Interaction of Bentazon and Imazethapyr Applied Postemergence to Nutsedge (*Cyperus* spp.)

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ABSTRACT

Field and greenhouse experiments evaluated purple nutsedge (*Cyperus rotundus* L.) and yellow nutsedge (*C. esculentus* L.) control with mixtures of bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] and imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid} applied postemergence. Mixtures of the sodium salt of bentazon at 0.6 or 1.1 kg ae/ha and the ammonium salt of imazethapyr at 35 or 70 g ae/ha were antagonistic on purple nutsedge in field and greenhouse experiments. Mixtures of bentazon at 0.6 kg/ha and imazethapyr at 35 or 70 g/ha were additive on yellow nutsedge in field experiments but antagonistic in greenhouse experiments. Mixtures of bentazon at 1.1 kg/ha and imazethapyr at 35 or 70 g/ha were antagonistic on yellow nutsedge in field and greenhouse experiments.

Key Words: *Cyperus esculentus* L., *Cyperus rotundus* L., antagonism, herbicide combinations, herbicide interactions.

Yellow nutsedge and purple nutsedge are among the most common and troublesome weeds of peanut in each of the eight major peanut-producing states in the United States (29). The effect of nutsedge on peanut yield is unknown as no research on competition of nutsedge with peanut has been published. Nutsedge is assumed to be less competitive than most other weeds (29). However, in addition to its effects on yield, nutsedge can reduce peanut quality and profits to producers. Nutsedge tubers contribute to foreign matter contamination and lead to difficulties in cleaning and processing harvested peanut (32).

Peanut producers have several options for control of yellow nutsedge (29). One option includes metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] applied preplant incorporated (PPI) alone or in combination with imazethapyr. Imazethapyr can be applied at the full rate PPI or as a split application with one-half the rate applied PPI and the other half applied postemergence (POST) (29). In North Carolina, imazethapyr in a split application has sometimes given better control of yellow and purple nutsedge than imazethapyr applied once at the same total rate (A. C. York, unpubl. data). Split applications of imazethapyr also have been at least as effective as single applications on a number of broadleaf weeds (31). Imazethapyr also will control yellow nutsedge if applied POST when the weed is small (5 to 10 cm tall) and rainfall is received within a few days after application (20, 24, 25, 27, 29). However, bentazon applied POST is usually more effective on larger yellow nutsedge (27, 29).

Imazethapyr is the only POST herbicide currently registered for peanut that controls purple nutsedge (29). Imazethapyr applied PPI or POST usually is more effective on purple nutsedge than on yellow nutsedge (8, 20, 25). Hence, a mixture of bentazon and imazethapyr applied POST would appear to be a logical treatment for mixed infestations of yellow and purple nutsedge.

Combinations of two or more herbicides or herbicides and other pesticides need to be evaluated carefully before recommending their use to growers because unexpected interactions may occur (6, 13). Both synergistic and antagonistic interactions may occur on weeds (2, 17, 18) and on crops (12, 30).

Little to no research has been published describing nutsedge response to mixtures of bentazon and imazethapyr. Mixed results have been reported with annual weeds. Hager and Renner (9) noted better control of common ragweed (*Ambrosia artemisiifolia* L.) with bentazon plus imazethapyr than with either herbicide applied alone. However, Cantwell *et al.* (3) reported antagonism on smooth pigweed (*Amaranthus hybridus* L.), jimsonweed (*Datura stramonium* L.), and giant foxtail (*Setaria faberi* Herrm.) with bentazon plus imazethapyr. Wilcut *et al.* (25) reported similar control of coffee senna (*Cassia occidentalis* L.), bristly starbur (*Acanthospermum hispidum* DC.), common cocklebur (*Xanthium strumarium* L.), prickly sida (*Sida spinosa* L.), *Ipomoea* morningglory species, and smallflower morningglory [*Jacquemontia tamnifolia* (L.) Griseb.] with bentazon plus imazethapyr and imazethapyr applied alone. Although both treatments controlled sicklepod [*Senna obtusifolia* (L.) Irwin and Barneby] and Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.] poorly, mixtures of imazethapyr plus bentazon were sometimes less effective than imazethapyr applied alone (25).

