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Rice Tolerance to Postemergence Applications of Penoxsulam

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Introduction

Penoxsulam (Grasp™) is a postemergence herbicide developed by Dow Agrosciences, LLC, which received registration in 2005 for weed control in southern U.S. rice (Lassiter et al. 2006). It is a triazolopyrimidine sulfonamide herbicide and acts by inhibiting the acetolactate synthase enzyme (ALS) (E.C. 4.1.3.18) in susceptible species. Use rates range from 0.031 to 0.044 pound of active ingredient per acre, and applications can be made preflood or postflood in drill-seeded rice. Penoxsulam provides control of *Echinochloa* spp. (Lassiter et al. 2006), annual sedges (*Cyperus* spp.) (Walton et al. 2005), and numerous broadleaf weeds, including alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.] (Lassiter et al. 2006; Willingham et al. 2006), ducksalad [*Heteranthera limosa* (Sw.) Willd.] (Lassiter et al. 2006), eclipta (*Eclipta prostrata* L.) (Lassiter et al. 2006), hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. ex A.W. Hill] (Lassiter et al. 2006; Williams and Bums 2006), northern jointvetch [*Aeschynomene virginica* (L.) B.S.P.] (Walton et al. 2005), *Polygonum* spp. (Lassiter et al. 2006), spreading dayflower (*Commelina diffusa* Burm. f.) (Walton et al. 2005), and Texasweed [*Caperonia palustris* (L.) St. Hil.] (Strahan 2004; Williams and Burns 2006).

Inhibitors of ALS can reduce transport of photosynthate from source leaves to roots, resulting in root growth inhibition (Devine 1989; Devine et al. 1990; Shaner 1991). Bispyribac-sodium (Regiment™) is an ALS-inhibitor with similar activity to penoxsulam, and rice injury has been reported after applications of bispyribac-sodium (Braverman and Jordan 1996; Zhang and Webster 2002). Braverman and Jordan (1996) reported rice foliar and root injury after applications of bispyribac-sodium at 0.018, 0.027, and 0.036 pound of active ingredient per acre. Zhang and Webster (2002) observed reductions in shoot and root growth of the medium-grain 'Bengal' at 2 and 3 weeks after bispyribac-sodium application. Rice injury also has been reported after application of penoxsulam. Ellis et al. (2005) reported 41–58% reduction in root mass on the long-grain cultivar 'Wells' after 0.031- and 0.063-pound applications of penoxsulam.

Rice cultivar and/or growth stage at application may influence rice tolerance to herbicides. Previous research has indicated medium-grain rice cultivars are injured more by herbicides than long-grain cultivars (Lanclos et al. 1999; Zhang and Webster 2002; Zhang et al. 2005). Tolerance of rice to bispyribac-sodium was both cultivar- and growth stage-dependent (Zhang and Webster 2002). The medium-grain cultivar Bengal was less tolerant to bispyribac-sodium compared with the long-grain cultivar 'Cocodrie.' Shoot and root growth of Bengal was inhibited more when

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bispyribac-sodium was applied to one- and two-leaf rice compared with two- to three-leaf rice. Zhang et al. (2005) observed that the long-grain cultivars Cocodrie, 'Cypress,' Wells, 'CLl61,' and 'CLl4I' were tolerant to 0.018- and 0.036-pound applications of bispyribac-sodium made to two- to three-leaf rice or four- to five-leaf rice. However, medium-grain cultivars 'Earl' and Bengal varied in tolerance to bispyribac-sodium applications. Ellis et al. (2005) reported reductions in root mass that ranged from 28–77% among the cultivars 'XL8,' Cocodrie, Bengal, and Wells after penoxsulam applications. They also reported that penoxsulam (0.031 and 0.063 pound) applied at the panicle initiation growth stage caused no reduction in root mass.

The objectives of this research were to evaluate the response of 10 commercial rice cultivars to penoxsulam applications and to compare the rice response to preflood applications of penoxsulam and bispyribac-sodium.

Materials and Methods

Study 1. A study to determine rice cultivar tolerance to early postemergence applications of penoxsulam was conducted in 2005 and 2006 at the Louisiana State University AgCenter Rice Research Station near Crowley, Louisiana, and at an on-farm site near Bonita, Louisiana. Soil at Crowley was a Crowley silt loam soil (fine montmorillinitic, thermic Typic Albaqualf) with a pH of 6.6 and 1.6% organic matter. Soil at Bonita was a Perry clay (very-fine, smectitic, thermic Chromic Epiaquerts) with a pH of 6.3 and 3.4% organic matter.

