WEED MANAGEMENT

Weed Management in Glyphosate-Resistant and Non-Glyphosate-Resistant Soybean Grown Continuously and in Rotation

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ABSTRACT

Management inputs that maximize economic return from the early soybean [*Glycine max* (L.) Merr.] production system have not been evaluated fully. Field studies were conducted near Stoneville, MS (33°26′ N lat.), to determine the effect of rotating maturity group (MG) IV and V glyphosate [*N*-(phosphonomethyl)glycine]-resistant (GR) and non-GR cultivars on weed populations, soybean seed yields, and net returns from nonirrigated plantings. Eight management systems, each containing a MG IV or MG V GR or non-GR cultivar grown continuously or in rotation with each other, and two weed management treatments [pre-emergent followed by postemergent weed management (PRE + POST) and postemergent-only weed management (POST)] were grown each year. Glyphosate-resistant cultivars using POST-only glyphosate was the most economical system each year. Maturity group effect on yield and net return resulted from weather differences during reproductive development. Rotating GR and non-GR cultivars had no consistent effect on weed populations and no significant effect on yield or net return in this 4-yr study. Using GR cultivars resulted in net returns that were greater than those from non-GR cultivars. These results indicate that production systems using either GR or non-GR cultivars grown continuously or in rotation with each other in this region can be utilized effectively with no effect on weed population shifts or reductions in seed yield and net return.

The early soybean production system (ESPS) uses early maturing cultivars that are planted from late March through late April in the midsouthern USA (Heatherly, 1999a). The ESPS produces maximum yields in this area (Heatherly and Spurlock, 1999; Heatherly, 1999a). Glyphosate-resistant cultivars have been quickly adapted into the ESPS, accounting for over 90% of the total acreage in the midsouthern USA (USDA-NASS, 2004a). Glyphosate is the predominate and often only herbicide used for managing weeds in this system.

Glyphosate-resistant cultivars offer producers the flexibility to control a broad spectrum of weeds in soybean (Reddy, 2001b). Despite higher seed costs associated with GR cultivars, increased profits are achieved because of lowered weed control costs (Reddy et al., 1999; Roberts et al., 1999; Webster et al., 1999; Reddy and Whiting, 2000; Reddy, 2001a; Heatherly et al., 2003a, 2004). This translates to increased profits if yields from GR cultivars are equal or nearly equal to those from non-GR cultivars (Reddy and Whiting, 2000). Research has shown that pre-emergent herbicides usually do not adversely affect GR soybean vs. non-GR cultivars (Gonzini et al., 1999; Nelson and Renner, 1999; Webster et al., 1999; Reddy, 2001a). This means that residual herbicides can be used on plantings of GR cultivars to prevent early-season weed competition in situations where a timely application of glyphosate is not possible (Corrigan and Harvey, 2000). Glyphosate applied at labeled rates does not affect GR soybean growth and yield (Nelson and Renner, 1999; Reddy et al., 2000; Elmore et al., 2001). Timely applications of glyphosate to sensitive weed species in GR soybean need no supplementation with nonglyphosate herbicides to achieve maximum weed control (Gonzini et al., 1999; Webster et al., 1999; Corrigan and Harvey, 2000; Reddy and Whiting, 2000; Reddy, 2001a). All of these advantages should translate to a reduction in management decisions for producers related to weed control in soybean when GR cultivars are used in the ESPS.

The continued and increasing use of glyphosate in crop production is being associated with weed resistance to glyphosate (Powles et al., 1998; Pratley et al., 1999; Lee and Ngim, 2000; VanGessel, 2001; Mueller et al., 2003; Koger et al., 2004). Alternative control strategies for GR weeds will be needed in production systems where they commonly occur, such as rotation with non-GR crops and herbicides. Repeated applications of bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) to bromoxynil-resistant (BR) cotton (*Gossypium hirsutum* L.) resulted in a shift in weed spectrum toward more tolerant species and a yield decline in continuous BR cotton (Reddy, 2004). Rotating BR cotton with GR cotton prevented this. The effect of rotating GR and non-GR soybean cultivars on existing weed populations has not been determined.

Inputs used for weed management in soybean represent a significant financial cost (Buhler et al., 1997; Johnson et al., 1997; Reddy and Whiting, 2000; Heatherly et al., 2001, 2002b). Cost and yield differences among weed management systems can mean significant differences in net returns (Poston et al., 1992; Heatherly et al., 1994; Buhler et al., 1997; Johnson et al., 1997; Nelson and Renner, 1999; Webster et al., 1999; Reddy and Whiting, 2000; Reddy, 2001a). Weed management in GR

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Abbreviations: BR, bromoxynil-resistant; ESPS, early soybean production system; GR, glyphosate resistant; MG, maturity group; MYA, market year average; POST, postemergent weed management; PRE, pre-emergent weed management.

and non-GR soybean generally involves two basic approaches: use of soil-applied pre-emergent herbicides followed by foliar-applied postemergent herbicides and use of postemergent-only herbicides. Both systems can be used effectively to control weeds (Reddy et al., 1999; Heatherly et al., 2002a, 2003a, 2003b) in midsouthern USA soybean plantings. Economically feasible weed control strategies using these different weed management systems with rotated GR and non-GR soybean cultivars have not been determined.

The objective of this project was to compare weed populations in, and soybean yields and net returns from, continuous and rotated GR and non-GR soybean production systems. Weed control, yields, and the economic returns from ESPS plantings of MG IV and MG V GR and non-GR soybean were measured and compared over a 4-yr period. An important aspect to this research was to determine if rotation of the two systems would be beneficial for economical weed control and enhance net return.

