (L.) Schlecht.], and several annual grasses and only suppresses purple nutsedge and johnsongrass [*Sorghum halepense* (L.) Pers.] (Corbett et al. 2004; Crooks et al. 2003; Porterfield et al. 2002b, 2003; Richardson et al. 2003). Cotton injury from trifloxysulfuron has been minimal, with symptoms of chlorosis and stunting; however, cotton at the five-leaf stage on warm, well-drained soils recovers rapidly (Burke and Wilcut 2004; Crooks et al. 2003; Richardson et al. 2004a; Thomas et al. 2006). Weed resistance to the ALS family of herbicides is widespread with 93 cases reported worldwide (Heap 2007).

Proactive weed-resistance management should take priority when developing weed-management systems in any crop. Weed-resistance management in cotton can be particularly problematic because of the limited POST options (glyphosate, pyrithiobac, and trifloxysulfuron); widespread weed resistance to the ALS herbicide family; and developing glyphosate-resistance concerns (Culpepper and York 2005). Multiple herbicide sites of action will be a key for controlling potential resistant biotypes. However, with the decrease in use of soil-applied herbicides because of the overwhelming success of GR cotton, the objective of this research was to evaluate a systems approach for POST control of several annual broadleaf and grass weeds across the Cotton Belt using herbicides with multiple sites of action.

Materials and Methods

Field studies were conducted in five states at six locations from 2002 through 2003. Two studies were conducted in North Carolina in 2002 and 2003 at the Caswell Research Station near Kinston, NC. Other studies were conducted at the Northeast Research Station near St. Joseph, LA, at the U.S. Department of Agriculture–Agricultural Research Service (USDA–ARS) Research Station near Stoneville, MS, at the Lockett Experiment Station near Vernon, TX, and at the Alabama Agricultural Experiment Station's Wiregrass Research and Extension Center near Headland, AL, in 2003. Cotton planting (e.g., dates, row spacing, varieties) and soil information varied for all locations and are presented in Table 1.

The experiments were arranged in a randomized complete-block design with a factorial treatment arrangement of two early POST (EPOST) treatment options, five POST/PDS treatment options, and two LAYBY treatment options, resulting in a total of 20 treatments. A nontreated check was also included for comparison. The EPOST herbicide options consisted of (1) glyphosate-trimethylsulfonium salt (glyphosate-TM)[1] at 840 g ae/ha, or (2) glyphosate-TM plus *s*-metolachlor[2] at 1,120 g ai/ha. The POST and PDS herbicide options consisted of (1) no herbicide, (2) trifloxysulfuron[3] at 5.3 g ai/ha applied POST, (3) trifloxysulfuron at 5.3 g ai/ha applied PDS, (4) trifloxysulfuron at

Table 2. Cotton and weed species, densities, height, and growth stages at application timings.[a]

