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# WEED SCIENCE

## Fluridone Carryover to Rotational Crops Following Application to Cotton

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### ABSTRACT

**There has been renewed interest in using fluridone herbicide to aid in control of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri* S. Watson) in cotton (*Gossypium hirsutum* L.). Section 18 Emergency Use Exemptions for fluridone in cotton have been granted recently in several states and the manufacturer is pursuing federal registration. Fluridone has long persistence in soil, leading to questions about rotational crop response. Field experiments were conducted in North Carolina to evaluate the potential for fluridone to carry over to corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.), grain sorghum [*Sorghum bicolor* (L.) Moench.], and soybean [*Glycine max* (L.) Merr.] grown in rotation with fluridone-treated cotton. Fluridone at 0, 280, 420, 560, 840, and 1120 g ai ha$^{-1}$ was applied preemergence to cotton and rotational crops were planted the following spring. The fluridone rates were well above proposed use rates. Only minor visible injury to cotton was observed and cotton yield was unaffected by fluridone. Fluridone also caused only minor visible injury to rotational crops and did not affect stands, early season height, or yield of rotational crops.**

Palmer amaranth (*Amaranthus palmeri* S. Watson) resistant to glyphosate and acetolactate synthase (ALS)-inhibiting herbicides is a widespread problem in cotton (*Gossypium hirsutum* L.) and other crops across the southern U.S. (Culpepper et al., 2006, 2010; Heap, 2015; Nandula et al., 2012; Poirier et al., 2014; Sosnoskie et al., 2011; Webster, 2013). Weed scientists encourage the use of residual herbicides in cotton weed management programs to aid in control of this and other herbicide-resistant species (Burgos et al., 2006; Culpepper, 2015; Marshall, 2015; Scott and Smith, 2011; Steckel, 2015; York, 2015). There are a limited number of herbicide modes of action available to control glyphosate- and ALS-resistant Palmer amaranth in cotton. Palmer amaranth can be controlled in systems utilizing glufosinate and protoporphyrinogen oxidase (PPO)-inhibiting herbicides such as flumioxazin and fomesafen (Everman et al., 2009; Gardner et al., 2006; Whitaker et al., 2011a,b), and growers are relying on these chemistries for Palmer amaranth management (Sosnoskie and Culpepper, 2014). This has led to concerns about the potential to select for resistance to these herbicides (Cahoon et al., 2014; Sosnoskie et al., 2011; York, 2015). Additional herbicide modes of action are needed to increase diversity in weed management programs to delay or avoid future herbicide-resistance evolution (Norsworthy et al., 2012).

Fluridone was evaluated for weed control in cotton in the 1970s. It was found to control a number of weeds and cotton tolerance was good (Albritton and Parka, 1978; Banks and Merkle, 1979a; Miller and Carter, 1983; Waldrep and Taylor, 1976; Webster et al., 1977). Miller and Carter (1983) reported fluridone had no effect on cotton emergence or stand. Similarly, Banks and Merkle (1979a) observed 4% or less cotton injury by fluridone applied preemergence (PRE). However, the cost of fluridone (Hill, 2015) and potential carryover to corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.), rice (*Oryza sativa* L.), grain sorghum [*Sorghum bicolor* (L.) Moench.], soybean [*Glycine max* (L.) Merr.], sunflower (*Helianthus annuus* L.), tomato (*Solanum lycopersicum* L.), and wheat (*Triticum aestivum* L.) were early concerns (Albritton and Parka, 1978; Banks et al., 1979; Crutchfield et al., 1980; Savage, 1978; Shea and Weber, 1980). Therefore, development for use in cotton was discontinued. Fluridone was subsequently developed for aquatic weed management and commonly is used to control hydrilla [*Hydrilla verticillata* (L. f.) Royle] and other aquatic weeds (Arnold, 1979; Fox et al., 1994; Koschnick et al., 2003).

