Weed Technology. 2004. Volume 18:310–314

Flumioxazin Preplant or POST-Directed Application Timing Followed by Irrigation at Emergence or After POST-Directed Spray Treatment Does Not Influence Cotton Yield[1]

ANDREW J. PRICE, JOHN W. WILCUT, and JOHN R. CRANMER[2]

Abstract: Three experiments were conducted in Lewiston, NC, from 1999 through 2002 to evaluate the influence of various application timings of flumioxazin preplant (PP) and postemergence-directed spray (PDS) on cotton injury. In experiment 1, flumioxazin was evaluated in a reduced-tillage system at 71, 105, or 140 g ai/ha in mixture with glyphosate, applied at 28, 14, or 7 d before planting (DBP), followed by irrigation at cotton emergence. Flumioxazin applied PP at any rate and irrigated at emergence injured cotton less than 7% at 2 wk after emergence (WAE) and less than 6% 5 WAE. In experiment 2, flumioxazin was evaluated in a conventional-tillage system at 71 or 105 g/ha as a PDS treatment applied to dry soil, wet soil, and dry soil irrigated immediately after application when cotton was 20 to 30 cm height. Cotton treated with flumioxazin PDS at either rate applied to dry soil, wet soil, or dry soil followed immediately by irrigation was not injured. In the third experiment, flumioxazin at 71 g/ha alone or in mixture with glyphosate at 1.12 g/ha was applied at 30, 21, 14, and 0 DBP in a conventional-tillage system. Flumioxazin applied alone or in mixture with glyphosate applied at any time did not injure cotton. In all experiments, cotton lint yields were not influenced by herbicide treatment.

Nomenclature: Flumioxazin; glyphosate; cotton, *Gossypium hirsutum* L., 'Deltapine 5415 RRBG', 'Paymaster 1218 RRBG', 'Suregrow 125'.

Additional index words: Burndown treatment, LAYBY treatment.

Abbreviations: COC, crop oil concentrate; DBP, days before planting; MSMA, monosodium salt of methylarsonic acid; NIS, nonionic surfactant; PDS, postemergence-directed spray; POST, postemergence; PP, preplant; PRE, preemergence; WAE, weeks after emergence.

INTRODUCTION

Common preplant (PP) burndown treatments used in cotton include paraquat and glyphosate (Brown and Whitwell 1985; Price and Wilcut 2002; White and Worsham 1990; York 1995). Both herbicides provide inexpensive winter cover burndown and broad-spectrum weed control (Wilcut et al. 1995). Unfortunately, neither herbicide effectively controls all weeds and does not provide residual weed control (Price and Wilcut 2002). Approximately 35 to 40% of North Carolina cotton hectarage does not receive soil-applied herbicide treatments at planting and reduced tillage production is increasing (A. C. York, personal communication). The exclusion of residual preemergence (PRE) herbicides at planting allows early-season weed interference which may be detrimental to cotton yield (Askew and Wilcut 1999; Buchanan and Burns 1970; Clewis et al. 2000; Culpepper and York 1998; Price and Wilcut 2002; Scott et al. 2001). A residual herbicide applied PP in mixture with nonselective herbicides like glyphosate or paraquat could allow flexibility of postemergence (POST) application timings while minimizing early-season weed competition (Price and Wilcut 2002).

Glyphosate-resistant cotton cultivars are planted on greater than 75% of the North Carolina cotton hectarage and similar percentages are planted in other cotton producing states (A. C. York and K. Edminsten, personal communication). Because glyphosate label restrictions do not allow over-the-top applications of glyphosate on greater than four-leaf cotton, most cotton growers in the southeast use POST-directed spray (PDS) applications (Anonymous 1999). At the time this research was initiated, the most common herbicides applied PDS in cotton

[1] Received for publication March 3, 2003, and in revised form June 30, 2003.

[2] Research Scientist, National Soil Dynamics Laboratory, Agriculture Research Service, United States Department of Agriculture, 411 South Donahue Drive, Auburn, AL 36832; Professor, Crop Science Department, P.O. Box 7620, North Carolina State University, Raleigh, NC 27695-7620; Field Market Development Scientist, Valent USA Corporation, Cary, NC 27511. Corresponding author's E-mail: aprice@ars.usda.gov.

include cyanazine, fluometuron, monosodium salt of methylarsonic acid (MSMA), and prometryn (Byrd 1999; Wilcut and Askew 1999; Wilcut et al. 1995).