Location	Weed and cotton	EPOST			POST			PDS			LAYBY		
		Growth stage	Density	Height	Growth stage	Density	Height	Growth stage	Density	Height	Growth stage	Density	Height
		LF no.	m^2	cm	LF no.	m^2	cm	LF no.	m^2	cm	LF no.	m^2	cm
Headland, AL (2003)	AMACH	6	1	—	4	1	—	4	1	—	4	1	—
	ELEIN	10	1	—	15	1	—	15	1	—	10	1	—
	GOSHI	3	—	12.7	8	—	25.4	12	—	35.6	24	—	45.7
St. Joseph, LA (2003)	AMACH	C 2	10	—	3–4	8	—	3–4	8	—	4–5	4	—
	CASOB	C 2	8	—	3–4	6	—	3–4	6	—	4–5	4	—
	DIGSA	C 2	10	—	3–4	8	—	3–4	8	—	4–5	3	—
	ECHCG	C 2	10	—	3–4	6	—	3–4	6	—	4–5	3	—
	ELEIN	C 2	8	—	3–4	4	—	3–4	4	—	4–5	2	—
	IPOHG	C 2	10	—	3–4	8	—	3–4	8	—	4–5	4	—
	IPOLA	C 2	12	—	3–4	10	—	3–4	10	—	4–5	5	—
	GOSHI	2	—	5.1	5–6	—	15.2	5–6	—	15.2	10–12	—	35.6
Stoneville, MS (2003)	AMACH	1–4	—	2.5–7.6	1–4	—	2.5–7.6	1–4	—	2.5–7.6	2–5	—	5.1–12.7
	BRAPP	1–2	—	2.5	1–2	—	2.5	2–4	—	5.1–12.7	3–4	—	7.6–17.8
	ECHCG	1–2	—	2.5	1–2	—	2.5	2–4	—	5.1–12.7	3–4	—	7.6–17.8
	IPOHG	1–2	—	2.5–7.6	1–2	—	2.5–7.6	1–3	—	2.5–12.7	2–4	—	5.1–17.8
	IPOLA	1–2	—	2.5–7.6	1–2	—	2.5–7.6	1–3	—	2.5–12.7	2–4	—	5.1–17.8
	GOSHI	C 4	—	7.6	5–12	—	10.2–30.5	5–12	—	10.2–30.5	14–20	—	10.2–35.6
Kinston, NC (2002)	AMACH	2–3	25	—	3–4	12	—	3–4	12	—	C 3	3	—
	BRAPP	1–3	8	—	2–4	9	—	2–4	9	—	1–2T	3	—
	CASOB	C 3	10	—	C 2	5	—	C 2	5	—	C 3	6	—
	ELEIN	1–3	15	—	1–3	12	—	1–3	12	—	3–3T	4	—
	IPOHG	C 2	8	—	C 2	5	—	C 2	5	—	C 3	3	—
	IPOLA	C 2	6	—	C 4	7	—	C 4	7	—	C 3	5	—
	GOSHI	2–3	—	7.6	4–6	—	20.3	4–6	—	20.3	8–10	—	45.7
Kinston, NC (2003)	AMACH	2–8	25	—	8	8	—	8	8	—	C 8	3	—
	CASOB	1–4	12	—	C 2	5	—	C 2	5	—	C 3	6	—
	DIGSA	1–6	20	—	1–3	8	—	1–3	8	—	1–3T	7	—
	ELEIN	1–5	15	—	1–3	10	—	1–3	10	—	1–2T	3	—
	IPOHG	C 4	10	—	C 3	5	—	C 3	5	—	C 3	8	—
	IPOLA	C 5	15	—	C 2	8	—	C 2	8	—	C 5	10	—
	GOSHI	3–4	—	12.7	7–8	—	25.4	7–8	—	25.4	14	—	45.7
Vernon, TX (2003)	AMACH	C 10	—	1.3–5.1	2–25	—	2.5–40.6	2–25	—	2.5–40.6	5–25	—	7.6–61.0
	GOSHI	C 4	—	2.5–10.2	5–12	—	10.2–30.5	5–12	—	10.2–30.5	14–20	—	10.2–35.6

[a] Abbreviations: in., inches; C, cotyledon; LF no., number of leaves; T, tiller; EPOST, early POST; PDS, POST-directed spray; LAYBY, late POST-directed; AMACH, smooth pigweed; BRAPP, broadleaf signalgrass; CASOB, sicklepod; DIGSA, large crabgrass; ECHCG, barnyardgrass; ELEIN, goosegrass; GOSHI, cotton; IPOHG, entireleaf morningglory; IPOLA, pitted morningglory.

5.3 g ai/ha applied in combination with MSMA at 2,240 g ai/ha PDS, or (5) trifloxysulfuron at 5.3 g ai/ha applied in combination with glyphosate-TM PDS. The LAYBY herbicide options consisted of (1) no herbicide, or (2) prometryn at 1,120 g ai/ha plus MSMA LAYBY. All treatments were replicated three to four times. All trifloxysulfuron applications and the LAYBY herbicide applications included a nonionic surfactant[4] at 0.25% (v/v). Herbicide application dates varied for each location and are listed in Table 1.

Annual grasses evaluated for control included barnyardgrass, broadleaf signalgrass, goosegrass, and large crabgrass. Broadleaf weeds evaluated for control included entireleaf morningglory, pitted morningglory, smooth pigweed, and sicklepod. Cotton growth stages and height along with weed species growth stages, densities, and height are listed in Table 2 by application timing. Weed control and cotton injury based on biomass and population reductions, were estimated visually on a scale of 0 to 100, where 0 is no control, and 100 is death of all plants (Frans et al. 1986). Three separate injury parameters (stunting, discoloration, and stand reduction) were visually estimated for cotton 7 to 10 d after POST treatments and after LAYBY treatments. Overall injury was also estimated as a combination of the three injury parameters. Mid- and late-season weed ratings are reported. The two center rows of each plot were harvested once with a spindle or stripper picker modified for small-plot research. Lint and seed yield were adjusted based on the 2-yr statewide average percentage of lint composition of each cultivar by each state.

