Weed Technology 2012 26:19–23

Evaluation of Imazosulfuron for Broadleaf Weed Control in Drill-Seeded Rice

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Field experiments were conducted in 2006, 2007, and 2008 at the Louisiana State University Agricultural Center's Northeast Research Station near St. Joseph, LA, to evaluate imazosulfuron programs involving rate, application timings, and tank mixes for PRE and POST broadleaf weed control in drill-seeded rice. Imazosulfuron showed residual activity against both Texasweed and hemp sesbania. PRE-applied imazosulfuron at 168 g ai ha^{-1} and higher rates provided 83 to 93% Texasweed control at 4 WAP. At 12 WAP, Texasweed control with 168 g ha^{-1} and higher rates was 92%. Hemp sesbania control with 168 g ha^{-1} and higher rates was 86 to 89% at 4 WAP and 65 to 86% at 12 WAP. Imazosulfuron at 224 g ha^{-1} applied EPOST provided 84 to 93% Texasweed control and 82 to 87% hemp sesbania control, and it was as effective as its tank mixture with bispyribac-sodium. When applied LPOST, four- to five-leaf Texasweed, imazosulfuron alone at 224 g ha^{-1} was not effective against Texasweed and hemp sesbania, but did improve weed control when mixed with bispyribac-sodium at 17.6 g ai ha^{-1}.

Nomenclature: Imazosulfuron; bispyribac-sodium; hemp sesbania, *Sesbania herbacia* (L.) SESEX; Texasweed, *Caperonia palustris* (L.) St. Hil. CNPPA; rice, *Oryza sativa* L. ORYSA.
Key words: Broadleaf weed control, V-10142.

En 2006, 2007 y 2008 se realizaron experimentos de campo en la estación de investigación noreste, del Centro Agrícola de la Universidad Estatal de Louisiana, cerca de St. Joseph, LA, para evaluar programas de imazosulfuron considerando dosis, tiempos de aplicación y mezclas en tanque, para el control PRE y POST de maleza de hoja ancha en arroz sembrado con maquinaria. El imazosulfuron mostró actividad residual contra *Caperonia palustris* y *Sesbania herbacia.* El imazosulfuron aplicado PRE a 168 g ia ha^{-1} y a dosis mayores, proporcionaron de 83 a 93% de control en *C. palustris* a 4 WAP. A 12 WAP, el control de *C. palustris* con 168 g ha^{-1} y a dosis mayores fue de 92%. El control de *S. herbacia* con 168 g ha^{-1} y a dosis mayores fue de 86 a 89% a 4 WAP y de 65 a 86% a 12 WAP. El imazosulfuron a 224 g ha^{-1} aplicado POST temprano, proporcionó de 84 a 93% de control en *C. palustris* y de 82 a 87% de control en *S. herbacia* y fue tan efectivo como cuando se mezcló con bispiribac sodio. Imazosulfuron solo asperjado POST tardío en dosis de 224 g ha^{-1} a *C. palustris* en su etapa de cuatro a cinco hojas, no fue efectivo contra esta especie ni contra *S. herbacia*, pero sí mejoró el control de maleza cuando se mezcló con bispiribac sodio a 17.6 g ia ha^{-1}.