A mixture of bentazon plus imazethapyr applied POST would seem to be a logical treatment for mixed infestations of yellow and purple nutsedge. However, because variable results with bentazon plus imazethapyr have been observed with other weed species, the objective of our experiments was to evaluate control of yellow and purple nutsedge with mixtures of these two herbicides.

Materials and Methods

Field Experiments

General Methods. Sites known to be heavily infested with nutsedge were disked in early to mid-May. Nutsedge was then allowed to grow undisturbed until treatment. No crop was planted and no fertilizer was added. Treatments

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were applied when purple nutsedge was 8 to 9 cm tall in North Carolina or 12 to 18 cm tall in Georgia. Yellow nutsedge was 10 to 12 cm tall in North Carolina or 15 to 35 cm tall in Georgia when treated.

Treatments included a factorial arrangement of 0, 35, and 70 g/ha of the ammonium salt of imazethapyr and 0, 0.6, and 1.1 kg/ha of the sodium salt of bentazon. Treatments were applied with CO_2-pressurized backpack sprayers equipped with flat fan nozzles delivering 198 L/ha at 276 kPa in North Carolina or 187 L/ha at 138 kPa in Georgia. A crop oil concentrate [Agri-Dex (83% paraffin-base petroleum oil and 17% surfactant blend), Helena Chemical Co., 5100 Poplar Ave., Memphis, TN 38147] at 2.1 L/ha was included with all treatments.

The experimental design was a randomized complete block with treatments replicated four times in North Carolina and three times in Georgia. Plot size was 1.8 m x 6 m. Control was estimated visually 4 wk after treatment (WAT) using a scale of 0 = no control to 100 = complete control.

Site Descriptions. Two experiments with purple nutsedge were conducted at Woodville, NC in 1993 on a Bonneau loamy sand (loamy, siliceous, thermic Arenic Paleudults) with 78% sand, 16% silt, 6% clay, 1.4% organic matter, and pH 6.3. The purple nutsedge infestation averaged 45 plants/m^2 in each experiment. Treatments were applied in late May in the first experiment. The second experiment was conducted in an adjacent area where the initial disking was delayed approximately 2 wk. Treatments in the second experiment were applied in mid-June.

One experiment with yellow nutsedge was conducted in 1994 at Clayton, NC. Soil was a Norfolk loamy sand (fine-loamy, siliceous, thermic, Typic Kandiudults) with 76% sand, 14% silt, 10% clay, 2.3% organic matter, and pH 5.8. The yellow nutsedge population averaged 30 plants/m^2. Treatments were applied during the first week in June.

Experiments in Georgia were conducted in 1994 at Tifton and Midville. Soil was Dothan loamy sand (fine-loamy, siliceous, thermic Kandiudults) with 85% sand, 10% silt, 5% clay, 0.9% organic matter, and pH 6.1 at Tifton and 83% sand, 13% silt, 4% clay, 0.9% organic matter, and pH 5.9 at Midville. Both locations were infested with yellow and purple nutsedge, with populations averaging 40 and 15 plants/m^2, respectively, at Tifton and 25 and 30 plants/m^2, respectively, at Midville. Treatments were applied during the first week in June at both locations.

Greenhouse Experiments

In separate experiments in North Carolina during the spring of 1994, yellow and purple nutsedge tubers were planted in 15-cm (diam.) plastic pots containing a loamy sand soil (84% sand, 8% silt, 8% clay) with 1.3% organic matter and pH 5.2. After emergence, plants were thinned to nine yellow nutsedge or six purple nutsedge plants per pot. Plants were fertilized with 100 kg/ha of a water-soluble 20-20-20 (N, P_2O_5, K_2O) fertilizer at 1 and 3 wk after emergence.

Treatments were the same as in the field experiments. Treatments were applied when yellow nutsedge was 15 cm tall with six to seven leaves and when purple nutsedge was 15 cm tall with 8 to 10 leaves. Applications were made with a spray table equipped with a single even-spray flat fan nozzle delivering 363 L/ha at 290 kPa. Pots were subirrigated prior to treatment. Beginning 24 hr after treatment, pots were watered from overhead with a sprinkler system to allow for root absorption of imazethapyr (20).

