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Annual Grass Control in Peanut (*Arachis hypogaea*) with Clethodim and Imazapic[1]

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Abstract: Field experiments were conducted to evaluate possible interactions of clethodim with imazapic applied as mixtures or sequentially for control of broadleaf signalgrass, fall panicum, goosegrass, and large crabgrass. Imazapic at 70 g ai/ha alone controlled grass weeds inconsistently, whereas clethodim at 140 g ai/ha alone controlled the same weeds at least 99%. Imazapic did not affect broadleaf signalgrass control by clethodim. Reduced control of fall panicum, goosegrass, and large crabgrass was observed when clethodim and imazapic were applied in mixture. Antagonism of clethodim occurred when clethodim was applied 1 d before or up to 3 d after application of imazapic (fall panicum and large crabgrass). Antagonism of goosegrass control was noted when imazapic was applied 3 d before or up to 7 d after application of clethodim. In other experiments, large crabgrass and Texas panicum control by clethodim (70 and 140 g/ha) applied alone or with imazapic (70 g/ha) or bentazon (1.1 kg ai/ha) plus 2,4-DB (0.28 kg ai/ha) either with or without ammonium sulfate (2.8 kg/ha) was evaluated. Texas panicum control by clethodim was reduced by imazapic regardless of the ammonium sulfate rate. However, large crabgrass control by imazapic was not affected in these experiments. Control of both grasses by clethodim was reduced substantially by bentazon plus 2,4-DB, although in some instances ammonium sulfate improved control when in mixture. Ammonium sulfate improved control by clethodim in some instances irrespective of the broadleaf–sedge herbicide treatments.

Nomenclature: Bentazon; clethodim; 2,4-DB; imazapic; broadleaf signalgrass, *Brachiaria platyphylla* (Griseb) Nash #[3] BRAPP; fall panicum, *Panicum dichotomiflorum* L. # PANDI; goosegrass, *Eleusine indica* L. Gaertn. # ELEIN; large crabgrass, *Digitaria sanguinalis* L. Scop. # DIGSA; Texas panicum, *Panicum texanum* Buckl. # PANTE.

Additional index words: Ammonium sulfate, antagonism, herbicide compatibility, herbicide interaction, sequential application.

INTRODUCTION

Imazapic is registered in peanut (*Arachis hypogaea* L.) for control of annual broadleaf weeds and purple nutsedge (*Cyperus rotundus* L.) and yellow nutsedge (*C. esculentus* L.) (Richburg et al. 1994; Warren and Coble 1999; Wilcut et al. 1996). Imazapic also suppresses and in some instances controls annual and perennial grasses (Jennings et al. 1995; Jordan and York 2002; Wilcut et al. 1995). Clethodim is registered in peanut to control annual and perennial grasses (Jordan and York 2002; Wilcut et al. 1995). Although imazapic controls annual grasses, control is often inconsistent compared with clethodim (Jordan and York 2002). Because timing of application of imazapic for broadleaf weed and perennial sedge control and timing of application of clethodim for grass control often coincide, determination of the compatibility of clethodim and imazapic would be beneficial in formulating weed management strategies.

Interactions of graminicides and broadleaf–sedge herbicides are well documented. Imazethapyr and imazaquin, both imidazolinone herbicides like imazapic, which inhibit acetolactate synthase (ALS, EC 4.1.3.18), often reduce efficacy of graminicides (Minton et al. 1989; Myers and Coble 1992). Furthermore, reduced grass control is often observed when broadleaf herbicides, such as acifluorfen, bentazon, and bromoxynil, are mixed with graminicides (Culpepper et al. 1999; Holshouser and Coble 1990; Rhodes and Coble 1984; Vidrine et al. 1995). Other herbicides that inhibit ALS can reduce grass control

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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.

by the cyclohexanedione herbicides clethodim and sethoxydim (Burke et al. 2003; Ferreira and Coble 1994; Foy and Witt 1992; Holshouser and Coble 1990; Jordan 1995). Although pyrithiobac suppresses annual and perennial grasses, it can cause antagonism of graminicides (Ferreira and Coble 1994; Jordan et al. 1993). In addition, the phenoxy herbicide 2,4-DB can reduce efficacy of clethodim (York et al. 1993).

