Residual Weed Control with Imazapic, Diclosulam, and Flumioxazin in Southeastern Peanut (*Arachis hypogaea*)

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ABSTRACT

Imazapic, diclosulam, and flumioxazin have been registered for use in peanut since 1996. These herbicides provide substantial residual control of broadleaf weeds in peanut. A comprehensive review was conducted for these residual herbicides to determine their role in future weed control systems in peanuts. Weed control data for research from over 100 experiments conducted from 1990-2000 by Georgia, Florida, and Auburn Universities and USDA-ARS scientists were compiled. Residual herbicide systems evaluated were imazapic postemergence (POST) at 71 g ai/ha, flumioxazin preemergence (PRE) at 70, 87, and 104 g ai/ha, diclosulam preplant incorporated (PPI) and PRE at 18 and 26 g ai/ha, and paraquat plus bentazon early POST (EPOST). Other treatments included the residual herbicides used in combination with paraquat plus bentazon EPOST, for a total of 17 treatments. Regionally important weeds were selected and included: sicklepod, Florida beggarweed, purple and yellow nutsedge, *Ipomoea* morningglory species, and smallflower morningglory. Sicklepod control with imazapic alone was 86% (50 tests), 73% (25 tests) with paraquat plus bentazon, and 63% or less with diclosulam and flumioxazin regardless of rate. Florida beggarweed control was 90% (29 tests) with flumioxazin (104 g/ha PRE); 78% (50 tests) with diclosulam 26 g/ha PPI; 72% (72 tests) with imazapic; and 70% (40 tests) with paraquat plus bentazon. Purple and yellow nutsedge control was 90% with imazapic. Yellow nutsedge control was 78% (18 tests) with diclosulam (26 g/ha PRE) and less than 69% with flumioxazin and paraquat plus bentazon. Paraquat plus bentazon increased weed control over residual herbicides alone.

Key Words: Early post, herbicides, postemergence, preplant incorporated.

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Herbicides applied to peanut early in the growing season often do not control weeds for the entire season and additional herbicides are needed for complete control. From 1940 to 1997, peanut yield increased from 0.79 to 2.68 t/ha partially as a result of improved weed control (Warren *et al.*, 1998). In a historical review, Buchanan *et al.* (1982) described the herbicide changes and weed shifts that occurred during the 1950s, 60s, and 70s. During this time, a wide range of herbicides was evaluated for efficacy and peanut tolerance. In the 1960s, dinoseb emerged as the most promising herbicide for postemergence (POST) weed control. Peanut could tolerate dinoseb concentrations that were detrimental to sicklepod [*Senna obtusifolia* (L.) H. Irwin & Braneby] and Florida beggarweed [*Desmodium tortuosum* (Sweet) DC.]. Dinoseb [2-*sec*-butyl-4,6-dinitriophenol(-91-methylpropyl)-4,6-dinitrophenol] was successfully integrated to control sicklepod for these and other broadleaf weeds in southeastern U.S. peanut production (Buchanan *et al.*, 1982). Dinoseb was extensively used until 1986, prior to cancellation of registrations due to toxicology reasons. This left a void for POST control of sicklepod and Florida beggarweed.

The introduction of dinitroanaline (DNA) herbicides led to more efficient control of small-seeded broadleaf weeds and annual grasses. However, these herbicides do not control sicklepod or Florida beggarweed (Buchanan *et al.*, 1982). Also, a weed shift toward purple nutsedge (*Cyperus rotundus* L.) and yellow nutsedge (*C. esculentus* L.) occurred in peanut with the advent of new herbicides and mechanization from 1955 to 1965 (Buchanan *et al.*, 1982).

Peanut tolerance to paraquat (1,1'-dimethyl-4,4'bipyridinium dichloride) was first noted in the late 1970s (Wilcut *et al.*, 1995). Wehtje *et al.* (1986) reported that paraquat controlled Texas panicum (*Panicum texanum* Buckl.) when applied sequentially, and Johnson *et al.* (1993) noted differences in cultivar tolerance. Paraquat is often tank-mixed with bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothia-diazin-4(3*H*)-one 2,2-dioxide] and can be applied up to 28 d after peanut emergence. Bentazon increases control of paraquat-tolerant species such as bristly starbur (*Acanthospermum hispidum* DC.), coffee senna (*Cassia occidentalis* L.), prickly sida (*Sida spinosa* L.), and smallflower morningglory [*Jacquemontia tamnifolia* (L.) Griseb.] (Wehtje *et al.*, 1992). Furthermore, bentazon reduces paraquat-induced injury to peanut (Wehtje *et al.*, 1992). Both paraquat and bentazon are mutually antagonistic toward foliar absorption of each other (Wehtje *et al.*, 1992). Mixtures of paraquat with bentazon have become a standard practice in southeastern U.S. peanut weed management (Wehtje *et al.*, 1992). However, this mixture lacks residual activity and has a narrow window of application (Wilcut *et al.*, 1995).

