Weed Technology. 2004. Volume 18:131–139

Weed Control and Species Shift in Bromoxynil- and Glyphosate-Resistant Cotton (*Gossypium hirsutum*) Rotation Systems[1]

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Abstract: A field study was conducted from 1999 through 2001 at Stoneville, MS, to determine the effects of bromoxynil-resistant (BR) and glyphosate-resistant (GR) cotton rotation systems under ultranarrow- (25-cm spacing) and wide- (102-cm spacing) row planting on weed control, weed density and shift, and cotton yield. The four rotations during 3 yr included BR–BR–BR, GR–GR–GR, BR–GR–BR, and GR–BR–GR, all with bromoxynil or glyphosate postemergence (POST) only or following fluometuron plus pendimethalin preemergence (PRE). Control of hemp sesbania, pitted morningglory, prickly sida, and hyssop spurge was ≥97% regardless of row width, rotation, and herbicide program. Control of common purslane, sicklepod, and smooth pigweed was higher with glyphosate POST in GR cotton than with bromoxynil POST in BR cotton. Broadleaf and yellow nutsedge weed biomass were higher with bromoxynil POST in BR cotton than with glyphosate POST in GR cotton. Continuous BR cotton system resulted in higher densities of common purslane, sicklepod, and yellow nutsedge (15.3, 1.5, and 373 plants/m^2, respectively) compared with continuous GR cotton (0.7, 0.1, and 1.0 plant/m^2, respectively). Seed cotton yield was consistently higher in wide- than in ultranarrow-row cotton. Seed cotton yield was lower in continuous BR cotton than in the other three rotation systems, and yields greatly improved when BR cotton was rotated with GR cotton. During a 3-yr period, seed cotton yields with glyphosate POST only (4,000 to 4,890 kg/ha) or after PRE herbicides (4,480 to 4,860 kg/ha) were similar in GR cotton, whereas in BR cotton, bromoxynil POST only (1,390 to 4,280 kg/ha) resulted in lower yield than did bromoxynil POST after PRE herbicides (2,550 to 4,480 kg/ha). The results indicated that the shift in spectrum of weeds toward more tolerant species and yield decline in continuous BR cotton can be prevented by rotating BR with GR cotton.

Nomenclature: Bromoxynil; fluometuron; glyphosate; pendimethalin; common purslane, *Portulaca oleracea* L. #[3] POROL; 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 & Barneby # CASOB; smooth pigweed, *Amaranthus hybridus* L. # AMACH; yellow nutsedge, *Cyperus esculentus* L. # CYPES; cotton, *Gossypium hirsutum* L. 'BXN 47', 'DP 436 RR'.

Additional index words: Bromoxynil, fluometuron, glyphosate, pendimethalin, rotation, transgenic cotton, weed density, weed shift.

Abbreviations: BR, bromoxynil resistant; GR, glyphosate resistant; POST, postemergence; PRE, preemergence; WAA, weeks after second POST application.

INTRODUCTION

Weed management systems in cotton typically include both soil-applied and postemergence (POST) herbicides. Fewer herbicides are available for POST over-the-top application to control certain broadleaf weeds in nontransgenic cotton. The development of bromoxynil-resistant (BR) and glyphosate-resistant (GR) cotton allows POST applications of bromoxynil and glyphosate, respectively, that previously would have killed the crop along with targeted weeds. There are advantages and limitations with BR and GR cotton weed management systems.

Glyphosate, a nonselective, broad-spectrum herbicide, controls most grass, sedge, and broadleaf weeds (Askew and Wilcut 1999; Culpepper and York 1999, 2000; Faircloth et al. 2001; Reddy and Whiting 2000). Bromoxynil

[1] Received for publication February 20, 2003, and in revised form May 12, 2003.

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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.

controls several broadleaf weeds but lacks activity on grasses and sedges (Anonymous 2000). However, both herbicides lack residual activity. Glyphosate has potential for total POST weed management with sequential glyphosate applications in GR cotton. Bromoxynil does not effectively control certain broadleaf weeds such as *Amaranthus* species and sicklepod in BR cotton (Culpepper and York 1999; Paulsgrove and Wilcut 1999, 2001; Reddy 2001). Bromoxynil tank mixtures with other POST herbicides and sequential applications are required to improve the spectrum of broadleaf weed control in BR cotton (Corbett et al. 2002; Culpepper and York 1999; Paulsgrove and Wilcut 1999; Reddy 2001). Residual preemergence (PRE) herbicides are usually necessary to reduce detrimental early-season weed interference and improve flexibility of POST herbicide applications for adequate broad-spectrum weed control in both BR and GR cotton. However, the need for PRE herbicides is more likely in BR cotton because of lack of activity on grasses and sedges and variable control of certain broadleaf weeds (Corbett et al. 2002; Paulsgrove and Wilcut 1999; Reddy 2001; Troxler et al. 2002) than in GR cotton (Askew et al. 2002; Askew and Wilcut 1999; Culpepper and York 1999; Faircloth et al. 2001).