The long-grain rice cultivars Cocodrie, 'Cheniere,' 'CL131,' CL161, 'Cybonnet,' 'Trenasse,' and 'XL723;' the medium-grain cultivars Bengal and 'Jupiter;' and the short-grain cultivar 'Pirogue' were drill-seeded on April 1, 2005, and March 14, 2006, at Crowley and April 28, 2005, and May 10, 2006, at Bonita. A seeding rate of 75 pounds per acre was used each site year for all cultivars except XL723, which is a hybrid cultivar. Because of its heterosis, a seeding rate of only 30 pounds per acre is recommended (Anonymous 2006b). Rice was drill-seeded using a small-plot grain drill equipped with double-disk openers and press wheels with 7.5 inches between each row. Individual plots consisted of 12 rows measuring 20 feet in length. Plots were maintained weed-free by an application of propanil plus molinate (Arrosolo™; 3 + 3 pounds of active ingredient per acre) before flooding each site year when rice reached the one-tiller growth stage. Plots were drained approximately 2 weeks before harvest maturity was reached. Rice was harvested with a small-plot combine at a moisture content of approximately 20%.

Treatments were arranged in a randomized complete block with a factorial arrangement of 10 rice cultivars (previously described) and two penoxsulam treatments (nontreated control and penoxsulam at 0.063 pound of active ingredient per acre). The penoxsulam treatment represented twice the labeled application rate of 0.031 pound (Anonymous 2006a). Penoxsulam applications were applied to rice at the two- to three-leaf growth stage with a CO_2-pressurized backpack sprayer equipped with regular flat-fan spray nozzles (TeeJet 110015 flat-fan spray tips; Spraying Systems Co., Wheaton, Illinois) set to deliver 15 gallons per acre at 30 psi. Penoxsulam applications included the addition of crop oil concentrate (COC; Agri-Dex®) at 2.5% (v/v). Days to 50% heading were determined by calculating the time from seedling emergence until 50% of rice had visible panicles. Average mature plant height was recorded before harvest by calculating the mean plant height of five plants measured from the soil surface to the tip of the panicle in each plot. Harvest dates were August 19, 2005, and July 26, 2006, at Crowley and September 13, 2005, and September 20, 2006, at Bonita. Final rice grain yields were adjusted to 12% moisture content. Data for mature plant height, number of days to 50% heading, and rice yield were converted to a percent of the nontreated control for the respective cultivar in each replication. Percent of nontreated control data were calculated by dividing data from the treated plot by that in the nontreated plot of the same cultivar and multiplying by 100.

Data were analyzed using the Mixed Procedure (SAS 2003) with years used as random-effect parameters testing all possible interactions of location and cultivar. Years, replications (nested within years), and all possible interactions containing these effects were considered random effects; all other variables (location and cultivar) were considered fixed effects. Type III statistics were used to test all possible fixed effects or interactions between the fixed effects, and least square means at $p \leq 0.05$ were used for mean separation.

Study 2. A related study to compare the rice response to applications of penoxsulam and bispyribac-sodium was conducted in 2004 and 2005 at the Mississippi State University Delta Research and Extension Center near Stoneville, Mississippi. Soil at Stoneville was a Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) with a pH of 8.2 and 2.1% organic matter.

The long-grain rice cultivar Cocodrie was drill-seeded on May 3, 2004, and May 4, 2005, at a seeding rate of 80 pounds per acre. The study was arranged in a randomized complete block experimental design. Plots were maintained weed-free each year by an application of clomazone (Command®) at 0.5 pound of active ingredient per acre immediately after planting and an application of propanil (Stam™) at 4 pounds of active ingredient per acre before flooding. Herbicide treatments consisted of penoxsulam at 0.031 or 0.063 pound of active ingredient per acre and bispyribac-sodium at 0.025 pound of active ingredient per acre applied to rice in the four-leaf growth stage. Penoxsulam applications included the addition of COC at 2.5% (v/v). An organosilicone and nonionic surfactant blend (Kinetic HV®) at 0.25% (v/v) was included with bispyribac-sodium applications. A nontreated control was included for comparison of rice yield.

