Weed Management in Transgenic and Non-Transgenic Cotton (*Gossypium hirsutum*) in the Texas High Plains

B. Scott Asher
BASF Corporation, 2006 93rd Place, Lubbock, TX 79423
J. Wayne Keeling
Texas Agricultural Experiment Station, Lubbock, TX
Peter A. Dotray
Texas Tech University, Texas Agricultural Experiment Station, and Texas Cooperative Extension, Lubbock, TX 79409-2122

ABSTRACT

Field experiments conducted at the Texas Agricultural Experiment Station near Lubbock in 1996 and 1997 evaluated Palmer amaranth (carelessweed), devil's-claw, and barnyardgrass control in cotton. Weed management systems included the following soil-applied treatments: Treflan (trifluralin) preplant incorporated (PPI), Caparol (prometryn) preemergence (PRE), or Treflan followed-by (fb) Caparol. Foliar treatments included Roundup Ultra (glyphosate) postemergence (POST) and postemergence-directed (PDIR) in Roundup Ready (Roundup-tolerant) cotton, Buctril (bromoxynil) POST in BXN (Buctril-tolerant) cotton, and Staple (pyrithiobac) POST in conventional (non-transgenic) cotton. Each of these foliar treatments was also used following the soil-applied treatments. In 1996, Roundup Ultra following any soil-applied herbicide treatment provided season-long Palmer amaranth control. Due to multiple Palmer amaranth flushes in 1997, two Roundup Ultra applications were required for control similar to 1996 in all Roundup Ultra-treated plots except for Treflan fb Caparol fb Roundup Ultra, which required only one Roundup Ultra application. Staple following any soil applied herbicide treatment controlled Palmer amaranth at least 96% at the end of the season in 1996, but control was only 75 to 94% at the end of the season in 1997. Neither Buctril nor Staple applied alone controlled Palmer amaranth, but when applied following soil-applied herbicides, control was at least 72% at the end of the season each year. Roundup Ultra or Buctril applied alone controlled devil's-claw at least 92% in both years. Staple applied alone controlled devil's-claw 70% and 92% in 1996 and 1997, respectively. Roundup Ultra was the only POST herbicide that controlled barnyardgrass and was the most consistent POST herbicide in both years. All POST herbicides improved weed control as compared to soil-applied herbicides used alone. Plots treated with Roundup Ultra alone yielded more than plots that received a soil-applied only treatment and yielded similar to plots that received a soil-applied fb foliar treatment.

KEYWORDS: Barnyardgrass, Buctril, BXN cotton, Caparol, Devil's-claw, Palmer amaranth, Roundup Ultra, Roundup Ready cotton, Staple, Treflan

Cotton, the major agronomic crop produced on the Texas High Plains, is planted annually on approximately 3.2 million acres in a 25-county, 100-mile radius surrounding Lubbock. Either Treflan or Prowl is applied to approximately 90% of the acreage planted to cotton in this area (Dotray et al. 1996). Current PPI and PRE herbicides control many small-seeded broadleaf weeds and annual grasses. However, other weeds including devil's-claw [*Proboscidea louisianica* (Mill.) Thellung], common cocklebur (*Xanthium strumarium* L.), morningglories (*Ipomoea spp.*), and silverleaf nightshade (*Solanum eleagnifolium* Cav.) are increasing, and are not controlled by these herbicides.

Staple herbicide, which received a Federal 3 registration for use in cotton in 1996, controls hemp sesbania [*Sesbania exaltata* (Raf.) Rybd. ex A.W. Hill], prickly sida (*Sida spinosa* L.), puncturevine (*Tribulus terrestris* L.), velvetleaf (*Abutilon theophrasti* Medic.), morningglory, and other broadleaf weeds (Holshouser and Chandler 1991, Jordan et al. 1993, Reinhart 1996, Sunderland and Coble 1994). Staple also controls Palmer amaranth (*Amaranthus palmeri* S. Wats) and devil's-claw if applied at appropriate rates and timings (Dotray et al. 1996). Staple applied POST controls weeds in the early seedling stage and has considerable soil residual activity (Crawford 1993). Staple does not control grasses and should be used in conjunction with an effective grass-control herbicide.