There has been renewed interest in using fluridone on cotton, primarily to aid in the management of

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glyphosate-resistant (GR) Palmer amaranth. Recent research has demonstrated good residual control of Palmer amaranth by fluridone (Braswell et al., 2014; Crow et al., 2014; Hill et al., 2014a; Marshall, 2014; Meier et al., 2014), and Section 18 Emergency Use Exemptions for use of fluridone, premixed with fomesafen, were granted in the states of Georgia, North Carolina, South Carolina, and Tennessee in 2014 (USEPA-OPP, 2015). To achieve adequate residual weed control, fluridone requires at least 1.3 cm of rainfall for activation (Anonymous, 2014). Marshall et al. (2013) reported fluridone controlled Palmer amaranth at least 91% 8 wk after treatment. The Emergency Use Exemptions were justified on the basis of fluridone having a mode of action not currently in use. Fluridone, a Group 12 herbicide (Mallory-Smith and Retzinger, 2003), inhibits phytoene desaturase, an enzyme necessary in the biosynthesis of carotenoids (Bartels and Watson, 1978; Chamovitz et al., 1993; Kowalczyk-Schroder and Sandmann, 1992). With norflurazon no longer sold for cotton, no Group 12 herbicides currently are used on agronomic crops in the U.S.

The long persistence of fluridone (Banks et al., 1979a; Miller and Carter, 1983; Schroeder and Banks, 1986b; Sharp et al., 1982) and hence the potential for carryover to rotational crops, remains a concern. The objective of this study was to determine the response of corn, grain sorghum, peanut, and soybean to fluridone applied to a preceding cotton crop. Typically, these crops are grown in rotation with cotton in North Carolina. Corn and grain sorghum were of particular interest due to reports of sensitivity in previous research.

## MATERIALS AND METHODS

The experiment was conducted on the Peanut Belt Research Station near Lewiston, NC; the Upper Coastal Plains Research Station near Rocky Mount, NC; the SePRO Research and Technology Campus near Whitakers, NC; and a private farm near Mount Olive, NC. Soils are described in Table 1. At locations with more than one rotational crop, adjacent areas of the same field were used for all crops. Cotton was planted in the first year of the 2-yr experiments; cultivars and planting dates are in Table 2. Aldicarb insecticide (Temik® 15G, Bayer CropScience, Research Triangle Park, NC) was applied at 840 g ai ha$^{-1}$ in the cotton seed furrow. Cotton was planted with conventional tillage in 2012 following a preplant incorporated (PPI) application of pendimethalin (Prowl H2O, BASF Corp., Research Triangle Park, NC) at 800 g ai ha$^{-1}$ at Lewiston or trifluralin (Treflan 4EC, Helena Chemical Co., Collierville, TN) at 560 g ai ha$^{-1}$ at Rocky Mount. Glyphosate potassium salt (Roundup PowerMax®, Monsanto Co., St. Louis, MO) at 1260 g ae ha$^{-1}$ was applied postemergence (POST) three times during the season to keep plots weed free. Cotton was planted no-till in 2013 following a preplant burndown application of glyphosate at 1260 g ha$^{-1}$ plus 2,4-D dimethyl amine salt (Weedar® 64, Nufarm Inc., Burr ridge, IL) at 532 g ae ha$^{-1}$ approximately 3 wk prior to planting. Acetochlor (Warrant®, Monsanto Co.) at 1260 g ai ha$^{-1}$ plus fomesafen sodium salt (Reflex®, Syngenta Crop Protection, Greensboro, NC) at 280 g ae ha$^{-1}$ were applied PRE to cotton in 2013 followed by glufosinate-ammonium (Liberty® 280 SL, Bayer CropScience) at 594 g ai ha$^{-1}$ applied POST twice.

