DOI: https://doi.org/10.24297/jaa.v11i.8618

Using Fluridone Herbicide Systems for Weed Control in Texas Cotton (Gossypium Hirsutum L.)

W. James Grichar[1*], Peter A. Dotray[2], and Josh A. McGinty[3]

[1.] Texas A&M AgriLife Research, 10345 State Highway 44, Corpus Christi, TX 78406

[2.] Texas Tech University, Texas A&M AgriLife Research, and Texas AgriLife Extension Service,

1102 East FM 1294, Lubbock, TX 79403

[3.] Texas A&M AgriLife Extension Service, 10345 State Highway 44, Corpus Christi, TX 78406

w-grichar@tamu.edu

Abstract

Studies were conducted during 2015 through 2018 in south-central, Coastal Bend, and Southern High Plains areas of Texas to evaluate fluridone herbicide systems for weed control and cotton response. Fluridone alone at 0.17 to 0.23 kg ai ha^{-1} followed by postemergence (POST) herbicides controlled *Amaranthus palmeri* 82 to 100% season-long while *Cucumis melo* control ranged from 92 to 100%. Control of *Urochloa texana* with fluridone alone ranged from 40 to 96% early-season while late-season control ranged from 37 to 96%. Fluridone plus fomesafen systems controlled *A. palmeri*, *C. melo*, and *U. texana* at least 98% early season; however, late-season control of *A. palmeri* was less than 70% while *C. melo* control was 91% and *U. texana* control was 80%. Adding a POST application of glyphosate to fluridone plus fomesafen improved control to at least 98% for all three weed species. Fluridone plus fluometuron combinations provided similar control to fluridone plus fomesafen. Adding glyphosate (POST) improved *A. palmeri* control to at least 82% season-long. Cotton yields reflect the level of weed control with significantly better yields from fluridone systems compared with the weedy check. However, in the one year when the untreated was maintained weed-free, no differences in cotton yield were noted between the weed-free and any herbicide treatment.

Keywords: Amaranthus palmeri S. Wats., Cucumis melo L., Cotton Yield, Gossypium hirsutum, Preemergence, Postemergence, Urochloa texana L.

Subject Classification: Agronomy

Type (Method/Approach): Field research

introduction

During the past twenty years, the use of glyphosate-resistant crop production systems has been adopted and used extensively in various regions of the US (Wiggins *et al.,* 2015). In 2009, nearly 61 million ha of soybean [*Glycine max* (L.) Merr.], cotton (*Gossypium hirsutum* L), and corn (*Zea mays* L.) contained a modified 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) gene that confers resistance to glyphosate (Anonymous, 2009). The wide use of row crops with glyphosate-resistance, the reduction of traditional herbicide and cultivation practices, and the use of intense management of weeds using glyphosate as the predominant control strategy has caused a shift in weed populations and created a selective advantage for glyphosate-resistant weeds (Culpepper, 2006; Owen, 2008).

Glyphosate-resistant weeds, specifically *Amaranthus* species, have become an issue across all the US corn and cotton-producing areas (Heap, 2014). Estimates are that more than 1.2 million ha of cropland in the US is now affected by glyphosate-resistant *Amaranthus* species (Heap, 2014). In cotton, Palmer amaranth (*Amaranthus*

Palmeri S. Wats.) has been shown to reduce lint yield by 57% when growing at a density of 10 plants 9.1 m row^{-1} (Morgan *et al*., 2001). Additionally, Palmer amaranth growing at densities higher than six plants 9.1 m row^{-1}, creates an environment where cotton may not be harvestable due to the potential for damage to harvest equipment (Morgan *et al*., 2001). A study by Smith et al. (2000) found that Palmer amaranth densities of 650 to 3260 ha^{-1} in dryland stripper-harvested cotton increased harvesting time by 2- to 3.5-fold.

Cotton growers have experienced more problems with weed resistance because of cotton's slower emergence after planting and fewer registered herbicides compared with other major crops (Norswothy *et al*., 2008). The first documented cases of glyphosate-resistant (GR) weeds in cotton occurred in 2000 in Lauderdale County, TN (Hayes *et al*., 2002) and 2003 in Edgecombe County, NC (Yancey, 2003). The first confirmed case of GR Palmer amaranth was documented in a biotype of Palmer amaranth growing in a Macon County, GA cotton field, where six- to eightfold levels of resistance to glyphosate were observed (Culpepper, 2006).

With the widespread adoption of glyphosate-resistant cotton after its introduction in 1997, cotton weed management practices largely shifted away from the use of soil-applied residual herbicides to POST herbicide programs based on glyphosate (Young, 2006). Studies conducted in 2006 and 2007 by Legleiter and Bradley (2008) confirmed glyphosate resistance in a biotype of common waterhemp (*A. rudis* Sauer) found in a Missouri soybean field following multiple glyphosate applications. Currently, glyphosate-resistant Palmer amaranth and common waterhemp have been reported in 27 and 18 US states, respectively (Heap, 2014). Through surveys sent to weed scientists across the US, Culpepper (2006) revealed that 50% of respondents indicated that weeds of the genus *Amaranthus* had increased significantly in cotton. The respondents also provided the following four recommendations for managing glyphosate-induced weed species shifts: tank-mix combinations of other herbicides with glyphosate for POST applications, rotating with non-glyphosate-resistant crops (though there was some disagreement among respondents), use of POST herbicides other than glyphosate, and using pre-plant incorporated (PPI) or preemergence (PRE) soil-applied herbicides.

