The *Journal of Cotton Science 10:328–338 (2006)*
http://journal.cotton.org, © The Cotton Foundation 2006

WEED SCIENCE

Management of Annual Grasses and *Amaranthus* spp. in Glufosinate-resistant Cotton

Andrew P. Gardner, Alan C. York*, David L. Jordan, and David W. Monks

ABSTRACT

Glufosinate may not adequately control annual grasses and *Amaranthus* spp. in glufosinate-resistant (GR) cotton (*Gossypium hirsutum* L.). A field experiment at six sites determined effects of residual herbicides and timing of initial glufosinate application on control of annual grasses, *Amaranthus* spp., *Ipomoea* spp., and common lambsquarters (*Chenopodium album* L.) in GR cotton. Glufosinate was initially applied early postemergence (EPOST) to 1- to 2-leaf cotton or mid-postemergence (MPOST) to 3- to 4-leaf cotton. Residual herbicides included fluometuron, fomesafen, pendimethalin, and pyrithiobac applied preemergence (PRE) and pyrithiobac mixed with glufosinate applied postemergence. All treatments included glufosinate late postemergence (6- to 7-leaf cotton) followed by prometryn plus MSMA postemergence-directed. Weed control and cotton yield were generally greater with glufosinate applied EPOST compared with MPOST. Greater early season control of annual grasses and *Amaranthus* spp. was noted at all sites when PRE herbicides preceded glufosinate. Greater late-season annual grass and *Amaranthus* spp. control was noted at four and two sites, respectively, with systems that included PRE herbicides. Differences among PRE herbicides were minor, except pyrithiobac was less effective on annual grasses. Pyrithiobac applied postemergence (POST) was less effective than PRE herbicides. *Ipomoea* spp. and common lambsquarters were controlled well by all herbicide systems. The PRE herbicides increased cotton yield at four of six sites, while pyrithiobac POST increased yield at one site. Good control of annual grasses, *Amaranthus* spp., *Ipomoea* spp., and common lambsquarters can be obtained in GR cotton with production systems that include PRE herbicides and well-timed glufosinate applications.

A. P. Gardner, A. C. York, D. L. Jordan, and D. W. Monks, Department of Crop Science, North Carolina State University, Box 7620, Raleigh, NC 27695-7620
*Corresponding author: alan_york@ncsu.edu

Glufosinate is an amino acid synthesis inhibitor that kills plants by inhibiting glutamine synthetase, the enzyme that catalyzes conversion of glutamic acid and ammonia into glutamine. Inhibition of glutamine synthetase leads to a rapid accumulation of ammonia and glyoxylate within the plant, which causes damage to chloroplast structures and a decrease and eventual termination of photosynthetic activity and ultimately necrosis of tissue (Coetzer and Al-Khatib, 2001; Devine et al., 1993;Wendler et al., 1990). Glufosinate was first registered for use in orchards, vineyards, and non-cropland areas (Singh and Tucker, 1987). More recently, it was registered for use in transgenic, glufosinate-resistant (GR) row crops (Anonymous, 2006a; 2006b).

Glufosinate-resistant cotton, commercialized in 2004, was created through insertion of a gene from the fungus *Streptomycyes viridochromogenes* that encodes for phosphinothricin acetyltransferase. This enzyme converts the active portion of the herbicide molecule, L-phosphinothricin, into the nontoxic acetylated form, *N*-acetyl-L-phosphinothricin (Devine et al., 1993; Hinchee et al., 1993). The transformed cotton has excellent tolerance of glufosinate, normally a non-selective herbicide, applied postemergence (POST) (Blair-Kerth et al., 2001). Glufosinate can be applied to GR cotton from cotton emergence until the early bloom stage (Anonymous, 2006a).

Glufosinate controls many annual weeds when applied in a timely manner; however, control of annual grasses and *Amaranthus* spp. can be marginal, especially in less than ideal growing conditions (Beyers et al., 2002; Coetzer et al., 2002; Corbett et al., 2004; Culpepper et al., 2000; Hill et al., 1997 Steckel et al., 1997; York and Culpepper, 2004). *Amaranthus* spp. are among the most troublesome weeds in cotton in the southeastern USA, and they have increased in significance in recent years (Webster, 2005; Webster and Coble, 1997). In 2005, Palmer amaranth (*Amaranthus palmeri* S.Wats.) was ranked among the top two most troublesome weeds in cotton in Georgia, Missouri, North Carolina, South Carolina, and Tennessee. *Amaranthus* spp., in general, are ranked among the top four most troublesome weeds in eight southern states (Webster, 2005). Corbett el al. (2004) reported greater control by glufosinate of 2-cm to 5-cm Palmer amaranth than 8-cm to 10-cm plants. Coetzer et al. (2002) controlled 2-cm to 5-cm, 7-cm to 10-cm, and 15-cm to 18-cm Palmer amaranth 81, 71, and 74%, respectively, with glufosinate. Redroot pigweed (*Amaranthus retroflexus* L.) followed a similar trend with reduced control as plant size increased. These data indicate the importance of timely application to *Amaranthus* spp. Time of application also impacts annual grass control by glufosinate (Dodds et al., 2005).

Control of annual grasses and *Amaranthus* spp. can be increased with multiple applications of glufosinate (Beyers et al., 2002; Coetzer et al., 2002; Culpepper et al., 2000; Murdock et al., 2003; Tharp and Kells, 2002; Wiesbrook et al., 2001). Regrowth may occur on plants not completely killed by glufosinate applied once, and new plants may emerge following a single application (Coetzer et al., 2002). Glufosinate has no soil residual activity (Vencill, 2002).

