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Article

Weed Management in Rice under Sprinkler and Flood Irrigation Systems

Manejo de Plantas Daninhas em Arroz Irrigado por Aspersão e Inundação

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ABSTRACT - This study aimed to assess the efficiency and selectivity of herbicides in rice submitted to sprinkler and flood irrigation systems. The experimental design was a randomized block design arranged in a 2 × 9 factorial scheme. Factor A consisted of irrigation systems (sprinkler and flood) and Factor B consisted of herbicide treatments (T1 – control; T2 – imazethapyr + imazapic, 75 + 25 g a.i. ha^{-1}; T3 – imazethapyr + imazapic, 150 + 50 g a.i. ha^{-1}; T4 – imazapic + imazapyr, 73.5 + 24.5 g a.i. ha^{-1}; T5 – imazapic + imazapyr, 147 + 49 g a.i. ha^{-1}; T6 – imazethapyr, 106 g a.i. ha^{-1}; T7 – imazethapyr, 212 g a.i. ha^{-1}; T8 – sequential application of imazethapyr + imazapic, 75 + 25 g a.i. ha^{-1}; and T9 – sequential application of imazapic + imazapyr, 73.5 + 24.5 g a.i. ha^{-1}). The application of imazethapyr and formulated mixtures of imazethapyr + imazapic and imazapyr + imazapic provided a control higher than 97% in flood and sprinkler irrigation systems. Herbicide selectivity is not altered in the sprinkler irrigation system when compared to the flood irrigation system.

Keywords: Clearfield system, *Oryza sativa*, persistence.

RESUMO - Objetivou-se neste trabalho avaliar a eficiência e a seletividade de herbicidas na cultura do arroz submetida aos sistemas de irrigação por aspersão e inundação. O delineamento experimental utilizado foi de blocos ao acaso, arranjado em esquema fatorial 2x9. No fator A foram alocados os sistemas de irrigação (aspersão ou inundação), e no B, os tratamentos herbicidas (T1 – sem herbicida; T2 – imazethapyr + imazapic - 75 + 25 g i.a. ha^{-1}; T3 – imazethapyr + imazapic - 150 + 50 g i.a. ha^{-1}; T4 – imazapic + imazapyr - 73,5 + 24,5 g i.a. ha^{-1}; T5 – imazapic + imazapyr - 147 + 49 g i.a. ha^{-1}; T6 – imazethapyr - 106 g i.a. ha^{-1}; T7 – imazethapyr - 212 g i.a. ha^{-1}; T8 e T9 – aplicação sequencial de imazethapyr + imazapic - 75 + 25 g i.a. ha^{-1} e imazapic + imazapyr - 73,5 + 24,5 g i.a. ha^{-1}, respectivamente). A aplicação de imazethapyr e das misturas formuladas de imazethapyr + imazapic e imazapyr + imazapic proporcionou controle maior que 97% nos sistemas de irrigação por inundação e aspersão. A seletividade dos herbicidas não é alterada no sistema de irrigação por aspersão, comparativamente ao sistema por inundação.

Palavras-chave: sistema Clearfield, *Oryza sativa*, persistência.

INTRODUCTION

Brazilian rice production is based on two production systems: upland (aerobic) and lowland (anaerobic). Lowland or flooded rice predominates in the South of Brazil, in the states of Rio Grande do Sul and Santa Catarina (Embrapa Clima Temperado, 2007). Flooded rice cultivation requires an intensive soil tillage to

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level the field aiming at achieving an adequate irrigation. With the systematization, soil physical properties are intensively modified and its compaction may occur due to soil tillage (Pinto et al., 2016).

Drought in the rice-growing season, which has been frequent in recent years, causes many problems for irrigation, mainly in the southern half of Rio Grande do Sul, due to a high water demand that the flooded system requires. Thus, studies on water use efficiency are necessary and the sprinkler irrigation system can make rice production feasible in areas with a lower water availability (Kato and Katsura, 2014; Pinto et al., 2016). This irrigation system can also facilitate the adoption of techniques for recovering degraded soils, such as the use of plants with abundant root system during the off-season, green manuring, and nitrogen-fixing plants. In addition to the advantages that the sprinkler irrigation system offers, aerobiosis conditions can be found in these areas, unlike those found in the flood irrigation system, where water depth occupies almost 100% of the porous space of soil. Thus, the presence of water-free pores in the soil leads to an environment favorable to microbial activity and hence to crop residue degradation (Kato and Katsura, 2014; Pinto et al., 2016).