Amaranthus species are some of the most common weed species found in annual crop production throughout the US, and Palmer amaranth is now ranked as the most troublesome weed found in the US (Van Wychen, 2015). It is a common weed in many major crops around the world and is found in all areas of Texas (Elmore, 1985). Up until the 1990's its distribution in North America was the southern half of the US (Elmore, 1985); however, since then it has become established in every state except the Northwestern US, including Washington, Oregon, Montana, and North Dakota (Anonymous, 2015). In Texas, Palmer amaranth can be found in all areas of the state (Correll and Johnston, 1979) and is one of the two Amaranthus species with confirmed resistant to glyphosate across Texas (common waterhemp is the other) (Light *et al*., 2011). It is a dioecious, summer-annual species that is native to the desert southwest region of the US. (Franssen *et al*., 2001a; Sauer, 1957). Plants of the genus Amaranthus are often very problematic weeds in agronomic crops due to their ability to germinate under a wide range of conditions, grow rapidly, and produce large numbers of seed, all while competing with the crop for sunlight, moisture, and nutrients. Despite its origin, Palmer amaranth can survive in many diverse environments because of its biological characteristics (Johnson *et al*., 2000; Sellers *et al*., 2003). It has a lengthy germination window, robust growth habit, and is a prolific seed producer (Bond and Oliver, 2006; Horak and Loughin, 2000; Keeley *et al*., 1987) and these characteristics make control of this weed difficult. Common waterhemp is an obligate outcrossing annual broadleaf weed that is capable of long-distance pollen dispersal (Franssen *et al*., 2001b). It germinates optimally between 20/25^{0} C and 30/35^{0} C (Guo and Al-Khatib, 2003), has an aggressive growth habit, may grow 1.6 mm per growing degree day (Horak and Loughin, 2000), and is capable of producing greater than 250,000 seed per plant (Sellers *et al*., 2003). These factors make it a strong competitor with most crops.

Fluridone controls weeds by inhibiting phytoene desaturase and thus preventing carotenoid biosynthesis (Bartels and Watson, 1978; Kowalczyk-Schroeder and Sandmann, 1992). Fluridone was developed in the early 1970's and is a pigment inhibitor classified as a Weed Science of America Group 12 herbicide (Waldrep and Taylor, 1976) that has been used extensively to control submerged and floating weeds such as hydrilla [*Hydrilla verticillata* (L. f.) Royle] in aquatic environments (Arnold, 1979; Fox *et al*., 1994; Richardson, 2008; Koschnick *et* *al*., 2003). Fluridone was first investigated for use in cotton in the 1970's. Banks and Merkle (1979) and Waldrep and Taylor (1976) reported good control of Amaranthus species with fluridone; however, potential carryover of fluridone to subsequent crops was a concern (Banks *et al*., 1979; Banks and Merkle 1979; Schroeder and Banks 1986). Research with fluridone during the 1970's was with rates of 0.3 to 0.9 kg ha^{-1} (Banks and Merkle 1979; Waldrep and Taylor, 1976). Miller and Carter (1983) found that preplant fluridone applied at 0.3 kg ha^{-1} provided 89 to 95% control of redroot pigweed (*Amaranthus retroflexus* L.) and 85 to 100% control of black nightshade (*Solanum nigrum* L.) in cotton. Variable control of redroot pigweed was observed when fluridone was applied at 0.2 or 0.1 kg ha^{-1} (61 to 100% and 30 to 86% control, respectively) (Miller and Carter 1983).

The objective of this research was to determine the feasibility of using a PRE-applied fluridone based herbicide program for control of problem weeds in Texas cotton production. Also, fluridone was compared with fluometuron, a commonly used herbicide in Texas cotton production systems, for weed efficacy and cotton tolerance.

Materials and Methods

Field studies were conducted under rainfed conditions during the 2015 through the 2017 growing seasons in south-central Texas at the Texas A&M AgriLife Research Site near Yoakum (29.276° N, 97.123° W), during the 2017 growing season in the Coastal Bend area of Texas at the Texas A&M AgriLife Research and Extension Center near Corpus Christi (27.772° N, 97.557° W), and during the 2017 and 2018 growing seasons in the Southern High Plains area of Texas near Halfway (34.188° N, 101.952° W). Soils at Yoakum were a Tremona loamy fine sand (thermic Aquic arenic Paleustalfs) with less than 1% organic matter and pH 7.0 to 7.2 while soils at Corpus Christi were a Victoria clay (fine, smectitic, hyperthermic Sodic Haplusterts) with 1.29% organic matter and pH of 8.4. Soils at Halfway were a Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) with less than 1% organic matter and pH 8.1.

The Yoakum site was infested with a natural population of smellmelon (*Cucumis melo* L.), 8 to 10 plants/m^2 (2015 only); Palmer amaranth (*Amaranthus Palmeri* S. Wats), 10 to 15 plants/m^2; and Texas millet (*Urochloa texana* Buckl.), 10 to 12 plants/m^2 while plots at Corpus Christi were infested with dense populations of Palmer amaranth at > 30 plants/m^2. Palmer amaranth populations at Halfway ranged from 10 to 12 plants/m^2.

The experimental design at all locations was a randomized complete block with three replications. Each plot at Yoakum was two rows wide spaced 97 cm apart by 7.9 m long, plots at Corpus Christi were four rows wide spaced 97 cm part by 9.5 m long, while plots at Halfway were four rows wide spaced 101.6 cm apart and 9.5 m long.

Since these studies were undertaken to determine the optimum use rate for fluridone alone or in combination and since cotton herbicide programs vary among the different cotton-growing regions of the state from region to region (McGinty *et al*., 2016), herbicide treatments varied across years and locations. All POST applications included either glyphosate or glufosinate; therefore, no additional surfactant was added since these two herbicides contain a surfactant. An untreated check was included for comparison; however, at Halfway in 2017 the untreated check was kept weed-free by hand weeding.