**Table 1. Description of soils at experiment sites[z]**

| Locations and GPS coordinates | Years | Soil series[z] | Soil texture | Sand fraction | Soil pH[y] | Soil humic matter[y] |
|---|---|---|---|---|---|---|
| | | | | % | | % |
| Lewiston | 2012-2013 | Goldsboro | Loamy sand | 70 to 90 | 5.7 | 1.0 |
| 36.138° N, -77.182° W | | | | | | |
| Rocky Mount | 2012-2013 | Norfolk | Loamy sand | 70 to 90 | 5.3 | 0.5 |
| 35.902° N, -77.675° W | | | | | | |
| Whitakers | 2013-2014 | Rains | Fine sandy loam | 45 to 85 | 6.0 | 0.4 |
| 36.136° N, -77.731° W | | | | | | |
| Mount Olive | 2013-2014 | Lakeland | Sand | 85 to 100 | 5.6 | 0.5 |
| 35.203° N, -77.968° W | | | | | | |

[z] Goldsboro: fine-loamy, siliceous, thermic Aquic Paleudults; Norfolk: fine-loamy, kaolinitic, thermic Typic Kandiudults; Rains: fine-loamy, siliceous, thermic Paleaquults; Lakeland: thermic, coated Typic Quartzipsamments.

[y] Soils characterized by the Agronomic Services Division of the North Carolina Department of Agriculture and Consumer Services. Soil humic matter determined according to Mehlich (1984).

**Table 2. Cotton cultivars and planting dates in first year of experiments and rotational crops, planting dates, and tillage systems in second year of experiments**

| Location | Cotton, first year | | Rotational crop, second year | | |
|---|---|---|---|---|---|
| | Cultivar | Planting date | Crop | Planting date | Tillage system |
| Lewiston | DP 0912 B2RF[z] | 15 May 2012 | Corn[w] | 16 April 2013 | No-till |
| | | | Sorghum[u] | 14 May 2013 | No-till |
| | | | Peanut[v] | 14 May 2013 | Conventional |
| Rocky Mount | FM 1944GLB2[y] | 1 May 2012 | Soybean[t] | 3 June 2013 | No-till |
| Mount Olive | FM 1944GLB2 | 9 May 2013 | Sorghum[u] | 5 May 2014 | No-till |
| | | | Soybean[t] | 5 May 2014 | No-till |
| Whitakers | ST 4946GLB2[y] | 10 May 2013 | Corn[w] | 21 May 2014 | Conventional |
| | | | Sorghum[u] | 7 May 2014 | No-till |
| | | | Soybean[t] | 21 May 2014 | Conventional |

[z] Monsanto Co., St. Louis, MO.

[y] Bayer CropScience, Research Triangle Park, NC.

[w] Hybrid DKC68-03, Monsanto Co., St. Louis, MO.

[v] Cultivar Bailey, North Carolina Crop Improvement Association, Raleigh, NC.

[u] Hybrid 83P17, Pioneer Hi-Bred International, Johnston, IA. Seed treated with fluxofenin (Concep III, Syngenta Crop Protection, Greensboro, NC) seed protectant.

[t] Cultivar AG5831, Monsanto Co., St. Louis, MO.

In addition to the PPI and PRE herbicides mentioned above, fluridone (experimental formulation containing 240 g ai $L^{-1}$, SePRO Corp., Carmel, IN) was applied broadcast PRE to cotton at 0, 280, 420, 560, 840, and 1120 g ai $ha^{-1}$. According to the Section 18 Emergency Use Exemption in 2014, the use rate of fluridone was 224 g ai $ha^{-1}$ on coarse-textured soils (Anonymous, 2014). Fluridone was applied using a $CO_2$-pressurized backpack sprayer equipped with flat-fan nozzles (DG11002 TeeJet® Drift Guard flat-spray nozzles, TeeJet Technologies, Wheaton, IL) delivering 140 L $ha^{-1}$ at 165 kPa.

Four-row plots were used in all crops except the peanut rotation, where six-row plots were used. Plot lengths included 21, 18, 18, and 15 m at Lewiston, Rocky Mount, Whitakers, and Mount Olive, respectively. Row spacing was 91 cm at Lewiston and Rocky Mount and 97 cm at Whitakers and Mount Olive. In the second year of the experiment, plots were shortened by 4 m (2 m off each end).

