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Use of Fluridone for Control of Palmer Amaranth (Amaranthus palmeri) in Cotton (Gossypium hirsutum) and on Ditchbanks

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Use of Fluridone for Control of Palmer Amaranth (*Amaranthus palmeri*) in Cotton (*Gossypium hirsutum*) and on Ditchbanks

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by

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Abstract

Since 2006, glyphosate-resistant Palmer amaranth has been considered the most problematic weed in agronomic crops across the Midsouth. As a result of glyphosate resistance, producers began to again utilize a diverse herbicide program for management of this weed, which consists of several soil-residual herbicides most notably diuron, fluometuron, fomesafen, and metolachlor. Fluridone inhibits phytoene desaturase in plants, and is unique in that its mechanism of action (MOA) is not currently registered for use in cotton. Studies were conducted to determine the length of residual that fluridone provides in controlling Palmer amaranth in Arkansas glyphosate- and glufosinate-resistant cotton programs and along field margins in comparison to other soil-residual herbicides. Furthermore, studies were conducted to assess the persistence of fluridone in Arkansas soils and the risk for injury to crops subsequently planted following fluridone use in cotton. Regardless of the cotton program, fluridone failed to provide season-long control of Palmer amaranth; hence, reducing the number of postemergence applications will not be recommended when applying fluridone at cotton planting. Additionally, fluridone failed to provide season-long control of Palmer amaranth along ditchbanks over that of other labeled soil-residual herbicides; however, when applied under favorable conditions fluridone applied preplant incorporated provided extended control of Palmer amaranth with or without a sequential application. Injury to wheat as a rotational crop from an application of fluridone to cotton was greater than that of other crops commonly rotated with cotton; albeit, injury was not severe enough to result in wheat yield reductions. Although fluridone did not provide season-long control of Palmer amaranth, introducing a herbicide with a unique MOA into current cotton would be beneficial for reducing the risk of resistance to herbicides that are currently used in cotton.

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Chapter I

Introduction

With the commercialization of glyphosate-resistant (GR) crops in the mid- to late 1990s, producers had the opportunity to utilize glyphosate as an early postemergence application in soybean [*Glycine max* (L.) Merr.] in 1996 and in cotton (*Gossypium hirsutum* L.) in 1997 (Viator et al. 2004); and in recent years improvements to GR technologies allowed for glyphosate to be applied more often throughout the season (Huff et al. 2010). As a broad-spectrum herbicide, glyphosate an inhibitor of 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) provides effective control of most grass and broadleaf weeds in cotton, corn (*Zea mays* L.), and soybean in Arkansas. In 2012, Arkansas was the third leading producer of upland cotton, with 236,746 ha harvested (USDA, NASS 2013). After the introduction of GR cotton in 1997, 37% of cotton hectares in Arkansas were planted with GR cultivars (USDA, NASS 2000) with this number increasing to almost 100% by 2011 (Norsworthy et al. 2011; USDA, NASS 2011).

For several years thereafter, producers abandoned the use of soil-residual herbicides solely relying on multiple applications of glyphosate for controlling problematic weeds. This selection pressure as a result of extensive glyphosate use undoubtedly resulted in an increased occurrence of glyphosate-resistant weeds (Young 2006). In 2003, GR horseweed (*Conyza canadensis* L. Cronq.) was the first confirmed herbicide-resistant agronomic weed in Arkansas, and has since quickly spread across the Mississippi River Delta (Norsworthy et al. 2007). With the continued use of glyphosate, more weeds were confirmed resistant to glyphosate, such as common (*Ambrosia artemisifolia* (L.) (2004)) and giant ragweed (*Ambrosia trifida* L. (2005)), Palmer amaranth (*Amaranthus palmeri* S. Wats. (2006)), johnsongrass (*Sorghum halepense* L.

Pers. (2007)), Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot (2008)), and tall waterhemp [*Amaranthus tuberculatus* (Mer.) Sauer (2015)] (Heap 2015).

In a survey conducted by Norsworthy et al. (2011), crop consultants across the Midsouth reported that Palmer amaranth was the most problematic agronomic weed of soybean and cotton. As well as evolving resistance to multiple herbicide MOAs, Palmer amaranth is considered one of the most troublesome weeds due to its extended emergence period (beginning in April until the first killing frost), high seed production ($\geq$ 250,000 seed female^{-1}), and one of the highest photosynthetic rates among C_4 plants (Jha et al. 2006; Keeley et al. 1987; Ehleringer 1983). Additionally, the growth rate of Palmer amaranth is several times that of row crops, including corn, which is also a C_4 plant, and cotton and soybean, which are slower growing C_3 plants (Ehleringer and Hammond 1987; Gibson 1998). This extremely competitive growth rate allows Palmer amaranth to grow more than 5 cm d^{-1} (Horak and Loughin 2000), reaching heights of 2 m or more (Horak and Peterson 1995; Norsworthy et al. 2008), which is greater than the heights that cotton and soybean reaches.

In order to reduce the spread of herbicide-resistant weeds, it was recommended that utilizing residual herbicides and maintaining full labeled rates of all herbicides are essential to control these weeds (Scott and Smith 2011). Additionally, Norsworthy et al. (2012) developed Best Management Practices (BMPS), which consider the use of all cultural, mechanical, and herbicidal options available for effective control of herbicide-resistant weeds. Of these BMPS, one practice emphasizes the use of multiple, effective MOAs against the most troublesome weeds and those prone to herbicide resistance (Norsworthy et al. 2012). Currently, the standard glyphosate- and glufosinate-resistant cotton herbicide programs consist of several residual and non-residual herbicides with multiple MOA applied throughout the growing season. However, the need for more effective residual herbicides is great so that two or more of the current residual herbicides can be replaced in order to reduce selection pressure for resistance evolution.

Fluridone (WSSA Group 12) was synthesized in the early 1970s and inhibits phytoene desaturase in plants; however, it was never labeled for use in field crops (Waldrep and Taylor 1976). Previous research evaluated fluridone at rates ranging from 0.3 to 2.4 kg ai ha^{-1}, and was found to be safe only when applied PRE in cotton (Waldrep and Taylor 1976), due to limited translocation of fluridone from cotton roots to the shoots (Berard et al. 1978). Additionally, at these rates, fluridone provides broad-spectrum preemergence control of several annual grass and broadleaf weeds including, redroot pigweed (*Amaranthus retroflexus* L.), barnyardgrass [*Echinochloa crus-galli* (L.) Beauv], johnsongrass [*Sorghum halepense* (L.) Pers.], and tall morningglory [*Ipomoea purpurea* (L.) Roth]. Weed emergence is not inhibited by fluridone, but within 4 to 7 d after emergence fluridone causes chlorosis of new tissues, growth retardation, leaf necrosis, and eventual plant death (Waldrep and Taylor 1976).

Banks et al. (1979) reported that fluridone has the ability to persist in the soil for an extended period of time. However, the level of persistence is dependent upon the percent organic matter and clay content in the soil to which fluridone binds (Shea and Weber 1983). In a Miller clay soil, only 10% of applied fluridone remained after 220 d, while 25% of fluridone remained in a Lufkin fine sandy loam soil up to 385 d (Banks et al. 1979). Due to its extended persistence in soils, fluridone has been reported to cause injury to crops planted the subsequent year after cotton (Albritton and Parka 1978; Banks and Merkle 1979). Hence, fluridone was never labeled for commercial use in cotton.

Growers have routinely managed weeds in fields without much regard for weeds growing along field edges; albeit, current recommendations are to effectively manage weeds in fields and field borders (Norsworthy et al. 2012). Noxious and invasive weed species frequently grow between the crop and the ditchbank along field edges, which gives these weeds a habitat to reproduce without competition, which adds more seed to the soil seedbank and further dispersal of seed to areas not infested by these weeds (Boutin 2006; Boutin et al. 2001). It has been reported that glyphosate-resistant Palmer amaranth is a serious problem along Arkansas roadsides, with approximately 95% of samples sites infested (Bagavathiannan and Norsworthy 2013). Additionally, weeds in ditchbanks and along roadsides are of serious concern because of the lack of effective control options (Bennett 2011). Glyphosate had been routinely used to manage weeds in and along field margins in the past, but today producers are beginning to rely on other means of preventing weed seed production, such as mowing, applying paraquat throughout the season, or sowing ditchbanks with less-weedy plants to reduce weed emergence (Norsworthy et al. 2012). Since 1986, fluridone has been registered for use on several types of waterways including irrigation ditches. Similar to its unique characteristics in cotton, fluridone could have a unique opportunity for controlling Palmer amaranth along field margins.

As herbicide-resistant Palmer amaranth continues to spread across the Midsouth, the need for an effective control measure in crop fields and along field margins is needed. In order to control herbicide-resistant weeds in cotton, producers began to rely on previously used soil-residual herbicides in combination with postemergence herbicides; however, this continued reliance year after year could increase the likelihood of weeds evolving resistance to these herbicides. Therefore, producers need to incorporate herbicides that have not been previously used in crops such as fluridone to control herbicide-resistant Palmer amaranth. Hence, the objectives of this research were to: 1) assess the potential for fluridone carryover to six crops commonly rotated with cotton, 2) determine the length of residual weed control provided by fluridone when applied alone as well as in a program approach in glufosinate-resistant cotton, 3) assess the potential for fluridone to reduce the number of postemergence herbicide applications in glyphosate-resistant cotton, and 4) determine the length of residual control of Palmer amaranth on turnrows and field margins with fluridone.

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Chapter II

Assessing the Potential for Fluridone Carryover to Six Crops Rotated with Cotton

Abstract. The herbicide fluridone is a soil-residual herbicide that should provide effective control of several problematic agronomic weeds, but because of herbicide persistence, injury to rotational crops may be probable. In this experiment, multiple rates of fluridone were applied preemergence (PRE) to cotton at four locations across Arkansas to determine the risk for fluridone to persist and injure subsequently planted wheat, corn, soybean, rice, grain sorghum, and sunflower. The multiple rates of fluridone were compared to fluometuron and evaluated for percent crop injury, crop density, and potential yield loss for each crop at the end of the subsequent growing season. Regardless of the location, wheat exhibited the greatest injury with 13 to 26% at Fayetteville (silt loam), 8 to 15% at Pine Tree (silt loam), 2 to 7% at Keiser (silty clay), and 3 to 8% at Rohwer (silty clay), which is probably because wheat was planted closer to application than the other crops. At Pine Tree, injury to grain sorghum ranged from 5 to 10% from all rates of fluridone. At Keiser, rice exhibited significant levels of injury (1 to 13%) from fluridone at 393 d after treatment. Along with high levels of injury to wheat, fluridone at 900 g ai ha^{-1} caused loss of wheat stands to 29 plants m^{-1} row compared to fluometuron which had stands of 49 plants m^{-1} row. Similarly, fluridone at 900 g ha^{-1} (11 plants m^{-1} row) reduced grain sorghum stands at Pine Tree over that of fluometuron (19 plants m^{-1} row). Although injury occurred in wheat at all locations, no rate of fluridone reduced wheat yields compared to fluometuron. At Pine Tree, a decrease in grain sorghum yields was observed from fluridone at 448, 673, and 900 g ha^{-1} compared to fluometuron. In conclusion, injury to a wheat rotational crop following an application of fluridone in cotton is more likely than injury in any other rotational crop with cotton, but yield reductions are not expected.

Nomenclature: corn, *Zea mays* L.; cotton, *Gossypium hirsutum* L.; grain sorghum, *Sorghum bicolor* L. Moench; rice, *Oryza sativa* L.; soybean, *Glycine max* L. Merr.; sunflower, *Helianthus annuus* L.; wheat, *Triticum aestivum* L.

Key words: preemergence; crop injury; crop density; yield loss.

Before the commercialization of glyphosate-resistant crops in the mid-1990s, soil-residual herbicides had been the foundation of nearly all weed management programs. Due to the increasing infestation of glyphosate-resistant weeds, producers are once again relying on weed management programs that consist of multiple soil-residual herbicide applications and herbicide mechanisms of action. Many soil-residual herbicides can persist for many months to more than a year after application, which could cause detrimental effects to rotational crops. Herbicide persistence is dependent on factors such as soil condition, environmental conditions, tillage, method of application, and the amount of herbicide applied.

The herbicide fluometuron is a photosystem II-inhibiting substituted urea herbicide that has been the most commonly used PRE herbicide in cotton weed management for decades. However, under certain circumstances, the persistence of fluometuron can cause injury in other crops such as soybean (Sharp et al. 1982). Compared to other substituted urea herbicides, fluometuron is more rapidly degraded by soil microorganisms (Bozarth and Funderburk 1971). With twenty herbicide-resistant weed biotypes being documented in Arkansas (Heap 2015), the utilization of new or not currently used herbicides is needed to reduce the likelihood of additional resistant weed biotypes evolving in the current cropping systems.

Fluridone is a phytoene desaturase inhibiting herbicide (Bartels and Watson 1978; Devlin et al. 1978) that was found to provide effective control of annual broadleaves and grasses, with cotton having tolerance to soil-applied applications (Waldrep and Taylor 1976). The tolerance of cotton to fluridone is due to the retention of the absorbed herbicide in the roots and basal region of the plant, whereas in the other sensitive crops fluridone is transported from the roots to the shoots of sensitive species (Berard et al. 1978). Fluridone uptake by sensitive plants results in the photooxidation of chlorophyll and bleaching of leaves (Anderson and Robertson 1960) followed by necrosis and eventual plant death (Waldrep and Taylor 1976).

Banks et al. (1979) reported that ≤ 10% of applied fluridone was recovered in a Miller clay soil after 250 d while in a Lufkin fine sandy loam soil approximately 20% of fluridone remained after 385 d in Texas. Similarly, Shroeder and Banks (1986b) conducted persistence experiments in Georgia and reported that in a Rome gravelly clay loam soil that fluridone levels were detected at 154 to 180 d after treatment (DAT) with 0.6 kg ha^{-1} and 194 to 227 DAT at 1.7 kg ha^{-1}.

Shea and Weber (1983a) reported that fluridone phytotoxicity increases with soil pH, which suggests that cultivation and liming of the soil have the potential to increase fluridone activity. Shroeder and Banks (1986a) reported that low water solubility of fluridone, which is 12 ppm at a pH of 7 (Waldrep and Taylor 1976), may have reduced herbicide movement in the soil allowing greater levels of the herbicide to be present in the top layers of the soil. This in part, allowed for greater concentrations of fluridone to be present when sensitive crops were planted after herbicide application. Because only some crops are tolerant to fluridone and because of its highly persistent characteristics, fluridone was not commercialized for use in cotton due to increased risk of injury from fluridone carryover to common rotational crops with cotton, as well as the increased cost of fluridone compared to that of other soil-residual herbicides available at that time.

Albritton and Parka (1978) evaluated fluridone uptake in fourteen crop species and ten weed species, finding excellent cotton tolerance to fluridone at 0.4 kg ha^{-1} whereas peanut (*Arachis hypogaea* L.), sunflower, and safflower (*Carthamus tinctorius* L.) were injured up to

30%. Wheat and barley (*Hordeum vulgare* L.) were severely injured when fluridone was applied to the seed and root zone, while only slight injury was observed when fluridone was applied to the shoot zone of wheat and barley; therefore, wheat and barley may be tolerant to fluridone when it is applied to the soil surface (Albritton and Parka 1978). The remaining crops evaluated included corn, soybean, rice, oat (*Avena sativa* L.), sorghum, cucumber (*Cucumis sativus*), mustard (*Brassica* L.), and tomato (*Solanum lycopersicum* L.), all of which were severely injured by fluridone regardless of the placement of the herbicide (Albritton and Parka 1978). Similarly, Miller and Carter (1983) reported that grain sorghum, tomato, and Japanese millet (*Echinchloa esculenta* (A. Braun) H. Scholtz) exhibited severe injury (≥ 95%) from fluridone applied at 0.3 kg ha^{-1} at 8 mo after treatment. Fluridone residues in this experiment were only observed in the top 10 cm of soil, which further suggests that the leaching ability of fluridone is limited. Furthermore, sufficient fluridone residue was present 14 mo after treatment to cause marked chlorosis of grain sorghum, regardless of the rate (Miller and Carter 1983).

Although fluridone can persist for long periods of time in the soil to cause severe injury to sensitive crops that are commonly rotated with cotton, it has been reported that when fluridone is applied multiple times its level of persistence decreases significantly (Shroeder and Banks 1986a). The decrease in fluridone persistence has been correlated to the degradation of fluridone residues by soil microorganisms. With the reduction of fluridone residues in the soil as a result of consecutive applications of the herbicide, Shroeder and Banks (1986a) reported that grain sorghum injury was significantly less 73 DAT in soils previously treated with fluridone.

Most of the fluridone persistence research conducted to date has been in Texas and Georgia under different rainfall patterns and soil textures than what is common in the Midsouth. Thus, research was conducted to understand the likelihood of fluridone carryover from cotton to subsequent crops grown on two soil textures common to Arkansas because the herbicide is currently being considered for registration in cotton.

Materials and Methods

Fluridone Carryover. A field experiment was conducted in 2012 and 2013 at four locations across Arkansas: Pine Tree Research Station near Colt, AR, on a Calloway silt loam soil (fine-silty, mixed, active, thermic Aquic Fraglossudalfs), Northeast Research and Extension Center in Keiser, AR, on a Sharkey silty clay soil (very-fine, smectitic, thermic Chromic Epiaquerts), University of Arkansas Research and Extension Center in Fayetteville, AR, on a Leaf silt loam soil (fine, mixed, active, thermic Typic Albaquults), and Southeast Research and Extension Center in Rohwer, AR, on a Sharkey silty clay soil (very-fine, smectitic, thermic Chromic Epiaquerts) (Table 2.1).

This experiment was conducted as a randomized complete block design with four replications. The experiment at each location was planted on 8-row plots; 9.1 m long plots at the Fayetteville and Rohwer locations, 12.2 m long plots at Pine Tree, and 15.2 m long plots at Keiser; with a 1 m alley between replications. There were six separate experiments at each location that would be later planted to wheat, soybean, corn, grain sorghum, rice, or sunflower following cotton. In 2012, Phytogen 375 WRF (Widestrike®, Genuity®, and Roundup Ready Flex®) cotton was planted in a stale seedbed system on raised planting beds at all four locations, except plots intended to be planted in rice the subsequent year; therefore, cotton was planted on level ground (Table 2.1).

The following treatments were applied in the spring of 2012: 1) fluridone PRE at 224 g ai ha^{-1}, 2) fluridone PRE at 448 g ha^{-1}, 3) fluridone PRE at 673 g ha^{-1}, 4) fluridone PRE at 900 g ha^{-}

^{1}, and 5) fluometuron PRE at 1,120 g ai ha^{-1} as a standard for comparison. At Fayetteville, Pine Tree, and Keiser herbicides were applied with a CO_2-pressurized backpack sprayer consisting of a handheld boom that contained six 110015 flat-fan nozzles (Teejet Technologies, Springfield, IL. 62703) on 48 cm spacing and was calibrated to deliver 140 L ha^{-1} at 276 kPa. However, at Rohwer herbicides were applied with a tractor equipped with a CO_2-pressurized multi-boom sprayer that contained eight 110015 flat-fan nozzles on 50 cm spacing and was calibrated to deliver 112 L ha^{-1} at 276 kPa. Treatments were applied in 2012 on May 11 at Fayetteville, May 14 at Keiser, May 17 at Pine Tree, and May 24 at Rohwer. Weeds were controlled throughout the season using multiple applications of glufosinate at 424 g ai ha^{-1} and clethodim was applied at rates from 110 to 280 kg ai ha^{-1} to control grass weeds. The 2012 crop solely served as an opportunity to apply the above herbicide treatments and evaluate them in the subsequent crop.