BR and GR cotton cultivars were commercialized in the United States in 1995 and 1997, respectively. In the United States, the area planted to BR cotton has increased from 0.1% in 1995 to 3.7% in 2001, and area planted to GR cotton has increased from 4% in 1997 to 70% in 2001 (Gianessi et al. 2002). The rapid increase in adoption of GR cotton was primarily attributed to simplicity and flexibility of weed control program and lower herbicide cost. The slow adoption of BR cotton may be because of lack of bromoxynil activity on grasses and certain broadleaf weeds. However, both BR and GR cotton expand the options for weed management. The limited number of herbicides for POST control of certain broadleaf weeds in nontransgenic cotton may also have encouraged growers to adopt herbicide-resistant cotton (Monks et al. 1999; Paulsgrove and Wilcut 2001).

Overreliance on either BR or GR cotton weed control systems could lead to problems such as weed species shifts and evolution of resistant weeds. The weed species most likely to increase in frequency in BR and GR cotton fields are those that either have a natural tolerance to these herbicides or are only partially controlled. BR and GR cotton offer growers the advantages of different modes of action to use against herbicide resistance. Weed species shifts can be delayed or prevented from occurring with a rotation of BR and GR cotton. Information on the impact of continuous BR and GR cotton production on weed control and species shifts and the benefits of rotation of these systems is lacking.

Cotton is traditionally grown in rows spaced 76 to 102 cm apart (Culpepper and York 2000; Heitholt et al. 1992; Kerby 1998; Robinson 1993). In the United States, ultranarrow-row cotton production has received considerable attention in recent years. Ultranarrow-row cotton is grown in rows of 19- to 25-cm spacing (Atwell 1996; Atwell et al. 1996; Culpepper and York 2000; Kerby 1998). Ultranarrow-row cotton is usually maintained less than 81 cm tall to promote early maturity and improve stripper harvesting efficiency (Atwell 1996; Kerby 1998). Unlike wide-row cotton, banded application of PRE herbicides, interrow cultivation, POST-directed herbicide sprays, and hooded sprayer applications are not possible in ultranarrow-row cotton (Hayes and Gwathmey 1999). Weed control in ultranarrow-row cotton is dependent on broadcast application of PRE and POST herbicides. The weed species encountered in both ultranarrow- and wide-row cotton are similar; however, there are fewer late-season options to control weeds in ultranarrow-row cotton, which escape early-season control. Effective management of weeds is essential in ultranarrow-row cotton production systems to minimize yield loss and grade reduction.

Although weed control and cotton yield response in ultranarrow-row cotton have been reported (Culpepper and York 2000; Reddy 2001), the information on side-by-side comparisons of ultranarrow- and wide-row cotton systems is lacking. Heitholt et al. (1992) addressed the question of side-by-side comparison and found that yields were similar in 50- and 100-cm wide-row cotton. Their study used a fixed population of 100,000 plants/ha for both 50- and 100-cm rows, whereas ultranarrow-row cotton is typically grown in 19- to 25-cm-wide rows with higher plant populations. Several other reports indicate a similar or higher cotton yield in ultranarrow- vs. wide-row cotton (Atwell et al. 1996; Bader et al. 2000; Brown et al. 1998; Kerby 1998). Although these studies used higher plant populations, the cotton yield data were compiled from different fields and lack side-by-side comparisons and statistical analysis.

The objectives of this study were to assess weed control, weed density and shifts, and cotton yield response in BR and GR cotton rotation systems involving bromoxynil and glyphosate POST applications alone or following PRE herbicides under ultranarrow- and wide-row spacing.

MATERIALS AND METHODS

A 3-yr field study was conducted from 1999 through 2001 at the USDA Southern Weed Science Research Farm, Stoneville, MS (33°26′N). The soil was a Dundee silt loam (fine-silty, mixed, thermic Aeric Ochraqualf) with pH of 7.1, 1.1% organic matter, a cation exchange capacity of 15 cmol/kg, and soil textural fractions of 26% sand, 55% silt, and 19% clay. The experimental area was naturally infested with common purslane (3 plants/m^2), hemp sesbania (3 plants/m^2), hyssop spurge (8 plants/m^2), pitted morningglory (5 plants/m^2), prickly sida (14 plants/m^2), sicklepod (3 plants/m^2), smooth pigweed (3 plants/m^2), and yellow nutsedge (5 plants/m^2). Weed densities were determined from one 0.84-m^2 area in eight untreated control plots at 5 wk after second POST application (WAA) in 1999. Field preparation consisted of fall subsoiling, disking, and bedding. In spring, beds were conditioned nearly flat to enable flood irrigation and to plant cotton in ultranarrow (25 cm) rows. Before cotton planting, the experimental area was treated with paraquat at 1.1 kg ai/ha to kill existing vegetation. Rainfall during the growing season (May–August) was 25, 35, and 49 cm in 1999, 2000, and 2001, respectively. The 30-yr average rainfall for the corresponding period is 37 cm. Cotton was flood irrigated on July 19 and August 13 in 1999, July 17 and August 8 in 2000, and June 19 and July 24 in 2001.