Rice was drill-seeded each site year using a small-plot grain drill with 8 inches between each row. Individual plots consisted of eight rows measuring 15 feet in length. Herbicide treatments were applied as described previously. Root injury data were collected 1 week after flood establishment (2 weeks after herbicide treatment) by removing the entire root system of five plants from treated plots with a hand-trowel and comparing them with root systems collected similarly from five plants in nontreated plots for each cultivar and replication. Root injury was visually estimated on a scale of 0 (no reduction in root mass) to 100% (plant death). Rice was harvested with a small-plot combine at a moisture content of approximately 20% on September 14, 2004, and September 18, 2005, and final grain yield was adjusted to 12% moisture.

Data were analyzed using the Mixed Procedure (SAS 2003) with herbicide treatment as a fixed effect and year as a random effect. Data from nontreated control plots were excluded from analysis of rice root injury data but were included in analysis of rice yield data. Type III statistics were used to test herbicide treatment effects, and least square means at $p \leq 0.05$ were used for mean separation.

Results and Discussion

Study 1. The main effects of location and cultivar and all interactions containing these variables were not significant for rice height, days to 50% heading, or grain yield. Application of twice the labeled rate of penoxsulam did not negatively impact the agronomic performance of the 10 rice cultivars in this study (Table 1).

Previous research has indicated varied results when evaluating rice cultivar tolerance to herbicides. Five long-grain rice cultivars exhibited equivalent tolerance, but two medium-grain cultivars exhibited differential tolerance to applications of bispyribac-sodium (Zhang et al. 2005). Fenoxaprop (Whip®) reduced grain yield of the medium-grain cultivar ‘Mars’ 6–20% over 2 years, but grain yields of the long-grain cultivars ‘Tebonnet’ and ‘Lemont’ were reduced only 1–17% and 1–14%, respectively, over 2 years (Griffin and Baker 1990).

Although earlier research established that medium- and short-grain cultivars may exhibit lower levels of tolerance

Table 1. Rice cultivar response to postemergent penoxsulam application (0.063 lb ai/A) at Crowley and Bonita, Louisiana, in 2005 and 2006.[1]

Cultivar	Rice height	Days to 50% heading	Yield
Long-grain			
Cheniere	100 a (33)	100 a (89)	103 a (8,450)
CL131	102 a (30)	100 a (87)	100 a (7,640)
CL161	101 a (36)	101 a (91)	101 a (8,040)
Cocodrie	101 a (33)	101 a (86)	94 a (8,410)
Cybonnet	99 a (33)	100 a (88)	108 a (7,610)
Trenasse	102 a (35)	101 a (82)	105 a (8,980)
XL723	98 a (42)	100 a (86)	100 a (10,330)
Medium-grain			
Bengal	100 a (33)	100 a (90)	95 a (9,290)
Jupiter	99 a (34)	99 a (91)	100 a (10,160)
Short-grain			
Pirogue	99 a (35)	99 a (90)	101 a (9,230)

[1]Data averaged across two locations and two experiments. Data expressed as a percent of nontreated control for the respective cultivar. Numbers in parentheses represent rice height (inches), number of days to 50% heading (days), and yield (lb/A) of nontreated control for each cultivar.

Table 2. Root injury and rice yield at Stoneville, Mississippi, in 2004 and 2005 after postemergence herbicide applications.[1]

Treatment	Rate	Root injury[2]	Yield
	lb ai/A	%	*lb/A*
Penoxsulam	0.031	71 a	8,510 b
Penoxsulam	0.063	76 a	9,250 a
Bispyribac-sodium	0.025	65 a	8,610 b
Nontreated control		—	8,700 b

[1]Means followed by same letter in a column are not significantly different at $p \leq 0.05$.
[2]Rice roots from nontreated control were used as comparison for visually estimating root injury in treated plots.

to a variety of herbicides, we did not observe any differences in cultivar response to penoxsulam. Equal herbicide tolerance among long-, medium-, and/or short-grain rice cultivars has been reported for some herbicides and/or production systems (Ellis et al. 2005; Scherder et al. 2004). Fourteen commercial long- and medium-grain cultivars and four experimental cultivar lines were tolerant to clomazone at 0.3 and 0.6 pound of active ingredient per acre in a drill-seeded production system (Scherder et al. 2004). Ellis et al. (2005) reported no differences in yield for the cultivars Bengal, Cocodrie, Wells, and XL8 after 0.031- and 0.063-pound applications of penoxsulam. Despite the lack of differences in rice cultivar response to an application of penoxsulam at twice the labeled rate with respect to height, days to 50% heading, and yield, rice yields were numerically greater for some cultivars (more than 100% of the nontreated control) after application.