Immediately following cotton harvest in the fall of 2012, wheat was planted into one of the experiments at each location. In 2013, cultivars of corn, grain sorghum, rice, soybean, and sunflower were planted in plots from the previous year. The same cultivar of each crop was planted at each location with varying seeding rates due to row spacing (Table 2.1). The cultivars for each crop were Pioneer 1685YHR (corn), Terral RV® 9782™ (grain sorghum), Clearfield® 152 (rice), Asgrow 4730® (soybean), PEREDOVIK 8044 (sunflower), and AgriPro Coker 9553 (wheat). Plots were visually evaluated every 7 d after planting until no injury was visibly evident. Injury ratings, primarily chlorosis and necrosis, were based on a scale of 0 to 100%, with 0 being no injury and 100% being the death of the plant. Plots were kept weed free throughout the 2013 growing season using standard herbicide programs for each crop. Crop stands were counted in 1 m of row at 1 to 2 wk after emergence. Soil samples were collected to determine soil pH, organic matter content, and soil texture at each location (Table 2.2). Each crop species was harvested with a small-plot combine (Massey Ferguson 8, AGCO, Duluth, GA 30096) to test for yield loss as a result of fluridone applications from the previous year.

All data were analyzed by ANOVA using JMP Pro Version 10.0 (SAS Institute Inc., Cary, NC 27513). There was a location and soil texture effect for crop injury, plant stands, and seed yield, resulting in the need to present each location separately. All means were separated with Fisher's LSD (α=0.05), and fluridone treatments were directly compared to the fluometuron standard.

Results and Discussion

Soil Characteristics and Environmental Conditions. In this experiment, multiple rates of fluridone were compared to fluometuron and evaluated to determine the potential of these soil-residual herbicides to persist in Arkansas soils and the potential of injuring common rotational crops with cotton (Table 2.2). From previous research by Banks et al. (1979), fluridone persisted in Texas clay and sandy loam soils from 250 to 385 d after treatment. Because of the high potential for fluridone persistence in the soil, it was evaluated at two silt loam sites and two silty clay sites in Arkansas. Although there are soil textural similarities for the soils at these sites, differences did exist in organic matter (OM) and clay contents (Table 2.2). Previous research reports that fluridone adsorption to soil particles is highly dependent on the percent OM content and clay content as well as the pH of the soil (Shea and Weber 1983b).

Following the application of treatments in this experiment in 2012, the planted cotton was either furrow-irrigated or overhead-irrigated depending on location. In the subsequent year, rice was flood-irrigated at all locations and all other crops were furrow-irrigated or overhead-irrigated as needed. Rainfall and irrigation amounts over the 2-yr period are reported in Table 2.3.

Irrigation and precipitation amounts varied across locations the year in which the herbicide treatments were applied.

Injury. Overall across crops, greater injury was observed on silt loam than silty clay soils (Table 2.4). Typical symptoms of fluridone injury were general chlorosis of young emerging plants followed by necrosis of the affected leaves, with visible symptoms dissipating 4 to 6 wk after planting. Of the crops evaluated, fluridone appeared most injurious to wheat likely because of the closer proximity to the fluridone application with a fall-seeded crop than the spring-seeded crops.

Wheat was injured 13 to 26% at Fayetteville and 8 to 15% at Pine Tree (Table 2.4). Injury to wheat was no more than 8% at the highest rate tested on the two silty clay soils. Webster et al. (1977) reported that the application of fluridone had no adverse effect on wheat grown in rotation with cotton in the southeast United States, whereas in west and south Texas fluridone caused significant injury to wheat.

For grain sorghum, no injury was observed at any of the evaluated fluridone rates at Keiser and Rohwer on a silty clay soil and at Fayetteville on a silt loam soil (Table 2.4). At Pine Tree, injury to grain sorghum ranged from 5 to 10% over the fluridone rates evaluated. The lack of injury at Fayetteville may be partially a result of a later planting date. Grain sorghum was initially planted in Fayetteville on April 17 but crop emergence was poor; hence, the crop was replanted on May 10. Injury to grain sorghum a year after fluridone application has also been reported in previous research (Albritton and Parka 1978; Banks and Merkle 1978; Miller and Carter 1983).

Although the percentages of fluridone residues in the soils were not tested in these experiments, obtaining these levels of injury to rotational crops at 390 d after application appear comparable to previous research where the amount of fluridone was quantified. Banks et al. (1979) reported that only 5 to 10% of fluridone persisted in a Miller clay soil at 250 d after application.

Currently, it appears that fluridone will soon be labeled in cotton as a PRE application in combination with fomesafen or fluometuron based on Section 18 labels that were approved in several southern U.S. states for the 2013, 2014, and 2015 growing seasons (Kyle Briscoe, personal communication). The fluridone component of this application cannot exceed 224 g ha^{-1}. At a fluridone rate of 448 g ha^{-1} (twice the labeled rate), less than 5% injury to sunflower and rice was observed at all locations and at several of the sites there was no visible injury. For soybean, no more than 6% injury was observed when fluridone was applied to the previous cotton crop at 448 g ha^{-1}, and the same rate caused no more than 7% injury to corn (Table 2.4).

Stand Counts. Stand counts were taken at the same time as injury ratings to determine if fluridone concentrations were severe enough to reduce plant stands of the rotational crops planted after fluridone was applied to cotton (Table 2.5). Although fluridone was more injurious to wheat than any other crop at all locations, fluridone did not result in a reduction of wheat stands at Fayetteville, Pine Tree, or Keiser. At Rohwer, plant stands were only reduced at the highest rate of fluridone.

Grain sorghum and corn stands at Pine Tree were reduced by fluridone at 900 g ha^{-1} compared to fluometuron (Table 2.5). Banks and Merkle (1979) reported grain sorghum stand reduction with fluridone applied PRE at 900 g ha^{-1} on a Lufkin fine sandy loam soil, with a 63%

reduction in plant stands 380 DAT and 70% at 450 DAT. Along with higher levels of injury, rice stands on the silty clay soil in Keiser were reduced 22% by fluridone at 900 g ha^{-1} and 16% by fluridone at 448 g ha^{-1} compared to fluometuron. Again, it should be noted that fluridone at 900 g ha^{-1} is likely four times the labeled rate for cotton in the Midsouth.

Yield. In this experiment, all crops planted the year after the application of fluridone were harvested to determine if fluridone concentrations were severe enough to reduce crop yields compared to fluometuron (Table 2.6). As seen from crop injury evaluations, higher rates of fluridone were more injurious to wheat than any other crop, but wheat yields were not reduced. Interestingly, wheat yields at Keiser were greater with fluridone at 673 g ha^{-1} and 900 g ha^{-1} compared to fluometuron. Wheat yields were not obtained at Rohwer due to flooding of the plots during the winter months.

Along with fluridone injury to grain sorghum at Pine Tree, fluridone at 448, 673, and 900 g ha^{-1} caused a decrease in yields up to 47% compared to fluometuron (Table 2.6). This level of yield reductions is likely attributed to grain sorghum plant stands reduced by higher rates of fluridone compared to fluometuron (Table 2.5). In other research, Banks and Merkle (1979) reported that fluridone rates of 448 and 900 g ha^{-1} did not reduce grain sorghum yields when planted a year after application on a clay soil.

Although no injury was observed or stand reduction measured in corn on the silty clay soil at Keiser, fluridone at 900 g ha^{-1} reduced corn yields compared to fluometuron. At Pine Tree, corn was not harvested due to the misapplication of postemergence herbicides. The loss of grain yield in corn and grain sorghum may be a reflection that the crop is experiencing a negative physiological response to low residues of fluridone even though symptoms were not readily seen early in the growing season.

Although minimal levels of injury were observed in sunflower at the two silt loam locations, no yield reductions were observed as a function of crop injury from fluridone at Fayetteville, Pine Tree, and Rohwer (Table 2.6). Due to failed sunflower stands at Keiser, crop injury and stand count evaluations as well as sunflower yields were not obtainable.

Practical Implications

There is potential for fluridone injury to rotational crops and the risk of injury appears greater on silt loam than on silty clay soils, especially for high rates of fluridone or areas in a field where overlap of rates may occur. Based on the results observed here, planting wheat directly behind cotton treated PRE with fluridone will cause noticeable injury even though yield lost was not observed at the fluridone rate likely to be labeled for use in cotton. Even though yield reductions occurred to corn and grain sorghum planted behind cotton treated with high rates of fluridone, it is unlikely that rates as high as those needed to cause this injury would ever be labeled. However, it should be noted that all of these trials were conducted under irrigated conditions which would likely favor microbial degradation of fluridone – the main means by which it is lost from soil. If cotton were grown under dryland conditions, which is rare in the Mississippi Delta region of the Midsouth, and fluridone was applied PRE, the risk of carryover to subsequent crops may be greater than that observed in this research.

The upcoming Section 18 labels for the fluridone pre-mixes are named Brake® F2 (fluridone/fomesafen) and Brake® FX (fluridone/fluometuron) (Anonymous 2015). Although a recommended application of Brake® F2 and Brake® FX contains a lower rate of fluridone than any treatment in this experiment, producers should understand that misapplication could result in injury to common rotational crops; however, the likelihood of yields being reduced is relatively low.

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Table 2.1. Planting dates, row spacings, and seeding rates of the six crops planted in Fayetteville, Pine Tree, Keiser, and Rohwer, AR.

Location	Crop [a]	Planting date	Row spacing	Seeding rate
			cm	1,000 seed ha^{-1}
Fayetteville	Corn	April 17, 2013	91	115
	Grain Sorghum	May 20, 2013	91	302
	Rice	May 10, 2013	19	4,200
	Soybean	April 17, 2013	91	344
	Sunflower	April 30, 2013	91	109
	Wheat	October 10, 2013	19	2,356
Pine Tree	Corn	April 25, 2013	76	91
	Grain Sorghum	April 25, 2013	76	239
	Rice	April 25, 2013	18	4,200
	Soybean	April 25, 2013	76	272
	Sunflower	April 25, 2013	76	86
	Wheat	October 25, 2012	18	2,356
Keiser	Corn	May 28, 2013	97	115
	Grain Sorghum	May 28, 2013	97	303
	Rice	May 28, 2013	18	4,200
	Soybean	May 28, 2013	97	344
	Sunflower	May 28, 2013	97	109
	Wheat	October 12, 2012	18	2,356
Rohwer	Corn	April 26, 2013	97	115
	Grain Sorghum	April 26, 2013	97	303
	Rice	April 26, 2013	18	4,200
	Soybean	April 26, 2013	97	344
	Sunflower	April 26, 2013	97	109
	Wheat	October 30, 2012	18	2,356

[a] Same crop varieties were planted at all locations.

Table 2.2. Physical and chemical characteristics of the soils.

Soil series and location	Family	Texture	pH	Organic matter	Sand	Silt	Clay
				------------------------------------	------- % -------	------------------------------------	
Leaf, Fayetteville	Typic Albaquults	Silt loam	6.9	1.5	34.4	52.8	12.8
Calloway, Pine Tree	Aquic Fraglossudalfs	Silt loam	6.7	2.4	9.3	73.3	17.4
Sharkey, Keiser	Chromic Epiaquerts	Silty clay	6.8	3.6	21.4	23.6	55.0
Sharkey, Rohwer	Chromic Epiaquerts	Silty clay	7.2	2.3	26.0	30.8	43.2

Table 2.3. Rainfall amounts observed throughout the year following fluridone applications at Fayetteville, Pine Tree, Keiser, and Rohwer, AR. [a,b]

Month/Year	Fayetteville		Pine Tree		Keiser		Rohwer	
	Irrigation	Rainfall	Irrigation	Rainfall	Irrigation	Rainfall	Irrigation	Rainfall
	-----------------	-----------------	-----------------	----------------- cm	-----------------	-----------------	-----------------	-----------------
May/2012	22.8	2.4	0.0	5.7	0.0	10.6	0.0	1.7
June/2012	3.8	2.5	5.0	1.0	4.5	6.4	0.0	10.7
July/2012	11.4	2.1	5.0	8.1	5.0	6.0	5.5	6.7
August/2012	19.1	3.3	5.0	6.3	0.0	2.9	2.5	18.0
September/2012	0.0	7.2	0.0	9.2	0.0	17.7	0.0	11.4
October/2012	0.0	5.1	0.0	7.1	0.0	8.9	0.0	9.3
November/2012	0.0	2.4	0.0	5.9	0.0	5.0	0.0	4.2
December/2012	0.0	7.1	0.0	11.1	0.0	10.9	0.0	13.1
January/2013	0.0	7.7	0.0	20.8	0.0	21.2	0.0	26.0
February/2013	0.0	6.8	0.0	11.0	0.0	10.2	0.0	12.2
March/2013	0.0	11.7	0.0	10.1	0.0	6.2	0.0	12.1
April/2013	0.0	12.6	0.0	16.3	0.0	19.8	0.0	15.5
May/2013	0.0	11.1	0.0	20.6	0.0	19.7	0.0	14.5
June/2013	0.0	14.3	0.0	14.7	0.0	12.3	0.0	5.3

[a] Treatments applied by location: May 11, 2012 (Fayetteville), May 17, 2012 (Pine Tree), May 15, 2012 (Keiser), May 24, 2012 (Rohwer).

[b] Irrigation type by location: overhead-irrigation (Fayetteville), furrow-irrigation (Pine Tree), overhead-irrigation (Keiser), furrow-irrigation (Rohwer).

Table 2.4. Injury to crops planted the subsequent growing season following a PRE application of fluometuron (standard) or four rates of fluridone in cotton on a silt loam soil in Fayetteville and Pine Tree, AR and on a silty clay soil in Keiser and Rohwer, AR.

Location[b,c,d,e]	Treatment	Rate	Injury[a]					
			Wheat	Corn	Soybean	Rice	Grain sorghum	Sunflower
		g ai ha^{-1}	%					
Fayetteville	Fluometuron	1,120	0 c	0 b	0 b	0 b	0	0 c
Fayetteville	Fluridone	224	13 b	4 ab	7 a	2 a	0	2 b
Fayetteville	Fluridone	448	21 a	6 ab	4 a	2 a	0	2 b
Fayetteville	Fluridone	673	21 a	9 a	11 a	4 a	0	5 a
Fayetteville	Fluridone	900	26 a	7 a	5 a	4 a	0	5 a
Pine Tree	Fluometuron	1,120	0 c	0	0 c	0 c	0 c	0 c
Pine Tree	Fluridone	224	0 c	0	0 c	3 ab	5 b	3 b
Pine Tree	Fluridone	448	8 b	0	2 b	1 b	8 ab	4 ab
Pine Tree	Fluridone	673	13 ab	0	6 a	1 b	7 ab	6 a
Pine Tree	Fluridone	900	15 a	0	8 a	6 a	10 a	6 a
Keiser	Fluometuron	1,120	0 d	0	0	0 c	0	---
Keiser	Fluridone	224	2 c	0	0	1 b	0	---
Keiser	Fluridone	448	3 c	0	0	4 b	0	---
Keiser	Fluridone	673	6 b	0	0	13 a	0	---
Keiser	Fluridone	900	8 a	0	0	13 a	0	---
Rohwer	Fluometuron	1,120	0 c	1 a	0	0	0	0
Rohwer	Fluridone	224	1 b	2 a	0	0	0	0
Rohwer	Fluridone	448	4 ab	1 a	0	0	0	0
Rohwer	Fluridone	673	7 a	2 a	0	0	0	0
Rohwer	Fluridone	900	7 a	1 a	0	0	0	0

[a] For a specific location, means within a column followed by the same lowercase letter are not statistically different based on Fisher's LSD (0.05).

[b] Treatment evaluation dates for Fayetteville: November 7, 2012 (wheat), May 12, 2013 (corn and soybean), June 7, 2013 (rice, grain

sorghum, and sunflower).

[c] Treatment evaluation dates for Pine Tree: November 20, 2012 (wheat), May 14, 2013 (corn, soybean, rice, grain sorghum, and sunflower).

[d] Treatment evaluation dates for Keiser: October 30, 2012 (wheat), June 12,2013 (corn, soybean, rice, grain sorghum), sunflower was not evaluated.

[e] Treatment evaluation dates for Rohwer: November 23, 2012 (wheat), May 21,2013 (corn, soybean, rice, grain sorghum, and sunflower).

Table 2.5. Stand counts of crops planted the subsequent growing season following a PRE application of fluometuron (standard) or four rates of fluridone in cotton on a silt loam soil in Fayetteville and Pine Tree, AR and on a silty clay soil in Keiser and Rohwer, AR.

Location [b,c,d,e]	Treatment	Rate	Stand counts [a]					
			Wheat	Corn	Soybean	Rice	Grain sorghum	Sunflower
		g ai ha^{-1}	------------------------------------ plants m^{-1} of row					--------------------------------------
Fayetteville	Fluometuron	1,120	64 a	7.8 a	20 a	27 a	5 a	3.5 a
Fayetteville	Fluridone	224	55 a	7.6 a	19 a	16 a	4 a	3 a
Fayetteville	Fluridone	448	62 a	7.8 a	19.5 a	19 a	4 a	3 a
Fayetteville	Fluridone	673	66 a	7.6 a	20 a	13 a	4 a	5 a
Fayetteville	Fluridone	900	53 a	7.8 a	19.5 a	14 a	2.5 a	2.5 a
Pine Tree	Fluometuron	1,120	59 a	6 a	23 a	66 a	19 a	10 a
Pine Tree	Fluridone	224	50 a	7 a	24 a	65 a	14 ab	9 a
Pine Tree	Fluridone	448	55 a	6 a	24 a	61 a	12 ab	8 a
Pine Tree	Fluridone	673	57 a	4 b	21 a	58 a	12 ab	7 a
Pine Tree	Fluridone	900	54 a	2 c	22 a	64 a	11 b	9 a
Keiser	Fluometuron	1,120	45 a	9 a	28 a	86 a	20 a	---
Keiser	Fluridone	224	45 a	8 a	28 a	80 ab	21 a	---
Keiser	Fluridone	448	43 a	8 a	29 a	72 b	20 a	---
Keiser	Fluridone	673	41 a	9 a	30 a	80 ab	22 a	---
Keiser	Fluridone	900	42 a	9 a	29 a	67 c	20 a	---
Rohwer	Fluometuron	1,120	49 a	11 a	26 a	82 a	20 a	14 a
Rohwer	Fluridone	224	50 a	10 a	25 a	85 a	20 a	13 a
Rohwer	Fluridone	448	41 ab	9 a	25 a	83 a	21 a	14 a
Rohwer	Fluridone	673	44 ab	10 a	25 a	84 a	20 a	14 a
Rohwer	Fluridone	900	29 b	10 a	26 a	86 a	21 a	14 a

[a] For a specific location, means within a column followed by the same lowercase letter are not statistically different based on Fisher's LSD (0.05).

[b] Treatment evaluation dates for Fayetteville: November 7, 2012 (wheat), May 12, 2013 (corn and soybean), June 7, 2013 (rice, grain

sorghum, and sunflower).

[c] Treatment evaluation dates for Pine Tree: November 20, 2012 (wheat), May 14, 2013 (corn, soybean, rice, grain sorghum, and sunflower).

[d] Treatment evaluation dates for Keiser: October 30, 2012 (wheat), June 12,2013 (corn, soybean, rice, grain sorghum), sunflower was not evaluated.

[e] Treatment evaluation dates for Rohwer: November 23, 2012 (wheat), May 21,2013 (corn, soybean, rice, grain sorghum, and sunflower).

Table 2.6. Seed yield of crops planted the subsequent growing season following a PRE application of fluometuron (standard) or four rates of fluridone in cotton on a silt loam soil in Fayetteville and Pine Tree, AR and on a silty clay soil in Keiser and Rohwer, AR.