MATERIALS AND METHODS

Nonirrigated field experiments were conducted on Tunica silty clay soil (clayey over loamy, smectitic, nonacid, thermic, Vertic Haplaquept) from 2000 through 2003 near Stoneville, MS (33°26′ N). In the fall of 1998, deep tillage to 0.45-m depth was performed on the entire study area. In the spring of 1999, an MG IV GR cultivar was grown on the entire study area, and glyphosate was applied during the growing season to control weeds. In the spring of 2000, the study was established using eight management systems (Table 1), each containing a GR or non-GR cultivar grown continuously or in rotation with each other.

The experimental design was a randomized complete block with a split-plot arrangement of treatments. There were eight main-unit treatments and two subunit treatments (Table 1). Basically, there was a factorial relationship between two MGs (IV and V) and four crop–system combinations (continuous GR, continuous non-GR, rotated in GR, and rotated in non-GR). The crop–system combinations had a nested treatment structure with three systems (continuous GR, continuous non-GR, and rotated) and two crops (GR and non-GR) within the rotated system. The additional nested structure in the ANOVA provided *f* tests about whether or not differences were due to the rotational treatments or the particular crop in the rotated sequence.

In early October of each year, the study area was shallow-tilled (<10 cm) using a disk harrow and/or spring-tooth cultivator. In January of 2003, an additional shallow tillage operation was done to finish smoothing the soil surface for planting. Plantings were made into a stale seedbed (untilled following fall/winter tillage and before planting in the spring; Heatherly, 1999b). Glyphosate was applied preplant at 840 g a.e. ha^{-1} to kill weed vegetation from 2000 through 2002. Air temperature data were collected about 4 km from the experimental site, whereas rain was measured on-site.

Seeds of GR MG IV 'Asgrow A4702' and MG V 'Asgrow A5701' and non-GR MG IV 'Agripro AP4882' and MG V 'Pioneer P9594' were planted on 20 Apr. 2000, 4 Apr. 2001, 15 Apr. 2002, and 25 Mar. 2003. All plantings were made as early as soil conditions allowed. Cultivars were chosen because of their consistent high performance on a large hectarage of producer fields in the region. A plate planter with double-disk openers and closing wheels to seal the seed trench was used. Seeds were treated with mefenoxam {(*R*)-2-[2,6-(dimethylphenyl)-methoxyacetylamino]-propionic acid methyl ester} fungicide before planting as a precaution against stand loss caused by damping-off soil pathogens. Row spacing was 0.5 m, and seeding rate was 15 to 18 seeds m^{-1} row, or 295 000 to 345 000 planted seeds ha^{-1}. All populations were within the range recommended for this area (Heatherly and Elmore, 2004). Plots were 30.5 m long and 8.1 m (16 rows) wide.

Weed management treatments were designed for effective control of the most common weeds that infest soybean in the lower Mississippi River valley and were selected along the following premises. First, uncontrolled weeds will reduce soybean yield; therefore, no weedy check was included. The intent in this experiment was to ensure that weed management treatments controlled weeds until canopy closure. Second, the inclusion of economic analyses in this study dictated that both weed management treatments be practical and realistic. Also, there was no intent to determine how weed management treatment related to an economically unattainable or infeasible weed-free environment. Based on these premises, weed management treatments were (i) pre-emergent followed by postemergent dicot and monocot weed management (PRE + POST) and (ii) postemergent dicot and monocot weed management (POST). Herbicides applied to each weed management treatment within GR and non-GR cultivars were the same and were applied at the same time within each year. Pre-emergent herbicides and postemergent dicot herbicides were

Table 1. Description of systems used in nonirrigated soybean experiments containing maturity group (MG) IV and V glyphosate-resistant (GR) and non-GR soybean cultivars grown with two weed management treatments at Stoneville, MS, 2000–2003.

Main treatment	MG	System	Weed management treatment†
1	IV	Continuous GR	1. PRE nonglyphosate + POST glyphosate 2. POST glyphosate
2	IV	Continuous non-GR	1. PRE + POST nonglyphosate 2. POST nonglyphosate
3	V	Continuous GR	1. PRE nonglyphosate + POST glyphosate 2. POST glyphosate
4	V	Continuous non-GR	1. PRE + POST nonglyphosate 2. POST nonglyphosate
5	IV	Rotated GR, non-GR	1. PRE nonglyphosate + POST glyphosate 2. POST glyphosate
6	IV	Rotated non-GR, GR	1. PRE + POST nonglyphosate 2. POST nonglyphosate
7	V	Rotated GR, non-GR	1. PRE nonglyphosate + POST glyphosate 2. POST glyphosate
8	V	Rotated non-GR, GR	1. PRE + POST nonglyphosate 2. POST nonglyphosate

† PRE + POST = pre-emergent followed by postemergent dicot and monocot weed control; POST = postemergent dicot and monocot weed control.

Table 2. Pre-emergent (PRE) and postemergent (POST) herbicides applied in two weed management treatments (PRE + POST and POST†) to nonirrigated glyphosate-resistant (GR) and non-GR soybean grown continuously (CONT) and in rotation (ROT) at Stoneville, MS, 2000–2003.

Weed management treatment/cultivar type	Herbicide‡
	2000
PRE + POST GR	PRE metribuzin + chlorimuron; POST glyphosate
POST GR	glyphosate (2×)
PRE + POST non-GR	PRE metribuzin + chlorimuron; POST sethoxydim
POST non-GR	sethoxydim fb bentazon + acifluorfen fb sethoxydim
	2001
PRE + POST GR	PRE metribuzin + chlorimuron; POST glyphosate
POST GR	glyphosate (2×)
PRE + POST non-GR	PRE metribuzin + chlorimuron; POST sethoxydim
POST non-GR	CONT: bentazon + acifluorfen + clethodim (2×)
	ROT: sethoxydim fb bentazon + acifluorfen + clethodim
	2002
PRE + POST GR	PRE imazaquin; POST glyphosate (2×)
POST GR	glyphosate (2×)
PRE + POST non-GR	PRE imazaquin; POST bentazon + acifluorfen fb sethoxydim fb fluazifop fb 2,4-DB + metribuzin
POST non-GR	bentazon + acifluorfen fb sethoxydim fb fluazifop fb 2,4-DB + metribuzin
	2003
PRE + POST GR	PRE imazaquin + metolachlor; POST glyphosate
POST GR	glyphosate (2×)
PRE + POST non-GR	PRE imazaquin + metolachlor; POST clethodim (2×)
POST non-GR	bentazon + acifluorfen fb clethodim (2×) fb 2,4-DB + linuron