The development of herbicide-tolerant cotton varieties may greatly alter weed management strategies on the Texas High Plains. Utilizing Roundup in Roundup Ready cotton in conjunction with traditional herbicides may provide options to economically control a broad spectrum of weeds in conventional and reduced tillage systems (Vidrine et al. 1996). In either conventional or conservation tillage cotton systems, Roundup Ultra applied POST improved weed control over residual herbicides applied alone (Keeling et al. 2000). Using Buctril-tolerant (BXN) cotton allows growers to apply Buctril POST from emergence to 60 days before harvest. Since Buctril will not control grass species or Palmer amaranth, it is recommended for use in conjunction with both a PPI grass herbicide and a PRE broadleaf herbicide (Collins 1996). Buctril controls many annual broadleaf weeds including black and hairy nightshade (*Solanum spp.*), common lambsquarters (*Chenopodium album* L.) and velvetleaf (Vargas et al. 2000).

Traditional PPI and PRE herbicides may still be necessary as a foundation treatment for weed control because neither Roundup Ultra nor Buctril have residual soil activity, and Staple and Buctril do not control grass weeds. The objective of this study was to evaluate weed control systems using Roundup Ultra, Buctril, or Staple applied alone and in combination with standard PPI and PRE herbicides.

MATERIALS AND METHODS

Field experiments were conducted in 1996 and 1997 at the Texas Agricultural Experiment Station near Lubbock on an Amarillo sandy clay loam soil (fine-loamy, mixed, thermic Aridic Paleustalf) with 0.8% organic matter and pH 7.8. Paymaster 2326 Roundup Ready (Roundup-tolerant), BXN 57 (Buctril-tolerant), and Paymaster HS 26 (non-transgenic) cotton varieties were planted at 15 lbs/ac on 40 in. rows on May 22, 1996 and May 23, 1997. Individual four-row plots, 13.3 by 50 ft in length, were arranged in a randomized complete block design with three replications.

Weed management systems included Treflan PPI at 0.75 lb ai/ac, Caparol PRE at 1.2 lb ai/ac, and Treflan PPI fb Caparol PRE at these rates. Sequential applications of

Roundup Ultra POST and PDIR at 0.56 lb ae/ac (in Roundup-tolerant cotton), Buctril POST at 0.5 lb ai/ac (in Buctril-tolerant cotton), or Staple POST at 0.063 lb ai/ac (in non-transgenic cotton) were applied alone or following soil-applied herbicide treatments. All herbicides were applied using a tractor-mounted compressed-air sprayer delivering 10 GPA at 30 PSI. PPI treatments were incorporated 2 to 4 in. deep using a spring-tooth field cultivator within 1 h of application.

Cotton was 3 to 6 in. tall with 3 to 4 leaves when the POST treatments were applied and 16 to 19 in. tall with 9 to 10 leaves when the PDIR (Redball hooded sprayer) treatments were applied. Palmer amaranth height at the POST application was 1 to 6 in. tall with 1 to 8 leaves and 3 to 9 in. tall with 4 to 10 leaves at the PDIR application. Devil's-claw height at the POST application was 1 to 4 in. tall with 1 to 4 leaves and 1 to 4 in. tall with 2 to 4 leaves at the PDIR application. Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] height at the POST application was 1 to 6 in. tall with 2 to 6 leaves and 2 to 7 in. tall with 2 to 6 leaves at the PDIR application. Row middles of all plots were cultivated three times during the growing season using a sweep cultivator to prevent blowing sand and to prepare the middles for furrow irrigation.

Palmer amaranth, devil's-claw, and barnyardgrass control was estimated visually using a scale of 0% (no weed control) to 100% (complete weed control). Yields were determined by hand-harvesting cotton from 6.6 ft in the center two rows of each plot. Burr cotton was ginned to determine the lint percentage and yields.

All data were subjected to an analysis of variance. Treatment means were separated using Fisher's Protected LSD using a P=0.05. Years were analyzed separately because of environmental differences (Table 1) that affected weed emergence and subsequent POST herbicide inputs.

Table1. Rainfall distribution by month in 1996 and 1997 and a 75-yr average.

