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Research Article

Off-season management with herbicides as an alternative to reduce weed infestation in paddy rice production systems

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The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Highlights

- The off-season management reduced the infestation of weedy rice only in the in water-seeded system.
- Flumioxazin was efficient in controlling giant arrowhead during the off-season in the in water-seeded system.
- The application of herbicides in the off-season reduced barnyardgrass infestation in drill-seeded system.

Abstract

Background: Weed management is a challenge in paddy rice production, mainly due to the dispersal of a population resistant to herbicides.
Objective: To assess the efficacy of chemical weed control in the off-season to reduce weedy rice and other species in water-seeded or drilled rice.
Methods: Two experiments were carried out in a flat field to water-seeded or drilled rice, in randomized block design. The water-seeded system treatments were organized in a split-plot design. In the plot were evaluated two water management in the off-season (with or without continuous flooding), and in the subplot nine herbicides-treatments were evaluated (Check, clomazone at 0.72 and 1.08 kg a.i. ha^{-1}, oxadiazon at 1.00 and 1.50 kg a.i. ha^{-1}, oxyfluorfen at 0.312 and 0.48 kg a.i. ha^{-1}, S-metolachlor at 1.44 kg a.i. ha^{-1}, and flumioxazin a 0.075 kg a.i. ha^{-1}). In the drilled rice experiment, the treatments were organized in a two-factor factorial. The factor A was nine herbicides treatments (the same herbicide and rates applied in water-seeded experiment) and the factor B was two application time (73 and 43 days before of rice-sowing).
Results: Off-season management was efficient to reduce weedy rice infestation only on the paddy rice system using the pre-germinated seeds. In this assay, flumioxazin was an efficient alternative to giant arrowhead control, however the selectivity of this herbicide treatment needs to be studied. In dry-seeded system, herbicide sprayed in off-season reduced barnyardgrass infestation until the paddy rice sowing.
Conclusions: The off-season management was efficient to reduce weedy rice and giant arrowhead infestation in water-seeded system, and barnyardgrass infestation in drill-seeded system.

1 Introduction

In Santa Catarina, paddy rice culture is carried out in two production systems (water-seeded and drill-seeded), covering approximately 80% and 20% of the cultivated area, respectively (Sosbai, 2018). The water-seeded system allows the reduction of herbicides used for weed control, and the soil preparation and seedbed leveling are performed with reduced ponding water depth. The seeding is made with pre-germinated seeds distributed in the ponding water depth (Machado et al, 2006; Sosbai, 2018; Gutz et al, 2019).

In the drill-seeded system, rice is seeded by direct sowing in a previously prepared soil, so that there is enough time for the formation of a vegetation cover, which is controlled by using broad-spectrum herbicides (Weber et al., 2003; Sosbai, 2018). In addition, the early preparation of the soil stimulates the germination of weedy rice seeds in the off-season, allowing the adoption of management practices that reduce the infestation of this species during the crop cycle.

Another characteristic of the “catarinense” production of water-seeded rice is the lack of crop rotation in the production fields (Eberhardt et al., 2016). The growing period can last from August to April or May, depending on the region, with off-season from May to July. In the off-season, the areas remain fallow, which contributes to increasing weed infestation by allowing the production and dispersion of seeds. So, off-season management arises as a possibility to control weeds avoiding the increase of the seed bank in the soil and reducing weed infestation in water-seeded rice crops. In addition, it is known that the application of herbicides with residual activity in the soil, such as alachlor, clomazone, S-metolachlor, pendimethalin, and trifluralin, proved to be an efficient alternative to control weedy rice in other production systems (Griffin and Harger, 1990; Askey et al., 1998).

Weedy rice (*Oryza sativa*) is one of the main weeds that affect irrigated rice crops worldwide (Chin, 2001; Sudianto et al., 2013). This species competes with paddy rice by nutrients, water, and light, being more efficient in nitrogen absorption than the crop itself (Burgos et al., 2006). The coexistence between cultivated and weedy rice results in losses, both in quantity as in quality, of the harvested product, which reduces the profitability of the production system. The reduction in yield of paddy rice may be higher than 80% in a high weedy rice infestation condition (Eleftherohorinos et al., 2002; Shivrain et al., 2010). Also, rice loses market value as the contamination by weedy rice increases (Ottis et al., 2005).

