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Weed Control and Economic Comparisons of Glyphosate-Resistant, Sulfonylurea-Tolerant, and Conventional Soybean (*Glycine max*) Systems[1]

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Abstract: A field study was conducted over 2 yr to compare efficacy and economics of glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean (*Glycine max*) weed control programs. Herbicide programs in the three soybean systems provided at least 90% control of browntop millet (*Brachiaria ramosa*), prickly sida (*Sida spinosa*), yellow nutsedge (*Cyperus esculentus*), pitted morningglory (*Ipomoea lacunosa*), and hemp sesbania (*Sesbania exaltata*) in most cases and postemergence (POST)-only programs were as effective as preemergence (PRE) followed by POST programs. Control of hyssop spurge (*Euphorbia hyssopifolia*) ranged from 93 to 100% in glyphosate-resistant soybean and from 88 to 100% in conventional soybean, but control was 60 to 100% in sulfonylurea-tolerant soybean. Sicklepod (*Senna obtusifolia*) control was at least 91% in glyphosate-resistant and sulfonylurea-tolerant soybean but was 81% for the standard SAN 582 plus imazaquin PRE and acifluorfen plus bentazon early POST treatment in conventional soybean. In glyphosate-resistant soybean, glyphosate applied sequentially resulted in an average yield of 3,020 kg/ha with a net return of $407/ha. In sulfonylurea-tolerant soybean, chlorimuron applied sequentially yielded 2,500 kg/ha with a net return of $271/ha. Conventional soybean yield with the standard herbicide program was 2,770 kg/ha with a net return of $317/ha. Yields for the cultivars were equivalent when the same standard herbicide program was used. When weed control is satisfactory and herbicide costs relatively comparable, yield potential of the cultivar and seed cost, including any technology fee, would be key factors in selecting a weed management system.

Nomenclature: Acifluorfen, 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid; bentazon, 3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide; chlorimuron, 2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid; glyphosate, *N*-(phosphonomethyl) glycine; imazaquin, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imadazol-2-yl]-3-quinolinecarboxylic acid; SAN 582 (proposed common name, dimethenamid), 2-chloro-*N*-(2,4-dimethyl-3-thienyl)-*N*-(2-methoxy-1-methylethyl)acetamide; browntop millet, *Brachiaria ramosa* (L.) Stapf #[3] PANRA; hemp sesbania, *Sesbania exaltata* (Raf.) Rydb. *ex* A.W. Hill # SEBEX; hyssop spurge, *Euphorbia hyssopifolia* L. # EPHHS; pitted morningglory, *Ipomoea lacunosa* L. # IPOLA; prickly sida, *Sida spinosa* L. # SIDSP; sicklepod, *Senna obtusifolia* (L.) Irwin and Barneby # CASOB; yellow nutsedge, *Cyperus esculentus* L. # CYPES; soybean, *Glycine max* (L.) Merr. 'DP 5806 RR,' 'DP 3571 S,' 'DP 3588.'

Additional index words: CASOB, CYPES, EPHHS, IPOLA, PANRA, SEBEX, SIDSP.

Abbreviations: EPOST, early postemergence; fb, followed by; LPOST, late postemergence; POST, postemergence; PRE, preemergence; WAP, weeks after planting.

INTRODUCTION

Transgenic soybean (*Glycine max*) resistant to glyphosate (Padgette et al. 1995, 1996) provides producers the flexibility to control a broad spectrum of weeds with minimal concern for crop damage (Askew et al. 1998; Ateh and Harvey 1999; Gonzini et al. 1999; McKinley et al. 1999; Scott et al. 1998). Use of glyphosate-resistant soybean offers an option for postemergence (POST) control of both broadleaf and grass weeds with glyphosate (Ateh and Harvey 1999; Nelson and Renner 1999; Reddy 1998; Smith et al. 1998; Webster et al. 1999). Use of a single broad-spectrum herbicide such as glyphosate would eliminate the concern over possible antagonism

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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.

