The *Journal of Cotton Science 20:76–85 (2016)*
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WEED SCIENCE

Residual Weed Control in Cotton with Fluridone

Zachary T. Hill*, Jason K. Norsworthy, L. Tom Barber, and Edward Gbur

ABSTRACT

Glyphosate-resistant Palmer amaranth is considered the most troublesome weed in agronomic crops in the Midsouth. The reliance on multiple herbicide mechanisms of action (MOA) and soil-residual herbicides has increased over the past several years due to the ever growing issue of herbicide-resistant weeds. Field experiments were conducted at several locations in Arkansas to determine the efficacy of fluridone on Palmer amaranth in glyphosate-resistant and glufosinate-resistant cotton herbicide programs and to determine the length of residual fluridone activity when applied preemergence (PRE). Fluridone has a unique MOA and is currently not registered as a stand-alone herbicide for use in cotton. In the length of residual experiment, when rainfall was adequate, fluridone applied PRE at rates greater than 224 g a.i. ha^{-1} provided > 90% Palmer amaranth control for 6 wk after application; however, effective season-long Palmer amaranth control was not achieved with any rate of fluridone alone. Fluridone alone applied 14-d preplant or PRE did not provide greater Palmer amaranth control than a standard herbicide application. When fluridone was integrated into a glufosinate-based herbicide program, PRE-applied fluridone at 224, 336, and 448 g ha^{-1} did not provide greater Palmer amaranth control than the standard herbicide program that included fluometuron. Based on these experiments, fluridone should not be applied as a stand-alone herbicide in cotton, nor will it reduce the number of POST applications needed for effective Palmer amaranth control in glufosinate-resistant cotton.

Prior to glyphosate-resistant cotton, weeds in the crop were controlled using a number of different techniques (Young, 2006). These included tillage, both prior to and after planting, selective herbicides applied preplant incorporated, preemergence (PRE), postemergence (POST), and post-directed, as well as nonselective herbicides applied in shielded or hooded sprayers. Glyphosate-resistant cotton became commercially available in 1997. which greatly changed weed management in cotton. By 2011, glyphosate-resistant cotton was adopted on almost 100% of the Midsouth cotton acreage (USDA-NASS, 2011). Additionally, the use of tillage for weed control steadily declined with increasing adoption of minimum tillage production systems (Young, 2006). Therefore, glyphosate-resistant cotton cultivars allowed producers to safely rely on multiple applications of glyphosate for weed control (Culpepper et al., 2006). As a result of the extensive use of glyphosate, 15 weed species have been confirmed resistant to glyphosate in the U.S., of which eight are found in Arkansas (Heap, 2015).

There are approximately 60 *Amaranthus* species native to the Americas (Sauer, 1967), infesting corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and soybean [*Glycine max* (L.) Merr.] throughout the southern U.S. The most problematic *Amaranthus* species in Arkansas crops is Palmer amaranth [*Amaranthus palmeri* (S. Wats.)]. Palmer amaranth is troublesome due to its extended emergence period (Jha et al., 2006) and prolific growth under a wide range of conditions (Horak and Loughin, 2000). The prolific growth of Palmer amaranth is due to it being a C_4 plant, and it has one of the highest photosynthetic rates among C_4 plants (Ehleringer, 1983). The growth rate of Palmer amaranth is up to four times that of most row crops (Ehleringer and Hammond, 1987), including corn, which is also a C_4 plant, as well as cotton and soybean, which are both slower-growing C_3 plants (Gibson, 1998). Extremely high growth rates give Palmer amaranth the ability to reach heights of 2 m or more (Horak and Peterson, 1995; Norsworthy et al., 2008), exceeding the height of cotton.

Z.T. Hill* and J.K. Norsworthy, University of Arkansas, Department of Crop, Soils, and Environmental Sciences, 1366 West Altheimer Drive, Fayetteville, AR 72701; L.T. Barber, University of Arkansas, Department of Crop, Soils, and Environmental Sciences, 102 Northeast Front Street Suite 2, Lonoke, AR 72086; and E. Gbur, University of Arkansas, Agriculture Statistics Lab, 935 West Maple Street, Fayetteville, AR 72701
*Corresponding author: zhill@uaex.edu

Palmer amaranth is one of the most competitive weeds of cotton, with lint yield reductions up to 92% from 0.9 plants m^{-2} (Rowland et al., 1999). Each Palmer amaranth plant (up to eight plants) added to a 10-m row of cotton reduces lint yield by 62 kg ha^{-1} (Morgan et al., 1997). Spatial movement of glyphosate-resistant Palmer amaranth originating from a single plant in a cotton field can result in complete loss of the crop in as few as 3 yrs when relying solely on glyphosate (Norsworthy et al., 2014).

