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Flumioxazin Preplant Burndown Weed Management in Strip-Tillage Cotton (*Gossypium hirsutum*) Planted into Wheat (*Triticum aestivum*)[1]

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Abstract: Experiments were conducted at two locations in North Carolina from 1999 to 2000 to evaluate flumioxazin preplant (PP) for weed management in strip-tillage cotton planted in winter-wheat cover. Flumioxazin PP was evaluated at two rates alone and in mixture with two commonly used PP herbicides and one experimental PP herbicide. Flumioxazin PP at 71 or 105 g ai/ha tank mixed with the isopropylamine salt of glyphosate at 1.12 kg ai/ha, paraquat at 1.05 kg ai/ha, or the trimethylsulfonium salt of glyphosate at 1.12 kg ai/ha controlled common chickweed, common lambsquarters, common ragweed, Palmer amaranth, and smooth pigweed ≥ 96% 29 to 43 d after treatment (DAT). Both glyphosate formulations and paraquat alone provided ≥ 91% control of common chickweed and henbit 29 to 43 DAT, but control of common lambsquarters, common ragweed, large crabgrass, Palmer amaranth, and smooth pigweed was ≤50%. Treatments including flumioxazin injured cotton (≤ 5%) at one location. In all comparisons within a location, cotton treated with flumioxazin PP at 71 or 105 g/ha in mixture with either glyphosate formulation or with paraquat provided equivalent or higher yields than did cotton not treated with flumioxazin PP.

Nomenclature: Flumioxazin; glyphosate; paraquat; common chickweed, *Stellaria media* L. Vill. #[3] STEME; common lambsquarters, *Chenopodium album* L. CHEAL; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; henbit, *Lamium amplexicaule* L. # LAMAM; large crabgrass, *Digitaria sanguinalis* (L.) Scop. # DIGSA; Palmer amaranth, *Amaranthus palmeri* L. # AMAPA; smooth pigweed, *Amaranthus hybridus* L. # AMACH; cotton, *Gossypium hirsutum* L. 'Paymaster 1218 RRBG', 'Paymaster 1220 RRBG'; wheat, *Triticum aestivum* L.

Additional index words: Burndown treatment, cover crops.

Abbreviations: COC, crop-oil concentrate; DAT, days after treatment; glyphosate-IP, isopropylamine salt of glyphosate; glyphosate-TM, trimethylsulfonium salt of glyphosate; PDS, postemergence-directed spray; POST, postemergence; PP, preplant; PRE, preemergence; WAP, weeks after planting.

INTRODUCTION

Many cotton growers in the southeast are using reduced-tillage operations. Reduced-tillage systems are primarily used to address concerns about soil erosion, water availability, and sandblasting of young cotton plants on windy, early spring days in sandy soils (Bradley 1995; York 1995). Legumes such as vetch (*Vicia sativa* L.) and crimson clover (*Trifolium incarnatum* L.), or small grains such as wheat or rye (*Secale cereale* L.) are commonly used as winter cover in reduced-tillage systems and must be desiccated 2 to 3 wk before planting (York 1995). Small-grain cover crops are preferred over legumes for no-till cotton because they are easier to establish and easier to destroy, provide more protection from soil erosion during the fall and winter months, more persistent mulch, and better weed suppression (Naderman et al. 2002). Commonly used preplant (PP) burndown treatments in cotton include paraquat and the isopropylamine salt of glyphosate (glyphosate-IP) (Brown and Whitwell 1985; White and Worsham 1990; York 1995). Both herbicides provide inexpensive winter-cover burndown and broad-spectrum weed control (Wilcut et al. 1995). But neither herbicide effectively controls all weeds, and they do not provide residual weed control.

Glyphosate-resistant cotton cultivars are planted on greater than 75% of the North Carolina cotton hectarage (A. C. York and K. Edminsten, North Carolina State

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

University, personal communication). The development of herbicide-resistant cotton cultivars and new herbicides registered for postemergence (POST) application over-the-top in cotton has allowed growers to use total POST-weed management systems that fit well in reduced-tillage operations. Approximately 35 to 40% of North Carolina cotton hectarage does not receive soil-applied herbicide treatments at planting (A. C. York, personal communication). But 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; Scott et al. 2001a). A residual herbicide applied PP in mixture with nonselective herbicides like glyphosate-IP or paraquat could allow flexibility of POST-application timings while minimizing early-season weed competition.

