Using penoxsulam ALS inhibitor as a broad-spectrum herbicide in Chilean rice

Marcelo Kogan[1],[2], Patricio Gómez[1], Albert Fischer[3], and Claudio Alister[1]

[1]Centro de Investigación Agrícola y Ambiental (CIAA). Universidad de Viña del Mar, Av. Agua Santa 7055, Campus Rodelillo, Viña del Mar, Chile.
[2]Facultad de Agronomía e Ingeniería Forestal, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Macul, Santiago, Chile.
[3]Department of Plant Sciences, University of California, CA 95616, Davis, California, USA.

Abstract

M. Kogan, P. Gómez, A. Fischer, and C. Alister. 2011. Using penoxsulam ALS inhibitor as a broad-spectrum herbicide in Chilean rice. Cien. Inv. Agr. 38(1): 83-93. The continuously-flooded rice production system in Chile has selected highly competitive aquatic weeds selection capable of reducing paddy yields by 25 to 50%. Penoxsulam is a broad-spectrum triazolopyrimidine (ALS inhibitor) commercially introduced in Chile in 2006, where *Alisma plantago aquatica* hads already evolved resistance to sulfonylurea herbicides (SU). Several field trials with water seeded rice were conducted during 2003 and 2004 in Chile to determine efficacy, timing of application, spectrum of control, and control of SU-resistant *A. plantago aquatica* with the herbicide penoxsulam, either in single applications or in sequence with other herbicides. Penoxsulam was applied a) 12 days after seeding (DAS) into the water (IW), b) in postemergence after draining the water from field (ADW) at 35 DAS or c) IW followed by ADW applications of MCPA, cyhalofop, bentazon, or triclopyr. Penoxsulam was tested at 20, 30, and 40 g a.i. ha^{-1}. Comparisons were made with recommended rates of other IW treatments (metsulfuron, bensulfuron and cyclosulfomuron) and sequential applications of molinate (IW) followed by ADW applications of MCPA, cyhalofop, bentazon, or triclopyr. One IW penoxsulam application was sufficient to achieve broad-spectrum control: *Echinochloa* spp. (100% control), *A.plantago-aquatica* (80 to 100%), *Schoenoplectus mucronatus* (50 to 80%), and *Cyperus difformis* (80 to 100%). Rice yields in penoxsulam-treated plots were 30 to 56% higher than in the untreated controls. Yields with penoxsulam IW (all rates) were similar (P>0.05) to those obtained using molinate (IW) followed by ADW applications of bentazon or MCPA. Although penoxsulam is an ALS inhibitor, it controlled *A. plantago-aquatica* resistant to metsulfuron and bensulfuron.

Key words: Penoxsulam, bensulfuron, metsulfuron, MCPA, bentazon, triclopyr, *Cyperus difformis, Schoenoplectus mucronatus, Alisma plantago-aquatica, Echinochloa crus-galli*, herbicide-resistance.

Introduction

Rice in Chile is water-seeded and continuously flooded. This system requires good land leveling to optimize water management and weed control through flooding. Unfortunately, most rice fields are not properly leveled and inadequate water management facilitates weed establishment and development during the early stages of rice growth.

Rice is grown in very poorly drained clay soils that allow establishment of continuously flood-

ed conditions for five to six months. This system provides favorable conditions for aquatic weed growth. The major weeds of Chilean rice belong to the following families: Alismataceae (*Alisma plantago-aquatica* L., ALSPA; *A. lanceolatum* With., ALSLA; *Sagittaria montevidensis* ssp. *chilensis* (Cham. & Schltdl.) Bogin., SAGMO), Cyperaceae (*Cyperus difformis* L., CYPDI; *Schoenoplectus mucronatus* (L.) Palla., SCPMU), and Poaceae (*Echinochloa crus-galli* L., ECHCG; *E. colona* L., ECHCO; *E. crus-pavonis (*Kunth) Schult., ECHCV; *E. oryzoides* (Ard.) Fritsch, ECHOR). Other weeds of lesser importance are *Eleocharis palustris* (L.) Roemer & Schult., ELOPA (Cyperaceae) and *Ludvigia peploides* spp. *montevidensis* (Spreng.) Raven, LUDPE (Onagraceae). The effects of weed competition on water-seeded and continuously flooded rice occur mostly during the first 30 to 45 days after seeding (DAS) (Ampong-Nyako and De Datta, 1991; Gibson *et al*., 2002). If weeds are not controlled during this critical period, yields of Chilean rice can be reduced by 25 to 50 % (Ormeño, 1992), mostly due to decreased tiller production by rice plants (Pedreros and Alvarado, 1994). There is a very limited number of commercial rice varieties in Chile, and the most important variety, "Diamante", competes poorly against weeds due to its slow initial growth rate; it requires about 50 to 60 days to reach full tillering and leaf area index = 1 (INIA, 2010).