Herbicide resistance in Palmer amaranth has had a detrimental effect on crop production over the past 20 yrs, with resistance being confirmed for five mechanisms of action (MOA): microtubule assembly inhibitors, photosystem (PS) II-inhibitors, acetolactate synthase inhibitors, 5-enolpyruvyl shikimate-3-phosphate synthase inhibitors, and protoporhyringon oxidase inhibitors (Heap, 2015). These five herbicide MOAs were frequently used for control of Palmer amaranth prior to the onset of resistance (Young, 2006).

During the past several years, glufosinate-resistant crops, such as soybean, cotton, and corn have been commercialized to improve control of glyphosate-resistant weeds. Although the use of glufosinate-resistant crop technologies is a good alternative to glyphosate-resistant technologies, studies have shown that control of *Amaranthus* spp. with glufosinate alone can be marginal when applied in less than ideal growing conditions (Corbett et al., 2004). Hence, the use of soil-residual herbicides such as fluridone and sequential POST herbicide applications along with cultural practices could further improve control of glyphosate-resistant Palmer amaranth compared to glufosinate alone.

With the unlikely commercialization of a new herbicide targeting a novel MOA in the foreseeable future, controlling herbicide-resistant Palmer amaranth will require that diverse MOAs be incorporated into current cropping systems to sustain the few herbicide options that are still effective. A herbicide with a unique or lightly used MOA for cotton that provides extended residual control would aid in resistance management. Fluridone is highly effective in controlling many weeds, and has been shown to provide a high level of redroot pigweed (*Amaranthus retroflexus* L.) control (Waldrep and Taylor, 1976), a weed closely related to Palmer amaranth.

Fluridone, a WSSA Group 12 herbicide developed by Eli Lilly as EL-171, was synthesized in the early 1970s and inhibits phytoene desaturase in plants (Waldrep and Taylor, 1976). Although fluridone was never labeled for use in field crops, studies were conducted to evaluate its effectiveness in row crop production systems. Waldrep and Taylor (1976) evaluated fluridone at rates ranging from 0.3 to 2.4 kg a.i. ha^{-1} for herbicidal activity and found it to be safe when applied PRE at these rates in cotton. Fluridone provided broad-spectrum residual control of annual grass and broadleaf weeds such as barnyardgrass [*Echinochloa crus-galli* (L.) Beauv], johnsongrass (*Sorghum halepense* L.), tall morningglory [*Ipomoea purpurea* (L.) Roth], and redroot pigweed. Fluridone was more active when applied PRE than when applied POST (Waldrep and Taylor, 1976). Because of greater weed control when applied PRE and significant injury to cotton from POST applications, fluridone was thought to be better suited as a soil-applied herbicide (Webster et al., 1977; Wills, 1977).

Due to the favorable characteristics of fluridone providing broad-spectrum residual control of annual grass and broadleaf weeds (Waldrep and Taylor, 1976) and extended persistence in the soil (Banks et al., 1979), incorporating fluridone into an Arkansas cotton herbicide program would be greatly beneficial. However, the previously discussed research was conducted in regions that have different environmental and soil characteristics than Arkansas. Hence, the objectives of this research were to 1) determine the optimum fluridone application rate and application method for residual control of Palmer amaranth in Arkansas cotton and 2) determine if fluridone provides a high level of season-long control when followed by an early-season application of glufosinate in Arkansas cotton.

MATERIALS AND METHODS

Residual Activity of Preplant (PP) and PRE Fluridone Versus Standards. A field experiment was conducted at the Arkansas Agricultural Research and Extension Center (AAREC) in Fayetteville, AR on a Captina silt loam soil (fine-silty, siliceous, active, mesic Typic Fragiudults) in 2012; on a Pembroke silt loam soil (fine-silty, mixed, active, mesic Mollic Paleudalfs) in 2013; and at the Lon Mann Cotton Research Center (LMCRC) near Marianna, AR on a Zachary silt loam soil (fine-silty, mixed, active, thermic Typic Albaqualfs) in 2012 and 2013.

A randomized complete-block (RCB) design with four replications was utilized at all locations. Cotton was planted in four 97-cm-wide rows at the LMCRC and in two 91-cm-wide rows at the AAREC. Plots were 7.6-m long with a 1.5-m alley between replications. Phytogen 375 WRF (Widestrike®, Genuity®, Roundup Ready Flex®) cotton was planted on raised beds on 23 May 2012 and on 30 May 2013 at LMCRC at a 2-cm depth. At AAREC, the same cultivar was planted on 14 May 2012, at a 2-cm depth. Cotton was not planted in the plots at AAREC in 2013 because excessive rainfall amounts at the time of PRE application. Cotton seeding rates at both locations ranged from 98,000 to 108,000 seeds ha^{-1}. Herbicide treatments were applied to a natural existing population of Palmer amaranth and other weeds such as pitted morningglory (*Ipomoea lacunosa* L.) and barnyardgrass. Herbicides evaluated were compared to a nontreated control and can be found in Table 1.

