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Weed Control and Cotton Response to Combinations of Glyphosate and Trifloxysulfuron[1]

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Abstract: Greenhouse and field studies were conducted to evaluate potential interactions between glyphosate and trifloxysulfuron on barnyardgrass, browntop millet, hemp sesbania, seedling johnsongrass, pitted morningglory, prickly sida, sicklepod, and velvetleaf control as well as cotton injury and yield. In the greenhouse, glyphosate at 840 g ae/ha controlled all weed species 62 to 99%, which was better than trifloxysulfuron at 2.5 or 5 g ai/ha. Control of four-leaf pitted morningglory and hemp sesbania was 80 to 88% when glyphosate and trifloxysulfuron were mixed compared with 62 to 66% control with glyphosate alone. Mixing trifloxysulfuron with glyphosate did not affect control of other species compared with glyphosate alone. In the field, glyphosate controlled barnyardgrass, prickly sida, sicklepod, seedling johnsongrass, and velvetleaf 68 to 100%. Trifloxysulfuron controlled hemp sesbania, seedling johnsongrass, and sicklepod 65 to 88%. All other species were controlled 36 to 72% with glyphosate and 10 to 60% with trifloxysulfuron. Combinations of glyphosate (840 g/ha) and trifloxysulfuron (5 g/ha) were applied postemergence over-the-top and postemergence-directed to three-, six-, and nine-leaf glyphosate-resistant cotton in the field. Cotton injury at 2 wk after treatment (WAT) was less than 13% for all herbicide treatments and less than 5% by 3 WAT. Herbicides did not affect the percent of open bolls or nodes per plant. Seed cotton yield ranged from 1,430 to 1,660 kg/ha, and only the sequential over-the-top applications of trifloxysulfuron reduced cotton yield compared with the weed-free, nontreated cotton.

Nomenclature: Glyphosate; trifloxysulfuron; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv. #[3] ECHCG; browntop millet, *Brachiaria ramosa* (L.) Stapf # PANRA; entireleaf morningglory, *Ipomoea hederacea* var. *integriuscula* Gray # IPOHG; hemp sesbania, *Sesbania exaltata* (Raf.) Rydb. ex A. W. Hill # SEBEX; johnsongrass, *Sorghum halepense* L. Pers. # SORHA; pitted morningglory, *Ipomoea lacunosa* L. # IPOLA; prickly sida, *Sida spinosa* L. # SIDSP; sicklepod, *Senna obtusifolia* (L.) Irwin & Barnaby # CASOB; velvetleaf, *Abutilon theophrasti* Medik. # ABUTH; cotton, *Gossypium hirsutum* L.

Additional index words: CGA-362622, crop injury, glyphosate-resistant cotton, herbicide interactions, pesticide interactions, tank mixtures.

Abbreviations: ALS, acetolactate synthase; EPOST, early postemergence; fb, followed by; GRC, glyphosate-resistant cotton; LPOST, late postemergence; MPOST, midpostemergence; PD, postemergence-directed; POST, postemergence; POT, postemergence over-the-top; WAT, weeks after treatment.

INTRODUCTION

Glyphosate provides broad-spectrum postemergence (POST) control of annual and perennial broadleaf, grass, and sedge weeds in glyphosate-resistant crops such as corn (*Zea mays* L.), cotton, and soybean [*Glycine max* (L.) Merr.] (Askew and Wilcut 1999; Ateh and Harvey 1999; Culpepper et al. 2000; Faircloth et al. 2001; Gonzini et al. 1999; Johnson et al. 2000; Reddy and Whiting 2000; Tharp and Kells 1999; Wilcut and Askew 1999; Young et al. 2001). Glyphosate-resistant cotton (GRC) was commercialized in 1997, and the area planted to GRC in the United States has increased from 323,750 ha in 1997 (Heering et al. 1998) to 4,470,000 ha in 2001 (NCC 2002). Glyphosate is applied postemergence over-the-top (POT) of GRC up to the four-leaf growth stage

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

(Anonymous 2004). Beyond the four-leaf growth stage, glyphosate must be applied postemergence-directed (PD) to GRC to minimize contact with leaf tissue. Treating plants with POT applications after the four-leaf growth stage can result in boll abortion in lower fruiting branches (Jones and Snipes 1999). Sequential applications must be spaced at least 10 d apart, and cotton must have at least two nodes of incremental growth between applications (Anonymous 2004).