Application timing for PRE treatments occurred from 0 to 3 days after cotton was planted, and POST treatments were applied approximately three weeks to almost five weeks after planting (Table 1). All other information about the trials is included in Table 1. At Yoakum, smellmelon was 15 to 25 cm long, Palmer amaranth was no higher than 30 cm tall, and Texas millet was no higher than 25 cm tall at the POST application. A second POST application at Yoakum in 2017 occurred two months after cotton was planted when Palmer amaranth and Texas millet were no higher than 15 cm in height. For POST applications at Corpus Christi, Palmer amaranth was 5 cm or less in height while Texas millet was 10 cm or less in height and at Halfway Palmer amaranth was 8 to 13 cm tall.

Table 1. Cotton variety, planting date, herbicide application dates, rainfall events, and application equipment for the studies using fluridone at various locations across Texas[a].

	Yoakum			Corpus Christi	Halfway	
Variable	**2015**	**2016**	**2017**	**2017**	**2017**	**2018**
Variety	ST 4946GLB2	PHY 499LVRF	DP 1725 B2XF	DP 1646 B2XF	NG 3406 B2XF	DP 1522 B2XF
Planting date	June 8	April 14	April 7	March 28	May 19	May 16
Herbicide application						
PRE	June 10	April 15	April 7	March 29	May 19	May 16
POST (1st application)	July 10	May 4	May 11	April 14	June 29	June 7
POST (2nd application)	-	-	June 8	-	-	-
Rainfall event after PRE	June 13	April 18	April 11	April 11	May 24	May 20
Rainfall amount (mm)	51.4	18.3	20.3	40.6	12.7	7.9
Herbicide application						
Sprayer type	CO_2 backpack	CO_2 backpack	CO_2 backpack	CO_2 backpack	CO_2 packpack	CO_2 backpack
Nozzle type	Teejet flat fan	Teejet flat fan	Teejet flat fan	Teejet flat fan	Teejet flat fan	Teejet flat fan
Nozzle size	DG 11002	DG 11002	DG 11002	AM 11002 (PRE) TTI 11002 (POST)	TU 11002 (PRE) TTI 11004 (POST)	TU 11002 (PRE) AI 11002 (POST)
Spray volume (L ha^{-1})	190	190	190	140	140	140

Weed control and cotton injury were estimated visually on a scale of 0 to 100 (0 indicating no control or plant death and 100 indicating complete control or plant death) relative to the untreated control (Frans *et al*. 1986). Weed control and cotton injury evaluations were recorded 3 to 6 weeks after planting and 8 to 16 weeks after planting. Cotton stunting and foliar necrosis and chlorosis were used when making the visual injury estimates.

Due to extremely dry conditions in 2015 and Hurricane Harvey in 2017, which resulted in over 450 mm of rain on the test location prior to harvest, cotton yields were obtained in Yoakum only in 2016. Each plot was hand-harvested separately and manually cleaned to remove seed and any trash. At Corpus Christi in 2017, Hurricane

Harvey destroyed all-cotton plots just prior to harvest. At Halfway, the center two rows of all plots were mechanically harvested, and lint cotton yields were determined based on calculated turnout.

Weed efficacy data were arcsine square-root transformed before analysis, but only the nontransformed data are reported because transformation did not affect data interpretation. The untreated control was not included in weed control analysis but was included in the yield analysis. Fisher's Protected LSD at the 0.05 level of probability was used for separation of mean differences.

Results and Discussion

Cotton injury. No cotton injury was observed at any location with any fluridone combination (data not shown). Other studies have not shown any cotton injury when using fluridone (Braswell *et al.*, 2016; Hill *et al.*, 2017).

Palmer amaranth control.

Early season. These evaluations were recorded either prior to or within a week of the POST herbicide applications, so weed control was based primarily on the activity of the PRE herbicides. At the Yoakum location in 2015, all fluridone systems controlled Palmer amaranth 86 to 98% while fluometuron alone controlled this weed 79 to 87% (Table 2). In both 2016 and 2017, fluridone systems and fluometuron alone provided no less than 99% control. At Corpus Christi, all fluridone systems and fluometuron alone provided complete control (Table 3). At Halfway in 2017, all fluridone systems controlled this weed at least 97% when evaluated six weeks after planting (WAP), while fluometuron alone provided 65 to 97% control. In 2018, early-season control with fluridone systems ranged from 82 to 97% while control with fluometuron was 65% or less (Table 3). Braswell *et al.* (2016) reported that fluridone alone applied PRE controlled Palmer amaranth 97% early-season and control by fluridone alone were similar to control by all fluridone-containing tank mixtures.

Late season. At Yoakum in 2015, the premix of fluridone plus fomesafen applied PRE, without a POST application of glyphosate, provided 68% control of Palmer amaranth while the addition of glyphosate POST following the premix of fluridone plus fomesafen PRE improved control to 99% when evaluated 16 WAP (Table 2). Similar results were seen with the premix of fluridone plus either fomesafen or fluometuron and fluometuron alone with improved late-season Palmer amaranth control with the addition of a POST herbicide application of glyphosate alone or glyphosate plus *S*-metolachlor over that without a POST herbicide. In 2016 when evaluated 12 WAP, Palmer amaranth control was at least 97% with all fluridone and fluometuron herbicide systems compared with 81% control with the POST-only system. In 2017 all herbicide systems, except fluridone at 0.23 kg ai ha^{-1} followed by glyphosate plus *S*-metolachlor applied POST, provided at least 97% control while the POST-only system controlled Palmer amaranth 94% when evaluated 13 WAP (Table 2). Scott *et al.* (2002) emphasized the need for an effective POST herbicide program to be used with a soil-residual herbicide to provide extended control of Palmer amaranth, especially in environments where soil-residual herbicides may not be activated.