Evaluation of Fluridone as a Soil-Applied Alternative in Cotton. A field experiment was conducted in 2012 and 2013 at the Northeast Research and Extension Center (NEREC) in Keiser, AR on a Sharkey silty clay soil (very-fine, smectitic, thermic Chromic Epiaquerts). The experiment was conducted using an RCB design with a three-by-two factorial arrangement of treatments, with four replications. Three PRE-herbicide treatments and two POST-herbicide programs, plus a standard program and a nontreated control were evaluated. Cotton was planted in four 97-cm-wide rows that were 7.6 m in length. 'Phytogen 375 WRF' was seeded at 136,000 seeds ha^{-1} on 14 May 2012 and on 28 May 2013 in a stale seedbed system on raised planting beds with a four-row planter. Palmer amaranth control was evaluated to determine if applications of fluridone provided season-long control and could replace existing soil-residual herbicides in a glufosinate-resistant cotton herbicide program. Herbicide programs evaluated in this experiment were compared to a nontreated control and can be found in Table 2.

General Experimental Procedures for Both Experiments. Treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1}. Paraquat (Gramoxone® SL 2.0, Syngenta Crop Protection, LLC, Greensboro, NC) at 1,050 g a.i. ha^{-1} was applied to the entire test area to control emerged weeds on the same day that the PRE treatments were applied. Throughout the growing season, escaped grasses were controlled with clethodim (Select Max®, Valent USA Corporation Agricultural Products, Walnut Creek, CA) at 280 g a.i. ha^{-1} as needed.

Plots were visually evaluated every 14 to 21 d after treatment (DAT) for herbicide efficacy and cotton injury on a scale of 0 to 100%, with 0 being no control or injury and 100% being death of the plant (Frans et al., 1986). Depending on the weeds evaluated, ratings were taken 2, 4, 6, and 9 wks after the preplant herbicide application (WAPP) for the length of residual experiment; whereas, for the glufosinate-resistant cotton experiment ratings were taken 2, 5, 8, and 11 wks after the preemergence (WAPP) application. Ratings were based on comparison to the nontreated control (NTC). All data were analyzed by ANOVA using JMP Pro Version 10.0 (SAS Institute Inc., Cary, NC), and means were separated with Fisher's LSD at a 5% level of significance. The 2 and 4 WAPP data were combined over the AAREC and LMCRC locations due to the lack of significant differences between locations. Due to the different environmental conditions for the 2012 and 2013 growing seasons, years were analyzed separately. Preplanned contrasts were conducted to compare: 1) PP versus PRE treatments and fluridone versus the standard herbicide (either fomesafen PP, fluometuron PRE, or diuron PRE) in the residual experiment and 2) fluridone PRE versus fluridone PRE + glufosinate, fluridone PRE versus standard, fluridone PRE + glufosinate versus standard, fluridone at 224 g ha^{-1} versus fluridone at 336 g ha^{-1}, and fluridone at 224 g ha^{-1} versus fluridone at 448 g ha^{-1} in the second experiment.

Table 1. Herbicide products used, production company, application rate, and application timing of treatments applied at the Arkansas Agricultural Research and Extension Center in Fayetteville and the Lon Mann Cotton Research Center near Marianna, AR, in 2012 and 2013

Treatment	Tradename	Company[x]	Rate(s)[y]	Application timing[z]
			g a.i. ha^{-1}	
Fluridone	Brake 2L	SePRO Corp.	112 to 560	14-d PP or PRE
Fomesafen	Reflex	Syngenta	280	14-d PP
Fluometuron	Cotoran 4L	ADAMA Ltd.	1,120	PRE
Diuron	Direx 4L	ADAMA Ltd.	1,120	PRE

[z] Abbreviations: PP, preplant; PRE, preemergence.

[y] Fluridone rates: 112, 224, 336, 448, and 560 g a.i. ha^{-1}.

[x] SePRO Corp. (11550 North Meridian Street Suite 600, Carmel, IN 46032)

Syngenta Crop Protection (Regional Headquarters P.O. Box 18300, Greensboro, NC 27409)

ADAMA USA Ltd. (3120 Highwoods Blvd. #100, Raleigh, NC 27604)

Table 2. Herbicide products used, production company, application rate, and application timing of treatments applied at the Northeast Research and Extension Center in Keiser, AR, in 2012 and 2013