Glyphosate controls many of the weeds found in cotton fields. However, pitted morningglory, hemp sesbania, and velvetleaf typically exhibit some tolerance to glyphosate (Jordan et al. 1997; Shaw and Arnold 2002). Limited control of these species with glyphosate is often attributed to weed size at the time of application. Lanie et al. (1994a) reported that glyphosate at 1.12 kg ai/ha controlled pitted morningglory and hemp sesbania 66 and 88% when plants were 3 to 15 cm tall, compared with 23 and 13% control when plants were 15 to 18 cm tall, respectively.

Applying mixtures of herbicides can increase weed control and weed spectrum efficacy compared with glyphosate alone or a separate application of each herbicide. Tank mixtures are often preferred over sequential applications because of less time and cost required to apply each herbicide separately. However, some herbicide mixtures can reduce weed control compared with separate applications of each herbicide. Shaw and Arnold (2002) reported that the addition of chlorimuron or cloransulam-methyl to glyphosate reduced control of pitted morningglory and hemp sesbania compared with glyphosate alone. Starke and Oliver (1998) found that combinations of chlorimuron, fomesafen, or sulfentrazone mixed with glyphosate reduced hemp sesbania, pitted morningglory, sicklepod, and velvetleaf control compared with glyphosate alone. However, Vidirine et al. (2002) reported increased control of hemp sesbania and entireleaf morningglory when chlorimuron was applied with glyphosate when compared with glyphosate alone. Chlorimuron did not antagonize glyphosate control of barnyardgrass (Jordan et al. 1997) or broadleaf signalgrass [Brachiaria platyphylla (Griseb.) Nash] (Shaw and Arnold 2002).

Pyrithiobac, an acetolactate synthase (ALS)–inhibiting herbicide, is the only POT herbicide currently available for broadleaf weed control in cotton that does not cause potential maturity delays and reduction in yield (Snipes and Mueller 1992; York and Culpepper 2000). In addition, pyrithiobac is the only POT broadleaf tank mixture option for transgenic herbicide-resistant cultivars, including those resistant to glyphosate and bromoxynil. Pyrithiobac is capable of controlling many important broadleaf weeds; however, control is often inconsistent (Dotray et al. 1996; Jordan et al. 1993; Reddy 2001; Shaw and Arnold 2002). Pyrithiobac does not control sicklepod or tall morningglory [*Ipomoea purpurea* (L.) Roth] (Culpepper and York 1997; Jordan et al. 1993; Scott et al. 2001).

Trifloxysulfuron[4] is a new ALS-inhibiting sulfonylurea herbicide registered for POST weed control in sugarcane (*Saccharum* spp.) and five-leaf or larger cotton in the United States. Trifloxysulfuron is also registered for weed control in Australia and Brazil cotton (Syngenta 2004a). Trifloxysulfuron controls several broadleaf, grass, and sedge weed species (Porterfield et al. 2002a, 2002b, 2003; Rawls et al. 2000; Richardson et al. 2004a). Trifloxysulfuron has activity on several broadleaf species such as pitted morningglory, hemp sesbania, and velvetleaf that are often not adequately controlled by glyphosate alone. Trifloxysulfuron is a potential tank mixture candidate with glyphosate for PD applications to GRC because the glyphosate registration requires PD applications once cotton is beyond the four-leaf growth stage. Currently, trifloxysulfuron is registered as a tank mixture partner with glyphosate applied PD or layby to five-leaf or larger GRC (Syngenta 2004b). However, the potential interactions of tank mixture of trifloxysulfuron and glyphosate for weed control and cotton injury have not been investigated. The objectives of this research were to evaluate potential interactions between trifloxysulfuron and glyphosate on four broadleaf and two grass weed species and to evaluate potential GRC injury in greenhouse and field studies.

MATERIALS AND METHODS

Greenhouse Study. Seeds of barnyardgrass, browntop millet, hemp sesbania, pitted morningglory, prickly sida, sicklepod, and velvetleaf were purchased locally from a commercial vendor[5] and were stored at 4 C before use. Seeds of each weed species and the GRC cultivar 'Deltapine 436RR' were planted in 9-cm-diam pots containing a mixture of soil (Bosket sandy loam, fine-loamy, mixed thermic Molic Hapludalfs) and potting soil[6] (1:1 v/v). Several plantings of each species were done so that plants of different sizes could be treated simultaneously. Plants were grown in a greenhouse with 32/25 C (±3

[4] Envoke, Syngenta Crop Protection Inc., P.O. Box 18300, Greensboro, NC 27419.

[5] Azlin Seed Service, P.O. Box 914, Leland, MS 38756.