Preemergence herbicides are often applied to control *Amaranthus* spp. and grassy weeds (Beyers et al., 2002; Culpepper and York, 1997; 2000; Murdock et al., 2003; Reddy, 2001; Toler et al., 2002). Beyers et al. (2002) reported that pendimethalin, sulfentrazone, cloransulam, or flumioxin applied preemergence (PRE) followed by glufosinate applied POST controlled common waterhemp (*Amaranthus rudis* Sauer), *Ipomoea* spp., giant foxtail (*Setaria faberi* Herrm.), prickly sida (*Sida spinosa* L.), and common cocklebur (*Xanthium strumarium* L.) in soybean [*Glycine max* (L.) Merr.] more effectively than glufosinate applied alone. Fomesafen applied PRE also controls *Amaranthus* spp., including Palmer amaranth (Culpepper et al., 2000; Hill et al., 1997, Murdock and Keeton, 1998). Fomesafen applied PRE followed by glufosinate POST in soybean 9 wk after planting controlled Palmer amaranth 97% compared with 78% control by glufosinate alone (Hill et al., 1997). Bauman et al. (1998) reported greater than 90% control of Palmer amaranth by fomesafen applied PRE with less than 10% cotton injury. Other preemergence herbicides commonly used in cotton include pendimethalin, pyrithiobac, and fluometuron (Culpepper and York, 1997; 2000; Reddy, 2001; Toler et al., 2002). Previous research indicated a benefit from PRE herbicides followed by early POST herbicides when weed populations are great enough to compete with cotton early in the season (Culpepper and York, 1998; Reddy, 2001; Toler et al., 2002).

Pyrithiobac applied either PRE or POST effectively controls *Amaranthus* spp. (Culpepper and York, 1997; 2000; Jordan et al., 1993b; Pitts, 1998). York and Culpepper (2004) reported increased control of Palmer amaranth with pyrithiobac mixed with glufosinate.

In an effort to develop more effective weed management systems in GR cotton, research was conducted to determine the effect of glufosinate application timing and residual herbicides, including PRE herbicides and pyrithiobac applied POST, on control of annual grasses and *Amaranthus* spp. in a glufosinate-based GR cotton weed management system.

MATERIALS AND METHODS

The experiment was conducted in North Carolina at two sites during 2004 and four sites during 2005. Soil types at the experiment sites are included in Table 1. Cotton cultivar FiberMax FM958LL (Bayer CropScience; Research Triangle Park, NC) was planted on 97-cm rows in two fields on the Central Crops Research Station at Clayton on 11 May 2004 and 9 May 2005. The same cultivar was planted on 91-cm rows at the Upper Coastal Plain Research Station at Rocky Mount on 12 May 2005 and at the Tidewater Research Station at Plymouth on 13 May

Table 1. Description of soils at experiment sites

Site	Year	Soil series[z]	Soil texture	Soil pH	Soil organic matter (%)
Clayton-1	2004	Norfolk	Loamy sand	6.3	0.7
Clayton-2	2004	Gilead	Sandy loam	5.6	1.0
Clayton-1	2005	Dothan	Loamy sand	5.7	0.9
Clayton-2	2005	Gilead	Sandy loam	5.5	0.7
Rocky Mount	2005	Norfolk	Loamy sand	5.5	0.5
Plymouth	2005	Cape Fear	Loam	5.7	5.4

[z]Norfolk is a fine-loamy, kaolinitic, thermic Typic Kandiudults. Gilead is a fine, kaolinitic, thermic Aquic Hapludults. Dothan is a fine-loamy, kaolinitic, thermic Plinthic Kandiudults. Cape Fear is a fine, mixed, semiactive, thermic Typic Umbraquults.

2005. One site each year at Clayton (referred to as Clayton-1) had redroot pigweed, while the other site (Clayton-2) had Palmer amaranth (Table 2). All sites had a mixture of annual grasses, including large crabgrass [*Digitaria sanguinalis* (L.) Scop.], goosegrass [*Eleusine indica* (L.) Gaertn.], broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash], and fall panicum (*Panicum dichotomiflorum* Michx.), and *Ipomoea* spp., including entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray), pitted morningglory (*Ipomoea lacunosa* L.), and tall morningglory [*Ipomoea purpurea* (L.) Roth] (Table 2). All sites except Clayton-2 in 2004 also had common lambsquarters.

Table 2. Weed species and densities at each experiment site and weed size at initial glufosinate application

Site	Year	Species	Density (no. m^{-2})[w]	Height (cm) at initial glufosinate application[x]	
				EPOST	MPOST
Clayton-1	2004	Redroot pigweed	50	5	9
		Ipomoea spp.[y]	25	4	18
		Common lambsquarters	4	10	15
		Annual grasses[z]	22	8	15
Clayton-2	2004	Palmer amaranth	40	3	18
		Ipomoea spp.[y]	3	3	6
		Annual grasses[z]	30	3	13
Clayton-1	2005	Redroot pigweed	16	5	9
		Ipomoea spp.[y]	10	3	8
		Common lambsquarters	5	3	13
		Annual grasses[z]	17	5	13
Clayton-2	2005	Palmer amaranth	55	5	20
		Ipomoea spp.[y]	4	3	8
		Common lambsquarters	12	4	10
		Annual grasses[z]	38	5	9
Plymouth	2005	Redroot pigweed	13	8	10
		Ipomoea spp.[y]	9	4	10
		Common lambsquarters	5	5	9
		Annual grasses[z]	49	8	15
Rocky Mount	2005	Redroot pigweed	6	6	11
		Ipomoea spp.[y]	25	13	18
		Common lambsquarters	18	6	19
		Annual grasses[z]	33	8	13

[w] Weed densities were recorded in non-treated checks 1 wk after MPOST application.

[x] Weed heights were recorded in plots not receiving preemergence herbicides. EPOST= early postemergence application to 1- to 2-leaf cotton. MPOST = mid-postemergence application to 3- to 4-leaf cotton.