BR and GR cotton were grown in a 3-yr rotation. The four rotation sequences were continuous BR cotton (BR–BR–BR), continuous GR cotton (GR–GR–GR), and rotations following each other (BR–GR–BR and GR–BR–GR). BR cotton cultivar 'BXN 47' and GR cotton cultivar 'DP 436 RR' were planted on May 10, 1999, April 21, 2000, and April 20, 2001. Cultivars were selected based on regional use patterns by producers and seed availability. Ultranarrow- and conventional wide-row spacings were used in the study. Cotton was planted in 25-cm (ultranarrow) rows at 312,000 seeds/ha using a Monosem NG plus precision planter.[4] Cotton in 102-cm (wide) rows was planted using a MaxEmerge 2 planter[5] at 111,000 seeds/ha.

Herbicide programs consisted of POST only, PRE + POST, and a no herbicide treatment. The POST-only treatment included two applications of bromoxynil at 0.56 kg ai/ha in BR cotton and two applications of glyphosate at 1.12 kg ai/ha in GR cotton. The PRE + POST treatment included fluometuron at 1.12 kg ai/ha plus pendimethalin at 1.12 kg ai/ha PRE, followed by two POST applications of bromoxynil at 0.56 kg ai/ha in BR cotton or two POST applications of glyphosate at 1.12 kg ai/ha in GR cotton. Fluometuron plus pendimethalin PRE was included as a conventional standard PRE herbicide program to make comparison of POST-only programs. PRE herbicides were applied broadcast immediately after planting. First POST and second POST treatments were applied at 1- to 2-leaf cotton (≈3 wk after planting) and 4- to 5-leaf cotton (≈5 wk after planting), respectively. Sethoxydim at 0.31 kg ai/ha was applied over all BR cotton plots 5 d after the first POST to control grass weeds. A paraffinic petroleum oil[6] was added to sethoxydim at 1.25% v/v as suggested by the manufacturer. Herbicide treatments were applied with a tractor-mounted sprayer with TeeJet 8004 standard flat spray tips delivering 187 L/ha water at 179 kPa. After the second POST application, wide-row cotton was cultivated once in 1999 and 2001 and two times in 2000.

Fertilizer application and insect control programs were standard for cotton production (Anonymous 2003; Reddy 2001). Disulfoton {*O*,*O*-diethyl *S*-[2-(ethylthio)ethyl] phosphorodithioate} at 1.12 kg ai/ha was applied in-furrow at cotton planting for early-season insect control. Acephate (*O*,*S*-dimethyl acetylphosphoramidothioate), dicrotophos (dimethyl phosphate of 3-hydroxy *N*,*N*-dimethyl-*cis*-crotonamide), profenofos [*O*-(4-bromo-2-chlorophenyl)*O*-ethyl *S*-propyl phosphorothioate], and malathion (*O*,*O*-dimethyl phosphorodithioate of diethyl mercaptosuccinate) were applied POST during the growing season as needed to control insects. Ultranarrow-row cotton plant height was kept short by applying mepiquat chloride (*N*,*N*-dimethylpiperidinium chloride) POST at the first matchhead square stage, followed by a second application 2 wk later. Harvest preparation consisted of defoliation by tribufos (*S*,*S*,*S*-tributyl phosphorotrithioate) and boll opening by ethephan [(2-chloroethyl)phosphonic acid], followed by desiccation with paraquat.

Control of individual weed species was visually estimated on the basis of reduction in weed population and plant vigor on a scale of 0 (no control) to 100% (complete control) at 2 WAA. Yellow nutsedge and broadleaf weeds were harvested from one 0.84-m^2 area within each plot 4 WAA, and dry weights were recorded. Weeds were counted by species in one 0.84-m^2 area in the middle of each plot at 4 WAA only in 2001. Cotton was

[4] Monosem NG Plus ultranarrow-row precision planter, Monosem ATI, Inc., 17135 West 116th Street, Lenexa, KS 66219.

[5] MaxEmerge 2 planter, Deere and Co., 501 River Drive, Moline, IL 61265.

[6] Agri-Dex is a proprietary blend of heavy-range, paraffin-based petroleum oil, polyol fatty acid esters, and polyethoxylated derivative nonionic adjuvant (99% active ingredient), Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38119.