[6] Jiffy mix, Jiffy Products of America Inc., 951 Swanson Drive, Batavia, IL 60510.

C) day/night temperature. Natural light was supplemented with light from sodium vapor lamps to provide a 14-h photoperiod. After emergence, plants were thinned to 1 plant/pot.

Herbicide treatments consisted of 420 and 840 g ae/ha of the isopropylamine salt of glyphosate,[7] 2.5 and 5 g ai/ha trifloxysulfuron,[4] 420 g/ha glyphosate plus 2.5 g/ha trifloxysulfuron, or 840 g/ha glyphosate plus 5 g/ha trifloxysulfuron applied to weeds in the two-leaf (early postemergence [EPOST]) and four-leaf (late postemergence [LPOST]) growth stages. A no-herbicide control for each growth stage by weed species combination was included. A nonionic surfactant[8] was added to all trifloxysulfuron treatments at 0.25% (v/v), as suggested by the manufacturer. Two additional glyphosate treatments of 420 and 840 g/ha plus nonionic surfactant (0.25% v/v) were included to determine the effects of surfactant on glyphosate efficacy. Treatments were applied using an air-pressurized indoor spray chamber equipped with an 8002E flat-fan nozzle[9] calibrated to deliver a spray volume of 190 L/ha at 140 kPa. After spraying, plants were returned immediately to the greenhouse.

Herbicide efficacy was assessed 3 wk after treatment (WAT) by clipping shoots at the soil surface and recording plant fresh weight. Data were expressed as percent shoot biomass reduction (%control) compared with nontreated plants. The experiment was conducted in a randomized complete block design with a factorial arrangement of treatments. Factors were plant growth stage, herbicide type, and herbicide rate. Treatments were replicated four times, and the experiment was repeated three times. Data were pooled across experiments.

Weed Control Field Study. The experiment was conducted in 2003 at the USDA Southern Weed Science Research Farm, Stoneville, MS (lat 33°N) and at the E. V. Smith Research Center, Shorter, AL (lat 32°N). Soils were a Dundee silt loam (fine-silty, mixed, thermic Aeric Ochraqualfs) at Stoneville and a Compass loamy sand (course-loamy, siliceous, subactive, thermic Plinthic Paleudults) at Shorter. Soil textural fractions were 26% sand, 55% silt, and 19% clay at Stoneville and 84% sand, 12% silt, and 4% clay at Shorter. Organic matter, pH, and cation exchange capacity were 1.1%, 7.0, and 15 cmol/kg at Stoneville and 0.5%, 5.0, 1.9 cmol/kg at Shorter, respectively. The field at Stoneville was disked twice and 100-cm-wide beds were prepared in the fall of 2002. Beds were conditioned nearly flat in March 2003 to enable planting of weed seeds. Seedbed preparation at Shorter consisted of disking and leveling before planting. Seeds[5] of barnyardgrass, johnsongrass, hemp sesbania, pitted morningglory, prickly sida, sicklepod, and velvetleaf were planted in 19-cm-wide rows on May 6, 2003, at Shorter and May 10, 2003, at Stoneville. Existing vegetation at planting at Stoneville was controlled with 840 g/ha glyphosate before emergence of planted weed seeds. Rainfall during the experiment (May through July) was 31 cm at Stoneville and 47 cm at Shorter. The 30-yr average rainfall for the corresponding period is 32 cm at Stoneville and 34 cm at Shorter. Plots were 4 m wide by 7 m long. Treatments were arranged in a randomized complete block design with four replications.

Herbicide treatments were applied POT of two- to three-leaf (EPOST) and five- to six-leaf (LPOST) weeds at 2 and 4 wk after planting. Herbicide treatments consisted of the potassium salt of glyphosate[10] at 840 g/ha EPOST and LPOST, trifloxysulfuron at 5 g/ha EPOST and LPOST, glyphosate at 840 g/ha plus trifloxysulfuron at 5 g/ha EPOST and LPOST, and a nontreated control. A nonionic surfactant[8] was added at 0.25% v/v to trifloxysulfuron. Herbicides were applied with a tractor-mounted sprayer using 8004 standard flat-fan spray nozzles[9] delivering 187 L/ha water at 180 kPa. Control of individual weed species was estimated visually 2 WAT. A scale between 0 and 100% was used, where 0 indicates no control or injury and 100 indicates death (Frans et al. 1986). Visual estimates of control were based on foliar chlorosis, necrosis, and plant stunting.