Before the introduction of sulfonylurea herbicides (SU), the main weed control program for rice in Chile consisted of molinate applied into the water (IW) about 12 DAS, to control *Echinochloa* spp. complemented by a sequential application of MCPA at about 50 DAS mainly to control *C. difformis* and *A. plantago-aquatica*. Water in the paddies had to be lowered for this second application in order to expose at least 75% of the weeds foliage to the herbicide. A commercial mixture of molinate and propanil was also very popular during the 80s; its application also required lowering paddy water levels. From 1995 to 1998, several SUs were introduced (bensulfuron-methyl, metsulfuron-methyl, cyclosulfamuron, and pyrazosulfuron). These herbicides were very effective against a wide spectrum of weeds, particularly bensulfu-

ron-methyl, applied at 10 to 15 DAS (IW). Rice producers adopted this new concept of a "one-shot" herbicide treatment very easily, since additional water management was not needed. By early 2002, several farmers had reported various levels of weed control failure with these SU herbicides, and an evolution of resistance was suspected. Therefore, it is imperative that new herbicides become available for use in paddy rice in order to counteract the effects of weed resistance and delay its further evolution. During 2003, penoxsulam (DE-638) was introduced in Chile as an experimental rice herbicide by Dow AgroSciences. Penoxsulam is a systemic herbicide that is absorbed mainly by leaves and secondarily by roots (Larelle *et al*., 2003). This herbicide is a member of the triazolopyrimidine sulfonamide (TP) chemical family, and its mechanism of action is the inhibition of the acetolactate enzyme (ALS), which impedes the biosynthesis of the branched-chain amino acids valine, leucine, and isoleucine. Although TP herbicides share with SUs the same mechanism of action, both types of chemicals differ in binding characteristics to ALS (Anonymous, 2003). The mechanism of resistance to bensulfuron-methyl and metsulfuron-methyl is not known for Chilean weed populations. Assuming target site-based resistance, cross resistance to penoxsulam was expected as SU- and TP-herbicides have identical structure activity relationship (Yang *et al*., 1999; Roux *et al*., 2005). The mutations in the ALS gene, known so far, confer that same cross-resistance pattern, except in one population (Tranel and Wright, 2002). However, from the literature different populations might have different responses to these herbicides. Penoxsulam (40 g ha^{-1}) does not affect rice yield or seed quality when applied between the two-leaf and mid-tillering stage of the crop, and it has a broad spectrum of weed control (*Echinochloa* spp., *A. plantago-aquatica*, *C. difformis*, *S. mucronatus* and others) (Larelle *et al*., 2003). Penoxsulam can be applied to drained (most common practice in the European Union) or to partially flooded paddies with about 4-5 cm of water, which can be re-flooded one to five days after application, without affecting final performance (Larelle *at al*., 2003). A granular formulation also allows for applications into flooded (10 cm) paddies in California (Fischer, 2005).

Several field efficacy trials were conducted in Chilean rice paddies in order to study: a) Efficacy of penoxsulam applied into the water (IW), b) Timing of IW applications of penoxsulam, c) Sequential applications of IW-applied penoxsulam followed by post-emergence herbicides (ADW), and d) Application of penoxsulam after draining the water from the paddies (ADW).

Materials and methods

General procedures

The experiments were conducted in two rice grower fields near Parral, VII region in Chile (latitude 71° 58′ S and longitude 35° 45′W) (Table 1). In the Valle Hermoso farm, *A. plantago-aquatica*, *C. difformis*, and *E. crus-galli* were the main weeds, while *A. plantago-aquatica*, *S. mucronatus*, and *E. crus-galli* predominated at El Rosal. A total of six on-farm field trials were performed during 2003 and 2004 rice cropping seasons. After spring tillage, the experimental plots (5 x 5 m) were flooded up to 10 to 15 cm deep. Individual plots were surrounded by 50 cm high and 35 cm wide levees. Rice seed (cv. Diamante) was presoaked for 48 hours, allowed to dry out for 24 hours and then broadcast into the water over all plots (140 kg ha^{-1}).