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 2002; Askew et al. 1999; Clewis et al. 2002; Grichar and Colburn 1996). Research indicates that flumioxazin may be applied as a postemergence-directed (PDS) or PP treatment in cotton (Altom et al. 2000; Askew et al. 2002; Cranmer et al. 2000; Main et al. 2000; Wilcut et al. 2000). Cotton injury due to flumioxazin-PP treatments may occur and is influenced by application timing with respect to planting (Askew et al. 2002). Cotton planted no-till in undisturbed cotton and corn stubble was injured ≤ 12% if flumioxazin was applied PRE on the day of planting but ≤ 3% if application was made at least 2 wk before planting.

Flumioxazin PRE controls common lambsquarters, common ragweed, entireleaf morningglory (*Ipomoea hederacea* var. *integruiscula* L.), ivyleaf morningglory (*Ipomoea hederacea* L. Jacq.), Palmer amaranth, pitted morningglory (*Ipomoea lacunosa* L.), prickly sida (*Sida spinosa* L.), smooth pigweed, 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 application alone or in mixture with various PP herbicides in cotton, existing winter cover, cotton, and weed response to these treatments is not known. Therefore, field studies were conducted to evaluate control of an existing wheat cover and weeds with flumioxazin applied PP alone and in mixture with various PP herbicides. Additionally, cotton response, which was kept weed free from the four-leaf stage to harvest, to flumioxazin PP was evaluated.

MATERIALS AND METHODS

Field experiments were conducted at the Upper Coastal Plain Research Station located near Rocky Mount, NC, and at the Central Crops Research Station near Clayton, NC, in 1999 and 2000. Soil at both locations was a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudults) with 1.1% organic matter and pH of 5.7 at Rocky Mount and 1.8% organic matter and pH of 5.8 at Clayton. Treatment combinations reflected a 3- by 4-factorial treatment arrangement of residual (flumioxazin) and nonresidual (glyphosate-IP, trimethylsulfonium salt of glyphosate [glyphosate-TM], and paraquat) PP herbicides. Residual treatments included flumioxazin at 71 g ai/ha or 105 g ai/ha alone or in mixture with one of the following nonresidual herbicides: glyphosate-IP or glyphosate-TM at 1.12 kg ai/ha or paraquat at 1.05 kg ai/ha. Glyphosate-IP or glyphosate-TM at 1.12 kg/ha or paraquat at 1.05 kg/ha were also applied alone, and a non-PP control was included to complete the factorial treatment arrangement. A hand-weeded control was not included in the design because our previous field research showed that cotton yield was not reduced by flumioxazin-PP treatments (Askew et al. 2002). A nonionic surfactant[4] (NIS) at 0.25% (v/v) was included in the paraquat-alone herbicide treatment, and crop-oil concentrate[5] (COC) at 1.67% (v/v) was included in all flumioxazin-containing treatments.

Soft red winter-wheat cover (22 to 25 seedlings per square foot) was established in cotton stubble using a no-till drill at both locations each year between October 20 and November 8. In the next spring the wheat cover and emerged weeds were broadcast treated with one of the previously mentioned treatments with a compressed CO_2 backpack sprayer delivering 140 L/ha at 147 kPa. The wheat was two to three-tillers; winter annual weeds in the untreated PP check (common chickweed, 1 to 20 weeds/m^2; henbit, 1 to 20 weeds/m^2) ranged from cotyledon to four-leaf in size at the time of PP application. Application dates were April 5, 1999 at Clayton; March 30, 1999 at Rocky Mount; April 10, 2000 at Clayton; and April 14, 2000 at Rocky Mount.

Land preparation included opening the soil with the subsoiler shank of a Ro-Till planter, with the planter units removed to open the soil and destroy the plowpans

[4] Induce® nonionic low foam wetter/spreader adjuvant containing 90% nonionic surfactant (alkylarylopolyoxyalkane ether and isopropanol), free fatty acids, and 10% water. Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38137.