Soil microbial activity also plays an important role in degrading the pesticides used to control weeds in rice cultivation. One of the examples found in the literature is when there is no aerobic degradation of imazethapyr in flooded soils or in soils with a water depth close to the soil surface (Kraemer et al., 2009), leading to leaching. Bundt et al. (2014) compared the leaching of different herbicides belonging to the imidazolinone group and found that imazapic is more leached than imazethapyr and imazapyr.

An important aspect in the management of irrigated rice by sprinkling is related to the method of production in which it is inserted. In this system, crop rotation is necessary because irrigated rice monoculture promotes a decrease in productivity over the years. In this case, there may be a higher intensity of insect pests, diseases, and increased infestation of weeds in the area, in addition to an allelopathic effect of rice on it, harming crop development. With the optimization of production using sprinkler irrigation, water use efficiency can be increased, which in the flood irrigation system is around 0.55 kg m^{-3} (Kahlown et al., 2007). Some studies have shown that water use efficiency in the sprinkler system is positive when compared to the flood system, leading to a more efficient rice production and maintaining its productive potential (Kato and Katsura, 2014; Pinto et al., 2016).

Among the several factors that can harm rice productivity, weed interference stands out. In this sense, red rice (*Oryza sativa* L.) is the species that causes more damage to the crop, interfering with growth and development, reducing profits, increasing production costs, and depreciating the quality of the final product (Fleck et al., 2008; Pinto et al., 2009). To control red rice in rice fields, the Clearfield® technology has been adopted. This technology stands out due to the use of imidazolinone herbicides and occupies about 50% of the commercial rice area of Rio Grande do Sul (SOSBAI, 2012). In Brazil, this technology consists of applying commercially formulated mixtures of imazethapyr + imazapic and imazapyr + imazapic in tolerant rice cultivars. Pre-emergence or post-emergence treatment is recommended when rice plants are in the phenological stage V3-V4 (SOSBAI, 2012).

However, attention should be paid to herbicides of the imidazolinone group (imazethapyr + imazapic and imazapyr + imazapic) due to their high persistence level in the soil, which may compromise the development of subsequent and sensitive crops and result in increased risk of surface water contamination (Hart et al., 1991). Studies by Pinto et al. (2009) showed that the formulated mixture of imazethapyr + imazapic remained active in the soil in a quantity capable of significantly reducing the average plant height, biological yield, one-thousand-grain weight, and germination of rye seeds sown under rotation after one year of Clearfield® rice cultivation. In addition, imazapyr persistence in the soil may range from 90 to 730 days (Ars, 2001) whereas imazethapyr persistence ranges from 60 to 360 days (Goetz et al., 1990; Mangels, 1991). Considering that the main mechanism of imidazolinone dissipation in the soil is the degradation through aerobic microbial metabolism (Loux and Reese, 1993; Flint and Witt, 1997), the persistence of these herbicides is influenced by soil characteristics such as texture, organic matter content, and moisture (Goetz et al., 1990). Thus, the irrigation system plays an important role in their decomposition.

In this sense, the knowledge of interactions between weed management and the use of sprinkler irrigation system in rice cultivation may not only allow water use efficiency but also a better use of herbicides, improving the sustainability of rice production chain. Thus, this study aimed to assess the effectiveness of weed control and herbicide selectivity to the crop when applied to rice submitted to sprinkler and flood irrigation systems.

MATERIAL AND METHODS

The experiments were conducted under field conditions in the 2012/2013 agricultural year at the experimental area of Embrapa Clima Temperado (2017). The soil is classified as a Planosol (Planossolo Háplico Eutrófico solódico, Brazilian Soil Classification System), Pelotas mapping unit (Embrapa, 2013). Soil physiochemical characteristics are shown in Table 1.