† PRE + POST = pre-emergent followed by postemergent dicot and monocot weed control; POST = postemergent dicot and monocot weed control.
‡ + indicates either a premixture or a tank mixture; 2× indicates two sequential applications; fb = followed by. Rates of herbicides, g a.i. (a.e. for glyphosate) ha^{-1}: metribuzin, 450, + chlorimuron, 75; imazaquin, 137; imazaquin, 137, + metolachlor, 1460; glyphosate, 840; sethoxydim, 213; bentazon, 560, + acifluorfen, 280, + clethodim, 140; bentazon, 560, + acifluorfen, 280; clethodim, 105; fluazifop, 213; 2,4-DB, 224, + metribuzin, 280; 2,4-DB, 224, + linuron, 560.

applied in 187 L water ha^{-1}, whereas postemergent monocot herbicides and glyphosate were applied in 94 L water ha^{-1}.

Within each weed management treatment for GR and non-GR cultivars, use of herbicides and their combinations was dictated by expected weed populations (PRE) or actual populations (POST). Selection of postemergent herbicides for the non-GR cultivars was based on weekly assessment of the presence and size of particular weed species in plots of each weed management treatment. The objective was to minimize weed competition within the constraints of each individual weed management treatment. Pre-emergent herbicides were applied immediately after planting each year. In 2000, 2001, and 2003, rainfall of >13 mm occurred within 10 d of the pre-emergent application. In 2002, rain of >13 mm did not occur until 14 d after planting, and imazaquin {2-[4,5-dihydro-4-methyl-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid} applied pre-emergent was ineffective, which increased the reliance on postemergent weed management (Table 2).

Herbicides (Table 2) were broadcast-applied each year at labeled rates with recommended adjuvants and in recommended tank mixes. Rates for pre-emergent herbicides applied to both GR and non-GR cultivars were a premix of metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] at 450 g a.i. ha^{-1} plus chlorimuron ethyl {ethyl 2-[[[[(4-chloro-6-methoxypyrimidin-2-yl)amino]carbonyl]amino]sulfonyl]benzoate} at 75 g a.i. ha^{-1} in 2000 and 2001, imazaquin at 137 g a.i. ha^{-1} in 2002, and a tank mixture of imazaquin at 137 g a.i. ha^{-1} plus S-metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)-(*S*)] at 1460 g a.i. ha^{-1} in 2003. Rates for postemergent herbicides applied to non-GR cultivars were premixture of 560 g a.i. ha^{-1} bentazon [3-(isopropyl)-1*H*-2,1,3-benzothiadiazin-4-(3*H*)-one 2,2-dioxide] and 280 g a.i. ha^{-1} acifluorfen {sodium [5-[2-chloro-4-(trifluoromethyl)phenox]-2-nitrobenzoate}, premixture of 560 g a.i. ha^{-1} bentazon plus 280 g a.i. ha^{-1} acifluorfen plus 140 g a.i. ha^{-1} clethodim {(*E*)-2[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one}, fluazifop {(*R*)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoate} at 213 g a.i. ha^{-1}, sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} at 213 g a.i. ha^{-1}, clethodim at 105 g a.i. ha^{-1}, a tank mixture of 2,4-DB [4-(2,4-dichlorophenoxy)butyric acid, dimethylamine salt] at 224 g a.i. ha^{-1} plus metribuzin at 280 g a.i. ha^{-1} in a directed spray underneath the soybean canopy in 2002, and a tank mixture of 2,4-DB at 224 g a.i. ha^{-1} plus linuron [3-(3, 4-dichlorophenyl)-1-methoxy-1-methylurea] at 560 g a.i. ha^{-1} in a directed spray underneath the soybean canopy in 2003. Postemergent non-GR herbicides were chosen to manage weed populations present in a given year; thus, POST non-GR herbicides differed across years.

Single and/or sequential applications of glyphosate (Roundup) at 840 g a.e. ha^{-1} were made postemergent to GR cultivars (Table 2). This is less than the maximum allowable rate of 1.68 kg a.e. ha^{-1} for a single application and less than the total allowable in-season rate of 2.52 kg a.e. ha^{-1}. Thus, an increase to the allowed maximum for individual and/or total in-season applications of glyphosate may have changed the results of this study. However, the intent of this study was to use a normal rate (840 g a.e. ha^{-1}) of glyphosate in GR soybean.

Density of individual weed species was estimated by counting plants in a 15.25-m^2 area between the fourth and fifth row (0.5 m wide) of a 16-row plot that was 30.5 m long. Weed counts were made on 20 June 2000, 18 June 2001, 11 June 2002, and 25 June 2003. These dates corresponded to 3, 4, 2, and 4 wk after the final postemergent weed control treatments had been applied in 2000 through 2003, respectively. In most plots, the weed species were either absent, or counts were under 10. Weed density data were normalized by subjecting them to square root transformation. The data were transformed before analysis using $(X + 0.5)^{0.5}$ transformation, where X is weed density. In 2003, weed control was determined after soybean leaf senescence to measure the effect of each system and weed control treatment across the 4 yr. Control of individual weed species was visually estimated

Table 3. After-planting weed management expense and total expense (excluding charges for land, management, and general farm overhead) for nonirrigated glyphosate-resistant (GR) and non-GR soybean cultivars grown under two weed management treatments in continuous (CONT) and rotated (ROT) systems near Stoneville, MS, 2000–2003.