In 2017 at Corpus Christi, all PRE herbicide systems followed by a POST system controlled Palmer amaranth at least 95% while the POST only system provided 97% control (Table 3). At Halfway, fluridone plus either diuron, fluometuron, or prometryn applied PRE followed by a POST herbicide system that included glyphosate plus *S*-metolachlor provided 87 to 98% control. Fluridone alone applied PRE followed by the same POST system controlled Palmer amaranth 85 to 94%. Diuron PRE applied alone followed by a POST system of glyphosate plus *S*-metolachlor provided 93% control while the PRE application of fluometuron followed by a POST system that included glyphosate provided variable control ranging from 20 to 93% control. Season-long poor control with fluometuron at 1.12 kg ai ha^{-1} followed by glyphosate plus S-metolachlor applied POST was due in part to glyphosate-resistant Palmer amaranth present at that location. The POST-only system provided 84% control (Table 3).

In 2018 at Halfway, fluridone alone at 0.17 kg ai ha^{-1} applied PRE followed by a POST treatment that included glyphosate controlled Palmer amaranth at least 87% while fluridone plus fluometuron PRE systems followed

Table 2. Early and late-season Amaranthus palmeri and *Cucumis melo* control with fluridone combinations near Yoakum in south-central Texas from 2015 to 2017[a].

PRE herbicide	Rate Kg ai ha^{-1}	POST herbicide[d]	Weed control							
			Amaranthus palmeri						***Cucumis melo***	
			2015		**2016**		**2017**		**2015**	
			Weeks after planting							
			4	**16**	**4**	**12**	**4**	**13**	**4**	**16**
			%							
Untreated	None	None	0	0	0	0	0	0	0	0
Fluridone	0.17	POST-1	-	-	100	100	-	-	-	-
Fluridone	0.17	POST-2	-	-	100	100	-	-	-	-
Fluridone	0.23	POST-2	-	-	-	-	99	83	-	-
Fluridone	0.23	POST-3	-	-	-	-	99	100	-	-
Fluometuron (F)	0.84	None	87	10	-	-	-	-	99	92
F	0.84	POST-1	79	77	-	-	-	-	99	99
F	1.12	None	79	37	-	-	-	-	99	90
F	1.12	POST-1	79	93	100	100	-	-	99	100
F	1.12	POST-2	-	-	100	100	100	99	-	-
F	1.12	POST-3	-	-	-	-	99	100	-	-
Fluridone + fomesafen[b]	0.17 + 0.23	None	98	68	-	-	-	-	100	91
Fluridone + fomesafen[b]	0.17 + 0.23	POST-1	98	99	-	-	-	-	100	100
Fluridone + F[c]	0.17 + 0.84	None	86	32	-	-	-	-	100	93
Fluridone + F[c]	0.17 + 0.84	POST-1	98	90	100	100	-	-	100	100
Fluridone + F[c]	0.17 + 0.84	POST-2	99	97	99	97	99	97	100	100
Fluridone +F[c]	0.17 + 0.84	POST-3	-	-	-	-	100	100	-	-
Fluridone + F[c]	0.2 + 1.1	POST-1	-	-	100	99	-	-	-	-
Fluridone + F[c]	0.2 + 1.1	POST-2	-	-	100	100	-	-	-	-
None	-	POST-2/3	-	-	93	81	0	94	-	-
LSD (0.05)			16	21	2	6	2	8	NS	6

[a] Abbreviations: NS, not significant at 0.05; PRE, preemergence; POST, postemergence.
[b] A premix marketed as Brake F2®.
[c] A premix marketed as Brake FX®.
[d] POST-1 (2015, 2016), glyphosate at 1.54 kg ae ha^{-1}; POST-2 (2015, 2016, 2017), glyphosate at 1.54 kg ae ha^{-1} + *S*-metolachlor at 1.07 kg ai ha^{-1}; POST-3 (2017), glyphosate at 1.54 kg ai ha^{-1} + dicamba (Engenia®) at 0.56 kg ae ha^{-1} + *S*-metolachlor at 1.07 kg ai ha^{-1}.

by a POST treatment provided 82 to 88% control. Fluometuron PRE alone followed by a POST application that included glyphosate, provided 66% or less Palmer amaranth control (Table 3).

Hill *et al*. (2017) reported when no POST herbicide was applied, no differences were observed among fluridone rates for Palmer amaranth control and that all rates of fluridone provided greater control than fluometuron applied PRE. They attributed the difference in control to the extended control of fluridone on *Amaranthus* weeds.

Smellmelon control. Early season. All herbicide systems controlled smellmelon at least 99% when evaluated 4 WAP (Table 2).

Late season. When evaluated 16 WAP, herbicide systems that did not include a POST application of glyphosate alone or glyphosate plus *S*-metolachlor provided 90 to 93% smellmelon control while systems that included a POST application of the above-mentioned herbicides provided at least 99% control (Table 2). Tingle *et al.* (2003) reported that glyphosate controlled 5- to 15-cm long smellmelon 97% but only controlled 45- to 60-cm long smellmelon 38% while fluometuron plus MSMA provided 98% control of small smellmelon and 72% control of larger smellmelon. In earlier work, Tingle and Chandler (1999) reported that herbicide tank mixes would improve control over herbicides applied alone.

Texas millet control.

Early season. In 2017 at Corpus Christi, all PRE systems that included fluridone or fluometuron provided 89 to 93% Texas millet control while the POST the only system controlled this weed 88% (Table 3). At Yoakum in 2015, the premix of either fluridone plus fomesafen or fluridone plus fluometuron provided 86 to 99% Texas millet control while fluometuron alone controlled this weed 79 to 87% (Table 4). In 2016, fluridone alone at 0.17 kg ai ha^{-1}controlled Texas millet 90 to 96% while fluometuron alone at 1.12 kg ai ha^{-1} provided 97% control. The premix of fluridone plus fluometuron PRE controlled Texas millet 93 to 98%. In 2017, fluridone alone at 0.23 kg ai ha^{-1} provided 40 to 57% control while fluometuron alone controlled Texas millet 57 to 75% and the premix of fluridone plus fluometuron provided 70 to 77% control (Table 4).