In both experiments, the experimental units were composed of 26 sowing rows with 4 m in length, spaced 17 cm from each other, totaling 17.68 m^2. Soil tillage was performed in the conventional cultivation system. The rice cultivar used was Puitá INTA CL at a density of 100 kg seeds ha^{-1}. Seeds were previously treated with the insecticide fipronil and the fungicide thiram at doses of 37.5 and 105 g per 100 kg of seeds for the preventive control of insects and fungi, respectively. Base fertilization was performed with 350 kg ha^{-1} of the formula 05-20-30, corresponding to 17.5 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1}, and 105 kg K_2O ha^{-1}. Topdressing nitrogen fertilization was carried out with urea 46% in three stages: at the beginning of tillering (V3-V4) with 70 kg N ha^{-1}, at the V6 stage with 30 kg N ha^{-1}, and at the beginning of floral primordia with 30 kg N ha^{-1}. The other cultural practices were carried out according to technical recommendations for irrigated rice in the South of Brazil (SOSBAI, 2012).

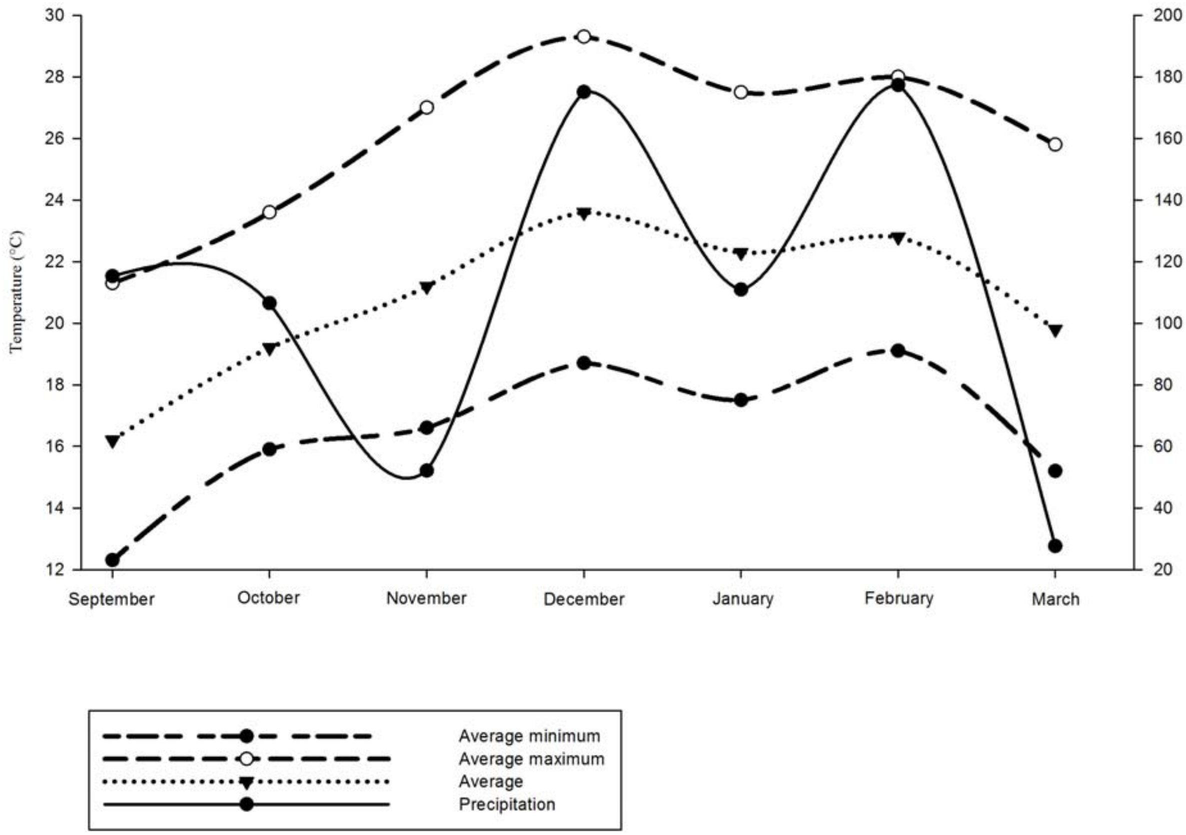
In both experiments, the experimental design was a randomized block design in a 2 x 9 factorial scheme with four replications. Factor A consisted of irrigation systems (sprinkler and flood) and Factor B consisted of herbicide treatments (T1 – control; T2 – imazethapyr + imazapic, 75 + 25 g a.i. ha^{-1}; T3 – imazethapyr + imazapic, 150 + 50 g a.i. ha^{-1}; T4 – imazapic + imazapyr, 73.5 + 24.5 g a.i. ha^{-1}; T5 – imazapic + imazapyr, 147 + 49 g a.i. ha^{-1}; T6 – imazethapyr, 106 g a.i. ha^{-1}; T7 – imazethapyr, 212 g a.i. ha^{-1}; T8 – sequential application of imazethapyr + imazapic, 75 + 25 g a.i. ha^{-1}; and T9 – sequential application of imazapic + imazapyr, 73.5 + 24.5 g a.i. ha^{-1}). Treatments T8 and T9 were used sequentially with half of the dose applied in the pre-emergence of crop and weeds and the other half in the post-emergence, as in the other treatments, when weeds presented 3 to 4 leaves and the crop was between the phenological stages V3 and V4. The application was performed with a precision backpack CO_2 pressurized sprayer equipped with four fan spray tips (110.015), calibrated to provide a spray solution volume of 150 L ha^{-1}.