Rotational crops were planted in the second year of experiments at locations and dates shown in Table 2. Peanut was planted with conventional tillage, whereas corn, grain sorghum, and soybean were planted no-till in 2013. Phorate insecticide (Thimet® 20G, AMVAC, Los Angeles, CA) was applied at 1120 g ai $ha^{-1}$ in the peanut seed furrow. Corn, grain sorghum, and soybean seed were treated with ipconazole plus metalaxyl plus trifloxystrobin plus clothianidin (Acceleron® corn insecticide/fungicide seed treatment, Monsanto Co.), clothianidin (Poncho® insecticide seed treatment, Bayer CropScience), and pyraclostrobin plus metalaxyl plus imidacloprid (Acceleron® soybean insecticide/fungicide seed treatment, Monsanto Co.), respectively. Corn and soybean at Whitakers in 2014 were initially planted no-till on 7 May but stands were marginal and the plots were lightly disked and replanted on 21 May. Sorghum at Mount Olive and Whitakers and soybean at Mount Olive were planted no-till. Where conventional tillage was performed, the land was disked in the same direction as the cotton rows to minimize lateral plot-to-plot soil movement. Herbicides used on rotational crops are listed in Table 3. Rotational crops were hand-weeded as necessary to remove escaped weeds.

Cotton injury was estimated visually at 3, 6, and 12 wk after planting (WAP) using a scale of 0 to 100, with 0 = no injury and 100 = complete crop death. Injury ratings consisted of chlorosis, necrosis, and growth reduction recorded separately. The center two rows of each plot were mechanically harvested in mid-October to mid-November to determine seed cotton yield. Rotational crop response to fluridone was estimated visually at 2, 4, and 8 WAP. Chlorosis, necrosis, and growth reduction were recorded separately for rotational crops. Rotational crop stands and plant heights were recorded 2 and 4 WAP, respectively. The two center rows of corn, sorghum, and soybean were harvested mechanically and yields adjusted to standard moisture contents of 15.5, 13.0, and 13.0%, respectively. Peanut was mechanically dug and allowed to dry in the field for 5 d. Pods from the center two rows of each plot were mechanically harvested and dried with conventional drying equipment. Yield was adjusted to 7% moisture. Data were subjected to analysis of variance using the PROC GLIMMIX procedure of SAS (version 9.3; SAS Institute Inc., Cary, NC). Herbicide treatments and locations were fixed factors, whereas replications were treated as random. The non-treated checks were excluded from the analysis for crop injury. Means were separated according to Fisher's Protected LSD test at $p = 0.05$. Predictive regression equations for cotton injury were determined using PROC REG of SAS (version 9.3; SAS Institute Inc., Cary, NC).