Late season. At Corpus Christi in 2017, Texas millet control was poor as all PRE herbicide systems followed by a POST application that contained glyphosate controlled Texas millet 45 to 53% and the POST-only system provided 42% control (Table 3). At Yoakum in 2015, fluridone systems followed by a POST treatment provided near-complete control (99 to 100%) while fluridone systems without a POST herbicide controlled Texas millet 47 to 80%. Fluometuron alone at either 0.84 or 1.12 kg ai ha^{-1} provided 47 and 30% control, respectively, while the addition of a POST herbicide application improved control to at least 98%. In 2016, fluridone alone followed by a glyphosate POST application provided 94 to 96% control while fluometuron alone followed by a glyphosate POST application controlled Texas millet 77 to 88% (Table 4). In comparison, the premix of fluridone plus fluometuron at 0.17 + 0.84 kg ai ha^{-1} or 0.2 + 1.1 kg ai ha^{-1} followed by a POST herbicide program provided 85 to 96% control. In 2017, poor Texas millet control with all herbicide systems that included either fluridone or fluometuron alone or fluridone plus fluometuron was season-long. When evaluated 16 WAP, no PRE herbicide system provided better than 55% control while two POST applications provided 88% control. The poor control can be partially attributed to appreciable heavy rainfall (231 mm) which fell for the first 10 weeks of the growing season.

Hill *et al*. (2017) reported that fluridone control of barnyardgrass (*Echinocloa crus-Galli* L. Beauv.) and broadleaf signalgrass [*Urochloa platyphyllla* (Nash) R.D. Webster] was variable with fluridone providing better control than fluometuron in one year but no differences in control between the two herbicides in another year. They also found that annual grass control was improved following the use of glyphosate in one or more POST applications. Previous research has shown that an application of glyphosate plus *S*-metolachlor will provide excellent season-long control of barnyardgrass (Scroggs *et al.*, 2007).

Table 3. Early and late-season weed control with fluridone combinations and cotton yield in the Coastal Bend area near Corpus Christi and High Plains area near Halfway during the 2017 through 2018 growing seasons[a].

PRE herbicide	Rate Kg ai ha^{-1}	POST herbicide[e,f]	AMAPA[g]						UROTE		Yield	
			2017				2018		2017		2017	2018
			Corpus		Halfway[h]		Halfway		Corpus		Halfway	
			Weeks after planting									
			%								Kg ha^{-1}	
			4	12	6	14	3	12	4	12		
Untreated	None	None	0	0	100	100	0	0	0	0	1591	1864
Fluridone	0.17	POST-1/5	100	95	-	-	82	87	89	50	-	2638
Fluridone	0.17	POST-2/6	100	98	-	-	91	91	90	53	-	2348
Fluridone	0.23	POST-3	-	-	97	85	-	-	-	-	1501	-
Fluridone	0.23	POST-4	-	-	97	94	-	-	-	-	1514	-
Fluridone + diuron	0.17 + 0.21	POST-3	-	-	98	97	-	-	-	-	1489	-
Fluridone + fluometuron[b]	0.17 + 0.84	POST-3	-	-	98	87	-	-	-	-	1465	-
Fluridone + fluometuron[b]	0.17 + 0.84	POST-4	-	-	100	98	-	-	-	-	1599	-
Fluridone + prometryn[b]	0.17 + 0.84	POST-3	-	-	100	97	-	-	-	-	1562	-
Fluridone + fluometuron[b]	0.17 + 0.98	POST-5	-	-	-	-	82	88	-	-	-	2252
Fluridone + fluometuron[b]	0.17 + 0.98	POST-6	-	-	-	-	97	82	-	-	-	1919
Fluridone + fluometuron[c]	0.17 + 0.84	POST-1	100	98	-	-	-	-	92	47	-	-
Fluridone + fluometuron[c]	0.17 + 0.84	POST-2	100	96	-	-	-	-	89	50	-	-
Diuron	1.12	POST-3	-	-	95	93	-	-	-	-	1489	-
Fluometuron	1.12	POST-1/3	100	98	65	20	-	-	91	45	134	-
Fluometuron	1.12	POST-2/3	100	98	95	93	-	-	93	52	1440	-
Fluometuron	1.12	POST-4	-	-	97	82	-	-	-	-	1575	-

Fluometuron	1.40	POST-5	-	-	-	-	65	66	-	-	-	1934
Fluometuron	1.40	POST-6	-	-	-	-	38	40	-	-	-	1620
None[d]	-	POST-2/4	100	97	87	84	-	-	88	42	1501	-
LSD (0.05)			NS	NS	5	8	21	15	NS	7	256	685

[a] Abbreviations: NS, not significant; PRE, preemergence; POST, postemergence.

[b] Not a premix

[c] Premix marketed as Brake FX®.

[d] POST only treatments include 2 applications.

[e] POST-1 (2017, Corpus Christi), glyphosate at 1.54 kg ae ha^{-1} + dicamba (Engenia®) at 0.56 kg ae ha^{-1}; POST-2 (2017, Corpus Christi), glyphosate at 1.54 kg ae ha^{-1} + S-metolachlor at 1.07 kg ha^{-1} + dicamba (Engenia®) at 0.56 kg ae ha^{-1}; POST-3 (2017, Halfway), glyphosate at 1.54 kg ae ha^{-1} + S-metolachlor at 1.07 kg ha^{-1}; POST-4 (2017, Halfway), glyphosate at 1.54 kg ae ha^{-1} + S-metolachlor at 1.07 kg ha^{-1} + dicamba (Engenia®) at 0.56 kg ae ha^{-1}; POST-5 (2018, Halfway), glyphosate at 1.11 kg ae ha^{-1} + dicamba (Extendima®) at 0.56 kg ae ha^{-1}; POST-6 (2018, Halfway), glufosinate at 1.09 kg ha^{-1} + ammonium sulfate at 2.86 kg ha^{-1}.