For the sprinkler irrigation experiment, irrigation was performed whenever the soil water tension reached a level of 0.2 kPa, which was monitored by sensors installed in the area. For the flood irrigation experiment, irrigation was performed 24 hours after herbicide application and the first application of nitrogen, maintaining a water depth of 8 cm until crop physiological maturation. In the flood irrigation experiment, plots were isolated from each other and irrigation was carried out individually to avoid contamination between plots. Temperature and precipitation observed during the experiments are shown in Figure 1.

Before herbicide application, a survey of weed species was carried out in the experimental area. It showed an average population of 287 plants per square meter composed of 22% of red rice (*Oryza sativa*), 39% of cockspur grass (*Echinochloa crus-galli*), 24% of jointvetch (*Aeschynomene denticulata*), and 15% of yellow nutsedge (*Cyperus esculentus*).

Table 1 - Soil physicochemical characteristics of the experimental area (Planosol)

pH_{water}	Clay	OM	Phosphorus	Potassium	Calcium	Magnesium	Aluminum
(1:1)	(%)		(mg dm^{-3})		($cmol_c$ dm^{-3})		
5.7	16	1.3	6.7	43	4.3	2.0	0.1



Source: Weather station of the Embrapa Clima Temperado (2017).

Figure 1 **-** Minimum (●), maximum (○), and average (▼) temperatures (ºC) and precipitations (mm) accumulated during the experimental period from September 2012 to March 2013. Capão do Leão, RS, Brazil.

The following variables were assessed: a) weed control and phytotoxicity to rice, determined visually at 7, 14, 21, and 60 days after herbicide application (DAH) by using a percentage scale, in which zero and 100 corresponded to the absence of symptoms and plant death, respectively; b) initial stand, determined seven days after emergence; and c) grain productivity, measured by harvesting rice plants in six square meters, being determined grain moisture and corrected to 13%.

Data were submitted to the analysis of variance ($p \leq 0.05$). When significant, the Tukey's test was used to compare the means between herbicide treatments and the Student t-test to compare the means between irrigation systems. All tests were analyzed at $p \leq 0.05$.

RESULTS AND DISCUSSION

For weed control, a significant difference was observed between herbicides in the assessment performed at seven days after herbicide application (DAH) (Table 2). Treatments with sequential application in pre- and post-emergence of the crop (V3-V4) of the formulated mixtures imazethapyr + imazapic (75 and 25 g a.i. ha^{-1}) and imazapyr + imazapic (73.5 and 24.5 g a.i. ha^{-1}) presented the best control levels, i.e. above 90% at 7 DAH, regardless of the tested irrigation systems.

For assessments at 14 and 21 DAH, an interaction was observed between the factors herbicide and irrigation systems. The treatment T6 (imazethapyr, 106 g a.i. ha^{-1}) at 14 DAH presented the lowest control for the sprinkler irrigation system when compared to the flood irrigation system, requiring twice the dose to be equivalent to the flood system. In the other treatments, control was higher than 90%. At 21 DAH, all treatments in the flood irrigation system have 100% control whereas, in the sprinkler irrigation system, control levels ranged between 94 and 100%.