Table 1. Common purslane and sicklepod control in ultranarrow- and wide-row BR and GR cotton rotation systems with PRE and POST herbicides in 1999, 2000, and 2001.[a,b]

	Control 2 WAA					
	Common purslane			Sicklepod		
Treatment	1999	2000	2001	1999	2000	2001
	%					
Main effects						
Row width						
Ultranarrow (25 cm)	75 a	75 a	75 a	93 a	89 b	92 a
Wide (102 cm)	75 a	75 a	75 a	84 a	95 a	92 a
Rotation						
BR–BR–BR	50 b	50 b	50 b	79 b	81 b	81 b
GR–GR–GR	100 a	100 a	100 a	100 a	100 a	100 a
BR–GR–BR	50 b	100 a	50 b	74 b	100 a	86 b
GR–BR–GR	100 a	50 b	100 a	100 a	87 b	100 a
Herbicide[c]						
POST only	50 b	50 b	50 b	78 b	84 b	87 b
PRE + POST	100 a	100 a	100 a	99 a	100 a	97 a
Interactions						
Rotation × herbicide						
BR–BR–BR × POST	0 b	0 b	0 b	59 b	63 c	73 b
BR–BR–BR × PRE + POST	100 a	100 a	100 a	100 a	99 a	90 a
GR–GR–GR × POST	100 a	100 a	100 a	100 a	100 a	100 a
GR–GR–GR × PRE + POST	100 a	100 a	100 a	100 a	100 a	100 a
BR–GR–BR × POST	0 b	100 a	0 b	52 b	100 a	76 b
BR–GR–BR × PRE + POST	100 a	100 a	100 a	96 a	100 a	96 a
GR–BR–GR × POST	100 a	0 b	100 a	100 a	74 b	100 a
GR–BR–GR × PRE + POST	100 a	100 a	100 a	100 a	100 a	100 a

[a] Abbreviations: BR, bromoxynil resistant; GR, glyphosate resistant; POST, postemergence; PRE, preemergence, WAA, weeks after second postemergence application.

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

[c] Fluometuron (1.12 kg/ha) and pendimethalin (1.12 kg/ha) were applied PRE. Bromoxynil (0.56 kg/ha) in BR and glyphosate (1.12 kg/ha) in GR cotton were applied POST twice.

manually harvested from the center four rows of 1-m length in ultranarrow-row spacing and the center two rows of 1-m length in wide-row spacing. Number of cotton plants and open bolls per plant were also counted from these areas at harvest. Because of heavy weed pressure, there was no cotton yield from untreated control plots.

The experiment was conducted in a split–split plot arrangement of treatments in a randomized complete block design, with row spacing as the main plot, rotation system as the subplot, and herbicide program as the sub-subplot with four replications. Each sub-subplot consisted of 16 rows spaced 25 cm apart and four rows spaced 102 cm apart, which were 13.7 m long. The identity of each treatment was maintained by assigning the same treatment to the same plot in all 3 yr. Data were analyzed separately for each year because of change in the cropping sequence. Data from the no-herbicide treatment were deleted before statistical analysis to stabilize variance. Data were subjected to analysis of variance using Proc Mixed, and the least squares means were calculated (SAS 1998). Treatment means were separated at the 5% level of significance using Fisher's Protected LSD test.

RESULTS AND DISCUSSION

Weed Control. Common purslane control 2 WAA was similar between ultranarrow- and wide-row cotton (Table 1). Common purslane control was higher in GR vs. BR cotton and PRE + POST vs. POST-only program. Within GR cotton, the glyphosate POST only provided complete control of common purslane as did the PRE + POST program in all 3 yr. Bromoxynil POST-only program in BR cotton did not control common purslane, and soil-applied herbicides (PRE + POST program) were required for complete control of common purslane in all 3 yr. Others have reported the need of a soil-applied herbicide for control of common purslane with bromoxynil (Blackley et al. 1999; Reddy 2001).

Sicklepod control at 2 WAA was 84 to 93%, regardless of row spacing in 1999 and 2001 (Table 1). In 2000, sicklepod control was 89% in ultranarrow-row compared

Table 2. Smooth pigweed and yellow nutsedge control in ultranarrow- and wide-row BR and GR cotton rotation systems with PRE and POST herbicides in 1999, 2000, and 2001.[a,b]

	Control 2 WAA					
	Smooth pigweed			Yellow nutsedge		
Treatment	1999	2000	2001	1999	2000	2001
	%					
Main effects						
Row width						
Ultranarrow (25 cm)	100 a	90 a	91 a	48 a	48 a	50 a
Wide (102 cm)	99 a	93 a	91 a	46 a	49 a	53 a
Rotation						
BR–BR–BR	99 a	83 b	78 c	0 b	0 b	0 d
GR–GR–GR	100 a	100 a	100 a	94 a	98 a	99 a
BR–GR–BR	99 a	100 a	87 b	0 b	97 a	23 c
GR–BR–GR	100 a	84 b	100 a	95 a	0 b	83 b
Herbicide[c]						
POST only	99 a	84 b	83 b	47 a	48 a	43 b
PRE + POST	100 a	100 a	99 a	48 a	50 a	48 a
Interactions						
Rotation × herbicide	NS			NS		
BR–BR–BR × POST	98	66 b	58 c	0	0 c	0 d
BR–BR–BR × PRE + POST	100	100 a	99 a	0	0 c	0 d
GR–GR–GR × POST	100	100 a	100 a	92	97 a	98 a
GR–GR–GR × PRE + POST	100	100 a	100 a	96	99 a	100 a
BR–GR–BR × POST	99	100 a	75 b	0	94 b	0 d
BR–GR–BR × PRE + POST	100	100 a	99 a	0	99 a	46 c
GR–BR–GR × POST	100	69 b	100 a	96	0 c	74 b
GR–BR–GR × PRE + POST	100	100 a	100 a	95	0 c	91 a

[a] Abbreviations: BR, bromoxynil resistant; GR, glyphosate resistant; POST, postemergence; PRE, preemergence; WAA, weeks after second postemergence application; NS, not significant.