Weed species, weed size at the time of graminicide application, herbicide rate, and adjuvant can influence interactions among graminicides and broadleaf–sedge herbicides (Corkern et al. 1999; Jordan 1995; Rhodes and Coble 1984; Wanamarta and Penner 1989). Ammonium sulfate and other adjuvants can reduce antagonism of clethodim and sethoxydim activity caused by broadleaf–sedge herbicides (Jordan 1995; Jordan and York 1989; Wanamarta and Penner 1989). Sequential applications of herbicides also reduce antagonism (Ferreira and Coble 1994; Myers and Coble 1992) as does increase in graminicide rate (Rhodes and Coble 1984).

Determining if addition of ammonium sulfate or application of herbicides sequentially reduces antagonism of clethodim by imazapic is important in applying these herbicides most effectively in peanut. Research was conducted to determine if imazapic reduces annual grass control by clethodim when applied in mixture and to determine if applying herbicides sequentially or with ammonium sulfate minimizes adverse interactions.

MATERIALS AND METHODS

Mixtures and Sequential Applications of Clethodim and Imazapic. Experiments were conducted in 2000 in separate fields at both the Central Crops Research Station located near Clayton, NC, and the Upper Coastal Plain Research Station located near Rocky Mount, NC. The experiment also was conducted at the Peanut Research Station located near Lewiston-Woodville, NC, in 2000. Soils were a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudults) with 1.8% organic matter and pH 5.6 at Clayton, a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudults) with 1.0% organic matter and pH 5.9 at Lewiston-Woodville, and a Conetoe loamy sand (loamy, mixed, thermic Arenic Hapludults) with 1.1% organic matter and pH 5.7 at Rocky Mount. Experiments were established in fields planted to peanut ‘NC 10C’ with natural infestations of broadleaf signalgrass, fall panicum, goosegrass, and large crabgrass at populations of $\geq$20 plants/m^2. Plot size was 3 by 6 m.

Clethodim and imazapic were applied alone and in mixture to grasses 30 to 40 cm in height. In addition, imazapic was applied 1, 3, 7, or 14 d before or after application of clethodim. All clethodim treatments were applied on the same day. A nontreated control was included. Clethodim and imazapic were applied at 140 and 70 g ai/ha, respectively. Crop oil concentrate[4] at 1.0% (v/v) was included with clethodim-containing treatments. Applications of imazapic alone included a nonionic surfactant[5] at 0.25% (v/v). Herbicides were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 187 L/ha aqueous solution at 140 kPa through XR-11002VS spray nozzles.[6]

Broadleaf signalgrass control was evaluated in separate fields at Rocky Mount and in one field at Lewiston-Woodville. Goosegrass and large crabgrass control was evaluated at Rocky Mount and Clayton. Fall panicum control was evaluated in two fields at Clayton.

Visual estimates of percent grass control were recorded 17 to 35 d after the final herbicide application using a scale of 0% (no control) to 100% (plant death) (Frans et al. 1986). Foliar chlorosis, necrosis, and plant stunting were considered when making visual estimates.

The experimental design was a randomized complete block with treatments replicated three times. Data were tested for homogeneity of variance by plotting residuals. The nontreated control was not included in the analysis of variance. Arcsine square-root transformation did not improve variance homogeneity, so nontransformed data were used in analysis and presentation. Field data were subjected to an analysis of variance using the general linear models procedure in SAS, and sums of squares were partitioned to evaluate the effect of imazapic and clethodim mixtures, sequential applications, and experiments (SAS 1998). Both experiment replication and experiments were considered random variables, and main effects and interactions were tested by the appropriate mean square associated with the random variable (McIntosh 1983). Mean separations were performed using Fisher’s protected LSD test at $P \leq 0.05$.