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

beneath the rows 2 wk before planting. Attached to the planter, fluted coulters 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. Cotton seeds were then planted using a conventional planter. Glyphosate-IP–resistant cotton cultivars, Paymaster 1220 RRBG in 1999 and Paymaster 1218 RRBG in 2000, were planted in seedbeds at 13 seeds/m of row on May 5, 1999 at Clayton; May 12, 1999 at Rocky Mount; May 9, 2000 at Clayton; and May 24, 2000 at Rocky Mount. Planting dates for each location varied after PP application because of weather, and the interval between PP treatments and planting was 29 to 43 d in 1999 and 2000, respectively, between the two locations. But within a location over years, the time interval between PP treatments and planting was 29 to 30 d at Clayton and 40 to 43 d at Rocky Mount. Askew et al. (2002) reported no influence on cotton treated with flumioxazin PP 2 to 10 wk before planting. Emerged summer annual weeds at the time of planting in the untreated PP check (common lambsquarters, 15 to 50 weeds/m^2; common ragweed, 10 to 60 weeds/m^2; large crabgrass, 20 to 35 weeds/m^2; Palmer amaranth, 15 to 40 weeds/m^2; and smooth pigweed, 12 to 30 weeds/m^2) ranged from cotyledon to two-leaf in size. The Clayton location had higher densities of emerging summer annual weeds than did the Rocky Mount location (data not shown). When cotton reached the four-leaf growth stage (26 to 28 d after planting), glyphosate-IP was applied over-the-top at 1.12 kg/ha to control the emerged weeds in all plots. The glyphosate-IP treatment was applied on June 5, 1999 at Clayton; June 7, 1999 at Rocky Mount; June 6, 2000 at Clayton; and June 19, 2000 at Rocky Mount, 57 to 69 d after the PP treatments. This treatment is standard for weed management in glyphosate-IP–resistant cotton in North Carolina and according to the glyphosate label (Anonymous 1999; Culpepper and York 1998; Scott et al. 2001a). Clethodim at 0.14 kg ai/ha plus 1.0% (v/v) COC was applied late-POST for annual grass control. 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) NIS[4], and hand weeding as needed were used to keep the plots weed free. This approach allowed us to evaluate early-season weed control (up to planting) with PP treatments and to ascertain weed-free crop response (after four-leaf cotton) to PP treatments. The experimental design was a randomized complete block with a 3- by 4-factorial treatment arrangement, and the treatments were replicated three times. Plots at Rocky Mount consisted of four rows, 92 cm wide and 9.1 m long, and plots at Clayton consisted of four rows, 97 cm wide and 9.1 m long.

Cotton injury was evaluated 2 and 5 wk after planting (WAP). Visual control estimates of winter annual weeds present at the time of PP application as well as evaluation of summer annual weed control were recorded at planting. Common chickweed, common lambsquarters, common ragweed, henbit, large crabgrass, Palmer amaranth, smooth pigweed, and wheat cover were each evaluated for control by PP treatments. Weed control and cotton injury, based on visual leaf discoloration, visual stunting, and visual biomass reductions, as compared with the non–PP-treated control, were 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 for lint and seed with a spindle picker modified for small-plot harvesting. Harvest dates were November 25, 1999 at Clayton; November 11, 1999 at Rocky Mount; October 17, 2000 at Clayton; and October 31, 2000 at Rocky Mount.

All data were subjected to ANOVA, using the general linear models procedure in SAS (SAS 1998) to evaluate the effect of a 3- (residual PPI) by 4- (nonesidual PPI) factorial herbicide treatment arrangement. Herbicide treatments were considered fixed effects, whereas year, location, and year by location effects were considered random variables. Nontransformed data for visual evaluations are presented because arcsine square root transformation did not affect data interpretation. ANOVA was conducted with and without the PP control to ensure that the control did not bias the conclusions because the visually estimated weed control ratings were zero. Conclusions are based on the inclusion of the checks in the analysis. Means for appropriate main effects and interactions were separated using Fisher's protected LSD test at $P = 0.05$. Where interactions occurred, data are presented separately, and where interactions did not occur, data are combined.

RESULTS AND DISCUSSION

Cotton Injury. At early evaluation (2 WAP), all treatments that included flumioxazin injured cotton $\leq$ 5% at Clayton in 2000 (data not shown), which was comparable with the injury levels reported by Askew et al. (2002). By 5 WAP, no cotton injury was observed in either year (data not shown). Although injury may occur when flumioxazin is applied PP, the levels of injury ob-

Table 1. Wheat and weed control at planting by preplant herbicide treatments applied 29 to 43 d before planting.

Preplant herbicides[a]	Wheat	AMACH[b]	AMBEL	AMAPA	CHEAL	DIGSA	LAMAM	STEME
	% control							
Flumioxazin, 71 g/ha	30	98	98	96	100	65	80	98
Flumioxazin, 105 g/ha	27	100	99	100	100	86	75	98
Flumioxazin, 71 g/ha plus glyphosate-IP, 1.12 kg/ha	96	97	98	96	100	63	97	100
Flumioxazin, 105 g/ha plus glyphosate-IP, 1.12 kg/ha	98	100	100	100	100	82	98	100
Flumioxazin, 71 g/ha plus paraquat, 1.05 kg/ha	78	97	100	98	100	67	100	100
Flumioxazin, 105 kg/ha plus paraquat, 1.05 kg/ha	77	100	100	97	100	80	100	100
Flumioxazin, 71 g/ha plus glyphosate-TM, 1.12 kg/ha	96	97	100	98	100	69	99	96
Flumioxazin, 105 g/ha plus glyphosate-TM, 1.12 kg/ha	99	100	100	99	100	80	100	100
Glyphosate-IP, 1.12 kg/ha	99	22	12	0	47	30	100	100
Paraquat, 1.05 kg/ha	98	19	18	1	50	33	100	100
Glyphosate-TM, 1.12 kg/ha	83	17	15	0	48	41	91	100
LSD	13	27	19	3	29	22	16	3