A number of PRE herbicides are available for early-season weed management in rice (Anonymous 2011). Clomazone and quinclorac are the two major PRE herbicides used in rice production in the USA (Anonymous 2011; U.S. Department of Agriculture [USDA] 2006). Thiobencarb and pendimethalin are also used, but to a lesser extent (USDA 2006). Imazethapyr is another residual herbicide but is solely registered for use in imidazolinone-tolerant rice. Clomazone is very effective on *Echinochloa* spp. (Webster et al. 1999; Zhang et al. 2005). Although clomazone controls many annual grasses and has very good residual activity in rice (Webster et al. 1999), it does not control several key broadleaf and sedge species when applied at recommended rates (Brommer et al. 2000; Williams et al. 2004). Quinclorac controls barnyardgrass (Baltazar and Smith 1994; Street and Muller 1993), hemp sesbania, pitted morningglory (*Ipomoea lacunose* L.), jointvetch (*Aeschynomene* spp.) (Grossmann 1998; Street and Mueller 1993), but has little to no activity on sprangletop (*Leptochloa* spp. L.) (Anonymous 2011; Jordan 1997). Development of quinclorac-resistant barnyardgrass (Lopez-Martinez 1997; Lovelace et al. 2007; Malik et al. 2010) has also limited its use in rice. Pendimethalin controls grasses and small-seeded broadleaf weeds (Byrd and York 1987) but is not effective against sedges and large seeded broadleaf weeds like spreading dayflower (*Commelina diffusa* Burm. f.), hemp sesbania, and Texasweed (Anonymous 2011). Thiobencarb provides good control of barnyardgrass, sprangletop, and annual sedges but has limited activity on broadleaf weeds; the period of residual control is also less than 3 wk (Anonymous 2011).

In general, currently registered PRE herbicides in rice are more effective against grasses than broadleaf weeds (Valverde et al. 2001). Moreover, the high degree of residual grass control provided by these herbicides allows the farmers to delay their POST herbicide applications up to 5 wk after planting (Bill Williams, personal communication). By that time many broadleaf weeds like Texasweed become large and difficult to control. Kurtz (2004) reported reduced activity of POST herbicides on three- to four-leaf Texasweed in soybean [*Glycine max* (L.) Merr.] and emphasized the need for its control at an early stage.

Imazosulfuron , V-10142 [2-chloro-N-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]imidazo[1,2-a]pyridine-3-sulfonamide],

DOI: 10.1614/WT-D-11-00063.1

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an acetolactate synthase (ALS, EC 4.1.3.18) inhibitor, has been developed by Valent Corporation (Walnut Creek, CA 94596) for weed control in drill- and water-seeded rice. Imazosulfuron controls broadleaf weeds and sedges and suppresses annual grasses (Baron 2006). Felix and Boydston (2010) reported that sequential application of imazosulfuron (PRE fb POST) at 336 g ai ha^{-1} provided 92% or higher control of common lambsquarters (*Chenopodium album* L.), Powell amaranth (*Amaranthus powelli* S. Wats.), redroot pigweed (*Amaranthus retroflexus* L.), and yellow nutsedge. Effectiveness of imazosulfuron against sedges has also been demonstrated in other studies (Henry and Sladek 2008). Imazosulfuron may prove to be an effective herbicide for broadleaf weed management in drill-seeded rice. Therefore, a study was conducted to evaluate imazosulfuron programs involving rate, application timings, and combinations with other herbicides for PRE and POST broadleaf weed control in drill-seeded rice.

Materials and Methods

Field experiments were conducted in 2006, 2007, and 2008 at the Louisiana State University Agricultural Center's Northeast Research Station near St. Joseph, LA, on Sharkey clay (very fine, montmorillonitic, nonacid, Vertic Haplaquept) with pH 6.1 and 2.1% organic matter. Field preparation during each year consisted of a fall disking followed by a spring disking and two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows set to operate 6 cm deep. 'Cocodrie' rice was drill-seeded on April 24, May 9, and April 29 in 2006, 2007, and 2008 respectively, at 100 kg ha^{-1} to plots measuring 2 m by 4.5 m.

The study area was surface irrigated immediately after the application of PRE herbicides and as needed until permanent floods were established. Permanent floods were established 5 to 6 wk after planting when rice reached four- to five-leaf stage. Nitrogen in the form of prilled urea (46–0–0) was applied at 126 kg ha^{-1} on the day of permanent flood establishment. At panicle initiation an additional 42 kg ha^{-1} of nitrogen was applied. Herbicide treatments were applied with the use of a CO_2 pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 276 kPa.

For the PRE weed control study, a randomized complete block design (RCB) with three replications was used in all the 3 yr. Treatments consisted of imazosulfuron (League™ herbicide label, Valent) rates: 56, 112, 168, 224, 336, 450, 504, and 560 g ai ha^{-1}. Clomazone (Command® 3 ME herbicide label, FMC Corporation, Agricultural Products Group, Philadelphia, PA) at 560 g ai ha^{-1} applied PRE and fenoxaprop-ethyl (Ricestar HT® herbicide label, Bayer CropScience, Research Triangle Park, NC) at 111 g ai ha^{-1} applied POST were used to control barnyardgrass in the experimental plots.