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

[c] Fluometuron (1.12 kg/ha) and pendimethalin (1.12 kg/ha) were applied PRE. Bromoxynil (0.56 kg/ha) in BR and glyphosate (1.12 kg/ha) in GR cotton were applied POST twice.

with 95% in wide-row cotton. These differences may be attributed to slow canopy closure in ultranarrow-row cotton because of weather (Reddy 2001) and to two cultivations of wide-row cotton. Sicklepod was completely controlled in GR cotton compared with ≤86% control in BR cotton regardless of crop rotation and year. PRE + POST program controlled sicklepod (97 to 100%) better than did POST-only (78 to 87%) program in all 3 yr. Within BR cotton, bromoxynil POST-only program resulted in ≤76% control of sicklepod and use of soil-applied herbicides (PRE + POST program) greatly enhanced sicklepod control (≥90%) in all 3 yr (Table 1). Bromoxynil is not considered an effective herbicide for sicklepod control; however, levels of sicklepod control with bromoxynil POST in this study were higher than those observed in other research (Paulsgrove and Wilcut 1999; Reddy 2001).

There were no differences in smooth pigweed control 2 WAA between ultranarrow- and wide-row cotton, regardless of year (Table 2). Smooth pigweed control was ≥99% among rotations in 1999. In 2000 and 2001, smooth pigweed was completely controlled in GR cotton compared with ≤87% control in BR cotton regardless of crop rotation. Between herbicide programs, there was no difference in smooth pigweed control in 1999, whereas control was higher with PRE + POST (≥99%) than with POST-only (≤84%) program in 2000 and 2001. Although there were no differences within BR cotton between POST-only and PRE + POST program in 1999, in 2000 and 2001, bromoxynil POST-only (58 to 75%) program resulted in less control of smooth pigweed and application of PRE herbicides followed by POST (≥99%) program greatly enhanced smooth pigweed control (Table 2). Bromoxynil POST provided inadequate control of smooth pigweed in other research (Askew et al. 2002).

Yellow nutsedge control 2 WAA was similar between ultranarrow- and wide-row cotton (Table 2). Control of yellow nutsedge was higher in GR compared with BR cotton regardless of rotation and year. Yellow nutsedge control was similar between POST-only and PRE + POST programs in 1999 and 2000, whereas in 2001, control was higher with PRE + POST than with POST-only program. Within GR cotton, glyphosate POST

Table 3. Broadleaf and yellow nutsedge weed dry biomass in ultranarrow- and wide-row BR and GR cotton rotation systems with PRE and POST herbicides in 1999, 2000, and 2001.[a,b]

Treatment	Broadleaf weed dry biomass[c]			Yellow nutsedge dry biomass[c]		
	1999	2000	2001	1999	2000	2001
	kg/ha					
Main effects						
Row width						
Ultranarrow (25 cm)	102 a	484 a	378 a	7 a	313 a	917 a
Wide (102 cm)	176 a	476 a	197 a	10 a	205 a	689 a
Rotation						
BR–BR–BR	159 b	814 a	489 a	1 a	625 a	2,570 a
GR–GR–GR	24 b	75 b	16 b	16 a	19 b	3 b
BR–GR–BR	328 a	95 b	622 a	1 a	112 b	516 b
GR–BR–GR	44 b	936 a	23 b	17 a	280 b	123 b
Herbicide[d]						
POST only	261 a	823 a	565 a	14 a	279 a	956 a
PRE + POST	17 b	137 b	10 b	3 a	239 a	650 a
Interactions						
Rotation × herbicide				NS	NS	NS
BR–BR–BR × POST	318 b	1,457 a	950 a	1	674	3,054
BR–BR–BR × PRE + POST	1 c	171 b	27 b	1	576	2,086
GR–GR–GR × POST	47 c	126 b	30 b	23	30	6
GR–GR–GR × PRE + POST	0 c	23 b	2 b	9	9	0
BR–GR–BR × POST	642 a	84 b	1,235 a	1	100	545
BR–GR–BR × PRE + POST	13 c	106 b	9 b	1	123	487
GR–BR–GR × POST	36 c	1,623 a	43 b	34	313	220
GR–BR–GR × PRE + POST	52 c	249 b	2 b	1	247	26

[a] Abbreviations: BR, bromoxynil resistant; GR, glyphosate resistant; POST, postemergence; PRE, preemergence; NS, not significant.