Table 2 - Control of the weeds red rice (*Oryza sativa* L.), cockspur grass (*Echinochloa crus-galli*), jointvetch (*Aeschynomene denticulata*), and yellow nutsedge (*Cyperus esculentus*) in the irrigated rice as a function of the sprinkler and flood irrigation management at 7, 14, 21, and 60 days after herbicide application

Treatment	Control (%)		
	Dose (g a.i. ha^{-1})	Sprinkler	Flood
		7 DAH[3]	
T1 – control	–	0 d[5]A[4]	0 cA
T2 – imazethapyr + imazapic[1]	75.0 + 25.0	83.75 abA	82.50 bA
T3 – imazethapyr + imazapic[1]	150.0 + 50.0	83.75 abA	92.50 aA
T4 – imazapyr + imazapic[1]	73.5 + 24.5	80.00 bcA	87.50 abA
T5 – imazapyr + imazapic[1]	147.0 + 49.0	83.75 abA	82.50 bA
T6 – imazethapyr[1]	106.0	73.75 cB	87.50 abA
T7 – imazethapyr[1]	212.0	80.00 bcA	86.25 abA
T8 – imazethapyr + imazapic[1,2]	22.5 + 12.5	91.25 aA	92.50 aA
T9 – imazapyr + imazapic[1,2]	36.75 + 12.25	92.50 aA	92.50 aA
		14 DAH[3]	
T1 – control	–	0 c[5]A[4]	0 cA
T2 – imazethapyr + imazapic[1]	75.0 + 25.0	92.50 abA	93.75 abA
T3 – imazethapyr + imazapic[1]	150.0 + 50.0	90.00 abB	100.0 aA
T4 – imazapyr + imazapic[1]	73.5 + 24.5	93.75 abA	98.75 aA
T5 – imazapyr + imazapic[1]	147.0 + 49.0	96.25 aA	87.50 bB
T6 – imazethapyr[1]	106.0	86.25 bB	97.50 aA
T7 – imazethapyr[1]	212.0	95.00 abA	97.50 aA
T8 – imazethapyr + imazapic[1,2]	32.5 + 12.5	95.75 aA	100.0 aA
T9 – imazapyr + imazapic[1,2]	36.75 + 12.25	98.75 aA	100.0 aA
		21 DAH[3]	
T1 – control	–	0 d[5]A[4]	0 bA
T2 – imazethapyr + imazapic[1]	75.0 + 25.0	96.25 bB	100.00 aA
T3 – imazethapyr + imazapic[1]	150.0 + 50.0	100.00 aA	100.00 aA
T4 – imazapyr + imazapic[1]	73.5 + 24.5	100.00 aA	100.00 aA
T5 – imazapyr + imazapic[1]	147.0 + 49.0	100.00 aA	100.00 aA
T6 – imazethapyr[1]	106.0	93.75 cB	100.00 aA
T7 – imazethapyr[1]	212.0	98.75 aA	100.00 aA
T8 – imazethapyr + imazapic[1,2]	32.5 + 12.5	98.25 abA	100.00 aA
T9 – imazapyr + imazapic[1,2]	36.75 + 12.25	99.50 aA	100.00 aA
		60 DAH[3]	
T1 – control	–	0 b[5]A[4]	0 bA
T2 – imazethapyr + imazapic[1]	75.0 + 25.0	97.50 aA	99.00 aA
T3 – imazethapyr + imazapic[1]	150.0 + 50.0	100.00 aA	100.00 aA
T4 – imazapyr + imazapic[1]	73.5 + 24.5	99.00 aA	98.75 aA
T5 – imazapyr + imazapic[1]	147.0 + 49.0	100.00 aA	99.50 aA
T6 – imazethapyr[1]	106.0	97.00 aB	100.00 aA
T7 – imazethapyr[1]	212.0	99.50 aA	100.00 aA
T8 – imazethapyr + imazapic[1,2]	32.5 + 12.5	98.25 aA	100.00 aA
T9 – imazapyr + imazapic[1,2]	36.75+12.25	99.00 aA	99.50 aA

[1] Post-emergence – rice plants with 3 to 4 leaves. [2] Pre-emergence – after sowing irrigated rice. [3] Days after herbicide application. [4] Means followed by different uppercase letters in the row differ from each other by the Student t-test ($p \leq 0.05$). [5] Means followed by different lowercase letters in the column differ from each other by the Tukey's test ($p \leq 0.05$).