**Table 3. Herbicides used and rate and time of application in rotational crops**

| Crop | Location | Herbicides | Trade names[z] | Application method[y] | Application rate[x] | Time of application[y] |
|---|---|---|---|---|---|---|
| | | | | | | WAP |
| Corn | Lewiston | alachlor + atrazine | Lariat® | PRE | 460 + 275 | 0 |
| | | glyphosate potassium salt | Roundup PowerMAX® | PRE | [1260] | 0 |
| | | glyphosate potassium salt | Roundup PowerMAX® | POST | [1260] | 2 |
| | | glyphosate potassium salt | Roundup PowerMAX® | POST | [1260] | 4 |
| | Whitakers | acetochlor | Warrant® | PRE | 1260 | 0 |
| | | glyphosate potassium salt | Roundup PowerMAX® | POST | [1260] | 4 |
| Peanut | Lewiston | *S*-metolachlor | Dual II Magnum® | PRE | 1604 | 0 |
| | | bentazon sodium salt | Basagran® | POST | [840] | 7 |
| | | acifluorfen sodium salt | Ultra Blazer® | POST | [280] | 7 |
| Sorghum | Lewiston | *S*-metolachlor + atrazine | Bicep II Magnum® | PRE | 1562 + 1210 | 0 |
| | | glyphosate potassium salt | Roundup PowerMAX® | PRE | [1260] | 0 |
| | Mount olive | paraquat dichloride | Parazone® | PRE | 840 | 0 |
| | | *S*-metolachlor + atrazine | Bicep II Magnum® | PRE | 1389 + 1075 | 0 |
| | Whitakers | paraquat dichloride | Parazone® | PRE | 840 | 0 |
| | | *S*-metolachlor + atrazine | Bicep II Magnum® | PRE | 1562 + 1210 | 0 |
| Soybean | Mount Olive | paraquat dichloride | Parazone® | PRE | 840 | 0 |
| | | S-metolachlor + | Prefix® | PRE | 1215 + | 0 |
| | | fomesafen sodium salt | | | [266] | |
| | | glyphosate potassium salt | Roundup PowerMAX® | POST | [1260] | 3 |
| | | cloransulam-methyl | FirstRate® | POST | 18 | 3 |
| | | glyphosate potassium salt | Roundup PowerMAX® | POST | [1260] | 6 |
| | | acetochlor | Warrant® | POST | 1260 | 6 |
| | Rocky Mount | *S*-metolachlor + | Prefix® | PRE | 1215 + | 0 |
| | | fomesafen sodium salt | | | [266] | |
| | | glyphosate potassium salt | Roundup PowerMAX® | POST | [1260] | 4 |
| | | fomesafen sodium salt | Reflex® | POST | 280 | 4 |
| | Whitakers | glyphosate potassium salt | Roundup PowerMAX® | PRE | [1260] | 0 |
| | | acetochlor | Warrant® | PRE | 1260 | 0 |
| | | glyphosate potassium salt | Roundup PowerMAX® | POST | [1260] | 4 |

[z] Sources of products: Lariat®, Roundup PowerMAX®, and Warrant® from Monsanto Co., St. Louis, MO; Bicep II Magnum®,Dual II Magnum®, Prefix®, and Reflex® from Syngenta Crop Protection, Greensboro, NC; Basagran® from Arysta LifeScience North America, Cary, NC; Ultra Blazer® from United Phosphorus, King of Prussia, PA; FirstRate® from Dow AgroSciences, Indianapolis, IN.

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

[x] Application rates enclosed in brackets [ ] expressed as g ae $ha^{-1}$; rates not enclosed in brackets expressed as g ai $ha^{-1}$.

## RESULTS AND DISCUSSION

**Cotton Tolerance of Fluridone.** Data for cotton injury and yield were averaged over locations as the location by fluridone rate interaction was not significant. Similar to previous reports (Banks and Merkle, 1979a; Meier et al., 2014; Miller and Carter, 1983; Waldrep and Taylor, 1976), cotton was tolerant of fluridone. Under the Section 18 Emergency Use Exemption in 2014, fluridone was used at 224 g ha$^{-1}$ in combination with 140 g ha$^{-1}$ of fomesafen on coarse-textured soils (Anonymous, 2014). Fluridone rates in our experiments were considerably greater (280, 420, 560, 840, and 1120 g ai ha$^{-1}$) and yet cotton injury was relatively minor (Table 4). Fluridone at 280 g ha$^{-1}$ reduced cotton growth 3% at 3 WAP and caused little to no chlorosis or necrosis. Injury increased as the fluridone rate increased. Linear regressions of nontransformed data were the best predictors of cotton injury 3 WAP (regression equations in Table 5). At the highest application rate, 1120 g ha$^{-1}$, fluridone caused only 10% growth reduction, 15% chlorosis, and 3% necrosis 3 WAP (Table 4). By 6 WAP, cotton had recovered from most of that injury. No injury was observed 12 WAP (data not shown), and lint yield was unaffected. Averaged over locations and treatments, cotton yielded 1445 kg ha$^{-1}$. Banks and Merkle (1979a) observed 7 to 13% cotton injury 30 d after application of fluridone at 900 g ha$^{-1}$ to sandy loam and clay soils but cotton yield was not adversely impacted.

