Chapter 2

Weed Management in Sprinkler-Irrigated Rice: Experiences from Southern Brazil

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Abstract

Sprinkler rice saves water compared to paddy rice. However, in paddy fields, the water table is efficient for weed suppression. In sprinkler rice, there is no water table on soil; thus, weed management used in paddy rice may not be suitable for sprinkler rice, since herbicides and water table are expected to interact. Weed pressure in sprinkler rice is higher than in paddy rice; annual grasses are the main weeds in both paddy and sprinkler rice. Barnyardgrass, goosegrass, crabgrass and Alexandergrass show vigorous growth in sprinkler rice. A 3-year study shows that weeds in sprinkler rice reduce grain yield between 11 and 95%. Herbicides used in conventional and Clearfield® rice (clomazone, imazethapyr + imazapic, imazapyr + imazapic, pendimethalin and penoxsulam) were tested, contrasting paddy and sprinkler rice. Additionally, the technique locally called "needle-point" (glyphosate applied over the first-day emerging rice) was combined with pre- and postemergence herbicides. When using only pre- or postemergence, weeds reduced rice grain yield; a combination of products was the best option for sprinkler-irrigated rice. The Clearfield technology was efficient in controlling most weeds. However, using it combined to the needle-point promoted the best results. The main approaches for weed management in sprinkler-irrigated rice were summarized.

Keywords: weed control, herbicides, management strategies, needle point

1. Introduction

Paddy rice is one of the most water demanding cropping systems in agriculture. Changing from surface to sprinkler irrigation can contribute to optimize water use in rice production. Under sprinkler irrigation, rice grain yield has reached similar levels as obtained in the traditional flooded system [1]. Sprinkler irrigation currently represents one of the best alternatives to improve water use efficiency in rice production.

However, weeds represent one of the main difficulties in sprinkler-irrigated rice. In the traditional surface-irrigation system, a layer of water (5–30 cm deep) remains permanently on soil during all rice cycle; the layer of water reduces free O_2 in soil, thereby suppressing the germination of most weeds. For the sprinkler-irrigated rice, the soil is maintained humid but not flooded, and oxygen levels are suitable for weed seed germination. In a practical sense, sprinkler irrigation facilitates weed establishment. This characteristic implies that weed management strategies that are successful in paddy rice usually not succeed under sprinkler irrigation [2].

In the roll of the main weed species in lowlands, annual grasses represent the most important group affecting rice, either in paddy as in sprinkler-irrigated [3]. The weeds barnyardgrass (the *Echinochloa* complex), goosegrass (*Eleusine indica*), southern crabgrass (*Digitaria ciliaris*) and Alexandergrass (*Urochloa plantaginea*) present vigorous growing under adequate soil humidity and high temperatures, and they reduce rice grain yield if not controlled efficiently. In **Table 1**, the most important weeds in rice fields of south Brazilian lowlands are listed. These weeds, besides red rice (the weedy *Oryza sativa*), are the most important species occurring in paddy rice fields of all sub-tropical South America [4].

Family/common name	Scientific name	Life cycle	Reproduction	Inf. level[2]
Poaceae				
Weedy rice (red rice)	*Oryza sativa*	Annual	Seeds	H
Barnyardgrass	*Echinochloa*[3]	Annual	Seeds	H
Goosegrass	*Eleusine indica*	Annual	Seeds	H
Alexandergrass	*Urochloa plantaginea*	Annual	Seeds	H
Crabgrass	*Digitaria ciliaris*	Annual	Seeds	H
	Digitaria sanguinalis			
German grass	*Echinochloa polystachya*	Perennial	Seeds, rhizomes	L
Cupgrass	*Eriochloa punctata*	Annual, perennial	Seeds	L
Marsh grass	*Hymenachne amplexicaulis*	Perennial	Seeds, stolons, rhizomes	L
Saramollagrass	*Ischaemum rugosum*	Annual	Seeds	L/I
Fall panicgrass	*Panicum dichotomiflorum*	Annual, perennial	Seeds, stolons	L
Brook crowngrass	*Paspalum acuminatum*	Perennial	Seeds, stolons	L
Knotgrass	*Paspalum distichum*	Perennial	Seeds, stolons, rhizomes	L
Water paspalum	*Paspalum modestum*	Perennial	Seeds, stolons	L
Mexican sprangletop	*Leptochloa uninervia*	Annual	Seeds	L
Southern cutgrass	*Leersia hexandra*	Perennial	Seeds, stolons	L
Peruvian watergrass	*Luziola peruviana*			