Cotton Tolerance Field Study. The experiment was conducted in 2003 adjacent to the weed control field study at Stoneville and Shorter. Soil information and field preparation is as described previously. The GRC cultivar 'Deltapine 451BGRR' was planted on April 31, 2003, at Shorter. The GRC cultivar 'Stoneville 4793RR' was planted May 10, 2003, at Stoneville. Cotton was planted in 100-cm-wide rows at 13 seeds/m of row. At Stoneville, existing vegetation at planting was controlled with 840 g/ha glyphosate. The experimental design was a randomized complete block, with each treatment replicated four times. Plots were four 100-cm-row wide and 7.7 m long. Rainfall during the experiment (May to September) was 48 cm at Stoneville and 70 cm at Shorter.

[7] Roundup UltraMAX™, Monsanto Company, 800 North Linbergh Boulevard, St. Louis, MO 63167.

[8] Induce® nonionic low foam wetter/spreader adjuvant contains 90% nonionic surfactant (alkylaryl and alcohol exthoxylate surfactants) and fatty acids and 10% water. Helena Chemical Company, Suite 500, 6075 Popular Avenue, Memphis, TN 38119.

[9] TeeJet, P.O. Box 7900, Wheaton, IL 60189-7900.

[10] Roundup WEATHERMAX™, Monsanto Company, 800 North Linbergh Boulevard, St. Louis, MO 63167.

The 30-yr average rainfall for the corresponding period is 46 cm at Stoneville and 54 cm at Shorter. During dry periods, plots at Stoneville were flood irrigated as needed.

Cultivation and hand-weeding were conducted as needed to keep plots weed free. Fertilizer application and insect control programs were standard for cotton production. Aldicarb [2-methyl-2-(methylthio)propionaldehyde-*O*-(methylcarbamoyl)oxime] at 0.5 kg ai/ha was applied in-furrow for early-season insect control. Acephate (*O*,S-dimethyl acetylphosphoramidothioate), dicrotophos (dimethyl phosphate of 3-hydroxy *N*, *N*-dimethyl-*cis*-crotonamide), and bifenthrin {2 methyl [1,1′-biphenyl]-3-yl) methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethyl-cyclopropanecarboxylate} were applied POT during the growing season as needed to control insects. Harvest preparation consisted of cotton defoliation by tribufos (*S*, *S*, *S*-tributyl phosphorotrithioate) and boll opening by ethephon [(2-chloroethyl)phosphonic acid] followed by (fb) desiccation with paraquat.

Herbicide treatments were applied POT to cotton in the three-leaf (EPOST), six-leaf (midpostemergence [MPOST]), and nine-leaf (LPOST) growth stages. Treatments were also applied PD to cotton in the MPOST growth stage. The POT herbicide treatments included trifloxysulfuron at 5 g/ha EPOST, MPOST, and MPOST fb LPOST, glyphosate[10] at 840 g/ha EPOST, and trifloxysulfuron at 5 g/ha plus glyphosate at 840 g/ha EPOST. The PD treatments were trifloxysulfuron at 5 g/ha MPOST, glyphosate at 840 g/ha MPOST, and trifloxysulfuron at 5 g/ha plus glyphosate at 840 g/ha MPOST. A nonionic surfactant was added at 0.25% v/v to trifloxysulfuron treatments. A nontreated control consisting of cultivation and hand-weeding only was included. The POT herbicide treatments were applied with a tractor-mounted sprayer using 8004 standard flat-fan spray nozzles[9] delivering 187 L/ha water at 180 kPa. The PD treatments were applied using 8001 off-center spray nozzles[9] delivering 187 L/ha at 158 kPa.

Cotton injury, based on leaf discoloration and plant stunting, was estimated visually 1 and 2 WAT, using a scale of 0 and 100%, where 0 indicates no injury and 100 indicates death (Frans et al. 1986). The total number of nodes and open and closed bolls were counted on five randomly selected plants from a 3-m row length in each of the two center rows of each plot at harvest. Cotton was manually harvested from all open bolls of plants in the same 3-m row length of the two center rows of each plot.