The soil type and characteristics were typically of the Vertisol type. All experiments were fertilized following the current farm practice with N, P, and K at 90, 60, and 133 kg ha^{-1}, respectively. Half of the total rate was incorporated in the soil before seeding and the rest at tillering initiation.

Commercial formulations of all herbicides: penoxsulam (Ricer, 24%, SC, Dow Agrosciences), molinate (Molirox, 74.7%, EC, BASF), metsulfuron-methyl (Ajax, 50%, WP, ANASAC SACI), bensulfuron-methyl (Stoke 60WP, 60%, WP, ANASAC SACI), MCPA (MCPA 750SL, 75%, SL, ANSAC SACI), Bentax (Bentazon 48SL, 48%, SL, ANASAC SACI), cyhalofop-buthyl (Clincher, 18%, EC, Dow Agrosciences), Bispiribac-Na (Nominee 40SC, 40%, SC, Bayer CropScience), propanil (STAM 80EDF, 80%, WG, Dow Agrosciences), triclopyr (Garlon 4, 61.6%, EC, Dow Agrosceinces), quinclorac (Exocet 35SC, 35%, SC, ANASAC SACI); were

applied using a manual backpack sprayer (15 L), equipped with four anti-drift nozzles (Albuz-Ari 11001) covering a 2.5-m swath, and spraying at 300 kPa to deliver 68 L ha^{-1} (into-the water applications, IW) or 200 L ha^{-1} (foliar applications after draining water from plots, ADW). Weed control efficacy was evaluated 35 days after herbicide applications (DAA) by counting weeds within three 300-cm^2 quadrats placed randomly in each plot, but at least 70 cm far from the plot levee.

At rice maturity, three square meter areas were harvested from each plot, and the percent moisture was determined (Farmex MT-PRO, Farmex Electronics, Streetsboro, Ohio). Rough rice yields were standardized to 14% moisture.

Statistical design and analysis

A randomized complete block design with four replications per treatment was used, and an untreated control was included in all experiments. Weed control efficacy and rice yield data were subject to analysis of variance using the Proc GLM (SAS®) procedure; all assumptions for this analysis were fulfilled and data transformations were not required. Means were separated using Least Significant Differences (LSD) test at the 5% level of significance.

Field experiments

Efficacy of penoxsulam applied into the water (IW)

For these experiments, rice was seeded on October 7, 2003 and harvested on April, 4th, 2004, and again seeded on November 20, 2004 at Valle Hermoso and on November 11, 2004 at El Rosal, and in both cases harvested on April 18th, 2005. Herbicide treatments (Table 1) were applied IW at 12 DAS, and water was maintained static in the plots during five days.

Timing of IW penoxsulam application

These experiments were seeded on October 30 and November 20, 2004, at El Rosal and Valle Hermoso, respectively, and harvested on April, 18th, 2005. Herbicides were applied IW at either 5 or

12 DAS when rice was at imperfect leaf unrolled and 1-2 leaves unfolded, respectively. Penoxsulam treatments were compared to a standard tank mix combination of bensulfuron-methyl + molinate (Table 2). Plots were maintained under static flood for five days following herbicide applications.

Post-emergence herbicides (ADW) following IW- applied penoxsulam

In 2004, two field trials were conducted to determine if weed control with penoxsulam (IW) would be improved by sequential post emergence (ADW) applications of herbicides with different modes of action (Table 3). The experiments were seeded on October 30 and November 20, 2004, in farms at El Rosal and Valle Hermoso, respectively, and harvested on April 18th, 2005. Treatments were made at 12 DAS (IW) and at 30 DAS (ADW). A non-ionic surfactant (0.1%) was used in conjunction with bispyribac-sodium.

Application of penoxsulam after draining the water from the paddies (ADW)

Penoxsulam (plus 0.1% non-ionic surfactant) was tested as a single postemergent (ADW) treatment in 2003 at the Valle Hermoso farm,

where it was compared to different sequential treatments involving IW followed by ADW applications of other herbicides (Table 4). Two experiments were seeded (October 17, and November 21, 2003, early and late seeded respectively) at this site and harvested on April 4th and 14th respectively. IW treatments were applied at 12 DAS and ADW treatments either at 30 DAS (tiller initiation) or, in the case of MCPA (amine salt) and triclopyr (potassium salt), at 50 DAS (end of tillering). The water level in paddies was maintained static for 48 h following IW applications, and after ADW applications, the water level was restored within 48 hours.