**Rotational Crop Response to Fluridone.** A location-by-fluridone rate interaction was not observed for any variable recorded, hence data for each rotational crop were averaged over locations.

Little to no visible injury was observed on any rotational crop. Growth reduction 2 WAP was 3% or less on corn, peanut, and soybean, and 8% or less on sorghum (data not shown). Chlorosis was 2% or less on soybean and 5% or less on sorghum. No chlorosis was noted on corn and peanut, and no necrosis was noted on any rotational crop. No injury was noted on any rotational crop 4 or 8 WAP (data not shown). Our results are similar to those of Hill et al. (2014b) who reported 12% or less injury to corn, grain sorghum, rice, soybean, and sunflower planted the year following application of 896 g ha$^{-1}$ of fluridone to a silt loam soil in Arkansas.

Fluridone applied the preceding year also had no effect on rotational crop stands, early season height, or yield (Table 6). Averaged over fluridone rates, corn, peanut, sorghum, and soybean yielded approximately 8980, 5200, 5000, and 3060 kg ha$^{-1}$ respectively, in these experiments.

**Table 4. Cotton injury and lint yield following fluridone applied preemergence[z]**

| Fluridone rate g ha$^{-1}$ | Cotton injury: Growth reduction 3 WAP[y] | Growth reduction 6 WAP | Chlorosis 3 WAP | Chlorosis 6 WAP | Necrosis 3 WAP | Necrosis 6 WAP | Lint yield |
|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | kg ha$^{-1}$ |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1440 a |
| 280 | 3 c | 3 a | 1 e | 0 b | 0 d | 0 a | 1460 a |
| 420 | 5 b | 4 a | 3 d | 0 b | 0 d | 0 a | 1410 a |
| 560 | 6 b | 5 a | 5 c | 2 a | 1 c | 0 a | 1430 a |
| 840 | 9 a | 6 a | 10 b | 4 a | 2 b | 0 a | 1440 a |
| 1120 | 10 a | 6 a | 15 a | 4 a | 3 a | 0 a | 1490 a |

[z] Means within a column followed by the same letter are not different according to Fisher's Protected LSD test at $p = 0.05$.
[y] Abbreviations: WAP, wk after planting.

**Table 5. Predictive regression equations for cotton injury caused by fluridone 3 wk after cotton planting[z]**

| Injury parameter | Regression equation[y] | $R^2$ | *p* value |
|---|---|---|---|
| Growth reduction | $Y = 0.0083x + 0.63$ | 0.13 | <0.0001 |
| Chlorosis | $Y = 0.016x – 4.71$ | 0.32 | <0.0001 |
| Necrosis | $Y = 0.0029x – 0.89$ | 0.11 | <0.0001 |

[z] Fluridone was applied immediately following cotton planting at 280, 420, 560, 840, and 1120 g ha$^{-1}$.
[y] Y = percent cotton injury; x = fluridone rate.

**Table 6. Rotational crop response to fluridone applied to a preceding cotton crop[z]**

| Fluridone rate | Plant stand[y] | | | | Plant height[x] | | | | Yield | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Corn | Peanut | Sorghum | Soybean | Corn | Peanut | Sorghum | Soybean | Corn | Peanut | Sorghum | Soybean |
| g ha$^{-1}$ | plants ha$^{-1}$ | | | | cm | | | | kg ha$^{-1}$ | | | |
| 0 | 21 | 37 | 61 | 56 | 43 | 11 | 34 | 13 | 8750 | 5430 | 4790 | 3160 |
| 280 | 21 | 35 | 60 | 57 | 43 | 10 | 33 | 14 | 8900 | 5290 | 5240 | 3070 |
| 420 | 20 | 37 | 57 | 58 | 41 | 10 | 33 | 13 | 8830 | 5190 | 4710 | 3010 |
| 560 | 20 | 37 | 59 | 57 | 39 | 10 | 33 | 13 | 8670 | 4950 | 4940 | 3090 |
| 840 | 20 | 35 | 62 | 55 | 41 | 10 | 32 | 14 | 9360 | 5150 | 5090 | 2960 |
| 1120 | 21 | 37 | 61 | 58 | 45 | 10 | 35 | 14 | 9370 | 5160 | 5210 | 3050 |