associated with tank mixing grass and broadleaf herbicides. Vidrine et al. (1995) reported that broadleaf herbicides applied in mixtures were antagonistic toward the activity of certain graminicides. Chlorimuron applied POST is commonly used in soybean to control broadleaf weeds (Claus 1987; Monks et al. 1993; Vidrine et al. 1993). Chlorimuron, however, does not effectively control common lambsquarters (*Chenopodium album* L.) (Monks et al. 1993) and prickly sida (*Sida spinosa*) (Vidrine et al. 1993; Wesley and Shaw 1992). Sulfonylurea-tolerant soybean attained through seed mutagenesis has increased tolerance for chlorimuron and other sulfonylurea herbicides due to the insensitive acetolactate synthase enzyme (Sebastian et al. 1989). With the introduction of sulfonylurea-tolerant soybean, single or multiple applications of chlorimuron alone or in combination with other sulfonylurea herbicides, as well as applications of certain imidazolinone and sulfonylurea herbicides alone or in combination, can improve season-long weed control and reduce soybean injury (Culpepper et al. 1997; Moshier and Freed 1997; Simpson and Stoller 1995). The spectrum of weed control can potentially be increased by combining conventional soil-applied programs with one or two POST applications of chlorimuron at higher rates. Weeds can be controlled with POST-only programs in glyphosate-resistant (Ateh and Harvey 1999; Gonzini et al. 1999; McKinley et al. 1999; Nelson and Renner 1999) and sulfonylurea-tolerant soybean (Culpepper et al. 1997; Simpson and Stoller 1995), offering flexibility to treat weeds on an as-needed basis.

The necessity of preemergence (PRE) herbicides to supplement POST-only programs in glyphosate-resistant soybean to maximize weed control, crop yield, and economic return has not been fully investigated. One or two applications of glyphosate can control a broad spectrum of weeds comparable to PRE herbicides followed by (fb) glyphosate (Gonzini et al. 1999; Miller et al. 1997; Reddy 1998). In most situations, PRE herbicides were not necessary to supplement total POST programs in glyphosate-resistant soybean for control of common weeds. However, improved weed control and soybean yield were achieved by tank-mixing SAN 582 with glyphosate compared with glyphosate only (Scott et al. 1998).

Soybean producers employ a wide range of weed management practices and strategies. A switch to an herbicide-resistant cultivar will be made only if there is a clear advantage or benefit, such as reduced cost for weed management, improved efficacy on hard-to-control weeds, or increased net returns. Use of any herbicide technology that includes a fee with the seed purchase must provide an economic benefit over traditional technologies (Reddy et al. 1999). In contrast to glyphosate-resistant soybean, there is no additional technology fee associated with sulfonylurea-tolerant soybean.

During the past 5 yr, research has generated information on glyphosate-resistant weed control programs. However, information on sulfonylurea-tolerant soybean weed control programs and side-by-side comparisons of glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean weed control programs is lacking. The cost of weed control varies considerably depending on the weed control program employed. This study examines efficacy and economics of glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean weed control programs.

MATERIALS AND METHODS

Studies were conducted in 1997 and 1998 at the Southern Weed Science Research farm, Stoneville, MS (33°N latitude) on a Dundee silt loam (fine-silty, mixed, thermic Aeric Ochraqualf) soil with pH 6.4 and 1.6% organic matter. The experimental area was naturally infested with browntop millet (*Brachiaria ramosa*, 24 plants/m^2), hemp sesbania (*Sesbania exaltata*, 9 plants/m^2), hyssop spurge (*Euphorbia hyssopifolia*, 4 plants/m^2), pitted morningglory (*Ipomoea lacunosa*, 1 plant/m^2), prickly sida (2 plants/m^2), sicklepod (*Senna obtusifolia*, 2 plants/m^2), and yellow nutsedge (*Cyperus esculentus*, 4 plants/m^2). Weed densities were determined in nontreated control plots from two 0.84-m^2 areas at the time of late POST (LPOST) application in both years. Weed densities represent means of both years (except sicklepod) averaged across three soybean weed control programs. Glyphosate-resistant (DP 5806 RR), sulfonylurea-tolerant (DP 3571 S), and conventional (DP 3588) soybean cultivars were used. The three determinant varieties evaluated were highly adaptive to the Mississippi Delta and belonged to the late V maturity group. Experimental plots consisted of eight rows 50 cm apart and 7.5 m long. A randomized complete block experimental design with four replications was used. Soybean was not irrigated in 1997, but in 1998 because of hot and dry weather, soybean was irrigated on August 12 and August 27.