Shoots were clipped at the soil surface 4 WAT, and shoot fresh weight was determined. The pots remained in the greenhouse for an additional 2 wk after which fresh weight of shoot regrowth was determined.

The experimental design was a randomized complete block with treatments replicated six times. The experiment with each species was repeated once. Day/night temperatures in the greenhouse averaged 35/25 C. Natural illumination was supplemented for 12 hr daily by a metal halide lighting system with a light intensity at plant level of 490 µE/µ^2/sec photosynthetic photon flux density.

Data Analysis

Data were subjected to analysis of variance with partitioning appropriate for the factorial treatment arrangement. Data from the greenhouse experiments were pooled over runs after checking for homogeneity of error variance. Data from field experiments were combined over locations where appropriate. Visual estimates of control in field experiments were arcsine square root transformed prior to analysis. Nontransformed data are presented with statistical interpretation based upon transformed data. Means were separated using Fisher's Protected LSD Test at P = 0.05.

A predicted response to herbicide mixtures was calculated according to Colby (5). Significance of differences between observed and predicted responses to herbicide mixtures was tested according to procedures described by Hamill and Penner (10). Although there are limitations to the Colby procedure (13), it is relatively easy to perform and is commonly used to describe responses to combinations of herbicides (1, 11, 16, 21).

Results and Discussion

Field Experiments

As expected (29), bentazon had little effect on purple nutsedge (Table 1). Imazethapyr at 35 and 70 g/ha controlled purple nutsedge 55 and 72%, respectively, in North Carolina and 32 and 53%, respectively, in Georgia. Imazethapyr is more efficacious on purple nutsedge when rainfall occurs shortly after application to move the

Table 1. Purple nutsedge control 4 wk after treatment with imazethapyr and bentazon mixtures in field experiments.[a]

Imazethapyr rate	Bentazon rate (kg/ha)		
	0	0.6	1.1
(g/ha)	%		
	North Carolina		
0	0 e	2 e	8 e
35	55 b	33 d (56)*	30 d (58)*
70	72 a	49 bc (74)*	42 c (75)*
	Georgia		
0	0 d	0 d	4 d
35	32 bc	29 c (32)	30 c (35)*
70	53 a	37 b (53)*	35 bc (55)*

[a]Means within a state followed by the same letter are not different at P = 0.05 according to Fisher's Protected LSD Test. Numbers in parentheses are predicted responses for herbicide mixtures according to Colby (5). Data pooled over two locations.

*Denotes a significant difference at P = 0.05 between the observed and the predicted response according to Hamill and Penner (9).

imazethapyr into the root zone (20). At all locations, the purple nutsedge was actively growing when treated. Additionally, 2.4 cm or more of rainfall was received within 5 d after application at each location (rainfall data not shown). The reduced control in Georgia compared with North Carolina was, therefore, attributed to the larger size of the purple nutsedge when treated. D. L. Jordan (unpubl. data, 1995) observed greater control of purple nutsedge by imazethapyr when the herbicide was applied to 2- to 6-cm weeds rather than 8- to 12-cm weeds.

Bentazon plus imazethapyr controlled purple nutsedge less than imazethapyr applied alone in North Carolina (Table 1). All combinations of bentazon and imazethapyr were antagonistic. Purple nutsedge control by the herbicides applied in combination was 23 to 33% less than predicted by the Colby procedure.

Although less pronounced than in North Carolina, antagonism on purple nutsedge also was noted in Georgia with bentazon at 1.1 kg/ha plus imazethapyr at 35 or 70 g/ha and with bentazon at 0.6 kg/ha plus imazethapyr at 70 g/ha (Table 1). Purple nutsedge control by imazethapyr at 70 g/ha plus bentazon was 16 to 20% less than predicted.

Bentazon applied once at 0.6 and 1.1 kg/ha controlled yellow nutsedge only 25 and 41%, respectively (Table 2). These results are similar to those of other researchers (7, 15) who found that two applications of bentazon often were necessary for acceptable control of yellow nutsedge. Bentazon applied once controlled yellow nutsedge 35 to 80% (15).