The control of weedy rice is a challenge, and the main reasons are the lack of specific and efficient herbicides to manage this weed. The non-chemical control methods are usually laborious and expensive, and weedy rice is easily dispersed along with the seed of cultivated rice, also establishing a persistent seed bank (Chin, 2001). So, the management of this weed should be based on integrated practices (Watanabe, 2011), which include using high-purity certified seeds, previous preparation of the soil, rotation of production systems (Kalsing et al., 2019), a fast establishment of the ponding water depth (Avila et al., 2005), and application of herbicides in pre-sowing (Noldin et al., 2002).

Based on this information, we formulated a hypothesis was that the use of herbicides with residual activity in the soil during the off-season would be an effective alternative to reduce the infestation of weedy rice in paddy rice. So, the objective of this work was to evaluate the efficiency of the off-season management with the application of herbicides in reducing the infestation of weedy rice and other weeds in the water-seeded and drill-seeded systems.

2 Material and Methods

2.1 Trial field

The experiments were carried out in a systematized area for paddy rice production, located in the city of Itajaí, SC (26º56’46’’ S, 48º45’37’’ O, and 6 meters of altitude). Experiment 1 was conducted in a water-seeded seed system, and experiment 2 in a drill-seeded system with sowing in drained soil. Both experiments were conducted between June 2015 and April 2016.

2.2 Experimental design and treatments

The experiments showed 18 treatments and were conducted in a randomized block design with four replications. The experimental units had a total area of 21 m^2 (3 x 7 m), and a usable area of 10 m^2 (2 x 5 m).

In the water-seeded system, the treatments were organized in a split-plot scheme. In the main plot, two water management systems were allocated in the off-season, from June to September 2015 (continuous flood or drained area). In each subplot, nine treatments were allocated (control, clomazone at 0.72 and 1.08 kg a.i. ha^{-1}, oxadiazon at 1.00 and 1.50 kg a.i. ha^{-1}, oxyfluorfen at 0.312 and 0.48 kg a.i. ha^{-1}, S-metolachlor at 1.44 kg a.i. ha^{-1}, and flumioxazin at 0.075 kg a.i. ha^{-1}).

In the drill-seeded, the treatments were arranged in a 9 x 2 two-factorial. The efficiency of nine treatments was evaluated (control, clomazone at 0.72 and 1.08 kg a.i. ha^{-1}, oxadiazon at 1.00 and 1.50 kg a.i. ha^{-1}, oxyfluorfen at 0.312 and

0.48 kg a.i. ha^{-1}, S-metolachlor at 1.44 kg a.i. ha^{-1}, and flumioxazin at 0.075 kg a.i. ha^{-1}), applied in two periods during the off-season (73 and 43 days before sowing the paddy rice).

The herbicides clomazone, oxadiazon, and oxyfluorfen are selective and registered for paddy rice. For this reason, it was decided to apply them in rates of 30% and 100% higher than the rate indicated in the insert package. The reference rates were 540, 750, and 240 g a.i. ha^{-1} for clomazone, oxadiazon, and oxyfluorfen, respectively. The herbicides S-metolachlor and flumioxazin are not registered to use in water-seeded rice, so the rates used were based on the package insert recommendations for other crops.

2.3 Infestation of the area with weedy rice

Before starting the experiment (water management in the water-seeded system or chemical management in drill-seeded system), on 06/11/2015, the infestation of the experimental area was performed with the SCS115 CL cultivar, at a density of 100 kg ha^{-1}. After the seed distribution, three operations were performed with a tractor equipped with a cage wheel, aiming at the superficial incorporation of the seeds. The SCS115 CL cultivar was used to simulate the infestation of weedy rice, due to its larger size and precocity compared to the SCS121 CL cultivar, which allows its differentiation during the reproductive stage. In addition, the SCS115 CL cultivar simulates an infestation of weedy rice imidazolinone-resistant. This type of infestation shows what occurs in the field when genotypes with distinct cycles or characteristics are used in succedaneum crops. The infestation of weedy rice was simulated due to the non-occurrence background of this infestation in the experimental area.