			Yield [a]					
Location [b,c,d,e]	Treatment	Rate	Wheat	Corn	Soybean	Rice	Grain sorghum	Sunflower
		g ai ha^{-1}	kg ha^{-1}					
Fayetteville	Fluometuron	1,120	4,300 a	10,290 a	3,030 a	4,290 a	4,900 b	320 a
Fayetteville	Fluridone	224	4,570 a	12,110 a	3,700 a	4,640 a	4,520 b	320 a
Fayetteville	Fluridone	448	3,900 a	10,420 a	3,360 a	5,550 a	6,590 a	300 a
Fayetteville	Fluridone	673	4,710 a	11,050 a	2,960 a	5,300 a	5,960 a	360 a
Fayetteville	Fluridone	900	4,370 a	10,170 a	3,030 a	5,550 a	4,080 b	470 a
Pine Tree	Fluometuron	1,120	4,910 a	----	3,900 a	2,020 a	4,710 a	320 a
Pine Tree	Fluridone	224	5,720 a	----	2,960 a	2,370 a	5,520 a	430 a
Pine Tree	Fluridone	448	4,840 a	----	3,090 a	2,270 a	2,830 c	610 a
Pine Tree	Fluridone	673	5,920 a	----	3,030 a	2,620 a	2,510 c	470 a
Pine Tree	Fluridone	900	5,850 a	----	2,890 a	2,270 a	3,450 b	610 a
Keiser	Fluometuron	1,120	3,000 b	6,730 a	5,600 a	11,010 a	5,360 a	---
Keiser	Fluridone	224	3,670 ab	8,470 a	5,200 a	10,610 a	5,790 a	---
Keiser	Fluridone	448	4,340 ab	6,290 ab	6,470 a	9,960 a	5,170 a	---
Keiser	Fluridone	673	4,670 a	5,670 ab	5,540 a	9,760 a	4,110 a	---
Keiser	Fluridone	900	5,070 a	3,430 b	5,470 a	9,610 a	5,420 a	---
Rohwer	Fluometuron	1,120	---	7,410 b	4,600 a	3,400 a	8,740 a	650 a
Rohwer	Fluridone	224	---	8,780 ab	4,540 a	3,200 a	9,210 a	810 a
Rohwer	Fluridone	448	---	9,840 a	6,070 a	2,950 a	9,470 a	841 a
Rohwer	Fluridone	673	---	10,270 a	5,870 a	4,800 a	9,270 a	970 a
Rohwer	Fluridone	900	---	9,650 a	5,070 a	3,850 a	8,410 a	870 a

[a] For a specific location, means within a column followed by the same lowercase letter are not statistically different based on Fisher's LSD (0.05).

[b] Harvest dates for Fayetteville: July 3, 2013 (wheat); September 6, 2013 (sunflower); October 3, 2013 (corn); October 4, 2013 (rice); October 18, 2013 (grain sorghum); November 3, 2013 (soybean).

[c] Harvest dates for Pine Tree: August 8, 2013 (wheat); August 26, 2013 (sunflower); September 23, 2013 (corn, soybean, rice, and grain sorghum).

[d] Harvest dates for Keiser: July 3, 2013 (wheat); October 16, 2013 (corn and grain sorghum); November 5, 2013 (soybean and rice); N/A.

[e] Harvest dates for Rohwer: N/A (wheat); August 21, 2013 (sunflower); September 12, 2013 (corn); September 16, 2013 (soybean and grain sorghum); November 7, 2013 (rice).

Chapter III

Residual Weed Control in Cotton with Fluridone

Abstract: Glyphosate-resistant Palmer amaranth is considered the most troublesome weed in agronomic crops across the Midsouth. In order to overcome the growing threat of resistance, the reliance on multiple herbicide mechanisms of action (MOA) and soil-residual herbicides has increased over the past several years. Field experiments were conducted at several locations across Arkansas to determine the efficacy of fluridone on Palmer amaranth in glyphosate-resistant and glufosinate-resistant cotton herbicide programs with the possibility of reducing the number of postemergence (POST) applications and to determine the length of residual fluridone activity when applied preemergence (PRE) alone. Fluridone is a unique MOA that is currently not registered for use in cotton. In the length of residual experiment in 2013 when rainfall was frequent, most PRE-applied fluridone rates greater than 224 g ha^{-1} provided > 90% Palmer amaranth control for the first 6 wk after application, but effective season-long control was not achieved with any rate of fluridone alone. Fluridone alone applied 14-d preplant or PRE was not better than a standard herbicide application in providing Palmer amaranth control. When fluridone was incorporated into a glufosinate-resistant herbicide program with the possibility of reducing POST application, PRE-applied fluridone at 224, 336, and 448 g ai ha^{-1} did not provide greater control of Palmer amaranth than the standard herbicide program that included fluometuron. Based on these experiments, fluridone will 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.

Nomenclature: Palmer amaranth, *Amaranthus palmeri* (S.) Wats; cotton, *Gossypium hirsutum* L.

Key words: glyphosate-resistant, glufosinate-resistant, preemergence (PRE), postemergence (POST), 14-d preplant, weed control.

In cotton production systems prior to glyphosate-resistant crops, weeds were controlled a number of different ways. Tillage was used for forming or rebuilding the beds and cultivation was a common means of weed control throughout much of the early growing season. Typical herbicide applications in cotton included preplant incorporated (PPI), preemergence (PRE), and multiple postemergence (POST) applications. Postemergence applications in cotton were applied broadcast, post-directed (PDIR) under the canopy, between the rows by using a hooded sprayer, and PDIR layby as the last application before harvest.

Once glyphosate-resistant cotton became commercially available in 1997, producers quickly began to utilize this new technology, with 37% of the cotton hectares being planted with herbicide-resistant cultivars and stacked gene cultivars (herbicide + insecticide) by 2000 (USDA, NASS 2000) and 66% of all cotton hectares in Arkansas were planted with stacked-gene cultivars in 2006 (USDA, NASS 2006). In 2011, the combined total of herbicide-resistant and stacked-gene cultivars planted across the Midsouth was approximately 100% (Norsworthy et al. 2011; USDA, NASS 2011). With glyphosate-resistant cotton cultivars, producers relied on multiple applications of glyphosate for weed control instead of utilizing multifaceted weed control programs (Culpepper et al. 2006). As a result of the extensive use of glyphosate, 14 weeds have been confirmed resistant to glyphosate in the United States (Heap 2015). The seven glyphosate-resistant weeds confirmed in Arkansas are horseweed [*Conyza canadensis* (L.) Cronquist] (2003), common ragweed (*Ambrosia artemisifolia* L.) (2004) giant ragweed (*Ambrosia trifida* L.) (2005), Palmer amaranth (2006), johnsongrass [*Sorghum halepense* (L.) Pers.] (2007), Italian ryegrass [*Lolium perenne* (L.) ssp. *multiflorum* Lam. Husnot] (2008), and tall waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] (2015).

Palmer amaranth is one of approximately 60 *Amaranthus* species native to the Americas (Sauer 1967), infesting corn (*Zea mays* L.), cotton, and soybean (*Glycine max* L. Merr.) throughout the southern United States. The most persistent *Amaranthus* species in Arkansas crops is Palmer amaranth, also known as "Palmer pigweed." The first reported glyphosate-resistant Palmer amaranth in Arkansas was found in Mississippi County in 2005 (Norsworthy et al. 2008a). Palmer amaranth is troublesome due to its extended emergence period (Jha et al. 2006) and prolific growth under a wide range of conditions. 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 most C_4 plants (Ehleringer 1983). Its rate of growth 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). This extremely competitive growth gives Palmer amaranth the ability to reach heights of 2 m or more (Norsworthy et al. 2008b; Horak and Peterson 1995), exceeding the height of both cotton and soybean.

Palmer amaranth is a dioecious annual plant, where male and female flowers are on separate plants (Horak and Peterson 1995). Female plants are easily distinguishable from male plants because the inflorescence on females reaches lengths of 0.5 m or greater. Female plants also have sharp bracts throughout the inflorescence.   Each female plant can produce 200,000 to 600,000 seeds, ensuring the chances of offspring emergence (Keeley et al. 1987). This high rate of seed production can result in seedling densities of 2,000 plants m^{-2} (Jha et al. 2006) if offspring emergence is successful. Palmer amaranth seed is extremely small and is easily dispersed by wind, water, animals, machinery, and crop residues such as gin trash (Norsworthy et al. 2009). Along with being a prolific seed producer with a high growth rate, Palmer amaranth is one of the most competitive weeds of crops, with one study showing cotton lint yield reductions up to 92% at 0.9 plants m^{-2} (Rowland et al. 1999). In another study, each Palmer amaranth plant (up to eight plants) added to a 10 m row of cotton reduced 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 years (Norsworthy et al. 2014).

Herbicide resistance in Palmer amaranth has had a detrimental effect on crops over the past 20 years, with resistance being confirmed to four mechanisms of action (MOA) (Heap 2015). Palmer amaranth has been confirmed resistant to microtubule assembly inhibitors (1989), photosystem (PS) II-inhibitors (1993), acetolactate synthase (ALS) inhibitors (1994), and 5-enolpyruvyl shikimate-3-phosphate synthase (EPSPS) inhibitors (2006) (Heap 2014); EPSPS synthase inhibition is the MOA of glyphosate. These four herbicide MOAs were used for control of Palmer amaranth prior to resistance. With no new MOAs in the foreseeable future, controlling the prevalent 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.

In Arkansas, the standard weed management program for Palmer amaranth control in glyphosate-resistant cotton is composed of a combination of seven herbicides beginning with fomesafen applied prior to planting followed by fluometuron applied PRE followed by tank mixtures of glyphosate + *S*-metolachlor applied at the 2-leaf stage and the 4- to 5-leaf stage of the cotton crop. Subsequently, glyphosate + diuron or prometryn applied PDIR at the 8- to 10-leaf stage followed by MSMA + flumioxazin applied PDIR at layby (Norsworthy, personal communication). There is need for more effective residual herbicides that can replace two or more of the current residual herbicides or be used as alternative choices in order to reduce the rate of resistance evolution. The herbicide fluridone, which is highly effective in controlling many weeds, is a unique MOA that is currently not labeled for use in cotton and is known to provide a high level of extended redroot pigweed (*Amaranthus retroflexus* L.) control (Waldrep and Taylor 1976), a weed closely related to Palmer amaranth.

Over the past several years, glufosinate-resistant technologies have been commercialized in order to effectively control glyphosate-resistant weeds, such as Palmer amaranth. University of Arkansas Cooperative Extension weed scientists have devised management practices to effectively control glyphosate-resistant Palmer amaranth in Arkansas cotton production (Scott and Smith 2011). One of these management practices is the use of glufosinate-resistant cotton cultivars to improve the control of glyphosate-resistant Palmer amaranth. Although the use of glufosinate-resistant technologies is a good alternative to glyphosate-resistant technologies, studies have shown that the control of *Amaranthus* spp. with glufosinate alone can be marginal when applied in less than ideal growing conditions (Corbett et al. 2004). In order to overcome the marginal levels of control with glufosinate, the use of soil-residual herbicides such as fluridone and consecutive POST applications along with cultural practices could provide effective control of glyphosate-resistant 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 as an herbicide. Waldrep and Taylor (1976) evaluated fluridone at rates ranging from 0.3 to 2.4 kg ai ha^{-1} for herbicidal activity and these rates were found to be safe as a PRE application for use in cotton. At the rates tested, fluridone provides broad-spectrum PRE control of annual grass and broadleaf weeds such as barnyardgrass [*Echinochloa* *crus-galli* (L.) Beauv], johnsongrass, tall morningglory [*Ipomoea purpurea* (L.) Roth], and redroot pigweed, with it being more active applied PRE than applied POST (Waldrep and Taylor 1976). Additionally, Waldrep and Taylor (1976) reported that the first symptoms caused by fluridone usually occurred 4 to 7 d after treatment (DAT) and following weed emergence. Fluridone does not inhibit weed emergence, but rather recent research has indicated that it may stimulate germination of some weeds (Goggin and Powles 2014). It was reported that under controlled situations fluridone stimulated the germination of Italian ryegrass, Mediterranean rocket (*Sisymbrium erysimoides* Desf.), Indian hedgemustard (*Sisymbrium orientale* L.), and ripgut brome (*Bromus diandrus* Roth) seeds. Fluridone is absorbed through the primordial root and is translocated to the leaves. The symptoms most often observed are chlorotic plants, growth retardation, leaf necrosis, and eventual plant death (Devlin et al. 1978).

Studies were also conducted to evaluate the control of six weeds with fluridone applied POST; large crabgrass [*Digitaria sanguinalis* (L.) Scop.], Italian foxtail [*Setaria italica* (L.) Beauv], tall morningglory, redroot pigweed, velvetleaf (*Abutilon theophrasti* Medik.), and zinnia (*Zinnia elegans* Jacq.) (Waldrep and Taylor 1976). Fluridone was applied at rates from 0.3 to 2.4 kg ai ha^{-1} when weeds were in the 2- to 3-leaf stage. The results of this study suggested that fluridone had been absorbed by the plant foliage and was translocated only into new plant growth that formed after the treatment was applied (Waldrep and Taylor 1976). Symptoms were growth retardation, continuous chlorosis in new leaf growth, and leaf necrosis; yet no weeds except for crabgrass and zinnia were completely controlled after 3 wk.

In other research, the effects of fluridone in cotton, corn, soybean, and rice (*Oryza sativa* L.) were evaluated (Berard et al. 1978). All species absorbed fluridone after crop emergence, with rice having the highest concentration. Fluridone was readily translocated into the shoots of soybean, rice, and corn. In cotton, fluridone was absorbed by the roots, with no further translocation past the basal region of the stem. Fluridone tolerance was higher in cotton due to the limited translocation (Berard et al. 1978). Additional studies showed that fluridone was safe on 15 cotton varieties grown in the United States (Waldrep and Taylor 1976).

Because of higher PRE control of annual grasses and broadleaf weeds and its significant injury to cotton applied POST, fluridone was thought to be better suited as a soil-applied herbicide (Webster et al. 1977; Wills 1977). Fluridone has been evaluated in cotton both PPI and PRE at rates of 0.2 to 0.5 kg ai ha^{-1}. Persistence of fluridone is known to vary with soil texture (Banks et al. 1979). Only 10% of fluridone remained after 220 d in a Miller clay soil, while 25% of fluridone remained in a Lufkin fine sandy loam soil up to 385 d (Banks et al. 1979).

The objectives of this research were to 1) determine the rate and application method of fluridone for extended residual control of Palmer amaranth in cotton and 2) determine whether fluridone would provide a high level of season-long control when followed by an early-season application of glufosinate in cotton.

Materials and Methods

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

This experiment was set up as a randomized complete block (RCB) design with four replications. It was planted in four-row plots with 97-cm-wide rows at the Marianna location and in two-row plots with 91-cm-wide rows at Fayetteville. 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 May 23, 2012, and on May 30, 2013, at Marianna at a 2.5-cm depth. In Fayetteville, the same cultivar was planted on May 14, 2012, at a 2-cm depth. Cotton was not planted in the plots at Fayetteville 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 population of Palmer amaranth and other weeds such as, pitted morningglory (*Ipomoea lacunosa* L.), barnyardgrass, and broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster]. The herbicide products evaluated were compared to a nontreated control and can be found in Table 3.1.

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 in Keiser, AR, on a Sharkey silty clay soil (very-fine, smectitic, thermic Chromic Epiaquerts). This experiment was set up as a RCB design with a three-by-two factorial arrangement of three PRE herbicide treatments and two POST herbicide programs, plus a standard program and a nontreated control. The experiment was planted using four-row plots 3.8 by 7.6 m with a 1.5 m alley between replications. Phytogen 375 WRF (Widestrike®, Genuity®, and Roundup Ready Flex®) cotton at a seeding rate of 136,000 seeds ha^{-1} was planted on May 14, 2012, and on May 28, 2013, in a stale seedbed system on raised planting beds with a four-row planter. All treatments were applied to a natural population of Palmer amaranth. In this experiment, control of Palmer amaranth was evaluated to determine if applications of fluridone could provide season-long control and replace existing soil-residual herbicides in a glufosinate-resistant cotton herbicide program. The herbicide programs evaluated in this experiment were compared to a nontreated control and can be found in Table 3.2.

General Experimental Procedures for Both Experiments. Treatments were applied with a CO_2-pressurized backpack sprayer consisting of a handheld boom equipped with 110015 flat-fan nozzles (Teejet Technologies, Springfield, IL. 62703) calibrated to deliver 140 L ha^{-1} at 276 kPa. The boom consisted of 4 or 6 nozzles depending on the experiment location, with 48 cm spacing between nozzles. In the length of residual experiment, the 14-d preplant treatments were applied to freshly tilled beds. Paraquat (Gramoxone® SL 2.0, Syngenta Crop Protection, LLC) at 1,050 g ai 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 U.S.A. Corporation Agricultural Products) at 280 g ai ha^{-1} as needed.

Plots were visually rated every 14 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. Depending on the weeds evaluated, ratings were taken at 2, 4, 6, and 9 weeks after the PP (WAPP) application for the length of residual experiment; whereas, for the glufosinate-resistant cotton experiment ratings were taken at 2, 5, 8, and 11 weeks after the PRE (WAP) application. Ratings were based on comparison with the nontreated control (NTC). All data were analyzed by ANOVA using JMP Pro Version 10.0 (SAS Institute Inc., Cary, NC 27513), and means were separated with Fisher’s LSD at a 5% level of significance. 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 vs. PRE treatments and fluridone vs. the standard herbicide (either fomesafen PP, fluometuron PRE, or diuron PRE) in the residual experiment and 2) fluridone PRE vs. fluridone PRE + glufosinate, fluridone PRE vs. standard, fluridone PRE + glufosinate vs. standard, fluridone at 224 g ha^{-1} vs. fluridone at 336 g ha^{-1}, and fluridone at 224 g ha^{-1} vs. fluridone at 448 g ha^{-1} in the second experiment.

Results and Discussion

Environmental Data and Cotton Growth. In these experiments, multiple rates of fluridone were compared to standard soil-residual herbicides to determine the length of residual Palmer amaranth control in cotton. In 2012, less than average rainfall was accumulated at both Fayetteville and Marianna trial locations; whereas in 2013, sufficient rainfall was received soon after the PRE applications (Figures 3.1 and 3.2). Rainfall greater than 2.5 cm was received within 5 to 7 d following the PRE application at the Keiser location 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, precipitation amounts in 2012 were lower than in 2013 and the 30-yr average (Table 3.3). Therefore, differences in precipitation amount and timing not only affected plant growth, but also likely impacted the effectiveness of most herbicide applications.

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

Residual Control with Fluridone Compared to Standards. *Palmer Amaranth Control.* Regardless of the experiment location in 2012, rainfall following both applications was approximately 0.5 cm and was received within 14 DAT (Figures 3.1 and 3.2). Decreased control of Palmer amaranth in 2012 is likely due to insufficient precipitation following herbicide application. Previous research suggests that fluridone requires nearly 2.5 cm of rainfall to be activated in the soil profile (Kyle Briscoe, personal communication).

Upon initial evaluation in 2012, control of Palmer amaranth was comparable between both PP treatments as evident by ≥ 90% control (Table 3.4). Palmer amaranth control continually decreased throughout the weeks following the PRE treatments. 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.

Variable Palmer amaranth control was observed from PP and PRE treatments at 6 WAPP in Fayetteville (34 to 76%) and Marianna (28 to 86%). Buchanan et al. (1970) reported that cotton requires a weed-free period of approximately 8 wk following germination to produce maximum yields, and this period was not achieved at either location in 2012. By 9 WAPP, Palmer amaranth had completely overtaken the cotton growing in the plots at Fayetteville; hence, herbicide efficacy was not evaluated. On the basis of contrasts, PRE treatments at Marianna in 2012 provided greater Palmer amaranth control than the 14 d PP applications (Table 3.4).

At both locations in 2013, greater than 1.3 cm of rainfall as well as multiple precipitation events occurred within 1 to 4 d of both application timings, which greatly affected herbicide efficacy (Figures 3.1 and 3.2). Control of Palmer amaranth ranging from 81 to 100% was observed for 6 wk following application of the PP herbicides (Table 3.4). These control levels are 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 3.4). Although no significant differences were observed at Fayetteville, both 14 d PP treatments provided numerically greater control of Palmer amaranth than the PRE treatments. However, an opposite affect was observed in Marianna where most PRE treatments provided greater Palmer amaranth control than the 14 d PP treatments.

Pitted Morningglory Control. Similar to Palmer amaranth control in 2012, herbicide efficacy was greatly affected by the lack of adequate and timely rainfall amounts (Table 3.5). Initially, PRE treatments at Fayetteville provided comparable (83 to 93%) control to both PP treatments, except for fluridone at 224 g ha^{-1} (78%). Waldrep and Taylor (1976) reported in a greenhouse experiment that fluridone at 336, 672, 1,200, and 2,400 g ha^{-1} applied PRE controlled *Ipomoea* spp. at 70, 95, 95, and 100%, respectively, 3 wk following the herbicide application. At 4 WAPP in Marianna, control of pitted morningglory was considerably reduced with no treatment providing ≥ 51%. This reduction in herbicide efficacy is likely attributed to the lack of rainfall (Figures 3.1 and 3.2). Although applied PRE, previous research has similarly reported that fomesafen at 280 g ha^{-1} provided minimal (< 60%) control of *Ipomoea* spp. at 2 to 3 wk after herbicide application (Stephenson et al. 2004) as well as providing comparable control to fluometuron at 1,120 g ha^{-1} applied PRE (Gardner et al. 2006). Pitted morningglory control from all treatments in Marianna continued to diminish throughout the growing season with variable (18 to 41%) control at 6 WAPP and no control by 9 WAPP.