POST weed control study was conducted in 2006 and 2007. In both years, an augmented two-factor factorial experiment with three replications was conducted in a RCB design. Factor A consisted of five herbicide treatments: imazosulfuron at 224 g ai ha^{-1}, bispyribac-sodium (Regiment™ herbicide label, Valent) at 17.6 g ai ha^{-1}, bispyribac-sodium at 17.6 g ha^{-1} plus imazosulfuron at 112 g ha^{-1}, bispyribac-sodium at 17.6 g ha^{-1} plus imazosulfuron at 168 g ha^{-1}, and bispyribac-sodium at 17.6 g ha^{-1} plus imazosulfuron at 224 g ha^{-1}. Crop oil concentrate (Agri-dex®, Helena Chemical Co., Collierville, TN) at 1% v/v was used in the treatments involving imazosulfuron alone and a proprietary blend (Dyne-A-Pak, Helena Chemical Co., Collierville, TN) of alkanolamides, alkanoates, trisiloxane, and carbamides at 1.5% v/v was used in the treatments involving bispyribac-sodium. Fenoxaprop-ethyl (Ricestar HT® herbicide label, Bayer CropScience, Research Triangle Park, NC) at 111 g ai ha^{-1} was also applied 3 d prior to flooding to all experimental plots for grass control. Factor B consisted of two application timings: early-postemergence (EPOST) and late-postemergence (LPOST), which were applied on May 9 and May 27 in 2006 and May 28 and June 9 in 2007, respectively. Texasweed was two- to three-leaf stage and four- to five-leaf stage at the time of EPOST and LPOST applications, respectively.

In all experiments, weed control was visually recorded at biweekly intervals on a 0 to 100% scale, where 0 = no control and 100 = complete weed control. Rice injury, in the form of stunting and chlorosis, was visually estimated with the use of a 0 to 100% scale where 0 = no injury and 100 = plant death. Rough rice yield was obtained with the use of a small-plot combine and was adjusted to 12% moisture.

Statistical Analysis. The preemergence study had a series of quantitative treatments; therefore, regression analysis was performed to model weed control as a function of imazosulfuron rates. The NLMIXED procedure of SAS (SAS 2003) was used to fit various nonlinear models. Year and replication were considered random effects. Null-model likelihood-ratio tests for nested models and Akaike's information criteria (AIC) values for unrelated models were used to compare different models and the criteria of better fit and parsimony were used to select final models. A three-parameter log-logistic model was found to best-fit Texasweed and hemp sesbania control data. The three-parameter log-logistic model is similar to that described by Seefeldt et al. (1995), but the lower limit is constrained to 0, so that the equation takes the form:

$$Y = Y_{\max}/(1 + \exp(b * (\ln(X + 0.25) - \ln(X_{20})))), \quad [1]$$

where Y represents the percent control, $Y_{\max}$ is the upper asymptote, X is the imazosulfuron rate (g ai ha^{-1}), X_{50} is the rate needed to provide 50% control, and b is the slope at X_{50}.

Rough rice yield as a function of imazosulfuron rate was best described by a three-parameter logistic model (Equation 2)

$$Y = Y_{\max}/(1 + ((Y_{\max} - Y_0)/Y_0) * \exp(-b * X)), \quad [2]$$

where $Y_{\max}$ represents the upper asymptote, Y_0 is the lower asymptote, and b is the slope.