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

[c] Broadleaf weed dry biomass in no-herbicide plot was 970, 1,300, and 2,790 kg/ha in 1999, 2000, and 2001, respectively. Predominant broadleaf weeds were common purslane, hemp sesbania, hyssop spurge, pitted morningglory, prickly sida, sicklepod, and smooth pigweed. Yellow nutsedge dry biomass in no-herbicide plot was 100, 360, and 1,110 kg/ha in 1999, 2000, and 2001, respectively. Weed dry weight was recorded 4 wk after the second POST.

[d] Fluometuron (1.12 kg/ha) and pendimethalin (1.12 kg/ha) were applied PRE. Bromoxynil (0.56 kg/ha) in BR and glyphosate (1.12 kg/ha) in GR cotton were applied POST twice.

only controlled 74 to 99% of yellow nutsedge in all 3 yr (Table 2). Bromoxynil, fluometuron, and pendimethalin lack activity on yellow nutsedge, and as a result bromoxynil POST-only and PRE + POST programs in BR cotton did not control yellow nutsedge. Yellow nutsedge management in BR cotton requires alternative herbicide options, similar to application of grass herbicides for grass weed control. Control of hemp sesbania, pitted morningglory, prickly sida, and hyssop spurge 2 WAA was ≥97% regardless of row width, rotation, and herbicide program in 1999, 2000, and 2001 (data not shown).

Weed Dry Biomass. Biomass of the predominant broadleaf weeds (common purslane, hemp sesbania, hyssop spurge, pitted morningglory, prickly sida, sicklepod, and smooth pigweed) was similar between ultranarrow- and wide-row cotton regardless of year (Table 3). Among rotations, broadleaf weed biomass was lowest in GR cotton (16 to 95 kg/ha) compared with BR cotton (159 to 936 kg/ha), regardless of rotation and year. Between herbicide programs, PRE + POST (17 to 137 kg/ha) program had lower broadleaf weed biomass compared with POST-only (261 to 823 kg/ha) program. Within BR cotton, broadleaf weed biomass was greatly reduced with bromoxynil POST after PRE herbicides compared with bromoxynil POST-only program. In contrast, glyphosate POST only in GR cotton was as effective as glyphosate POST following PRE herbicides in reducing broadleaf weed biomass. There were no differences in yellow nutsedge biomass regardless of row width and herbicide program and year (Table 3). Among rotations, there were no differences in yellow nutsedge biomass in 1999, whereas in 2000 and 2001, yellow nutsedge biomass was higher in continuous BR cotton than in other rotation systems. Furthermore, yellow nutsedge biomass has increased from 1 kg/ha in 1999 to 2,570 kg/ha in 2001 in continuous BR cotton, and biomass has greatly decreased when continuous BR cotton sequence was interrupted by GR cotton (e.g., BR–GR–BR and GR–BR–GR). Overall, biomass of broadleaf weed and yellow nutsedge reflects the degree of weed control discussed in the above section.

Table 4. Weed density 4 WAA in ultranarrow- and wide-row BR and GR cotton rotation systems with PRE and POST herbicides in 2001.[a,b]

	Weed density						
Treatment	Common purslane	Hyssop spurge	Pitted morningglory	Prickly sida	Sicklepod	Smooth pigweed	Yellow nutsedge
	plants/m²						
Main effects							
Row width							
Ultranarrow (25 cm)	11.3 a	0.8 a	0.0 a	0.2 a	0.6 a	1.3 a	131 a
Wide (102 cm)	5.8 a	0.8 a	0.1 a	0.4 a	0.6 a	0.3 a	90 a
Rotation							
BR–BR–BR	15.3 a	0.7 a	0.0 a	0.1 a	1.5 a	1.6 a	373 a
GR–GR–GR	0.7 b	0.7 a	0.1 a	0.4 a	0.1 b	0.1 a	1 b
BR–GR–BR	14.1 a	0.5 a	0.1 a	0.2 a	0.8 ab	0.4 a	54 b
GR–BR–GR	4.0 b	1.3 a	0.0 a	0.4 a	0.1 b	1.2 a	14 b
Herbicide[c]							
POST only	17.0 a	1.1 a	0.0 a	0.4 a	0.9 a	1.5 a	149 a
PRE + POST	0.1 b	0.5 a	0.1 a	0.2 a	0.3 b	0.1 b	71 b
Interactions							
Rotation × herbicide		NS	NS	NS		NS	
BR–BR–BR × POST	30.6 a	0.5	0	0.2	0.8 ab	3.1	519 a
BR–BR–BR × PRE + POST	0.0 b	0.9	0	0	1.2 a	0	227 b
GR–GR–GR × POST	1.5 b	0.9	0	0.3	0.0 b	0.2	1 c
GR–GR–GR × PRE + POST	0.0 b	0.5	0.2	0.5	0.2 b	0	1 c
BR–GR–BR × POST	28.0 a	0.9	0	0.5	1.2 a	0.8	54 c
BR–GR–BR × PRE + POST	0.1 b	0.2	0.2	0	0.3 ab	0	54 c
GR–BR–GR × POST	8.1 b	1.9	0	0.6	0.2 b	2.1	24 c
GR–BR–GR × PRE + POST	0.0 b	0.6	0	0.2	0.0 b	0.3	4 c

[a] Abbreviations: BR, bromoxynil resistant; GR, glyphosate resistant; POST, postemergence; PRE, preemergence; WAA, weeks after second postemergence application; NS, not significant.