Program	Tradename	Company	Rate(s) [y]	Application Timing [z]
			g a.i. ha^{-1}	
Fluometuron	Cotoran 4L	ADAMA Ltd.	1,120	PRE
Glufosinate	Liberty	Bayer Crop Science	424	4- to 5-leaf
S-metolachlor	Dual Magnum	Syngenta	1,070	4- to 5-leaf
Glufosinate	Liberty	Bayer Crop Science	424	8- to 10-leaf
S-metolachlor	Dual Magnum	Syngenta	1,070	8- to 10-leaf
MSMA	MSMA 6 Plus	Drexel Chemical Co.	2,240	Layby
Flumioxazin	Valor SX	Valent U.S.A.	72	Layby
Fluridone	Brake 2L	SePRO Corporation	224 to 448	PRE
MSMA	MSMA 6 Plus	Drexel Chemical Co.	2,240	Layby
Flumioxazin	Valor SX	Valent U.S.A.	72	Layby
Fluridone	Brake 2L	SePRO Corporation	224 to 448	PRE
Glufosinate	Liberty	Bayer Crop Science	424	AFR
MSMA	MSMA 6 Plus	Drexel Chemical Co.	2,240	Layby
Flumioxazin	Valor SX	Valent U.S.A.	72	Layby

[z] Abbreviation: PRE, preemergence; AFR, after first rainfall.

[y] Fluridone rates: 224, 336, and 448 g a.i. ha^{-1}.

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Syngenta Crop Protection (Regional Headquarters P.O. Box 18300, Greensboro, NC 27409)

ADAMA USA Ltd. (3120 Highwoods Blvd. #100, Raleigh, NC 27604)

Drexel Chemical Co. (1700 Channel Ave., Memphis, TN 38106)

Valent U.S.A (1600 Riviera Ave Suite 200, Walnut Creek, CA 94596)

Bayer Crop Science U.S.A (P.O. Box 12014, Research Triangle Park, NC 27709)

RESULTS AND DISCUSSION

Environmental Data and Cotton Growth. Multiple rates of fluridone were compared to commonly used soil-applied residual herbicides to determine the length of residual Palmer amaranth control in cotton. In 2012, activating rainfall was not received at AAREC and LMCRC locations; whereas in 2013, sufficient rainfall (≥ 1.27 cm) was received soon after the PRE applications for activation. Rainfall greater than 2.5 cm was received within 5 to 7 d following the PRE application at NEREC in both years. Previous research has shown that an adequate amount of rainfall following the application of soil-residual herbicides greatly affects herbicide efficacy (Buhler and Werling, 1989; Salzman and Renner, 1992). Furthermore, rainfall amounts in 2012 were lower than in 2013 and the 30-yr average (Table 3). Therefore, differences in rainfall amount and timing not only affected plant growth, but also likely impacted the effectiveness of herbicide applications.

Furrow irrigation was initiated within 3 to 14 d after the application of PRE herbicides at AAREC and LMCRC in an attempt to overcome the lack of rainfall in 2012. Consequently, early-season cotton growth was delayed at both locations; however, no herbicide injury was observed in either growing season (data not shown).

Weed Control with Fluridone Compared to Standards. *Palmer Amaranth Control.* Two weeks after planting in 2012, Palmer amaranth control was comparable between both PP treatments and was ≥ 90% (Table 4). Palmer amaranth control continually decreased throughout the weeks following PRE applications. At 4 WAPP, no treatment provided ≥ 86% Palmer amaranth control. The lack of effective control of Palmer amaranth this early in the 2012 growing season is partially a result of the dry conditions following the application of PRE herbicides.

Differences in Palmer amaranth control were observed from PP and PRE treatments at 6 WAPP at AAREC (34 to 76%) and LMCRC (28 to 86%). By 9 WAPP, Palmer amaranth had completely overtaken the cotton growing in the plots at AAREC; hence, herbicide efficacy was not evaluated. On the basis of contrasts, PRE treatments at LMCRC in 2012 provided greater Palmer amaranth control at 9 WAPP than the 14 d PP applications (Table 4). By 9 WAPP at LMCRC, no treatment provided greater than 66% control of Palmer amaranth.

At both locations in 2013, greater than 1.3 cm of rainfall occurred within 1 to 4 d of both application timings, which greatly affected herbicide efficacy. Palmer amaranth control ranged from 81 to 100% for 6 wk following application of the PP herbicides (Table 4), with PP fluridone providing significantly less control of Palmer amaranth than the remaining treatments. Control was similar to previous research that reported fluridone rates ranging from 224 to 448 g ha^{-1} provided ≥ 96% control of *Amaranthus* spp. at 4 to 6 wk after application (Webster et al., 1977). At 9 WAPP, orthogonal contrasts revealed that Palmer amaranth control differed between PP and PRE applications (Table 4). In LMCRC at 9 WAPP, both PP treatments, fluridone applied PRE at 112 g ha^{-1}, and fluometuron provided significantly less (< 80%) control of Palmer amaranth.