[f] POST applications indicates either/or depending on the year.

[g] Bayer code for weeds: AMAPA, *Amaranthus Palmeri* S. Wats.; UROTE, *Urochloa texana* (Buckl.).

[h] The untreated check at Lubbock in 2017 was maintained weed-free.

Seed Cotton yields. Due to extremely dry weather conditions during the growing season at Yoakum in 2015 and the effects of Hurricane Harvey prior to harvest at Yoakum and Corpus Christi in 2017, cotton yield was obtained only at Lubbock in 2017 and 2018 and Yoakum in 2016.

At Halfway in 2017, only fluometuron alone at 1.12 kg ai ha^{-1} produced yield that were less than the weed-free untreated check (Table 3). Early- and late–season Palmer amaranth control was poor (≤ 65%), and this contributed to the poor yields. In 2018, fluridone at 0.17 kg ai ha^{-1} followed by a POST treatment that included glyphosate resulted in cotton yields which were higher than the untreated check. Fluometuron applied PRE and followed by a POST treatment that included glufosinate controlled Palmer amaranth 40% or less and produced cotton yields that were less than the fluridone treatment (Table 3). Hill *et al.* (2017) also reported reduced cotton yield when Palmer amaranth control was poor due to the shading effects and competition for moisture. In 2016 at Yoakum, either fluridone or fluometuron alone at 0.17 or 1.12 kg ai ha^{-1}, respectively, and fluridone plus fluometuron at 0.2 + 1.1 kg ai ha^{-1} applied PRE and followed by a POST treatment that included glyphosate produced cotton yields that were greater than the POST-only system (Table 4). All herbicide systems provided cotton yields that were greater than the untreated check.

Conclusions

These studies demonstrated the ability of fluridone-based herbicide systems to provide excellent control of Palmer amaranth and smellmelon, which are two common broadleaf weeds found in Texas cotton-producing areas. The fluridone-based systems provided weed control that was equal to or surpassed the fluometuron-based system. Use of fluridone in cotton could reduce selection pressure from herbicides with other mechanisms of action, especially glyphosate and PPO inhibitors that are widely used in cotton and several other crops (Braswell *et al.*, 2016). However, fluridone applied PRE will not provide season-long control of Palmer amaranth and supplemental POST applications will be needed.

Table 4. Early and late-season *Urochloa texana* control and cotton yield with fluridone combinations near Yoakum in south-central Texas from 2015 to 2017[a].

PRE herbicide	Rate Kg ha^{-1}	POST herbicide[d]	Weed control *Urochloa texana* 2015		2016		2017		Yield 2016
			Weeks after planting						
			4	16	4	12	4	16	
			%						Kg ha^{-1}
Untreated	None	None	0	0	0	0	0	0	323
Fluridone	0.17	POST-1	-	-	90	96	-	-	1059
Fluridone	0.17	POST-2	-	-	96	94	-	-	1149
Fluridone	0.23	POST-2	-	-	-	-	40	50	-
Fluridone	0.23	POST-3	-	-	-	-	57	37	-
Fluridone + fomesafen[b]	0.17 + 0.23	None	98	80	-	-	-	-	-
Fluridone + fomesafen[b]	0.17 + 0.23	POST-1	98	100	-	-	-	-	-
Fluridone + fluometuron[c]	0.17 + 0.23	None	86	47	-	-	-	-	-
Fluridone + fluometuron[c]	0.17 + 0.23	POST-1	98	99	93	85	-	-	1028
Fluridone + fluometuron[c]	0.17 + 0.23	POST-2	99	100	96	89	70	47	1090
Fluridone + fluometuron[c]	0.17 + 0.23	POST-3	-	-	-	-	77	55	-
Fluridone + fluometuron[c]	0.2 + 1.1	POST-1	-	-	97	95	-	-	1166
Fluridone + fluometuron[c]	0.2 + 1.1	POST-2	-	-	98	96	-	-	1122
Fluometuron	0.84	None	87	47	-	-	-	-	-
Fluometuron	0.84	POST-1	79	99	-	-	-	-	-
Fluometuron	1.12	None	79	30	-	-	-	-	-

Fluometuron	1.12	POST-1	79	98	97	88	-	-	993
Fluometuron	1.12	POST-2	-	-	97	77	75	20	1131
Fluometuron	1.12	POST-3	-	-	-	-	57	40	-
None	-	POST-2/3[e]	-	-	99	91	0	88	956
LSD (0.05)			16	26	4	10	22	14	174

[a] Abbreviations: PRE, preemergence; POST, postemergence.

[b] A premix marketed as Brake F2®.

[c] A premix marketed as Brake FX®.

[d] POST-1, glyphosate at 1.54 kg ae ha^{-1}; POST-2, glyphosate at 1.54 kg ae ha^{-1} + *S*-metolachlor at 1.07 kg ha^{-1}; POST-3; glyphosate at 1.54 kg ae ha^{-1} + dicamba (Engenia®) at 0.56 kg ae ha^{-1} + *S*-metolachlor at 1.07 kg ai ha^{-1}.

[e] In 2016, one application of POST-2; in 2017, two applications of POST-3.