During the 1980s and continuing into the 1990s, the development and introduction of preplant incorporated (PPI), preemergence (PRE), EPOST, and POST herbicides emphasized the control of these broadleaf and nutsedge species. Lack of extended residual activity, variation in weed control spectrum, rotational restrictions, and treatment cost limited herbicide use and options for season-long weed control. These factors limited the domination of any one particular herbicide in peanut weed control. Comprehensive reviews of herbicide use in peanut in the southeastern U.S. can be found elsewhere (Buchanan *et al.*, 1982; Brown, 1994; Wilcut *et al.*, 1995).

Imazapic {(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid} was registered in 1996 for PRE or EPOST application, diclosulam [*N*-(2,6-dichlorophenyl)-5-ethoxy-7-fluoro(1,2,4)triazolo(1,5-*c*)pyrimidine-2-sulfonamide] was registered for PPI and PRE application in 2000, and flumioxazin {2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2*H*-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1*H*-isoindole-1,3(2*H*)-dione} was registered for PRE application in 2001. These herbicides provide substantial residual weed control. While much literature has been published on the peanut weed control spectrum of these herbicides (Newsom *et al.*, 1993; Richburg *et al.*, 1995a,b; Grichar and Colburn, 1996; Wilcut *et al.*, 1996, 2001; Dotray and Keeling, 1997; Grichar, 1997; Grichar *et al.*, 1997; Grichar and Nester, 1997; Webster *et al.*, 1997; Askew *et al.*, 1999; Bailey *et al.*, 1999a, b, 2000; Jordan, 1999; Grey *et al.*, 2000, 2001, 2002; Grichar and Sestak, 2000; Wehtje *et al.*, 2000a,b; Dotray *et al.*, 2001) and data bases have been developed to establish herbicide application decision support system programs such as peanut HERB (White and Coble, 1997; MacDonald *et al.*, 1998; Wilcut *et al.*, 1999) and now HADSS (Prostko *et al.*, 2003). However, a composite of weed control data for field research in southeastern U.S. has not been developed. To summarize current and future weed control options for peanut producers, research, extension, and agricultural chemical industry personnel in this region, and to assist in augmenting herbicide recommendations, a review was developed for imazapic, diclosulam, flumioxazin, and paraquat plus bentazon. Weed control data for research from over 100 experiments conducted from 1990-2000 from Auburn Univ., Univ. of Florida, Univ. of Georgia, and USDA-ARS scientists were compiled.

Materials and Methods

Data from over 100 separate experiments conducted in Alabama, Flordia, and Georgia were reviewed. In order to make comparisons between herbicides, standards were selected that included PPI, PRE, EPOST, and POST treatments. Paraquat and paraquat-tank mixtures were applied to 110% (multiple herbicides applications to the same field) of the 1998 Georgia peanut crop.

Herbicide treatments selected were diclosulam PPI and PRE (18 and 26 g ai/ha), flumioxazin PRE (70, 87, and 104 g ai/ha), sulfentrazone PRE (168, 224, and 280 g ai/ha), imazapic POST (71 g ai/ha), and the standard of paraquat plus bentazon EPOST (280 plus 500 g ai/ha). A complete list of herbicide treatments is provided in Table 1.

Visual estimates of percentage weed control using a scale of 0 to 100 where 0 = no control and 100 = complete control. Weeds compared are among the most common and troublesome in peanut (Dowler, 1998). Morningglory species included smallflower [*Jacquemonita tamnifolia* (L.) Griseb.], tall [*I. purpurea* (L.) Roth], pitted (*I. lacunose* L.), entireleaf (*Ipomoea hederacea* var. *integriuscula* Gray), and ivyleaf [(*I. hederacea* (L.) Jacq.]. All weed control ratings reflect midseason weed control (July-Aug.) except for Florida beggarweed which are from late season ratings (Sept.). Chlorosis, necrosis, plant stunting, and weed population were considered when making the visual estimates. Experimental design differed among states, researchers, and years. However, the dominant experimental design was a randomized complete block with treatments replicated three or four times. The average of the replicates was considered as the experimental unit for our research. Weed control was averaged across test and years to report average weed control, standard deviation, and number of test (Nutter and Schultz, 1995).