[z] Means within the same column are not different according to Fisher's Protected LSD test at $p = 0.05$. Data averaged over two locations for corn and three locations for sorghum and soybean. Injury data for non-treated control were excluded from means separation analysis.

[y] Stand recorded 2 wk after rotational crop planting.

[x] Height recorded 4 wk after rotational crop planting.

Lack of injury to peanut was not surprising. Based upon a growth chamber experiment, Banks and Merkle (1979c) found the concentration of fluridone necessary to reduce chlorophyll content in peanut was 65% of the concentration necessary for the same response in cotton. Albritton and Parka (1978) found no injury to cotton and less than 30% injury to peanut grown in soil receiving 400 g ha$^{-1}$ of fluridone. Jordan et al. (2014) reported 10% or less injury from fluridone applied PRE to peanut at 168 g ha$^{-1}$ in North Carolina. Collins et al. (1980) stated that fluridone applied PPI or PRE at rates up to 670 g ha$^{-1}$ produced little phytotoxicity to peanut in Alabama. Soybean has been considered to be susceptible to fluridone (Albritton and Parka, 1978). Savage (1978) and Shea and Weber (1980) reported soybean phytotoxicity 100 to 130 d and 63 d, respectively, after field application of fluridone. Sharp et al. (1982) noted 54 to 63% injury to soybean planted 29 d after application of 340 g ha$^{-1}$ of fluridone on a silt loam soil. Recent research by the fluridone manufacturer (Kyle Briscoe, SePRO Corporation, personal communication) has indicated 27% or less injury by fluridone plus fomesafen applied PRE to soybean at 224 plus 280 g ha$^{-1}$ on sandy loam soils in North Carolina. However, the only published research focusing on soybean planted the year following fluridone application did not show any carryover in coarse-textured soils of the southeastern U.S. (Webster et al., 1977).

Corn and sorghum are more sensitive to fluridone than peanut or soybean (Albritton and Parka, 1978; Banks and Merkle, 1979c), and most of the reports of fluridone carryover have been with sorghum in western states. Miller and Carter (1983) observed 96% growth reduction of sorghum planted 8 mo after application of fluridone at 300 g ha$^{-1}$ in California. Banks and Merkle (1979a) reported 60 to 70% injury and 56 to 89% injury to sorghum planted 1 yr after application of fluridone at 900 g ha$^{-1}$ on a clay soil and a sandy loam soil, respectively, in Texas. Crutchfield et al. (1980) observed carryover to sorghum 36 mo after application of 400 to 600 g ha$^{-1}$ applied to a clay loam soil in West Texas. In contrast, Keeling and Abernathy (1983) reported no injury to sorghum planted 13 mo after 1120 g ha$^{-1}$ of fluridone applied to a sandy clay loam soil in West Texas. Using sorghum as a bioassay species, Schroeder and Banks (1986a) found that fluridone at 1700 g ha$^{-1}$ applied to loamy sand, sandy loam, or clay loam soils in Georgia persisted less than 1 yr.