[a] All flumioxazin-containing treatments included crop-oil concentrate at 1.67% (v/v). The paraquat-alone treatment included nonionic surfactant at 0.25% (v/v). When cotton reached the four-leaf growth stage (26 to 28 d after planting), glyphosate-IP was applied over-the-top at 1.12 kg/ha to control the emerged weeds in all plots. Abbreviations: glyphosate-IP, isopropylamine salt of glyphosate; glyphosate-TM, trimethylsulfonium salt of glyphosate.

[b] WSSA computer codes, weed size, and densities in the untreated PP check at planting: LAMAM, henbit (four-leaf, 1 to 20 weeds/m^2); STEME, common chickweed (four-leaf, 15 to 20 weeds/m^2), AMACH, smooth pigweed (cotyledon to two-leaf, 12 to 30 weeds/m^2); AMAPA, Palmer amaranth (cotyledon to two-leaf, 15 to 40 weeds/m^2); AMBEL, common ragweed (cotyledon to two-leaf, 10 to 60 weeds/m^2); CHEAL, common lambsquarters (cotyledon to two-leaf, 15 to 50 weeds/m^2); and DIGSA, large crabgrass (one-to two-leaf, 20 to 35 weeds/m^2).

served in this study are not likely to be biologically significant. Fluometuron PRE has been widely used 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).

Wheat Cover Control. There was no year or location effect for control of the wheat cover; therefore, data were combined over years and locations. Flumioxazin alone controlled the wheat cover ≤ 30% at planting, regardless of rate (Table 1). Flumioxazin at 71 or 105 g/ha with glyphosate formulation in mixture or alone controlled the wheat cover ≥ 96% at planting. Paraquat alone or in mixture with either rate of flumioxazin controlled the wheat cover ≤ 83% at planting.

Weed Control. There was no year or location effect for weed control; therefore, data were combined over years and locations. Flumioxazin PP at both rates alone or in mixture with either glyphosate formulation or with paraqat controlled common chickweed, common lambsquarters, common ragweed, henbit, Palmer amaranth, and smooth pigweed ≥ 96% at planting 29 to 43 d after PP treatment (Table 1). Flumioxazin at 71 g/ha controlled large crabgrass 65% 29 to 43 d after PP treatment. Increasing the flumioxazin rate to 105 g/ha increased large crabgrass control to 86%. Flumioxazin does provide some residual control of grasses, but it does not provide season-long control (Askew et al. 1999; Grichar and Colburn 1996). The addition of either glyphosate formulation or paraquat improved large crabgrass control. Glyphosate-IP and paraquat alone provided complete (100%) control of common chickweed and henbit at planting, 29 to 43 d after PP treatment. Glyphosate-TM alone controlled common chickweed and henbit 100 and 91%, respectively, 29 to 43 d after treatment (DAT). But control of common lambsquarters, common ragweed, large crabgrass, and smooth pigweed by either glyphosate formulation or paraquat alone was ≤ 50% 29 to 43 d after PP application. These herbicides do not provide residual control, thus the later germinating weeds escape. These weeds are typical summer annuals found in the Southeast that germinate at least into late June (authors' personal observations). Research trials in peanut with flumioxazin at similar rates have also shown residual control of common lambsquarters, common ragweed, and smooth pigweed (Askew et al. 1999; Scott et al. 2001b, 2002).

Cotton Yield. There was a year by location interaction for cotton yield; therefore, locations are presented separately. At Clayton in 1999, cotton treated with flumioxazin at both rates alone or in mixture with glyphosate-IP, glyphosate-TM, or paraquat yielded similarly (660 to 700 kg lint/ha) (Table 2). Cotton treated with either glyphosate formulation or paraqat alone yielded less (500 to 520 kg/ha). The non-PP control yielded 280 kg/ha. At Rocky Mount in 1999, cotton treated with flumioxazin at both rates alone or in mixture with either glyphosate formulation or with paraqat provided equivalent lint yields (750 to 820 kg/ha). Cotton treated with either glyphosate formulation or paraquat alone yielded less (700

Table 2. Cotton lint yield after preplant herbicide treatments at two locations in North Carolina in 1999 and 2000.