Soybeans were planted June 5, 1997, and May 5, 1998. Planting was delayed in 1997 due to rainfall. Preemergence herbicides were applied immediately after planting. Early POST (EPOST) and LPOST treatments were applied 2 and 4 wk after planting (WAP), respectively, in 1997 and 4 and 6 WAP, respectively, in 1998.

Poor establishment of weeds during a 3-wk dry period after planting followed by a week of wet conditions delayed EPOST applications in 1998. Herbicide treatments were applied with a tractor-mounted sprayer with 8004 flat fan spray tips[4] delivering 187 L/ha water at 179 kPa. A nonionic surfactant[5] at 0.25% (v/v) was added to all POST treatments except glyphosate.

The glyphosate-resistant soybean weed control treatments included: glyphosate EPOST at 1.12 kg ai/ha fb LPOST at 0.56 kg ai/ha; SAN 582 PRE at 1.31 kg ai/ha or imazaquin PRE at 0.14 kg ai/ha fb glyphosate EPOST at 1.12 kg ai/ha; SAN 582 PRE at 1.22 kg ai/ha plus imazaquin PRE at 0.14 kg ai/ha fb glyphosate EPOST at 1.12 kg ai/ha or acifluorfen plus bentazon (EPOST at 0.28 + 0.56 kg ai/ha); and glyphosate EPOST at 1.12 kg ai/ha fb chlorimuron LPOST at 0.011 kg ai/ha (Table 1). For the sulfonylurea-tolerant soybean, treatments included: chlorimuron EPOST at 0.022 kg ai/ha fb LPOST at 0.022 kg ai/ha; sulfentrazone {*N*-[2,4-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1*H*-1,2,4-triazol-1-yl]phenyl]methanesulfonamide} PRE at 0.211 kg ai/ha plus chlorimuron PRE at 0.043 kg ai/ha fb chlorimuron EPOST at 0.011 kg ai/ha; SAN 582 PRE at 1.31 kg ai/ha or imazaquin PRE at 0.14 kg ai/ha fb chlorimuron EPOST at 0.022 kg ai/ha; and SAN 582 PRE at 1.22 kg ai/ha plus imazaquin PRE at 0.14 kg ai/ha fb chlorimuron EPOST at 0.022 kg ai/ha or acifluorfen plus bentazon (EPOST at 0.28 ; pl 0.56 kg ai/ha). The conventional soybean treatments included: SAN 582 PRE at 1.22 kg ai/ha plus imazaquin PRE at 0.14 kg ai/ha fb acifluorfen plus bentazon (EPOST at 0.28 + 0.56 kg ai/ha) and sulfentrazone PRE at 0.211 kg ai/ha plus chlorimuron PRE at 0.043 kg ai/ha fb chlorimuron EPOST at 0.011 kg ai/ha. A nontreated control was included for each soybean system. A conventional soil-applied standard of SAN 582 plus imazaquin fb acifluorfen plus bentazon POST at the previously listed rates was included to compare yield potential of three soybean cultivars.

Estimated costs of production were determined for each weed management program using budgets compiled by the Mississippi Agricultural and Forestry Experiment Station (Anonymous 1997, 1998). Land preparation and planting costs of $75.30/ha in 1997 and $74.88/ha in 1998 were identical for all treatments. Costs directly associated with each treatment included seeds, herbicides, adjuvants, and application costs. A technology fee was assessed for glyphosate-resistant soybean. Average seed price in 1997 and 1998 was $61.88/ha for DP 5806 RR (including technology fee) and $39.38/ha for both DP

[4] TeeJet flat fan spray tips. Spraying Systems Co., North Avenue and Schmale Road, Wheaton, IL 60189.

[5] Induce® nonionic low foam wetter/spreader adjuvant contains 90% nonionic surfactant (alkylarylpolyoxyalkane ether and isopropanol), free fatty acids, and 10% water. Helena Chemical Co., Suite 500, 6075 Poplar Avenue, Memphis, TN 38137.