[y] *Ipomoea* spp. distribution consisted of the following: Clayton-1 in 2004, 65% entireleaf morningglory and 35% pitted morningglory; Clayton-2 in 2004, 100% tall morningglory; Clayton-1 in 2005, 40% entireleaf morningglory, 35% tall morningglory, and 25% pitted morningglory; Clayton-2 in 2005, 75% tall morningglory and 25% entireleaf morningglory; Rocky Mount, 75% tall morningglory and 25% entireleaf morningglory; and Plymouth, 65% tall morningglory, 20% entireleaf morningglory, and 15% pitted morningglory.

[z] Annual grass species distribution consisted of the following: Clayton-1 in 2004, 50% large crabgrass, 30% goosegrass, and 20% broadleaf signalgrass; Clayton-2 in 2004, 95% goosegrass and 5% large crabgrass; Clayton-1 in 2005, 45% goosegrass, 40% large crabgrass, and 15% fall panicum; Clayton-2 in 2005, 60% goosegrass and 40% large crabgrass; Rocky Mount, 55% goosegrass and 45% large crabgrass; and Plymouth, 50% goosegrass, 40% fall panicum, and 10% large crabgrass.

The experimental design was a randomized complete block with treatments replicated four times. Plots were four rows wide by 9.1 m long. Treatments consisted of a factorial arrangement of six residual herbicide options by two initial glufosinate application timings. Residual herbicide options included the following: no residual herbicide; fluometuron (Cotoran 4L; Griffin LLC; Valdosta, GA) applied PRE at 1120 g a.i. ha^{-1}; fomesafen (Reflex; Syngenta Crop Protection, Inc.; Greensboro, NC) applied PRE at 280 g a.i. ha^{-1}; pendimethalin (Prowl H2O; BASF Ag Products; Research Triangle Park, NC) applied PRE at 1120 g a.i. ha^{-1}; pyrithiobac (Staple; E. I. du Pont de Nemours and Co.; Wilmington, DE) applied PRE at 36 g a.i. ha^{-1}; and pyrithiobac at 36 g ha^{-1} mixed with glufosinate and applied POST. The PRE herbicides were applied immediately after planting. Initial glufosinate (Ignite; Bayer CropScience; Research Triangle Park, NC) application timings included early postemergence (EPOST) to 1- to 2-leaf cotton and mid-postemergence (MPOST) to 3- to 4-leaf cotton. A non-treated check also was included. All treatments, except the non-treated check, included glufosinate applied late postemergence (LPOST) to 6- to 7-leaf cotton and prometryn (Caparol 4L; Syngenta Crop Protection, Inc.; Greensboro, NC) at 1120 g a.i. ha^{-1} plus MSMA (MSMA 6.6; Platte Chemical Co.; Greeley, CO) at 2220 g a.i. ha^{-1} plus nonionic surfactant (Induce; Helena Chemical Co.; Memphis, TN) at 0.25% by volume applied postemergence-directed (POST-DIR) when cotton averaged 46 cm in height. The glufosinate rate was 470 g a.i. ha^{-1} in all applications.

Herbicides were broadcast PRE and POST using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles (TeeJet XR 11002 nozzles; Spraying Systems Co.; Wheaton, IL) calibrated to deliver 140 L ha^{-1} at 159 kPa. Postemergence-directed sprays were broadcast using a CO_2-pressurized backpack sprayer equipped with three flat-fan nozzles (TeeJet XR 110015 nozzles; Spraying Systems Co.; Wheaton, IL) per row middle calibrated to deliver 140 L ha^{-1} at 152 kPa.

Weed control and crop injury were estimated visually 3 wk after PRE herbicide application (before EPOST herbicide application), 1 wk after EPOST, MPOST, and LPOST herbicide applications, and late in the season (early September) using a scale of 0 to 100, where 0 = no control or injury to 100 = death of all plants (Frans et al., 1986). The center two rows of each plot were harvested using a spindle picker modified for small-plot harvesting. A sample of mechanically harvested seedcotton was collected from each plot at all sites except Plymouth and used to determine lint percentage and fiber quality. Seedcotton was ginned on a laboratory gin without lint cleaning. Cotton grades are not presented, because they would not be representative of cotton ginned commercially. Fiber upper half mean length, fiber length uniformity index, fiber strength, and micronaire were determined by high volume instrumentation testing (Sasser, 1981).

Data were subjected to analysis of variance using the PROC MIXED procedure of the Statistical Analysis System (version 9.1; SAS Institute Inc.; Cary, NC) with partitioning appropriate for the 6 by 2 factorial arrangement of treatments. Locations were considered as random effects (McIntosh, 1983). Data were averaged over sites as appropriate, and means of significant main effects and interactions were separated using Fisher's protected LSD at $P = 0.05$.

RESULTS AND DISCUSSION

Rainfall was adequate for PRE herbicide activation at each site. Both sites at Clayton received 1.2 and 3.4 cm of rainfall during the first 7 d after planting in 2004 and 2005, respectively (data not shown). Rocky Mount and Plymouth received 3.5 and 1.7 cm of rainfall, respectively, within 1 wk after planting.

***Amaranthus* control.** Residual herbicides increased *Amaranthus* spp. control in glufosinate-based systems. All PRE herbicides controlled *Amaranthus* spp. greater than 90% 3 wk after planting and prior to the initial glufosinate application (Table 3). Fomesafen was more effective on *Amaranthus* spp. than fluometuron or pyrithiobac. Excellent control of *Amaranthus* spp. by fomesafen applied PRE has been reported previously (Baumann et al., 1998; Kendig et al., 2000; Murdock and Keeton, 1998).

Amaranthus spp. control 1 wk after the initial glufosinate application and 1 wk after the LPOST glufosinate application was greater when PRE herbicides were included in the system (Table 4). Control was similar when fluometuron, fomesafen, pendimethalin, or pyrithiobac applied PRE preceded the initial glufosinate application but 10 to 15% greater than systems with no PRE herbicide. Pyrithiobac mixed with glufosinate increased *Amaranthus* spp. control 4 to 6% compared with glufosinate alone. Control by glufosinate plus pyrithiobac was less than control by a PRE herbicide followed by glufosinate. Pyrithiobac kills susceptible plants slowly, so a 1-wk interval after application may not have been sufficient for the maximum effect to be expressed.