Table 3. Precipitation from May, June, and July 2012 and 2013 at the Arkansas Agricultural Research and Extension Center (AAREC), Lon Mann Cotton Research Center (LMCRC), and Northeast Research and Extension Center (NEREC) and the 30-yr average

Location	Precipitation (2012)	Precipitation (2013)	Average 30-yr Precipitation [z]
	cm		
AAREC			
May	2.4	11.1	11.5
June	2.5	14.3	8.9
July	2.1	7.1	6.8
LMCRC			
May	3.8	18.9	12.3
June	2.0	1.9	9.1
July	6.5	13.6	9.4
NEREC			
May	10.6	19.8	13.6
June	6.4	12.3	9.9
July	6.0	9.9	10.4

[z] Average 30-yr precipitation May, June, and July from 1984 to 2013.

Table 4. Palmer amaranth control following preplant and preemergence applications of fluridone and current standards at the Arkansas Agricultural Research and Extension Center in Fayetteville, AR and the Lon Mann Cotton Research Center near Marianna, AR, in 2012 and 2013z,y

Treatment	Rate	Timing	Control										
			2012					2013					
			2 WAPP	4 WAPP	6 WAPP		9 WAPP	2 WAPP	4 WAPP	6 WAPP		9 WAPP	
			Comb	Comb	AAREC	LMCRC	LMCRC	Comb	Comb	AAREC	LMCRC	AAREC	LMCRC
	g a.i. ha^{-1}		%										
Fluridone	336	PP	90 a	79 b	49 b	83 a	24 c	89 b	100	81 b	86 a	94 a	73 b
Fomesafen	280	PP	93 a	83 a	76 a	84 a	66 a	97 a	100	100 a	89 a	91 a	73 b
Fluridone	112	PRE[x]	---	80 b	63 a	41 c	35 bc	---	100	92 a	83 b	84 a	78 b
Fluridone	224	PRE	---	75 c	42 c	49 c	26 c	---	100	96 a	96 a	86 a	88 a
Fluridone	336	PRE	---	79 b	60 a	43 c	44 b	---	100	98 a	96 a	88 a	87 a
Fluridone	448	PRE	---	85 a	64 a	80 a	43 b	---	100	99 a	90 a	89 a	90 a
Fluridone	560	PRE	---	86 a	75 a	86 a	64 a	---	100	100 a	89 a	93 a	93 a
Fluometuron	1,120	PRE	---	81 b	34 c	28 d	21 c	---	100	100 a	93 a	95 a	76 b
Diuron	1,120	PRE	---	74 c	46 b	66 b	25 c	---	100	95 a	91 a	88 a	83 a
Contrast[w]													
Fluridone vs. Standard							NS					NS	NS
PP vs. PRE												0.0126*	0.0486*

[z] Abbreviations: WAPP, weeks after preplant application; AAREC, Arkansas Agricultural Research and Extension Center; LMCRC, Lon Mann Cotton Research Center, combined over Fayetteville and Marianna; PP, preplant; PRE, preemergence.

[y] Means within a column followed by the same lowercase letter are not statistically different based on Fisher's LSD (0.05).

[x] The PRE timing was 2 wks after the PP application.

[w] Asterisks (*) indicate statistical difference based on Fisher's LSD (α=0.05).

Pitted Morningglory Control. Similar to Palmer amaranth control observed in 2012, the lack of timely rainfall likely affected herbicide efficacy (Table 5). Initially, PRE treatments at AAREC provided comparable (83 to 93%) control to both PP treatments, except for fluridone at 224 g ha^{-1} (78%). Waldrep and Taylor (1976) reported that fluridone at 336; 672; 1,200; and 2,400 g ha^{-1} applied PRE controlled *Ipomoea* spp. 70, 95, 95, and 100%, respectively, 3 wk following the herbicide application. At 4 WAPP at LMCRC, pitted morningglory control was considerably reduced, with no treatment providing ≥ 51% control. Pitted morningglory control from all treatments at LMCRC continued to diminish throughout the growing season with variable (18-41%) control at 6 WAPP and no control by 9 WAPP. Even with adequate rainfall in 2013, regardless of the application timing and rate, fluridone treatments were comparable to the standard PP and PRE herbicides, with all treatments providing ≤ 80% control (Table 5).

Barnyardgrass Control. Generally, barnyardgrass control was variable within and across locations in 2012 (Table 6). At 4 WAPP, barnyardgrass control ranged from 58 to 96% at AAREC and 55 to 88% at LMCRC, with most rates of fluridone at LMCRC providing greater control than the standard PP and PRE herbicides. Regardless of the application timing, Banks and Merkle (1978) reported that control of *Echinocloa* spp. and broadleaf signalgrass [*Urochloa platyphylla* (Nash.) R.D. Webster] was 88 to 100% from fluridone at rates ranging from 448 to 900 g ha^{-1}. By 9 WAPP in 2012, barnyardgrass control was less than 38%. Orthogonal contrasts revealed that all fluridone rates provided greater barnyardgrass control than the current standard herbicides used. Additionally, a difference in barnyardgrass control was observed between the PRE treatments over that of the PP treatments. Greater barnyardgrass control from the PRE treatments could be a result of them being applied 14 d after the PP treatments.