For the postemergence weed control study, data were analyzed with the use of the MIXED procedure of SAS (SAS 2003). Year, replication (nested within year) and all interactions involving either of these effects were considered random effects. Observation dates, WAP, were used as repeated measures to compare weed control over time. Type III statistics were used to test significance of fixed effects. For

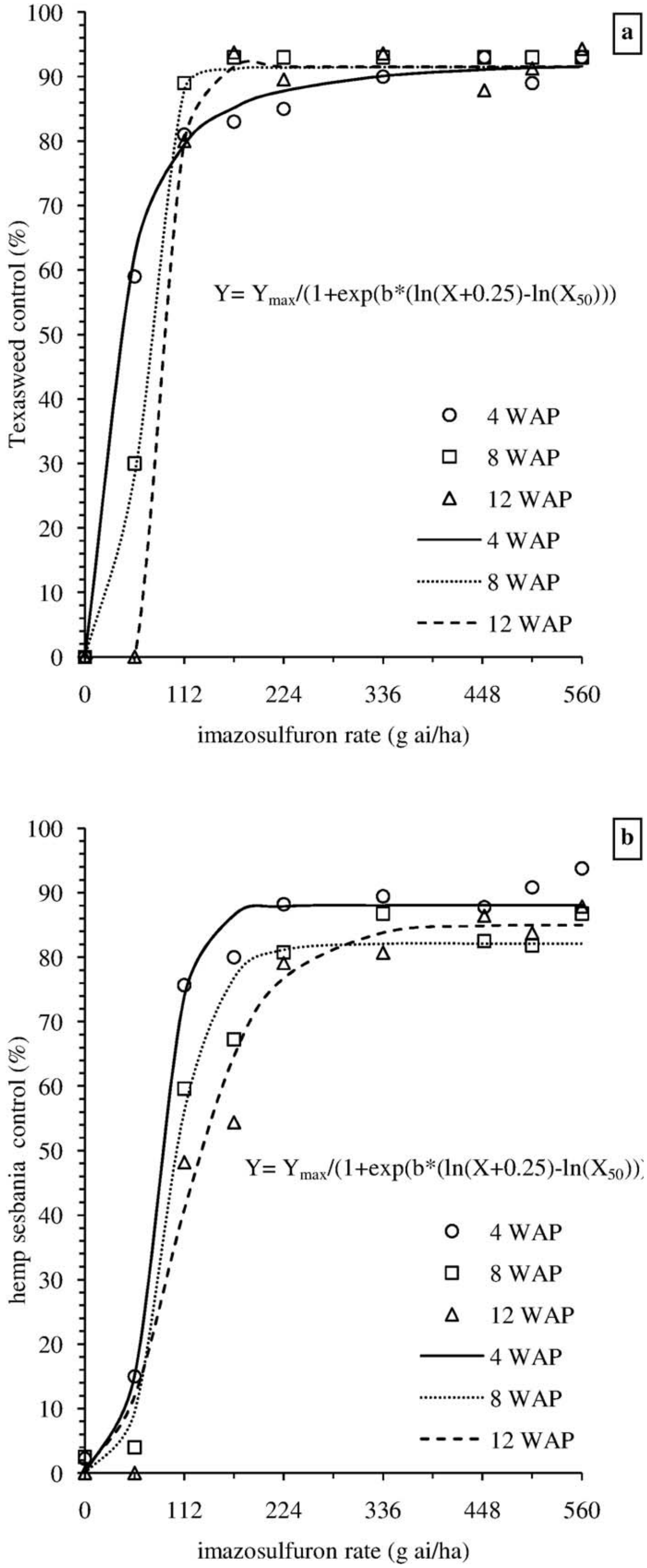

Figure 1. Observed and predicted (a) Texasweed and (b) hemp sesbania control at 4, 8, and 12 wk after planting (WAP) as a function of imazosulfuron applied PRE. Symbols and lines represent observed mean and predicted responses, respectively. Clomazone at 560 g ai ha^{-1} PRE and fenoxaprop-ethyl at 111 g ai ha^{-1} POST were applied to all treatments for grass control. Parameter estimates and standard errors are presented in Table 1.