Results and discussion

Efficacy of IW penoxsulam

Sulfonylurea herbicides did not control *A. plantago-aquatica* in Valle Hermoso, and their effect on *C. difformis* was variable across years; nevertheless, densities of both species were reduced by the herbicides, but not statistically significant in some cases (P>0.05) (Table 1). Preliminary studies (Kogan, unpublished data) have established that *A. plantago-aquatica* has evolved resistance to bensulfuron at this site. Although it is also an ALS inhibitor, penoxsulam completely

Table 1. Rice yields and weed densities as a result of into-the-water (IW) herbicide treatments applied 12DAS to paddy rice, at two sites near Parral, Chile in 2003 and 2004. Data are means of four replications.

Herbicide	Rate (g ha⁻¹)	Valle Hermoso 2003			Valle Hermoso 2004				El Rosal 2004		
		ALSPA[2]	CYPDI[3]	Yield (t ha⁻¹)	ALSPA	CYPDI	ECHCG[4]	Yield (t ha⁻¹)	ALSPA	SCPMU	Yield (t ha⁻¹)
		x 1,000 plants ha⁻¹			x 1,000 plants ha⁻¹				x 1,000 plants ha⁻¹		
MSM + BSM[1]	2.5 + 72	2,056	2,811	6.51	--	--	--	--	--	--	--
BSM + Molinate	72 + 3.740	2,586	2,542	7.03	2,612	77	0	5.21	0	149	7.08
MSM + Molinate	2.5 + 3.740	2,155	4,326	6.80	2,813	141	0	6.07	0	555	6.62
Penoxsulam	20	111	956	7.72	--	--	--	--	--	--	--
Penoxsulam	30	73	2,037	8.00	820	0	38	5.63	0	230	6.62
Penoxsulam	40	216	2,742	8.41	488	0	35	6.97	0	41	7.88
Untreated	--	3,483	6,010	5.50	2,827	1,874	1,005	2.99	112	1,155	5.32
LSD (P≤0.05)		699.1	1,616.6	1.71	1,017.4	147.4	423.1	1.93	22.9	260.3	2.48

[1]MSM +BSM = metsulfuron-methyl + bensulfuron-methyl.
[2]ALSPA= *Alisma plantago-aquatica* L.
[3]CYPDI= *Cyperus difformis* L.
[4]ECHCG= *Escherichia crus-galli.*

Table 2. Rice yield and weed densities in experimental plots applied IW 5 and 12 DAS, in paddy rice, Parral, Chile in 2004. Data are means of four replications.

Herbicide	Rate (g ha⁻¹)	Application Time (DAS)	Valle Hermoso ALSPA	CYPDI	ECHCG	Yield (t ha⁻¹)	El Rosal ALSPA	SCPMU	Yield (t ha⁻¹)
			x 1,000 plants ha⁻¹				x 1,000 plants ha⁻¹		
Penoxsulam	30	5[2]	1.241	0	0	7.13	0	445	7.25
Penoxsulam	40	5	376	38	0	5.92	0	262	7.34
Penoxsulam	30	12[3]	873	0	37	5.63	0	223	6.71
Penoxsulam	40	12	478	0	36	6.96	0	99	7.98
BSM[1] + Molinate	3,740 + 72	12	2,671	74	0	5.21	0	148	7.88
Untreated	--	--	2,856	1,844	1,009	2.85	100	1,130	5.41
LSD (P≤0.05)			922.1	290.6	182.2	1.71	11.3	320.3	2.56

[1]BSM= bensulfuron-methyl.
[2]Rice imperfect leaf unrolled.
[3]Rice 1-2 leaves unfolded.

Table 3. Rice yield and weed densities as a result of different herbicide treatments applied into the water (IW) and after draining the water from the plots (ADW) ,12 and 30 DAA, respectively, in paddy rice, during 2004 cropping season, Parral, Chile. Data are means of four replications.

Herbicide IW (12 DAS)	ADW (30 DAS)	Rate (g ha⁻¹)	Valle Hermoso ALSPA	CYPDI	ECHCG	Yield (t ha⁻¹)	El Rosal ALSPA	SCPMU	CYPDI	ECHCG	Yield (t ha⁻¹)
			x 1,000 plants ha⁻¹				x 1,000 plants ha⁻¹				
Penoxsulam	--	30	257	0	37	6.96	0	37	0	0	8.33
Penoxsulam	Bentazon	30 + 960	164	0	167	6.77	0	0	0	0	9.17
Penoxsulam	Propanil	20 + 2,880	56	0	0	7.59	0	0	0	0	7.99
Penoxsulam	Propanil + Triclopir[1]	30 + 2,880 + 444	111	0	57	7.36	0	0	0	0	8.40
Penoxsulam	Bispiribac-Na + Surfactant[2]	30 + 40 + 0.1%	111	0	50	6.25	0	37	0	0	8.20
Molinate	Bentazon	3,740+ 960	557	500	279	6.79	0	185	37	0	7.35
Untreated			1,500	2,000	1,166	4.01	1,129	774	560	365	5.30
LSD (P<0.05)			237.3	426.4	183.0	1.45	214.9	121.7	26.4	32.6	2.12