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

[c] Fluometuron (1.12 kg/ha) and pendimethalin (1.12 kg/ha) were applied PRE. Bromoxynil (0.56 kg/ha) in BR and glyphosate (1.12 kg/ha) in GR cotton were applied POST twice.

Weed Density and Species Shift. Seven predominant weed species were counted in 2001 (third year of rotation) to assess the level of weed density and species shift as a consequence of BR and GR cotton rotation systems. Densities of common purslane, hyssop spurge, pitted morningglory, prickly sida, sicklepod, smooth pigweed, and yellow nutsedge in ultranarrow-row cotton were not different from those of wide-row cotton (Table 4). There were no differences in densities of hyssop spurge, pitted morningglory, prickly sida, and smooth pigweed among the four rotation systems. After 3 yr of rotation, densities of common purslane, sicklepod, and yellow nutsedge were higher in continuous BR cotton (15.3, 1.5, and 373 plants/m², respectively) than in continuous GR cotton (0.7, 0.1, and 1.0 plant/m², respectively). This shift can be attributed to higher activity of glyphosate than to no or limited activity of bromoxynil on these weed species. Hyssop spurge, pitted morningglory, and prickly sida densities were similar between POST-only and PRE + POST programs. However, densities of common purslane, sicklepod, smooth pigweed, and yellow nutsedge decreased with POST programs after soil-applied herbicides compared with POST-only programs (Table 4). The decrease in densities of common purslane and smooth pigweed due to PRE herbicides was more apparent in BR cotton than in GR cotton. In other research, purple nutsedge (*Cyperus rotundus* L.) population shift due to differential activity of herbicides has been documented (Bryson et al. 2003). Bryson et al. (2003) in a 4-yr ultranarrow-row cotton–soybean rotation observed that purple nutsedge population markedly decreased with glyphosate-based program compared with non–glyphosate-based program in continuous cotton, whereas in continuous soybean both glyphosate- and non–glyphosate-based programs were equally effective in reducing purple nutsedge populations.

Seed Cotton Yield. Untreated plots were not harvested because of severe weed infestations and were excluded from statistical analysis. Plant population at harvest in ultranarrow-row cotton was higher than in wide-row cotton as expected (Table 5). Generally, higher plant populations are used in ultranarrow-row cotton (Culpepper and York 2000; Reddy 2001) to keep the plants slender than in wide-row cotton (Atwell 1996; Heitholt et al. 1992; Kerby 1998). Decreased row width reduced lateral

Table 5. Cotton population at harvest, open bolls, and seed cotton yield in ultranarrow- and wide-row BR and GR cotton rotation systems with PRE and POST herbicides in 1999, 2000, and 2001.[a–c]

Treatment	Cotton population			Open bolls			Seed cotton		
	1999	2000	2001	1999	2000	2001	1999	2000	2001
	plants/ha (×1,000)			no/plant			kg/ha		
Main effects									
Row width									
Ultranarrow (25 cm)	270 a	230 a	178 a	3.4 b	3.3 b	4.3 b	3,240 b	2,780 b	2,540 b
Wide (102 cm)	105 b	89 b	69 b	6.8 a	7.5 a	9.4 a	5,540 a	5,330 a	4,500 a
Rotation									
BR–BR–BR	191 a	142 b	116 a	4.8 b	4.5 c	4.3 b	4,380 ab	2,900 c	2,130 b
GR–GR–GR	181 a	180 a	126 a	5.7 a	5.7 ab	8.2 a	4,730 a	4,870 a	4,240 a
BR–GR–BR	189 a	170 a	128 a	4.9 b	6.1 a	6.7 a	4,010 b	4,990 a	3,610 a
GR–BR–GR	190 a	146 b	123 a	5.1 b	5.4 b	8.0 a	4,440 a	3,460 b	4,100 a
Herbicide[d]									
POST only	186 a	153 b	123 a	5.1 a	4.6 b	6.2 b	4,300 a	3,310 b	3,010 b
PRE + POST	189 a	166 a	124 a	5.1 a	6.3 a	7.4 a	4,480 a	4,800 a	4,020 a
Interactions									
Rotation × herbicide	NS	NS	NS	NS		NS	NS		NS
BR–BR–BR × POST	183	129	114	4.8	2.8 c	3.4	4,280	1,390 b	1,700
BR–BR–BR × PRE + POST	199	155	118	4.8	6.3 ab	5.1	4,480	4,400 a	2,550
GR–GR–GR × POST	180	178	118	5.8	5.9 b	8.6	4,710	4,890 a	4,000
GR–GR–GR × PRE + POST	183	181	133	5.6	5.6 b	7.8	4,750	4,860 a	4,480
BR–GR–BR × POST	196	170	133	4.7	5.9 b	5.5	3,920	4,880 a	2,870
BR–GR–BR × PRE + POST	181	169	124	5.1	6.3 ab	7.9	4,100	5,090 a	4,340
GR–BR–GR × POST	187	133	125	5.2	3.7 c	7.3	4,290	2,080 b	3,480
GR–BR–GR × PRE + POST	193	159	120	5.0	7.1 a	8.8	4,590	4,830 a	4,730