Control levels were maintained throughout crop cycle (60 DAH), with no significant difference between herbicide treatments and irrigation systems, and control levels above 97%. This behavior is due to the residual effect of herbicides, which prevents the germination and emergence of new weeds. In accordance with these results, Masson and Webster (2001) verified that the residual activity of imazethapyr provided a control of cockspur grass above 90%, regardless of the height of the used water depth.

The positive effect of maintaining the water depth on weed control has been verified by several authors, such as Concenço et al. (2006) and Machado et al. (2006), who reported its action in terms of a physical barrier on the soil surface, reducing the available oxygen and preventing weed growth and development. Although there was no physical control provided by the water depth as in the flood irrigation system, weed control was satisfactory in the sprinkler irrigation system when herbicide application was adopted.

Weed control provided by applying twice the recommended dose of herbicides (T3, T5, and T7) did not differ from the other herbicides at the recommended doses. These results showed no need of increasing herbicide doses to control weeds in the experiments in both irrigation systems.

Weed control in rice under sprinkler irrigation may be feasible if a management program is planned involving early desiccation and use of pre-emergent herbicides, exploiting their maximum potential. The sequential application showed efficacy due to the lack of water depth in the sprinkler irrigation system. The soil under this system remains close to the field capacity, providing a soil moisture ideal for herbicide action.

The practice of sequential application of herbicides in pre- and post-emergence of weeds and rice has been showing good results in several studies, being an interesting alternative for controlling the weed community. Villa et al. (2006) observed a higher red rice control by applying 75 g ha^{-1} of imazethapyr + imazapic in pre-emergence followed by 50 g ha^{-1} of this herbicide in the post-emergence period. According to Oliveira Júnior et al. (2006), the sequential application of a dose of a particular herbicide may increase its selectivity and increase control efficiency. No significant difference in control was observed among the assessed species as a function of the irrigation system (data not shown).

In the assessment of phytotoxicity performed at 7 DAH, a significant difference was observed only between herbicide treatments, standing out the values in T8 and T9, which were below 4% phytotoxicity, while the other treatments presented average values of 10% (Table 3). Marchezan et al. (2010) also observed that the phytotoxicity caused by imazethapyr is more severe with the post-emergence application when compared to the pre-emergence application in the crop.

This difference in phytotoxicity between irrigation systems was observed at 14 DAH, with an interaction between herbicides and irrigation systems. In the sprinkler irrigation system, phytotoxicity values remained constant for all treatments, while in the flood irrigation system, a damage reduction was observed mainly in T2, T6, and T7. Despite this difference between treatments, phytotoxicity values are relatively low. At 21 DAH, rice plants recovered from herbicide-induced damages, regardless of the irrigation system (Table 3).

This fact evidences that the recovery capacity of plants and the metabolization speed of the herbicide, together with the application in the initial development stage, contributed to the significant difference in the phytotoxicity observed in treatments applied in pre-emergence when compared to those applied in post-emergence, which was also observed by Kraemer et al. (2009).

According to the analysis of variance, no interaction was observed between irrigation systems and herbicides for the initial plant stand, and uniform emergence of seedlings was observed (Table 4).

For grain productivity, only T1 (control) differed from the other treatments, showing the lowest values due to the competition between crop and weeds in the area (Table 4). The treatments T2 and T9 presented the highest rice grain productivities, not differing statistically from the other treatments. This result is mainly related to the good control provided by these treatments, thus preventing weeds from competing with rice and reducing grain yield. According to some studies, when weeds of irrigated rice are not controlled, losses ranging from 4 to 30% may occur depending on crop management (Freitas, 2004; Galon et al., 2007). Freitas (2004) reported an increase in rice grain productivity by associating the application of herbicides with a residual effect for weed control, which is in accordance with that reported in our study.