One concern with using a fluridone-based system has been the long term persistence of fluridone in the soil. The potential for fluridone to persist and injure rotational crops can be influenced by tillage, application method, soil texture, organic matter content, rainfall, and irrigation amounts, and soil pH (Cahoon *et al.*, 2015). Fluridone is a weak base (Weber, 1980) and is absorbed to organic matter and clay, and absorption is inversely related to soil pH (Shea and Weber, 1980). Weber *et al.* (1986) found that less fluridone was desorbed from soils incubated 28 d under hot, moist conditions than when incubated under cool, dry conditions, suggesting soil temperature and moisture could affect the amount of fluridone available to the plant. In south-central Texas, no adverse effects have been seen with corn and grain sorghum planted the following spring after a fluridone application to cotton or peanut in April or June, respectively, the previous growing season (author's personal observation).

Conflicts of Interest

There are no conflicts of interest.

Funding Statement

This research was supported by the SePRO Corporation, Carmel, IN 46032.

References

1. Anonymous. (2009). Monsanto Biotechnology Trait Acres: Fiscal Years 1996-2009. Available: http://www.monsanto.com/investors/documents/2009/q4.biotech.acres. [11 February, 2019].

2. Anonymous. Palmer amaranth –weed of two years-2014-2015. (2015).]. Available:

   https://www.ag.ndsu.edu/weeds/weed-of-the-year-files/palmer-amaranth-2. [11 February, 2019].

3. Arnold, W. R. (1979). Fluridone-a new aquatic herbicide. J. Aquat. Plant Manag. 7: 30-33.

4. Banks, P. A, Ketchersid, M. L., and Merkle, M. G. (1979). The persistence of fluridone to various soils under field and controlled conditions. Weed Sci. 27: 631-633.

5. Banks, P. A., and Merkle, M. G. (1979). Field evaluations of the herbicide effects of fluridone on two soils. Agron. J. 71: 759-762.

6. Bartels, P.G., and Watson, C. W. (1978). Inhibition of carotenoid biosynthesis by fluridone and norflurazon. Weed Sci. 26: 198-203.

7. Bond, J. A., and Oliver, L. R. (2006). Comparative growth of Palmer amaranth (Amaranthus Palmeri) accessions. Weed Sci. 54: 121-126.

8. Braswell, L. R., Cahoon, Jr. C. W., Seagroves, R. W., Jordan, D. L., and York, A. C. (2016). Integrating fluridone into a glufosinate-based program for Palmer amaranth control in cotton. J. Cotton, Sci. 20: 394-402.

9. Cahoon, C. W., York, A. C., Jordan, D. L., Seagroves, R. W., Everman, W. J., and Jennings, K. M. (2015). Fluridone carryover to rotational crops following application to cotton. J. Cotton, Sci. 19: 631-640.

10. Correll, D. S., and Johnston, M. C. (1979). Manual of the Vascular Plants of Texas, 2nd ed. University Texas at Dallas, Richardson, TX. Pp 555-556.

11. Culpepper, A. S. (2006). Glyphosate-induced weed shifts. Weed Technol. 20: 277-281.

12. Owen, M. D. K. (2008). Weed species shifts in glyphosate-resistant crops. Pest Manage. Sci. 64: 377-387.

13. Elmore, C. D., editor. (1985). Weed Identification Guide, Champaign, Ill.: South. Weed Sci. Soc. 225 p.

14. Fox, A. M., Haller, W. T., and Shilling, D. G. [1994]. Use of fluridone for hydrilla management in the Withlacooche River, Florida. J. Aquat. Plant Manage. 32: 47-55.

15. Franssen, A. S., Skinner, D. Z., Al-Khatib, K., Horak, M. J., and Kulakow, P. A. (2001a). Interspecific hybridization and gene flow of ALS-resistance in Amaranthus species. Weed Sci. 49: 598-606.

16. Franssen, A. S., Skinner, D. Z., Al-Khatib, K., and Horak, M. J. (2001b). Pollen morphological differences in Amaranthus species and interspecific hybrids. Weed Sci. 49: 732-737.

17. Frans, R., Talbert, R., Marx, D., and Crowley, H. (1986). Experimental design and techniques for measuring and analyzing plant responses to weed control practices. In: Camper, N. D., (ed.). Research Methods in Weed Science. 3rd ed. Champaign, IL: Southern Weed Science Society. Pp. 29-46.

18. Guo, P., and Al-Khatib, K. (2003). Temperature effects on germination and growth of redroot pigweed (*Amaranthus retroflexus*), Palmer amaranth (*A. Palmeri*), and common waterhemp (*A. rudis*). Weed Sci. 51: 329-333.

19. Hayes, R. M., Mueller, T. C., Willis, J. B., and Montgomery, R. F. (2002). Glyphosate-resistant horseweed and factors influencing its control. Proc. South. Weed Sci. Soc. 55: 119-120.

20. Heap, I. The international survey of herbicide-resistant weeds. (2014). Available: http://www.weedscience.com. pdf. [8 February 2019].

21. Hill, Z.T., Norsworthy, J. K., Barber, L. T., and Gbur, E. (2017). Assessing the potential for fluridone to reduce the number of postemergence herbicide applications in glyphosate-resistant cotton. J. Cotton Sci. 21: 175-182.

22. Horak, M. J., and Loughin, T. M. (2000). Growth analysis of four Amaranthus species. Weed Sci. 48: 347-355.

23. Johnson, W. G., Bradley, P. R., Hart, S. E., Buesinger, M. .L, and Massey, R. E. (2000). Efficacy and economics of weed management in glyphosate-resistant corn (*Zea mays*). Weed Technol. 14: 578-585.

24. Keeley, P. E., Carter, C. H., and Thullen, R. J. (1987). Influence of planting date on growth of Palmer amaranth (Amaranthus Palmeri). Weed Sci. 35: 199-204.