In 2013, overall control of pitted morningglory at both locations was greater than in 2012, with most treatments providing 88 to 99% control (Table 3.5). However, fomesafen (49%) was not comparable to fluridone (98%) when applied PP. Fluridone applied PRE at rates greater than 336 g ha^{-1} provided moderate to effective pitted morningglory control up to 6 WAPP. Regardless of the application timing and rate, fluridone failed to provide effective season-long pitted morningglory control and was comparable to the standard PP and PRE herbicides, with all treatments providing ≤ 80% control.

Barnyardgrass Control. Generally, barnyardgrass control was variable within and across locations in 2012 (Table 3.6). At 4 WAPP, barnyardgrass ranged from 58 to 96% at Fayetteville and 55 to 88% at Marianna, with most rates of fluridone at Marianna providing greater control than the standard PP and PRE herbicides. Regardless of the application timing, Banks and Merkle (1978) reported that control of an *Echinocloa* spp. and broadleaf signalgrass were 88 to 100% with fluridone at rates ranging from 448 to 900 g ha^{-1}. Unlike other evaluated weeds, differences in barnyardgrass control across locations were observed at 6 WAPP, with treatments providing ≥ 98% control at Fayetteville and highly variable (36 to 80%) control at Marianna. By 9 WAPP in 2012, barnyardgrass was not effectively controlled by any treatment at either location. Orthogonal contrasts revealed that all fluridone rates provided greater barnyardgrass control than the current standard herbicides used in this trial. Additionally, the PRE treatments provided superior barnyardgrass control over the PP treatments by the final evaluation. The greater control with the PRE treatments may be a result of them being applied 14 d after the PP treatments.

Because barnyardgrass was not present at Fayetteville in 2013, control was evaluated only at Marianna (Table 3.6). The initial evaluation of barnyardgrass control suggests that all herbicide treatments provided ≥ 98% control, regardless of the herbicide application. More precipitation was received closer to applications in 2013 than in 2012, which led to greater barnyardgrass control (Figures 3.1 and 3.2). As seen with the control of broadleaf weeds, good barnyardgrass control was observed up to 6 WAPP from all treatments in 2013; however, a reduction was observed by 9 WAPP for most treatments. Fluridone applied PRE at 224, 336, 448, and 560 g ha^{-1} provided ≥ 90% barnyardgrass control through the final evaluation 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.

Broadleaf Signalgrass Control. Broadleaf signalgrass control was only evaluated at Marianna (Table 3.7). In 2012, fluridone applied PP provided 96% control at 4 WAPP, which was considerably greater than fomesafen applied PP (73%). By 6 WAPP, broadleaf signalgrass control differed greatly among treatments (40 to 86%), with efficacy diminishing for all treatments over earlier evaluations. On the basis of contrast at 6 WAPP, the 14 d PP treatments provided greater control of broadleaf signalgrass than the PRE treatments. Fluridone applied PP (86%) and PRE at rates of 448 and 560 g ha^{-1} (78 and 73%) continued to provide the greatest control when compared to all other treatments (40 to 66%). Although broadleaf signalgrass control was less than acceptable in all treatments, several rates of fluridone provided greater control than the standard treatments.

At 4 WAPP in 2013, all applications of fluridone were comparable to the standard PP and PRE herbicides, with ≥ 98% broadleaf signalgrass control (Table 3.7). Similar control of broadleaf signalgrass was observed by Gardner et al. (2006), where fomesafen at 280 g ha^{-1} and fluometuron at 1,120 g ha^{-1} applied PRE provided ≥ 90% control 3 wk after application.

Additionally, Banks and Merkle (1979) reported that fluridone applied PRE at 112 to 448 g ha^{-1} provided 64 to 88% broadleaf signalgrass control. Two weeks later, control remained ≥ 94% from all treatments, except for fomesafen applied PP which provided 85% control. By 9 WAPP, broadleaf signalgrass control had decreased considerably with most treatments. Based on orthogonal contrasts, fluridone at the rates tested in these trials provided greater broadleaf signalgrass control than the standard herbicides. Furthermore, broadleaf signalgrass control was greater for the PRE than for the PP applications.

Evaluation of Fluridone as a Soil-Applied Alternative in Cotton. *Palmer Amaranth Control.* At 3 WAP in 2012, all treatments provided ≥ 92% control of Palmer amaranth; however, fluometuron provided greater control than most fluridone treatments (Table 3.9). 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 ranging from 66 to 83%, the three fluridone treatments greatly benefited from the glufosinate applied 2 wk after the PRE application (after first rainfall) (Table 3.8 and 3.9). Similarly, other researchers suggest good control of Palmer amaranth 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.

Control of Palmer amaranth greater than 95% was still observed at 8 WAP following the application of the second POST application of glufosinate plus *S*-metolachlor in the standard program (Table 3.9). At this later evaluation, 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 likely a result of two POST over-the-top glufosinate applications.

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 3.9). Additionally, contrasts revealed that the standard herbicide program provided greater Palmer amaranth control over 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 control of Palmer amaranth than fluometuron (Table 3.9). This is likely a result of receiving excessive rainfall amounts following the application of PRE herbicides in 2013 (Figure 3.3). While glufosinate did improve Palmer amaranth control, many plants did emerge and the failure to use 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). Unlike in 2012, POST herbicide applications were delayed in 2013 due to precipitation events occurring at the desired application time (Table 3.8; Figure 3.3), which is possibly the reason why control of Palmer amaranth was decreased in the fluometuron and fluridone treatments without an AFR glufosinate application.

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 (Table 3.8 and 3.9). At the same timing, the added control from glufosinate diminished from the 224 g ha^{-1} fluridone treatment (66%). However, control was still comparable to fluridone at 336 and 448 g ha^{-1} (81 and 78%, respectively).

At 11 WAP in 2013, several contrasts were revealed between treatments (Table 3.9). 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} (Table 3.9). The lower rate of fluridone provided less control of Palmer amaranth than the higher rates, regardless of whether glufosinate was applied.

Barnyardgrass and Pitted Morningglory Control. Throughout the 2013 growing season, all herbicide programs provided > 90% control of both barnyardgrass and pitted morningglory (Table 3.10). This level of season-long control of barnyardgrass and pitted morningglory is likely due to a combination of greater initial control than observed with Palmer amaranth, as well as increased competition with cotton and non-controlled Palmer amaranth.

Practical Implications

In general, the utilization of soil-residual herbicides to provide 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. Fluridone could provide effective control of Palmer amaranth for nearly two months following application when applied PRE at a desirable rate and under good environmental conditions. However, in order 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 consisting of multiple herbicide MOA. As a result of using multiple MOA, Palmer amaranth control could increase while reducing the chance of Palmer amaranth seed production, which diminishes the soil seedbank and increases herbicide sustainability.

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Table 3.1. Herbicide products used, Production Company, application rate, and application timing of treatments applied at Fayetteville and Marianna, AR in 2012 and 2013.

Treatment	Tradename	Company	Rate(s) [b]	Application timing [a]
			g ai 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	MANA Inc.	1,120	PRE
Diuron	Direx 4L	MANA Inc.	1,120	PRE

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

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

Table 3.2. Herbicide products used, Production Company, application rate, and application timing of treatments applied at Keiser, AR in 2012 and 2013.

Program	Tradename	Company	Rate(s) [b]	Application Timing [a]
			g ai ha^{-1}	
Fluometuron	Cotoran 4L	MANA Inc.	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

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

[b] Fluridone rates: 224, 336, and 448 g ai ha^{-1}.

Table 3.3. Precipitation from May, June, and July of 2012 and 2013 for Fayetteville, Marianna, and Keiser, AR, and the 30-year average.

Location	Precipitation (2012)	Precipitation (2013)	Average 30-year Precipitation [a]
	----------------------------------	cm	------------------------------------
Fayetteville			
May	2.4	11.1	11.5
June	2.5	14.3	8.9
July	2.1	7.1	6.8
Marianna			
May	3.8	18.9	12.3
June	2.0	1.9	9.1
July	6.5	13.6	9.4
Keiser			
May	10.6	19.8	13.6
June	6.4	12.3	9.9
July	6.0	9.9	10.4

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

Table 3.4. Palmer amaranth control following preplant and preemergence applications of fluridone and current standards at Fayetteville and Marianna, AR in 2012 and 2013. [a,b]

			Control										
			2012					2013					
			2 WAPP	4 WAPP	6 WAPP		9 WAPP	2 WAPP	4 WAPP	6 WAPP		9 WAPP	
Treatment	Rate	Timing	Comb	Comb	Fay	Mar	Mar	Comb	Comb	Fay	Mar	Fay	Mar
	g ai 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[c]	---	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													
Fluridone vs. Standard							NS					NS	NS
PP vs. PRE							0.0030*					0.0126*	0.0486*

[a] Abbreviations: WAPP, weeks after preplant application; Fay, Fayetteville; Mar, Marianna; Comb, combined over Fayetteville and Marianna; PP, preplant; PRE, preemergence.

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

[c] The PRE timing was 2 weeks after the PP application.

Table 3.5. Pitted morningglory control following preplant and preemergence applications of fluridone and current standards at Fayetteville and Marianna, AR in 2012 and 2013. [a,b]

			Control									
			2012					2013				
			4 WAPP		6 WAPP		9 WAPP	4 WAPP		6 WAPP		9 WAPP
Treatment	Rate	Timing	Fay	Mar	Fay	Mar	Mar	Fay	Mar	Fay	Mar	Fay
	g ai 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[c]	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												
Fluridone vs. Standard							NS					NS
PP vs. PRE							NS					NS

[a] Abbreviations: WAPP, weeks after preplant application; Fay, Fayetteville; Mar, Marianna; PP, preplant; PRE, preemergence.

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

[c] The PRE timing was 2 weeks after the PP application.

Table 3.6. Barnyardgrass control following preplant and preemergence applications of fluridone and current standards at Fayetteville and Marianna, AR in 2012 and 2013. [a,b]

			Control							
			2012					2013		
			4 WAPP		6 WAPP		9 WAPP	4 WAPP	6 WAPP	9 WAPP
Treatment	Rate	Timing	Fay	Mar	Fay	Mar	Mar	Mar	Mar	Mar
	$g\ ai\ ha^{-1}$		%							
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[c]	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										
Fluridone vs. Standard							0.0191*			0.0012*
PP vs. PRE							0.0414*			0.0007*

[a] Abbreviations: WAPP, weeks after preplant application; Fay, Fayetteville; Mar, Marianna; PP, preplant; PRE, preemergence.

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

[c] The PRE timing was 2 weeks after the PP application.

Table 3.7. Broadleaf signalgrass control following preplant and preemergence applications of fluridone and current standards at Marianna, AR in 2012 and 2013. [a,b]

			Control				
			2012		2013		
Treatment	Rate	Timing	4 WAPP	6 WAPP	4 WAPP	6 WAPP	9 WAPP
	g ai ha^{-1}		------------------------ %	------------------------	------------------------	------------------------	------------------------
Fluridone	336	PP	96 a	86 a	100 a	94 a	80 a
Fomesafen	280	PP	73 b	60 b	99 a	85 a	51 c
Fluridone	112	PRE[c]	68 b	50 c	99 a	96 a	76 b
Fluridone	224	PRE	69 b	40 d	100 a	98 a	91 a
Fluridone	336	PRE	80 a	53 c	100 a	98 a	96 a
Fluridone	448	PRE	85 a	78 a	100 a	95 a	93 a
Fluridone	560	PRE	86 a	73 a	100 a	96 a	94 a
Fluometuron	1,120	PRE	75 b	66 b	98 a	96 a	80 a
Diuron	1,120	PRE	75 b	59 b	100 a	97 a	81 a
Contrast							
Fluridone vs. Standard				NS			0.0004*
PP vs. PRE				0.0010*			0.0002*

[a] Abbreviations: WAPP, weeks after preplant application; Fay, Fayetteville; Mar, Marianna; PP, preplant; PRE, preemergence.

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

[c] The PRE timing was 2 weeks after the PP application.

Table 3.8. Planting and application dates at Keiser, AR in 2012 and 2013. [a,b]

			Planting date		Application date	
Program	Rate	Timing	2012	2013	2012	2013
	g ai ha^{-1}					
Fluometuron	1,120	PRE	5/14	5/15	5/14	5/15
Glufosinate	424	4- to 5-lf			6/7	6/27
S-metolachlor	1,060	4- to 5-lf			6/7	6/27
Glufosinate	424	8- to 10-lf			6/19	7/10
S-metolachlor	1,060	8- to 10-lf			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

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

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

Table 3.9. Palmer amaranth control with fluridone containing herbicide programs versus a standard herbicide program in cotton at Keiser, AR in 2012 and 2013. [a,b,c]

			Control							
			2012				2013			
Program	Rate	Timing	2 WAP	5 WAP	8 WAP	11 WAP	2 WAP	5 WAP	8 WAP	11 WAP
	g ai ha^{-1}		%							
Fluometuron	1,120	PRE								
Glufosinate	424	4- to 5-lf								
S-metolachlor	1,060	4- to 5-lf								
Glufosinate	424	8- to 10-lf								
S-metolachlor	1,060	8- to 10-lf								
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								
MSMA	2,240	Layby								
Flumioxazin	72	Layby	92 b	66 c	68 d	13 b	88 a	21 c	35 c	44 d
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	94 b	71 c	84 b	81 a	91 a	81 a	78 a	70 b

Glufosinate	424	AFR		
MSMA	2,240	Layby		
Flumioxazin	72	Layby		
Contrast				
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*

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

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

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

Table 3.10. Barnyardgrass and pitted morningglory control with fluridone containing herbicide programs versus a standard herbicide program in cotton at Keiser, AR in 2013. [a,b,c]

			Control						
			Barnyardgrass			Pitted morningglory			
Program	Rate	Timing	5 WAP	8 WAP	11 WAP	2 WAP	5 WAP	8 WAP	11 WAP
	g ai ha^{-1}		%						
Fluometuron	1,120	PRE							
Glufosinate	424	4- to 5-lf							
S-metolachlor	1,060	4- to 5-lf							
Glufosinate	424	8- to 10-lf							
S-metolachlor	1,060	8- to 10-lf							
MSMA	2,240	Layby							
Flumioxazin	72	Layby	98 a	95 a	100 a	93 a	96 a	96 a	99 a
Fluridone	224	PRE							
MSMA	2,240	Layby							
Flumioxazin	72	Layby	100 a	95 a	100 a	98 a	100 a	92 a	98 a
Fluridone	336	PRE							
MSMA	2,240	Layby							
Flumioxazin	72	Layby	99 a	95 a	100 a	98 a	100 a	97 a	95 a
Fluridone	448	PRE							
MSMA	2,240	Layby							
Flumioxazin	72	Layby	99 a	95 a	97 b	98 a	99 a	91 a	99 a
Fluridone	224	PRE							
Glufosinate	424	AFR							
MSMA	2,240	Layby							
Flumioxazin	72	Layby	100 a	97 a	100 a	100 a	100 a	90 a	98 a
Fluridone	336	PRE							
Glufosinate	424	AFR							
MSMA	2,240	Layby							
Flumioxazin	72	Layby	98 a	98 a	100 a	100 a	99 a	93 a	100 a
Fluridone	448	PRE							
Glufosinate	424	AFR	100 a	100 a	100 a	100 a	100 a	97 a	100 a

MSMA	2,240	Layby		
Flumioxazin	72	Layby		
Contrast			NS	NS
Fluridone PRE vs. Fluridone PRE + Gluf			NS	NS
Fluridone PRE vs. Standard			NS	NS
Fluridone PRE + Gluf vs. Standard			NS	NS
Fluridone 224 vs. Fluridone 336			NS	NS
Fluridone 224 vs. Fluridone 448			NS	NS

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

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

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

Figure 3.1. Rainfall amounts and furrow-irrigation events at Fayetteville, AR in 2012 and 2013. Small arrows indicate an irrigation event, while large arrows indicate application time. [a]

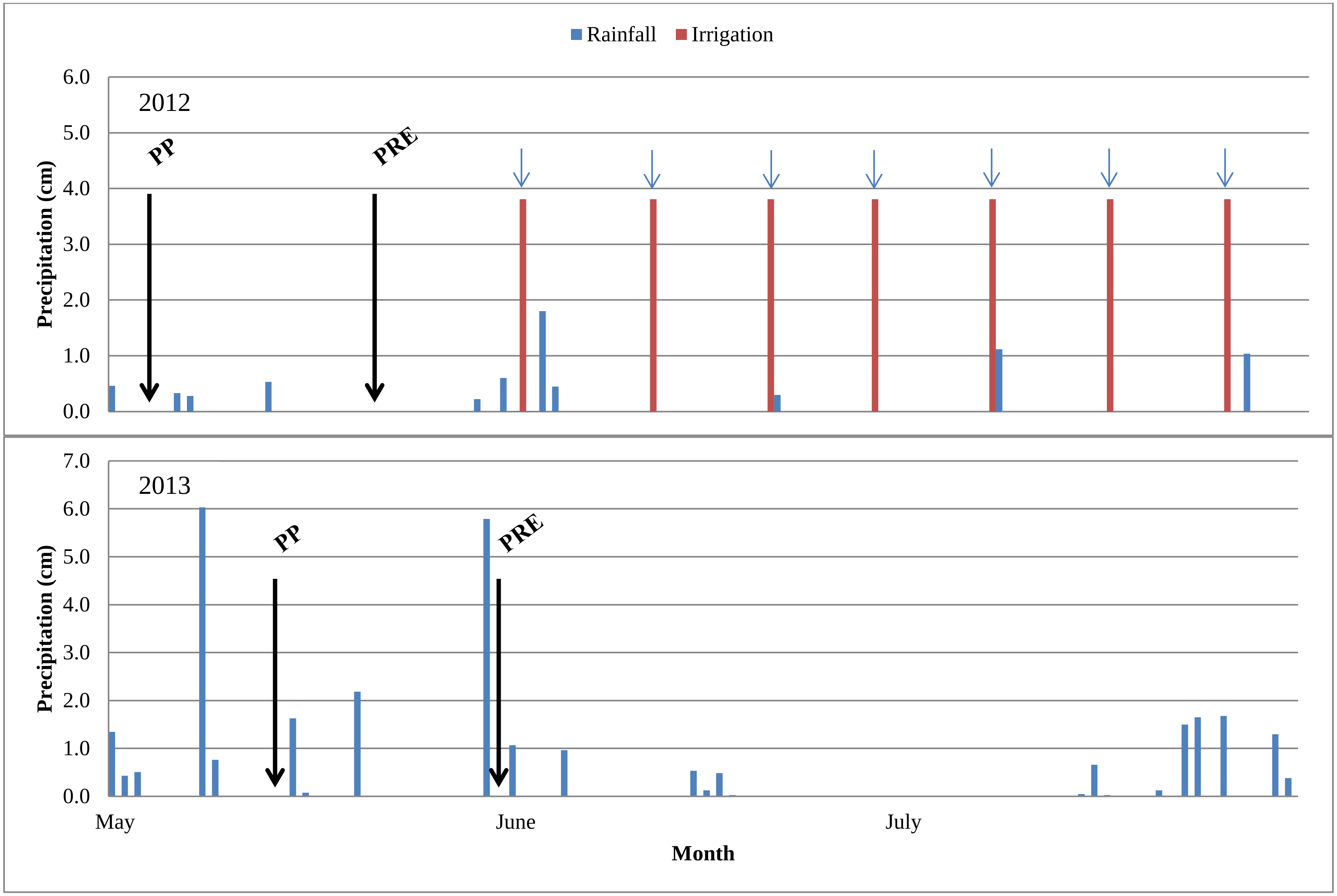


Figure 3.2. Rainfall amounts and furrow-irrigation events at Marianna, AR in 2012 and 2013. Arrows indicate irrigation event. [a]

