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Flumioxazin Systems for Weed Management in North Carolina Peanut (*Arachis hypogaea*)[1]

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Abstract: A study was conducted to evaluate flumioxazin preemergence (PRE) at 71 and 105 g ai/ha, when used with dimethenamid PRE, dimethenamid preplant incorporated (PPI), or ethalfluralin PPI, for crop injury, weed control, and yield. Peanut injury from treatments including flumioxazin 2 wk after soil-applied treatment (WAST) was less than 2% at two locations and 50 to 67% at a third location. Peanut injury increased with flumioxazin rate. Soil-applied treatments that included flumioxazin at either rate controlled common lambsquarters and prickly sida at least 96 and 89%, respectively. Addition of postemergence (POST) herbicides to any soil-applied program controlled prickly sida and ivyleaf morningglory at least 94 and 98%, respectively. Treatments that included ethafluralin or dimethenamid controlled goosegrass at least 82%. With a few exceptions, peanut yields were not improved by use of POST herbicides. Where peanut injury occurred, increased flumioxazin rate resulted in lower peanut yield when averaged over PPI and POST herbicide treatments.

Nomenclature: Dimethenamid; ethalfluralin; flumioxazin; common lambsquarters, *Chenopodium album* L. #[3] CHEAL; goosegrass, *Eleusine indica* (L.) Gaertn. # ELEIN; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. # IPOHE; prickly sida, *Sida spinosa* L. # SIDSP; peanut, *Arachis hypogaea* L. 'NC 7', 'NC 10C'.

Additional index words: Acifluorfen, bentazon, 2,4-DB, imazapic.

Abbreviations: fb, followed by; POST, postemergence; PPI, preplant incorporated; PRE, preemergence; WAPT, weeks after POST treatment; WAST, weeks after soil-applied treatment.

INTRODUCTION

Peanut producers typically apply herbicides preplant incorporated (PPI), preemergence (PRE), or both to control annual grass and broadleaf weeds. However, few soil-applied herbicides labeled for use in peanut exist for control of common broadleaf weeds such as morningglory (*Ipomoea* spp.) and prickly sida. Currently, soil-applied herbicides and multiple applications of POST herbicides are required for control of these weeds (Bailey et al. 1999; Richburg et al. 1996; Wilcut et al. 1994). The lengthy peanut-growing season ($\geq$ 140 d), the broader opportunity for weed seedling emergence, and the lack of residual control by many POST herbicides make season-long weed control difficult and costly (Wilcut et al. 1994). Others have examined flumioxazin used PRE with diclosulam, metolachlor, pendimethalin, or trifluralin (Askew et al. 1999; Clewis et al. 2002; Grichar and Colburn 1996; Main et al. 2000; Scott et al. 2001; Wilcut 1997). Integration of flumioxazin into weed management systems for peanut, which includes other commonly used soil-applied herbicides such as ethalfluralin and dimethenamid with POST herbicides, is needed (Bridges et al. 1994; Jordan 1999). Therefore, trials were initiated at several locations in North Carolina to evaluate peanut response, crop yield, and weed control using flumioxazin applied PRE at two rates with other registered soil-applied herbicides alone or followed by commercial POST herbicide treatments.

MATERIALS AND METHODS

A study was conducted at the Peanut Belt Research Station near Lewiston, NC, in 1997 and at the Upper Coastal Plain Research Station near Rocky Mount, NC, in 1996 and 1997. Soil was Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudults) with 1.0% organic matter and pH 5.9 at Lewiston and with 1.1% organic matter and pH 5.6 to 5.8 at Rocky Mount.

Peanut NC 7 and NC 10C were planted at Rocky Mount and Lewiston, respectively, in 1997. Peanut was planted at 120 to 130 kg/ha, 5 cm deep in smooth seed-

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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.

Table 1. Weed growth stages and densities in the nontreated control at the time of postemergence (POST) treatments.[a]

Weed species	Growth stage			Weed density		
	Lewiston	Rocky Mount		Lewiston	Rocky Mount	
Weed Species	1997	1996	1997	1997	1996	1997
	leaf/plant			plants/m²		
Common lambsquarters	4–6	2–8	3–8	6	15	10
Goosegrass	1–2	2–3	4–6	5	15	12
Ivyleaf morningglory	5–6	1–7	1–4	6	50	4
Prickly sida	—	1–4	3–6	—	10	5

[a] POST treatments were applied on June 10, 1997 in Lewiston and on June 20, 1996 and July 2, 1997 in Rocky Mount.

beds. Plots consisted of four 91-cm spaced rows, 6.1 m long. Planting dates were May 23, 1996 and May 22, 1997 at Rocky Mount and May 7, 1997 at Lewiston.