Cultivar type	Weed management treatment†	Weed expense‡	Total expense§
		$ ha^{-1}	
	2000		
GR	PRE + POST	93	335–326
	POST	49	288–280
Non-GR	PRE + POST	83	324–315
	POST	80	320–311
	2001		
GR	PRE + POST	93	281–289
	POST	67	251–259
Non-GR	PRE + POST	80	265–276
	POST	121(CONT)−93(ROT)	305(CONT)/276(ROT) 318(CONT)/290(ROT)¶
	2002		
GR	PRE + POST	104	321–322
	POST	66	278–280
Non-GR	PRE + POST	171	392–394
	POST	133	352–355
	2003		
GR	PRE + POST	117	310–309
	POST	68	259–260
Non-GR	PRE + POST	133	328–328
	POST	143	337–341

† PRE + POST = pre-emergent followed by postemergent dicot and monocot weed control; POST = postemergent dicot and monocot weed control.
‡ Includes costs associated with herbicides, adjuvants, application, and the extra cost for seed of GR cultivars ($21 ha^{-1} in 2000 and $23.50 ha^{-1} in 2001 through 2003).
§ First number for MG IV cultivar and second number for MG V cultivar.
¶ In this instance, the first two numbers are for MG IV cultivar, and the second two numbers are for MG V cultivar. These values are attributable to different planting seed costs and different hauling expenses associated with yield response.

based on weed cover in each plot on a scale of 0 (no weed control) to 100 (complete weed control).

A field combine modified for small plots was used to harvest the center four rows from each of the two planter passes (eight rows harvested) in plots on 11 (MG IV) and 21 (MG V) Sept. 2000, 14 Sept. (MG IV) and 4 Oct. (MG V) 2001, 29 Aug. (MG IV) and 2 Oct. (MG V) 2002, and 18 Aug. (MG IV) and 17 Sept. (MG V) 2003. Harvested seeds were weighed, moisture content of seeds from each plot was determined using a Burrows Model 700 Digital Moisture Computer, and yields were based on an adjusted moisture basis of 130 g moisture kg^{-1} seed.

Estimates of total expenses and returns were developed for each annual cycle of each experimental unit using the Mississippi State Budget Generator (Spurlock and Laughlin, 1992). Total specified expenses were calculated using actual inputs in each year of the experiment and included all operating expenses and machinery ownership costs but excluded charges for land, management, and general farm overhead, which were assumed to be the same for all treatment combinations. Machinery ownership costs for tractors, self-propelled harvesters, implements, and sprayers were estimated by computing the annual capital recovery charge for each machine and applying its per-hectare rate to each field operation. Operating expenses included herbicides, adjuvants, seed, and labor; fuel, repair, and maintenance of machinery; hauling harvested seed; and interest on operating capital. Weed management expenses after planting were calculated for each system and included costs associated with herbicides, adjuvants, application, and the extra cost for seed of GR cultivars (Table 3). All application charges included both operating expenses and ownership costs associated with machinery. Costs for machinery and operating expenses were based on prices paid by Mississippi farmers each year as assigned by the Mississippi State Budget Generator.

An average price for soybean was derived for the 4-yr period of 2000 through 2003 and used to compute the revenue (soybean yield multiplied by price received) from each treatment. The Mississippi Agricultural Statistics Service publishes (USDA-NASS, 2004b) the market year average (MYA; 1 Sept. through 31 Aug.) price of soybean received by producers. The MYA price includes transactions in cash markets and through forward contracts but does not include government program payments. However, in a year when market prices are below the USDA loan rate, eligible producers are allowed to collect loan deficiency payments and/or marketing loan gains. Therefore, government payments essentially raise the value received to the Mississippi loan rate. Market prices were below the USDA loan rate of $0.197 kg^{-1} for Mississippi in 2000 and 2001; thus, the Mississippi loan rate was used in place of the MYA price in those years to compute a 4-yr average soybean value. Beginning in the 2002 marketing year, market prices were greater than the loan rate; MYA price for 2002 was $0.203 kg^{-1}. For 2003, the average of the October and November 2003 monthly prices ($0.246 kg^{-1}) was used. From these values, a 4-yr average value for Mississippi soybean was estimated at $0.210 kg^{-1}, and this value was used to compute revenue each year.

Weighted means of weed density were obtained by converting transformed data back to actual values. The means were expressed as plants per hectare rather than plants per square meter to avoid clutter with decimals. Analysis of variance [PROC MIXED (SAS Inst., 1996, 2001)] was used to evaluate the significance of system and weed management treatment effects on weed density, weed control, seed yield, and net return. Analyses across years treated year as a fixed effect to determine interactions involving year. Analyses for individual years treated system and weed management treatment as fixed effects. Mean separation was achieved with an $LSD_{0.05}$.

RESULTS AND DISCUSSION

Weather and Seed Yield

During the planting to beginning bloom (R1) period, cultivars experienced above-normal average maximum

Table 4. Average daily maximum air temperature (max. T), rain, and pan evaporation during indicated periods of maturity group (MG) IV and V soybean cultivars, and departure from 30-yr normals† (in parentheses) at Stoneville, MS, 2000–2003.