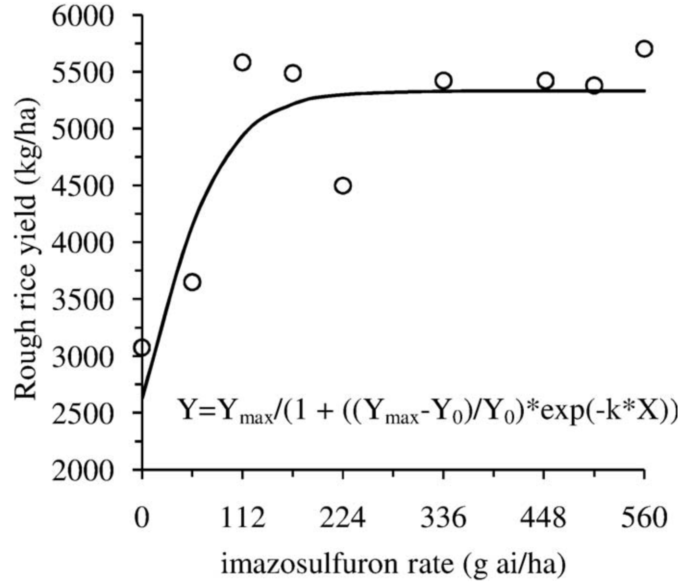

Figure 2. Observed and predicted rough rice yield as a function of imazosulfuron rate applied PRE. Symbols and lines represent observed mean and predicted responses, respectively. Clomazone at 560 g ai ha^{-1} PRE and fenoxaprop-ethyl at 111 g ai ha^{-1} POST were applied to all treatments for grass control. Parameter estimates and standard errors (in parentheses) were Y_{max} = 5,331 (78), Y_0 = 2,633 (180), and k = 0.02275 (0.003524).

the postemergence test, least-square means were used and mean separation was carried out with the use of Tukey's test at an overall P = 0.05. Letter groupings were generated with the use of the PDMIX800 macro in SAS (Saxton 1998).

Results and Discussion

PRE Weed Control Study. Imazosulfuron demonstrated PRE activity against both hemp sesbania and Texasweed (Figure 1). At 4 WAP imazosulfuron at 168 g ha^{-1} provided 85% Texasweed and 86% hemp sesbania control. Texasweed control increased with time and at 12 WAP, 168 g ha^{-1} imazosulfuron provided 92% Texasweed control, which was equal to that provided by higher rates. Hemp sesbania control with 168 g ha^{-1} or lower imazosulfuron rates decreased over time (Figure 1b). The ability of hemp sesbania to emerge in flushes after each rainfall or irrigation event might be responsible for the decrease in its control with time. Both hemp sesbania and Texasweed control with imazosulfuron rates higher than 224 g ha^{-1} remained more or less constant over the entire duration of the experiment. Hemp sesbania control with imazosulfuron at 336 g ha^{-1} and 560 g ha^{-1} was 83% and 86%, respectively (Figure 1b).

No significant rice injury was observed in any of the treatments (data not shown). PRE application of imazosulfuron resulted in up to 102% increase in rough rice yield over

Table 1. Parameter estimates for regression models of Texasweed and hemp sesbania control at 4, 8, and 12 wk after planting (WAP) by imazosulfuron applied PRE.

Weed	WAP	Parameter estimates (± SE)[a]		
		Y_{max}	X_{50}	b
Texasweed	4	92.9 (2.0)	35.4 (4.3)	−1.5404 (0.2836)
	8	91.5 (1.0)	64.6 (0.9)	−5.8074 (0.3978)
	12	91.5 (0.8)	105.1	−29.420
Hemp sesbania	4	88.6 (1.5)	78.9 (2.7)	−4.4954 (0.4809)
	8	83.4 (2.2)	92.4 (3.2)	−3.8099 (0.4879)
	12	87.4 (2.6)	114.5 (5.4)	−2.7250 (0.3418)

[a] Regression model used to predict weed control was $Y = Y_{max}/(1 + \exp(b * (\ln(X + 0.25) - \ln(X_{50}))))$, where Y represents the percent control, Y_{max} is the upper asymptote, X is the imazosulfuron rate (g ai ha^{-1}), X_{50} is the rate needed to provide 50% control, and b is the slope at X_{50}. SE = standard error of the estimates.

untreated check (Figure 2). Yield increase for 168 g ha^{-1} imazosulfuron rate was 98%.