Statistical Analysis. Data were subjected to arcsine square root transformations. Interpretations were not different from nontransformed data; therefore, nontransformed data are presented. Nontreated control data of all studies were deleted before statistical analysis to stabilize variance. The method described by Colby (1967) was used to calculate the expected response for herbicide combinations. To determine the potential for interaction, expected and observed values were compared at the 0.05 level of significance using Fisher's protected LSD calculated for the observed data (Hicks et al. 1998; Wehtje and Walker 1997). If the observed response of a herbicide combination was either significantly lower or greater than the expected value, the combination was declared antagonistic or synergistic, respectively. Combinations were considered to be additive (no interaction) when the observed and expected responses were similar. Data were subjected to ANOVA using the general linear models procedure in SAS (SAS 2001). Means were separated using Fisher's protected LSD test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Greenhouse Study. Growth stage by herbicide rate interactions were significant for all species; thus, data are presented for growth stage by herbicide rate for each species. Herbicide rate had a significant effect on control of all weed species except broadleaf signalgrass (Tables 1 and 2). Enhanced efficacy with higher herbicide rates was especially evident at the LPOST timing, where pitted morningglory, hemp sesbania, velvetleaf, sicklepod, prickly sida, and barnyardgrass were controlled 4 to 68% with 420 g/ha glyphosate and 2.5 g/ha trifloxysulfuron applied alone, vs. 23 to 99% control with 840 g/ha glyphosate and 5 g/ha trifloxysulfuron.

Overall, weed control was better with glyphosate than with trifloxysulfuron. Trifloxysulfuron at 5 g/ha controlled barnyardgrass and browntop millet 87 and 48% EPOST and 60 and 38% LPOST, respectively. In contrast, glyphosate at 840 g/ha controlled barnyardgrass, browntop millet, and velvetleaf 97 to 99% at both growth stages. Trifloxysulfuron at 5 g/ha had little activity on velvetleaf and prickly sida with 44 and 48% control, respectively, at EPOST and 23 and 36% control, respectively, at LPOST. Glyphosate at 840 g/ha controlled velvetleaf and prickly sida 73 to 99% at both growth stages. Glyphosate at 840 g/ha controlled pitted morningglory and hemp sesbania better than 5 g/ha trifloxysulfuron. However, control of pitted morningglory and hemp sesbania at LPOST was often not satisfactory with 840 g/ha glyphosate, which controlled these species 62 and 66% at the LPOST timing.

Pitted morningglory and hemp sesbania have shown

Table 1. Control of two-leaf (EPOST) and four-leaf (LPOST) pitted morningglory, hemp sesbania, velvetleaf, sicklepod, and prickly sida 3 WAT with glyphosate and trifloxysulfuron alone and in combination in greenhouse experiments.[a]

			Shoot reduction 3 WAT[b,c]				
Herbicide[d]	Rate	Application timing	Pitted morningglory	Hemp sesbania	Velvetleaf	Sicklepod	Prickly sida
	g/ha		%				
No herbicide			0	0	0	0	0
Glyphosate	420	EPOST	43	80	99	70	99
Glyphosate	840	EPOST	85	85	99	94	99
Trifloxysulfuron	2.5	EPOST	34	40	48	63	26
Trifloxysulfuron	5.0	EPOST	40	57	44	73	48
Glyphosate plus trifloxysulfuron	420 + 2.5	EPOST	58 (62)	88 (80)	99 (99)	83 (88)	99 (99)
Glyphosate plus trifloxysulfuron	840 + 5.0	EPOST	90 (91)	93 (93)	99 (99)	98 (99)	99 (99)
Glyphosate	420	LPOST	40	52	49	53	52
Glyphosate	840	LPOST	62	66	99	85	73
Trifloxysulfuron	2.5	LPOST	35	40	4	50	4
Trifloxysulfuron	5.0	LPOST	40	51	23	71	36
Glyphosate plus trifloxysulfuron	420 + 2.5	LPOST	62 (61)	76 (71)	52 (52)	70 (76)	51 (53)
Glyphosate plus trifloxysulfuron	840 + 5.0	LPOST	80 (77)	88 (83)	99 (99)	90 (96)	86 (82)
LSD (0.05)			7	9	9	6	10

[a] Abbreviations: EPOST, early postemergence; LPOST, late postemergence; WAT, weeks after treatment.

[b] Control is expressed as percent fresh weight reduction compared with no-herbicide treatment.

[c] Means within parentheses are expected control values of the adjacent observed control; expected values were calculated as described by Colby (1967). Interactions were considered significant if differences between observed and expected control exceeded the appropriate LSD value.