The expected response for herbicide mixtures and sequential treatments was calculated according to Colby (1967). Expected and observed values were compared using the appropriate LSD value at $P \leq 0.05$. If the observed response for the herbicide mixture or sequential application was either significantly less than or great-

[4] Agri-Dex (83% paraffin-base petroleum oil and 17% surfactant blend), Helena Chemical Co., 5100 Poplar Avenue, Memphis, TN 38137.

[5] Induce (90% alkylarylpolyoxylkaneether and free fatty acids), Helena Chemical Co., 5100 Poplar Avenue, Memphis, TN 38137.

[6] TeeJet Spray Nozzles, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189.

Table 1. Fall panicum, large crabgrass, and goosegrass control by imazapic and clethodim applied alone, in mixture, and sequentially.

Herbicide sequence[a]	Sequence interval	Fall panicum[b]	Large crabgrass		Goosegrass	
			Clayton	Rocky Mount	Clayton	Rocky Mount
	d	%				
Clethodim	—	100	99	100	99	100
Imazapic	—	82	76	95	37	62
Clethodim then imazapic	14	100	99	100	96	100
Clethodim then imazapic	7	100	99	98	95	100
Clethodim then imazapic	3	99	94	98	83*	100
Clethodim then imazapic	1	98	73*	91*	63*	97
Clethodim plus imazapic	0	88*[c]	66*	82*	54*	79*
Imazapic then clethodim	1	92*	81*	93*	51*	87*
Imazapic then clethodim	3	92*	88*	96	65*	92
Imazapic then clethodim	7	98	93	98	88*	94
Imazapic then clethodim	14	100	97	99	95	99
LSD (0.05)		4	10	7	9	9

[a] Clethodim and imazapic applied at 140 and 70 g/ha, respectively. All clethodim treatments were applied on the same day.

[b] Data are pooled over two experiments.

[c] Interactions were evaluated by the method described by Colby (1967), an * denotes antagonism, and no marking indicates an additive effect. Interactions were significant only if the differences between the observed and expected values exceeded the appropriate LSD values.

er than the expected value, the combination was declared either antagonistic or synergistic, respectively. Mixtures or sequential applications were considered additive (i.e., no interaction) when differences between observed and expected responses were not significant (Hicks et al. 1998).

Mixtures of Clethodim with Herbicides Applied Alone and with Ammonium Sulfate. The experiment was conducted in 1999 in three separate fields at the Peanut Belt Research Station located near Lewiston-Woodville, NC, on the Norfolk loamy sand soil described previously and in 2002 at the Upper Coastal Plain Experiment Station located near Rocky Mount, NC, on a Goldsboro sandy loam (fine-loamy, siliceous, thermic Aquic Paleudults) with 2.1% organic matter and pH 5.9. The experiment also was conducted at the Coastal Plain Research Station located near Tifton, GA, in 1999 on a Tifton fine sand (fine-loamy siliceous Plinthic Kandiudults) with 0.9% organic matter and pH 5.8. Experiments in 1999 in North Carolina were conducted in fields planted to peanut ‘NC 7’ with a natural infestation of large crabgrass. Texas panicum control was evaluated in a fallow area at Tifton. In 2002, the experiment was conducted in a fallow field at Rocky Mount. Large crabgrass and Texas panicum density ranged from 10 to 60 plant/m^2. Plot size was 2 by 6 m.

Clethodim (70 and 140 g/ha) was applied alone or with imazapic (70 g/ha) or bentazon plus 2,4-DB (1.1 plus 0.28 kg ai/ha) when grasses were 15 to 30 cm in height. Bentazon and 2,4-DB are applied routinely to peanut (Jordan and York 2002). Each of these herbicide treatments was applied with or without ammonium sulfate (2.8 kg/ha). A nontreated control was included. Herbicides were applied in 187 L/ha aqueous solution at 140 kPa using 8002 regular flat-fan nozzles.[6]

The experimental design was a randomized complete block with three or four replications. Visual estimates of percent large crabgrass and Texas panicum control were recorded 21 d after treatment using the scale described previously.