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Family/common name	Scientific name	Life cycle	Reproduction	Inf. level[2]
Cyperaceae				
Sedges	*Cyperus*[4]	Annual	Seeds	I/H
–	*Cyperus laetus*	Annual	Seeds, rhizomes	I
Yellow nutsedge	*Cyperus esculentus*	Perennial	Seeds, tubers	I
Fringerush	*Fimbristylis miliacea*	Annual	Seeds	I/H
Pontederiaceae				
Kidneyleaf mudplantain	*Heteranthera reniformis*	Perennial	Seeds, stolons	L
Alimastaceae				
Arrowhead	*Sagittaria guyanensis*	Perennial	Seeds, rhizomes, tubers	L
Giant arrowhead	*Sagittaria montevidensis*			
Fabaceae				
Jointvetches	*Aeschynomene denticulata*	Annual	Seeds	I
	Aeschynomene. indica			
	Aeschynomene sensitiva			
Amaranthaceae				
Alligator weed	*Alternanthera philoxeroides*	Perennial	Seeds, vegetative parts	I
Convolvulaceae				
Morning glory	*Ipomoea grandifolia*	Annual	Seeds	L
Onagraceae				
Waterprimrose	*Ludwigia elegans*	Annual, perennial	Seeds	L
	Ludwigia longifolia			
	Ludwigia octovalvis	Perennial		
Polygonaceae				
Smartweed	*Polygonum hydropiperoides*	Annual	Seeds	L/I

[1]Adapted from Ref. [5].

[2]Infestation level varies according to region, cropping system, crop rotation and herbicides (L = low; I = intermediary; H = high).

[3]Several barnyardgrass species are found, as *Echinochloa colona*, *Echinochloa crus-galli*, *Echinochloa mitis* and *Echinochloa helodes*.

[4]Several sedges species are found, as *C. difformis*, *Cyperus ferax*, *Cyperus iria* and *Cyperus brevifolius*.

Table 1. Main weeds found in lowlands cultivated under sprinkler-irrigated rice in southern Brazil [1].

The main paddy rice weeds in Brazil are commonly classified into narrow- and broad-leaved weeds. Main narrow leaves are weedy rice (*Oryza sativa*), barnyardgrass (*Echinochloa* sp.), Alexandergrass (*U. plantaginea*), crabgrass (*Digitaria horizontalis*), goosegrass (*E. indica*), the aquatic grasses (*Leersia hexandra* and *Luziola peruviana*) and the sedges (*Cyperus difformis*, *Cyperus* *esculentus*, *Cyperus ferax*, and *Cyperus laetus*). Some monocotyledonous weeds that are common in corn, sorghum and soybeans are expanding due both to the increase in crop diversification in lowland areas, and to the continued use of Acetolactate Synthase (ALS)-inhibitors herbicides with abandonment of propanil. Some locations also reported the presence of perennial weeds such as Olive hymenachne (*Hymenachne amplexicaulis*), ribbed murainagrass (*Ischaemum rugosum*), Mexican sprangletop (*Leptochloa uninervia*), Fall panicum (*Panicum dichotomiflorum*), Knotgrass (*Paspalum distichum*) and *Paspalum modestum*. As broad-leaved weed representatives, there are the jointvetches (*Aeschynomene* spp.) and in some areas some species of morning glory (*Ipomoea* spp.), water pepper (*Polygonum hydropiperoides*) and alligator weed (*Alternanthera philoxeroides*). The aquatic weeds, associated mainly with fields grown in the water-seeded system (with pre-germinated seeds) are globe fringerush (*Fimbristylis miliacea*), arrowheads (*Sagittaria montevidensis* and *Sagittaria guyanensis*), water hyacinth (*Eichhornia crassipes*), kidneyleaf mudplantain (*Heteranthera reniformis*) and the Ludwigia complex (*Ludwigia elegans*, *Ludwigia longifolia* and *Ludwigia octovalvis*).