Table 5. Pitted morningglory control following preplant and preemergence applications of fluridone and current standards at the Arkansas Agricultural Research and Extension Center in Fayetteville, AR and the Lon Mann Cotton Research Center near Marianna, AR in 2012 and 2013[z,y]

Treatment	Rate	Timing	Control									
			2012					2013				
			4 WAPP		6 WAPP		9 WAPP	4 WAPP		6 WAPP		9 WAPP
			AAREC	LMCRC	AAREC	LMCRC	LMCRC	AAREC	LMCRC	AAREC	LMCRC	AAREC
	g a.i. ha^{-1}		%									
Fluridone	336	PP	93 a	49 a	91 a	41 a	0	98 a	99 a	89 a	89 a	58 ab
Fomesafen	280	PP	85 a	41 a	90 a	26 b	0	49 b	99 a	64 b	86 a	58 ab
Fluridone	112	PRE[x]	84 a	30 b	87 a	18 c	0	94 a	98 a	69 b	84 a	74 a
Fluridone	224	PRE	78 b	40 a	84 a	25 b	0	88 a	99 a	78 b	86 a	74 a
Fluridone	336	PRE	84 a	38 ab	91 a	20 b	0	96 a	99 a	92 a	85 a	74 a
Fluridone	448	PRE	83 a	49 a	90 a	34 a	0	97 a	99 a	96 a	90 a	79 a
Fluridone	560	PRE	91 a	51 a	92 a	41 a	0	98 a	99 a	90 a	85 a	80 a
Fluometuron	1,120	PRE	88 a	35 b	93 a	23 b	0	99 a	99 a	79 b	90 a	76 a
Diuron	1,120	PRE	83 a	36 b	76 b	20 b	0	99 a	99 a	81 b	88 a	53 b
Contrast[w]												
Fluridone vs. Standard							NS					NS
PP vs. PRE							NS					NS

[z] Abbreviations: WAPP, weeks after preplant application; AAREC, Arkansas Agricultural Research and Extension Center; LMCRC, Lon Mann Cotton Research Center; PP, preplant; PRE, preemergence.

[y] Means within a column followed by the same lowercase letter are not statistically different based on Fisher's LSD (0.05).

[x] The PRE timing was 2 wks after the PP application.

[w] Asterisks (*) indicate statistical difference based on Fisher's LSD (α=0.05).

Because barnyardgrass was not present at AAREC in 2013, control was evaluated only at LMCRC (Table 6). All herbicide treatments provided ≥ 98% control at 4 WAPP. Good barnyardgrass control was observed up to 6 WAPP from all treatments in 2013; however, a reduction in control was observed at 9 WAPP for most treatments. Fluridone applied PRE at 224 to 560 g ha^{-1} provided ≥ 90% barnyardgrass control at 9 WAPP. Fluridone at these rates provided greater control than fluometuron (79%) and diuron (81%) at this time. This coincides with contrasts that revealed greater control with fluridone compared to the standard herbicides and with PRE applications compared to PP applications.

Evaluation of Fluridone as a Soil-Applied Alternative in Cotton. Timing of each herbicide application is shown in Table 7. At 2 WAP in 2012, all treatments provided ≥ 92% control of Palmer amaranth; however, fluometuron provided greater control than most fluridone treatments (Table 8). This further emphasizes the need for sufficient rainfall to activate the PRE herbicides evaluated in this experiment (Salzman and Renner, 1992). Although fluometuron applied PRE provided greater (96%) control than fluridone treatments at 5 WAP (66-83%), the three fluridone treatments greatly benefited from the glufosinate applied 2 wk after the PRE application (after first rainfall) (Tables 7 and 8). Similarly, other researchers suggest adequate Palmer amaranth control can be obtained in a glufosinate-resistant cotton herbicide program when PRE herbicides are followed by timely applications of glufosinate (Gardner et al., 2006). By 5 WAP, the first POST treatment of glufosinate plus *S*-metolachlor had been applied, and this increased Palmer amaranth control over that provided by all fluridone-based programs.

Palmer amaranth control greater than 95% was observed at 8 WAP following the second POST application of glufosinate plus *S*-metolachlor in the standard program in 2012 (Table 8). At 8 WAP, fluridone at 224, 336, and 448 g ha^{-1} followed by glufosinate after the first rain (AFR) provided ≥ 83% Palmer amaranth control whereas fluridone treatments alone provided ≤ 76% control. Following the layby application, the standard herbicide program continued to provide effective Palmer amaranth control (98%), which was greater than all fluridone treatments. Greater control with the standard program leading up to the layby application is a result of two POST over-the-top glufosinate applications.