Table 3. Control of weeds by herbicides applied preemergence

Herbicide	Rate (g ha^{-1})	Control (%)[w]			
		Amaranthus spp.[x]	Common lambsquarters	*Ipomoea* spp.[y]	Annual grasses[z]
Fluometuron	1120	93 b	98 a	50 a	91 a
Fomesafen	280	98 a	80 b	48 a	90 a
Pendimethalin	1120	95 ab	98 a	35 a	90 a
Pyrithiobac	36	91 b	93 a	54 a	71 b

[v] Data were recorded 3 wk after planting and prior to early postemergence application of glufosinate and averaged over five sites for common lambsquarters or six sites for other species. Means within a column followed by the same letter are not different according to Fisher's Protected LSD at *P* = 0.05.

[x] *Amaranthus* spp. consisted of redroot pigweed and Palmer amaranth.

[y] *Ipomoea* spp. consisted of mixtures of entireleaf morningglory, pitted morningglory, and tall morningglory.

[z] Annual grasses consisted of mixtures of two or more of the following: large crabgrass, goosegrass, broadleaf signalgrass, and fall panicum.

Table 4. Control of weeds 1 wk after initial and 1 wk after late-postemergence glufosinate application as affected by residual herbicides

Residual herbicides[w]		Control (%)[v]			
		1 wk after initial application			
Preemergence	Postemergence	*Amaranthus* spp.[x]	Common lambsquarters	*Ipomoea* spp.[y]	Annual grasses[z]
Fluometuron	Glufosinate	97 a	100 a	97 ab	96 a
Fomesafen	Glufosinate	98 a	92 b	96 b	94 ab
Pendimethalin	Glufosinate	96 a	100 a	94 b	94 ab
Pyrithiobac	Glufosinate	96 a	99 a	99 a	90 b
None	Glufosinate	83 c	86 c	96 b	83 c
None	Glufosinate + pyrithiobac	87 b	91 b	98 ab	82 c
		1 wk after late-postemergence application			
Fluometuron	Glufosinate	98 a	100 a	98 ab	-
Fomesafen	Glufosinate	100 a	100 a	98 ab	-
Pendimethalin	Glufosinate	98 a	100 a	98 ab	-
Pyrithiobac	Glufosinate	98 a	100 a	98 ab	-
None	Glufosinate	88 c	97 c	97 b	-
None	Glufosinate + pyrithiobac	94 b	99 b	99 a	-

[v] Data averaged over EPOST (early postemergence, 1- to 2-leaf cotton) and MPOST (mid-postemergence, 3- to 4-leaf cotton) glufosinate applications and five sites for common lambsquarters or six sites for other species. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at *P* = 0.05.

[w] Fluometuron, fomesafen, pendimethalin, and pyrithiobac applied preemergence at 1120, 280, 1120, and 36 g ha^{-1}, respectively. Glufosinate and pyrithiobac applied postemergence at 470 and 36 g ha^{-1}, respectively.

[x] *Amaranthus* spp. consisted of redroot pigweed and Palmer amaranth.

[y] *Ipomoea* spp. consisted of mixtures of entireleaf morningglory, pitted morningglory, and tall morningglory.

[z] Annual grasses consisted of mixtures of two or more of the following: large crabgrass, goosegrass, broadleaf signalgrass, and fall panicum.

A site by residual herbicide interaction was noted for *Amaranthus* spp. control late in the season. Following the POST-DIR application of prometryn plus MSMA, *Amaranthus* spp. at four of the six sites were controlled at least 98% by all herbicide systems (Table 5). At Clayton-2 in 2004 and at Rocky Mount in 2005, however, greater *Amaranthus* spp. control was noted in systems with residual PRE herbicides or with pyrithiobac mixed with the initial glufosinate application. All PRE herbicides were more effective than pyrithiobac

POST at Rocky Mount, but fomesafen was the only PRE herbicide more effective than pyrithiobac POST at Clayton-2 in 2004. Few *Amaranthus* spp. emerged following the POST-DIR application at any site. Poorer late-season control in the absence of residual herbicides at Clayton-2 in 2004 and Rocky Mount was due primarily to some weeds being too large for effective spray coverage and control by prometryn plus MSMA applied POST-DIR.

Time of initial glufosinate application affected control of *Amaranthus* spp. 1 wk after the initial glufosinate application. Slightly greater control (100 vs. 99%) was noted when glufosinate was initially applied EPOST compared with MPOST (Table 6). The *Amaranthus* spp. were smaller at time of EPOST application, and glufosinate typically is more effective on smaller *Amaranthus* spp. (Coetzer et al., 2002; Corbett et al., 2004). Similar results were noted 1 wk after the LPOST glufosinate application (data not shown). Larger *Amaranthus* spp. not killed by glufosinate initially applied at MPOST were also not controlled as well following the LPOST glufosinate application.

Common lambsquarters. Prior to glufosinate application, fluometuron, pendimethalin, and pyrithiobac applied PRE controlled common lambsquarters 93 to 98% (Table 3). Each of these herbicides was more effective than fomesafen, which controlled common lambsquarters 80%.

At 1 wk after the initial glufosinate application, common lambsquarters was controlled 99 to 100% in systems that included fluometuron, pendimethalin, or pyrithiobac applied PRE compared with 86% control by glufosinate in the absence of PRE herbicides (Table 4). Similar to observations prior to glufosinate application, control of common lambsquarters was less in systems with fomesafen applied PRE than in systems with the other PRE herbicides. Pyrithiobac mixed with glufosinate increased common lambsquarters control 5%, but control by glufosinate plus pyrithiobac was less than control by fluometuron, pendimethalin, or pyrithiobac applied PRE followed by glufosinate. A minor increase in control also was noted 1 wk after the LPOST application in systems including a PRE herbicide or pyrithiobac POST (Table 4). Glufosinate applied twice controlled common lambsquarters 97% at this time.