Nontreated control plots could not be harvested because of weed biomass interference with machinery. Therefore, the nontreated controls were removed before analysis. Homogeneity of variance was examined by plotting residuals. Data were subjected to an ANOVA using the general linear models procedure of SAS (SAS 1998), and sums of squares were partitioned to evaluate location and herbicide treatments (McIntosh 1983). Data for visually estimated weed control and crop injury were converted to square roots of the arcsine to stabilize variance (Gomez and Gomez 1984). All data are

Table 3. POST/PDS treatment main effects on mid- and late-season cotton injury averaged over EPOST and LAYBY applications and experiment locations.[a]

POST treatments[b,c]	Mid-season injury	Late-season injury
g ai/ha	%	
No POST	0 b	1 b
Trifloxysulfuron POST (5.3)	11 a	9 a
Trifloxysulfuron PDS (5.3)	1 b	2 b
Trifloxysulfuron (5.3) plus MSMA (2,240) PDS	1 b	2 b
Trifloxysulfuron (5.3) plus glyphosate-TM (840) PDS	1 b	2 b
Locations[d]	6	6

[a] Values of control within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] Abbreviations: glyphosate-TM, glyphosate-trimethylsulfonium salt; PDS, POST-directed spray.

[c] Means represent the average injury from five POST or PDS herbicide treatments. A nonionic surfactant at 0.25% (v/v) was included with all trifloxysulfuron treatments.

[d] Location number indicates the number of experiment locations where data were collected for each variable. See Table 1.

shown nontransformed for reader clarity. If location effects were not significant, data were pooled; otherwise, data are presented by location.

Results and Discussion

Crop Response. Early season cotton injury and discoloration was minimal (< 1%) with all treatments (data not shown). The POST/PDS herbicide treatment main effect for mid- and late-season cotton injury was significant, but interaction with EPOST and LAYBY herbicide treatments was not significant (Table 3). Data are presented averaged over EPOST and LAYBY herbicide treatments and experiment locations. Mid- and late-season cotton injury was ≤ 2% for all trifloxysulfuron PDS treatments. However, trifloxysulfuron POST injured cotton 11 and 9% at mid- and late-season evaluations, respectively. This level of injury to cotton in North Carolina and Virginia is not uncommon (Crooks et al. 2003; Porterfield et al. 2003; Richardson et al. 2004a, 2004b). Injury was visually apparent as a chlorosis, discoloration of treated cotton foliage, and stunting (data not shown). Cotton injury may occur when trifloxysulfuron POST applications are made to smaller cotton over-the-top in saturated soils (Anonymous 2007). Because metabolism of trifloxysulfuron has been reported to be the main basis for tolerance (Askew and Wilcut 2002), it is possible that cool and wet conditions may influence the rate of metabolism, consequently reducing tolerance. Branson et al. (2002) reported significantly greater cotton injury from trifloxysulfuron under cool, saturated soil conditions in controlled environment studies.

Weed Control. Only late-season evaluations of weed control are presented because harvesting efficiency and, therefore, yield are influenced by weed presence late in the season (Wilcut et al. 1995). There were significant main effects for EPOST, POST/PDS, and LAYBY treatments for barnyardgrass, broadleaf signalgrass, entireleaf morningglory, goosegrass, large crabgrass, pitted morningglory, sicklepod, and smooth pigweed control, with no significant location, year, or treatment interactions (Tables 4 and 5).

Annual Grasses. Annual grass control ranged from 65 to 81% with glyphosate-TM EPOST alone when averaged over POST/PDS and LAYBY treatments (Table 4). For annual grasses evaluated, inclusion of *s*-metolachlor to glyphosate-TM EPOST increased control 11 to 20 percentage points. In

Table 4. Early POST (EPOST), POST/POST-directed spray (PDS), and late POST-directed (LAYBY) treatment main effects on late-season annual grass control averaged over experiment locations.[a]