POST Weed Control Study. A significant interaction between herbicide treatment, application timing and observation date, WAP, was observed (P value < 0.001). EPOST applications of imazosulfuron and bispyribac-sodium alone provided 86% and 88% hemp sesbania control at 4 WAP, respectively (Table 2). Hemp sesbania control with EPOST applied bispyribac-sodium alone decreased with time; hemp sesbania control was 74% and 31% control at 8 and 12 WAP, respectively. Imazosulfuron, on the other hand, provided consistent (>80%) control throughout the duration of the experiment. The greater efficacy of imazosulfuron compared to bispyribac-sodium at EPOST timing may be due to residual activity of imazosulfuron, which prevented new flushes of hemp sesbania. The preemergence study discussed above also showed significant residual weed control by imazosulfuron (Figure 1). Bispyribac-sodium, on the other hand, is not reported to have any residual activity (Esqueda and Rosales 2004). Tank-mixing imazosulfuron with bispyribac-sodium increased its efficacy on hemp sesbania. Observations made at 8 and 12 WAP showed that even 112 g ha^{-1} imazosulfuron in combination with bispyribac-sodium at 17.6 g ha^{-1} provided greater hemp sesbania control than bispyribac-sodium alone (Table 2).

LPOST application of imazosulfuron alone did not provide satisfactory hemp sesbania control at 12 WAP (Table 2). However, bispyribac-sodium and its tank mixes with imazosulfuron provided more than 90% hemp sesbania control. Bispyribac-sodium alone when applied LPOST was as effective as its tank mixes with imazosulfuron. Bispyribac-sodium was more effective on hemp sesbania when applied LPOST than EPOST. Lesser hemp sesbania control by EPOST applied than LPOST applied bispyribac-sodium can also be explained in terms of its residual soil activity. Hemp sesbania emerged in several flushes until permanent flood establishment (personal observations) and was not effectively controlled by bispyribac-sodium due to lack of residual soil activity (Esqueda and Rosales 2004). However, by the time of LPOST application, most of the hemp sesbania had emerged. Emerged hemp sesbania is effectively controlled by bispyribac-sodium (Pearson et al. 2008). Williams and Burns (2006) also reported similar findings with penoxsulam. Penoxsulam at 36 g ai ha^{-1} applied to one-leaf hemp sesbania was less effective than later timing; new hemp sesbania emergence following EPOST application was reported to be the most likely reason.

The effect of herbicide, rate, and application timings were more evident in terms of Texasweed control (Table 2). At 4 WAP, EPOST application of imazosulfuron and bispyribac-sodium provided 84% and 77% Texasweed control, respectively. Imazosulfuron showed greater residual activity than bispyribac-sodium. At 12 WAP, Texasweed control with bispyribac-sodium alone decreased to 2%, whereas imazosulfuron provided 90% Texasweed control. Moreover, EPOST application of imazosulfuron alone was as effective as its tank mixes with bispyribac-sodium.

LPOST applications of either imazosulfuron at 224 g ha^{-1} or bispyribac-sodium at 17.6 g ha^{-1} alone did not provide satisfactory Texasweed control (Table 2). For 224 g ha^{-1} rate,

Table 2. Hemp sesbania and Texasweed control at 4, 8 and 12 wk after planting (WAP) in different POST treatments.[a]

Treatment	Rate	Application time[b]	Hemp sesbania control			Texasweed control		
			4 WAP	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP
	(g ha^{-1})		%[c]					
Nontreated	–	–	0	0	0	0	0	0
Imazosulfuron	224	EPOST	86 abc	87 abc	82 abcd	84 a	93 a	90 a
Bispyribac	17.6	EPOST	88 abcd	74 cd	31 e	77 abc	52 de	2 g
Bispyribac plus imazosulfuron	17.6 + 112	EPOST	89 abc	88 abc	72 d	88 a	89 a	87 a
Bispyribac plus imazosulfuron	17.6 + 168	EPOST	93 ab	87 abc	83 abcd	88 a	93 a	93 a
Bispyribac plus imazosulfuron	17.6 + 224	EPOST	92 ab	85 abc	88 abc	88 a	93 a	92 a
Imazosulfuron	224	LPOST		90 abc	81 bcd		60 cd	15 fg
Bispyribac	17.6	LPOST		92 ab	90 abc		52 d	32 ef
Bispyribac plus imazosulfuron	17.6 + 122	LPOST		93 ab	90 abc		78 ab	62 bcd
Bispyribac plus imazosulfuron	17.6 + 168	LPOST		92 ab	94 a		93 a	77 abc
Bispyribac plus imazosulfuron	17.6 + 224	LPOST		88 abc	93 ab		88 a	84 a