2. Weed management in the traditional flooded-irrigated (paddy) rice in southern Brazil

Integrated weed management in paddy rice is characterized by the association of agronomic practices to minimize the negative effect of weeds [5]. Besides the layer of water on soil, which naturally reduces germination and establishment of various weed species, other measures such as the use of vigorous genotypes and an adequate rice plant density, provide a more competitive crop against weeds. Early soil preparation, which stimulates weed germination out of rice growing season is used, concomitantly to minimum tillage. Minimum tillage is an effective way to reduce the presence of some annual *Poaceae* species. The early seeding of rice, the application of nonselective herbicides using the needle-point technique, early weed control and early irrigation are a set of commonly used measures to reduce weed impact in flooded rice areas. Moreover, it is important to highlight that in the RS state (the larger rice producer in Brazil, supplying about 70% of Brazilian production), almost 75% of the rice is tolerant to imidazolinones (Clearfield® rice). This technology first started to be used by farmers in the cropping season 2003/2004.

3. Weed management in sprinkler-irrigated rice

Despite the several alternatives for weed management available for farmers [5], the most used method for weed control in flooded-irrigated rice is the association of chemical control (herbicides) with an early formation of water layer in the soil surface, provided by irrigation [6]. However, in sprinkler-irrigated rice there is not such water layer, and weed seed germination is, in fact, mostly stimulated by irrigation in sprinkler systems [2, 7]. The strategies for weed management in sprinkler-irrigated rice are, in this way, more complex than for the flooded system.

Studies conducted at EMBRAPA—Terras Baixas Experimental Station, in Pelotas, southern Brazil, show that in sprinkler-irrigated rice weeds can reduce rice grain yield in up to 95% [3], depending on the weed control provided by herbicides (**Table 2**). In such condition, rice yield

			Dry mass		Weed ctrl 70DAE		Grain yield	
			Npoint[2]	Norm	NPoint	Norm	NPoint	Norm
Herbicide	**Doses (g ha^{-1})**	**Appl. time[1]**	**(g m^{-2})**		**(%)**		**(t ha^{-1})**	
Clomazone[3]	400	PRE	174bc	182b	29d	31c	4.38bc	1.92cde
Clomazone[3]	700	PRE	69cd	112b	56bc	36bc	6.59ab	3.46bc
Pendimethalin	1250	PRE	306a	629a	3e	4e	3.55cd	0.67de
Pendimethalin	1750	PRE	322a	763a	6e	7de	0.98d	0.44e
Penoxsulam	24	POS	104bc	194b	65b	29cd	5.77b	3.85bcd
Penoxsulam	60	POS	182b	155b	41cd	24cd	4.23bc	2.32cde
Imazethapyr + imazapic	37.5 + 12.5	PRE	66cd	70b	68b	57b	6.14ab	4.61bc
Imazethapyr + imazapic	37.5 + 12.5	POS						
Imazethapyr + imazapic	56.25 + 18.75	PRE	2d	8c	95a	91a	9.58a	8.14ab
Imazethapyr + imazapic	56.25 + 18.75	POS						
Imazapyr + imazapic	73.5 + 24.5	POS	29d	35bc	95a	88a	9.70a	9.16a

Adapted from Ref. [3].

[1]PRE = preemergent; POS = postemergent.

[2]NPoint = treatment associated to the needle-point technique; Norm = treatment not associated to the needle-point technique.

[3]Seeds treated with dietholate (Permit®).

[4]Sequential applications. Means of columns followed by same letter are not significant different (Duncan test, $P \leq 0.05$).

Table 2. Herbicides, doses, application time, weed dry mass, weed control and rice yield in sprinkler-irrigated rice.

can be reduced to zero if weeds are not controlled. The main herbicides registered for weed control in rice in Brazil are listed in **Table 3**.