Herbicide treatments[b,c]	Barnyardgrass	Broadleaf signalgrass	Goosegrass	Large crabgrass
	%			
EPOST main effects				
Glyphosate-TM (840)	66 b	65 b	81 b	72 b
Glyphosate-TM (840) plus *s*-metolachlor (1,120)	86 a	85 a	92 a	88 a
POST/PDS main effects				
No POST	60 c	55 c	82 b	68 c
Trifloxysulfuron POST (5.3)	80 b	77 b	83 b	82 b
Trifloxysulfuron PDS (5.3)	76 b	75 b	82 b	79 b
Trifloxysulfuron (5.3) plus MSMA (2,240) PDS	74 b	82 b	93 a	80 b
Trifloxysulfuron (5.3) plus glyphosate-TM (840) PDS	90 a	93 a	94 a	90 a
LAYBY main effects				
No LAYBY	65 b	57 b	78 b	67 b
Prometryn (1,120) plus MSMA (2,240)	87 a	93 a	96 a	92 a
Locations[d]	2	2	3	3

[a] Values of control within a column and main treatment effects followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] Abbreviations: glyphosate-TM, glyphosate-trimethylsulfonium salt.

[c] A nonionic surfactant at 0.25% (v/v) was included with prometryn plus MSMA and all trifloxysulfuron treatments. Herbicide rates expressed in g ai/ha are in parentheses.

[d] Location number indicates the number of experiment locations where data were collected for each variable. See Table 1.

Table 5. Early POST (EPOST), POST/POST-directed spray (PDS), and late POST-directed (LAYBY) treatment main effects on late-season broadleaf control averaged over experiment locations.[a]

Herbicide treatments[b,c]	Entireleaf morningglory	Pitted morningglory	Sicklepod	Smooth pigweed
	———	——— % ———	———	———
EPOST main effects				
Glyphosate-TM (840)	77 b	82 b	87 a	91 b
Glyphosate-TM (840) plus *s*-metolachlor (1,120)	86 a	87 a	86 a	98 a
POST/PDS main effects				
No POST	57 c	65 c	64 b	76 b
Trifloxysulfuron POST (5.3)	87 ab	89 ab	90 a	97 a
Trifloxysulfuron PDS (5.3)	81 b	84 b	91 a	98 a
Trifloxysulfuron (5.3) plus MSMA (2,240) PDS	88 ab	90 ab	94 a	99 a
Trifloxysulfuron (5.3) plus glyphosate-TM (840) PDS	95 a	94 a	94 a	99 a
LAYBY main effects				
No LAYBY	68 b	74 b	77 b	88 b
Prometryn (1,120) plus MSMA (2,240)	96 a	95 a	96 a	99 a
Locations[d]	3	4	3	4

[a] Values of control within a column and main treatment effects followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] Abbreviations: glyphosate-TM, glyphosate-trimethylsulfonium salt.

[c] A nonionic surfactant at 0.25% (v/v) was included with prometryn plus MSMA and all trifloxysulfuron treatments. Herbicide rates expressed in g ai/ha are in parentheses.

[d] Location number indicates the number of experiment locations where data were collected for each variable. See Table 1.

other studies, grass control was increased when glyphosate systems included a residual herbicide (Askew et al. 2002; Clewis et al. 2006; Culpepper and York 1999). Continuous use of glyphosate has lead to resistant biotypes of goosegrass in Malaysia (Baerson et al. 2002). However, there has been no documented case of resistance to goosegrass with *s*-metolachlor or metolachlor (Heap 2007). Thus, the addition of *s*-metolachlor EPOST, or MSMA PDS or LAYBY, to glyphosate systems would provide a resistance-management tool as well as increased control of goosegrass and other annual grasses (Mallory-Smith and Retzinger 2003).

Trifloxysulfuron plus glyphosate-TM applied PDS, averaged over EPOST and LAYBY treatments, was the most-effective POST option for control of annual grasses (90 to 94%) (Table 4). However, trifloxysulfuron plus MSMA PDS averaged over EPOST and LAYBY treatments controlled goosegrass similarly at 93% equal to trifloxysulfuron plus glyphosate-TM PDS. Treatments that included trifloxysulfuron POST, or PDS alone or in combination with MSMA PDS, controlled barnyardgrass, broadleaf signalgrass, and large crabgrass equally (74 to 82%). Compared with no POST herbicide treatment, goosegrass control was not improved with trifloxysulfuron POST or PDS. Previous research has shown that trifloxysulfuron alone does not control annual grasses, including broadleaf signalgrass, fall panicum (*Panicum dichotomiflorum* Michx.), goosegrass, and large crabgrass (Burke et al. 2002; Crooks et al. 2003), whereas glyphosate formulations controlled annual grass populations at the time of treatment and was not influenced by trifloxysulfuron in mixture (Thomas et al. 2006). However, trifloxysulfuron may provide some suppression of annual grasses until a LAYBY application can be applied (Thomas et al. 2006).