Month	1996	1997	75-Year Avg.
	---------- inches ----------		
Jan	0.22	0.25	0.51
Feb	0.02	1.34	0.64
Mar	0.06	0.03	0.79
Apr	0.07	5.78	1.20
May	2.27	2.66	2.59
Jun	2.59	2.74	2.54
Jul	1.60	1.81	2.23
Aug	6.20	1.49	2.03
Sep	0.75	1.59	2.54
Oct	0.39	1.44	2.02
Nov	0.41	0.65	0.64
Dec	0.01	1.92	0.63
Total	14.59	21.70	18.36

RESULTS AND DISCUSSION

Palmer Amaranth Control

1996 Growing Season. All soil applied (residual) herbicides controlled Palmer amaranth at least 90% 16 days after planting (DAP) (Table 2). Roundup Ultra was the only POST herbicide that controlled Palmer amaranth at least 90% 40 DAP. Staple alone controlled Palmer amaranth 78% and Buctril controlled Palmer amaranth 17% 40 DAP. Palmer amaranth control by Treflan, Caparol, and Treflan fb Caparol was 98% at 40 DAP.

Table 2. Palmer amaranth control in cotton weed management systems in 1996 and 1997[a].

Herbicide[b]				1996 Days after planting			1997 Days after planting			
PPI	PRE	POST	PDIR	16[c]	40	120	22	35	61	111
				%						
Treflan				98 a	98 ab	93 ab	75 a-d	67 ef	73 b-e	75 abc
	Caparol			100 a	98 ab	60 c	73 a-d	57 f	55 ef	43 d
Treflan	Caparol			99 a	98 ab	92 ab	93 a	83 bcd	84 abc	72 abc
Treflan		Roundup Ultra	Roundup Ultra[d]	90 b	100 a	95 ab	85 abc	85 a-d	97 a	88 ab
	Caparol	Roundup Ultra	Roundup Ultra[d]	99 a	99 a	93 ab	57 d	72 def	93 ab	86 ab
Treflan	Caparol	Roundup Ultra		100 a	100 a	98 a	87 abc	89 abc	93 ab	97 a
		Roundup Ultra	Roundup Ultra[d]	0 d	93 b	83 b	0 e	67 ef	91 ab	67 bcd
Treflan		Staple[e]		97 a	100 a	96 a	72 a-d	83 bcd	82 abc	88 ab
	Caparol	Staple		100 a	100 a	97 a	60 cd	80 cde	80 a-d	75 abc
Treflan	Caparol	Staple		99 a	100 a	97 a	88 ab	93 abc	100 a	94 a
		Staple		0 d	78 c	40 d	0 e	60 f	45 f	50 cd
Treflan		Buctril		90 b	100 a	93 ab	68 a-d	85 a-d	88 abc	93 ab
	Caparol	Buctril		100 a	100 a	88 ab	85 abc	88 abc	86 abc	72 abc
Treflan	Caparol	Buctril		100 a	99 a	96 a	92 a	95 abc	98 a	88 ab
		Buctril		0 d	17 d	7 e	0 e	60 f	60 def	20 e

[a]Values followed by same letter within a column are not different at P=0.05, according to Fisher's Protected LSD test.

[b]Treflan: 0.75 lb ai/ac PPI, Caparol: 1.2 lb ai/ac PRE; Roundup Ultra: 0.56 lb ae/ac POST or PDIR; Staple: 0.063 lb ai/ac POST; Buctril: 0.5 lb ai/ac POST.

[c]Post treatments were applied 16 DAP in 1996 and 22 DAP in 1997.

[d]Second Roundup Ultra application was applied in 1997 PDIR.

[e]All Staple treatments received crop oil concentrate at 1% v/v.

Treflan and Treflan fb Caparol controlled Palmer amaranth at least 90% 120 DAP. Roundup Ultra was the only POST treatment that controlled Palmer amaranth at least 80% 120 DAP. Treflan or Treflan fb Caparol or fb any other POST herbicide controlled Palmer amaranth 92% 120 DAP. Caparol alone was the only soil residual treatment that benefited from a sequential POST herbicide treatment (Table 2). Roundup Ultra applied following Treflan or Treflan fb Caparol did not increased Palmer amaranth control 40 DAP or 120 DAP as compared to Treflan or Treflan fb Caparol applied alone. These results were different from Goldmon et al. (1996) who reported

that residual herbicides did not improve early-season weed control compared to a Roundup Ultra only treatment.

During the 1996 growing season there was only one early-season flush of Palmer amaranth and the few late-emerging Palmer amaranth plants were controlled by cultivation. The lack of rainfall in-season limited differences in Palmer amaranth control among treatments with and without POST herbicides.