[d] The isopropylamine salt formulation of glyphosate was applied for all glyphosate treatments.

some tolerance to glyphosate (Jordan et al. 1997; Lanie et al. 1994a, 1994b; Lich et al. 1997; Starke and Oliver 1998; Taylor 1996). Lanie et al. (1994a) reported pitted morningglory and hemp sesbania control as low as 23% with 1.12 kg ai/ha glyphosate. Differences in control were attributed to weed size at application, with decreased control with increased plant age. Decreased pitted morningglory and hemp sesbania control with increased plant size was also evident in this research. Glyphosate at 840 g ae/ha controlled these two species 85% at the EPOST timing compared with 62 and 66% at the LPOST timing. Mixing trifloxysulfuron with glyphosate was neither synergistic nor antagonistic in controlling any broadleaf or grass weed species, regardless of growth stage and herbicide rate, compared with glyphosate alone (Table 1). However, at LPOST, control of

Table 2. Control of two-leaf (EPOST) and four-leaf (LPOST) barnyardgrass and browntop millet, and injury to two- and four-leaf cotton 3 WAT with glyphosate and trifloxysulfuron alone and in combination in greenhouse experiments.[a]

			Shoot reduction 3 WAT[b,c]		
Herbicide[d]	Rate	Application timing	Barnyardgrass	Brown top millet	Cotton
	g/ha		%		
No herbicide			0	0	0
Glyphosate	420	EPOST	96	99	8
Glyphosate	840	EPOST	99	99	10
Trifloxysulfuron	2.5	EPOST	60	46	13
Trifloxysulfuron	5.0	EPOST	87	48	20
Glyphosate plus trifloxysulfuron	420 + 2.5	EPOST	99 (98)	99 (99)	15 (20)
Glyphosate plus trifloxysulfuron	840 + 5.0	EPOST	99 (99)	99 (99)	20 (28)
Glyphosate	420	LPOST	68	88	0
Glyphosate	840	LPOST	97	97	4
Trifloxysulfuron	2.5	LPOST	43	42	0
Trifloxysulfuron	5.0	LPOST	60	38	2
Glyphosate plus trifloxysulfuron	420 + 2.5	LPOST	77 (81)	92 (93)	2 (2)
Glyphosate plus trifloxysulfuron	840 + 5.0	LPOST	98 (99)	96 (98)	5 (6)
LSD (0.05)			8	10	8

[a] Abbreviations: EPOST, early postemergence; LPOST, late postemergence; WAT, weeks after treatment.

[b] Control is expressed as percent fresh weight reduction compared with no-herbicide treatment.

[c] Means within parentheses are expected control values of the adjacent observed control; expected values were calculated as described by Colby (1967). Interactions were considered significant if differences between observed and expected control exceeded the appropriate LSD value.

[d] The isopropylamine salt formulation of glyphosate was applied for all glyphosate treatments.

Table 3. Control of two- to three-leaf (EPOST) and four- to five-leaf (LPOST) pitted morningglory, hemp sesbania, velvetleaf, and sicklepod 2 wk after glyphosate and trifloxysulfuron were applied alone and in combination in field experiments at Stoneville, MS, and Shorter, AL.

		Control[a]			
Herbicide[b]	Application timing[c]	Pitted morningglory	Hemp sesbania	Velvetleaf	Sicklepod
		%			
No herbicide		0	0	0	0
Glyphosate	EPOST	72	42	79	96
Trifloxysulfuron	EPOST	60	88	36	74
Glyphosate plus trifloxysulfuron	EPOST	95 (89)	99 (93)	85 (86)	96 (99)
LSD (0.05)		14	12	6	12
Glyphosate	LPOST	36	39	68	88
Trifloxysulfuron	LPOST	46	65	16	46
Glyphosate plus trifloxysulfuron	LPOST	70 (66)	86 (79)	69 (74)	83 (94)
LSD (0.05)		13	15	15	14

[a] Means within parentheses are expected control values of the adjacent observed control; expected values were calculated as described by Colby (1967). Interactions were considered significant if differences between observed and expected control exceeded the appropriate LSD value.

[b] The potassium salt formulation of glyphosate (840 g ae/ha) was applied for all glyphosate treatments, and 5 g ai/ha trifloxysulfuron was applied for all trifloxysulfuron treatments.

[c] EPOST, early postemergence; LPOST, late postemergence.

pitted morningglory and hemp sesbania was 18 to 22 percentage points higher (additive) with 840 g/ha glyphosate plus 5 g/ha trifloxysulfuron compared with glyphosate alone.