Flumioxazin is a *N*-phenylphthalimide herbicide registered for PRE treatment in peanut (*Arachis hypogaea* L.) and as an early-PP burndown treatment in cotton (Anonymous 2002a, 2002b; Askew et al. 1999; Burke et al. 2002; Clewis et al. 2002; Grichar and Colburn 1996; Main et al. 2003). Previous research indicated that flumioxazin may be applied as PP or PDS treatments in cotton (Askew et al. 2002; Cranmer et al. 2000; Main et al. 2000). Cotton injury due to flumioxazin PP treatments may occur and is influenced by application timing in respect to planting (Askew et al. 2002). Cotton injury due to flumioxazin PDS treatments has the potential to injure cotton less than 30-cm tall if the herbicide contacts green stem material or foliage because of rain splash or misapplication (Altom et al. 2000; Wilcut et al. 2000). Thus, rainfall or precipitation when cotton seedlings are emerging could be of concern.

Flumioxazin applied PP or PDS controls common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), entireleaf morningglory (*Ipomoea hederacea* var. *integruiscula* L.), ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.], Palmer amaranth (*Amaranthus palmeri* L.), pitted morningglory (*Ipomoea lacunosa* L.), prickly sida (*Sida spinosa* L.), smooth pigweed (*Amaranthus retroflexus* L.), and tall morningglory [*Ipomoea purpurea* (L.) Roth] (Askew et al. 2002; Clewis et al. 2002; Niekamp et al. 1999). Although flumioxazin would appear to be a good fit for PP or PDS applications alone or in mixture with various PP and PDS herbicides in cotton, the effects of rainfall at cotton emergence after flumioxazin PP treatment or the effects of rainfall before or soon after flumioxazin PDS application on cotton are not known. Therefore, field studies were conducted to determine (1) cotton response in a weed-free environment to flumioxazin PP followed by irrigation at cotton emergence, (2) cotton response in a weed-free environment to flumioxazin PDS applied to dry soil, wet soil, or dry soil followed by irrigation immediately after application, and (3) cotton response in a weed-free environment to flumioxazin plus glyphosate PP tank mixture.

MATERIALS AND METHODS

Field experiments were conducted at the Peanut Belt Research Station located near Lewiston-Woodville, NC, in 1999 through 2002. Soils were a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudults) with 1.0 to 1.1% organic matter and pH ranging from 5.7 to 5.9.

PP Irrigation Experiment. The PP irrigation study was conducted in 2000 and 2001, and treatments were arranged as a four by three factorial of flumioxazin rate and PP application timing with three replications of treatments. Flumioxazin treatments applied to a stale seedbed included flumioxazin at 0, 71, 105, or 140 g ai/ha in mixture with glyphosate at 0 or 1.12 kg ai/ha applied at 28, 14, or 7 d before planting (DBP). Cotton 'Deltapine 5415 RRBG' was planted into corn residue on May 16, 2000, and 'Paymaster 1218 BGRR' was planted into peanut residue on May 15, 2001. A crop oil concentrate[3] (COC) at 1.67% (v/v) was included with all flumioxazin-containing PP treatments. All plots were broadcast treated with a compressed CO_2-backpack sprayer delivering 140 L/ha at 147 kPa. Cotton seed were planted at 13 to 20 seed per meter of row using a conventional planter (Edmisten 2002). Plots were four 92-cm rows wide and 9.1 m long.

Land preparation for planting included opening the soil with the subsoiler shank to open the soil and destroy plow pans beneath the rows 4 wk before planting. Fluted coulters attached to the subsoiler smoothed the soil and broke up large clods. Rolling crumblers that were mounted immediately behind the fluted coulters served to further smoothen the seedbed. Approximately 60% of the surface residue remained in the tilled area and 90 to 95% of the nontilled area was covered with residue after seedbed preparation.