A time of initial glufosinate application by site interaction was noted for common lambsquarters control 1 wk after the initial glufosinate application. At Clayton-2 in 2005, common lambsquarters control was 29% greater when glufosinate was applied EPOST compared with MPOST application (data not shown). An explanation for this observation is not readily apparent. The weeds at this site were generally no larger at time of MPOST glufosinate application than at other sites (Table 2). Following the LPOST application of glufosinate, excellent control of common lambsquarters was noted with all treatments regardless of timing of the initial glufosinate application. At this time, the weed was controlled 100 and 99% in systems with glufosinate initially applied EPOST and MPOST, respectively (data not shown). Time of initial glufosinate application had

Table 5. Late season control of *Amaranthus* spp. as affected by residual herbicides

Residual herbicides[z]		Control (%)[y]					
		2004		2005			
Preemergence	Postemergence	Clayton-1	Clayton-2	Clayton-1	Clayton-2	Plymouth	Rocky Mount
Fluometuron	Glufosinate	100 a	96 ab	100 a	99 a	100 a	99 a
Fomesafen	Glufosinate	100 a	98 a	100 a	100 a	100 a	100 a
Pendimethalin	Glufosinate	100 a	92 ab	100 a	99 a	100 a	97 a
Pyrithiobac	Glufosinate	100 a	86 b	100 a	100 a	100 a	99 a
None	Glufosinate	99 a	71 c	98 a	99 a	100 a	74 c
None	Glufosinate + pyrithiobac	99 a	85 b	98 a	100 a	100 a	80 b

[y] Data averaged over six sites and two times of initial glufosinate application (1- to 2-leaf or 3- to 4-leaf cotton). All systems included a late-postemergence (6- to 7-leaf cotton) application of glufosinate and a lay-by application of prometryn plus MSMA. *Amaranthus* spp. consisted of redroot pigweed at four sites and Palmer amaranth at two sites. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[z] Fluometuron, fomesafen, pendimethalin, and pyrithiobac applied preemergence at 1120, 280, 1120, and 36 g ha^{-1}, respectively. Glufosinate plus pyrithiobac applied postemergence at 470 and 36 g ha^{-1}, respectively.

no effect on common lambsquarters control at the remaining five sites, where the weed was controlled at least 95% regardless of time of initial glufosinate application. No differences in late-season common lambsquarters control were noted among treatments. All treatments controlled common lambsquarters at least 96% (data not shown).

Morningglory control. The PRE herbicides controlled *Ipomoea* spp. poorly, with control ranging from 35 to 54% (Table 3). Glufosinate, however, controlled *Ipomoea* spp. very well. Regardless of PRE herbicide, *Ipomoea* spp. were controlled at least 94 and 97% by all treatments 1 wk after the initial glufosinate application and 1 wk after the LPOST application, respectively (Table 4). Time of initial glufosinate application affected *Ipomoea* spp. control 1 wk after the initial glufosinate application, where control was 5% greater with EPOST application compared with MPOST application (Table 6). An effect of timing of the initial glufosinate application was not observed 1 wk after LPOST glufosinate application, when all treatments controlled *Ipomoea* spp. at least 97% (Table 4). All treatments controlled *Ipomoea* spp. at least 97% late in the season (data not shown). These results are consistent with previous reports of excellent *Ipomoea* spp. control by glufosinate (Corbett et al., 2004; Culpepper et al., 2000).

Annual grass control. Annual grasses were controlled 90 to 91% 3 wk after PRE application of fluometuron, fomesafen, and pendimethalin (Table 3). Pyrithiobac was less effective (71%) in controlling annual grasses. Greater control of annual grasses was noted in systems with a PRE herbicide 1 wk after the initial glufosinate application (Table 4). The PRE herbicides increased control of annual grasses 7 to 13%. Only minor differences were noted among the PRE herbicides, and fluometuron was more effective than pyrithiobac. Pyrithiobac applied POST in combination with glufosinate did not impact annual grass control. Pyrithiobac applied POST typically controls annual grasses poorly (Jordan et al., 1993a).

Time of initial glufosinate application affected annual grass control 1 wk after initial application. Control of annual grasses was 9% greater when glufosinate was applied EPOST compared with MPOST application (Table 6). Timing of initial glufosinate application did not affect annual grass control 1 wk after the LPOST application or late in the season (data not shown).

Table 6. Effect of glufosinate application timing on weed control 1 wk after initial glufosinate application

Time of initial glufosinate application[w]	Control (%)[v]		
	Amaranthus spp.[x]	*Ipomoea* spp.[y]	Annual grasses[z]
EPOST	100	100	93
MPOST	99*	97	84*

[v] Data recorded 1 wk after EPOST application or 1 wk after MPOST application and averaged over residual herbicides. An asterisk (*) denotes a significant difference between EPOST and MPOST means according to Fisher's Protected LSD test at $P = 0.05$.

[w] EPOST = early postemergence application to 1- to 2-leaf cotton; MPOST = mid-postemergence application to 3- to 4-leaf cotton.

[x] *Amaranthus* spp. consisted of redroot pigweed and Palmer amaranth.

[y] *Ipomoea* spp. consisted of mixtures of entireleaf morningglory, pitted morningglory, and tall morningglory.

[z] Annual grasses consisted of mixtures of two or more of the following: large crabgrass, goosegrass, broadleaf signalgrass, and fall panicum.