2.4 Soil management

Before the application of the treatments in the water-seeded system experiment, the experimental area was prepared to aim for the cultivation of pre-germinated seeds. The preparation of the soil involved a harrowing operation, sludge formation with a rotary hoe, and soil leveling for the formation of the seedbed. At the end of soil preparation, the plots were isolated using PVC laminate sheets.

The systematization of the drill-seeded area was performed before the infestation with weedy rice, simulating the management of the crop residues after harvest. In this operation it was used a knife roller for the superficial incorporation of crop residues and, subsequently, drains have been installed to the surface, which ensured the drainage area during the off-season. Burndown was performed with glyphosate (1.080 g e.a. ha^{-1}), a week before sowing.

2.5 Application of the treatments

In the water-seeded system, the treatments were applied on 08/28/2015 (44 days before sowing irrigated rice), in soil prepared for sowing. The weather conditions were adequate (24 ºC, 70% RH, 3.4 km h^{-1} wind, clear sky, and moist soil). In the drill-seeded system, the treatments were applied twice, the first on 7/2/2015 (73 DAS), and the second on 7/31/2015 (43 DAS). The applications were performed in the morning, in favorable weather conditions (23 to 24 ºC, 63 to 65% RH, 0,6 to 1.5 km h^{-1} wind, partly cloudy sky, and moist soil).

All applications were carried out with a CO_2 backpack sprayer with flat nozzle 110.015, working pressure of 208 kPa, travel speed of 1 m s^{-1}, and application rate at 150 L ha^{-1}.

2.6 Sowing and crop practices

The SCS121 CL cultivar was used in both cultivation systems. In the water-seeded, seeds were sown 44 days after treatment (10/05/2015), while 120 kg ha^{-1} of pre-germinated seeds were distributed in the water depth. After sowing, the area was not drained to ensure the establishment of the rice on the ponding water depth. In the drill-seeded, the sowing was performed on 09/14/2015, by distributing 90 kg ha^{-1} of seeds, and 0.17 m of spacing between rows. In this system, the ponding water depth was established when the crop presented four fully expanded leaves (V_4).

Weeds such as barnyardgrass (*Echinochloa crus-galli*) and giant arrowhead (*Sagitaria montevidensis*) were managed in post-emergence with a tank-mixing of penoxsulam + bentazon (60 + 960 g i.a. ha^{-1}). The option was to control the barnyardgrass and giant arrowhead in post-emergence because the research objective was to evaluate the effectiveness of treatments on the weedy rice control. The other crop practices adopted while conducting the crop followed the technical recommendations for paddy rice in Santa Catarina.

2.7 Evaluated variables

In the water-seeded system, the control of giant arrowhead (*Sagittaria monteviensis*) was evaluated six days after sowing (DAS), phytotoxicity in water-seeded rice, at 15 DAS, infestation by weedy rice, at 120 DAS, and grain yield, with moisture corrected to 13%.

In the drill-seeded, it was evaluated the density of weedy rice and barnyardgrass (*Echinochloa* spp.) before the burndown for water-seeded rice sowing, weedy rice infestation at 120 DAS, and grain yield, with moisture corrected to 13%.

2.8 Data analysis

The data were submitted to analysis of variance by the F test and the means compared by the Tukey test. The results of the weed infestation density were transformed into $\sqrt{x+0.5}$ before the analysis of variance. The significance level adopted was 5% ($p<0.05$).

3 Results and Discussion

3.1 Water-seeded system

The interaction between herbicide treatment and off-season water management was not significant for control of the giant arrowhead 6 DAS (Table 1). The water management adopted in the off-season also did not influence in the control of giant arrowhead. This result was not expected, since it was predicted a higher infestation in the area that remained flooded during the off-season, due to the ecological requirements of the species (Cassol et al., 2008).