Photolysis is thought to be the primary mechanism of fluridone degradation in water (Muir and Grift, 1982; Saunders and Mosier, 1983). In field soil, however, dissipation appears to be biologically mediated (Banks et al., 1979; Schroeder and Banks, 1986b), and Malik and Drennan (1990) reported more rapid dissipation in moist soil under laboratory conditions. Fluridone is not very mobile in soil (Banks and Merkle, 1979b); hence rainfall during the summer months likely has a greater effect on dissipation than rainfall during winter months. In our experiments, rainfall during the first 150 d after fluridone application (basically early May through late September) was 31% above normal at Rocky Mount but within 8% or less of normal at the other three locations (Table 7). However, rainfall varied during the summer months. Lewiston was drier than normal during the first 60 d after application and wetter than normal during the second 60-d period. The reverse was observed at Mount Olive and Whitakers. Rainfall at Rocky Mount was well above normal during the first 30 d and from 61 to 120 d but less than normal during 31 to 60 d after application. Persistence cannot be correlated with rainfall because there was little to no carryover at any location.

**Table 7. Precipitation at experiment sites**

| Days after fluridone application | Rainfall received | | | | Deviation from normal rainfall[z] | | | |
|---|---|---|---|---|---|---|---|---|
| | Lewiston | Mount Olive | Rocky Mount | Whitakers | Lewiston[y] | Mount Olive[x] | Rocky Mount[y] | Whitakers[w] |
| | cm | | | | % | | | |
| 0-30 | 9.0 | 13.7 | 17.6 | 15.7 | - 10 | + 46 | + 91 | + 59 |
| 31-60 | 7.6 | 18.5 | 5.7 | 16.4 | - 34 | + 70 | - 40 | + 74 |
| 61-90 | 21.2 | 11.7 | 17.9 | 7.5 | + 64 | - 14 | + 64 | - 28 |
| 91-120 | 14.1 | 5.1 | 20.6 | 8.2 | + 13 | - 65 | + 76 | - 25 |
| 121-150 | 6.8 | 11.3 | 8.9 | 7.8 | - 40 | - 10 | - 29 | - 30 |
| 0-150 | 58.7 | 60.3 | 70.7 | 55.6 | + 1 | 0 | + 31 | + 8 |
| 151-180 | 9.6 | 7.4 | 6.3 | 9.1 | + 37 | + 3 | - 23 | + 17 |
| 181-270 | 23.0 | 31.8 | 18.5 | 23.8 | - 12 | + 14 | - 23 | - 11 |
| 271-360 | 20.9 | 36.7 | 23.1 | 26.5 | - 23 | + 25 | - 18 | - 5 |

[z] Normal precipitation is 30-yr average, recorded 1971 to 2000 by the State Climate Office of North Carolina, Raleigh, NC.

[y] Normal precipitation recorded on site.

[x] Normal precipitation recorded at Goldsboro, NC, 15 km from experiment site.

[w] Normal precipitation recorded at Enfield, NC, 7 km from experiment site.

The potential for fluridone to persist and injure rotational crops can be influenced by application method, soil texture, organic matter content, and soil pH. Previous research has shown that fluridone is sometimes more persistent when applied PPI compared with PRE application (Banks et al., 1979). Fluridone is a weak base (Weber, 1980). It is adsorbed to organic matter and clay, and adsorption is inversely related to soil pH (Shea and Weber, 1983). Weber et al. (1986) found that less fluridone was desorbed from soils incubated 28 d under hot, moist conditions than when incubated under cool, dry conditions, suggesting soil temperature and moisture could affect the amount of "biologically available" fluridone. In our experiments, fluridone was applied PRE to coarse-textured, low organic matter soils typical of cotton production in the southeastern U.S. The soil pH (Table 1) was below the optimum pH of 6.2 to 6.5 for cotton (Crozier and Hardy, 2015). Carryover might have been more likely to occur if our soil pH had been higher and the summer months were drier. However, the highest rate of fluridone in our experiments, 1120 g $ha^{-1}$, was five times greater than the rate suggested under the 2014 Section 18 Emergency Use Exemption (Anonymous, 2014), and little to no carryover was observed. In light of that, we conclude that fluridone applied at recommended use rates is unlikely to impact corn, grain sorghum, peanuts, or soybean grown as a rotational crop on the typical soils used for cotton production in North Carolina.

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