Herbicide[1]	Dose (a.i.) g ha^{-1}	Time/mode of application[2]
Bentazon	960	Post
Bispyribac-sodium	100–125 mL	Post
Clomazone	360–612	Pre
Cyhalofop-butyl	360–630	Post
2,4-D	240	Post
Fenoxaprop-P-ethyl	69	Post
Glyphosate	2.160	Pre (NPoint[3])
Imazapyr + imazapic	725 + 175/725 + 175	Pre/post
Metsulfuron-methyl	2	Post
Pendimethalin	1500	Pre
Penoxsulam	48–54	Pre/post
Propanil	2800	Post
Propanil + thiobencarb	1200 + 2400–600 + 3200	Post
Pyrazosulfuron-ethyl	15–20	Post
Quinclorac	375	Post

[1]Herbicides named by their technical names, not by their commercial names.
[2]Pre = preemergent; Post = postemergent.
[3]NPoint = treatment associated to the needle-point technique.

Table 3. Main herbicides registered for weed control in paddy rice in Brazil.

Recent studies with the most used herbicides (>90% of the Brazilian lowland rice area) clomazone, imazethapyr + imazapic, imazapyr + imazapic, pendimethalin, penoxsulam and glyphosate applied at the "needle point" [8] were evaluated under a range of weed species in sprinkler-irrigated and flooded-irrigated rice (**Figure 1**). The result of these experiments, conducted between 2011 and 2015, showed that using only conventional preemergent herbicides (clomazone, pendimethalin and penoxsulam) was not sufficient to fully control weeds, and consequently rice yield was affected (**Table 2**). However, associating the preemergent clomazone (700 g ha^{-1}), to the needle-point technique [8], was an effective way to reduce weeds, and this treatment resulted in high grain yield.

Penoxsulam, applied alone in preemergence, was efficient to control sedges like *Cyperus difformis* and *Cyperus iria*. However, for grasses, after two consecutive seasons the same rates of herbicides (penoxsulam (36 and 48 g ha^{-1}), clomazone (up to 360 g ha^{-1}) and pendimethalin

Figure 1. Seeds of rice at S_3 stage (commonly called the "needle-point"). Source: Refs. [7, 8].

(1250 and 1750 g ha^{-1}) were not able to fully control species like *E. indica*, *Digitaria* sp. and *U. plantaginea*. In these cases, there was the need for a complimentary postemergent application of the ACCase-inhibitor cyhalofop-butyl (360 g ha^{-1}).

When the option for weed control was based on the Clearfield® technology, the sequential application of imazethapyr + imazapic (56.25 + 18.75 g ha^{-1}) in preemergence ($^1/_2$ dose) and post emergence ($^1/_2$ dose), provided adequate results. Smaller doses of imazethapyr + imazapic, applied without other supplementary herbicide, were not effective and resulted in poor weed control and in a reduced rice production. However, when the reduced dose was associated to the needle-point technique, the weed biomass was reduced and rice grain yield was improved. The commercial mix of imazapyr + imazapic (73.5 + 24.5 g ha^{-1}), applied either in pre- or postemergence, was efficient to reduce weed biomass, which allowed rice to express a high grain yield (**Table 2**). In the fields using the Clearfield technology, however, also occurred some uncontrolled plants of *E. indica*, *Digitaria* sp. and *U. plantaginea*. In these cases, an additional application of the ACCase-inhibitor cyhalofop-butyl was needed.

Another option for chemical weed control evaluated was the split of clomazone application. To test this treatment, the first application of clomazone was at preemergence (360 g ha^{-1}), at the beginning of rice germination (the needle-point stage); the second application was in postemergence (360 g ha^{-1}). Clomazone was supplemented by the ACCase inhibitor cyhalofop-butyl, applied at early postemergence (17 days after rice emergence). This combination presented a high level of control for annual grasses. However, as neither clomazone nor cyhalofop control efficiently sedges, fields with sedge infestation can require different strategies for weed management.