Cotton injury was the highest at the EPOST timing (Table 2) when cotton was in the two-leaf growth stage. Herbicide rate had no effect on cotton injury at the EPOST timing; however, injury with 5 g/ha trifloxysulfuron (20%) was higher compared with 840 g/ha glyphosate (10%). Mixing trifloxysulfuron with glyphosate had no effect on cotton injury at the EPOST growth stage (15 and 20%) when compared with trifloxysulfuron (13 and 20%) or glyphosate alone (8 and 10%). Cotton injury at the LPOST growth stage was no more than 5% with all treatments. Schraer et al. (2003) also documented more cotton injury (>25%) with trifloxysulfuron applied POT of four-leaf or smaller cotton compared with <15% injury to five- to eight-leaf cotton. Richardson et al. (2004a) also reported mixtures of trifloxysulfuron and glyphosate did not injury GRC cotton more than did trifloxysulfuron alone.

Weed Control Field Study. There was no treatment by location interaction; thus, data were averaged over Stoneville and Shorter locations. Weed control was better with glyphosate than trifloxysulfuron for all species except pitted morningglory and hemp sesbania (Tables 3 and 4). Glyphosate controlled sicklepod, prickly sida, barnyardgrass, and johnsongrass 96 to 100% at the EPOST application timing and 88 to 98% at the LPOST

Table 4. Control of two- to three-leaf (EPOST) and four- to five-leaf (LPOST) prickly sida, barnyardgrass, and seedling johnsongrass 2 wk after glyphosate and trifloxysulfuron were applied alone and in combination in field experiments at Stoneville, MS, and Shorter, AL.

		Control[a]		
Herbicide[b]	Application timing[c]	Prickly sida	Barnyardgrass	Seedling johnsongrass
		%		
No herbicide		0	0	0
Glyphosate	EPOST	99	99	100
Trifloxysulfuron	EPOST	20	60	78
Glyphosate plus trifloxysulfuron	EPOST	99 (99)	100 (99)	99 (99)
LSD (0.05)		6	2	5
Glyphosate	LPOST	95	93	98
Trifloxysulfuron	LPOST	14	10	81
Glyphosate plus trifloxysulfuron	LPOST	92 (96)	84 (94)	98 (99)
LSD (0.05)		7	11	4

[a] Means within parentheses are expected control values of the adjacent observed control; expected values were calculated as described by Colby (1967). Interactions were considered significant if differences between observed and expected control exceeded the appropriate LSD value.

[b] The potassium salt formulation of glyphosate (840 g ae/ha) was applied for all glyphosate treatments, and 5 g ai/ha trifloxysulfuron was applied for all trifloxysulfuron treatments.

[c] EPOST, early postemergence; LPOST, late postemergence.

Table 5. Cotton injury, fruiting characterization, number of nodes, and yield of glyphosate-resistant cotton as affected by glyphosate and trifloxysulfuron applied alone and in combination over-the-top and PD to cotton in field experiments at Stoneville, MS, and Shorter, AL.[a]

		Visual injury		Fruiting characterization			
Herbicide[b]	Application timing[c]	1 WAT	2 WAT	Open bolls	Closed bolls	Number of nodes	Cotton lint yield
		%		No/plant		No/plant[d]	kg/ha
Weed-free check		0	0	8	1	18	1,610
Glyphosate	EPOST-POT	2	8	8	1	18	1,630
Trifloxysulfuron	EPOST-POT	10	9	8	1	18	1,640
Glyphosate plus trifloxysulfuron	EPOST-POT	15	12	8	1	19	1,600
Glyphosate	MPOST-PD	0	1	8	1	18	1,610
Trifloxysulfuron	MPOST-PD	0	0	8	1	18	1,660
Glyphosate plus trifloxysulfuron	MPOST-PD	0	1	8	1	18	1,530
Trifloxysulfuron	MPOST-POT	2	3	8	2	18	1,570
Trifloxysulfuron	MPOST fb LPOST-POT	12	7	8	1	18	1,430
LSD (0.05)		8	5	NS	NS	NS	130

[a] Abbreviations: EPOST, early postemergence; MPOST, midpostemergence; LPOST, late postemergence; PD, postemergence-directed; POT, postemergence over-the-top; NS, not significant; fb, followed by; WAT, weeks after treatment.

[b] The potassium salt formulation of glyphosate (840 g ae/ha) was applied for all glyphosate treatments, and 5 g ai/ha trifloxysulfuron was applied for all trifloxysulfuron treatments.

[c] EPOST treatments were applied to three-leaf cotton, MPOST treatments were applied to six-leaf cotton, and LPOST treatment was applied to nine-leaf cotton.