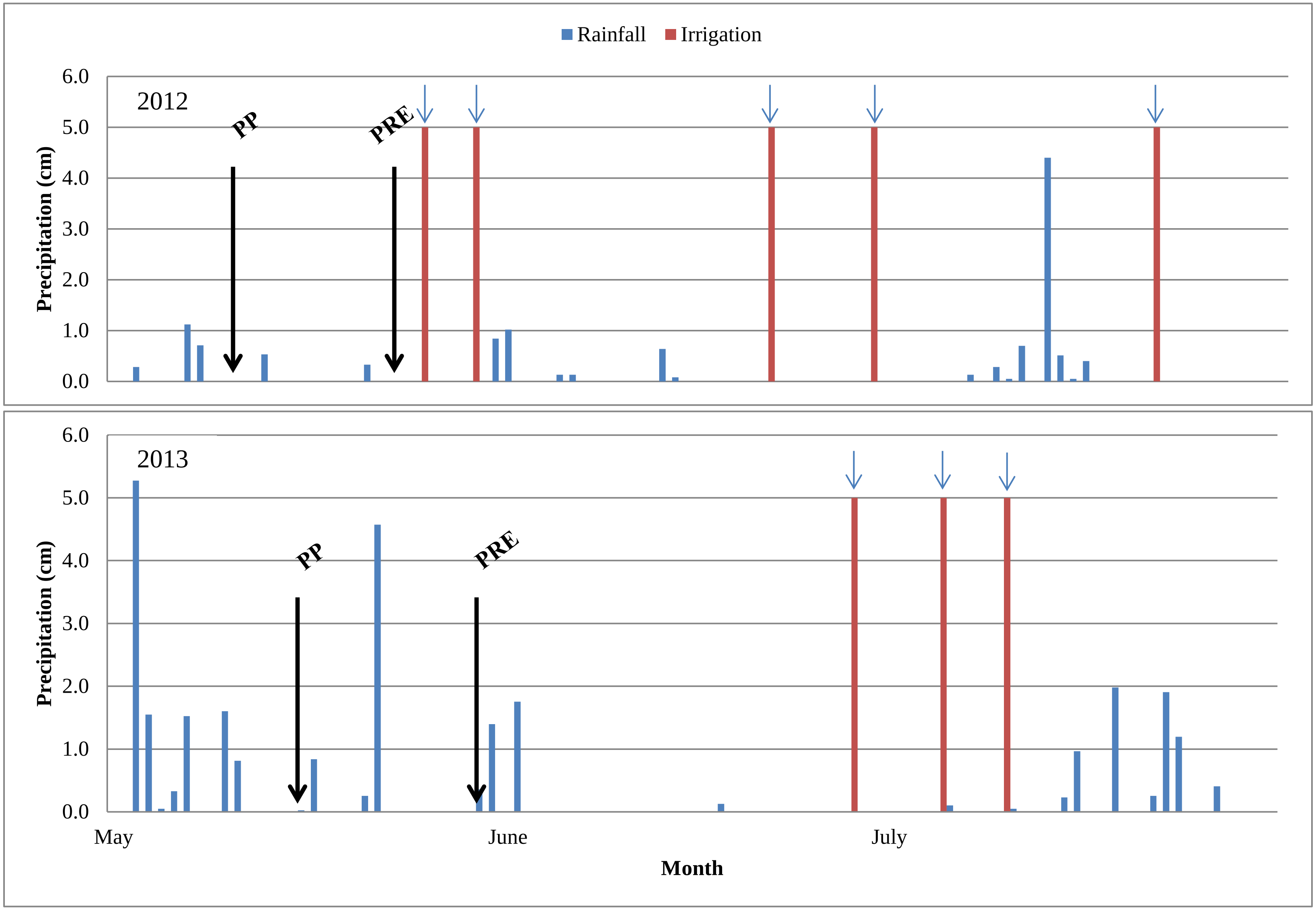
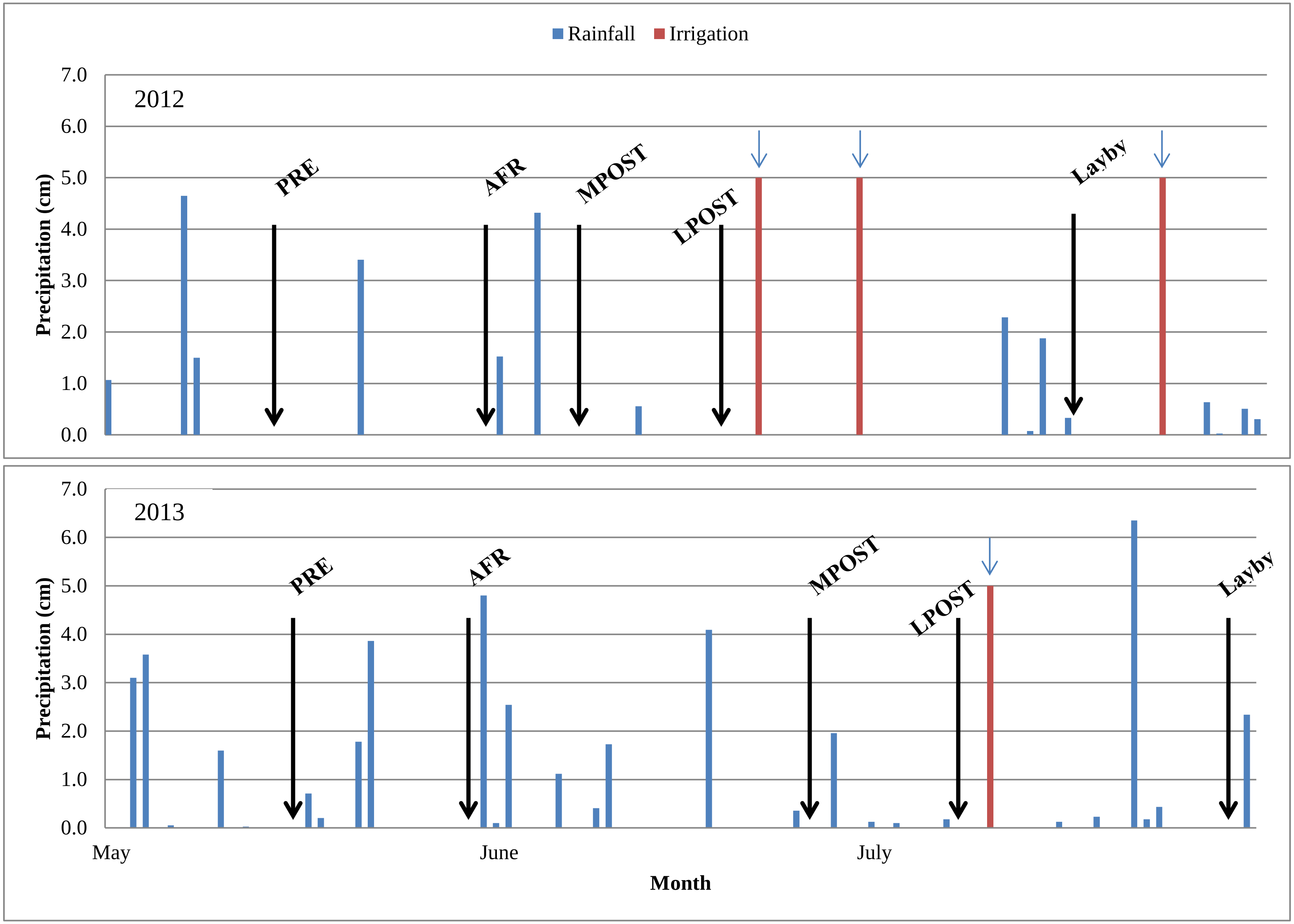


Figure 3.3. Rainfall amounts and furrow-irrigation events at Keiser, AR in 2012 and 2013. Small arrows indicate irrigation event. [a]



Chapter IV

Assessing the Potential for Fluridone to Reduce the Number of Postemergence Herbicide Applications in Glyphosate-Resistant Cotton

Abstract. Following the evolution of weed resistance to glyphosate, producers again began to rely on multiple applications of soil-residual herbicides tank-mixed with postemergence (POST) herbicides. Although the standard glyphosate-resistant cotton herbicide program consists of multiple herbicide mechanisms of action (MOAs), the same few MOAs are being utilized year after year, which could inevitably lead to resistance to currently effective herbicides. A field experiment was conducted in 2012 and 2013 to determine if fluridone applied preemergence (PRE) would provide effective season-long control of Palmer amaranth in glyphosate-resistant cotton as well as reduce the number of POST applications throughout the season. Preemergence-applied fluridone at 224, 336, and 448 g ai ha^{-1} did not eliminate the need for subsequent herbicides for Palmer amaranth control in cotton in either year. When applied PRE, fluridone at 224, 336, and 448 g ha^{-1} provided comparable control to fluometuron in 2012; however in 2013, fluometuron provided less control than the three rates of fluridone. Although moderate season-long control was observed in 2013, greater yields were obtained in 2013 than in 2012, which is likely a result of greater control during the critical period of weed control. Based on this experiment, fluridone will not provide effective season-long Palmer amaranth control in the absence of a multiple POST herbicide program.

Nomenclature: Palmer amaranth, *Amaranthus palmeri* (S.) Wats; cotton, *Gossypium hirsutum* L.

Key words: glyphosate-resistant, preemergence (PRE), postemergence (POST), weed control.

Prior to the commercialization of glyphosate-resistant (GR) crops in 1997, weed management in cotton relied upon combining several factors: 1) multiple soil-residual herbicide applications, 2) multiple POST herbicide applications, and 3) tillage (Young 2006; Burke et al. 2005). Since then, the adoption of this technology has increased from 37% utilization in 2000 to almost 100% utilization by 2011 (USDA, NASS 2000; USDA, NASS 2011; Norsworthy et al. 2011). For several years following GR cotton commercialization, producers were limited to applying glyphosate after the 4-leaf cotton growth stage; however, in 2006 enhanced glyphosate-resistant (Roundup Ready Flex®) cotton was commercialized allowing multiple applications of glyphosate throughout the growing season (Huff et al. 2010). Additional benefits of utilizing glyphosate-resistant technology included less reliance on tillage, reduced herbicide costs, and minimal crop injury (Young 2006).

As a result of these benefits, producers began to rely on glyphosate as a sole means of weed control, which encouraged the evolution of glyphosate-resistant weeds. Currently, 14 weeds have been confirmed resistant to glyphosate in the United States (Heap 2015). Seven of the 14 GR weeds in the United States have been confirmed in Arkansas which includes horseweed (*Conyza canadensis* L. Cronq. (2003)), common ragweed (*Ambrosia artemisifolia* L. (2004)), giant ragweed (*Ambrosia trifida* L. (2005)), Palmer amaranth (*Amaranthus palmeri* (2006)), johnsongrass (*Sorghum halepense* L. (2007)), Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum* Lam. Husnot (2008)), and tall waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] (Heap 2015).

Of these seven weeds, Palmer amaranth has been the most troublesome glyphosate-resistant weed across the southern United States for several years, due in part to its extended emergence period (Jha et al. 2006; Jha and Norsworthy 2009) and prolific growth capabilities

(Norsworthy et al. 2008) which can be attributed to it being a C_4 plant (Ehleringer 1983), with a growth rate up to four times that of other agronomic crops. This prolific growth rate allows Palmer amaranth to reach heights greater than 2 m (Horak and Loughin 2000), which exceeds the heights of soybean [*Glycine max* (L.) Merr.] and cotton; both of which are slower growing C_3 plants (Gibson 1998).

As a dioecious plant (male and female flowers on separate plants), female plants are easily distinguishable from male plants with a thick, spiked inflorescence up to 0.5 m in length and sharp bracts throughout the inflorescence (Horak and Peterson 1995). Furthermore, to ensure greater offspring emergence a single female Palmer amaranth plant can produce up to 600,000 seeds (Keeley et al. 1987). The high dispersal of both pollen (Sonoskie et al 2009) and seed (Norsworthy et al. 2009; Norsworthy et al. 2014) by Palmer amaranth allows for the glyphosate-resistant trait to rapidly spread across a field and larger geographies. As a result of these characteristics, Palmer amaranth can be extremely competitive with agronomic crops such as cotton, with cotton lint yield reductions up to 92% at 0.9 plants m^{-2} (Rowland et al. 1999).

Currently in Arkansas, the standard cotton weed management program for glyphosate-resistant cotton consists of seven to nine herbicides applied periodically throughout the season (L.T. Barber, personal communication). For instance, the burndown application of glyphosate + dicamba is followed by fomesafen applied prior to planting followed by fluometuron + paraquat at planting followed by two applications of glyphosate + *S*-metolachlor at the 2-leaf and 4- to 5-leaf stage of cotton. Subsequently, a post-directed tank mixture of glyphosate + prometryn is applied at the 8- to 10-leaf stage followed by a layby application of MSMA + flumioxazin. Previous research has reported that the exclusion of soil-residual herbicides at the layby application could allow late-season weed interference, for which the likelihood of cotton lint yield reduction is highly probable (Tingle and Chandler 2004).

Most of the herbicides that make up the standard cotton weed management program in Arkansas are soil-residual herbicides belonging to multiple herbicide MOAs. WSSA Group 7 (fluometuron and diuron), Group 14 (fomesafen and flumioxazin), and Group 15 (metolachlor and acetochlor) herbicides are heavily relied upon for residual weed control in cotton. With the high propensity for Palmer amaranth to evolve resistance to herbicides, it would be beneficial to use another effective MOA for its control in cotton, especially since the aforementioned herbicides are commonly used in soybean in addition to cotton.

Developed as EL-171 in the early 1970s, fluridone is a pigment inhibitor classified as a WSSA Group 12 herbicide (Waldrep and Taylor 1976); however, fluridone was never labeled for use in field crops. At the rates tested of 0.3 to 2.4 kg ai ha^{-1}, fluridone was found safe when applied PRE to cotton, as well as providing broad-spectrum PRE control of annual grass and broadleaf weeds such as barnyardgrass (*Echinocloa crus-galli* L. Beauv), johnsongrass, tall morningglory (*Ipomoea purpurea* L. Roth), and redroot pigweed (*Amaranthus retroflexus* L.) (Waldrep and Taylor 1976). Fluridone does not inhibit weed emergence, but rather causes chlorosis of new tissues, growth retardation, leaf necrosis, and eventual plant death, with symptoms occurring soon after emergence.

Fluridone has been reported to persist in the soil for an extended period of time (Banks et al. 1979), which is dependent upon the percent organic matter and clay content in the soil (Shea and Weber 1983). Fluridone applied at rates of 0.22, 0.45, and 0.9 kg ha^{-1} still had 5% of the herbicide remaining in a Miller clay soil 250 d after treatment (DAT), whereas in a Lufkin fine sandy loam soil 20% of the herbicide remained 385 DAT. Further research suggests that the dissipation of fluridone is likely the result of microbial degradation in the soil, most importantly when subsequent applications of fluridone are made (Banks et al. 1979; Shroeder and Banks 1986).

As a result of herbicidal activity and lengthy persistence of fluridone in multiple soils, the objectives of this experiment were to evaluate the efficacy of PRE-applied fluridone compared to fluometuron as well as potential for fluridone to reduce the POST herbicide applications needed for effective Palmer amaranth control in glyphosate-resistant cotton.

Materials and Methods

A field experiment was conducted in 2012 and 2013 at the Lon Mann Research Station in Marianna, AR, on a Zachary silt loam soil (fine-silty, mixed, active, thermic Typic Albaqualfs) with 8% sand, 80% silt, 12% clay, 1.8% O.M., and a pH of 6.9. The experiment was conducted as a randomized complete block design in a four-by-five factorial arrangement of four PRE-herbicide treatments and five POST-applications, plus three additional treatments.

The PRE-applied herbicides included fluometuron at 1,120 g ai ha^{-1} and fluridone at 224, 336, and 448 g ha^{-1}. The POST-applied herbicide treatments included 1) no POST herbicide (hereafter referred to as NO POST), 2) MSMA at 2,240 g ai ha^{-1} + flumioxazin at 72 g ai ha^{-1} applied post-directed/layby (PDIR/LAYBY) (hereafter referred to as 1-POST), 3) glyphosate at 840 g ae ha^{-1} + prometryn at 1,120 g ai ha^{-1} applied to 8- to 10-leaf cotton fb MSMA + flumioxazin (PDIR/LAYBY) (hereafter referred to as 2-POST), 4) glyphosate + *S*-metolachlor at 1,070 g ai ha^{-1} applied to 4- to 5-leaf cotton fb glyphosate + prometryn to 8- to 10-leaf cotton fb MSMA + flumioxazin (PDIR/LAYBY) (hereafter referred to as 3-POST), and 5) glyphosate + *S*-

metolachlor (2-leaf) fb glyphosate + *S*-metolachlor (4- to 5-leaf) fb glyphosate + prometryn (8- to 10-leaf) fb MSMA + flumioxazin (PDIR/LAYBY) (hereafter referred to as 4-POST). Although no evaluated the three additional treatments in this experiment included a nontreated control, fluridone applied PRE at 112 g ha^{-1} fb glyphosate + *S*-metolachlor (2-leaf) fb glyphosate + *S*-metolachlor (4- to 5-leaf) fb glyphosate + prometryn (8- to 10-leaf) fb MSMA + flumioxazin, and fluridone at 112 g ha^{-1} fb glyphosate + *S*-metolachlor (4- to 5-leaf) fb glyphosate + prometryn (8- to 10-leaf) fb MSMA + flumioxazin. Formulations and manufacturers of all herbicide products evaluated in this experiment can be found in Table 4.1.

Phytogen 375 WRF (Widestrike®, Genuity®, Roundup Ready Flex®) cotton cultivar was seeded at 11 seeds m^{-1} row onto 96 cm wide freshly cultivated raised beds with a New Holland 8260 (New Holland Agriculture, New Holland, PA 17557) tractor equipped with a 4-row John Deere 7300 (Deere and Company World Headquarters, Moline, IL 61265) vacuum planter. Seeding took place on May 9, 2012 and on May 16, 2013. The four-row plots were 3.8 by 7.6 m with a 1.5 m alley between replications. In both years, the test site contained a natural population of mixed glyphosate-resistant and -susceptible Palmer amaranth plants.

Herbicide treatments were applied with a CO_2-pressurized backpack sprayer consisting of a handheld boom that contained six 110015 flat-fan nozzles (Teejet Technologies, Springfield, IL 62703) on 48 cm spacing and calibrated to deliver 140 L ha^{-1} at 276 kPa. Plots were visually rated every 7 to 14 DAT for weed control and cotton injury on a scale of 0 to 100%, with 0 being no control or injury and 100% being death of the plant or crop. Ratings were based on comparison with the nontreated control. Cotton was harvested in both on November 2, 2012 and on October 25, 2013 with a 2-row Case IH 1822 (CNH

Industrial, NV) plot cotton picker equipped with a Weightronix WI-130 (Avery Weightronix, LLC) weigh system to evaluate the relationship between weed control and cotton lint yield.

In both years, herbicide efficacy was evaluated at 3 and 12 weeks after the PRE (WAP) application. Furthermore, all data were analyzed by ANOVA using JMP Pro Version 10.0 (SAS Institute Inc., Cary, NC 27513), and means were separated with Fisher's LSD (α=0.05). Due to observed interactions with year, treatments were analyzed separately for 2012 and 2013. Seven preplanned contrasts were constructed to compare: 1) fluridone PRE at 224 g ha^{-1} vs. fluometuron, 2) fluridone PRE at 336 g ha^{-1} vs. fluometuron, 3) fluridone PRE at 448 g ha^{-1} vs. fluometuron, 4) 4-POST program vs. 3-POST program, 5) 4-POST program vs. 2-POST program, 6) 4-POST program vs. 1-POST program, 7) 4-POST program vs. NO-POST program, with significant differences reported at a p-value less than 0.05.

Results and Discussion

Environmental Data and Cotton Growth. In this experiment, multiple rates of fluridone were compared to the standard PRE herbicide fluometuron and evaluated to determine if these soil-residual herbicides could provide season-long control of Palmer amaranth as well as reducing the number of POST applications in cotton. As with most soil-residual herbicides, precipitation is key to activating the herbicide; hence, the lack of sufficient and timely precipitation at Marianna in 2012 likely affected weed control in this experiment (Figure 4.1). In an attempt to overcome the lack of precipitation in 2012, furrow-irrigation was utilized approximately 2 weeks after the early POST application. Early season cotton growth was slowed as a result of limited rainfall, particularly in herbicide programs lacking an early POST application. Additionally, no cotton injury was observed following any herbicide application (data not shown).