An interaction of residual herbicides by sites was noted for annual grass control 1 wk after LPOST glufosinate application. All treatments controlled annual grasses 98 to 100% at both Clayton sites in 2005 (Table 7). All PRE herbicides, except fomesafen at Clayton-2 in 2004, increased annual grass control 6 to 27% at the remaining three sites. Pyrithiobac mixed with glufosinate at the initial application impacted annual grass control 1 wk after LPOST glufosinate application only at Plymouth, where pyrithiobac POST increased annual grass control 5%. An interaction of residual herbicides by sites was also noted for annual grass control late in the season. Trends for annual grass control late in the season at both Clayton sites in 2004 and at Rocky Mount were similar to those observed 1 wk after LPOST glufosinate application (Table 7). At these sites, all PRE herbicides increased late-season annual grass control 9 to 42% (Table 7). Annual grass control at both Clayton sites in 2005 was generally less late in the season than 1 wk after LPOST glufosinate application. The cotton canopy never closed at Clayton in 2005 due to dry conditions from mid-season until harvest. The open row middles allowed annual grasses to emerge after the POST-DIR application of prometryn plus MSMA. The opposite response was noted at Plymouth where the cotton tended to be excessively vegetative. All treatments at Plymouth controlled annual grasses at least 97%

late in the season. Greater control late in the season as compared with 1 wk after LPOST glufosinate application is indicative of control by prometryn plus MSMA applied POST-DIR followed by a closed cotton canopy. Pyrithiobac mixed with glufosinate increased annual grass control late in the season only at Clayton-2 in 2004.

Cotton response. Cotton injury determined 3 wk after planting and before EPOST application of glufosinate was similar for all PRE herbicides and ranged from 13 to 16% (data not shown). Pyrithiobac mixed with glufosinate injured cotton 6% when applied EPOST. Injury from all other treatments was 2% or less following EPOST application, and no injury was noted later in the season (data not shown).

Yields of non-treated check plots were assumed to be zero as these plots were decimated by weeds and could not be harvested mechanically. Residual herbicides had no effect on seedcotton yield at Plymouth or Clayton-2 in 2005 (Table 8). At the remaining four sites, all PRE herbicides, except pyrithiobac at Clayton-1 in 2005, increased seedcotton yield. Yields were similar with the four PRE herbicides at Clayton-2 in 2004, Clayton-1 in 2005, and Rocky Mount. At Clayton-1 in 2004, yields were greatest with fluometuron, intermediate with fomesafen and pendimethalin, and lowest with pyrithiobac. Compared with glufosinate alone, PRE herbicides increased yields by an average of 57, 32, 19, and 36% at Clayton-1 in 2004, Clayton-2 in 2004, Clayton-1 in 2005, and Rocky Mount, respectively. Pyrithiobac applied POST with glufosinate increased yield 27% at Clayton-2 in 2004 but had no effect at the remaining sites. Time of initial glufosinate application affected seedcotton yield at four of the six sites (Table 9). Seedcotton yields were 6 to 13% greater when glufosinate was initially applied EPOST compared with MPOST application.

Percentage lint and selected fiber quality parameters were determined at five of the six sites. No differences among herbicide treatments were noted for percentage lint, fiber length, fiber length uniformity, fiber strength, or micronaire. Averaged over herbicide treatments and sites, percentage lint,

Table 7. Control of annual grasses 1 wk after late–postemergence glufosinate application and at late-season as affected by residual herbicides

Residual herbicides[z]		Control (%)[y]					
		1 wk after late-postemergence application					
		2004		2005			
Preemergence	Postemergence	Clayton-1	Clayton-2	Clayton-1	Clayton-2	Plymouth	Rocky Mount
Fluometuron	Glufosinate	90 a	97 a	100 a	100 a	92 ab	90 a
Fomesafen	Glufosinate	91 a	90 ab	100 a	100 a	92 ab	90 a
Pendimethalin	Glufosinate	88 a	96 a	100 a	100 a	94 a	93 a
Pyrithiobac	Glufosinate	77 b	94 a	100 a	100 a	89 b	80 b
None	Glufosinate	66 c	80 b	100 a	100 a	83 c	66 c
None	Glufosinate + pyrithiobac	67 c	83 b	98 a	100 a	88 b	65 c
		Late-season control					
Fluometuron	Glufosinate	98 a	94 a	93 a	94 ab	99 a	99 a
Fomesafen	Glufosinate	97 a	87 ab	90 a	95 ab	99 a	98 a
Pendimethalin	Glufosinate	97 a	94 a	91 a	97 a	100 a	98 a
Pyrithiobac	Glufosinate	92 ab	85 ab	86 ab	94 ab	100 a	89 a
None	Glufosinate	83 c	66 c	80 b	90 b	100 a	56 b
None	Glufosinate + pyrithiobac	89 bc	79 b	78 b	94 ab	97 a	49 b

[y]Data averaged over six sites and two times of initial glufosinate application (1- to 2-leaf or 3- to 4-leaf cotton). All systems included a late-postemergence (6- to 7-leaf cotton) application of glufosinate. Annual grasses consisted of a mixture of two or more of the following: large crabgrass, goosegrass, broadleaf signalgrass, and fall panicum. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[z] Fluometuron, fomesafen, pendimethalin, and pyrithiobac applied preemergence at 1120, 280, 1120, and 36 g ha^{-1}, respectively. Glufosinate and pyrithiobac applied postemergence at 470 and 36 g ha^{-1}, respectively.

upper half mean fiber length, fiber length uniformity index, fiber strength, and micronaire were 43%, 29 mm, 83%, 32 kN m kg^{-1}, and 4.5, respectively (data not shown).

This research, along with previously reported work (Murdock et al., 2003; York and Culpepper, 2004), demonstrates that good weed control can be achieved in glufosinate-resistant cotton. Of the commonly encountered weeds, annual grasses and *Amaranthus* spp. are among the most difficult to control with glufosinate (Coetzer et al., 2002; Corbett et al., 2004, Culpepper et al., 2000). This research indicates that annual grasses and *Amaranthus* spp. can be controlled in glufosinate-based management systems that integrate PRE herbicides and timely applied glufosinate.