MG	Period	Dates	Max. T	Rain	Pan evaporation
			°C	mm d^{-1}	
			2000		
IV	Planting–R1	20 Apr.–26 May	27.6 (+0.9)	4.8 (+0.3)	6.0 (−0.1)
	R1–R6	27 May–7 Aug.	33.5 (+1.1)	2.7 (−0.4)	6.9 (−0.1)
V	Planting–R1	20 Apr.–14 June	29.2 (+1.1)	4.6 (+0.6)	6.6 (+0.2)
	R1–R6	15 June–30 Aug.	34.9 (+2.2)	1.4 (−1.2)	7.0 (+0.4)
			2001		
IV	Planting–R1	29 Mar.–6 May	25.2 (+1.6)	3.0 (−1.7)	5.6 (+0.7)
	R1–R6	7 May–18 July	31.4 (+0.4)	3.7 (+0.2)	7.1 (0)
V	Planting–R1	29 Mar.–25 May	26.8 (+1.8)	3.2 (−1.3)	6.3 (+0.8)
	R1–R6	26 May–31 Aug.	32.3 (0.0)	4.4 (+1.7)	6.3 (−0.5)
			2002		
IV	Planting–R1	15 Apr.–17 May	28.3 (+2.6)	2.5 (−2.2)	6.5 (+0.5)
	R1–R6	18 May–2 Aug.	31.8 (−0.1)	3.0 (−0.2)	6.5 (−0.5)
V	Planting–R1	15 Apr.–7 June	28.8 (+1.5)	2.0 (−2.2)	6.7 (+0.4)
	R1–R6	8 June–26 Aug.	33.0 (+0.3)	3.3 (+0.1)	6.4 (−0.7)
			2003		
IV	Planting–R1	25 Mar.–8 May	25.3 (+1.9)	2.6 (−2.0)	5.2 (+0.6)
	R1–R6	9 May–12 July	30.0 (−1.0)	4.4 (+1.6)	6.6 (−0.2)
V	Planting–R1	25 Mar.–28 May	26.1 (+1.2)	2.8 (−1.7)	5.6 (+0.4)
	R1–R6	29 May–25 Aug.	32.3 (−0.1)	3.1 (−0.5)	6.4 (−0.8)

† 1964–1993 (Boykin et al., 1995).

air temperatures in all years (Table 4). Rainfall from planting to R1 was slightly above normal in 2000 and substantially below normal in the other years. No visible weather-related stresses occurred from planting to R1 of any year, and all cultivars achieved a full canopy every year. During R1 to full seed (R6), all cultivars experienced above-normal temperatures in 2000 and near-normal temperatures in the other years. The greatest deviations from normal rain during the R1 to R6 periods were the below-normal rain for MG V cultivars in 2000, the above-normal rain for MG V cultivars in 2001, and the above-normal rain for MG IV cultivars in 2003. Yield patterns of the 4 yr were correlated ($r = -0.80$; $p < 0.001$) with pan evaporation (an estimate of potential evapotranspiration) during R1 to R6.

Weed Management Expense and Total Expense

Cost of weed management for GR cultivars was always less with POST than with PRE + POST treatments (Table 3). Cost differences for non-GR cultivars were not as clearly defined between PRE + POST and POST treatments. The 4-yr average weed management cost for GR cultivars (includes extra seed cost shown in Table 3) using PRE + POST was \$102 ha^{-1}, whereas the cost for POST weed management was \$62.50 ha^{-1}. For non-GR cultivars, the 4-yr average costs for PRE + POST and POST were \$117 and \$116 ha^{-1}, respectively. Thus, weed management expense for non-GR compared with GR cultivars was greater within each weed management treatment, even with a higher cost for seed of GR cultivars. Differences in total expenses (excluding charges for land, management, and general farm overhead) followed the same pattern as the differences in weed management expenses (Table 3).

Weed Control

Twenty-one weed species were present in the experimental area. The predominant weed species were hyssop spurge (*Euphorbia hyssopifolia* L.), johnsongrass [*Sorghum halepense* (L.) Pers.], pitted morningglory (*Ipomoea lacunosa* L.), prickly sida (*Sida spinosa* L.), redvine [*Brunnichia ovata* (Walt.) Shinners], trumpetcreeper [*Campsis radicans* (L.) Seem. ex Bureau], and yellow nutsedge (*Cyperus esculentus* L.). Overall, control of the 14 other species was excellent; their densities were too low to justify reporting.

Redvine and trumpetcreeper densities in continuous GR and non-GR soybean were not different from those rotated with each other regardless of MG and year (Table 5). The PRE + POST and POST-only weed management treatments had similar densities of redvine and trumpetcreeper, and neither treatment provided complete control of these perennial, deep-rooted vines. Glyphosate and acifluorfen applied POST killed foliage of these weeds, but control was temporary, and new shoots were produced from rootstocks. In other research, one or two POST applications of glyphosate alone or in mixture with acifluorfen had no effect on redvine density but reduced trumpetcreeper density by 34 to 78% compared with no herbicide in GR soybean. Glufosinate applied POST with or without acifluorfen had no effect on densities of redvine or trumpetcreeper in glufosinate-resistant soybean (Reddy and Chachalis, 2004). Herbicides alone cannot provide adequate control of redvine and trumpetcreeper; thus, additional control tactics may be necessary by producers. Research conducted recently at the same location indicates that increased redvine presence in soybean is not associated with a yield decline (Heatherly et al., 2004).

Hyssop spurge, pitted morningglory, and prickly sida densities were generally low compared with redvine and trumpetcreeper (Table 6). Hyssop spurge and pitted morningglory densities were similar among the eight management systems in the first 3 yr of the study. In 2003, densities of hyssop spurge were higher in continuous and rotated MG IV non-GR soybean compared

Table 5. Redvine and trumpetcreeper density in nonirrigated maturity group (MG) IV and MG V glyphosate-resistant (GR) and non-GR soybean cultivars grown using pre-emergent plus postemergent (PRE + POST)† or POST-only weed management in continuous (CONT) and rotated (ROT) systems near Stoneville, MS, 2000–2003.