[d] Number of nodes between cotyledon scars and plant terminal at harvest.

timing. Trifloxysulfuron controlled these four species 20 to 78% at EPOST and 10 to 81% at LPOST. Trifloxysulfuron had little activity on prickly sida, with 20 and 14% control at EPOST and LPOST timings, respectively. Control of pitted morningglory, hemp sesbania, and velvetleaf with glyphosate was 36 to 79% regardless of application timing. Pitted morningglory and velvetleaf control with trifloxysulfuron was 16 to 60% across both application timings. Trifloxysulfuron controlled hemp sesbania 88% at the EPOST timing; however, control decreased to 65% by the LPOST timing.

The addition of trifloxysulfuron to glyphosate did not synergize or antagonize control of any weed species when compared with glyphosate alone (Tables 3 and 4). However, control of pitted morningglory and hemp sesbania was improved, additively, when trifloxysulfuron was added to glyphosate compared with glyphosate alone. The addition of trifloxysulfuron to glyphosate controlled pitted morningglory and hemp sesbania 95 and 99% at EPOST compared with 72 and 42% control with glyphosate alone. Pitted morningglory and hemp sesbania control decreased to 70 and 86% with trifloxysulfuron plus glyphosate by the LPOST application timing. However, mixing the two herbicides controlled these two species better than glyphosate alone (36 and 39%). Others have also found that mixing trifloxysulfuron with glyphosate improves control of certain broadleaf weeds compared with glyphosate alone. Barber et al. (2002) as well as Branson et al. (2004) reported that the addition of trifloxysulfuron to glyphosate controlled pitted morningglory more effectively than glyphosate alone.

Cotton Tolerance Field Study. There was no treatment by location interaction; thus, data were averaged over Stoneville and Shorter locations. Single applications of trifloxysulfuron or glyphosate plus trifloxysulfuron POT of three-leaf cotton (EPOST) or sequential applications of trifloxysulfuron POT of six-leaf fb nine-leaf cotton (MPOST fb LPOST) resulted in 10 to 15% cotton injury compared with 0 to 2% with all other treatments by 1 WAT (Table 5). Cotton injury at 2 WAT was less than 13% for all herbicide treatments. Injury by 3 WAT was less than 5% for all treatments (data not shown). Cotton injury was characterized by chlorosis and stunting, which is typical for ALS-inhibiting herbicides. Porterfield et al. (2002b) also reported limited transient injury (<16%) in seven cotton cultivars treated with trifloxysulfuron at 7.5 and 15 g/ha.

The number of open and unopened bolls and number of nodes per plant at cotton harvest was not different across all herbicide treatments (Table 5). Seed cotton yield ranged from 1,430 to 1,660 kg/ha among all treatments. Only the sequential POT trifloxysulfuron treatment reduced cotton yield compared with weed-free control. No reduction in cotton lint yields after POT applications of trifloxysulfuron has also been reported previously (Porterfield et al. 2002a, 2002b, 2003; Richardson et al. 2004b).

These results suggest that glyphosate alone controlled barnyardgrass, browntop millet, prickly sida, seedling johnsongrass, sicklepod, and velvetleaf more effectively than trifloxysulfuron alone. Control of pitted morningglory and hemp sesbania with glyphosate was dependent on plant size at time of application. Addition of trifloxysulfuron to glyphosate did not antagonize control of any weed species and was additive for control of pitted morningglory and hemp sesbania compared with glyphosate alone. Cotton injury from trifloxysulfuron alone or in combination with glyphosate was less than 21% at 1 WAT, and the injury was transient, with less than 5% observed by 3 WAT in field studies. Herbicide treatments evaluated had no effect on fruit development, fruit opening, or number of nodes per plant. Single and mixture POT and PD applications of glyphosate and trifloxysulfuron to cotton had no effect on cotton yield, and only sequential over-the-top applications of trifloxysulfuron reduced cotton yield. Trifloxysulfuron rates evaluated in this research were similar to registered rates for POST applications (Syngenta 2004b).

On the basis of these data, addition of trifloxysulfuron to glyphosate can provide improved control of pitted morningglory and hemp sesbania in GRC with little or no long-term cotton injury when applied in a postdirected or layby application setting. Others have repeatedly observed no severe injury to nontransgenic and transgenic cotton after POST applications of trifloxysulfuron (Barber et al. 2002; Schraer et al. 2002). However, over-the-top applications of glyphosate plus trifloxysulfuron have been reported to injure GRC more severely than the two herbicides applied alone in a grower's field in Mississippi (C. H. Koger, unpublished data) and in several small plot experiments in North Carolina (J. Wilcut, personal communication). The physiological behavior of cotton to mixtures of glyphosate and trifloxysulfuron under varying environmental conditions is currently under investigation.

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