25. Koschnick, T. J., Haller, W. T., Vandiver, W., and Santra, U. (2003). Efficacy and residue comparisons between two slow-release formulations of fluridone. J. Aquat. Plant Manage. 41: 25-27.

26. Kowalczyk-Schroder, S., and Sandmann, G. (1992). Interference of fluridone with the desaturation of phytoene by membranes of the cyanobacterium *Aphanocapsa*. Pestic. Biochem. Phys. 42: 7-12.

27. Legleiter, T., and Bradley, K. (2008). Glyphosate and multiple herbicide resistance in common waterhemp (*Amaranthus rudis*) populations from Missouri. Weed Sci. 56: 582-587.

28. Light, G. G., Mohammed, M. Y., Dotray, P. A., Chandler, J. M., and Wright, R. J. (2011). Glyphosate-resistant common waterhemp (Amatanthus rudis) confirmed in Texas. Weed Technol. 25: 480-485.

29. McGinty, J., Kimura, E., Baumann, P., Dotray, P., and Morgan, G. (2016). Weed management in Texas cotton. Dept. Soil and Crop Science, Texas A&M AgriLife Extension Service. SC-2016-16. Avaliable: http://soilcrop.tamu.edu [11 February 2019].

30. Miller, J. H., and Carter, C. H. (1983). Fluridone for annual weed control in western irrigated cotton (*Gossypium hirsutum*). Weed Sci. 21: 290-293.

31. Morgan, G., Baumann, P., and Chandler, J. (2001). Competitive impact of Palmer amaranth (*Amaranthus Palmeri*) on cotton (*Gossypium hirsutum*) development and yield. Weed Technol. 15: 408-412.

32. Norsworthy, J. K., Griffith, G. M., Scott, R. C., Smith, K. L., and Oliver, L. R. (2008). Confirmation and control of glyphosate-resistant Palmer amaranth (*Amaranthus Palmeri*) in Arkansas. Weed Technol. 22: 108-113.

33. Owen, M. D. K. (2008). Weed species shifts in glyphosate-resistant crops. Pest Manage. Sci. 64: 377-387.

34. Richardson, R. J. (2008). Aquatic plant management and the impact of emerging herbicide resistance issues. Weed Technol. 22: 8-15.

35. Sauer, J. D. (1957). Recent migration and evolution of the dioecious amaranths. Evolution. 11: 11-31.

36. Scott, G. H., Askew, S. D., and Wilcut, J. W. (2002). Glyphosate systems for weed control in glyphosate-resistant cotton (*Gossypium hirsutum*). Weed Technol. 16: 191-198.

37. Scroggs, D. M., Miller, D. K, Griffin, J. L., Steckel, L. E., Blouin, D. C., Stewart, A. M, and Vidrine, P. R. (2007). Reduced-input, postemergence weed control with glyphosate and residual herbicides in second-generation glyphosate-resistant cotton. Weed Technol. 21: 997-1001.

38. Sellers, B. A., Smeda, R. J., Johnson, W. G., Kendig, J. A., and Ellersieck, M. R. (2003). Comparative growth of six Amaranthus species in Missouri. Weed Sci. 51: 329-333.

39. Schroeder, J., and Banks, P. A. (1986). Persistence and activity of norflurazon and fluridone in five Georgia soils under controlled conditions. Weed Sci. 34: 599-606.

40. Shea, P. J., and Weber, J. B. (1980). Effect of pH and soil constituents on the persistence and availability of fluridone. Proc. South. Weed Sci. Soc. 33: 240-246.

41. Smith, D., Baker, R., and Steele, D. (2000). Palmer amaranth (*Amaranthus Palmeri*) impacts on yield, harvesting, and ginning in dryland cotton (*Gossypium hirsutum*). Weed Technol. 14: 122-126.

42. Tingle, C. H., and Chandler, J. M. (1999). Smellmelon (*Cucumis melo*) and entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula*) control with Staple and Roundup Ultra combinations in Roundup Ready cotton. Proc. South. Weed Sci. Soc. 52: 256.

43. Tingle, C. H., Steele, G. L., and Chandler, J. M. (2003). Competition and control of smellmelon (*Cucumis melo* var. *dudaim* Naud.) in cotton. Weed Sci. 51: 586-591.

44. Van Wychen, L. (2015). Baseline survey of the most common and troublesome weeds in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. Available:

http://wssa.net/wp-content/Uploads/2015_Weed_Survey_Final.xlsx. [13 February 2019].

45. Waldrep, T. W., and Taylor, H. M. (1976). 1-methyl-3-phenyl-5-[3-(trifluoromethyl) phenyl]-4(1H)-pyridinone, a new herbicide. J. Agric. Food Chem. 24: 1250-1251.

46. Weber, J. B. (1980). Ionization of buthidazole, VEL 3510, tebuthiuron, fluridone, metribuzin, and prometryn. Weed Sci. 28: 467-474.

47. Weber, J. B., Shea, P. H., and Weed, S. B. [1986]. Fluridone retention and release in soils. Soil Sci. Soc. Am. J. 50: 582-588.

48. Wiggins, M. S., McClure, M.A., Hayes, R., and Steckel, L. E. (2015). Integrating cover crops and POST herbicides for glyphosate-resistant Palmer amaranth (*Amaranthus Palmeri*) control in corn. Weed Technol. 29: 412-418.

49. Yancy, C. H. (2003). Glyphosate-resistant horseweed causing concern in North Carolina. Southeast Farm Press. Available: http://www.southeastfarmpress.com/glyphosate-resistant-horseweed-causing-concern-north-carolina. [15 February 2019].

50. Young, B. (2006). Changes in herbicide use patterns and production practices resulting from glyphosate-resistant crops. Weed Technol. 20: 301-307.