Data for large crabgrass and Texas panicum control were subjected to analysis of variance for a 2 (clethodim rate) by 3 (broadleaf–sedge herbicide treatment) by 2 (ammonium sulfate rate) factorial treatment arrangement. Means of significant main effects and interactions were separated using Fisher’s protected LSD test at $P \leq 0.05$ using the procedures outlined previously.

RESULTS AND DISCUSSION

Mixtures and Sequential Applications of Clethodim and Imazapic. Broadleaf signalgrass control by clethodim and imazapic applied alone, in mixture, or sequentially was at least 98% (data not shown). In contrast, differences in control of fall panicum, goosegrass, and large crabgrass were noted among herbicide treatments (Table 1). Lack of an experiment by herbicide treatment interaction allowed pooling of data over experiments for fall panicum control. Clethodim and imazapic, each applied alone, controlled fall panicum 100 and 82%, respectively (Table 1). In comparison, fall panicum control by clethodim was reduced by 12 percentage points to

Table 2. Large crabgrass and Texas panicum control by clethodim applied with imazapic and bentazon + 2,4-DB.

Broadleaf–sedge herbicides[a]	Large crabgrass			Texas panicum[d]
	1999[b]	2002[c] 0 kg/ha	2002[c] 2.8 kg/ha	
	%			
None	94	88	90	97
Imazapic	91	92	90	90
Bentazon plus 2,4-DB	62	68	86	81
LSD (0.05)	6	7		5

[a] Imazapic, bentazon, and 2,4-DB applied at 70 g/ha, 1.1 kg/ha, and 0.28 kg/ha, respectively.

[b] Data are pooled over three experiments, clethodim rates of 70 and 140 g/ha, and ammonium sulfate rates of 0 and 2.8 kg/ha.

[c] Data are pooled over clethodim rates of 70 and 140 g/ha and are from one experiment in 2002. Ammonium sulfate was added at the rates of 0 and 2.8 kg/ha.

[d] Data are pooled over clethodim rates of 70 and 140 g/ha and ammonium sulfate rates of 0 and 2.8 kg/ha.

Table 3. Influence of clethodim and ammonium sulfate rates on large crabgrass and Texas panicum control by clethodim.[a]

Clethodim rate	Ammonium sulfate rate: Large crabgrass 0 kg/ha	Large crabgrass 2.8 kg/ha	Texas panicum 0 kg/ha	Texas panicum 2.8 kg/ha
g/ha	%			
70	77	90	80	93
140	89	88	90	94
LSD (0.05)	6		5	

[a] Data are pooled over broadleaf–sedge herbicides. Data for large crabgrass are from 2002. Data for Texas panicum are from 1999.

88% when it was applied with imazapic in mixture. Applying clethodim before imazapic provided at least 98% control. However, when clethodim was applied 1 or 3 d after imazapic, control was reduced when compared with clethodim alone.

The interaction of experiment by treatment was significant for large crabgrass control. Therefore, data are presented separately for the two locations. Imazapic controlled large crabgrass 76% at Clayton and 95% at Rocky Mount, whereas control by clethodim alone was at least 99% at both locations (Table 1). Large crabgrass control at Clayton and Rocky Mount was reduced to 66 and 82%, respectively, when imazapic and clethodim were applied in mixture. Application of clethodim 1 d before or 1 and 3 d after imazapic resulted in less control than when clethodim was applied alone at Clayton, whereas at Rocky Mount, application of clethodim 1 d before or after imazapic reduced control when compared with clethodim alone.

The interaction of experiment by treatment was significant for goosegrass control. Goosegrass control by imazapic alone was lower (37 to 62%) than control by clethodim alone (at least 99%) (Table 1). Goosegrass control at Clayton and Rocky Mount was reduced by 45 and 21 percentage points, respectively, when imazapic was applied with clethodim compared with clethodim applied alone (Table 1). At Clayton, control was reduced when imazapic was applied first followed by clethodim 1, 3, or 7 d later when compared with clethodim alone. Control at Rocky Mount also was reduced when imazapic was applied first followed by clethodim 1 d later. Goosegrass control at Rocky Mount was reduced when imazapic was applied 1 d before clethodim.