1997 Growing Season. In 1997, early-season Palmer amaranth control with Treflan or Caparol applied alone was not as effective as in 1996. In 1996, due to the lack of rainfall and the subsequent lack of multiple weed flushes, both Treflan and Caparol applied alone controlled Palmer amaranth at least 90% 16 DAP. In 1997, these treatments controlled Palmer amaranth 73 to 75% 22 DAP (Table 2). Treflan fb Caparol controlled Palmer amaranth 93% 22 DAP.

At 14 days after the initial POST treatment (35 DAP), Treflan applied alone, Caparol applied alone, or any POST herbicide treatment applied alone provided similar Palmer amaranth control. The sequential treatment of Treflan fb Caparol controlled Palmer amaranth more effectively than any POST herbicide treatment applied alone and did not benefit from a sequential POST application 35 DAP (Table 2). At 35 DAP, Treflan was the only soil-applied treatment that benefited from a sequential POST application of either Roundup Ultra, Staple, or Buctril.

Due to multiple flushes of Palmer amaranth, a second application of Roundup Ultra, which was applied PDIR, was needed to effectively control Palmer amaranth. Treatments that contained soil residual herbicides fb Roundup Ultra did not require a second Roundup Ultra application. This result was similar to that observed by Goldmon (1996).

At 61 DAP, all treatments controlled Palmer amaranth similarly except for Treflan and Caparol applied alone and the POST treatments of Staple and Buctril applied alone. Roundup Ultra applied alone was the only POST treatment that controlled Palmer amaranth $\geq$ 90%. All POST herbicide treatments increased control when applied following Caparol compared to Caparol applied alone.

At 111 DAP, any soil applied treatment fb one or two applications of Roundup Ultra controlled Palmer amaranth at least 86% (Table 2). Treflan fb Caparol fb any POST herbicide treatment controlled Palmer amaranth at least 88% 111 DAP. Caparol was the only soil-applied herbicide that benefited from a POST herbicide treatment at 111 DAP. A sequential POST application used with Treflan or Treflan fb Caparol resulted in similar control.

Devil's-claw Control

1996 Growing Season. Treflan or Caparol applied alone only controlled devil's-claw $\leq$ 27% (Table 3). The sequential treatment of Treflan fb Caparol did not improve control. Poor control of devil's-claw with traditional PPI or PRE herbicides was also observed by Keeling et al. (1999), which indicates the need for an effective POST herbicide for devil's-claw control.

All POST herbicide treatments had good activity on devil's-claw. At 40 DAP, Roundup Ultra and Buctril controlled devil's-claw at least 95% when applied alone or following soil-applied herbicides (Table 3). Staple applied alone did not control devil's claw as effectively as Roundup Ultra or Buctril applied alone.

Table 3. Devil's-claw control in cotton weed management systems in 1996 and 1997[a].

Herbicide[b]				1996 Days after planting			1997 Days after planting		
PPI	PRE	POST	PDIR	16[c]	40	80	22	48	61
				%					
Treflan				25 a-e	0 e	0 e	23 cde	52 d	52 c
	Caparol			27 a-d	47 d	53 g	42 bc	58 d	60 bc
Treflan	Caparol			28 a-d	48 d	72 ef	57 b	70 c	68 b
Treflan		Roundup Ultra	Roundup Ultra[d]	15 e-f	100 a	100 a	18 ef	88 ab	100 a
	Caparol	Roundup Ultra	Roundup Ultra[d]	13 f	98 a	98 a	53 b	95 abc	100 a
Treflan	Caparol	Roundup Ultra		27 a-d	97 a	97 a	85 a	90 ab	92 a
		Roundup Ultra	Roundup Ultra[d]	0 g	95 a	95 a	0 f	85 b	100 a
Treflan		Staple[e]		20 c-f	73 c	73 c	20 ef	90 ab	94 a
	Caparol	Staple		28 a-d	92 ab	92 ab	40 bcd	98 a	97 a
Treflan	Caparol	Staple		35 a	85 b	85 b	48 b	95 abc	100 a
		Staple		0 g	70 c	70 c	0 f	92 ab	92 a
Treflan		Buctril		22 b-f	98 a	98 a	22 de	93 abc	93 a
	Caparol	Buctril		30 abc	97 a	97 a	85 a	96 ab	93 a
Treflan	Caparol	Buctril		33 ab	100 a	100 a	80 a	98 a	98 a
		Buctril		0 g	95 a	92 ab	0 f	98 a	97 a