Table 1. Seed, herbicide, adjuvant, and application cost for various glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean weed control programs in 1997 and 1998.[a]

Soybean cultivar	Herbicide treatment[b]	Rate	Application timing[c]	Seed, herbicide, adjuvant, and application cost[d] 1997	1998
		kg ai/ha		$/ha	
DP 5806 RR	No herbicide	—	—	61.16	61.16
	Glyphosate	1.12	EPOST	127.85	127.85
		0.56	LPOST		
	SAN 582	1.31	PRE	151.05	149.30
	Glyphosate	1.12	EPOST		
	Imazaquin	0.14	PRE	156.69	137.68
	Glyphosate	1.12	EPOST		
	SAN 582	1.22	PRE	192.79	182.29
	Imazaquin	0.14	PRE		
	Glyphosate	1.12	EPOST		
	SAN 582	1.22	PRE	195.36	184.86
	Imazaquin	0.14	PRE		
	Acifluorfen	0.28	EPOST		
	Bentazon	0.56	EPOST		
	Glyphosate	1.12	EPOST	141.34	129.73
	Chlorimuron	0.011	LPOST		
DP 3571 S	No herbicide	—	—	38.92	38.92
	Chlorimuron	0.022	EPOST	171.07	124.76
		0.022	LPOST		
	Sulfentrazone	0.211	PRE	121.10	109.49
	Chlorimuron	0.043	PRE		
	Chlorimuron	0.011	EPOST		
	SAN 582	1.31	PRE	153.72	128.81
	Chlorimuron	0.022	EPOST		
	Imazaquin	0.14	PRE	159.35	117.20
	Chlorimuron	0.022	EPOST		
	SAN 582	1.22	PRE	195.45	161.80
	Imazaquin	0.14	PRE		
	Chlorimuron	0.022	EPOST		
	SAN 582	1.22	PRE	173.12	162.62
	Imazaquin	0.14	PRE		
	Acifluorfen	0.28	EPOST		
	Bentazon	0.56	EPOST		
DP 3588	No herbicide	—	—	38.92	38.92
	SAN 582	1.22	PRE	173.12	162.62
	Imazaquin	0.14	PRE		
	Acifluorfen	0.28	EPOST		
	Bentazon	0.56	EPOST		
	Sulfentrazone	0.211	PRE	121.10	109.49
	Chlorimuron	0.043	PRE		
	Chlorimuron	0.011	EPOST		

[a] Glyphosate-resistant program used soybean cultivar DP 5806 RR (Roundup Ready); sulfonylurea-tolerant program used soybean cultivar DP 3571 S; and conventional program used soybean cultivar DP 3588.

[b] A nonionic surfactant at 0.25% (v/v) was added to all postemergence treatments except glyphosate.

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

[d] Herbicide and adjuvant prices were based on retail quotes from local suppliers.

Table 2. Browntop millet, prickly sida, pitted morningglory, hyssop spurge, and sicklepod control 4 wk after late postemergence herbicide application in glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean weed control programs in 1997 and 1998.[a]