Imazethapyr at 35 and 70 g/ha controlled yellow nutsedge 29 and 37%, respectively (Table 2). Yellow nutsedge control by imazethapyr was less than reported previously (25, 26) and may have been due to the relatively large size of the yellow nutsedge when treated (27, 29). The lack of competition from a crop may also partially explain the poor control.

Bentazon at 0.6 kg/ha plus imazethapyr at 35 or 70 g/ha were additive on yellow nutsedge (Table 2). Observed responses to these herbicide mixtures were very similar to predicted responses. However, bentazon at 1.1 kg/ha plus imazethapyr at 35 or 70 g/ha were antagonistic.

Table 2. Yellow nutsedge control 4 wk after treatment with imazethapyr and bentazon mixtures in field experiments.[a]

Imazethapyr rate	Bentazon rate (kg/ha)		
	0	0.6	1.1
(g/ha)	%		
0	0 e	25 d	41 c
35	29 d	47 b (47)	49 b (58)*
70	37 c	54 a (53)	40 c (63)*

[a]Means followed by the same letter are not different at P = 0.05 according to Fisher's Protected LSD Test. Numbers in parentheses are predicted responses for herbicide mixtures according to Colby (5). Data pooled over two locations in Georgia and one location in North Carolina.

*Denotes a significant difference at P = 0.05 between the observed and the predicted response according to Hamill and Penner (9).

Observed control was 9 and 23% less than predicted with bentazon at 1.1 kg/ha plus imazethapyr at 35 and 70 g/ha, respectively.

These results are in contrast to those from a previously reported study (25) where similar control of yellow and purple nutsedge was obtained with imazethapyr applied alone and mixed with bentazon. However, yellow and purple nutsedge in that study were in competition with a crop and were smaller when treated than in our experiments. Additionally, no reduction in control of several broadleaf weeds was noted in that study (25) when bentazon was applied in combination with imazethapyr. Cantwell *et al.* (3) observed antagonism with mixtures of bentazon and imazethapyr applied to giant foxtail, smooth pigweed, and jimsonweed.

Greenhouse Experiments

Bentazon applied at 0.6 or 1.1 kg/ha reduced purple nutsedge shoot fresh weight 4 WAT only 11% (Table 3). Imazethapyr at 35 and 70 g/ha reduced purple nutsedge shoot fresh weight 62 and 82%, respectively. Yellow nutsedge shoot fresh weight was reduced 43 and 77% by bentazon at 0.6 and 1.1 kg/ha, respectively, and 46 and 51% by imazethapyr at 35 and 70 g/ha, respectively.

Purple nutsedge shoot fresh weight reduction by imazethapyr at 35 g/ha plus bentazon at 0.6 or 1.1 kg/ha was less than that by imazethapyr alone at 35 g/ha (Table 3). Reduction by imazethapyr at 70 g/ha plus bentazon at 0.6 kg/ha was less than that by imazethapyr at 70 g/ha alone. Reduction was similar with imazethapyr at 70 g/ha plus bentazon at 1.1 kg/ha and imazethapyr at 70 g/ha alone. All combinations of imazethapyr and bentazon were antagonistic. Observed reductions in purple nutsedge shoot fresh weight were 9 to 19% less than predicted.

Yellow nutsedge shoot fresh weight reduction by bentazon at 0.6 kg/ha plus imazethapyr at 35 or 70 g/ha was similar to that by bentazon or imazethapyr applied

Table 3. Reduction in purple nutsedge and yellow nutsedge shoot fresh weight 4 wk after treatment with imazethapyr and bentazon mixtures in greenhouse experiments.[a]

Imazethapyr rate	Bentazon rate (kg/ha)		
	0	0.6	1.1
(g/ha)	%		
	Purple nutsedge		
0	0 e	11 d	11 d
35	62 b	47 c (65)*	50 c (65)*
70	82 a	65 b (84)*	75 a (84)*
	Yellow nutsedge		
0	0 d	43 c	77 a
35	46 bc	48 bc (75)*	78 a (88)*
70	51 bc	53 b (77)*	77 a (89)*

[a]Means within a species followed by the same letter are not different at P = 0.05 according to Fisher's Protected LSD Test. Numbers in parentheses are predicted responses for herbicide mixtures according to Colby (5).