[a]Values followed by same letter within a column are not different at P=0.05, according to Fisher's Protected LSD test.
[b]Treflan: 0.75 lb ai/ac PPI, Caparol: 1.2 lb ai/ac PRE; Roundup Ultra: 0.56 lb ae/ac POST or PDIR; Staple: 0.063 lb ai/ac POST; Buctril: 0.5 lb ai/ac POST.
[c]Post treatments were applied 16 DAP in 1996 and 22 DAP in 1997.
[d]Second Roundup Ultra application was applied in 1997 PDIR.
[e]All Staple treatments received crop oil concentrate at 1% v/v.

At 80 DAP, all POST herbicides applied alone or sequentially improved devil's-claw control over soil-applied herbicides used alone. POST treatments of Roundup Ultra or Buctril did not benefit from soil-applied herbicides (Table 3). Staple alone or applied sequentially with soil residual herbicides controlled devil's-claw 70 to 92% 80 DAP. This control was not equal to the level obtained with other POST herbicides applied sequentially with soil residual herbicides, but was still more effective than soil residual herbicides applied alone.

1997 Growing Season. Similar to the results recorded in 1996, soil residual herbicides applied alone or sequentially did not effectively control devil's-claw. At 48 DAP, soil residual treatments controlled devil's-claw 52 to 70%, whereas the POST herbicide treatments controlled devil's-claw at least 85% (Table 3). By 61 DAP, all treatments that received a POST treatment alone or sequentially controlled devil's-claw at least 92%. All soil-applied herbicides benefited from a sequential POST treatment. Contrary to 1996, Staple alone controlled devil's-claw equal to that of the other POST treatments. Similar to 1996, POST treatments did not benefit from a soil residual treatment.

Barnyardgrass Control

1996 Growing season. All weed management systems containing Treflan controlled barnyardgrass ≥ 98% 16 DAP (Table 4). Since Roundup Ultra is the only POST herbicide that has grass activity, it was the only POST treatment that effectively controlled barnyardgrass 40 DAP. At 80 DAP, Treflan alone or sequentially treated plots controlled barnyardgrass at least 97% (Table 4.) Roundup Ultra alone controlled barnyardgrass 90% 80 DAP, and was similar to all plots that received Treflan. Treflan applied alone or sequentially with Caparol did not benefit from a sequential POST treatment.

Table 4. Barnyardgrass control in cotton weed management systems in 1996 and 1997[a].

Herbicide[b]				1996 Days after planting			1997 Days after planting		
PPI	PRE	POST	PDIR	16[c]	40	80	35	48	61
				%					
Treflan				99 a	96 ab	97 ab	83 ab	92 a	92 ab
	Caparol			100 a	83 c	80 c	47 c	60 b	73 c
Treflan	Caparol			100 a	98 ab	98 ab	94 a	96 a	94 ab
Treflan		Roundup Ultra	Roundup Ultra[d]	100 a	100 a	100 a	97 a	98 a	100 a
	Caparol	Roundup Ultra	Roundup Ultra[d]	93 a	99 ab	93 ab	57 bc	92 a	100 a
Treflan	Caparol	Roundup Ultra		100 a	100 a	100 a	88 a	93 a	98 a
		Roundup Ultra	Roundup Ultra[d]	0 c	95 ab	90 abc	83 ab	92 a	100 a
Treflan		Staple[e]		100 a	99 ab	100 a	83 ab	92 a	97 a
	Caparol	Staple		100 a	90 bc	87 bc	33 c	65 b	72 c
Treflan	Caparol	Staple		100 a	98 ab	98 ab	87 a	97 a	100 a
		Staple		0 c	30 e	28 d	35 c	37 c	32 d
Treflan		Buctril		98 a	100 a	100 a	93 a	97 a	98 a
	Caparol	Buctril		69 b	97 ab	80 c	50 c	65 b	68 c
Treflan	Caparol	Buctril		100 a	100 a	100 a	93 a	100 a	100 a
		Buctril		0 c	0 f	0 e	0 d	23 c	20 d

[a]Values followed by same letter within a column are not different at P=0.05, according to Fisher's Protected LSD test.