[1]Triclopyr (potassium salt).
[2]Non ionic Surfactant (Zoom®).

controlled *A. plantago-aquatica* in 2003; the efficacy of this herbicide's was lower in 2004, but still higher than the SU herbicides. *C. difformis* was susceptible to all treatments, but its control was more difficult in 2003 where densities of this weed were about twice those found in 2004. Penoxsulam efficacy on this weed appeared higher than the other herbicides. However, control of *C. difformis* with penoxsulam was erratic as suggested by the lack of a dose response in 2003 (Table 1). This lack of consistent *C. difformis* control has also been observed in California (Fischer, 2003), where rice is grown under a very similar water-seeded system, and the penoxsulam label for California does not include *C. difformis* among the weeds expected to be fully controlled by this herbicide (Dow, 2009). The presence of *E. crus-galli* was only relevant in 2004 at the Valle Hermoso experiment where it was controlled by all treatments.

At the El Rosal site, *S. mucronatus* was almost the only weed present on the trial, since *A. plantago-aquatica* densities were very low (< 0.2×10^6 plants ha^{-1}) (Table 1). Both weeds were very susceptible to all treatments; *A. plantago-aquatica* had not evolved resistance to ALS inhibitors at this site. Bensulfuron-methyl (BSM) efficacy was higher than metsulfuron-methyl (MSM) and very similar than penoxsulam (30 g ha^{-1}).

Weed infestations significantly (P≤ 0.05) impacted rice yields at both sites. On average, herbicides prevented about 40 and 46% yield loss at Valle Hermoso in 2003 and 2004, respectively.

At El Rosal farm, weed competition, mostly by *S. mucronatus*, reduced rice yields by 27% with respect to the average yield in herbicide-treated plots (Table 1). This weed was susceptible to all herbicides and its density was brought down to low level of interference, thus yields did not differ among treatments.

Timing IW penoxsulam applications

Weed infestations in Valle Hermoso were similar as in the preceding experiment for 2004. All treatments controlled *C. difformis* and *E. crus-galli* (Table 2). The dominant weed, *A. plantago-aquatica,* was poorly controlled by bensulfuron + molinate, since it had evolved resistance to bensulfuron in this site. This weed was strongly suppressed by penoxsulam at al rates and timings, and a maximum of 87% control was obtained at the highest rate. Highest yields were obtained when penoxsulam was applied early (5 DAS) at the lowest rate, or at 40 g ha^{-1} if applied at 12 DAS (Table 2); higher yields at 5 DAS reflected the benefits of earlier weed control during the critical period of weed competition with rice (Gibson *et al.*, 2002). Yields tended to be lower somewhat when 40 g ha^{-1} of penoxsulam was applied at 5 DAS, but no significant differences were found. This is probably due to light crop injury. Data from California (Fischer, 2003) suggest that penoxsulam applied much earlier than the 2 leaf-stage of growth can stunt rice and retard its growth. As noted in the pre-

ceding section, in 2004 at Valle Hermoso, large differences in *A. plantago-aquatica* control did not translate into significant yield loss (Tables 1 and 2). For example BSM+molinate and penoxsulam 30 g ha^{-1} at 12 DAS controlled *C. difformis* and *E. crus-galli*, but differed greatly in *A. plantago-aquatica* control. Yet, yields under those two treatments did not differ significantly. Also, herbicide treatments never fully controlled *A. plantago-aquatica* at this site in 2004. This suggests that under the conditions prevailing in 2004, *A. plantago-aquatica,* in spite of high infestation level, may have been a rather weak competitor with rice. *A. plantago-aquatica* control by penoxsulam in Valle Hermoso was excellent in 2003, unlike control by the other ALS inhibitors (Table 1). Therefore, cross resistance between SU herbicides and penoxsulam may not be the reason for the lack of full control in 2004. It is apparent that *E. crus-galli* was an important competitor and was controlled by both BSM and penoxsulam. Greenhouse studies had shown that *E. crus-galli* is more competitive for nutrients than the other rice weeds (Kogan, unpublished data). In any case, while SU herbicides failed, penoxsulam provided the best *A. plantago-aquatica* control and the control of this weed was almost always correlated with higher yields (Table 2).