The inclusion of a LAYBY herbicide treatment regardless of the EPOST or POST treatments increased season-long annual grass control 18 to 36 percentage points compared with not applying a LAYBY treatment (Table 4). The improvement in annual grass control by the addition of prometryn plus MSMA at LAYBY illustrates the importance of a contact (MSMA) and a residual herbicide (prometryn) component for season-long control of annual grasses (Clewis et al. 2006; Porterfield 2002b; Thomas et al. 2006).

Broadleaf Weeds. When averaged over POST/PDS and LAYBY treatment options, glyphosate-TM EPOST alone controlled entireleaf morningglory, pitted morningglory, smooth pigweed, and sicklepod 77 to 91% (Table 5). The inclusion of *s*-metolachlor to glyphosate-TM EPOST increased control of entireleaf morningglory, pitted morningglory, and smooth pigweed (5 to 9 percentage points), but sicklepod control was not improved. The rapid growth rate of some weed species allows later-germinating broadleaf weeds, especially pigweed species, to quickly grow too tall for adequate spray coverage with PDS or LAYBY herbicides. Consequently, a residual herbicide, such as *s*-metolachlor, in the tank mixture with glyphosate-TM EPOST may allow for greater control of smaller broadleaf weeds at the time of PDS or LAYBY application (Clewis et al. 2006; Porterfield et al. 2003).

The main effect of POST/PDS treatments was significant (Table 5). The addition of POST or PDS herbicide treatments increased control of *Ipomoea* spp. 24 to 38 percentage points compared with no POST herbicide treatment. All trifloxysulfuron POST and PDS treatments controlled smooth pigweed and sicklepod equally and control was at least 90%. Compared with not applying a POST treatment, control of smooth pigweed was increased 21 to 23 percentage points, and control of sicklepod was increased 26 to 30 percentage points. Previous research has shown that season-long control of broadleaf weeds requires a residual

Table 6. Early POST (EPOST), POST/POST-directed spray (PDS), and late POST-directed (LAYBY) treatment main effects on cotton lint yield averaged over experiment locations.[a]

Herbicide treatment[b,c]	Cotton lint yield
	kg/ha
EPOST main effects	
Glyphosate-TM (840)	1,530 b
Glyphosate-TM (840) plus *s*-metolachlor (1,120)	1,950 a
POST/PDS main effects	
No POST	1,240 c
Trifloxysulfuron POST (5.3)	1,570 b
Trifloxysulfuron PDS (5.3)	1,880 ab
Trifloxysulfuron (5.3) plus MSMA (2,240) PDS	1,860 ab
Trifloxysulfuron (5.3) plus glyphosate-TM (840) PDS	2,150 a
LAYBY main effects	
No LAYBY	1,520 b
Prometryn (1,120) plus MSMA (2,240)	1,960 a
Locations[d]	6

[a] Values of control within a column and main treatment effects followed by the same letter are not significantly different at the 5% level as determined by Fisher's Protected LSD test.

[b] Abbreviations: glyphosate-TM, glyphosate-trimethylsulfonium salt.

[c] A nonionic surfactant at 0.25% (v/v) was included with prometryn plus MSMA and all trifloxysulfuron treatments. Herbicide rates expressed in g ai/ha are in parentheses.

[d] Location number indicates the number of experiment locations where data were collected for each variable. See Table 1.

herbicide or multiple herbicide applications (Culpepper and York 1997; Scott et al. 2001). Trifloxysulfuron POST alone, or with the addition of glyphosate-TM PDS or MSMA PDS, controlled *Ipomoea* spp. similarly (87 to 95%). Trifloxysulfuron PDS, with or without the addition of MSMA PDS and trifloxysulfuron POST, provided equal levels of control. Similar benefits with trifloxysulfuron have been reported for smooth pigweed, sicklepod, and *Ipomoea* spp. (Porterfield et al. 2002a; Thomas et al. 2006).

A LAYBY treatment of prometryn plus MSMA, averaged over locations, EPOST, and POST/PDS treatments, controlled entireleaf morningglory, pitted morningglory, smooth pigweed, and sicklepod at least 95% compared with 68 to 88% control when no LAYBY was applied (Table 5). This level of increased control demonstrates the importance of LAYBY herbicides for weed control to avoid late-season weed competition and potentially reduced harvesting efficiency (Thomas et al. 2006).