	Redvine				Trumpetcreeper			
Treatment	2000	2001	2002	2003	2000	2001	2002	2003
	plants ha^{-1}							
Rotation system								
CONT MG IV GR	1 718 a‡	7341 a	9 602 a	7509 a	2454 a	495 a	501 a	581 a
CONT MG IV non-GR	6 014 a	6973 a	10 859 a	7255 a	2365 a	1433 a	1353 a	1288 a
CONT MG V GR	5 523 a	1848 a	5 045 a	2124 a	201 a	173 a	192 a	14 a
CONT MG V non-GR	494 a	2126 a	4 949 a	2555 a	3209 a	365 a	403 a	493 a
ROT MG IV GR	3 439 a	4379 a	2 974 a	5280 a	1135 a	230 a	546 a	223 a
ROT MG IV non-GR	3 942 a	4357 a	5 620 a	3792 a	290 a	1857 a	353 a	2550 a
ROT MG V GR	11 352 a	3601 a	4 615 a	3705 a	290 a	418 a	102 a	166 a
ROT MG V non-GR	12 813 a	6204 a	6 728 a	7595 a	2043 a	153 a	431 a	101 a
Weed management treatment								
PRE + POST	5 291 a	5042 a	4 688 a	5489 a	1043 a	408 a	329 a	454 a
POST only	4 415 a	3758 a	7 621 a	4044 a	1458 a	658 a	547 a	496 a

† PRE + POST = pre-emergent followed by postemergent dicot and monocot weed control; POST only = postemergent dicot and monocot weed control.
‡ Average values (detransformed) within a column and within rotation system or weed management treatment followed by the same letter are not significantly different at $p \leq 0.05$ as determined by Fisher's protected LSD test using square root transformations.

with the other systems, whereas pitted morningglory densities were higher in MG IV GR cultivars regardless of rotation. Prickly sida density did not differ among the eight management systems in any year. The density of prickly sida did vary year to year, with a decrease in 2003 compared with 2000. Use of PRE + POST vs. POST-only herbicides was beneficial in reducing densities of hyssop spurge, pitted morningglory, and prickly sida in 3, 1, and 2 of the 4 yr, respectively.

Results for johnsongrass and yellow nutsedge densities were variable (Table 7). Johnsongrass densities were statistically similar among the eight management systems in 2001 and 2002. Differences in johnsongrass densities among the eight management systems occurred in 2000 and 2003, but there was no clear trend in the differences. The trend from 2000 through 2002 was greater johnsongrass densities in non-GR cultivars. Differences between weed management treatments occurred in 2001 and 2003, with higher johnsongrass densities in PRE + POST. In the PRE + POST systems, metolachlor was added in 2003 to help reduce johnsongrass densities compared with 2002. Yellow nutsedge densities were not different among the eight management systems in 2000 and 2002 (Table 7). Yellow nutsedge densities were generally greater in continuous MG IV non-GR, rotated MG IV GR, and rotated MG IV non-GR compared with the other systems. A less dense canopy formed by MG IV compared with MG V cultivars may have favored establishment of yellow nutsedge. The PRE + POST weed management treatment was more effective in reducing yellow nutsedge density than was POST only. Chlorimuron, imazaquin, and metolachlor are known to provide various levels of yellow nutsedge control (Anonymous, 2000).

Weed control at harvest in 2003 of prickly sida, redvine, and trumpetcreeper was statistically similar among the management systems (Table 8). Control of hyssop spurge and yellow nutsedge was generally less in the continuous MG IV non-GR system. Control of johnsongrass in the rotated MG IV GR system (95%) was less than in the other weed management treatments (98 to 100%). Control of pitted morningglory generally was less in systems with MG IV cultivars, but level of control in all systems exceeded 92% (Table 8). Control of hyssop spurge, prickly sida, and yellow nutsedge was greater in the PRE + POST than in the POST-only weed man-

Table 6. Hyssop spurge, pitted morningglory, and prickly sida density in nonirrigated maturity group (MG) IV and MG V glyphosate-resistant (GR) and non-GR soybean cultivars grown using pre-emergent plus postemergent (PRE + POST)† or POST-only weed management in continuous (CONT) and rotated (ROT) systems near Stoneville, MS, 2000–2003.

	Hyssop spurge				Pitted morningglory				Prickly sida			
Treatment	2000	2001	2002	2003	2000	2001	2002	2003	2000	2001	2002	2003
	plants ha^{-1}											
Rotation system												
CONT MG IV GR	3473 a‡	68 a	0 a	453 bc	438 a	647 a	175 a	7990 a	4135 a	48 a	14 a	1139 a
CONT MG IV non-GR	2305 a	287 a	3896 a	2161 ab	55 a	676 a	14 a	2043 bc	6697 a	1208 a	3829 a	832 a
CONT MG V GR	565 a	0 a	1250 a	0 c	1866 a	60 a	86 a	612 bc	4130 a	14 a	782 a	48 a
CONT MG V non-GR	2282 a	0 a	634 a	350 bc	55 a	49 a	0 a	500 c	3318 a	0 a	0 a	38 a
ROT MG IV GR	290 a	48 a	199 a	721 bc	771 a	325 a	14 a	3901 a	4491 a	379 a	14 a	732 a
ROT MG IV non-GR	1603 a	209 a	1514 a	3175 a	290 a	241 a	0 a	1654 bc	4206 a	220 a	71 a	343 a
ROT MG V GR	369 a	0 a	26 a	14 c	438 a	14 a	14 a	791 bc	2302 a	0 a	0 a	14 a
ROT MG V non-GR	3429 a	0 a	215 a	745 bc	4405 a	26 a	0 a	452 c	6530 a	0 a	0 a	14 a
Weed management treatment												
PRE + POST	107 b	40 a	120 b	305 b	649 a	227 a	2 b	1542 a	2304 b	75 a	5 a	38 b
POST only	4819 a	36 a	1456 a	1082 a	746 a	146 a	56 a	1961 a	7082 a	139 a	613 a	678 a

† PRE + POST = pre-emergent followed by postemergent dicot and monocot weed control; POST only = postemergent dicot and monocot weed control.
‡ Average values (detransformed) within a column and within rotation system or weed management treatment that are followed by the same letter are not significantly different at $p \leq 0.05$ as determined by Fisher's protected LSD test using square root transformations.

Table 7. Johnsongrass and yellow nutsedge density in nonirrigated maturity group (MG) IV and MG V glyphosate-resistant (GR) and non-GR soybean cultivars grown using pre-emergent plus postemergent (PRE + POST)† or POST-only weed management in continuous (CONT) and rotated (ROT) systems near Stoneville, MS, 2000–2003.