At cotton emergence, 3 cm of water was applied to all plots with a lateral movement overhead irrigation system. When cotton reached the four-leaf growth stage (26 to 28 d after planting), glyphosate was applied over-the-top at 1.12 kg/ha to control emerged weeds in all plots. This treatment is standard for weed management in glyphosate-resistant cotton in North Carolina and according to the glyphosate label (Anonymous 1999; Culpepper and York 1998; Scott et al. 2001). A late PDS application of prometryn at 1.12 kg ai/ha plus MSMA at 2.24 kg ai/ha plus 0.25% (v/v) nonionic surfactant (NIS)[4] and hand weeding as needed were used to keep plots weed free. This approach allowed evaluation of early-season

[3] Agridex®, 83% paraffin base petroleum oil and 17% surfactant blend. Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38137.

[4] Induce® nonionic low foam wetter–spreader adjuvant containing 90% nonionic surfactant (alkylarylopolyoxyalkane ether and isopropanol), free fatty acids. Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38137.

cotton injury to PP treatments and to ascertain weed-free crop response to PP treatments.

Cotton was evaluated for PP treatment injury 2 and 5 wk after emergence (WAE). Cotton injury, on the basis of visual leaf discoloration, visual stunting, and visual stand reductions was estimated on a scale of 0 (no injury symptoms) to 100 (complete death of all plants or no plants present) (Frans et al. 1986). The center two rows of each plot were harvested once with a spindle picker modified for small-plot harvesting.

PDS Irrigation Experiment. For the PDS irrigation study conducted in 1999 and 2000, the experimental area was prepared conventionally, then treated with trifluralin preplant incorporated at 0.94 kg ai/ha, fluometuron PRE at 1.12 kg ai/ha plus pyrithiobac PRE at 0.036 kg ai/ha, followed by pyrithiobac at 0.07 kg/ha POST. Pyrithiobac POST treatments included 0.25% (v/v) NIS. Cotton 'Suregrow 125' was planted on May 5, 1999, and May 10, 2000. Cotton seeding rate and plot size were as mentioned previously. PDS treatments applied in factorial treatment arrangement included (1) flumioxazin at 0, 71, or 105 g/ha, (2) cyanazine at 0 or 0.84 kg ai/ha, or (3) prometryn at 0 or 1.12 kg ai/ha. These herbicides were applied to dry soil, moist soil, or dry soil that was immediately irrigated after treatment with 3 cm of water as described previously. Treatments were replicated three times. An NIS at 0.25% (v/v) was included with all cyanazine-, flumioxazin-, and prometeryn-containing treatments. Herbicides were applied in 20 to 30 cm cotton in 1999 and 2000 with a backpack sprayer as described previously.

Cotton was evaluated for PDS treatment injury 2 and 5 wk after treatment. Cotton injury was estimated as described previously. The center two rows of each plot were harvested as described previously.

Flumioxazin Plus Glyphosate PP Application Timing Study. The third experiment was conducted in 2001 and 2002. Treatment combinations reflected a three by four factorial treatment arrangement of PP treatment and PP application timing with three replications of treatments. PP treatments applied to a stale seedbed at 30, 21, 14, and 0 DBP included (1) flumioxazin at 0 or 71 g/ha, (2) flumioxazin at 71 g/ha in mixture with glyphosate at 1.12 g/ha, or (3) glyphosate at 0 or 1.12 g/ha. A COC at 1.67% (v/v) was included with all flumioxazin-containing treatments. Land was prepared for planting as described in the first experiment. Cotton Paymaster 1218 BGRR was planted into peanut residue on May 15, 2001, and cotton residue April 15, 2002. Cotton seeding rate and plot size were as mentioned previously. Treatments were applied with a backpack sprayer as described previously.

Cotton was evaluated for PP treatment injury 2 and 5 WAE. Cotton injury was estimated as described previously. The center two rows of each plot were harvested as described previously.

All data in all experiments were subjected to ANOVA using the general linear models procedure in SAS (SAS 1998) to evaluate the effect of each factorial herbicide treatment arrangement. Herbicide treatments were considered fixed effects whereas year, location, and year by location effects were considered random variables (McIntosh 1983). Nontransformed data for visual evaluations are presented because arcsine square root transformation did not affect data interpretation. Means for appropriate main effects and interactions were separated using Fisher's protected LSD test at $P = 0.05$. Data were combined where interactions did not occur; data were presented separately when interactions occurred.