At El Rosal, *S. mucronatus* control with penoxsulam was variable, depending on the rate and timing of application, but control was about 90% with the highest rate applied 12 DAS. The BSM/molinate tank mixture also controlled this weed. Weed control efficacy was reflected in rice production (Table 2). Yields and *S. mucronatus* control from plots treated with penoxsulam (40 g ha^{-1}) were not statistically different from those obtained with the standard bensulfuron/molinate treatment. In both cases, yields were about 47% greater than that of the untreated control.

ADW post-emergence applications following IW penoxsulam

Weed infestations differed among sites (Table 3). At Valle Hermoso, *C. difformis* was the predominant species (2.0×10^6 plants ha^{-1}), followed by *A. plantago-aquatica* (1.5×10^6 plants ha^{-1}) and *E. crus-galli* (1.0×10^6 plants

Table 4. Rice yield and weed densities as a result of penoxsulam applied after draining water from plots (ADW) and sequential treatments applied in the water (IW) followed by others applied after drainage the water from the plots (ADW), during 2003 season, Parral, Chile. Data are means of four replications.

Herbicide		Rate (g ha^{-1})	Early seeding (10/17/2003)			Late seeding (11/21/2003)			
			ALSPA	CYPDI		ALSPA	CYPDI	ECHCG	
IW (12 DAS)	ADW (30 DAS)		x 1,000 plants ha^{-1}		Yield (t ha^{-1})	x 1,000 plants ha^{-1}			Yield (t ha^{-1})
	Penoxsulam + surfactant[1]	20	334	556	8.09	1,057	782	302	5.78
	Penoxsulam + surfactant[1]	30	612	145	7.62	1,569	865	110	5.64
	Penoxsulam + surfactant[1]	40	505	139	8.63	1,333	807	56	5.43
Molinate	MCPA amine[2]	3,740 + 370	83	120	9.25	500	582	0	5.81
Molinate	Triclopyr[2]	3,740 + 444	2,038	445	6.92	--	--	--	--
Molinate	Bentazon	3,740 + 960	--	--	--	969	253	0	6.87
MSM	Cyhalofop-butyl[3]	2.5 + 360	1,421	1,970	6.69	1,978	2,414	250	4.41
CSM	Cyhalofop-butyl[3]	49 + 360	865	1,611	6.82	1,950	1,204	0	3.27
MSM	Quinclorac[3]	2.5 + 625	890	1,000	7.89	1,677	555	581	3.16
CSM	Quinclorac[3]	49 + 625	876	1,614	6.52	2,164	762	306	3.62
Untreated		--	1,719	1,089	5.67	1,742	1,377	917	2.90
LSD (p<0.05)			479.2	518.5	1.66	579.4	473.6	130.7	1.51

[1]Non ionic surfactant (Zoom®) at 0.1%.
[2]Applied 50 DAS (End of tillering).
[3]Applied 30 DAS (Beginning of tillering).
[4]CSM: ciclosulfomuron; MSM: metsulfuron-methyl.

ha[-1]). Moderate infestations of *A. plantago-aquatica* and *S. mucronatus* (1.1×10⁶ and 0.7×10⁶ plants ha^{-1}, respectively) were found at El Rosal, where infestations by *C. difformis* and *E. crus-galli* were less important. On average, herbicide treatments prevented 42 and 35.4% yield losses at Valle Hermoso and El Rosal, respectively (Table 3). Penoxsulam IW (30 g ha^{-1}) controlled *E. crus-galli* and *C. difformis* effectively at both locations and *A. plantago-aquatica* by about 83% at Valle Hermoso and completely at El Rosal (Table 3). The sequential postemergent (ADW) applications of bentazon, propanil, triclopyr, or bispiripac-Na following penoxsulam applied IW, did not improve weed control significantly, thus yields were not different among herbicide treatments (Table 3). Penoxsulam applied IW was as effective as the currently used standard sequence of molinate (IW) followed by bentazon applied ADW at 30 DAS.

At El Rosal, IW penoxsulam was an effective broad-spectrum herbicide (Table 3). Plots treated with penoxsulam (30 g ha^{-1}) 12 DAS IW followed by bentazon ADW (35 DAS) achieved the highest yield, but there were no statistical differences among herbicide treatments (Table 3).