The herbicide factor was significant, and most of the treatments provided a low level of control of the giant arrowhead, except for flumioxazin, which presented a mean control higher than 89% (Table 1). Similarly, Richardson et al. (2008) concluded that the herbicide flumioxazin was efficient in controlling *Alternanthera philoxeroides, Salvinia molesta*, and *Pistia stratiotes*, also aquatic plants, at rates from 36 g ha^{-1}. Despite good efficiency, flumioxazin was the only treatment that caused phytotoxicity to the rice. The symptoms shown were a slow establishment of the plants and suppression of initial growth. The other treatments did not promote symptoms of phytotoxicity (data not shown).

These results indicate the efficiency of flumioxazin in control of the giant arrowhead, which is one of the most frequent species in water-seeded rice crops in Santa Catarina, due to its adaptation to the water-seeded system and multiple resistance to herbicides that inhibit ALS and bentazon (photosystem inhibitor II) (Moura et al., 2016). However, its selectivity for paddy rice in the water-seeded production system needs to be studied.

Table 1 - Percentage of control of giant arrowheads at six days after sowing (DAS). Experiment in the water-seeded system. Itajaí, SC, 2015/2016

Treatment	Rate (kg ha^{-1})	Off-season flood		
		With	Without	Mean
Infested control	-	0.0	0.0	0.0 e
Clomazone	0.72	33.8	26.3	30.0 bcd
Clomazone	1.08	35.0	28.8	31.9 bc
Oxadiazon	1.00	15.8	20.0	17.9 cd
Oxadiazon	1.50	15.0	16.3	15.6 de
Oxyfluorfen	0.312	18.8	18.8	18.8 cd
Oxyfluorfen	0.48	24.3	18.8	21.5 cd
S-metolachlor	1.44	46.3	37.5	41.9 b
Flumioxazin	0.075	90.8	87.8	89.3 a
Mean		31.1 A	28.2 A	
CV (%)		33.6		

Means followed by the same lowercase letter in the column or uppercase in the row do not differ by the Tukey test (p>0.05).

It was observed in the variable weedy rice number of panicles that the interaction between factors was not significant, except for the isolated factors. The maintenance of the flooded area during the off-season contributed to the reduction of the infestation of weedy rice (Table 2). Most of the evaluated treatments significantly reduced the weedy rice infestation, excluding treatments based on clomazone and oxyfluorfen at the lowest rate, which showed similar infestation to the infested control (Table 2).

Table 2 - Infestation of weedy rice (panicles m^{-2}) at 120 DAS. Experiment in the water-seeded system. Itajaí, SC, 2015/2016

Treatment	Rate (kg ha^{-1})	Off-season flooding		
		With	Without	Mean
Infested control	-	0.73 (1)	0.83	0.78 a
Clomazone	0.72	0.40	0.68	0.54 ab
Clomazone	1.08	0.28	0.53	0.40 b
Oxadiazon	1.00	0.28	0.50	0.39 b
Oxadiazon	1.50	0.20	0.35	0.28 b
Oxyfluorfen	0.312	0.40	0.65	0.53 ab
Oxyfluorfen	0.48	0.48	0.40	0.44 b
S-metolachlor	1.44	0.43	0.20	0.31 b
Flumioxazin	0.075	0.28	0.38	0.33 b
Mean		0.38 B (2)	0.50 A	
CV (%)			21.8	

Means followed by the same lowercase letter in the column or uppercase in the row do not differ by the Tukey test (p>0.05). (1) Original data. (2) Analysis of the data transformed in $\sqrt{x+0.5}$.

The decision to increase the rate in the herbicides clomazone and oxyfluorfen was a successful practice, emphasizing that this decision was made because these herbicides were selective for water-seeded rice when used in smaller rates (Cavero et al., 2011; Agrofit, 2019). Similarly, Shrestha et al. (2019) demonstrated that flumioxazin at a rate of 72 g ha^{-1} was effective in controlling 51 genotypes of weedy rice. The efficiency of S-metolachlor in the control of weedy rice is due to its toxicity to the species. Liu et al. (2012) have shown that this herbicide is responsible for reducing the elongation of the aerial part, root, and number of secondary roots in rice seedlings. In addition, these authors identified an increase in the activity of superoxide dismutase, peroxidases, cytochrome P450, glutathione-S-transferase, glutathione content, and adverse effects on leaf cells.