Table 6. Barnyardgrass control following preplant and preemergence applications of fluridone and current standards at the Arkansas Agricultural Research and Extension Center in Fayetteville, AR and the Lon Mann Cotton Research Center near Marianna, AR, in 2012 and 2013[z,y]

Treatment	Rate	Timing	Control															
			2012										2013					
			4 WAPP				6 WAPP				9 WAPP		4 WAPP		6 WAPP		9 WAPP	
			AAREC		LMCRC		AAREC		LMCRC		LMCRC		LMCRC		LMCRC		LMCRC	
	g a.i. ha^{-1}		%															
Fluridone	336	PP	93	a	80	a	100	a	78	a	30	a	99	a	94	a	79	b
Fomesafen	280	PP	86	a	55	c	100	a	36	c	15	c	99	a	85	a	60	c
Fluridone	112	PRE[x]	58	b	70	a	100	a	65	b	20	b	98	a	89	a	76	b
Fluridone	224	PRE	65	b	71	a	100	a	55	b	18	b	99	a	95	a	92	a
Fluridone	336	PRE	87	a	76	b	100	a	66	b	33	a	99	a	95	a	96	a
Fluridone	448	PRE	91	a	85	a	100	a	73	a	33	a	99	a	96	a	90	a
Fluridone	560	PRE	86	a	88	a	100	a	80	a	38	a	99	a	96	a	94	a
Fluometuron	1,120	PRE	96	a	75	b	98	b	66	b	28	a	99	a	93	a	79	b
Diuron	1,120	PRE	85	a	71	a	100	a	54	b	26	b	99	a	94	a	81	b
Contrast [w]																		
Fluridone vs. Standard											0.0191*						0.0012*	
PP vs. PRE											0.0414*						0.0007*	

[z] Abbreviations: WAPP, weeks after preplant application; AAREC, Arkansas Agricultural Research and Extension Center; LMCRC, Lon Mann Cotton Research Center; PP, preplant; PRE, preemergence.

[y] Means within a column followed by the same lowercase letter are not statistically different based on Fisher's LSD (0.05).

[x] The PRE timing was 2 wks after the PP application.

[w] Asterisks (*) indicate statistical difference based on Fisher's LSD (α=0.05).

Table 7. Planting and application dates at the Northeast Research and Extension Center in Keiser, AR in 2012 and 2013[z,y]

Program	Rate	Timing	Planting date		Application date	
			2012	2013	2012	2013
	g a.i. ha^{-1}					
Fluometuron	1,120	PRE	5/14	5/15	5/14	5/15
Glufosinate	424	4- to 5-leaf			6/7	6/27
S-metolachlor	1,060	4- to 5-leaf			6/7	6/27
Glufosinate	424	8- to 10-leaf			6/19	7/10
S-metolachlor	1,060	8- to 10-leaf			6/19	7/10
MSMA	2,240	Layby			7/16	7/29
Flumioxazin	72	Layby			7/16	7/29
Fluridone	224	PRE			5/14	5/15
MSMA	2,240	Layby			7/16	7/29
Flumioxazin	72	Layby			7/16	7/29
Fluridone	336	PRE			5/14	5/15
MSMA	2,240	Layby			7/16	7/29
Flumioxazin	72	Layby			7/16	7/29
Fluridone	448	PRE			5/14	5/15
MSMA	2,240	Layby			7/16	7/29
Flumioxazin	72	Layby			7/16	7/29
Fluridone	224	PRE			5/14	5/15
Glufosinate	424	AFR			5/29	5/28
MSMA	2,240	Layby			7/16	7/29
Flumioxazin	72	Layby			7/16	7/29
Fluridone	336	PRE			5/14	5/15
Glufosinate	424	AFR			5/29	5/28
MSMA	2,240	Layby			7/16	7/29
Flumioxazin	72	Layby			7/16	7/29
Fluridone	448	PRE			5/14	5/15
Glufosinate	424	AFR			5/29	5/28
MSMA	2,240	Layby			7/16	7/29
Flumioxazin	72	Layby			7/16	7/29

[z] Abbreviations: PRE, preemergence; AFR, after first rainfall.

[y] Preemergence herbicides were applied the day of cotton planting.

Contrasts at 11 WAP revealed that fluridone applied PRE followed by glufosinate provided greater control of Palmer amaranth than fluridone treatments not followed by a glufosinate application (Table 8). Additionally, contrasts revealed that the standard herbicide program provided greater Palmer amaranth control than the fluridone-based programs that lacked POST residual herbicides.