The design was a randomized complete block with three replications of treatments. Soil-applied herbicides included dimethenamid at 1,300 g ai/ha PPI or PRE, or ethalfluralin at 840 g ai/ha PPI, followed by (fb) flumioxazin at 71 or 105 g ai/ha PRE. Ethalfluralin at 840 g/ha PPI and dimethenamid at 1,300 g/ha PPI were also applied alone. Soil-applied herbicide systems that included flumioxazin with ethalfluralin PPI or dimethenamid PRE were evaluated with three POST options: (1) no POST, (2) acifluorfen at 280 g ai/ha plus bentazon at 560 g ai/ha plus 2,4-DB at 280 g ai/ha (standard), or (3) imazapic at 36 g ai/ha. Dimethenamid PPI at 1,300 g/ha fb flumioxazin PRE at 71 or 105 g/ha was evaluated alone or fb acifluorfen at 280 g/ha plus bentazon at 560 g/ha plus 2,4-DB at 280 g/ha POST. POST treatments were applied on June 10, 1997 in Lewiston and on June 20, 1996 and July 2, 1997 in Rocky Mount. Herbicides were applied with a compressed-CO_2 backpack sprayer calibrated to deliver 187 L/ha at 206 kPa. Nonionic surfactant[4] at 0.25% (v/v) was included with the POST applications. A nontreated check was added for comparison.

Weed growth stages and densities at the time of POST applications are presented in Table 1. Weed control and peanut injury were visually estimated on a scale of 0 (no control) to 100% (complete plant death) (Frans et al. 1986). Peanut injury was evaluated 2 and 8 wk after soil-applied treatment (WAST) by visual estimation based on overall injury, stand reduction, discoloration, and stunting. Common lambsquarters, goosegrass, ivyleaf morningglory, and prickly sida control were visually estimated 4 and 12 wk after POST treatment (WAPT). Because peanut yield and harvesting efficiency are affected by weed presence late in the season, only the late-season evaluations of weed control are presented (Wilcut et al. 1994). The center two rows of each plot were harvested in late October each year using conventional harvesting equipment. Peanut pods were dug and dried in the field for approximately 2 wk to determine peanut pod yields. The pods were harvested with a combine modified for small-plot research and weighed.

Data were subjected to an analysis of variance using the general linear models procedure of SAS (1998), and sums of squares were partitioned to evaluate location and herbicide treatments (McIntosh 1983). Visual estimates of crop injury and weed control data from the nontreated were removed before analysis. Data for weed control and crop injury were converted to square roots of the arcsine to stabilize variance. The transformation did not change the data interpretation, and the data are presented using the nontransformed analysis. If location effects were not significant, data were pooled; otherwise data are presented by location.

RESULTS AND DISCUSSION

Peanut Injury. There was a treatment by location interaction ($P \leq 0.05$) for peanut injury, thus data are presented by location. At 2 WAST, herbicides did not injure peanut at Rocky Mount in 1996 and Lewiston in 1997 (Table 2). But peanut treated with flumioxazin was injured 50 to 68% at Rocky Mount in 1997. Peanut injury from flumioxazin PRE at both rates was similar for dimethenamid and ethalfluralin treatments. Dimethenamid and ethalfluralin injured peanut 9 and 11%, respectively. At 8 WAST, peanut injury from flumioxazin was 18% or less. Early peanut injury by treatments that did not contain flumioxazin was transient and not significant 8 WAST. In numerous trials conducted since 1989 in Georgia, North Carolina, Texas, and Virginia, early-season injury from flumioxazin never exceeded 15% (Clewis et al. 2002; Eastin et al. 1993; Grichar and Colburn 1996; Wilcut 1997). Additionally, flumioxazin did not affect the peanut yield or grade of eight peanut cultivars in a 2-yr North Carolina study (Wilcut et al. 2001). Main et al. (2000) also reported no herbicide treatment differences for injury on the peanut cultivar 'Georgia Green' in Florida, and peanut grades were not influenced by flumioxazin treatment.