	Johnsongrass				Yellow nutsedge			
Treatment	2000	2001	2002	2003	2000	2001	2002	2003
	plants ha^{-1}							
Rotation system								
CONT MG IV GR	55 c‡	1324 a	112 a	586 bcd	1038 a	361 c	446 a	175 c
CONT MG IV non-GR	5667 ab	2512 a	30 471 a	252 cde	1183 a	23 052 a	28 770 a	41 448 a
CONT MG V GR	0 c	14 a	653 a	175 cde	1711 a	1 979 bc	452 a	14 c
CONT MG V non-GR	1931 abc	519 a	4 189 a	1211 ab	2179 a	657 c	1 146 a	736 c
ROT MG IV GR	1395 abc	1569 a	641 a	2763 a	1183 a	11 633 ab	22 602 a	19 740 ab
ROT MG IV non-GR	931 bc	1770 a	3 183 a	26 e	1421 a	2 326 bc	24 771 a	6 315 bc
ROT MG V GR	290 c	26 a	1 618 a	813 bc	565 a	101 c	14 a	48 c
ROT MG V non-GR	7490 a	498 a	25 667 a	212 cde	6958 a	91 c	333 a	26 c
Weed management treatment								
PRE + POST	1126 a	1493 a	8 966 a	882 a	1434 a	782 b	1 079 a	785 b
POST only	1693 a	286 b	1 999 a	308 b	2081 a	5 806 a	12 334 a	8 451 a

† PRE + POST = pre-emergent followed by postemergent dicot and monocot weed control; POST only = postemergent dicot and monocot weed control.
‡ Average values (detransformed) within a column and within rotation system or weed management treatment that are followed by the same letter are not significantly different at $p \leq 0.05$ as determined by Fisher's protected LSD test using square root transformations.

agement treatment, whereas control of other weed species was similar across these two treatments. Control in all management systems of all weed species except redvine and yellow nutsedge was >86%. Across cultivars, control in both weed management treatments (PRE + POST and POST alone) of all weed species except redvine was >92%. Our initial goal was to apply weed management programs that provided effective control across multiple weed species; this was achieved.

Seed Yield and Net Return

Across-years analyses revealed significant year, year × MG, year × weed management treatment, and/or year × system × weed management treatment interactions for seed yield and net return. Weather patterns mentioned earlier, and shown in Table 4, were different among the 4 yr, and this contributed to the interactions by benefiting cultivars of a particular MG. Because of the significant interactions involving year, individual-year results are discussed and related to data shown in Tables 9 and 10.

2000

Maturity group and system significantly interacted to affect soybean seed yield and net return (Tables 9 and 10). Maturity Group IV cultivars (2916 to 3799 kg ha^{-1}) outyielded MG V cultivars (2037 to 2482 kg ha^{-1}) in all systems. This effect was related to the more favorable air temperature and rainfall patterns during R1 to R6 of MG IV cultivars (Table 4). Within MG IV cultivars, the continuous GR system (3761 kg ha^{-1}) outyielded the other systems (Table 9). Net returns from the continuous GR system ($479 ha^{-1}) and the rotated system with GR cultivars ($418 ha^{-1}) were similar and higher than net returns from systems with non-GR cultivars (Table 10). Within MG V cultivars, all systems produced similar yields and net returns. Rotation and weed management treatment did not significantly affect yield or net return in this first year of the study.

2001

Maturity Group V cultivars (3432 kg ha^{-1}) significantly outyielded MG IV cultivars (2109 kg ha^{-1}) across

Table 8. Percentage control of hyssop spurge, johnsongrass, pitted morningglory, prickly sida, redvine, trumpetcreeper, and yellow nutsedge at harvest time of nonirrigated maturity group (MG) IV and MG V glyphosate-resistant (GR) and non-GR soybean cultivars grown using pre-emergent plus postemergent (PRE + POST)† or POST-only weed management in continuous (CONT) and rotated (ROT) systems near Stoneville, MS, 2003.

Treatment	Hyssop spurge	Johnsongrass	Pitted morningglory	Prickly sida	Redvine	Trumpetcreeper	Yellow nutsedge
	%						
Rotation system							
CONT MG IV GR	93 ab‡	99 a	94 ab	96 a	81 a	94 a	98 a
CONT MG IV non-GR	89 b	99 a	96 ab	91 a	74 a	93 a	78 b
CONT MG V GR	100 a	99 a	100 a	100 a	90 a	99 a	100 a
CONT MG V non-GR	100 a	99 a	100 a	100 a	94 a	96 a	100 a
ROT MG IV GR	96 ab	95 b	93 b	96 a	84 a	96 a	96 a
ROT MG IV non-GR	94 ab	100 a	93 b	94 a	73 a	86 a	95 a
ROT MG V GR	100 a	99 a	100 a	100 a	90 a	98 a	100 a
ROT MG V non-GR	100 a	100 a	100 a	100 a	80 a	98 a	100 a
Weed management treatment							
PRE + POST	99 a	98 a	93 a	100 a	83 a	95 a	98 a
POST only	93 b	99 a	93 a	95 b	83 a	95 a	93 b

† PRE + POST = pre-emergent followed by postemergent dicot and monocot weed control; POST only = postemergent dicot and monocot weed control.
‡ Average values within a column and within rotation system or weed management treatment that are followed by the same letter are not significantly different at $p \leq 0.05$ as determined by Fisher's protected LSD test.

Table 9. Seed yield from nonirrigated maturity group (MG) IV and MG V glyphosate-resistant (GR) and non-GR soybean cultivars grown using two weed management treatments† in continuous (CONT) and rotated (ROT) systems near Stoneville, MS, 2000–2003.