Despite the artificial infestation, a low infestation of weedy rice was observed (< 1,0 m panicle m^{-2}). This could have occurred due to how the experiment was conducted in the water-seeded system, combined with the establishment of the crop in ponding water depth. The anaerobic environment of the water-seeded system significantly reduces the infestation of weedy rice (Avila et al., 2000).

The interaction between the factors, as well as the herbicide treatments evaluated, did not affect the grain yield. These results indicate that the treatments evaluated were selective to water-seeded rice, cultivar SCS121 CL, in the water-seeded system. The grain yield of the area that remained flooded during the off-season was significantly higher than the presented in the area that remained drained, and this difference was greater than 1,000 kg ha^{-1} (Table 3).

Table 3 - Grain yield of water-seeded rice (kg ha^{-1}) according to herbicide treatment and off-season water management. Experiment in the water-seeded system. Itajaí, SC, 2015/2016

Treatment	Rate (kg ha^{-1})	Off-season flooding		
		With	Without	Mean
Infested control	-	7.304	6.070	6.687 a
Clomazone	0.72	7.335	6.481	6.908 a
Clomazone	1.08	7.287	6.146	6.717 a
Oxadiazon	1.00	7.386	5.390	6.388 a
Oxadiazon	1.50	7.714	6.821	7.267 a
Oxyfluorfen	0.312	7.529	6.650	7.089 a
Oxyfluorfen	0.48	7.350	6.326	6.838 a
S-metolachlor	1.44	7.302	5.965	6.634 a
Flumioxazin	0.075	6.939	6.306	6.623 a
Mean		7.349 A	6.239 B	
CV (%)		9.9		

Means followed by the same lowercase letter in the column or uppercase in the row do not differ by the Tukey test (p>0.05).

A lower weedy rice infestation was observed in the area flooded in the off-season, and the superiority was maintained in grain yield. However, it is noteworthy that these results are not conclusive, and the pertinence of the practice of keeping the area flooded in the off-season in a water-seeded system needs further research. In the water-seeded system, the off-season management with the application of herbicides with residual activity 44 days before sowing proved to be an efficient alternative to reduce the infestation of weedy rice in water-seeded rice crop.

3.2 Drill-seeded system

There was no interaction between the herbicide factors and the interval between application and sowing, neither the isolated effect of the herbicides for the variable weedy rice density in the pre-sowing evaluation of water-seeded rice in the drill-seeded system (Table 4). Significance was observed only for the interval factor between application and sowing, where the lowest infestation occurred when this interval was shorter (43 days) (Table 4). The off-season management was not an efficient alternative to reduce the weedy rice density in pre-sowing of the drill-seeded rice. These results contradict Chin (2001), who reported that oxadiazon would be an efficient alternative for chemical control of weedy rice.

Table 4 - Infestation of weedy rice (plants m^{-2}) in water-seeded rice pre-sowing. Experiment in the drill-seeded system. Itajaí, SC, 2015/2016

Treatment	Rate (kg ha^{-1})	Interval between application and sowing		
		73 days	43 days	Mean
Infested control	-	66.5[(1)]	14.5	40.5 a
Clomazone	0.72	50.0	6.0	28.0 a
Clomazone	1.08	49.0	5.5	27.3 a
Oxadiazon	1.00	50.5	21.5	36.0 a
Oxadiazon	1.50	60.0	28.5	44.3 a
Oxyfluorfen	0.312	68.0	11.5	39.8 a
Oxyfluorfen	0.48	40.0	15.0	27.5 a
S-metolachlor	1.44	33.0	17.5	25.3 a
Flumioxazin	0.075	33.5	25.5	29.5 a
Mean		50.1 A[(2)]	16.2 B	
CV (%)		30.1		

Means followed by the same lowercase letter in the column or uppercase in the row do not differ by the Tukey test (p>0.05). [(1)] Original data. [(2)] Analysis of the data transformed in $\sqrt{x+0.5}$.