[a] Untreated check plots were not harvested because of heavy weed pressure.

[b] Abbreviations: BR, bromoxynil resistant; GR, glyphosate resistant; POST, postemergence; PRE, preemergence; NS, not significant.

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

[d] Fluometuron (1.12 kg/ha) and pendimethalin (1.12 kg/ha) were applied PRE. Bromoxynil (0.56 kg/ha) in BR and glyphosate (1.12 kg/ha) in GR cotton were applied POST twice.

branch length, whereas mepiquat chloride reduced vertical growth, resulting in columnar plant type compared with conical plant type in wide-row cotton. This has resulted in lower open bolls per plant in ultranarrow-row cotton than in wide-row cotton (Table 5). Cotton populations were similar among rotation systems and herbicide programs in 1999 and 2001. In 2000, cotton population at harvest was reduced in BR vs. GR cotton and in POST-only vs. PRE + POST program. This stand reduction was attributed to mortality of cotton plants due to severe competition for resources from weeds in bromoxynil POST-only program in BR cotton.

Seed cotton yield was consistently higher in wide-row than in ultranarrow-row cotton regardless of year (Table 5). It should be stressed, however, that planting, plant population, weed management, cotton management, and harvesting practices in ultranarrow-row cotton production are substantially different from those used in wide-row cotton production systems. Therefore, yield difference between ultranarrow- and wide-row cotton could be a consequence of these inherent differences in production practices. Previous reports suggest that yields in ultranarrow-row (19- to 50-cm spacing) cotton were comparable to (Heitholt et al. 1992; Kerby 1998) or better (Atwell et al. 1996; Bader et al. 2000; Brown et al. 1998) than those of wide-row (91- to 102-cm spacing) cotton. However, the levels of seed cotton yield in ultranarrow-row cotton in this study were similar to those reported for ultranarrow-row BR and GR cotton by others (Bryson et al. 2003; Reddy 2001).

Among rotations, seed cotton yield was higher in continuous GR and GR–BR–GR system than in BR–GR–BR system in 1999 (Table 5). In 2000 and 2001, seed cotton yield was lowest in continuous BR cotton compared with the other three systems. Furthermore, seed cotton yields improved when continuous BR cotton sequence was interrupted by GR cotton (e.g., BR–GR–BR or GR–BR–GR). The low yield in continuous BR cotton was primarily the result of inadequate control of certain weed species (Tables 1 and 2) and lower open bolls per plant (Table 5).

There was no difference in seed cotton yield between two herbicide programs in 1999. In 2000 and 2001, PRE + POST program resulted in higher seed cotton yield than did POST-only program (Table 5). A similar trend was observed in open bolls per plant. The increased yield in PRE + POST program was likely the result of improved weed control with soil-applied herbicides compared with POST-only program. The increase in seed cotton yield as a result of PRE herbicides was more apparent in BR cotton than in GR cotton.

Results of this study indicate that weed management with POST-only program is feasible in the short term (first year) but involves risk in subsequent years. The risk was greater with bromoxynil POST-only than with glyphosate POST-only program because bromoxynil provides poor control of certain broadleaf weed species although both herbicides lack residual activity. Apparently, use of residual soil-applied herbicides was critical in BR cotton compared with GR cotton to reduce detrimental early-season interference from certain weeds and to ensure adequate control of broad-spectrum of weeds in cotton. Densities of common purslane, sicklepod, and yellow nutsedge were higher in continuous BR cotton than in continuous GR cotton. This study demonstrated that continuous BR cotton production resulted in weed species shift toward common purslane, sicklepod, and yellow nutsedge. In BR cotton, adequate control of common purslane, sicklepod, smooth pigweed, and yellow nutsedge requires additional PRE or POST herbicide options (or both). Seed cotton yield was consistently higher in wide- than in ultranarrow-row cotton, regardless of year. Seed cotton yield was lowest in continuous BR cotton compared with the other three rotation systems. Seed cotton yields of continuous BR cotton can be improved by rotating with GR cotton. Cotton producers could prevent these weed species shifts from occurring by simply rotating BR cotton with GR cotton.

ACKNOWLEDGMENTS

I thank Albert Tidwell and Terry Newton for technical assistance in fieldwork.

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