Penoxsulam as a postemergence foliar spray (ADW)

In the 2003 early seeded trial in Valle Hermoso, *A. plantago-aquatica* and *C. difformis* were the only two weeds present (Table 4). Molinate (IW) does not normally control these weeds, but MCPA following molinate was the most effective on both species (Table 4). Also, the foliar application of penoxsulam at 35 DAS was very active (best at 40 g ha⁻¹) against these weeds. As seen with the IW treatments (Table 1), SU-herbicides (IW) failed to control *A. plantago-aquatica* on this site, presumably due to evolution of resistant biotypes of this species. *C. difformis* appeared to be not very susceptible to SU- herbicides applied IW (Table 1) at Valle Hermoso in 2003 and 2004 seasons, probably because the efficacy of SU-herbicides applied IW is low, compared to ADW treatments. In general, weed control efficacy in 2003 was lower than in 2004 (Tables 1 and 3). Although present at lower densities, *E. crus-galli* infestations were relevant and were well controlled in the late seeded trial by the high rate of penoxsulam and the SU/cyhalofop-butyl sequences; the sequences with quinclorac also suppressed this weed, and all herbicide treatments that included molinate (IW) were very effective against *E. crus-galli*. Rice yields were highly correlated to weed control efficacy (Table 4). Triclopyr is a fairly narrow-spectrum herbicide in rice, and the molinate/triclopyr sequence was only active against *C. difformis*. On average, plots treated with penoxsulam (ADW) or with sequential applications of molinate (IW) followed by post emergence herbicides (ADW) yielded twice as much as the untreated control. In treatments that included a SU herbicides (MSM, CSM) applied IW yield was very similar to the untreated control.

The lack of *A. plantago-aquatica* control with SU herbicides during 2003 and 2004 confirm preliminary tests suggesting target-site resistance to this group of herbicides has evolved in *A. plantago-aquatica* populations at the Valle Hermoso site (Kogan, 2003 unpublished data). This resistance of *A. plantago-aquatica* to BSM is now widespread in most of the Chilean rice area (Figueroa *et al*., 2008), following selection pressure with this herbicide for several years in the absence of resistance prevention strategies. At the Valle Hermoso farm, SU herbicides have been used annually for the past 10 years.

Resistance of *A. plantago-aquatica* to bensulfuron was first reported in Portugal (Calha *et al*., 1999). In Italy, use of ALS-inhibitors in rice began in 1988 and *A. plantago-aquatica*, *S. mucronatus* and *C. difformis* have evolved resistance since 1994 (Tabacchi *et al*. 2004). Although, penoxsulam is also an ALS-inhibitor, field–level results do not suggest BSM-resistant *A. plantago-aquatica* was also cross-resistant to penoxsulam. Wide cross-resistance patterns have been documented in ALS-resistant *A. plantago-aquatica* populations from Italian rice fields. These biotypes exhibited high levels of resistance to SU herbicides but resistance was possibly lower to the triazolopyrimidine herbicide family, to which penoxsulam belongs (Sattin *et al*., 1999; Tabacchi *et al*., 2004). Different mutations on the ALS gene endow target-site resistance to ALS inhibitors, but mutations endowing SU resistance may not necessarily result in cross resistance to triazolopyrimidine herbicides (Tranel and Wrigth, 2002). Therefore, bensulfuron-resistant *A. plantago-aquatica* in Chile could be susceptible to penoxsulam, or have a lower-level of resistance as observed in Italy by Sattin *et al*. (1999) and Tabacchi *et al*. (2004). The selection pressure imposed on weeds in rice fields by repeated use of bensulfuron may have also advanced the evolution of resistance in other weeds. Resistance is often recognizable in the field when the proportion of resistant individuals is beyond about 30% (Gressel, 1991), thus it is possible that undetected resistance might already be present in populations of *C. difformis* and *S. mucronatus*. Various patterns of cross-resistance to ALS inhibitors have been found in *C. difformis* and *S. mucronatus* biotypes collected in rice fields of Italy, Spain and California (Busi *et al*. 2006). But, as already discussed for *A. plantago-aquatica*, resistance to SU herbicides not always resulted in cross-resistance to TP herbicides, namely penoxsulam. Of all bensulfuron-resistant *C. difformis* samples collected by Merotto *et al*.

(2005) throughout rice fields of California, only 25% exhibited cross-resistance to penoxsulam.