Eleftherohorinos and Dhima (2002) reported that the weedy rice can be efficiently controlled by the application of herbicides with residual control in pre-sowing, obtaining control equal to or greater than 84% with the application of alachlor, dimethenamid, metolachlor, and acetochlor. However, it is noteworthy that the interval between application and sowing in the work of these authors was at 15 days.

The interval interaction between application and sowing, and herbicide treatment was significant for barnyardgrass (Table 5). Treatments with oxyfluorfen (0.312 kg ha^{-1}) and flumioxazin presented lower infestation of barnyardgrass when the interval between application and sowing was 43 days (Table 5). Most treatments reduced the density of barnyardgrass in pre-sowing, the only exception was the application of flumioxazin 73 days before sowing, which presented

Table 5 - Infestation of barnyardgrass (plants m^{-2}) in water-seeded rice pre-sowing. Experiment in the drill-seeded system. Itajaí, SC, 2015/2016

Treatment	Rate (kg ha^{-1})	Interval between application and sowing	
		73 days	43 days
Infested control	-	20.5$^{(1)}$ Aab$^{(2)}$	30.0 Aa
Clomazone	0.72	3.5 Abc	0.0 Ab
Clomazone	1.08	1.5 Ac	0.0 Ab
Oxadiazon	1.00	2.5 Ac	0.5 Ab
Oxadiazon	1.50	0.0 Ac	0.0 Ab
Oxyfluorfen	0.312	9.0 Abc	1.5 Bb
Oxyfluorfen	0.48	3.0 Abc	0.0 Ab
S-metolachlor	1.44	7.0 Abc	1.0 Ab
Flumioxazin	0.075	41.5 Aa	6.5 Bb
CV (%)		53.4	

Means followed by the same lowercase letter in the column or uppercase in the row do not differ by the Tukey test (p>0.05). $^{(1)}$ Original data. $^{(2)}$ Analysis of the data transformed in $\sqrt{x+0.5}$.

infestation similar to that of the infested control (Table 5). The results of the off-season management for barnyardgrass are encouraging, since in most of the treatments evaluated there was a significant reduction of infestation in rice pre-sowing. The efficiency in controlling barnyardgrass was expected since the herbicides clomazone, oxadiazon, oxyfluorfen, and S-metolachlor are registered for the control of these weeds (Agrofit, 2019), which proves it's efficiency.

In addition, using the off-season to manage the barnyardgrass and reduce the potential of infestation during the crop cycle is an interesting strategy, mainly because it allows the application of herbicides with an action mechanism, barely used for the control of Poaceae in water-seeded rice, such as Protox inhibitors and biosynthesis inhibitors of very long chain fatty acids. Also, one should not forget that the control of barnyardgrass has become a challenge in paddy rice areas in Santa Catarina, mainly due to the presence of biotypes with multiple resistance to synthetic auxin/cell wall inhibitor, and ALS and ACCase inhibitors (Eberhardt et al., 2016).

The evaluation of the weedy rice infestation during paddy rice crop cycle (at 120 DAS) revealed that the herbicide factors and the interval between application and sowing had no significant effect, meaning the density of the weedy rice was similar in all treatments (Table 6). The density of panicles in weedy rice (m^{-2}) was low, with the infestation varying from 0.35 to 1.30 panicles m^{-2}. These results reinforce that the off-season management with herbicides was not an efficient strategy to reduce weedy rice infestation in the drill-seeded system.