Mixtures of Clethodim with Herbicides Applied Alone and with Ammonium Sulfate. The interaction of experiment by clethodim rate by broadleaf–sedge herbicide by ammonium sulfate rate as well as two-way and three-way interactions of these treatment factors were not significant for large crabgrass control in 1999. Although the main effect of broadleaf herbicide was significant, main effects of clethodim rate and ammonium sulfate rate were not significant. When pooled over experiments, clethodim rate, and ammonium sulfate rate, large crabgrass control by clethodim alone or mixed with imazapic or bentazon plus 2,4-DB was 94, 91, and 62%, respectively (Table 2). In contrast, the interaction of broadleaf–sedge herbicide by ammonium sulfate rate was significant in 2002. Although ammonium sulfate did not affect large crabgrass control by clethodim alone or when clethodim was mixed with imazapic, ammonium sulfate did eliminate antagonism caused by bentazon plus 2,4-DB. Previous research (Corkern et al. 1999; Jordan and York 1989; Wanamarta and Penner 1989) suggests that antagonism of clethodim by bentazon can be reduced when ammonium sulfate is applied with these herbicides. However, as these experiments suggest, alleviation of antogonism may be inconsistent (Jordan 1995; Jordan and York 1989).

In contrast to results for large crabgrass control, Texas panicum control by clethodim was reduced when clethodim and imazapic were applied in mixture (Table 2). Bentazon plus 2,4-DB, however, reduced control more than did imazapic.

The interaction of clethodim rate by ammonium sulfate rate was significant for large crabgrass control in 2002 and for Texas panicum control. Control of these weeds by clethodim at 70 g/ha increased when ammonium sulfate was included but not when clethodim was applied at 140 g/ha (Table 3). Previous research (York et al. 1990) suggests that ammonium sulfate often increases efficacy of sethoxydim when applied at rates below those recommended by the manufacturer.

In summary, reduced grass control was observed most often when clethodim was applied within 3 d of application of imazapic, when grasses were relatively large (30 to 40 cm in height). For sequential applications, the greatest reduction in grass control occurred when clethodim was applied 1 d before or 1 d after the application of imazapic. The reduction in grass control by imazapic in mixture with clethodim was greater than that reported for other ALS inhibitors, such as chlorimuron, thifensulfuron, and imazethapyr, when applied in mixture with cyclohexanedione herbicides (Foy and Witt 1992; Jordan 1995; Myers and Coble 1992; Vidrine et al. 1995). However, imazapic did not reduce efficacy of clethodim in all experiments, especially when herbicides were applied to smaller and younger grasses, as was the case in the ammonium sulfate study. Chlorimuron, when mixed with clethodim or sethoxydim, reduced control of johnsongrass [*Sorghum halapense* (L.) Pers.] and barnyardgrass [*Echinocloa crus-galli* (L.) P. Beauv.] compared with clethodim or sethoxydim alone, although the reduction in control was inconsistent (Jordan 1995; Vidrine et al. 1995). Chlorimuron did not antagonize broadleaf signalgrass control with clethodim (Jordan 1995; Myers and Coble 1992).

Sequential applications of at least 3 d between treatments were required to overcome antagonism by imazapic. Although ammonium sulfate did not decrease antagonism by imazapic, antagonism was relatively minor in the experiments where ammonium sulfate was included. Additional research is needed to determine if the response to ammonium sulfate would be similar if herbicides were applied to larger or older grasses. Ammonium sulfate reduced antagonism by bentazon plus 2,4-DB in some instances. Although ammonium sulfate often reduces antagonism of cyclohexanedione herbicides by bentazon, the effect of ammonium sulfate on antagonism of clethodim by 2,4-DB has not been studied.

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