Injury resulting from flumioxazin at Rocky Mount in 1997 consisted of stunting and discoloration (data not shown). Necrotic spots on foliage characterized the dis-

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

Table 2. Peanut injury 2 and 8 WAST in 1996 and 1997.[a,b]

Herbicide[c]	POST herbicides[d]	Peanut injury (2 WAST) Lewiston 1997	Peanut injury (2 WAST) Rocky Mount 1996	Peanut injury (2 WAST) Rocky Mount 1997	Peanut injury (8 WAST) Lewiston 1997	Peanut injury (8 WAST) Rocky Mount 1996	Peanut injury (8 WAST) Rocky Mount 1997
		%					
Dimethenamid PRE + flumioxazin PRE (71 g/ha)	None	0	0	50	0	0	11
	Acifluorfen + bentazon + 2,4-DB	—	—	—	0	9	8
	Imazapic	—	—	—	2	13	11
Dimethenamid PRE + flumioxazin PRE (105 g/ha)	None	0	1	67	0	0	11
	Acifluorfen + bentazon + 2,4-DB	—	—	—	2	7	14
	Imazapic	—	—	—	4	11	12
Dimethenamid PPI + flumioxazin PRE (71 g/ha)	None	0	1	56	0	13	3
	Acifluorfen + bentazon + 2,4-DB	—	—	—	0	6	14
Dimethenamid PPI + flumioxazin PRE (105 g/ha)	None	0	2	64	3	0	10
	Acifluorfen + bentazon + 2,4-DB	—	—	—	3	6	12
Ethalfluralin PPI + flumioxazin PRE (71 g/ha)	None	0	0	56	2	0	9
	Acifluorfen + bentazon + 2,4-DB	—	—	—	0	7	15
	Imazapic	—	—	—	3	12	13
Ethalfluralin PPI + flumioxazin PRE (105 g/ha)	None	0	0	68	3	0	18
	Acifluorfen + bentazon + 2,4-DB	—	—	—	5	7	17
	Imazapic	—	—	—	3	10	13
Dimethenamid PPI	None	0	0	9	0	0	2
Ethalfluralin PPI	None	0	0	11	1	0	3
LSD (0.05)		NS	NS	7	NS	3	10

[a] Means within each column were separated using Fisher's protected LSD test ($P < 0.05$).

[b] Abbreviations: PPI, preplant incorporated; PRE, preemergence; POST, postemergence; WAST, weeks after soil-applied herbicide treatment.

[c] The rate was 1,300 g/ha for dimethenamid and 840 g/ha for ethalfluralin.

[d] POST treatment included bentazon (560 g/ha) plus acifluorfen (280 g/ha) plus 2,4-DB (280 g/ha). Imazapic was applied at 36 g/ha.

coloration. These symptoms were consistent with those observed in other studies (Askew et al. 1999; Yoshida et al. 1991). The injury attributed to flumioxazin was probably facilitated by cold and wet conditions during the period between application and rating at Rocky Mount in 1997. Before injury ratings, day and night temperatures for a 2-d period were below 10 and 5 C, respectively. Cumulative rainfall was 5.7 cm during the period from treatment and planting to the 2-WAST injury rating. Flumioxazin enters plants mainly by root and shoot uptake, and tolerant crop species avoid injury by rapid metabolism (Hatzios 1998; Yoshida et al. 1991). Wet conditions could have increased flumioxazin uptake, whereas cool temperatures may have slowed metabolism (Yoshida et al. 1991).

Weed Control. There was no treatment by location interaction, so data were pooled over locations and years for common lambsquarters, ivyleaf morningglory, and prickly sida (Table 3). Treatments that included ethalfluralin PPI dimethenamid PPI or PRE controlled goosegrass > 82%. These herbicides have controlled annual grasses in other studies (Grichar et al. 1999; Scott et al. 2001).

Treatments that included flumioxazin PRE at either rate without POST treatments controlled common lambsquarters at least 96% (Table 3). Control was greater for dimethenamid and flumioxazin combinations than for single applications of dimethenamid PPI or ethalfluralin PPI, which provided 51 and 85% control, respectively. Because the level of common lambsquarters control was so high, further improvements in control were not seen with the addition of a POST herbicide.