In a general overview, we observed benefits for weed control when we associated preemergence herbicides to the needle-point technique in sprinkler-irrigated rice. Glyphosate, applied at very early rice emergence, is very effective against most of annual grasses occurring in rice, like *Echinochloa*, *Urochloa*, *Digitaria* and others. This association effectively reduced weed biomass, enabling to attain high levels of control even at a late rice stage, as 70 days after emergence (**Figure 2**).

From these experiments, we elaborated **Table 4** with some strategies for chemical weed control in sprinkler-irrigated rice. Surely, in fields with a low weed infestation it is possible to use less herbicides than are here presented. A scale of colors was used to highlight the efficiency

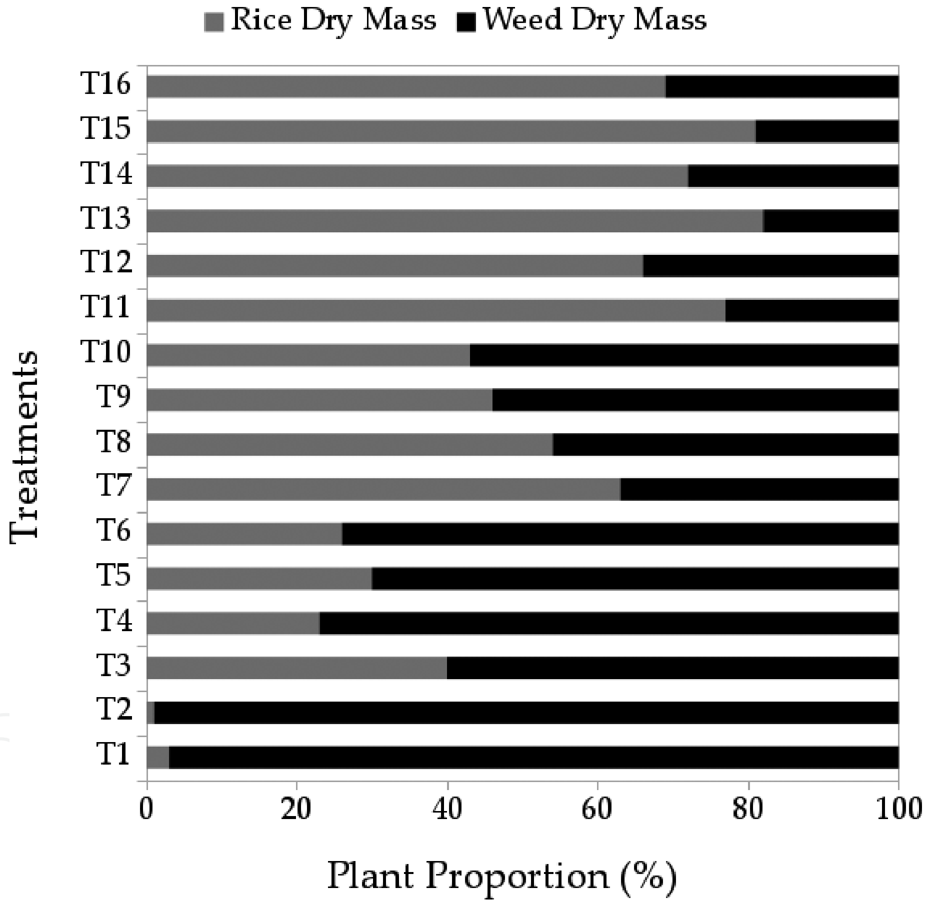

Figure 2. Dry mass of rice and of weeds as a function of chemical treatments for weed control in sprinkler-irrigated rice. (T1) glyphosate, applied at the needle-point of rice, (T2) no weed control, (T3) glyphosate*/clomazone 360 g a.i. ha^{-1} preemergence, (T4) clomazone 360 g a.i. ha^{-1} preemergence, (T5) glyphosate*/clomazone 450 g a.i. ha^{-1} preemergence, (T6) clomazone 450 g a.i. ha^{-1} preemergence, (T7) glyphosate*/penoxsulam 48 g a.i. ha^{-1} pre and postemergence, (T8) penoxsulam 48 g a.i. ha^{-1} pre- and postemergence, (T9) glyphosate*/penoxsulam 36 g a.i. ha^{-1} pre- and postemergence, (T10) penoxsulam 36 g a.i. ha^{-1} pre- and postemergence, (T11) glyphosate*/imazethapyr+imazapic (75 + 25 g a.i. ha^{-1}) preemergence, (T12) imazethapyr + imazapic (75 + 25 g a.i. ha^{-1}) preemergence, (T13) glyphosate*/imazethapyr + imazapic (75 + 25 g a.i. ha^{-1}) pre- and postemergence, (T14) imazethapyr + imazapic (37.5 + 12.5 g a.i. ha^{-1}) pre- and postemergence, (T15) glyphosate*/imazapyr + imazapic (73.5 + 3.5 g a.i. ha^{-1}) preemergence, (T16) imazapyr + imazapic (73.5 + 3.5 g a.i. ha^{-1}) preemergence. *Glyphosate at 720 g e.a. ha^{-1} applied at the needle-point of rice.