Two weeks following the PRE application in 2013, fluridone at 336 g ha^{-1} or higher provided greater Palmer amaranth control than fluometuron (Table 8). This is likely a result of receiving multiple rainfall events > 3 cm following the application of PRE herbicides in 2013. Whereas glufosinate did improve Palmer amaranth control, the lack of a residual herbicide with the glufosinate application allowed for continued Palmer amaranth emergence. It is possible that the high clay content of the soil resulted in the low level of residual control from fluridone. Previous research has reported that fluridone strongly absorbs to both clay and organic matter in soils (Shea and Weber, 1983; Weber, 1980).

By 8 WAP in 2013, the first POST treatment of glufosinate plus *S*-metolachlor was applied, yet Palmer amaranth control was still comparable to the fluridone rates not followed by an AFR glufosinate application (Tables 7 and 8). By 11 WAP in 2013, contrasts indicated that fluridone applied PRE followed by glufosinate provided greater control of Palmer amaranth than fluridone treatments not followed by an AFR application. Furthermore, the standard herbicide program provided greater Palmer amaranth control than all fluridone treatments, except for fluridone at 336 and 448 g ha^{-1} followed by glufosinate. Differences in control were observed when fluridone treatments at 224 g ha^{-1} were compared to fluridone treatments at 336 and 448 g ha^{-1}. The lower application rate of fluridone provided less control of Palmer amaranth than higher application rates, regardless of glufosinate application.

Table 8. Palmer amaranth control with fluridone containing herbicide programs versus a standard herbicide program in cotton at the Northeast Research and Extension Center in Keiser, AR in 2012 and 2013z,y,x

Program	Rate	Timing	Control							
			2012				2013			
			2 WAP	5 WAP	8 WAP	11 WAP	2 WAP	5 WAP	8 WAP	11 WAP
	g a.i. ha^{-1}		%							
Fluometuron	1,120	PRE								
Glufosinate	424	4- to 5-leaf								
S-metolachlor	1,060	4- to 5-leaf								
Glufosinate	424	8- to 10-leaf								
S-metolachlor	1,060	8- to 10-leaf								
MSMA	2,240	Layby								
Flumioxazin	72	Layby	98 a	96 a	100 a	98 a	79 b	24 c	49 b	83 a
Fluridone	224	PRE								
MSMA	2,240	Layby								
Flumioxazin	72	Layby	92 b	73 b	73 c	36 b	74 b	46 b	55 b	51 d
Fluridone	336	PRE	92 b	66 c	68 d	13 b	88 a	21 c	35 c	44 d
MSMA	2,240	Layby								
Flumioxazin	72	Layby								
Fluridone	448	PRE								
MSMA	2,240	Layby								
Flumioxazin	72	Layby	95 ab	76 b	75 c	40 b	89 a	33 b	39 c	56 c
Fluridone	224	PRE								
Glufosinate	424	AFR								
MSMA	2,240	Layby								
Flumioxazin	72	Layby	93 b	83 b	85 b	86 a	86 a	70 a	66 ab	60 c
Fluridone	336	PRE								
Glufosinate	424	AFR								
MSMA	2,240	Layby								
Flumioxazin	72	Layby	95 ab	75 b	83 b	76 a	91 a	86 a	81 a	83 a
Fluridone	448	PRE								
Glufosinate	424	AFR								
MSMA	2,240	Layby								
Flumioxazin	72	Layby	94 b	71 c	84 b	81 a	91 a	81 a	78 a	70 b
Contrast [w]										
Fluridone PRE vs. Fluridone PRE + Gluf.						<0.0001*				<0.0001*
Fluridone PRE vs. Standard						<0.0001*				<0.0001*
Fluridone PRE + Gluf. vs. Standard						NS				0.0014*
Fluridone 224 vs. Fluridone 336						NS				0.0118*
Fluridone 224 vs. Fluridone 448						NS				0.0071*

[z] Abbreviations: PRE, preemergence; WAP, weeks after planting; AFR, after first rainfall.

[y] Preemergence herbicides were applied the day of cotton planting.

[x] Means within a column followed by the same lowercase letter are not statistically different based on Fisher's LSD (0.05).

[w] Asterisks (*) indicate statistical difference based on Fisher's LSD (α=0.05).

Practical Implications. The use of soil-residual herbicides for effective weed control is highly dependent upon receiving sufficient amounts of rainfall for optimum activation in the soil. In years similar to 2012, drastic reductions in herbicide efficacy are typical when soil-residual herbicides such as fluridone are applied and prolonged dry conditions occur. Although fluridone provided nearly two months of effective Palmer amaranth control, it should not be applied as a stand-alone herbicide in cotton. Hence, to provide effective season-long control of Palmer amaranth, a fluridone-based herbicide program would benefit from the inclusion of multiple POST herbicide applications similar to current recommendations.

ACKNOWLEDGMENT

This research was supported by SePRO Corporation.

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