Soybean cultivar	Herbicide treatment	Rate	Application timing[b]	Browntop millet		Prickly sida		Pitted morningglory		Hyssop spurge		Sicklepod[c]
				1997	1998	1997	1998	1997	1998	1997	1998	1998
		kg ai/ha		%								
DP 5806 RR	No herbicide	—	—	0	0	0	0	0	0	0	0	0
	Glyphosate	1.12	EPOST	100	100	100	100	100	100	98	100	100
		0.56	LPOST									
	SAN 582	1.31	PRE	100	100	100	100	100	100	100	100	100
	Glyphosate	1.12	EPOST									
	Imazaquin	0.14	PRE	98	100	100	100	100	100	100	100	100
	Glyphosate	1.12	EPOST									
	SAN 582	1.22	PRE	100	100	100	100	100	100	100	100	100
	Imazaquin	0.14	PRE									
	Glyphosate	1.12	EPOST									
	SAN 582	1.22	PRE	100	98	98	100	98	90	93	100	90
	Imazaquin	0.14	PRE									
	Acifluorfen	0.28	EPOST									
	Bentazon	0.56	EPOST									
	Glyphosate	1.12	EPOST	96	100	100	100	100	100	98	100	100
	Chlorimuron	0.011	LPOST									
DP 3571 S	No herbicide	—	—	0	0	0	0	0	0	0	0	
	Chlorimuron	0.022	EPOST	96	65	100	100	93	80	100	100	
		0.022	LPOST									
	Sulfentrazone	0.211	PRE	99	94	99	100	100	100	100	100	96
	Chlorimuron	0.043	PRE									
	Chlorimuron	0.011	EPOST									
	SAN 582	1.31	PRE	98	90	75	100	85	91	60	99	100
	Chlorimuron	0.022	EPOST									
	Imazaquin	0.14	PRE	98	79	100	100	100	90	65	94	100
	Chlorimuron	0.022	EPOST									
	SAN 582	1.22	PRE	100	96	100	100	98	95	63	98	100
	Imazaquin	0.14	PRE									
	Chlorimuron	0.022	EPOST									
	SAN 582	1.22	PRE	100	98	100	100	100	95	86	100	93
	Imazaquin	0.14	PRE									
	Acifluorfen	0.28	EPOST									
	Bentazon	0.56	EPOST									
DP 3588	No herbicide	—	—	0	0	0	0	0	0	0	0	0
	SAN 582	1.22	PRE	98	100	100	100	100	98	88	100	81
	Imazaquin	0.14	PRE									
	Acifluorfen	0.28	EPOST									
	Bentazon	0.56	EPOST									
	Sulfentrazone	0.211	PRE	100	99	99	99	100	98	98	100	91
	Chlorimuron	0.043	PRE									
	Chlorimuron	0.011	EPOST									
LSD (0.05)[d]				7		5		6		10		8

[a] Glyphosate-resistant program used soybean cultivar DP 5806 RR (Roundup Ready); sulfonylurea-tolerant program used soybean cultivar DP 3571 S; and conventional program used soybean cultivar DP 3588.

[b] PRE, preemergence; EPOST, early postemergence; LPOST, late postemergence.

[c] Data for 1998 only.

[d] LSD for comparing year by weed control program interaction means within each weed species except sicklepod.

3571 S and DP 3588. Herbicide and adjuvant price was obtained from major suppliers in the region. Herbicide application cost of $10.00/ha was charged for each PRE, EPOST, or LPOST application. Harvest and hauling charges of $64.00/ha in 1997 and $64.02/ha in 1998 were identical for all treatments. Average cost of weed control programs (seed, herbicide, adjuvant, and application costs) is shown in Table 1. Gross income was calculated for each treatment using an average soybean price of $0.25/kg in 1997 and $0.20/kg in 1998. Net return to land and management was determined by subtracting the estimated costs of production from gross income for each weed management program (Ghosheh and Chandler 1998; Johnson et al. 1997).

Control of individual weed species was estimated visually on a scale of 0 (no weed control) to 100% (complete weed control) at 4 wk after LPOST application. Soybean was harvested using a combine and grain yield was adjusted to 13% moisture. Weed control data were subjected to arcsine square root transformations. However, interpretations were not different from untransformed data; therefore, untransformed data are presented. The no-herbicide treatment (nontreated check) for each cultivar was deleted from the statistical analysis of weed control data. Weed control, soybean yield, and net return data were subjected to analysis of variance, and means were separated at the 5% level of significance by Fisher's protected LSD test. Data were averaged across years where appropriate and presented for each year when interactions occurred.

RESULTS AND DISCUSSION

Weed Management. All herbicide programs provided at least 96% control of browntop millet regardless of soybean system in 1997 (Table 2). In 1998, control of browntop millet was at least 90% with the exception of imazaquin PRE fb chlorimuron EPOST (79%) in sulfonylurea-tolerant soybean. Prickly sida control among the three soybean weed control programs was at least 98% in both years except for the sequential chlorimuron POST treatment (65%) and SAN 582 PRE fb chlorimuron EPOST (75%) in 1997 (Table 2). Control of pitted morningglory was at least 90% in all herbicide programs regardless of soybean system in both years, with the exception of SAN 582 PRE fb chlorimuron (EPOST) in 1997 (Table 2). Control of hyssop spurge ranged from 93 to 100% and 88 to 100% in glyphosate-resistant and conventional soybean weed control programs, respectively, in both years (Table 2). However, in sulfonylurea-tolerant soybean, control of hyssop spurge was 60 to 100%. In 1997, sulfentrazone plus chlorimuron PRE fb chlorimuron EPOST provided complete hyssop spurge control compared to 63 to 86% control with other herbicides. However, in 1998, control was at least 94% for all herbicide programs. All herbicide programs provided at least 96% sicklepod control with the exception of SAN 582 plus imazaquin PRE fb acifluorfen plus bentazon EPOST in the glyphosate-resistant (90%), sulfonylurea-tolerant (93%), and conventional (81%) soybean weed control programs and sulfentrazone plus chlorimuron PRE fb chlorimuron EPOST in the conventional soybean weed control program (91%) (Table 2). Control of yellow nutsedge and hemp sesbania averaged across years was at least 93% regardless of soybean systems (Table 3).