[b]Treflan: 0.75 lb ai/ac PPI, Caparol: 1.2 lb ai/ac PRE; Roundup Ultra: 0.56 lb ae/ac POST or PDIR; Staple: 0.063 lb ai/ac POST; Buctril: 0.5 lb ai/ac POST.

[c]Post treatments were applied 16 DAP in 1996 and 22 DAP in 1997.

[d]Second Roundup Ultra application was applied in 1997 PDIR.

[e]All Staple treatments received crop oil concentrate at 1% v/v.

1997 Growing Season. Barnyardgrass control 61 DAP in 1997 was similar to control achieved in 1996. All plots that contained Treflan controlled barnyardgrass season-long (92 to 100%), and the addition of a sequential POST treatment did not improve control (Table 4). Similar to 1996, Roundup Ultra alone controlled barnyardgrass equal to any treatment that contained Treflan.

Cotton Yield

1996 Growing Season. In 1996, one application of Roundup Ultra applied alone was sufficient to control all weed species in this study and these plots produced yields greater than plots that received Buctril or Staple applied alone. In addition, plots treated with Roundup Ultra only yielded more than plots treated with Treflan or Caparol applied alone (Table 5). The lowest yields were recorded from plots treated with Buctril alone (56 kg/ha).

Table 5. Cotton yields in weed management systems, 1996-1997[a].

Herbicide[b]					
PPI	PRE	POST	PDIR	1996	1997
				----------lb/ac ----------	
Treflan				388 c-f	423 b-f
	Caparol			418 c-f	356 def
Treflan	Caparol			550 bcd	475 a-d
Treflan		Roundup Ultra	Roundup Ultra[c]	610 abc	458 a-d
	Caparol	Roundup Ultra	Roundup Ultra[c]	725 ab	453 a-d
Treflan	Caparol	Roundup Ultra		558 bcd	590 a
		Roundup Ultra	Roundup Ultra[c]	714 ab	528 ab
Treflan		Staple[d]		329 def	405 b-f
	Caparol	Staple		684 ab	380 b-f
Treflan	Caparol	Staple		597 abc	496 a-d
		Staple		282 efg	392 b-f
Treflan		Buctril		407 c-f	443 a-e
	Caparol	Buctril		507 b-e	402 b-f
Treflan	Caparol	Buctril		395 c-f	460 a-d
		Buctril		53 g	274 f

[a]Values followed by same letter within a column are not different at P=0.05, according to Fisher's Protected LSD test.
[b]Treflan: 0.75 lb ai/ac PPI, Caparol: 1.2 lb ai/ac PRE; Roundup Ultra: 0.56 lb ae/ac POST or PDIR; Staple: 0.063 lb ai/ac POST; Buctril: 0.5 lb ai/ac POST.
[c]Second Roundup Ultra application was applied in 1997 PDIR.
[d]All Staple treatments received crop oil concentrate at 1% v/v.

1997 Growing Season. Similar to 1996, plots treated with Roundup Ultra only produced yields higher than plots treated with any residual herbicide alone, and equal to plots treated with residual herbicides fb POST herbicides. Plots treated with Treflan fb Caparol fb Roundup Ultra yielded similar to plots that received two applications of Roundup Ultra (Table 5). Similar to 1996, the use of a sequential POST herbicides with soil residual herbicides did not consistently increase yields over plots treated with soil-applied herbicides alone. Plots treated with Roundup Ultra alone produced yields equal to plots that received a soil residual herbicide fb a sequential POST Roundup Ultra application. This is contrary to what had been reported by Murdock and Graham (2000)

who found that the Roundup Ultra alone plots produced more cotton than the plots that received a soil residual herbicide fb a sequential POST Roundup Ultra treatment.

Based on the weed species in this study, Roundup Ultra used in Roundup Ready cotton consistently controlled Palmer amaranth, devil's-claw, and barnyardgrass. Although Roundup Ultra applied alone controlled these weeds in both years of this study, a total POST weed control program on the Texas High Plains may be too risky because of unpredictable weather conditions may delay timely POST applications. A PPI herbicide fb Roundup Ultra POST was the most reliable treatment to control Palmer amaranth, devil's-claw, and barnyardgrass.

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