The interaction between the evaluated factors was significant for grain yield (Table 7). In general, the

Table 6 - Infestation of weedy rice (panicles m^{-2}) at 120 days after sowing (DAS). Experiment in the drill-seeded system. Itajaí, SC, 2015/2016

Treatment	Rate (kg ha^{-1})	Interval between application and sowing		
		73 days	43 days	Mean
Infested control	-	0.73$^{(1)}$	0.78	0.75 a
Clomazone	0.72	0.48	0.35	0.41 a
Clomazone	1.08	0.68	1.30	0.99 a
Oxadiazon	1.00	0.48	0.63	0.55 a
Oxadiazon	1.50	1.03	0.23	0.63 a
Oxyfluorfen	0.312	0.35	0.85	0.60 a
Oxyfluorfen	0.48	0.90	0.30	0.60 a
S-metolachlor	1.44	0.35	0.40	0.38 a
Flumioxazin	0.075	0.45	0.35	0.40 a
Mean		0.60 A$^{(2)}$	0.58 A	
CV (%)		53.5		

Means followed by the same lowercase letter in the column or uppercase in the row do not differ by the Tukey test (p>0.05). $^{(1)}$ Original data. $^{(2)}$ Analysis of the data transformed in $\sqrt{x+0.5}$.

herbicides were selective for water-seeded rice, cultivar SCS121 CL, because the yield of the treatments was similar or higher than the control without herbicide (Table 7). Regarding the interval between application and sowing, it was observed that the application of S-metolachor and clomazone (in two evaluated rates) with a 43 day interval for sowing, significantly reduced grain yield. The interval of 73 days between herbicide application and sowing was harmful only for the herbicide oxyfluorfen in the higher evaluated rate (Table 7). This result was not expected, since in general, the increase in the interval between the application of the residual herbicide and the sowing of the crop decreases the risk of intoxication (Guerra et al., 2011).

Table 7 - Grain yield of water-seeded rice (kg ha^{-1}) according to herbicide the interval between the application of herbicide and sowing paddy rice. Experiment in the drill-seeded system. Itajaí, SC, 2015/2016

Treatment	Rate (kg ha^{-1})	Interval between application and sowing	
		73 days	43 days
Infested control	-	5.200 Ab	5.315 Aab
Clomazone	0.72	6.091 Aab	4.675 Bb
Clomazone	1.08	6.612 Aa	5.640 Bab
Oxadiazon	1.00	5.743 Aab	5.375 Aab
Oxadiazon	1.50	5.574 Aab	5.205 Aab
Oxyfluorfen	0.312	5.918 Aab	6.009 Aa
Oxyfluorfen	0.48	5.184 Bb	6.132 Aa
S-metolachlor	1.44	4.918 Ab	5.848 Bab
Flumioxazin	0.075	5.642 Aab	6.044 Aa
CV (%)		10.2	

Means followed by the same lowercase letter in the column or uppercase in the row do not differ by the Tukey test (p>0.05).

For the drill-seeded system, the off-season management performed 43 days before sowing reduced the infestation of barnyardgrass in the crop pre-sowing; however, this practice was not efficient to reduce the infestation of weedy rice during paddy rice crop. For barnyardgrass, the results were promising, since the off-season management was efficient in reducing the infestation of this weed.

In short, the off-season management was efficient in reducing the infestation of weedy rice during the water-seeded rice crop only in the water-seeded system. The elaborated hypothesis is that this result is due to the shorter interval between the application of the treatments and crop sowing, combined with the early soil saturation, initiated at the time of its preparation. These factors contribute to the lower dependence of the herbicide residual activity on the soil, and the integration of effective methods in the control of weedy rice (chemical control + physical control). In the water-seeded system, flumioxazin proved to be an efficient alternative to controlling giant arrowheads in the off-season; however, the selectivity of this practice needs to be better evaluated. In the drill-seeded system, the application of herbicides in the off-season reduced the barnyardgrass infestation.

4 Conclusions

In the water-seeded system, the off-season management reduced the infestation of the weedy rice and giant arrowhead. In the drill-seeded system, the application of herbicides in the off-season reduced the infestation of barnyardgrass until the paddy rice sowing.

5 Contributions

All authors have planned and outlined the experiments. AMON and JAN: have conducted the experiments. AMON and NG: have analyzed the data and wrote the manuscript. JAN: reviewed the manuscript. All authors have approved the submission of the manuscript.

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