Table 1. Cotton injury 2 and 5 WAE[a] from flumioxazin or glyphosate preplant treatment 28, 14, or 7 DBP[a] in North Carolina in 2000 and 2001.

Herbicide treatment	DBP	2000 2 WAE	2000 5 WAE	2001 2 WAE	2001 5 WAE
		% injury			
Flumioxazin 71 g/ha	28	0 b[b]	0 c	1 b	1 b
Flumioxazin 105 g/ha	28	0 b	0 c	2 b	1 b
Flumioxazin 140 g/ha	28	1 a	0 c	3 b	2 b
Glyphosate 1.12 kg/ha	28	1 a	2 b	0 c	0 c
Flumioxazin 71 g/ha	14	0 b	1 b	1 b	1 b
Flumioxazin 105 g/ha	14	0 b	3 b	2 b	5 a
Flumioxazin 140 g/ha	14	2 a	3 b	7 a	4 ab
Glyphosate 1.12 kg/ha	14	1 a	1 b	0 c	1 b
Flumioxazin 71 g/ha	7	3 a	3 b	1 b	2 b
Flumioxazin 105 g/ha	7	3 a	6 a	3 b	4 ab
Flumioxazin 140 g/ha	7	2 a	3 b	3 b	6 a
Glyphosate 1.12 kg/ha	7	0 b	0 c	1 b	2 b

[a] DBP, days before planting; WAE, weeks after emergence.

[b] Injury was separated using Fisher's protected LSD test on nontransformed data. Means in a column followed by the same letter are not significantly different.

RESULTS AND DISCUSSION

PP Irrigation Experiment. *Cotton injury.* There was a treatment by year interaction for cotton injury; therefore, data are presented by year. In 2000 at the early evaluation (2 WAE), flumioxazin treatments applied at 71 or 105 g/ha applied at 28 or 14 DBP or glyphosate applied at 7 DBP did not injure cotton (Table 1). All other herbicides injured cotton 3% or less. By 5 WAE, no visible injury was observed on cotton treated with flumioxazin (any rate) at 28 DBP or glyphosate applied at 7 DBP.

Flumioxazin applied at 105 g/ha at 7 DBP injured cotton 6%. All other herbicides injured cotton 1 to 3%. In 2001, injury 2 and 5 WAE was 7% or 6% or less, respectively. In 2000, plots received approximately 1.7 cm of natural precipitation between treatments applied at 28 and 14 DBP, with no other precipitation occurring until after irrigation. In 2001, 3.2 cm of precipitation occurred between 28 and 14 DBP treatments. In addition, 0.3 cm occurred between 14 and 7 DBP treatments and also between 7 DPB treatments and planting. Observed cotton injury to flumioxazin PP was comparable to injury levels previously reported (Askew et al. 2002; Price and Wilcut 2002). Although injury may occur when flumioxazin is applied PP, the levels of injury observed in this study are not likely to be of agricultural importance. Fluometuron PRE has been used widely in North Carolina for over two decades and early-season cotton injury of 15% is not uncommon (A. C. York, personal communication). Cotton is able to recover from less than 25% early-season injury and avoid yield loss (Chandler and Savage 1980; Hayes et al. 1981; Walsh et al. 1993).

Cotton yield. Treatments as well as the year by treatment interaction for cotton lint yield were not significant ($P > 0.05$); therefore, treatments were combined for presentation. However, there was a significant year main effect for cotton yield; consequently, yields are presented separately by year. Cotton lint yields averaged 1,650 kg/ha in 2001 and 1,980 kg/ha in 2002 (data not shown). A typical lint yield for North Carolina is around 800 kg/ha (North Carolina Department of Agriculture Statistics 1998–2000). Yields in these studies are likely due to the optimal growth conditions resulting from plots being weed free and irrigated production. These studies agree with previous research that reported cotton yields were not influenced by flumioxazin at 71 g/ha PP when applied between 0 and 10 wk before planting (Askew et al. 2002).