Results and Discussion

Sicklepod control by diclosulam (PPI or PRE) and flumioxazin (PRE) was 54% or less and 63% or less, respectively, regardless of rate (Table 1). Previous reports have emphasized the lack of sicklepod control with diclosulam (Grey *et al.*, 2001) and flumioxazin (Grey *et al.*, 2002). Imazapic POST controlled sicklepod 86%. Previous research has documented effective control of sicklepod by imazapic POST (Richburg *et al.*, 1995b; Wilcut *et al.*, 1996; Webster *et al.*, 1997; Wehtje *et al.*, 2000) and this has attributed to its acceptance in southeastern peanut production. Paraquat plus bentazon EPOST controlled sicklepod 73%. Sicklepod can germinate over the course of the season (Teem *et al.*, 1980). Lack of any soil residual activity from paraquat or bentazon contributed to the marginal control of this weed (Wilcut *et al.*, 1996).

The combination of residual herbicides (diclosulam or flumioxazin) and paraquat plus bentazon EPOST increased sicklepod control regardless of residual herbicide rate (Table 1). Sicklepod control by paraquat plus bentazon EPOST followed by imazapic POST was 94%. Paraquat plus bentazon can be applied up to 28 d after peanut emergence (DAE) providing good weed control (Wehtje *et al.*, 1986), but this application timing can be hard for some producers to achieve due to large hectarage productions (Wilcut *et al.*, 1996). However, imazapic POST applied up to 45 DAE provides contact and residual control of sicklepod.

Florida beggarweed control by flumioxazin PRE at 70, 87, and 104 g/ha was 89, 91, and 90%, respectively (Table 1). These data suggest that flumioxazin effectively controls Florida beggarweed regardless of rate. Diclosulam PPI at 18 and 26 g/ha controlled Florida beggarweed 73 and 78%, respectively (Table 1). Diclosulam PRE applied at 18 and 26 g/ha control was 84 and 87%, respectively. PRE applied diclosulam will not be effective until rainfall or irrigation has incorporated it into the soil (Anon., 2000) and Bailey *et al.* (1999) attributed inconsistent weed control for diclosulam PRE to variable rainfall. Greater Florida beggarweed control with diclosulam PRE than PPI reported here could be due to a dilution affect caused by PPI that results in a less concentrated zone of herbicide available for uptake by germinating weed seeds.

Imazapic POST and paraquat plus bentazon EPOST provided similar Florida beggarweed control (72 and 70%, respectively). Control with imazapic POST may have been reduced due to the timing of the application. Foliar entry is more critical than root entry for imazapic (Wehtje *et al.*, 2000b). Control by PRE or PPI applications of imazapic can be erratic (Webster *et al.*, 1997). The developing crop canopy can cover Florida beggarweed seedlings and inhibit herbicide spray contact (Cardina and Brecke, 1991). This can limit imazapic POST weed contact resulting in variable Florida beggarweed control.

Sequential applications of paraquat plus bentazon EPOST followed by imazapic POST controlled Florida beggarweed 88% (Table 1). This level of control was comparable to control by flumioxazin either alone or followed by paraquat plus bentazon. Additionally, the combination of diclosulam PPI or PRE followed by paraquat plus bentazon EPOST controlled Florida beggarweed 84 to 93%. Paraquat plus bentazon EPOST is necessary for acceptable control of Florida beggarweed when using imazapic or diclosulam.

Midseason bristly starbur control was greater than 87% with diclosulam PRE or PPI regardless of rate while imazapic POST controlled this weed 80%. Previous research (Wilcut *et al.*, 1996; Webster *et al.*, 1997; Wehtje *et al.*, 2000) reported at least 94% control of bristly starbur by imazapic POST. Flumioxazin PRE at 70 and 104 g/ha controlled bristly starbur 78 and 76%, respectively. Paraquat plus bentazon EPOST controlled bristly starbur 68%, most likely due to the lack of residual control (Grey *et al.*, 1995). However, when paraquat plus bentazon EPOST was used in combination with diclosulam PRE or PPI, flumioxazin PRE, or imazapic POST, control of this weed was

Table 1. Summary of residual EPOST herbicide treatments for sicklepod, Florida beggarweed, and bristly starbur control in Alabama, Florida, and Georgia peanut (1990-2000).