Cotton Lint Yield. Cotton lint yields, as affected by the EPOST herbicide treatment main effects, pooled over locations, POST/PDS, and LAYBY herbicide treatments, were increased by 420 kg/ha where glyphosate-TM was applied in combination with *s*-metolachlor compared with glyphosate-TM EPOST alone (Table 6). This increase in cotton lint yield reflects the increased weed control with tank mixtures of *s*-metolachlor plus glyphosate-TM EPOST compared with glyphosate-TM EPOST alone (Tables 4 and 5). Residual herbicides may be particularly important in cotton weed-control systems because cotton is very sensitive to early season weed interference (Askew and Wilcut 1999; Buchanan and Burns 1970).

Cotton lint yields were increased 330 to 910 kg/ha by POST/PDS herbicide applications compared with no POST herbicide treatment when pooled over locations, EPOST, and LAYBY herbicide treatments (Table 6). Yields were similar for cotton treated with trifloxysulfuron POST alone, PDS alone, or in combination with MSMA PDS. Cotton treated with trifloxysulfuron in combination with glyphosate-TM PDS produced lint yield of 2,150 kg/ha, which was greater than trifloxysulfuron POST but equal to cotton treated with trifloxysulfuron PDS alone or in mixture with MSMA PDS. Cotton treated with trifloxysulfuron POST alone yielded 290 to 580 kg/ha less than cotton treated with PDS herbicide treatments. Although these yield differences are not statistically different, the yield differentials may reflect the mid- and late-season cotton injury seen when trifloxysulfuron was applied POST on smaller cotton (Table 3). The significance of timely POST herbicide applications is critical to avoiding a cotton lint yield loss of at least 330 or more kg/ha as seen when no POST herbicide treatment is used.

Cotton lint yields, as affected by LAYBY herbicide applications, pooled over locations, EPOST, and POST/PDS herbicide treatments, were increased 440 kg/ha with the inclusion of a LAYBY herbicide treatment compared with not applying a LAYBY (Table 6). These results reflect improved weed control seen with the inclusion of a LAYBY herbicide as well as the importance of full-season weed control to ensure efficient cotton harvesting (Table 5). Similar responses have been reported in other studies showing that inclusion of a LAYBY application increased cotton yields compared with systems without a LAYBY herbicide treatment (Clewis et al. 2006; Porterfield et al. 2002b, 2003; Thomas et al. 2006).

The addition of *s*-metolachlor to glyphosate-TM EPOST improved control of barnyardgrass, broadleaf signalgrass, goosegrass, large crabgrass, entireleaf morningglory, pitted morningglory, and smooth pigweed and increased yields compared with systems without *s*-metolachlor. The inclusion of *s*-metolachlor in a total POST weed control system is important to providing flexibility in subsequent application timings by controlling problematic grasses and smooth pigweed. The addition of *s*-metolachlor also provides an alternate mode of action in a proactive resistance-management program, reducing the reliance on a single mode of action (Mallory-Smith and Retzinger 2003). The addition of trifloxysulfuron in combination with glyphosate-TM PDS provided additional control of annual grasses compared with trifloxysulfuron POST alone, trifloxysulfuron PDS alone, or trifloxysulfuron in combination with MSMA PDS. The inclusion of a LAYBY herbicide treatment increased control of both the annual grasses and broadleaf weeds evaluated and increased cotton lint yields. To maintain a total POST herbicide system in GR cotton, timely applications must be made to small weeds throughout the growing season. Glyphosate in combination with herbicides such as *s*-metolachlor or trifloxysulfuron may broaden the application window and provide additional control of difficult weeds and also provide multiple sites of action for resistance management across the Cotton Belt.

Sources of Materials

[1] Touchdown®. Supplied by Syngenta Crop Protection, Inc., P.O. Box 18300, Greensboro, NC 27419.

[2] Dual II Magnum®. Supplied by Syngenta Crop Protection, Inc., P.O. Box 18300, Greensboro, NC 27409.

[3] Envoke®, formulated product with 75% ai. Supplied by Syngenta Crop Protection, Inc., P.O. Box 18300, Greensboro, NC 27409.

[4] Induce®, blend of alkylarylpolyoxyalkane ether, free fatty acids, and isopropyl (90%), and water and formulation acids (10%). Supplied by Helena Chemical Corporation, 5100 Popular Avenue, Memphis, TN 38137.

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