In summary, the present work sought to assess opportunities for using penoxsulam as a broad-spectrum rice herbicide by exploring its use at different timings, comparing its effectiveness against combinations of other products providing a similar spectrum of control, and by complementing its action with herbicides with different mechanism of action applied either prior or after penoxsulam. Penoxsulam proved to be a very versatile herbicide that could be applied into the water (IW) and after draining the water from the field (ADW), being the first timing of application the most convenient to farmers. However, this is an herbicide with a mechanism of action known to rapidly evolve resistance in weed populations, where there already exists a resistance to ALS inhibitors. Therefore, a sound stewardship for this herbicide from a resistance management standpoint is to avoid its repeated use as a single herbicide tool in these fields, as well as its use in mixture or sequence with other ALS inhibitors. In order to delay the evolution of resistance, penoxsulam should preferentially be used in mixtures or sequences with herbicides of different mechanism of action but effective on the same target weeds (Gressel and Segel, 1990). Therefore, using penoxsulma to control weeds

like *C. difformis*, *A. plantago-aquatica* or *S. mucronatus* in these rice fields, our results support the recommendation of sequential postemergent (ADW) applications of bentazon, propanil, or MCPA following IW treatments with penoxsulam. Sequences involving triclopyr would miss *A. plantago-aquatica* and thus open the possibility for this weed to evolve resistance to penoxsulam. Since penoxsulam is a broad-spectrum herbicide that controls *E. crus-galli*, treatments with penoxsulam in sequences involving either molinate, propanil, cyhalofop-buthyl, quinclorac, or other grass herbicides should also be sought. The use of bispyribac-sodium in conjunction with penoxsulam should be discouraged, since both are ALS inhibitors (Osuna *et al*., 2002). Penoxsulam IW treatment should not be applied more than two consecutive crop seasons. At the third year, penoxsulan ought to be applied ADW early post in mixture with bentazone or other herbicide with different mechanism of action that controls *A. plantago-aquatica*, to avoid possible selection of resistant individuals.

Acknowledgment

Resumen

M. Kogan, P. Gómez, A. Fischer y C. Alister. 2011. Eficacia de penoxsulam, inhibidor ALS, para el control de *Alisma plantago-aquatica*, resistente a sulfonilureas, en arroz en Chile. Cien. Inv. Agr. 38(1): 83-93. La producción de arroz en Chile ha seleccionado malezas acuáticas muy competitivas (25-50% reducción de rendimiento). Penoxsulam, inhibidor ALS (Triazolopyrimidina), herbicida de amplio espectro introducido en Chile el 2006, para el control de *Alisma plantago-aquatica*, la cual ha presentado resistencia a herbicidas sulfonilureas (SU). Se realizaron varios estudios de campo entre el 2003 y 2004 en la zona arrocera para determinar la eficacia, tiempo de aplicación, espectro de control y control de *A. plantago-aquatica* resistente a SU en base a aplicaciones solas de penoxsulam o en secuencia con otros herbicidas. Penoxsulam se evaluó en dosis de 20, 30 y 40 g ha^{-1} aplicándose: 12 días después de siembra (DDS) sobre el agua (IW), en postemergencia bajando el agua (ADW) 35 DDS, IW seguido de aplicaciones ADW de MCPA, cyhalofop, bentazon y triclopyr; en comparación con otros tratamientos IW (metsulfuron, bensulfuron y cyclosulfomuron) y con aplicaciones secuenciales de molinate (IW) seguido de MCPA, cyhalofop, bentazon y triclopyr ADW. Penoxsulam aplicado IW fue suficiente para controlar: *Echinochloa spp*. (100%), *A.plantago-aquatica* (80 to 100%), *Schoenoplectus mucronatus* (50 to 80%) y *Cyperus difformis* (80 to 100%). El

rendimiento del arroz en las parcelas con penoxsulam fue 30 a 56% mayor que el testigo. Rendimientos obtenidos con penoxsulam IW, en todas sus dosis, fueron similares (P>0.05) a los obtenidos con aplicación de molinate (IW), seguido de aplicaciones ADW de bentazon o MCPA. Es importante destacar que Penoxsulan controló *A. plantago-aquatica* resistente a metsulfuron y bensulfuron, siendo estos tres herbicidas inhibidores ALS.

Palabras clave: Penoxsulam, bensulfuron, metsulfuron, MCPA, bentazon, triclopyr, *Cyperus difformis, Schoenoplectus mucronatus, Alisma plantago-aquatica, Echinochloa crus-galli*, resistencia.

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