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		Applic. time	Herbicide	Label dose (ge.a/i.a ha^{-1})	Main weeds and herbicide efficiency#							Estim. Cost (US$ ha^{-1})##
					Weedy rice	Barnyardgrass	Alexandergrass	Crabgrass	Goosegrass	Cyperus*	Broadleaves**	
1	Only for Clearfield® cultivars	Burndown	Glyphosate	1400								19.0
		PRE[1]	Imazethapyr + imazapic	56.25 + 18.75								20.4
		PAg[2]	Glyphosate	720								6.4
		POS[3]	Imazethapyr + imazapic	56.25 + 18.75								20.4
		POS[4]	Cyhalofop-butyl	360								59.8
2												=US$ 126
		Burndown	Glyphosate	1400								19.0
		PRE[1]	Imazapyr + imazapic	73.5 + 24.5								27.5
		PAg[2]	Glyphosate	720								6.4
		POS[3]	Cyhalofop-butyl	360								59.8
												=US$ 112.7

		Applic. time	Herbicide	Label dose (ge.a/i.a ha^{-1})	Main weeds and herbicide efficiency[#]							Estim. Cost (US$ ha^{-1})[##]
					Weedy rice	Barnyardgrass	Alexandergrass	Crabgrass	Goosegrass	Cyperus[*]	Broadleaves[**]	
3	For all rice cultivars	Burndown	Glyphosate	1400								19.0
		PRE[1]	Clomazone	360								21.8
		PAg[2]	Glyphosate	720								6.4
		POS[3]	Cyhalofop-butyl	360								59.8
		POS[4]	Cyhalofop-butyl	360								59.8
		POS[3]	Metsulfuron-methyl	2								2.7
		POS	Bentazon	960								14.1
4												=US$ 183.6
		Burndown	Glyphosate	1400								19.0
		PRE[1]	Penoxsulam	48								32.8
		PAg[2]	Glyphosate	720								6.4
		PRE[1]	Clomazone	360								21.8
		POS[4]	Cyhalofop-butyl	360								59.8
		POS[4]	Cyhalofop-butyl	360								59.8
												=US$ 199.6

		Applic. time	Herbicide	Label dose (ge.a/i.a ha⁻¹)	Main weeds and herbicide efficiency#							Estim. Cost (US$ ha⁻¹)##
					Weedy rice	Barnyardgrass	Alexandergrass	Crabgrass	Goosegrass	Cyperus*	Broadleaves**	
5	Conv. tillage system	PRE[1]	Clomazone	360	red	green	green	green	green	red	red	21.8
		PAg[2]	Glyphosate	720	green	green	green	green	green	green	green	6.4
		POS[3]	Cyhalofop-butyl	360	red	green	green	green	green	red	red	59.8
		POS[3]	Cyhalofop-butyl	360	red	green	green	green	green	red	red	59.8
												=US$ 147.8

*Ciperaceae (*C. difformis*, *C. esculentus*, *C. ferax*, *C. iria* and *C. brevifolia*).