*Denotes a significant difference at P = 0.05 between the observed and the predicted responses according to Hamill and Penner (9).

alone (Table 3). Shoot fresh weight reduction by bentazon at 1.1 kg/ha plus imazethapyr at 35 or 70 g/ha was similar to that by bentazon alone and greater than that by imazethapyr alone. However, all combinations of bentazon and imazethapyr were antagonistic on yellow nutsedge. Observed reductions in shoot fresh weight were 10 to 27% less than predicted.

Data for shoot regrowth suppression 2 wk after clipping (Table 4) were similar to those for suppression of original shoot fresh weight (Table 3) in that bentazon was more efficacious on yellow nutsedge while imazethapyr was more efficacious on purple nutsedge. All combinations of bentazon and imazethapyr were found to be antagonistic on both purple nutsedge and yellow nutsedge (Table 4). Observed reductions in fresh weight of shoot regrowth were 23 to 29% and 3 to 12% less than predicted for purple nutsedge and yellow nutsedge, respectively.

Table 4. Reduction in fresh weight of purple nutsedge and yellow nutsedge shoot regrowth 2 wk after clipping and 6 wk after treatment with imazethapyr and bentazon mixtures in greenhouse experiments.[a]

Imazethapyr rate	Bentazon rate (kg/ha)							
	0		0.6			1.1		
(g/ha)	%							
	Purple nutsedge							
0	0	d	4	d		31	c	
35	33	c	7	d	(36)*	26	c	(54)*
70	71	a	43	bc	(72)*	57	ab	(80)*
	Yellow nutsedge							
0	0	e	49	bc		83	a	
35	12	d	52	b	(55)*	78	a	(85)*
70	12	d	43	c	(55)*	78	a	(85)*

[a]Means within a species followed by the same letter are not different at P = 0.05 according to Fisher's Protected LSD Test. Numbers in parentheses are predicted responses for herbicide mixtures according to Colby (5).

*Denotes a significant difference at P = 0.05 between the observed and the predicted response according to Hamill and Penner (9).

The cause for antagonism between imazethapyr and bentazon applied to purple nutsedge and yellow nutsedge is unknown. However, bentazon can reduce foliar absorption of sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} by grasses (14, 19). The interaction occurs outside the cuticle and only when the two herbicides are in direct contact before absorption occurs (4, 22). Bentazon also reduces foliar absorption of chlorimuron {2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]-sulfonyl]benzoic acid} and paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) (23, 28). Bentazon may reduce foliar absorption of imazethapyr by purple nutsedge when the two herbicides are applied in combination. Because bentazon has little activity on purple nutsedge, control by bentazon would not mask the effect of reduced imazethapyr absorption.

Although combinations of bentazon and imazethapyr often were antagonistic on yellow nutsedge, especially at higher rates of bentazon, control of yellow nutsedge by mixtures of bentazon plus imazethapyr was at least as great as control by bentazon at the same rate applied alone. One can speculate that imazethapyr has no adverse effect on absorption of bentazon or activity of bentazon within the plant. Further, one can speculate that bentazon reduces imazethapyr absorption by yellow nutsedge but that reduced control by imazethapyr is masked by control from bentazon. If reduction in imazethapyr absorption is dependent upon bentazon rate, this might explain why mixtures of imazethapyr plus bentazon at 0.6 kg/ha were additive while mixtures of imazethapyr plus bentazon at 1.1 kg/ha were antagonistic.

Conclusions

Our results support previous observations (29) that bentazon is at least as efficacious as imazethapyr on yellow nutsedge while imazethapyr is more efficacious than bentazon on purple nutsedge. Combinations of bentazon plus imazethapyr would, therefore, appear to be well suited for controlling mixtures of purple nutsedge and yellow nutsedge. Results of our experiments, however, clearly demonstrate that combinations of bentazon and imazethapyr are antagonistic on purple nutsedge and should be avoided. Depending upon the rate of bentazon, mixtures of bentazon plus imazethapyr also may be antagonistic on yellow nutsedge. Research is needed to determine if imazethapyr applied PPI or early POST followed by a later POST application of bentazon would be a more effective strategy in managing mixed populations of yellow and purple nutsedge.

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