In 2013, timely rainfall was received throughout the growing season, most importantly nearly 5 cm of rainfall occurred within days following the application of PRE herbicides. Furthermore, cotton growth benefited from the frequent precipitation and irrigation events received throughout the growing season. Similarly as in 2012, no injury to cotton was observed in 2013 throughout the growing season (data not shown).

Palmer Amaranth and Pitted Morningglory Control. Three weeks following the PRE herbicide application in 2012, it was evident that achieving effective control of Palmer amaranth and pitted morningglory would not be possible without sufficient rainfall to activate the PRE herbicides. Less than 1 cm of rainfall occurred the two weeks following the PRE applications. Unfortunately, most cotton grown in Arkansas lacks overhead-irrigation. As in this study, furrow-irrigation is the main means of irrigating the crop, with irrigation most often beginning no earlier than the 5-leaf stage. Partially as a result of dry conditions, no PRE treatment provided ≥ 89% control of Palmer amaranth at 3 weeks after planting (WAP) (Table 4.2). Based on contrasts at 12 WAP, all fluridone-containing programs provided comparable Palmer amaranth control to the fluometuron-containing programs. Averaged over PRE herbicides, the 4-POST program provided superior control of Palmer amaranth over POST programs having two or fewer timings, whereas the 3-POST program was comparable to the 4-POST program. Scott et al. (2002) further emphasizes the need for an effective POST herbicide to be tank-mixed with soil-residual herbicides in cotton to provide extended control of Palmer amaranth, most importantly in instances where soil-residual herbicides are not activated.

Overall initial control of Palmer amaranth in 2013 was greater than seen in 2012, which is likely a result of better activation of soil-residual herbicides applied PRE. By 3 WAP, Palmer amaranth control was comparable with all herbicide programs providing ≥ 89% control (Table

4.2). By 12 WAP, variable (48 to 93%) control of Palmer amaranth was observed across the herbicide programs; albeit, none provided complete control. For the PRE treatments that did not have a subsequent POST herbicide, greater Palmer amaranth control was observed with each of the fluridone treatments over that of fluometuron. This difference in control is likely a result of the extended residual control of fluridone on *Amaranthus* weeds as noted previously (Waldrep and Taylor 1976). Based on orthogonal contrasts at 12 WAP, the fluridone-based programs were superior to the fluometuron-based programs in regards to Palmer amaranth control. Contrasts also revealed that a 4-POST program was better in controlling Palmer amaranth than any other POST program with fewer applications.

Similar to Palmer amaranth control in 2012, pitted morningglory control was variable (63 to 91%) depending on the number of POST herbicides applied (Table 4.2). Greater activity of fluridone over fluometuron on pitted morningglory was evident based on contrasts. However, multiple POST applications were necessary to achieve effective control of pitted morningglory throughout the growing season.

In 2013, greater than 90% pitted morningglory control was observed at 3 WAP from most of the applied treatments (Table 4.2). These results suggests that when fully activated, soil-residual herbicides like fluridone and fluometuron can provide moderate to effective early season control of pitted morningglory. By 12 WAP, pitted morningglory control ranged from 86 to 100% when PRE herbicides were followed by three or four POST applications. Similarly, contrasts revealed that pitted morningglory control for the 4-POST program was superior to all programs that had two or fewer POST applications. Most of the POST applications contained glyphosate, and Scott et al. (2002) reported that the addition of glyphosate with soil-residual herbicides was beneficial for providing effective control of multiple *Ipomoea* spp. in cotton.

Barnyardgrass and Broadleaf Signalgrass Control. Generally, barnyardgrass and broadleaf signalgrass control in this experiment were similar (Table 4.3). In both years, barnyardgrass and broadleaf signalgrass control were benefitted from the use of glyphosate in one or more of the POST applications as evident by the 2-POST programs being superior to the 1-POST or NO POST programs. Similarly, previous research has shown that an application of *S*-metolachlor with glyphosate can provide excellent season-long control of barnyardgrass (Scoggs et al. 2007). In 2012, greater barnyardgrass at 12 WAP was obtained when fluridone was applied at either 336 or 448 g ha^{-1} than when fluometuron was applied based on contrasts. Differences in barnyardgrass and broadleaf signalgrass control with fluridone and fluometuron were not apparent at 12 WAP in 2013.

Seedcotton Yield. Controlling troublesome weeds such as Palmer amaranth throughout the growing season is highly important in achieving adequate cotton yields. In 2012 without sufficient herbicide activation early in the season, herbicide programs that did not consist of multiple POST applications had a significant decrease in cotton yield (Table 4.4). The overshadowing of cotton by Palmer amaranth along with its other competitive characteristics greatly contributed to the low cotton yields observed in 2012. In 2013, cotton yields were markedly improved with no differences among treatments when any of the PRE treatments were followed by either 3-POST or 4-POST programs (Table 4.3). However, it should be noted that Palmer amaranth was present in all plots at harvest both years, which should not be surprising considering that no more than 93% Palmer amaranth control occurred at 12 WAP. Rowland et al. (1999) reported that as few as 0.9 plants m^{-2} can reduce cotton lint yields up to 92%.

Based on contrasts, seedcotton yield in fluridone-based programs was often comparable to fluometuron-containing programs over both years (Table 4.4). Furthermore, the value and need for multiple POST applications to protect against cotton yield reductions from weed interference was apparent in the drier year when the programs having 4-POST applications resulted in greater yield than those having 2-POST applications or fewer. In 2013, when the PRE-applied herbicides were activated, the need for POST herbicides to protect against cotton yield loss was less obvious, with only the 1-POST program having lower yields than the 4-POST program ($p = 0.0419$).

Practical Implications

As residual herbicides, fluridone and fluometuron require activation in the soil by rainfall or overhead-irrigation. Although not evaluated here, it is important to note that the specific amount of rainfall or irrigation needed for optimum activation may differ between these two herbicides (Norsworthy, unpublished data). Over two vastly different years, fluridone-based herbicide programs in cotton were always equal to or superior to ones beginning with fluometuron. The benefit of the longer residual of fluridone over fluometuron will be most obvious in a wetter year. Although fluridone has been reported to persist in the soil for a long period of time (Banks et al. 1979) as well as provide an extended level of control of redroot pigweed (Waldrep and Taylor 1976), fluridone alone will not provide season-long control of Palmer amaranth and supplemental POST applications will be needed similar to current recommendations. In both years, Palmer amaranth was present at crop harvest, regardless of the intensity of the weed control program. Producers should be frequently reminded that escapes persisting through harvest will greatly contribute to the soil seedbank and the further spread of herbicide resistance (Norsworthy et al. 2014); hence, alternative methods such as hand removal or other means of preventing seed additions to the seedbank may be needed.

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Table 4.1. Herbicide products used and Production Company of treatments applied at Marianna, AR in 2012 and 2013.

Herbicide	Trade Name	Company	Rate(s) [a,b]
			g ai or ae ha^{-1}
Fluometuron	Cotoran 4L	MANA, Inc.	1,120
Fluridone	Brake 2L	SePRO Corporation	224 to 448
Glyphosate	Roundup PowerMax	Monsanto	840 g ae ha^{-1}
S-metolachlor	Dual Magnum	Syngenta	1,070
Prometryn	Caparol 4L	Syngenta	1,120
MSMA	MSMA 6 Plus	Drexel Chemical Co.	2,240
Flumioxazin	Valor SX	Valent	72

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

[b] Glyphosate rate is acid equivalent.

Table 4.2. Palmer amaranth and pitted morningglory control as influenced by preemergence herbicide and postemergence application timing at Marianna, AR in 2012 and 2013. [a]

			Control							
			2012				2013			
			Palmer amaranth		Pitted morningglory		Palmer amaranth		Pitted morningglory	
Treatment	Rate	POST application[b]	3 WAA	12 WAA	3 WAA	12 WAA	3 WAA	12 WAA	3 WAA	12 WAA
	g ai ha^{-1}		%							
Fluometuron	1,120	NO POST	68 b	25 c	63 c	20 e	84 b	48 c	94 a	54 c
Fluridone	224	NO POST	76 a	18 cd	70 b	20 e	94 a	80 ab	95 a	64 b
Fluridone	336	NO POST	73 b	21 c	79 a	43 d	96 a	79 ab	100 a	86 b
Fluridone	448	NO POST	70 b	11 d	76 b	43 d	94 a	73 b	98 a	68 b
Fluometuron	1,120	1-POST	65 b	35 c	71 b	46 c	93 a	71 b	95 a	84 a
Fluridone	224	1-POST	75 a	15 d	69 b	44 cd	90 a	65 b	93 a	71 b
Fluridone	336	1-POST	66 b	16 d	76 b	50 c	91 a	81 ab	91 a	68 b
Fluridone	448	1-POST	71 b	21 c	73 b	51 c	90 a	64 bc	94 a	65 b
Fluometuron	1,120	2-POST	69 b	35 c	74 b	85 b	90 a	66 b	99 a	86 a
Fluridone	224	2-POST	78 a	63 b	86 a	100 a	91 a	71 b	89 a	83 a
Fluridone	336	2-POST	81 a	65 b	84 a	100 a	96 a	78 ab	91 a	83 a
Fluridone	448	2-POST	76 a	56 b	88 a	100 a	96 a	80 ab	96 a	100 a
Fluometuron	1,120	3-POST	75 a	79 a	84 a	100 a	89 a	78 ab	90 a	95 a
Fluridone	224	3-POST	60 b	74 a	68 b	100 a	93 a	83 a	85 b	100 a
Fluridone	336	3-POST	73 b	81 a	79 a	100 a	89 a	85 a	99 a	100 a
Fluridone	448	3-POST	45 c	60 b	70 b	100 a	94 a	84 a	93 a	86 a
Fluometuron	1,120	4-POST	85 a	84 a	81 a	100 a	95 a	89 a	98 a	100 a
Fluridone	224	4-POST	85 a	85 a	91 a	100 a	94 a	90 a	95 a	100 a
Fluridone	336	4-POST	89 a	78 a	89 a	100 a	96 a	89 a	99 a	99 a
Fluridone	448	4-POST	76 a	75 a	78 a	100 a	95 a	93 a	98 a	99 a
	Contrast									
Fluridone 224 vs. Fluometuron				NS		NS		0.0363*		NS
Fluridone 336 vs. Fluometuron				NS		0.0006*		0.0002*		NS
Fluridone 448 vs. Fluometuron				NS		0.0005*		0.0090*		NS

4-POST vs. 3-POST	NS	NS	0.0257*	NS
4-POST vs. 2-POST	<0.0001*	NS	<0.0001*	0.0471*
4-POST vs. 1-POST	<0.0001*	<0.0001*	<0.0001*	<0.0001*
4-POST vs. NO POST	<0.0001*	<0.0001*	<0.0001*	<0.0001*

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

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

[b] Timing of POST applications: (4-POST) glyphosate plus *S*-metolachlor (2-lf) followed by glyphosate plus *S*-metolachlor (4- to 5-lf) followed by glyphosate plus prometryn (8- to 10-lf directed) followed by MSMA plus flumioxazin (Layby directed); (3-POST) glyphosate plus *S*-metolachlor (4- to 5-lf) followed by glyphosate plus prometryn (8- to 10-lf directed) followed by MSMA plus flumioxazin (Layby directed); (2-POST) glyphosate plus prometryn (8- to 10-lf directed) followed by MSMA plus flumioxazin (Layby directed); (1-POST) MSMA plus flumioxazin (Layby directed). See text for rates of each POST herbicide.

Table 4.3. Barnyardgrass and broadleaf signalgrass control as influenced by preemergence herbicide and postemergence application timing at Marianna, AR in 2012 and 2013. [a]

			Control							
			2012				2013			
			Barnyardgrass		Broadleaf signalgrass		Barnyardgrass		Broadleaf signalgrass	
Treatment	PRE	POST application[b]	3 WAA	12 WAA	3 WAA	12 WAA	3 WAA	12 WAA	3 WAA	12 WAA
	g ai ha^{-1}		%							
Fluometuron	1,120	NO POST	71 cd	28 f	73 c	29 d	93 a	65 d	100 a	76 b
Fluridone	224	NO POST	66 d	20 f	66 d	19 f	99 a	79 c	94 a	78 b
Fluridone	448	NO POST	80 bc	41 e	85 b	40 c	99 a	80 c	99 a	93 a
Fluridone	560	NO POST	83 b	55 d	83 b	40 c	100 a	80 c	96 a	78 b
Fluometuron	1,120	1-POST	79 c	79 c	78 b	24 e	100 a	89 b	93 a	91 a
Fluridone	224	1-POST	39 f	85 c	76 c	39 c	100 a	81 c	95 a	80 a
Fluridone	448	1-POST	58 e	84 c	76 c	39 c	100 a	79 c	95 a	78 b
Fluridone	560	1-POST	71 cd	78 c	74 c	23 e	99 a	86 b	98 a	86 a
Fluometuron	1,120	2-POST	88 b	89 b	79 b	40 c	99 a	88 b	100 a	93 a
Fluridone	224	2-POST	96 a	100 a	93 a	96 a	93 a	90 b	93 a	93 a
Fluridone	448	2-POST	85 b	94 b	78 b	94 a	100 a	86 b	93 a	86 a
Fluridone	560	2-POST	79 c	100 a	79 b	93 b	100 a	100 a	95 a	100 a
Fluometuron	1,120	3-POST	83 b	100 a	84 b	100 a	100 a	99 a	96 a	100 a
Fluridone	224	3-POST	78 c	100 a	76 c	100 a	93 a	98 a	91 a	98 a
Fluridone	448	3-POST	86 b	100 a	80 b	99 a	99 a	100 a	95 a	100 a
Fluridone	560	3-POST	36 f	100 a	56 e	100 a	100 a	99 a	99 a	100 a
Fluometuron	1,120	4-POST	93 a	100 a	93 a	100 a	100 a	100 a	100 a	100 a
Fluridone	224	4-POST	95 a	100 a	94 a	100 a	100 a	100 a	100 a	100 a
Fluridone	448	4-POST	98 a	100 a	95 a	100 a	100 a	100 a	100 a	100 a
Fluridone	560	4-POST	90 a	100 a	89 a	100 a	100 a	100 a	99 a	100 a
Contrast										
Fluridone 224 vs. Fluometuron				NS		<0.0001*		NS		NS
Fluridone 336 vs. Fluometuron				0.0003*		<0.0001*		NS		NS

Fluridone 448 vs. Fluometuron	<0.0001*	<0.0001*	NS	NS
4-POST vs. 3-POST	NS	NS	NS	NS
4-POST vs. 2-POST	0.0025*	<0.0001*	0.0495*	NS
4-POST vs. 1-POST	<0.0001*	<0.0001*	0.0007*	0.0002*
4-POST vs. NO POST	<0.0001*	<0.0001*	<0.0001*	<0.0001*

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

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

[b] POST timing applications: (4-POST) glyphosate plus *S*-metolachlor (2-lf) followed by glyphosate plus *S*-metolachlor (4- to 5-lf) followed by glyphosate plus prometryn (8- to 10-lf directed) followed by MSMA plus flumioxazin (Layby directed); (3-POST) glyphosate plus *S*-metolachlor (4- to 5-lf) followed by glyphosate plus prometryn (8- to 10-lf directed) followed by MSMA plus flumioxazin (Layby directed); (2-POST) glyphosate plus prometryn (8- to 10-lf directed) followed by MSMA plus flumioxazin (Layby directed); (1-POST) MSMA plus flumioxazin (Layby directed). See text for rates of each POST herbicide.

Table 4.4. Seedcotton yield at Marianna, AR in 2012 and 2013. [a]

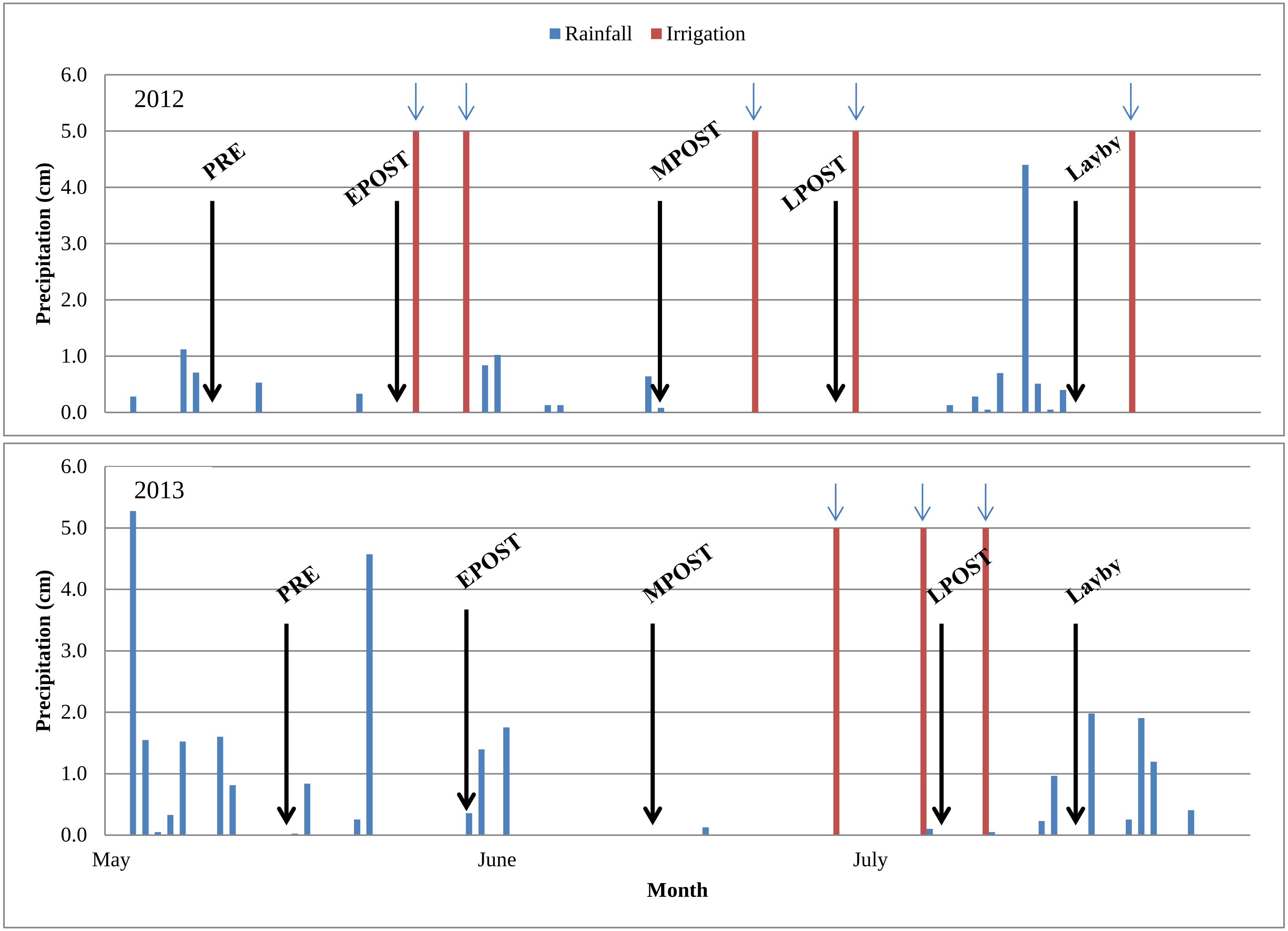
Treatment	Rate	POST application[b]	Control			
			2012		2013	
	g ai ha^{-1}		kg ha^{-1}			
Fluometuron	1,120	NO POST	360	c	1,090	b
Fluridone	224	NO POST	360	c	1,660	a
Fluridone	336	NO POST	530	c	1,780	a
Fluridone	448	NO POST	530	c	1,570	a
Fluometuron	1,120	1-POST	390	c	1,540	a
Fluridone	224	1-POST	410	c	1,330	b
Fluridone	336	1-POST	440	c	1,830	a
Fluridone	448	1-POST	390	c	1,280	b
Fluometuron	1,120	2-POST	770	b	1,450	ab
Fluridone	224	2-POST	890	b	1,300	b
Fluridone	336	2-POST	1,120	a	1,720	a
Fluridone	448	2-POST	1,040	a	1,660	a
Fluometuron	1,120	3-POST	1,120	a	1,780	a
Fluridone	224	3-POST	1,040	a	1,570	a
Fluridone	336	3-POST	1,070	a	2,040	a
Fluridone	448	3-POST	860	b	2,010	a
Fluometuron	1,120	4-POST	1,240	a	1,780	a
Fluridone	224	4-POST	1,240	a	1,750	a
Fluridone	336	4-POST	1,100	a	1,750	a
Fluridone	448	4-POST	950	a	1,950	a
	Contrast					
Fluridone 224 vs. Fluometuron			NS		NS	
Fluridone 336 vs. Fluometuron			NS		0.0305*	
Fluridone 448 vs. Fluometuron			NS		NS	
4-POST vs. 3-POST			NS		NS	
4-POST vs. 2-POST			0.0480*		NS	
4-POST vs. 1-POST			<0.0001*		0.0419*	
4-POST vs. NO POST			<0.0001*		NS	

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

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

[b] POST timing applications: (4-POST) glyphosate plus *S*-metolachlor (2-lf) followed by glyphosate plus *S*-metolachlor (4- to 5-lf) followed by glyphosate plus prometryn (8- to 10-lf directed) followed by MSMA plus flumioxazin (Layby directed); (3-POST) glyphosate plus *S*-metolachlor (4- to 5-lf) followed by glyphosate plus prometryn (8- to 10-lf directed) followed by MSMA plus flumioxazin (Layby directed); (2-POST) glyphosate plus prometryn (8- to 10-lf directed) followed by MSMA plus flumioxazin (Layby directed); (1-POST) MSMA plus flumioxazin (Layby directed). See text for rates of each POST herbicide.