In glyphosate-resistant soybean, POST-only programs consisting of glyphosate sequential applications and glyphosate EPOST fb chlorimuron LPOST provided at least 96% control of all weeds in both years, which was equal to all other PRE fb glyphosate EPOST programs (Tables 2 and 3). Other researchers have reported little or no

Table 3. Yellow nutsedge and hemp sesbania control 4 wk after late postemergence herbicide application in glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean weed control programs.[a]

Soybean cultivar	Herbicide treatment	Rate	Application timing[b]	Control[c] Yellow nutsedge	Control[c] Hemp sesbania
		kg ai/ha		%	%
DP 5806 RR	No herbicide	—	—	0	0
	Glyphosate	1.12 0.56	EPOST LPOST	100 a	99 ab
	SAN 582 Glyphosate	1.31 1.12	PRE EPOST	99 ab	99 a
	Imazaquin Glyphosate	0.14 1.12	PRE EPOST	96 ab	98 ab
	SAN 582 Imazaquin Glyphosate	1.22 0.14 1.12	PRE PRE EPOST	99 ab	98 ab
	SAN 582 Imazaquin Acifluorfen Bentazon	1.22 0.14 0.28 0.56	PRE PRE EPOST EPOST	100 a	98 ab
	Glyphosate Chlorimuron	1.12 0.011	EPOST LPOST	98 ab	98 ab
DP 3571S	No herbicide	—	—	0	0
	Chlorimuron	0.022 0.022	EPOST LPOST	100 a	99 a
	Sulfentrazone Chlorimuron Chlorimuron	0.211 0.043 0.011	PRE PRE EPOST	96 ab	98 ab
	SAN 582 Chlorimuron	1.31 0.022	PRE EPOST	96 ab	98 ab
	Imazaquin Chlorimuron	0.14 0.022	PRE EPOST	99 ab	95 bc
	SAN 582 Imazaquin Chlorimuron	1.22 0.14 0.022	PRE PRE EPOST	95 b	93 c
	SAN 582 Imazaquin Acifluorfen Bentazon	1.22 0.14 0.28 0.56	PRE PRE EPOST EPOST	98 ab	98 ab
DP 3588	No herbicide	—	—	0	0
	SAN 582 Imazaquin Acifluorfen Bentazon	1.22 0.14 0.28 0.56	PRE PRE EPOST EPOST	96 ab	97 ab
	Sulfentrazone Chlorimuron Chlorimuron	0.211 0.043 0.011	PRE PRE EPOST	100 a	98 ab

[a] Glyphosate-resistant program used soybean cultivar DP 5806 RR (Roundup Ready); sulfonylurea-tolerant program used soybean cultivar DP 3571 S; and conventional program used soybean cultivar DP 3588.

[b] PRE, preemergence; EPOST, early postemergence; LPOST, late postemergence.