Dimethenamid plus flumioxazin PRE at 71 or 105 g/ha controlled ivyleaf morningglory 61 and 68%, respectively (Table 3). Single applications of dimethenamid PPI and ethalfluralin PPI did not control ivyleaf morningglory (≤ 17%). Dimethenamid or ethalfluralin PPI fb flumioxazin PRE at 71 g/ha controlled ivyleaf morningglory 78 and 88%, respectively. With dimethenamid PPI or PRE, increasing the flumioxazin rate increased control of ivyleaf morningglory by 7 to 15 percentage points. With ethalfluralin PPI, increasing the flumioxazin rate did not increase ivyleaf morningglory control. The addition of acifluorfen plus bentazon plus 2,4-DB POST or imazapic POST to any soil-applied herbicide treatment increased ivyleaf morningglory control to 98 to 100%. Askew et al. (1999) reported no differential response among entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray), ivyleaf morningglory, and pitted morningglory (*Ipomoea lacunosa* L.) at equivalent rates of flumioxazin when used in combination with *s*-metolachlor. In Texas, flumioxazin PRE con-

Table 3. Ivyleaf morningglory, common lambsquarters, and prickly sida control by herbicide systems averaged over locations in North Carolina in 1996 and 1997.[a,b]

Herbicide[c]	POST herbicides[d]	Common lambsquarters	Ivyleaf morningglory	Prickly sida
		%		
Dimethenamid PRE + flumioxazin PRE (71 g/ha)	None	99	61	92
	Acifluorfen + bentazon + 2,4-DB	100	98	100
	Imazapic	99	99	100
Dimethenamid PRE + flumioxazin PRE (105 g/ha)	None	97	68	96
	Acifluorfen + bentazon + 2,4-DB	100	99	100
	Imazapic	100	98	99
Dimethenamid PPI + flumioxazin PRE (71 g/ha)	None	96	78	98
	Acifluorfen + bentazon + 2,4-DB	99	100	99
Dimethenamid PPI + flumioxazin PRE (105 g/ha)	None	100	93	99
	Acifluorfen + bentazon + 2,4-DB	100	99	100
Ethalfluralin PPI + flumioxazin PRE (71 g/ha)	None	100	88	89
	Acifluorfen + bentazon + 2,4-DB	100	100	94
	Imazapic	100	100	97
Ethalfluralin PPI + flumioxazin PRE (105 g/ha)	None	98	94	89
	Acifluorfen + bentazon + 2,4-DB	100	100	98
	Imazapic	100	100	96
Dimethenamid PPI	None	51	0	15
Ethalfluralin PPI	None	85	17	0
LSD (0.05)		9	6	10

[a] Means within each column were separated using Fisher's protected LSD test ($P < 0.05$).

[b] Abbreviations: PPI, preplant incorporated; PRE, preemergence; POST, postemergence.

[c] The rate was 1,300 g/ha for dimethenamid and 840 g/ha for ethalfluralin.

[d] POST treatment included bentazon (560 g/ha) plus acifluorfen (280 g/ha) plus 2,4-DB (280 g/ha). Imazapic was applied at 36 g/ha.

trolled pitted morningglory at least 88% (Grichar and Colburn 1996).

Dimethenamid or ethalfluralin alone controlled prickly sida ≤ 15% (Table 3). All flumioxazin PRE systems controlled prickly sida at least 89%. Control of prickly sida was similar with both flumioxazin rates, and control in these systems was not increased by the use of POST herbicides. Similar levels of prickly sida control with flumioxazin have been reported in other studies (Wilcut 1997).

Yield. There was a treatment by location interaction ($P \leq 0.05$) for peanut yield, thus data are presented by location (Table 4). The location interaction may be due to injury occurring early in the season at Rocky Mount in 1997 compared with either Lewiston in 1997 or Rocky Mount in 1996.

At Lewiston in 1997, peanut treated with either rate of flumioxazin and no POST herbicides yielded at least 2,860 kg/ha (Table 4). Addition of POST herbicides to systems including dimethenamid plus flumioxazin at either rate did not increase yield. Yield was increased with the addition of imazapic POST to ethalfluralin PPI fb flumioxazin PRE at either rate. At Rocky Mount in 1996, flumioxazin-treated peanut yielded higher than peanut treated with a single application of dimethenamid PPI. The yields of flumioxazin-treated peanut at this location were not increased with the addition of a POST application and reflect the high weed control levels obtained with soil-applied herbicides.