PDS Irrigation Experiment. *Cotton injury.* Treatments as well as the year by treatment interaction for cotton injury were not significant; therefore, data were combined ($P > 0.05$). In 1999 and 2000, no cotton stem injury or rain splash injury was observed at either evaluation (data not shown). These results differ from those observed in previous research. Intense rainfall encountered in thunderstorms may have caused reported injury in previously reported research (Altom et al. 2000; Wilcut et al. 2000). The water droplet size and intensity generated by the lateral movement overhead irrigation system used in this experiment was less than the intensity in a thunderstorm (A. J. Price, personal observation). The lack of rain splash injury may be attributed to other reasons including differing soil texture or extent of canopy closure of these studies compared with those reported previously. Also, cotton injured by the PDS application in the study reported by Wilcut et al. (2000) was 15 cm or less in height compared with cotton 20 to 30 cm in height in this study.

Previous research showed that flumioxazin PDS injury on the cotton stem was related to cotton growth stage, and that once cotton gained a bark layer on the lower stem, injury was reduced (Price et al. 2001). The lack of injury on the cotton stem in this study is likely attributed to more precise PDS application and the presence of a bark layer on the more mature cotton in this experiment at time of application. Results from this and other experiments suggest that flumioxazin applied PDS at 71 g/ha would be safe for use in irrigated and nonirrigated cotton if cotton was at least 20 cm in height and had developed a bark layer on lower stem. However, rain splash from intense thunderstorms may have the potential to injure cotton.

Cotton yield. The influence of herbicide treatment as well as the year by treatment interaction for cotton lint yields were not significant ($P > 0.05$); therefore, treatments were combined for presentation. However, there was a significant year main effect for cotton yield; consequently, yields are presented separately by year. Cotton lint yields averaged 1,480 kg/ha in 1999 and 1,820 kg/ha in 2000 (data not shown).

Flumioxazin Plus Glyposate PP Application Timing Experiment. *Cotton injury.* Treatments as well as the year by treatment interaction for cotton injury were not significant; therefore, data were combined ($P > 0.05$). Less than 3% cotton injury was observed at either evaluation in either year (data not shown). Observed cotton injury to flumioxazin PP was less than injury levels reported by Askew et al. (2002) and Price and Wilcut (2002).

Cotton yield. Treatments as well as the year by treatment interaction for cotton lint yield were not significant ($P > 0.05$); therefore, treatments were combined for presentation. However, there was a significant year main effect for cotton yield; consequently, average yields are presented separately by year. Cotton lint yields averaged 1,650 kg/ha in 2001 and 640 kg/ha in 2002 (data not shown). Low yield was attained in 2002 because of drought.

These data suggest that flumioxazin is a safe herbicide for use in cotton as a PP treatment at 7 DBP or earlier on similar soils if rainfall occurs between herbicide application and planting. These data also support flumioxazin PP labels for PP burndown uses at 71 g/ha at least 30 DBP with at least 3 cm of rainfall or irrigation before planting (Anonymous 2002a, 2002b). The inclusion of a residual herbicide such as flumioxazin in a PP treatment should reduce early-season weed interference in production systems that do not use herbicides or tillage at planting to control emerged vegetation. Because many reduced-tillage systems plant glyphosate-resistant cultivars in North Carolina, flumioxazin PP in a tank mixture with a nonselective herbicide such as glyphosate or paraquat may reduce the density of problematic winter annuals weeds found in reduced tillage and glyphosate-resistant cotton systems (Price and Wilcut 2002). These data also suggest that flumioxazin is a safe herbicide for use in cotton as a PDS on 20- to 30-cm-tall cotton on similar soil when followed by irrigation or equivalent intensity rainfall. However, intense natural rainfall occurring after flumioxazin application on small cotton and previous to a less intense precipitation event may have the potential to cause injury after flumioxazin applied PDS, and further investigation of this potential issue may be warranted.

ACKNOWLEDGMENTS

Statistical assistance was provided by Dr. Cavell Brownie, Professor of Statistics. We also wish to thank the station personnel at the Peanut Belt Research Station for their assistance. This research was partially funded by Cotton Incorporated, the North Carolina Cotton Growers Association, and Valent USA.

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