Currently available glufosinate-resistant cultivars have not performed well in North Carolina's official cultivar trials (Bowman, 2006). Efforts are being made to transfer the glufosinate-resistance trait into cultivars that are better adapted to the southeastern United States (Klingenberg, 2005). Once such cultivars are commercialized, a glufosinate-based weed management system may be a viable alternative to glyphosate-based systems and offer growers an additional tool to manage herbicide-resistant weeds.

ACKNOWLEDGMENT

This research was partially supported by the cotton growers of North Carolina through Cotton Incorporated's state support program.

Table 8. Seedcotton yield as affected by residual herbicides in a glufosinate-based weed management system

Residual herbicides[z]		Yield (kg ha^{-1}) [y]					
		2004		2005			
Preemergence	Postemergence	Clayton-1	Clayton-2	Clayton-1	Clayton-2	Plymouth	Rocky Mount
Fluometuron	Glufosinate	3170 a	2900 a	2580 a	3290 a	3220 a	2960 a
Fomesafen	Glufosinate	2930 b	2750 a	2580 a	3310 a	3320 a	2870 a
Pendimethalin	Glufosinate	2890 b	2920 a	2530 a	3240 a	3420 a	3000 a
Pyrithiobac	Glufosinate	2410 c	2950 a	2390 ab	3480 a	3530 a	2970 a
None	Glufosinate	1810 d	2180 b	2120 b	3450 a	3280 a	2170 b
None	Glufosinate + pyrithiobac	1970 d	2760 a	1810 b	3230 a	3180 a	2200 b

[y] Data averaged over early postemergence (1- to 2-leaf cotton) and mid-postemergence (3- to 4-leaf cotton) glufosinate applications. All systems included a late-postemergence (6- to 7-leaf cotton) application of glufosinate and a postemergence-directed (40-cm cotton) application of prometryn plus MSMA. Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $P = 0.05$.

[z] Fluometuron, fomesafen, pendimethalin, and pyrithiobac applied preemergence at 1120, 280, 1120, and 36 g ha^{-1}, respectively. Glufosinate and pyrithiobac applied postemergence at 470 and 36 g ha^{-1}, respectively.

Table 9. Seedcotton yield as affected by time of initial glufosinate application in a glufosinate-based weed management system

Time of initial glufosinate application[z]	Yield (kg ha^{-1}) [y]					
	2004		2005			
	Clayton-1	Clayton-2	Clayton-1	Clayton-2	Plymouth	Rocky Mount
EPOST	2600	2910	2460	3310	3380	2820
MPOST	2460*	2580*	2220*	3360	3270	2570*

[y] Data averaged over residual herbicides. An asterisk (*) denotes a significant difference between EPOST and MPOST means according to Fisher's Protected LSD test at $P = 0.05$.

[z] EPOST, early postemergence to 1- to 2-leaf cotton; MPOST, mid-postemergence to 3- to 4-leaf cotton.

LITERATURE CITED

Anonymous. 2006a. Ignite herbicide label. Bayer CropScience, Research Triangle Park, NC [Online]. Available at http://www.cdms.net/1dat/1d6ER002.pdf (verified 14 Mar. 2006).

Anonymous. 2006b. Liberty herbicide label. Bayer CropScience, Research Triangle Park, NC [Online]. Available at http://www.cdms.net/1dat/1d3NU014.pdf (verified 14 Mar. 2006).

Baumann, P. A., J. W. Keeling, G. D. Morgan, and J. W. Smith. 1998. Evaluation of fomesafen for weed control in Texas cotton. p. 43-44. *In* Proc. South. Weed Sci. Soc., Birmingham, AL. 26-28 Jan. 1998. South. Weed Sci. Soc., Champaign, IL.

Beyers, J. T., R. J. Smeda, and W. G. Johnson. 2002. Weed management programs in glufosinate-resistant soybean (*Glycine max*). Weed Technol. 16:267-273.

Blair-Kerth, L. K., P. A. Dotray, J. W. Kneeling, J. R. Gannaway, M. J. Oliver, and J. E. Quisenberry. 2001. Tolerance of transformed cotton to glufosinate. Weed Sci. 49:375-380.

Bowman, D. T. 2006. Weed management in cotton. p. 27-36. *In* 2005 Cotton Information. Publ. AG-417. North Carolina Coop. Ext. Serv., Raleigh, NC.

Coetzer, E., and K. Al-Khatib. 2001. Photosynthetic inhibition and ammonium accumulation in Palmer amaranth after glufosinate application. Weed Sci. 49:454-459.

Coetzer, E., K., Al-Khatib, and D. E. Peterson. 2002. Glufosinate efficacy on *Amaranthus* species in glufosinate-resistant soybean (*Glycine max*). Weed Technol. 16:326-331.

Corbett, J. L., S. D. Askew, W. E. Thomas, and J. W. Wilcut. 2004. Weed efficacy evaluations for bromoxynil, glufosinate, glyphosate, pyrithiobac, and sulfosate. Weed Technol. 18:443-453.

Culpepper, A. S., and A. C. York. 1997. Weed management in no-tillage bromoxynil-tolerant cotton (*Gossypium hirsutum*). Weed Technol. 11:335-345.

Culpepper, A. S., and A. C. York. 1998. Weed management in glyphosate-tolerant cotton. J. Cotton Sci. 2:174-185 [Online]. Available at http://www.cotton.org/journal/1998-02/4/upload/jcs02-174.pdf.

Culpepper, A. S., and A. C. York. 2000. Weed management in ultra narrow row cotton (*Gossypium hirsutum*). Weed Technol. 14:19-29.

Culpepper, A. S., A. C. York, R. B. Batts, and K. M. Jennings. 2000. Weed management in glufosinate- and glyphosate-resistant soybean (*Glycine max*). Weed Technol.14:77-88.