At Rocky Mount in 1997, any treatment that included flumioxazin PRE resulted in a higher yield than did a single application of dimethenamid PPI or ethalfluralin PPI (Table 4). The yield from flumioxazin soil-applied systems was not increased by the additional use of POST herbicides at Rocky Mount in 1997. Peanut yield decreased as the rate of flumioxazin PRE increased when applied with ethalfluralin PPI. Peanut treated with dimethenamid PPI or PRE plus 105 g/ha flumioxazin PRE plus imazapic POST yielded less than the same system with 71 g/ha flumioxazin PRE at Rocky Mount in 1997. Although weed control was similar with both flumioxazin rates, peanut injury increased with flumioxazin rate (Table 2).

To examine the effect of flumioxazin rate on yield more closely, comparison treatments were removed and the data subjected to an analysis of variance to reflect the factorial structure within treatments that included different flumioxazin rates. There was a significant flumioxazin rate by location interaction ($P = 0.05$) for peanut yield. When averaged over other herbicides, there was no difference between yields for either rate of flumioxazin at Lewiston in 1997 or at Rocky Mount in 1996 (data not shown). However, peanut at Rocky Mount in 1997 treated with flumioxazin PRE at 71 and

Table 4. Peanut yield at three North Carolina locations as influenced by soil-applied and POST herbicides.[a]

Herbicide[b,c]	POST herbicides[d]	Peanut yield: Lewiston 1997	Rocky Mount 1996	Rocky Mount 1997
		kg/ha		
Dimethenamid PRE + flumioxazin PRE (71 g/ha)	None	3,030	5,120	3,510
	Acifluorfen + bentazon + 2,4-DB	3,240	5,710	3,290
	Imazapic	3,390	5,650	3,700
Dimethenamid PRE + flumioxazin PRE (105 g/ha)	None	3,180	5,670	3,520
	Acifluorfen + bentazon + 2,4-DB	3,310	5,710	3,170
	Imazapic	3,510	5,910	3,070
Dimethenamid PPI + flumioxazin PRE (71 g/ha)	None	3,390	5,020	3,120
	Acifluorfen + bentazon + 2,4-DB	3,570	5,430	3,150
Dimethenamid PPI + flumioxazin PRE (105 g/ha)	None	3,120	5,040	3,420
	Acifluorfen + bentazon	3,600	5,350	3,260
Ethalfluralin PPI + flumioxazin PRE (71 g/ha)	None	2,970	5,240	3,970
	Acifluorfen + bentazon + 2,4-DB	3,460	5,640	3,450
	Imazapic	3,730	5,940	3,530
Ethalfluralin PPI + flumioxazin PRE (105 g/ha)	None	2,860	5,420	3,210
	Acifluorfen + bentazon + 2,4-DB	3,400	5,440	3,160
	Imazapic	3,500	5,940	3,000
Dimethenamid PPI	None	2,690	1,880	1,980
Ethalfluralin PPI	None	2,690	—	2,070
Nontreated		2,000	610	1,220
LSD (0.05)		520	850	530

[a] Means within each column were separated using Fisher's protected LSD test ($P < 0.05$).
[b] Abbreviations: PPI, preplant incorporated; PRE, preemergence; POST, postemergence.
[c] The rate was 1,300 g/ha for dimethenamid and 840 g/ha for ethalfluralin.
[d] POST treatment included bentazon (560 g/ha) plus acifluorfen (280 g/ha) plus 2,4-DB (280 g/ha). Imazapic was applied at 36 g/ha.

105 g/ha yielded 3,480 and 3,200 kg/ha, respectively, and these yields were significantly different ($P = 0.05$). At a quota price support of $0.67/kg of peanut, this yield reduction would represent a loss of $187.60/ha plus the additional cost of the higher rate of flumioxazin treatment.

Weed control and yield with systems including flumioxazin were similar with or without POST applications. These data indicate that flumioxazin PRE at the lower rate would benefit peanut weed management systems in North Carolina when prickly sida and ivyleaf morningglory are a problem. Flumioxazin could allow peanut farmers to exclude or delay POST treatments by providing residual weed control from planting to canopy closure. The potential for peanut injury from flumioxazin is likely increased by cool, wet conditions, and injury increases with a higher rate of treatment where conditions are favorable for injury. Further research into the physiological behavior of flumioxazin in peanut as influenced by temperature and moisture is under investigation.

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