**Broadleaves, as *Alternathera philoxeroides*, *Polygonum persicaria* and *Aeschynomene denticulata*.

#Herbicide efficiency: red = low control; yellow = intermediary control; green = high control.

##Prices surveyed in the local market on October 28, 2015 (1 US$ = 3.90 R$). Only herbicide costs.

[1]Preemergence (at the needle-point stage of rice) or at postemergence, closest to first postemergence application.

[2]At the needle-point stage of rice (no more than five days after seeding).

[3]Early postemergence (two to four leaves)—adjuvants can be required. Please consult the herbicide label.

[4]Late postemergence (more than five leaves). In some cases, even three applications can be needed to full grass control.

Table 4. Strategies for chemical weed control in sprinkler-irrigated rice, in a highly weed-infested field.

of the treatments, based on experimental data. The presented costs are the commercial prices paid by farmers for the treatments in south of Brazil, as in December 2015.

4. Final remarks

Weed occurrence can reduce grain yield in sprinkler-irrigated rice, and the reduction probably will be significant if the weeds are not efficiently controlled. Sprinkler irrigation is a convenient system for crop rotation, avoidance of drought effects, water savings in rice production and to obtain high yields from crops. These advantages, however, do not minimize the importance of weeds, which are still one of most important pests in fields irrigated by sprinklers. Cultural measures of weed management are needed to reduce the overall impact of weeds in all production systems. However, for the sprinkler-irrigated rice, the special condition provided by the frequent irrigation gives additional advantages to the weeds. Without any water restriction, weeds normally grow faster than in rainfed fields, and can attain high density, since the germination is stimulated by the high soil humidity. In this way, the chemical control has been the most important tool to reduce the impact of weeds in sprinkler-irrigated rice.

Rice conducted under sprinkler irrigation should, preferably, start without weeds growing together with the crop. This is important to avoid the initial competition between the weeds and the rice. Moreover, if the weeds are already established, the difficulties to control increase, and the control levels, consequently, are prejudiced. The simple increase in the herbicide doses not always increase weed control. This is especially valid for the fields with resistant weeds and for those situations where the farmer already applied the highest dose allowed for an herbicide.

For those reasons, it is important to associate several strategies for weed management, which can reduce weed density, attenuate the weed growth and improve the performance of chemical control. In fields with a large seed bank, for example, some techniques can be used to reduce seed viability, as the summer- or fall-tillage, which stimulates the weed seeds to germinate out of rice growing season; additionally, cover crops, no-tillage and crop rotation can be used to increase the amount of residues in and on the soil, which reduce seed viability.

Maintaining residues (mulching) in the soil surface, from crops or cover crops cultivated during winter, can reduce weeds in sprinkler-irrigated rice, cultivated in no-tillage in the succeeding summer. Some grass weeds, like *Urochloa plantaginea*, are very sensitive to this form of suppression. Apart from cultural measures, the use of preemergent herbicides, combined with nonselective weed control previously to rice emergence (the needle-point technique, using glyphosate or other nonselective herbicide) is an efficient option for chemical weed control in sprinkler-irrigated rice.

Besides these alternatives, the use of the Clearfield system, which uses rice cultivars resistant to imidazolinone herbicides, currently is one of the most powerful tools for weed control in irrigated rice in south Brazil. However, as the Clearfield system is based on ALS-inhibitor herbicides, some potential drawbacks related to weed resistance and carryover to nontolerant species cannot be ignored. For these reasons, farmers are advised to always monitor the

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fields regarding weeds not controlled (escapes) and strictly follow the doses indicated by the label.

Finally, the studies with sprinkler-irrigated rice emphasize the high potential of this system regarding productivity, water savings and diversification in the production system. Under the scope of pest management, the sprinkler-irrigated rice requires integrated strategies for a successful, effective weed control. Weeds are highly favored by this system, and the use of herbicides should be accompanied by preventive and cultural measures against the weeds. Moreover, it is important to monitor the fields to know which species of weeds are occurring, to choose the best alternative for chemical control. Finally, we advise farmers to always consult the label of herbicides before use, as well as follow the regional recommendations provided by official institutions.

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