Table 3 **-** Phytotoxicity in irrigated rice under sprinkler and flood irrigation management at 7 and 14 days after herbicide application

Treatment	Dose (g a.i. ha^{-1})	Control (%) Sprinkler		Control (%) Flood	
		7 DAH(3)			
T1 – control	–	0	c(4)	0	D
T2 – imazethapyr + imazapic(1)	75.0 + 25.0	10.00	a	7.50	Abc
T3 – imazethapyr + imazapic(1)	150.0 + 50.0	10.00	a	8.75	Ab
T4 – imazapyr + imazapic(1)	73.5 + 24.5	8.75	ab	7.50	Abc
T5 – imazapyr + imazapic(1)	147.0 + 49.0	11.25	a	10.00	A
T6 – imazethapyr(1)	106.0	10.00	a	10.00	A
T7 – imazethapyr(1)	212.0	8.75	ab	8.75	Ab
T8 – imazethapyr + imazapic(1,2)	22.5 + 12.5	3.75	bc	2.50	Cd
T9 – imazapyr + imazapic(1,2)	36.75 + 12.25	1.25	c	3.75	Bcd
		14 DAH(3)			
T1 – control	–	0	e(5)A(4)	0	cA
T2 – imazethapyr + imazapic(1)	75.0 + 25.0	8.75	abcA	2.50	bcB
T3 – imazethapyr + imazapic(1)	150.0 + 50.0	8.75	abcA	3.75	abcA
T4 – imazapyr + imazapic(1)	73.5 + 24.5	7.50	bcdA	5.00	abcA
T5 – imazapyr + imazapic(1)	147.0 + 49.0	7.50	bcdA	8.75	aA
T6 – imazethapyr(1)	106.0	12.50	abA	2.50	bcB
T7 – imazethapyr(1)	212.0	13.75	aA	6.25	abB
T8 – imazethapyr + imazapic(1,2)	32.5 + 12.5	3.75	cdeA	1.25	bcA
T9 – imazapyr + imazapic(1,2)	36.75 + 12.25	2.50	deA	3.75	abcA

(1) Post-emergence – rice plants with 3 to 4 leaves. (2) Pre-emergence – after sowing irrigated rice. (3) Days after herbicide application. (4) Means followed by different uppercase letters in the row differ from each other by the Student t-test ($p \leq 0.05$). (5) Means followed by different lowercase letters in the column differ from each other by the Tukey's test ($p \leq 0.05$).

Table 4 **-** Initial stand and grain productivity of irrigated rice as a function of sprinkler and flood irrigation management and herbicide treatments

Treatment	Dose (g a.i. ha^{-1})	Initial stand (plants m^{-2})	Grain productivity(5) (kg ha^{-1})	
T1 – control	–	232 ns(3)	6671.37	c(4)
T2 – imazethapyr + imazapic(1)	75.0 + 25.0	288	8490.41	ab
T3 – imazethapyr + imazapic(1)	150.0 + 50.0	272	7761.85	abc
T4 – imazapyr + imazapic(1)	73.5 + 24.5	243	7532.02	bc
T5 – imazapyr + imazapic(1)	147.0 + 49.0	267	7714.43	abc
T6 – imazethapyr(1)	106.0	271	7863.62	abc
T7 – imazethapyr(1)	212.0	279	7946.68	abc
T8 – imazethapyr + imazapic(1,2)	32.5 + 12.5	260	7912.17	abc
T9 – imazapyr + imazapic(1,2)	36.75+12.25	281	8926.78	a
Sprinkler		269 ns(3)	---	
Flood		261	7868.82	
Mean		265	7868.82	
CV (%)		19.73	11.76	

(1) Post-emergence – rice plants with 3 to 4 leaves. (2) Pre-emergence – after sowing irrigated rice. (3) Not significant ($p \geq 0.05$). (4) Means followed by different letters in the column differ from each other by Tukey's test ($p \leq 0.05$). (5) Productivity of irrigated rice in the flood system.

The use of herbicides with residual activity in the soil, such as imazethapyr and formulated mixtures of imazethapyr + imazapic and imazapyr + imazapic, provide an efficient weed control (>97%) in flood and sprinkler irrigation systems. The absence of water depth in the sprinkler irrigation system does not affect weed control. Weed control in rice under sprinkler irrigation system can be carried out safely with the same resources used in the flood irrigation system. Sequential application of formulated mixtures of imazethapyr + imazapic and imazapyr + imazapic is a viable alternative for weed control. Herbicide dose fractionation results in an increase of herbicide selectivity to the rice and in the efficiency of weed control.

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