Treatment	Treatment timing[a]	Rate	Sicklepod		Florida beggarweed		Bristly starbur	
			None	Paraquat + bentazon[b]	None	Paraquat + bentazon	None	Paraquat + bentazon
		g/ha	%		%		%	
Diclosulam	PPI	18	44 (19; 28)[c]	78 (19; 19)	73 (19; 31)	84 (14; 20)	NA	95 (4; 6)
	PPI	26	54 (19; 38)	74 (18; 18)	78 (21; 50)	88 (12; 21)	94 (5; 23)	93 (10; 9)
	PRE	18	41 (16; 11)	65 (21; 6)	84 (14; 15)	84 (13; 11)	87 (20; 9)	NA
	PRE	26	44 (14; 13)	73 (16; 7)	87 (12; 21)	89 (11; 13)	97 (2; 10)	NA
Flumioxazin	PRE	87	48 (24; 11)	60 (31; 5)	91 (12; 16)	94 (4; 7)	94 (6; 7)	NA
	PRE	104	62 (21; 20)	73 (23; 6)	90 (17; 29)	91 (13; 8)	76 (24; 17)	NA
Imazapic	POST	71	86 (13; 50)	94 (8; 24)	72 (19; 72)	88 (9; 30)	80 (22; 29)	94 (5; 12)
Paraquat + bentazon	EPOST	--	73 (21; 25)	--	70 (22; 40)	--	68 (21; 13)	--

[a]Abbreviations: Preplant incorporated, PPI; preemergence, PRE; early post emergence, EPOST; post emergence, POST.

[b]Paraquat plus bentazon at 280 and 500 g/ha, respectively.

[c]Treatment average followed by standard deviation and number of tests averaged for that treatment in parentheses.

improved to at least 87%.

Control of both purple and yellow nutsedge by imazapic was 90%. This supports research by other (Richburg *et al.*, 1995b; Wilcut *et al.*, 1996; Dotray and Kelling, 1997; Grichar and Nester, 1997; Webster *et al.*, 1997) showing effective season long control of purple and yellow nutsedge. Purple and yellow nutsedge control by diclosulam PPI or PRE was less than that by imzapic (Table 2). However, sequential applications of diclosulam PPI or PRE followed by paraquat plus bentazon EPOST improved control (68-86%). Diclosulam PPI control of yellow nutsedge has been inconsistent (Grey *et al.*, 2001). Flumioxazin PRE controlled purple 38% or less and yellow nutsedge 42% or less regardless of rate. Poor control of both species by flumioxazin has been reported previously (Askew *et al.*, 1999; Grey *et al.*, 2002). Paraquat plus bentazon EPOST controlled purple and yellow nutsedge 64 and 59%, respectively. Sequential applications of flumioxazin PRE followed by paraquat plus bentazon EPOST improved control of yellow nutsedge (77-78%).

Morningglories were controlled 83% or more by diclosulam

Table 2. Summary of residual EPOST herbicide treatments for purple and yellow nutsedge control in Alabama, Florida, and Georgia peanut (1990-2000).

			Purple nutsedge		Yellow nutsedge	
Treatment	Treatment timing[a]	Rate	None	Paraquat + bentazon[b]	None	Paraquat + bentazon
		g/ha	-----%-----		-----%-----	
Diclosulam	PPI	18	72 (17; 6)[c]	68 (21; 6)	73 (25; 9)	82 (12; 6)
	PPI	26	59 (28: 9)	73 (19; 7)	78 (19; 18)	81 (19; 7)
	PRE	18	65 (15; 10)	76 (13; 6)	NA	NA
	PRE	26	73 (15; 6)	84 (12; 6)	78 (9; 5)	NA
Flumioxazin	PRE	70	NA	NA	38 (31; 11)	NA
	PRE	87	NA	NA	40 (37; 10)	72 (20; 7)
	PRE	104	38 (28; 7)	NA	42 (32; 15)	NA
Imazapic	POST	71	90 (19; 11)	95 (4; 5)	90 (15; 18)	86 (22; 6)
Paraquat + bentazon	EPOST	--	64 (21; 9)	--	59 (13; 7)	--

[a]Abbreviations: Preplant incorporated, PPI; preemergence, PRE; early post emergence, EPOST; post emergence, POST.