Preplant herbicides[a]	Clayton 1999	Rocky Mount 1999	Clayton 2000	Rocky Mount 2000
	(kg/ha)			
Flumioxazin, 71 g/ha	660	800	790	1,620
Flumioxazin, 105 g/ha	700	750	800	1,600
Flumioxazin, 71 g/ha plus glyphosate-IP, 1.12 kg/ha	680	800	900	1,650
Flumioxazin, 105 g/ha plus glyphosate-IP, 1.12 kg/ha	680	750	880	1,670
Flumioxazin, 71 g/ha plus paraquat, 1.05 kg/ha	700	820	960	1,680
Flumioxazin, 105 g/ha plus paraquat, 1.05 kg/ha	670	800	900	1,650
Flumioxazin, 71 g/ha plus glyphosate-TM, 1.12 kg/ha	680	760	930	1,590
Flumioxazin, 105 g/ha plus glyphosate-TM, 1.12 kg/ha	700	800	900	1,620
Glyphosate-IP, 1.12 kg/ha	520	710	740	1,190
Paraquat, 1.05 kg/ha	500	700	720	1,160
Glyphosate-TM, 1.12 kg/ha	500	710	720	1,140
Non-PP control	280	610	560	1,160
LSD	100	80	110	130

[a] All flumioxazin-containing treatments included crop-oil concentrate at 1.67% (v/v). The paraquat-alone treatment included nonionic surfactant at 0.25% (v/v). When cotton reached the four-leaf growth stage (26 to 28 d after planting), glyphosate-IP was applied over-the-top at 1.12 kg/ha to control the emerged weeds in all plots. Abbreviations: glyphosate-IP, isopropylamine salt of glyphosate; glyphosate-TM, trimethylsulfonium salt of glyphosate.

to 710 kg/ha). The non-PP control yielded 610 kg/ha. A typical cotton yield for North Carolina is around 800 kg/ha (North Carolina Department of Agriculture Statistics 1998–2000). Yield reductions at the Clayton location are likely due to increased densities of emerging summer annual weeds as compared with Rocky Mount.

At Clayton in 2000, lint yields from cotton treated with flumioxazin at either rate in mixture with glyphosate formulation or with paraqat were similar (880 to 960 kg/ha). Cotton treated with either rate of flumioxazin, with either glyphosate formulation or with paraqat applied alone yielded less (720 to 740 kg/ha). The non-PP control yielded 560 kg/ha. At Rocky Mount in 2000, cotton treated with flumioxazin at both rates alone or in mixture with either glyphosate formulation or with paraqat yielded more (1,590 to 1,680 kg/ha) than did the non-PP control and cotton treated with either glyphosate formulation or paraqat alone (1,140 to 1,190 kg/ha). The increased yield at Rocky Mount may be attributed to the ideal growing conditions that were present throughout the season in 2000 at this location (weather data not shown). In all comparisons within a location, cotton treated with flumioxazin at 71 or 105 g/ha in mixture with either glyphosate formulation or with paraqat provided yields that were at least equivalent and frequently greater than did cotton treated with either glyphosate formulation or paraqat alone. Because flumioxazin minimally injured cotton 2 WAP at one location in 1 yr and these experiments were kept weed free after cotton reached the four-leaf stage, we believe that the differences in yield reflect early-season weed interference. Similar results showing yield reductions from early-season weed interference have been reported (Askew and Wilcut 1999; Buchanan and Burns 1970; Clewis et al. 2000; Culpepper and York 1998; Scott et al. 2001a). In previous research cotton yields were not influenced by flumioxazin at 70 g/ha PP when applied between 0 and 10 wk before planting (Askew et al. 2002).

These data suggest that flumioxazin is a safe herbicide for use as a PP treatment 29 to 43 d before cotton planting on similar soils. These data also support the flumioxazin PP label for burndown uses at 71 g/ha at least 30 d before planting cotton. 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 weeds. Because many reduced-tillage systems plant glyphosate-resistant cultivars in North Carolina, flumioxazin PP may reduce the density of problematic weeds found in reduce-tillage and glyphosate-resistant cotton systems. Also, the use of flumioxazin PP should delay the first glyphosate application in glyphosate-resistant cotton systems compared with systems that exclude residual PP herbicides.

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