	System								
	CONT GR		CONT non-GR		ROT GR/non-GR		ROT non-GR/GR		
MG	PRE + POST	POST	PRE + POST	POST	PRE + POST	POST	PRE + POST	POST	Means‡
	kg ha^{-1}								
						2000			
IV	3799	3722	3024	2916	3497	3418	3429	3225	
Means‡	3761 a§		2970 c		3458 b		3327 b		
V	2118	2159	2143	2170	2064	2228	2482	2037	
Means	2138 d		2157 d		2146 d		2260 d		
						2001			
IV	2136	2109	2119	2164	2062	2014	2074	2105	2109 b
V	3439	3165	3380	3652	3489	3523	3450	3444	3432 a
						2002			
IV	3689	3594	3205	3699	3865	3697	3936	3650	
V	3757	3683	3148	3954	3554	3574	3499	3551	
Means	3723 a	3638 a	3177 b	3827 a	3710 a	3636 a	3718 a	3600 a	
						2003			
IV	3495	3221	3400	3080	3491	3208	3489	3008	3461 (PRE + POST) a 3136 (POST) b
V	3077	3042	3096	3358	3542	3346	3577	3651	3244 (PRE + POST) b 3299 (POST) ab

† PRE + POST = pre-emergent followed by postemergent dicot and monocot weed control; POST = postemergent dicot and monocot weed control.
‡ Means of significant main effect (2001) or interactions (2000, 2002, 2003).
§ Average values within a year that are followed by the same letter are not significantly different at $p \leq 0.05$.

all systems and weed management treatments (Table 9). This was largely due to rainfall during R1 to R6 of MG IV cultivars being less than for MG V cultivars (Table 4). Maturity Group IV cultivars produced a lower average net return ($171 ha^{-1}) than MG V cultivars ($440 ha^{-1}). System and weed management treatment did not significantly affect yield or net return.

2002

System and weed management treatment significantly interacted to affect both soybean seed yield (Table 9) and net return (Table 10). Seed yield from the continuous non-GR system with PRE + POST weed management (3177 kg ha^{-1}) was significantly lower than yields from all other system/weed management combinations, which were similar and ranged from 3600 to 3827 kg ha^{-1}. Because of differences in weed management expenses among the systems and weed management treatments (Table 3), differences in net returns did not follow the same pattern as differences in seed yields. The lowest net return ($278 ha^{-1}) was realized from the continuous non-GR system with PRE + POST weed manage-

Table 10. Net return from nonirrigated maturity group (MG) IV and MG V glyphosate-resistant (GR) and non-GR soybean cultivars grown using two weed management treatments† in continuous (CONT) and rotated (ROT) systems near Stoneville, MS, 2000–2003.

	System								
	CONT GR		CONT non-GR		ROT GR/non-GR		ROT non-GR/GR		
MG	PRE + POST	POST	PRE + POST	POST	PRE + POST	POST	PRE + POST	POST	Means‡
	$ ha^{-1}								
						2000			
IV	464	495	314	295	402	434	397	358	
Means‡	479 a§		304 c		418 ab		378 b		
V	120	175	137	146	109	189	206	118	
Means	148 d		141 d		149 d		162 d		
						2001			
IV	169	193	181	150	154	173	172	167	171 b
V	436	409	435	451	446	482	450	435	440 a
						2002			
IV	457	478	285	427	493	499	434	417	
V	468	495	270	477	427	472	342	394	
Means	463 ab	487 a	278 d	452 ab	460 ab	486 a	388 c	406 bc	
						2003			
IV	426	419	388	325	426	416	406	296	410 (PRE + POST) a 362 (POST) b
V	340	381	311	367	435	444	424	427	365 (PRE + POST) b 394 (POST) ab

† PRE + POST = pre-emergent followed by postemergent dicot and monocot weed control; POST = postemergent dicot and monocot weed control.
‡ Means of significant main effect (2001) or interactions (2000, 2002, 2003).
§ Average values within a year that are followed by the same letter are not significantly different at $p \leq 0.05$.

ment (also had lowest yield) while the highest net returns (\$452 to \$487 ha^{-1}) were realized from GR systems and the continuous non-GR system with POST weed management. The rotation system with the non-GR cultivars had high yields, but cost of weed management in this system resulted in intermediate net return. Rotation did not significantly affect seed yield and net return.

2003

Maturity group and weed management treatment significantly interacted to affect both seed yield (Table 9) and net return (Table 10). Average yield of MG IV cultivars following PRE + POST weed management was 3461 kg ha^{-1}, which is greater than the 3136 kg ha^{-1} following POST weed management. Average yield from MG V cultivars was not significantly affected by weed management treatment. Differences in net returns followed the same pattern as differences in seed yield. System did not significantly affect seed yield and net return.

CONCLUSIONS

In this nonirrigated study conducted on a clayey soil in the midsouthern USA, rotating GR and non-GR cultivars had no significant effect on weed populations, weed control, soybean seed yield, and net return. These results indicate that production systems using either GR or non-GR cultivars grown continuously or in rotation with each other in this region can be utilized effectively with no effect on weed population shifts or reductions in seed yield and net return. This conclusion is made without considering weed resistance to glyphosate that may develop with its sole use in POST-only weed management systems for GR cultivars.

Using GR cultivars produced net returns that were equal to or greater than those from using non-GR cultivars. This supports earlier findings at this (Heatherly et al., 2002a, 2003b) and other locations (Culpepper et al., 2000). Based on these results, using GR cultivars in the ESPS results in greater revenue.

These results indicate that use of PRE + POST vs. POST-only weed management is not necessary for achieving highest yields and net returns with either non-GR or GR cultivars grown either continuously or in rotation. This agrees with the findings of Gonzini et al. (1999), Nelson and Renner (1999), Roberts et al. (1999), Corrigan and Harvey (2000), Payne and Oliver (2000), and Heatherly et al. (2003b, 2004). This affirmation of the superior cost effectiveness of POST-only weed management in soybean meshes well with the underlying premise of POST-only weed management in a GR soybean production system.

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