Devine, M., S. O. Duke, and C. Fedtke. 1993. Inhibition of amino acid biosynthesis. p.251-294. *In* Physiology of herbicide action. P T R Prentice Hall, Englewood Cliffs, NJ.

Dodds, D. M., D. B. Reynolds, J. J. Walton, and M. T. Kirkpatrick. 2005. The use of residual herbicides in conjunction with early postemergence applications of glyphosate or glufosinate in transgenic weed control programs. p. 2930-2931. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 4-7 Jan. 2005. Natl. Cotton Counc. Am., Memphis, TN.

Frans, R. E., R. Talbert, D. Marx, and H. Crowley. 1986. Experimental design and techniques for measuring and analyzing plant responses to weed control practices. p. 29-46. *In* N. D. Camper (ed.) Research methods in weed science. Southern Weed Sci. Soc., Champaign, IL.

Hill, A. S., E. C. Murdock, and A. Keeton. 1997. Weed control in Liberty Link corn and soybeans. p. 58-59. *In* Proc. South. Weed Sci. Soc., Houston, TX. 20-22 Jan. 1997. Southern Weed Sci. Soc., Champaign, IL.

Hinchee, M.A.W., S. R. Padgette, G. M. Kishore, X. Delannay, and R. T. Fraley. 1993. Herbicide-tolerant crops. p. 243-263. *In* S. Kung and R. Wu (ed.) Transgenic plants. Academic Press, Inc., San Diego, CA.

Jordan, D. L., R. E. Frans, and M. R. McClelland. 1993a Interactions of DPX-PE350 with fluazifop-P, sethoxydim, clethodim, and quizalofop-P. Weed Technol. 7:605-610.

Jordan, D. L., R. E. Frans, and M. R. McClelland. 1993b. Total postemergence herbicide programs in cotton (*Gossypium hirsutum*) with sethoxydim and DPX-PE350. Weed Technol. 7:196-201.

Kendig, A., A. Ohmes, R. Barham, and P. Ezell. 2000. Performance of Reflex (fomesafen) in Missouri cotton. p. 1461. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis TN.

Klingenberg, J. P. 2005. Breeding new Fibermax varieties with improved lint yield and premium fiber for the Southeastern USA. p. 1045. In Proc. Beltwide Cotton Conf., New Orleans, LA. 4-7 Jan. 2005. Natl. Cotton Counc.. Am., Memphis, TN.

McIntosh, M. S. 1983. Analysis of combined experiments. Agron. J. 75:153-155.

Murdock, E. C., and A. Keeton. 1998. Where does fomesafen fit in South Carolina cotton weed management programs? p. 12-13. *In* Proc. South. Weed Sci. Soc., Birmingham, AL. 26-28 Jan. 1998. Southern Weed Sci. Soc., Champaign, IL.

Murdock, E. C., M. A. Jones, J. E. Toler, and R. F. Graham. 2003. South Carolina results: weed control in glufosinate-tolerant cotton. p.8. *In* Proc. South. Weed Sci. Soc., Houston, TX. 27-29 Jan. 2003. Southern Weed Sci. Soc., Champaign, IL.

Pitts, J. R. 1998. Preemergence weed control in west Texas with Staple herbicide. p. 840-841. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5-9 Jan. 1998. Natl. Cotton Counc. Am., Memphis, TN.

Reddy, K. N. 2001. Broadleaf weed control in ultra narrow row bromoxynil-resistant cotton (*Gossypium hirsutum*). Weed Technol. 15:497-504.

Sasser, P. E. 1981. The basics of high volume instruments for fiber testing. p. 191-193. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 4-8 Jan. 1981. Natl. Cotton Counc. Am., Memphis, TN.

Singh, M., and D.P.H. Tucker. 1987. Glufosinate (Ignite): a new promising postemergence herbicide for citrus. p.58-60. *In.* J. E. Barrett (ed.). Proc. Fla. State. Hortic. Soc., Orlando, FL. 2-5 Nov. 1987. Fla. State Hortic. Soc., Lake Alfred, FL.

Steckel, G. J., L. M. Wax, F. W. Simmons, and W. H. Phillips II. 1997. Glufosinate efficacy on annual weeds is influenced by rate and growth stage. Weed Technol. 11:484-488.

Tharp, B. E., and J. J. Kells. 2002. Residual herbicides used in combination with glyphosate and glufosinate in corn (*Zea mays*). Weed Technol. 16:274-281.

Toler, J. E., E. C. Murdock, and A. Keeton. 2002. Weed management systems for cotton (*Gossypium hirsutum*) with reduced tillage. Weed Technol. 16:773-780.

Vencill, W. K., ed. 2002. Glufosinate. p. 229-230. *In* Herbicide handbook. 8^{th} ed. Weed Sci. Soc. Amer., Lawrence, KS.

Webster, T. M. 2005. Weed survey – southern states: broadleaf crops subsection. p. 291-306. *In* Proc. South. Weed Sci. Soc., Charlotte, NC. 24-26 Jan. 2005. Southern Weed Sci. Soc., Champaign, IL.

Webster, T. M., and H. D. Coble. 1997. Changes in the weed species composition of the southern United States: 1974 to 1995. Weed Technol. 11:308-317.

Wendler, C.M., M. Barniske, and A. Wild. 1990. Effect of phosphinothricin (glufosinate) on photosynthesis and photorespiration of C3 and C4 plants. Photosynth. Res. 24:55-61.

Wiesbrook, M. L., W. G. Johnson, S. E. Hart, P. R. Bradley, and L. M. Wax. 2001. Comparison of weed management systems in narrow-row, glyphosate- and glufosinate-resistant soybean (*Glycine max*). Weed Technol. 15:122-128.

York, A. C., and A. S. Culpepper. 2004. Weed management in Liberty Link and Roundup Ready Flex cotton. p. 2932. *In* Proc. South. Weed Sci. Soc., Memphis TN. 26-28 Jan. 2004. South. Weed. Sci. Soc., Champaign, IL.