[c] Means within each column followed by the same letter are not significantly different at the 5% level as determined by Fisher's protected LSD test. Data represent an average across years.

benefit to PRE herbicides in glyphosate-resistant soybean systems (Gonzini et al. 1999; Miller et al. 1997; Reddy 1998; Roberts et al. 1999). In conventional soybean, both herbicide programs provided at least 91% control of all weeds evaluated except for hyssop spurge in 1997 and sicklepod, indicating the effectiveness of nonglyphosate programs. In sulfonylurea-tolerant soybean, two applications of chlorimuron controlled at least 93% of all weeds studied in both years, with the exception of prickly sida (65%) and hyssop spurge (80%) in 1997. Compared with a glyphosate program, addition of PRE herbicides or tank mix partners with chlorimuron may be necessary to improve control of certain weeds. Control of hyssop spurge, pitted morningglory, and prickly sida was 99 to 100% when chlorimuron EPOST followed sulfentrazone plus chlorimuron PRE. Morningglory (*Ipomoea* spp.) control was improved when chlorimuron was applied POST in combination with thifensulfuron {3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid} in sulfonylurea-tolerant soybean (Culpepper et al. 1997). Thifensulfuron in combination with imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid} improved control of common lambsquarters, velvetleaf (*Abutilon theophrasti* Medicus), and morningglory over that of the herbicide applied alone in sulfonylurea-tolerant soybean (Simpson and Stoller 1995).

Soybean Yield. In glyphosate-resistant soybean, there were no differences in soybean yield among herbicide programs, whether glyphosate was applied alone or following PRE herbicides (Table 4). Soybean yield with two applications of glyphosate averaged 3,020 kg/ha. For the glyphosate treatments, yields were at least 31% greater than the nontreated (no herbicide) control. In sulfonylurea-tolerant soybean, soybean yields were equivalent for the herbicide programs regardless of whether chlorimuron was applied alone or following PRE herbicides. Chlorimuron sequential applications yielded 2,500 kg/ha and yield was 25% greater than the nontreated control. In conventional soybean, the conventional herbicide program of SAN 582 plus imazaquin PRE fb acifluorfen plus bentazon EPOST yielded 2,770 kg/ha, 32% greater than the nontreated control.

Yield potential of glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean cultivars used in the study was the same as evidenced by yields obtained with a standard conventional herbicide program of SAN 582 plus imazaquin PRE fb acifluorfen plus bentazon EPOST (Table 4). There were no differences in plant populations among three varieties (data not shown), and soybean population averaged 230,000 plants/ha. Mean plant height at harvest was 68 cm in DP 5806 RR, 91 cm in DP 3571 S, and 90 cm in DP 3588. Visible injury of 15% was noted where chlorimuron was applied POST

Table 4. Soybean yield and net return in various glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean weed control programs.[a]

Soybean cultivar	Herbicide treatment	Rate	Application timing[b]	Soybean yield[c]	Net return[c,d]
		kg ai/ha		kg/ha	$/ha
DP 5806 RR	No herbicide	—	—	2,180 cd	277 c–f
	Glyphosate	1.12 0.56	EPOST LPOST	3,020 a	407 ab
	SAN 582 Glyphosate	1.31 1.12	PRE EPOST	2,880 ab	356 a–d
	Imazaquin Glyphosate	0.14 1.12	PRE EPOST	2,850 ab	354 a–d
	SAN 582 Imazaquin Glyphosate	1.22 0.14 1.12	PRE PRE EPOST	3,000 a	339 a–e
	SAN 582[e] Imazaquin Acifluorfen Bentazon	1.22 0.14 0.28 0.56	PRE PRE EPOST EPOST	2,810 ab	304 c–f
	Glyphosate Chlorimuron	1.12 0.011	EPOST LPOST	3,080 a	415 a
DP 3571 S	No herbicide	—	—	2,000 d	261 ef
	Chlorimuron	0.022 0.022	EPOST LPOST	2,500 bc	271 d–f
	Sulfentrazone Chlorimuron Chlorimuron	0.211 0.043 0.011	PRE PRE EPOST	2,740 ab	363 a–c
	SAN 582 Chlorimuron	1.31 0.022	PRE EPOST	2,600 b	302 c–f
	Imazaquin Chlorimuron	0.14 0.022	PRE EPOST	2,560 b	299 c–f
	SAN 582 Imazaquin Chlorimuron	1.22 0.14 0.022	PRE PRE EPOST	2,540 bc	253 f
	SAN 582[e] Imazaquin Acifluorfen Bentazon	1.22 0.14 0.28 0.56	PRE PRE EPOST EPOST	2,780 ab	315 c–f
DP 3588	No herbicide	—	—	2,100 d	291 c–f
	SAN 582[e] Imazaquin Acifluorfen Bentazon	1.22 0.14 0.28 0.56	PRE PRE EPOST EPOST	2,770 ab	317 c–f
	Sulfentrazone Chlorimuron Chlorimuron	0.211 0.043 0.011	PRE PRE EPOST	2,610 b	329 b–f

[a] Glyphosate-resistant program used soybean cultivar DP 5806 RR (Roundup Ready); sulfonylurea-tolerant program used soybean cultivar DP 3571 S; and conventional program used soybean cultivar DP 3588.