[a] Clomazone at 560 g ai ha^{-1} PRE and fenoxaprop-ethyl at 111 g ai ha^{-1} POST were applied to all treatments for grass control; crop oil concentrate (COC, Agri-dex®, Helena Chemical Co., 225 Schilling Boulevard, Suite 300, Collierville, TN 38017) at 1% v/v was used in treatments involving imazosulfuron alone and Dyne-A-Pak (Helena Chemical Co.) at 1.5% v/v was used in treatments involving bispyribac-sodium.

[b] EPOST = two- to three-leaf Texasweed; LPOST = four- to five-leaf Texasweed.

[c] Means followed by a common letter within each column are not significantly different at P = 0.05 with the use of Tukey's test.

the level of Texasweed control at 12 WAP decreased from 90 to 15% as imazosulfuron application timing changed from two- to three-leaf Texasweed (EPOST) to four- to five-leaf Texasweed (LPOST). These results suggest that imazosulfuron is more effective against smaller Texasweed. Similar conclusions were drawn by Kurtz (2004) for Texasweed control in soybean. LPOST application of bispyribac-sodium and imazosulfuron tank mixes improved Texasweed control; however, there appeared to be a response to increasing imazosulfuron rates in the mixtures. Bispyribac-sodium at 17.6 g ha^{-1} plus imazosulfuron at 224 g ha^{-1} provided 88 and 84% Texasweed control at 8 and 12 WAP, respectively. No significant rice injury was observed in any of the treatments (data not shown).

In summary, imazosulfuron demonstrated residual activity against both Texasweed and hemp sesbania. PRE applied imazosulfuron at 168 g ha^{-1} and higher rates provided 83 to 93% Texasweed control and 86 to 89% hemp sesbania control. PRE applied imazosulfuron at 168 g ha^{-1} and higher rates resulted in 98 to 102% yield increase. Godara et al. (2010) also reported the importance of early-season Texasweed control for avoiding rice yield loss. At 4 WAP, Texasweed and hemp sesbania control with EPOST application of imazosulfuron at 224 g ha^{-1} was also about 85%. Therefore, if PRE application is not feasible for some reason imazosulfuron can be applied EPOST to control emerged broadleaf weeds and provide their residual control. When applied LPOST, imazosulfuron at 224 g ha^{-1} alone was not effective on Texasweed and hemp sesbania.

Despite its residual activity, PRE applied imazosulfuron may not provide 100% Texasweed and hemp sesbania control at 4 WAP or later observation dates. Late-season hemp sesbania can cause yield losses in rice. Smith (1968) reported 19% rice yield loss from season-long interference from hemp sesbania at 5 plants m^{-2}. Broadleaf weeds like Texasweed can reduce crop harvest efficiency (Bennett 2003). They can also increase weed seed bank and pose a problem in subsequent crops. Therefore, a follow-up POST herbicide will be needed to control weeds escaping PRE imazosulfuron application. We suggest that imazosulfuron can be applied PRE at 168 to 224 g ha^{-1} to provide about 85% Texasweed and hemp sesbania control up to 4 WAP. Bispyribac-sodium or any other broad-spectrum POST herbicide can then be applied at about 4 WAP to achieve near 100% control of both the weeds.

Acknowledgment

The authors appreciate the funding provided for this research by the Louisiana Rice Research Board.

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Received May 5, 2011, and approved September 8, 2011.