Study 2. No differences in root injury were detected among herbicide treatments, but root injury up to 76% was observed after the 0.063-pound penoxsulam application (Table 2). Rice root injury appeared as a reduction in root mass and length compared with the nontreated control. Ellis et al. (2005) reported 65% and 77% root injury 7 days after 0.031- and 0.063-pound penoxsulam treatments, respectively, when applications were made to rice in the four- to five-leaf growth stage. The penoxsulam label indicates that severe rice injury may be observed after application when soil pH is higher than 7.8 (Anonymous 2006a). The soil pH at Stoneville was 8.2, so bioavailability of penoxsulam at the high soil pH most likely impacted the root injury observed after penoxsulam application. Other herbicides are also more injurious at high soil pH levels (Hutchinson et al. 2005). The pK_a of penoxsulam is 5.1 (Anonymous 2004), and Jabusch and Tjeerdema (2005) reported that penoxsulam is present almost entirely as the anionic species at near-neutral pH. The reductions in rice root mass observed in our study could be a product of increased penoxsulam absorption by rice roots resulting from exposure to higher concentrations over a longer time because of less soil adsorption and slower hydrolysis at high soil pH. Furthermore, we speculate that the injury observed at high soil pH may be due to a greater availability of higher proportions of the applied rate in the soil solution rather than an influence on the physiology of absorption.

Rice grain yield was 6–9% higher after the 0.063-pound penoxsulam application compared with the nontreated control and the 0.031-pound penoxsulam or 0.025-pound bispyribac-sodium applications (Table 2). According to Ellis et al. (2005), although Cocodrie root injury was 77% after a 0.063-pound penoxsulam application, rice grain yield was not negatively impacted. An explanation in our study for the increased grain yield after application of penoxsulam at twice the labeled rate was not apparent. Obviously, rice recovered from the injury to roots observed after the herbicide application. However, overcoming the observed reductions in root mass would seemingly require the plant to reallocate resources into roots, thereby depriving the aboveground plant sections of photosynthates needed for growth and ultimately yield. At some point between root injury evaluation and harvest, rice was able to recover from the injury and actually produce higher grain yields. Rice may have responded to the stress caused by the root injury by producing more tillers, which could influence final grain yield, or by producing more adventitious roots, which could influence the efficiency of nutrient uptake from the soil. Previous research has indicated variable results with the use of ALS-inhibiting herbicides. In an imazaquin (Scepter®) carryover study in Arkansas, rice yield decreased after imazaquin applied preplant incorporated and preemergence to soybean [*Glycine max* (L.) Merr] at 0.13 pound of active ingredient per acre compared with the higher rate of 0.26 pound (Helms et al. 1989). Webster and Shaw (1996) reported similar results with soybean following pyrithiobac (Staple®) applied to cotton (*Gossypium hirsutum* L.).

Other researchers reported that differences in herbicide tolerance among rice cultivars were more easily distinguished when twice the registered rate of the herbicide was used for screening tolerance (Zhang and Webster 2002; Zhang et al. 2004). Our cultivar tolerance study utilized penoxsulam at 0.063 pound of active ingredient per acre, twice the labeled application rate. Therefore, our data indicate that commercial rice cultivars currently grown in the southern U.S. rice belt exhibit tolerance to postemergence applications of penoxsulam based on rice height, number of days to 50% heading, and grain yield. Substantial reductions in root mass may occur after penoxsulam application, particularly when soil pH is high. This reduction in root mass could complicate management of the rice crop by delaying flood establishment or compounding difficulties associated with rice water weevil (*Lissorhoptrus oryzophilus* Kuschel) infestations. However, in our study, rice grain yield was greater when the higher use rate was applied and injury was severe. The yield increases that occurred are not easily explained and warrant further investigation into the response of the rice plant to root injury observed after application of penoxsulam.

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