Figure 4.1. Rainfall amounts and furrow-irrigation events at Marianna, AR in 2012 and 2013. Small arrows indicate irrigation event. [a]



Chapter V

Residual Control of Palmer amaranth along Field Margins with Fluridone

Abstract. Glyphosate-resistant Palmer amaranth has been a growing concern for several years in agronomic crops across the Midsouth. Controlling this weed along field margins is a critical component of current herbicide resistance management practices. Without the ability to use glyphosate, reliance upon soil-residual herbicides throughout the season is the most likely means of providing effective control. Two experiments were conducted in 2012 and 2013 to determine the effectiveness of fluridone on Palmer amaranth when applied preplant incorporated (PPI) on turnrows and preemergence (PRE) on ditchbanks. Under favorable conditions in the turnrow experiment, fluridone applied PPI with or without a sequential application provided comparable control to diuron, with all treatments providing > 80% control of Palmer amaranth up to 12 wk after initial application (WAIA). In the ditchbank experiment in 2012, fluridone provided comparable control of Palmer amaranth to the remaining treatments with all treatments providing < 80% control. In 2013, fluridone provided 68% control of Palmer amaranth, which was significantly less than aminopyralid and saflufenacil with 95 and 97% control, respectively. In addition to the lack of Palmer amaranth control in either year, fluridone (22 to 37%) failed to provide comparable or greater levels of grass groundcover than aminopyralid and saflufenacil, which provided > 60% grass groundcover. Based on these experiments, fluridone applied PPI could provide good control of Palmer amaranth up to 12 WAIA when applied in favorable environmental conditions. However, fluridone will not be recommended as a stand-alone soil-residual herbicide when applied PRE on ditchbanks for season-long control of Palmer amaranth.

Nomenclature: Palmer amaranth, *Amaranthus palmeri* (S.) Wats; redroot pigweed, *Amaranthus retroflexus* L.

Key words: glyphosate-resistant, preplant incorporated (PPI), preemergence (PRE), turnrow, ditchbank, wk after initial application (WAIA).

Palmer amaranth exerts an economic and physically damaging impact on almost all crop fields that it infests. Although weeds in fields must be controlled, it is also important to control weeds along field margins such as ditchbanks and turnrows. Palmer amaranth and other weeds in these non-cropped areas naturally disperse seeds into fields through senescence, during rainfall events or flooding, and through field edge maintenance involving tillage or mowing (Bagavathiannan et al. 2013). Problematic weeds in these non-cropped areas are a concern because they have greater opportunities to contaminate other fields, add to the soil seedbank, and restrict water flow in ditches without competition from crops (Charles et al. 2002; Bennett 2011).

Norsworthy et al. (2012) developed best management practices (BMP) to reduce the risks of herbicide resistance evolving. A critical component of these BMPS is the management of weeds along field edges to prevent an influx of weeds into production fields. These field edges would include turnrows and ditchbanks. Challenges exist in regards to controlling weeds in these non-crop areas because there are few chemical control options labeled for this use and secondly the absence of a crop can allow for season-long emergence, especially for Palmer amaranth that emerges over a 4 to 5 mo period. The number of preemergence-(PRE) and postemergence-applied (POST) herbicides that are registered for non-cropped use along field borders adjacent to irrigation and drainage canals is quite limited (Richardson 2008). Additionally, time constraints and added management costs limit the willingness of producers to manage field borders (Norsworthy et al. 2012).

In recent years, there has been great emphasis placed on managing weed infestations along field margins, especially in regions that have confirmed glyphosate-resistant Palmer amaranth. Glyphosate has historically been the main means of weed control on turnrows and along ditchbanks (Bagavathiannan and Norsworthy 2013). In the predominant row crop agricultural region of Arkansas, Bagavathiannan and Norsworthy (2013) found that > 95% of the Palmer amaranth growing along roadsides, including ditchbanks adjacent to production fields, was resistant to glyphosate and pyrithiobac. Palmer amaranth in this environment lacks competition with a crop and it is likely that seed production by this weed is greater than that in the field where interference with a crop occurs for much of the growing season. With glyphosate-resistant Palmer amaranth and other glyphosate-resistant weeds predominant along roadsides and field edges, alternative herbicides to glyphosate are desperately needed.

Studies in Saskatchewan, Canada in the 1970s were initiated to test the use of the soil-residual herbicides atrazine, simazine, bromacil, and monuron at high rates as soil sterilants (Grover et al. 1980). In the initial year, the four herbicides controlled all weeds on ditchbanks; weeds treated with atrazine and simazine were controlled the second year after treatment whereas control with bromacil and monuron had decreased by the second year (Grover et al. 1980). Higher rates of soil-residual herbicides than those used in crops are needed to control weeds such as glyphosate-resistant Palmer amaranth on ditchbanks and turnrows throughout the spring and summer months. Plant groundcover, preferably a low-growing dense forming grass, aids reduction in weed emergence along ditchbanks and turnrows (Grover et al. 1980). However, soil-residual and POST-applied herbicides can be injurious to the plant groundcover, which in turn will result in increased risk for erosion in areas of turnrows and ditchbanks where barren soil exists (Grover et al. 1980). To prevent soil erosion, grass cover crops have been sown on ditchbanks and turnrows to reduce weed seed germination and to reduce erosion.

Fluridone, a WSSA group 12 herbicide, was developed and synthesized by Eli Lilly in the early 1970s and was found to inhibit phytoene desaturase in plants. Due to carryover concerns, fluridone was never labeled for use in field crops; however in 1979, studies were conducted at the Lilly Research Laboratories in Indiana to evaluate the aquatic herbicidal properties of fluridone (McCowen et al. 1979). In this experiment, fluridone provided excellent control of floating and submersed plants at the lowest tested dose of 1 part per million (ppm). Fluridone continued to provide > 95% control of aquatic weeds at levels as low as 0.03 ppm for 8 weeks after treatment (McCowen et al. 1979).

In 1986, the United States Environment Protection Agency approved the use of fluridone (Sonar®, SePRO Corporation) for control of aquatic weeds in fresh water ponds, lakes, and drainage and irrigation canals. Since then, fluridone has been widely used to provide effective control of hydrilla [*Hydrilla verticillata* (L. f.) Royle] without affecting native aquatic vegetation (Doong et al. 1993; Pons 2005). In addition to an aquatic registration, fluridone is currently labeled for use along water-containing ditchbanks (Anonymous 2015a). Due to the long-lasting residual activity of fluridone, it may provide a season-long control option for producers that are currently battling glyphosate-resistant Palmer amaranth along field margins.

Due to fluridone being labeled for use along ditchbanks and other waterways, the objectives of these experiments were to determine the level of Palmer amaranth control with fluridone relative to diuron in the absence of a crop and to evaluate Palmer amaranth control and grass tolerance to spring-applied herbicides labeled for use on ditchbanks.

Materials and Methods

Control on Turnrows. A bareground field experiment was conducted at the University of Arkansas Research and Extension Center in Fayetteville, AR, on a Captina silt loam soil (fine-silty, siliceous, active, mesic Typic Fragiudults) in 2012 and on a Pembroke silt loam soil (fine-silty, mixed, active mesic Mollic Paleudalfs) in 2013. Treatments were applied onto 1.8 by 7.6

m long plots with a 1.5 m alley between replications. No crop was planted in this experiment, and all treatments were applied to a natural population of Palmer amaranth.

The following treatments were evaluated: 1) nontreated control, 2) fluridone (Brake 2L, SePRO Corporation) at 224 g ai ha^{-1} applied preplant incorporated (PPI) followed by (fb) fluridone at 224 g ha^{-1} 6 weeks after the initial treatment (WAIA), 3) fluridone at 448 g ha^{-1} PPI, 4) fluridone at 336 g ha^{-1} PPI fb fluridone at 336 g ha^{-1} 6 WAIA, 5) fluridone at 673 g ha^{-1} PPI, 6) diuron (Direx® 4L, MANA – Makhteshim Agan North America, Inc.) at 1,120 g ai ha^{-1} PPI fb diuron at 1,120 g ha^{-1} 6 WAIA, and 7) diuron at 2,240 g ha^{-1} PPI.

Treatments were applied with a CO_2-pressurized backpack sprayer consisting of a handheld boom that contained three 110015 flat-fan nozzles (Teejet Technologies, Springfield, IL. 62703) on 51 cm spacing and calibrated to deliver 140 L ha^{-1} at 276 kPa. PPI treatments were incorporated approximately 7.5 cm into the soil profile with the use of a John Deere 6200 (Deere & Company World Headquarters, Moline, IL 61265) tractor equipped with a field cultivator. Plots were visually rated every 7 d after treatment (DAT) for herbicide efficacy on a scale of 0 to 100%, with 0 being no control and 100% being the death of the plant. Ratings were based on comparison with the nontreated control. In 2012 and 2013, data were analyzed separately as a randomized complete block (RCB) design with four replications. For significant effects in the analysis of variance, least square means were separated using Fisher's protected LSD. All analyses were carried out using JMP Pro Version 10.0 (SAS Institute Inc., Cary, NC. 27513).

Palmer Amaranth Control and Grass Tolerance to Herbicides on Ditchbanks. An experiment was conducted in 2012 and 2013 at the Northeast Research and Extension Center in

Keiser, AR, on a Sharkey silty clay soil (very-fine, smectitic, thermic Chromic Epiaquerts). Treatments were applied to the bank of a drainage ditch near the water line on March 23, 2012 and March 8, 2013 prior to the green-up of weedy and grass vegetation. Grasses growing on the ditchbank mainly consisted of a mixture of bermudagrass [*Cynodon dactylon* (L.) Pers.], barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], and broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R. D. Webster]. These grasses provided 80 to 90% groundcover along the ditchbank in both years. The treated area for each plot was 3.1 by 7.6 m long. No crops were planted in this experiment, and all treatments were applied prior to Palmer amaranth or annual grass emergence.

All evaluated herbicide treatments are currently labeled for use on ditchbanks. These treatments included 1) fluridone at 1,120 g ha^{-1}, 2) fluridone at 2,240 g ha^{-1}, 3) diuron at 2,240 g ha^{-1}, 4) diuron at 4,480 g ha^{-1}, 5) diuron at 6,720 g ha^{-1}, 6) diuron at 8,960 g ha^{-1}, 7) diuron at 11,200 g ha^{-1}, 8) diuron at 13,440 g ha^{-1}, 9) imazapyr (Habitat® herbicide, BASF Specialty Products) at 210 g ai ha^{-1}, 10) imazapyr at 420 g ha^{-1}, 11) imazapyr at 700 g ha^{-1}, 12) aminopyralid (Milestone® Specialty Herbicide, Dow AgroSciences, LLC) at 120 g ai ha^{-1}, 13) indaziflam (Alion® herbicide, Bayer CropScience at 95 g ai ha^{-1}, and 14) saflufenacil (Sharpen® herbicide, BASF Ag Products) at 150 g ai ha^{-1}. A nontreated control was also included.

Herbicides were applied with a CO_2-pressurized backpack sprayer consisting of a handheld boom that contained six 11003 flat-fan nozzles on 51 cm spacing and calibrated to deliver 280 L ha^{-1} at 276 kPA. Plots were visually rated at approximately 2, 4, and 6 months after application for herbicide efficacy and grass tolerance on a scale of 0 to 100%, with 0 being no control or tolerance and 100% being complete control of Palmer amaranth or the grass mixture. For 2012 and 2013, data were analyzed separately as a RCB design with four replications. Herbicides and rates within each herbicide product were considered as fixed effects. Rating times were treated as a repeated measure. For significant effects in the analysis of variance, least square means were separated using Fisher's protected LSD at $\alpha = 0.05$. All analyses were carried out using SAS® Version 9.4 (SAS Institute, Inc., Cary, NC).

Results and Discussion

Environmental Data. Timing of rainfall events relative to application of the residual herbicides and the amount of rainfall that occurred over the course of the growing season likely impacted activity of the residual herbicides evaluated in both the turnrow and ditchbank experiments. Compared to the 30-yr average rainfall (115.60 cm) (data not shown) in Fayetteville, rainfall amounts in Fayetteville were 50 cm lower in 2012 whereas rainfall amounts in 2013 were within 2 cm of the 30-yr average (Figure 5.1). However, little to no rainfall was received following the final herbicide application, which could greatly affect the efficacy of soil-residual herbicides (Buhler and Werling 1989). In Keiser, rainfall in 2012 was 33.6 cm less than the 30-yr average (127.70 cm) (data not shown); whereas, 23.4 cm more rainfall was accumulated than the 30-yr average (Figure 5.2).

Weed Control on Turnrows. *Palmer Amaranth Control.* Six weeks after the initial application (WAIA) in 2012, Palmer amaranth control was marginal and deemed ineffective for all treatments (Table 5.1). This low level of control is likely due to receiving insufficient rainfall amounts to activate the herbicides in the soil profile. By 6 wk after the final application (WAFA), complete loss of Palmer amaranth control was observed for all treatments. Although applied to cotton, previous research suggests that fluridone applied PPI at 0.22 and 0.45 kg ha^{-1}

provided 68 and 85% control, respectively, of an *Amaranthus* spp. at 6 wk after application (WAA) (Banks and Merkle 1979).

In 2013, moderate to effective Palmer amaranth control was observed from all treatments at 6 WAIA, with high rates of most PPI alone treatments providing greater control than the lower PPI rates that were eventually part of a sequential application (Table 5.1). The increase in control compared to that in 2012 is likely a result of receiving multiple rainfall events ranging from 1.5 to 6 cm within 2 WAIA (Figure 5.1). Previous research suggests that fluridone requires approximately 2.5 cm of rainfall to be activated in the soil (Kyle Briscoe, personal communication). By the final evaluation, Palmer amaranth control continued to remain ≥ 82% for all treatments. Although fluridone could provide extended control of Palmer amaranth, previous research suggests that the build-up of fluridone in the soil from sequential applications could cause increased soil microbial degradation, which decreases effectiveness of future fluridone applications (Shroeder and Banks 1986).

Pitted Morningglory Control. Although not compared to Palmer amaranth control, some inconsistencies in herbicide efficacy were observed with PPI treatments providing moderate to effective control of pitted morningglory in 2012 (Table 5.1). Initially, fluridone at 224 g ha^{-1} followed by a sequential application provided comparable pitted morningglory control to fluridone at 448 g ha^{-1} alone and diuron at 2,240 g ha^{-1} alone with 91, 84, and 85% control, respectively. As seen for Palmer amaranth control in 2012, complete loss of control was observed by the final rating date.

Further inconsistencies were observed in 2013 where greater precipitation was accumulated than in 2012 to activate these soil-residual herbicides; yet, pitted morningglory control was lacking at both rating dates (Table 5.1). The only treatment to provide > 80% pitted morningglory control at 6 WAIA was fluridone at 673 g ha^{-1}, while all remaining treatments provided < 75% control. Similar levels of control were observed by the final evaluation, with fluridone at 673 g ha^{-1} being the only treatment to provide moderate control of pitted morningglory.

Johnsongrass Control. Initially in 2012, all treatments provided > 90% johnsongrass control, except for fluridone applied PPI at 224 and 448 g ha^{-1} (Table 5.2). Similar to other evaluated weeds in 2012, complete lack of johnsongrass control was observed by 6 WAFA. In 2013, all treatments provided < 80% johnsongrass control by 6 WAIA, except for fluridone applied PPI at 673 g ha^{-1} with 92% control (Table 5.2). By 6 WAFA, johnsongrass control continued to diminish, with control ranging from 25 to 79% across treatments. Banks and Merkle (1979) reported significant differences in johnsongrass control between years when fluridone was applied PPI to a Miller clay soil at various rates. In the first year, fluridone at 0.45 and 0.9 kg ha^{-1} provided 80 to 90% control of rhizome johnsongrass at 7 WAA. However in the following year, fluridone at the same rates failed to provide greater than 40% control of rhizome johnsongrass at 8 WAA. The inconsistency in performance of fluridone observed on johnsongrass, Palmer amaranth, and pitted morningglory in this research makes it challenging for growers to expect consistent results. However, it should be noted that the highest rate of fluridone evaluated in this research always performed comparable to the current diuron standard on each of these three weeds in two differing rainfall environments.

Palmer Amaranth Control and Grass Tolerance on Ditchbanks. *Grass Groundcover.* In both years, grass groundcover was evaluated at the end of each season (27 WAA) to assess the percentage of annual and perennial grasses remaining following the application of soil-residual herbicides (Table 5.3). Naturally occurring grasses aid in the suppression of Palmer amaranth on ditchbanks by providing a dense mat of cover that is known to decrease emergence (Jha and Norsworthy 2009). Additionally, the presence of grasses will suppress other weeds and reduce soil erosion (Hartwig and Ammon 2002; Malik et al. 2000). In both years, only the effect of herbicide selection was significant; hence, treatments were averaged over herbicide rates (Table 5.3).

For the herbicides evaluated, grass groundcover ranged from 8 to 64% at 27 WAA in 2012 (Table 5.3). Aminopyralid, indaziflam, and saflufenacil provided the greatest level of grass groundcover. This was not surprising for aminopyralid and saflufenacil because these two herbicides are labeled for use in either range and pasture or turf for broadleaf weed control (Anonymous 2015b; Anonymous 2015c). In comparison, a significantly less amount of grass groundcover was present in plots treated with fluridone, imazapyr, and diuron. These herbicides can be quite effective on barnyardgrass and broadleaf signalgrass (Anonymous 2015a; Anonymous 2015d; Anonymous 2015e).

Similar to 2012, aminopyralid and saflufenacil provided numerically the highest level of grass groundcover in 2013; albeit, statistically similar to indaziflam and imazapyr (Table 5.3). Fluridone and diuron provided greater levels of grass groundcover in 2013 than in 2012 likely because of greater rainfall in 2013 (Table 5.3; Figure 5.2), which may have resulted in quicker dissipation or loss of both herbicides as observed elsewhere (Mueller et al. 2010).