[b] PRE, preemergence; EPOST, early postemergence; LPOST, late postemergence.

[c] Means within each column followed by the same letter are not significantly different at the 5% level as determined by Fisher's protected LSD test. Data represent an average across years.

[d] Net return was calculated by subtracting variable costs from gross income.

[e] Standard treatment included to allow comparison of yield potential of the three cultivars.

in DP 5806 RR, but soybean recovery was rapid (data not shown).

Economic Analysis. In glyphosate-resistant soybean, seed, herbicide, adjuvant, and application costs for the sequential treatment of glyphosate ($128/ha) or glyphosate EPOST fb chlorimuron LPOST ($130/ha) in 1998 was less than PRE herbicides fb glyphosate EPOST ($138 to $182/ha) (Table 1). In sulfonylurea-tolerant soybean, total cost in 1998 for sulfentrazone plus chlorimuron PRE fb chlorimuron EPOST was $109/ha compared with $125/ha for sequential applications of chlorimuron. In conventional soybean, total cost of a standard PRE fb EPOST herbicide program was $163/ha in 1998. Overall in 1998, costs of two applications of glyphosate ($128/ha) in glyphosate-resistant soybean and two applications of chlorimuron ($125/ha) in sulfonylurea-tolerant soybean were less compared with a standard conventional program ($163/ha). When considering that yield potential of the cultivars were the same, it becomes apparent that unless the price of conventional herbicides is reduced, the conventional program would not be competitive with the other programs.

Overall, the net return (total cost subtracted from gross income based on yield) was higher in glyphosate-resistant soybean with sequential applications of glyphosate POST ($407/ha) compared to sulfonylurea-tolerant soybean with sequential applications of chlorimuron POST ($271/ha) and conventional soybean with standard PRE fb EPOST herbicide program ($317/ha) (Table 4). In contrast, economic analysis by Webster et al. (1999) showed that a conventional cultivar with conventional herbicide program resulted in higher net returns ($92 to $123/ha) compared with a glyphosate-resistant cultivar using glyphosate with or without PRE herbicides (−$60 to $39/ha). The distinct advantage of conventional soybean was greater yield potential over that of the glyphosate-resistant cultivar. In the present study, yield differences among cultivars used in the various programs were not a factor. Rather, the cost of the individual programs, which included seed cost, technology fee, herbicide, adjuvant, and application costs, were the contributing factors to differences in net return. This becomes apparent when comparing the standard conventional herbicide program used in each cultivar, where net returns are equivalent ($304 to $317/ha). For the glyphosate-resistant program, net return was no greater when glyphosate followed a PRE herbicide than when glyphosate was applied alone. In contrast, net return when chlorimuron followed sulfentrazone plus chlorimuron PRE in the sulfonylurea-tolerant program was 34% greater than when chlorimuron was applied alone. Culpepper et al. (1997) reported no economic advantage to using PRE herbicides in sulfonylurea-tolerant soybean.

Profitability of soybean production is dependent on three important factors: yield potential of the cultivar, cost of production, and price (Williams 1999). Soybean producers can potentially improve profits through prudent crop production decisions that maximize yield and minimize production costs. Herbicide cost accounts for the largest direct-cost item in soybean production (Anonymous 1997, 1998; Williams 1999). In this research, both glyphosate- and chlorimuron-based programs effectively controlled weeds. Currently, glyphosate-resistant soybean cultivars are available with yield potential equal to or greater than conventional soybean cultivars (Anonymous 1999). When yields are comparable among soybean cultivars, whether herbicide-resistant or conventional, net return will be dictated by the cost of the herbicide program, including seeds, any associated technology fee, and herbicide cost. Producers should carefully strive to select a high-yielding cultivar and cost-effective herbicide program that will maximize yield and net returns.

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