[b]Paraquat plus bentazon at 280 and 500 g/ha, respectively.

[c]Treatment average followed by standard deviation and number of tests averaged for that treatment in parentheses.

Table 3. Summary of residual EPOST herbicide treatments for smallflower, tall, pitted, and ivyleaf morngingloryc ontrol in Alabama, Florida, and Georgia peanut (1990-2000).

			Morningglory species[b]		Smallflower morningglory	
Treatment	Treatment timing[a]	Rate	None	Paraquat + bentazon[c]	None	Paraquat + bentazon
		g/ha	-----%-----		-----%-----	
Diclosulam	PPI	18	85 (17; 4)[d]	NA	NA	NA
	PPI	26	89 (10; 9)	85 (24; 4)	94 (9; 9)	84 (26; 4)
	PRE	18	99 (1: 3)	NA	NA	NA
	PRE	26	99 (1; 3)	99 (1; 3)	96 (3; 6)	NA
Flumioxazin	PRE	70	81 (9; 4)	NA	NA	NA
	PRE	87	91 (6; 5)	88 (18; 2)	NA	NA
	PRE	104	88 (5; 8)	92 (7; 3)	92 (14; 9)	96 (3; 4)
Imazapic	POST	71	97 (4; 13)	100 (1; 4)	91 (20; 9)	98 (3; 3)
Paraquat + bentazon	EPOST	--	79 (28; 5)	--	82 (16; 3)	--

[a]Abbreviations: Preplant incorporated, PPI; preemergence, PRE; early post emergence, EPOST; post emergence, POST.

[b]Morningglory species control of tall, pitted, entireleaf, and ivyleaf.

[c]Paraquat plus bentazon at 280 and 500 g/ha, respectively.

[d]Treatment average followed by standard deviation and number of tests averaged for that treatment in parentheses.

PRE and PPI, flumioxazin PRE at 87 and 104 g/ha, and imazapic POST (Table 3). Control by paraquat plus bentazon was 79% (Table 3). Similar levels of control have been reported for diclosulam PPI and PRE (Bailey *et al.*, 1999a,b), flumioxazin PRE (Grichar and Colburn, 1996; Askew *et al.*, 1997), and imazapic POST (Richburg *et al.*, 1995b; Wilcut *et al.*, 1996; Grichar, 1997; Webster *et al.*, 1997). Applying paraquat plus bentazon EPOST following diclosulam PPI or PRE, flumioxazin PRE, or imazapic POST improved morningglory control in some, but not all instances.

Control of smallflower morningglory was at least 90% for diclosulam PPI and PRE, flumioxazin PRE, and imazapic POST. Paraquat plus bentazon EPOST controlled this weed no more than 82% (Table 3). Excellent control of smallflower morningglory by imazapic POST has been reported previously (Richburg *et al.*, 1995b; Wilcut *et al.*, 1996; Webster *et al.*, 1997; Wehtje *et al.*, 2000).

Conclusions

Results from this review suggest that imazapic POST controls sicklepod, purple and yellow nutsedge, and smallflower morningglory. However, paraquat plus bentazon EPOST is needed to control Florida beggarweed in programs containing imazapic as the only residual herbicide. Diclosulam PPI and PRE controls bristly starbur, smallflower morningglory, and other morningglory species. Sicklepod, Florida beggarweed, and purple and yellow nutsedge control will be improved if diclosulam PPI or PRE is supplemented with EPOST applications of paraquat plus bentazon. Flumioxazin PRE controls Florida beggarweed, smallflower and other morningglory species, and bristly starbur. Sicklepod and purple and yellow nutsedge control will be improved if flumioxazin PRE is supplemented with paraquat plus bentazon EPOST.

Recent changes in the federal farm legislation have substantially decreased the economic value of peanut at the farm level (Bullen and Smith, 2002; Chvosta *et al.*, 2002). The number of residual herbicides available for peanut producers to choose from has increased significantly with the registration of imazapic, diclosulam, and flumioxazin. While numerous herbicide options exist, peanut producers will need to use these herbicides judiciously in management strategies that optimize economic return.

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