Palmer Amaranth Control. Regardless of the year, excessive amounts of rainfall were received throughout both seasons, which could greatly affect herbicide efficacy (Figure 5.2). In both years, only an effect of herbicide choice was significant; therefore, treatments were averaged across herbicide rates and rating dates. In 2012, no herbicide provided > 80% Palmer amaranth control over the course of the growing season (Table 5.4). Although it is necessary to ensure activation of soil-residual herbicides in the soil, rainfall has a clear direct and indirect effect on herbicide dissipation with possible leaching further into the soil (Mueller et al. 2014). Another possible reason for the lack of control from soil-residual herbicides is the binding of herbicide molecules to soil particles; characteristics such as organic matter, pH, and clay content can greatly affect the level of which herbicides persist in the soil (Shea and Weber 1983a; Shea and Weber 1983b; Fast et al. 2010). The soil at this site was Sharkey silty clay and it is well documented that clay soils tightly bind fluridone (Banks et al. 1979; Shroeder and Banks 1986). In 2013, over the course of 27 weeks, aminopyralid provided an average of 95% Palmer amaranth control and saflufenacil provided 97% control, which was superior to all other herbicides tested (Table 5.4). In addition to control by herbicides, grass groundcover was higher in aminopyralid and saflufenacil treated plots, which could have increased the suppression of Palmer amaranth (Hartwig and Ammon 2002) (Table 5.3). It should be noted that variability in control was observed between replications in both years for all weeds evaluated, which is likely a result of various levels of grass groundcover observed across replications. In some replications where grass groundcover was likely low, weed control levels began to fail earlier in the summer whereas in replications where grass groundcover was high weed control levels were likewise higher.

Barnyardgrass Control. In both years, only the main effect of herbicide choice was significant for barnyardgrass control; hence, treatments were averaged across herbicide rates and rating dates (Table 5.4). Barnyardgrass control ranged from 42 to 85% in 2012, with imazapyr (82%), indaziflam (84%), and diuron (85%) providing superior control to other herbicides, including fluridone with 69% control. Similar to 2012, indaziflam provided moderate control of barnyardgrass in 2013, as well as providing comparable control to most of the herbicides tested including fluridone, diuron, saflufenacil, and aminopyralid (Table 5.4). These data coincides with the level grass groundcover observed in both years with aminopyralid and saflufenacil providing poor control of barnyardgrass; albeit, superior grass groundcover than other herbicides (Table 5.3).

Horsenettle Control. In 2013, the main effect of herbicide choice was significant for horsenettle control; therefore, treatments were averaged over herbicide rates and rating dates (Table 5.5). Over the course of 27 weeks, horsenettle control ranged from 65 to 95% with imazapyr (86%) and aminopyralid (95%) providing superior control than most herbicides tested (Table 5.5).

Pitted Morningglory and Horseweed Control. The interaction of herbicide choice by herbicide rate was significant for pitted morningglory control in 2012 and horseweed control in 2013; hence, treatment means were averaged across rating dates for both weeds (Table 5.6). In 2012, no treatment provided ≥ 81% pitted morningglory control. Diuron at 11,200 and 13,400 g ha^{-1} provided marginal to moderate control of pitted morningglory throughout the season with 75 and 81% control, respectively; however, control was comparable to that provided by fluridone at 2,240 g ha^{-1} (63%), diuron at 8,960 g ha^{-1} (64%), and aminopyralid (63%).

In 2013, good control of horseweed was observed, with most treatments providing > 80% control throughout the season (Table 5.6). However, fluridone at 1,120 g ha^{-1} and diuron at 4,480 g ha^{-1} failed to provide comparable control to the other herbicide treatments tested. The high level of control throughout the 2013 season is likely attributed to greater initial control of emerged horseweed seedlings and a lack of subsequent emergence since most emergence occurs during the fall and spring months.

Practical Implications

In general, utilizing soil-residual herbicides to control problematic weeds along field margins is highly beneficial as long as sufficient levels of grass groundcover are present to reduce soil erosion and weed seedling emergence; however, season-long control of these weeds is unlikely from any residual herbicide. When applied PPI and followed by favorable environmental conditions, sequential applications of fluridone have the potential to provide 12 weeks of moderate to effective Palmer amaranth control. However, fluridone did not provide significantly greater control of Palmer amaranth than the current labeled diuron standard. At current prices, diuron would be the cheaper of the two options. Although fluridone will not be a stand-alone residual herbicide for season-long control, it does have a unique mechanism of action that is not commonly used in Arkansas. More emphasis should be placed on integrating aminopyralid and saflufenacil into ditchbank weed control programs based on the performance of these herbicides on Palmer amaranth and the fact that their potential to negatively affect soil erosion is likely least among the herbicides tested.

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Table 5.1. Palmer amaranth and pitted morningglory control following preplant incorporated and postemergence applications of fluridone versus diuron at Fayetteville, AR in 2012 and 2013. [a,b]

			Control							
			2012				2013			
			Palmer amaranth		Pitted morningglory		Palmer amaranth		Pitted morningglory	
Treatment	Rate	Timing	6 WAIA	6 WAFA	6 WAIA	6 WAFA	6 WAIA	6 WAFA	6 WAIA	6 WAFA
	g ai ha^{-1}		%							
Fluridone	224	PPI								
Fluridone	224	6 WAIA	51 a	0	91 a	0	88 a	88 a	63 b	68 b
Fluridone	448	PPI	73 a	0	85 a	0	90 a	93 a	68 b	74 ab
Fluridone	336	PPI								
Fluridone	336	6 WAIA	56 a	0	75 b	0	83 b	90 a	60 b	68 b
Fluridone	673	PPI	68 a	0	66 b	0	97 a	98 a	91 a	87 a
Diuron	1,120	PPI			a					
Diuron	1,120	6 WAIA	54 a	0	79 b	0	81 b	82 a	44 c	45 c
Diuron	2,240	PPI	60 a	0	84 a	0	87 a	88 a	74 b	45 c

[a] Abbreviations: preplant incorporated (PPI); weeks after initial application (WAIA); weeks after final application (WAFA).

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

Table 5.2. Johnsongrass control following preplant incorporated and postemergence applications of fluridone versus diuron at Fayetteville, AR in 2012 and 2013. [a,b]

			Control			
			2012		2013	
Treatment	Rate	Timing	6 WAIA	6 WAFA	6 WAIA	6 WAFA
	g ai ha^{-1}		%			
Fluridone	224	PPI				
Fluridone	224	6 WAIA	79 b	0	48 c	25 d
Fluridone	448	PPI	85 b	0	75 b	59 b
Fluridone	336	PPI				
Fluridone	336	6 WAIA	98 a	0	60 b	46 b
Fluridone	673	PPI	96 a	0	92 a	79 a
Diuron	1,120	PPI				
Diuron	1,120	6 WAIA	96 a	0	13 d	31 c
Diuron	2,240	PPI	91 a	0	47 c	38 c

[a] Abbreviations: preplant incorporated (PPI); weeks after initial application (WAIA); weeks after final application (WAFA).

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

Table 5.3. Percent grass groundcover following preemergence applications of fluridone versus standard ditchbank herbicides at Keiser, AR in 2012 and 2013. [a,b]

Treatment	Grass groundcover	
	2012	2013
	--------------------------------- %	----------------------------------
Fluridone [c]	22 b	37 b
Diuron [c]	8 c	33 b
Imazapyr [c]	19 b	50 a
Aminopyralid	64 a	66 a
Indaziflam	43 a	40 ab
Saflufenacil	54 a	64 a

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

[b] Percent grass groundcover was only evaluated at 27 WAA in 2012 and 2013.

[c] Multiples rates of fluridone (1,120 and 2,240 g ha^{-1}), diuron (2,240, 4,480, 6,720, 8,960, 11,200, and 13,400 g ha^{-1}), and imazapyr (210, 420, and 700 g ha^{-1}) were included in the analysis. Individual rates of herbicides were not statistically different based on the ANOVA F-test (0.05), means within a column are averaged across herbicide rates

Table 5.4. Palmer amaranth and barnyardgrass control following preemergence applications of fluridone versus standard ditchbank herbicides at Keiser, AR in 2012 and 2013. [a.b]

	Control			
	2012		2013	
Treatment	Palmer amaranth	Barnyardgrass	Palmer amaranth	Barnyardgrass
	%			
Fluridone [c]	74 a	62 b	68 b	81 a
Diuron [c]	79 a	85 a	79 ab	70 a
Imazapyr [c]	53 b	82 a	67 b	56 b
Aminopyralid	72 a	51 b	95 a	59 ab
Indaziflam	74 a	84 a	80 ab	84 a
Saflufenacil	80 a	42 c	97 a	65 ab

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

[b] As a repeated measures, no statistical differences were observed between evaluation times (weeks) based on the ANOVA F-test (0.05). Means within a column are averaged across three evaluations in 2012 [11 weeks after application (WAA), 16 WAA, and 27 WAA] and 2013 (15 WAA, 22 WAA, and 27 WAA).

[c] Multiples rates of fluridone (1,120 and 2,240 g ha^{-1}), diuron (2,240, 4,480, 6,720, 8,960, 11,200, and 13,400 g ha^{-1}), and imazapyr (210, 420, and 700 g ha^{-1}) were included in the analysis. Individual rates of herbicides were not statistically different based on the ANOVA F-test (0.05), means within a column are averaged across herbicide rates.

Table 5.5. Horsenettle control following preemergence applications of fluridone versus standard ditchbank herbicides at Keiser, AR in 2013. [a,b]

Treatment	Control
	%
Fluridone [c]	65 b
Diuron [c]	72 b
Imazapyr [c]	86 a
Aminopyralid	95 a
Indaziflam	68 b
Saflufenacil	75 ab

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

[b] As a repeated measures, no statistical differences were observed between evaluation times (weeks) based on the ANOVA F-test (0.05). Means within a column are averaged across three evaluations in 2012 [11 weeks after application (WAA), 16 WAA, and 27 WAA] and 2013 (15 WAA, 22 WAA, and 27 WAA).

[c] Multiples rates of fluridone (1,120 and 2,240 g ha^{-1}), diuron (2,240, 4,480, 6,720, 8,960, 11,200, and 13,400 g ha^{-1}), and imazapyr (210, 420, and 700 g ha^{-1}) were included in the analysis. Individual rates of herbicides were not statistically different based on the ANOVA F-test (0.05), means within a column are averaged across herbicide rates.

Table 5.6. Pitted morningglory and horseweed control following preemergence applications of fluridone versus standard ditchbank herbicides at Keiser, AR in 2012 and 2013. [a,b]

		Control			
		2012		2013	
Treatment	Rate	Pitted morningglory		Horseweed	
	g ai ha^{-1}	%			
Fluridone	1,120	41	bc	38	c
Fluridone	2,240	63	ab	83	a
Diuron	2,240	44	bc	82	a
Diuron	4,480	30	c	65	b
Diuron	6,720	61	b	83	a
Diuron	8,960	64	ab	93	a
Diuron	11,200	75	a	93	a
Diuron	13,440	81	a	78	a
Imazapyr	210	43	bc	96	a
Imazapyr	420	63	ab	91	a
Imazapyr	700	43	bc	85	a
Aminopyralid	120	63	ab	99	a
Indaziflam	95	58	b	83	a
Saflufenacil	150	48	bc	88	a

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

[b] As a repeated measures, no statistical differences were observed between evaluation times (weeks) based on the ANOVA F-test (0.05). Means within a column are averaged across three evaluations in 2012 [11 weeks after application (WAA), 16 WAA, and 27 WAA] and 2013 (15 WAA, 22 WAA, and 27 WAA).

Figure 5.1. Rainfall amounts at Fayetteville, AR in 2012 and 2013. Abbreviations: preplant incorporated (PPI); weeks after initial application (WAIA). Arrows indicate the time of application. [a]

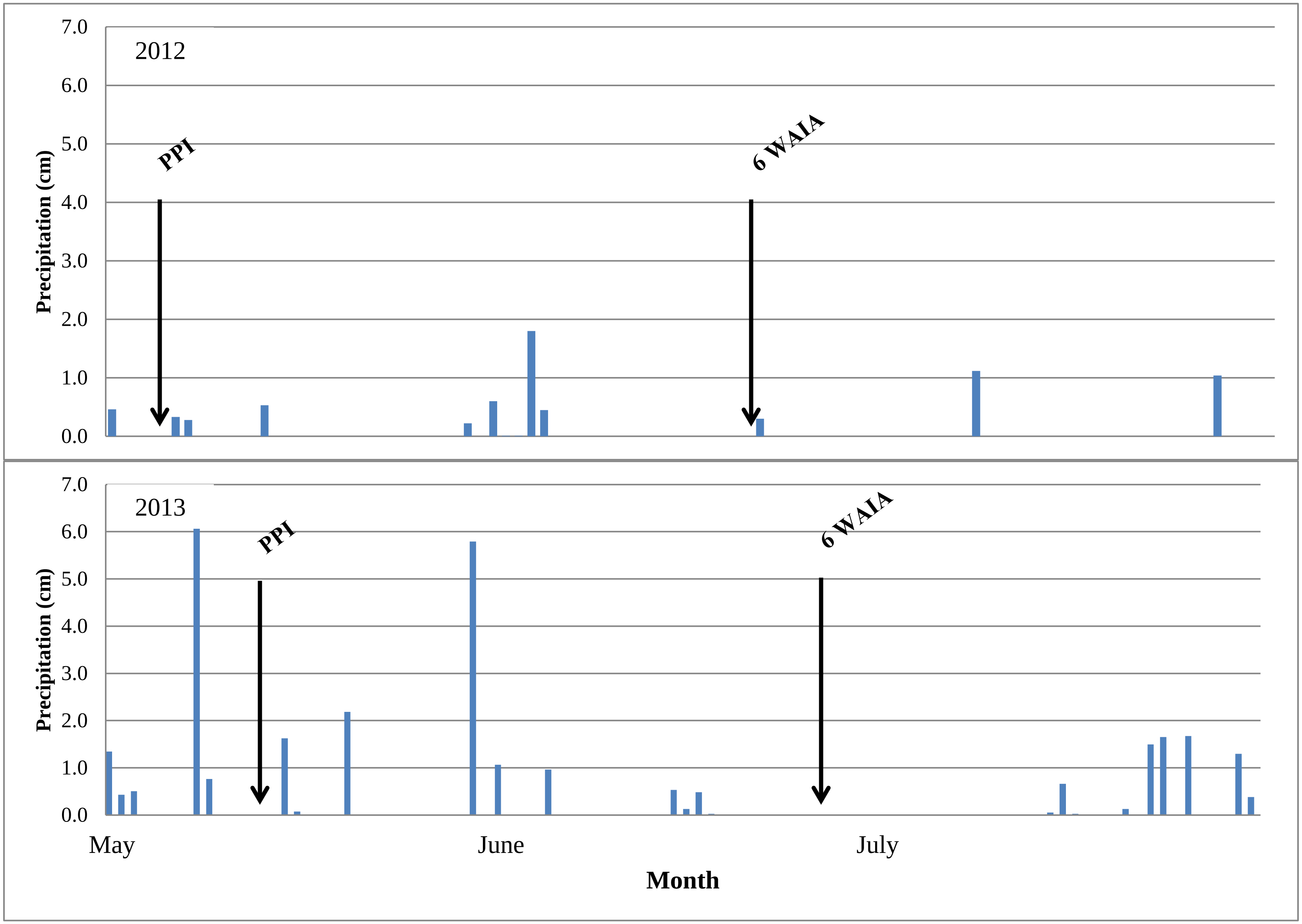
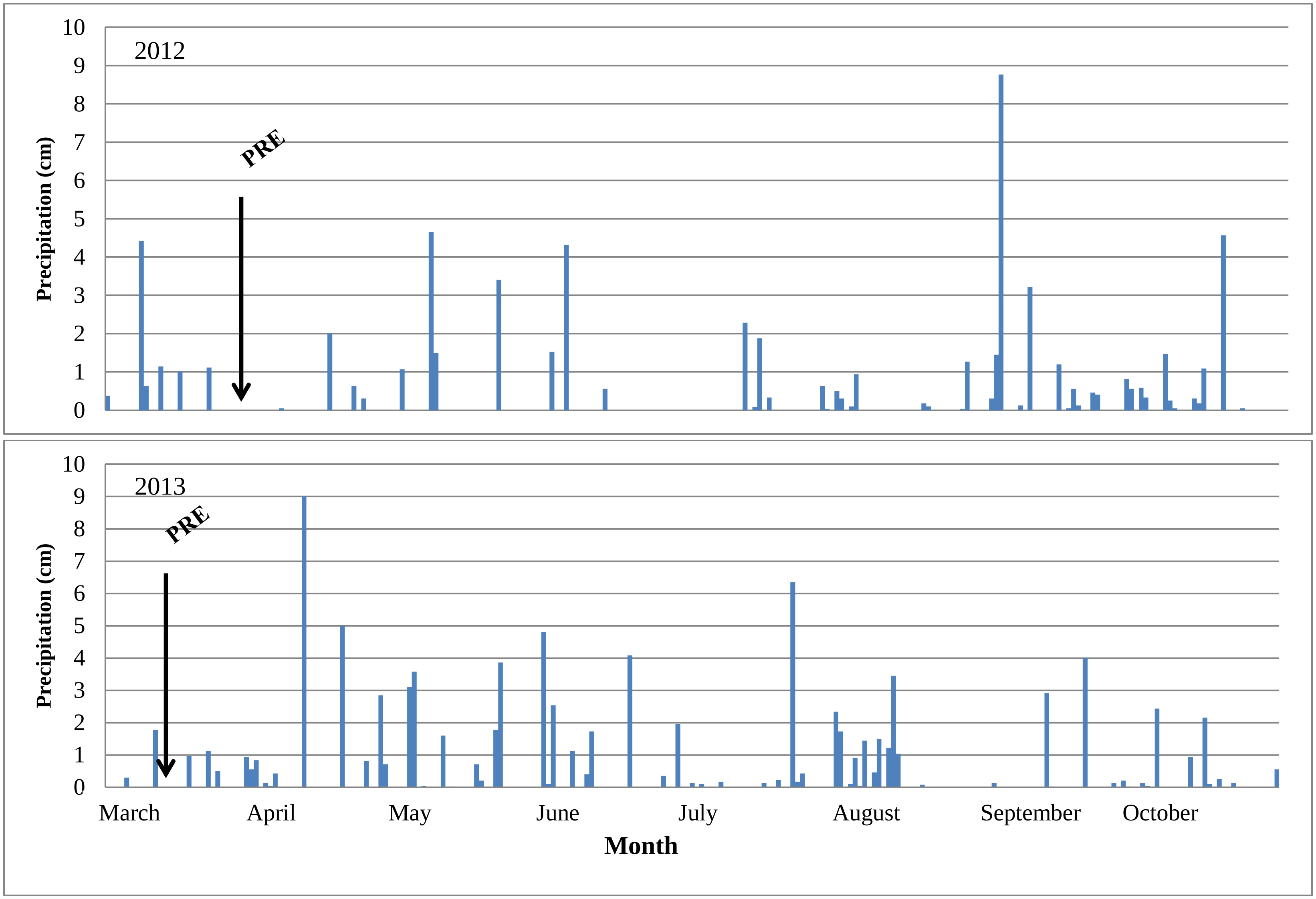


Figure 5.2. Rainfall amounts at Keiser, AR in 2012 and 2013. Abbreviations: preemergence (PRE). Arrows indicate the time of application. [a]



Chapter VI

Conclusions

In terms of weed control, this research suggests that fluridone has the potential to effectively control Palmer amaranth and other agronomic weeds for 6 weeks after application. However, adequate rainfall, which is likely 2.5 cm, is required to ensure that fluridone is activated in the soil within two weeks after application. Since season-long control of Palmer amaranth is not feasible, integrating fluridone as the preemergence foundation of our current cotton weed management programs could provide comparable if not greater control than that of fluometuron, our current standard. Additionally, the use of fluridone incorporates a unique herbicide mechanism of action, which reduces the chance of weeds evolving resistance to currently effective herbicides. Unfortunately however, fluridone will not provide season-long control of Palmer amaranth along field margins comparable to that of other herbicides labeled for this use pattern, and its use can be detrimental to some grasses that aid in reducing erosion along ditchbanks.

Previous concerns with labeling fluridone were the risks of injury to crops commonly rotated with cotton. This research suggests that the likelihood of fluridone to cause significant injury to most rotational crops is minimal, except for wheat due to it being planted in closer proximity to the fluridone application in cotton. However, injury to wheat is transient and no reductions in wheat yields were observed in this research.

In conclusion, producers should continue to utilize a herbicide program involving mechanisms of action to properly manage glyphosate-resistant Palmer amaranth. In doing so, the addition of fluridone to the current herbicide program in cotton could be highly efficacious when applied under favorable environmental conditions; albeit, comparable to current standards. Furthermore, the unique mechanism of action of fluridone could decrease the likelihood of weeds evolving resistance to currently effective residual herbicides, which in turn reduces the spread of herbicide-resistant weeds when properly managed.