



Interaction between saflufenacil and imazapyr+imazapic in the management of barnyardgrass and weedy rice and selectivity for irrigated rice

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ABSTRACT: *The use of imidazolinone-tolerant rice cultivars allows selective control of weedy rice and barnyardgrass. However, in many situations, there is a need to add herbicides from other chemical groups to increase the spectrum of weed control. In this sense, saflufenacil has the potential to be used in mixture with imidazolinone herbicides. This study aimed to evaluate the interaction effects of the imazapyr+imazapic and saflufenacil herbicides in weedy rice and barnyardgrass and to investigate their impacts on the yield of the irrigated rice cultivar Puitá INTA CL. To reach these aims, greenhouse and field experiments were carried out during two growing seasons, with herbicide treatments sprayed separately and in mixtures of saflufenacil with imazapyr+imazapic. Results showed that saflufenacil did not interfere with control of weedy rice and barnyardgrass obtained with imazapyr+imazapic. The D_{50} values of imazapyr+imazapic for weedy rice control were 14.5+5, 9.1+3 and 12.5+4.2 g ha⁻¹ of imazapyr+imazapic for combinations with 0, 3.06 and 6.12 g ha⁻¹ of saflufenacil, respectively. In the field experiments, all doses of imazapyr+imazapic applied isolated or in mixture with saflufenacil provided control levels barnyardgrass above 90% at 28 days after herbicides application. Furthermore, saflufenacil did not cause damage or loss in the yield of the rice crop when mixed with imazapyr+imazapic. The Puitá INTA CL rice cultivar was tolerant of the tested herbicides, whether applied alone or in mixture, reaching grain yield of 9.987 kg ha⁻¹ when applied 42 g ha⁻¹ of saflufenacil plus 147+49 g ha⁻¹ of imazapyr+imazapic.*

Key words: herbicides, imidazolinone, pyrimidinedione, *Oryza sativa*.

Interação entre saflufenacil e imazapyr+imazapic no manejo de capim-arroz e arroz-daninho e a seletividade para cultura do arroz irrigado

RESUMO: *A utilização de cultivares de arroz tolerantes às imidazolinonas possibilita um controle seletivo de arroz-daninho. No entanto, em muitas situações existe a necessidade de adição de herbicidas de outros grupos químicos para aumentar o espectro de controle de plantas daninhas. Neste sentido, saflufenacil apresenta potencial para ser utilizado em mistura com herbicidas imidazolinonas. Este estudo teve como objetivo avaliar os efeitos da interação dos herbicidas imazapyr+imazapic e saflufenacil em arroz-daninho e capim-arroz; e averiguar os impactos sobre a produtividade do cultivar de arroz irrigado Puitá INTA CL. Para alcançar esses objetivos, foram realizados experimentos em casa de vegetação e a campo em duas estações de cultivo, com os tratamentos herbicidas aplicados separadamente e em misturas de saflufenacil com imazapyr+imazapic. Os resultados mostraram que a adição de saflufenacil não interferiu no controle de arroz-daninho e capim-arroz obtido com imazapyr+imazapic. Os valores D_{50} de imazapyr+imazapic para o controle de arroz-daninho foram 14,5+5; 9,1+3 e 12,5+4,2 g ha⁻¹ de imazapyr+imazapic para combinações com 0; 3,06 e 6,12 g ha⁻¹ de saflufenacil. No experimento de campo todas doses de imazapyr+imazapic, aplicadas isoladas ou em mistura, proveram níveis de controle de capim-arroz superiores a 90% aos 28 dias após a aplicação dos herbicidas. Além disso, saflufenacil não causou injúrias ou perda de rendimento da cultura do arroz quando misturado com imazapyr+imazapic. O cultivar Puitá INTA CL foi tolerante aos herbicidas testados, sejam aplicados isolados ou em mistura, atingindo uma produtividade de 9.987 Kg ha⁻¹ quando aplicado 42 g ha⁻¹ de saflufenacil mais 147+49 g ha⁻¹ de imazapyr+imazapic.*

Palavras-chave: herbicidas, imidazolinona, pirimidinadiona, *Oryza sativa*.

INTRODUCTION

The Clearfield® system has become an indispensable tool for selective control of Poaceae weed species, as weedy rice and barnyardgrass. In this system, imidazolinone-resistant cultivars are grown with the application of imidazolinone herbicides in pre and/or post-emergence (IRGA, 2018; SOSBAI,

2018). However, the intensive adoption and misuse of this technology has led to the selection of resistant weeds, not only the weedy rice (*Oryza sativa*) but also the barnyardgrass (*Echinochloa crus-galli*) and giant arrowhead (*Sagittaria montevidensis*); and this has led the use of other herbicides to control these species (MENEZES et al., 2013; MOURA et al., 2016; NUNES et al., 2016; HEAP, 2018).

Thus, some changes have been established to aid in the chemical management, among them, the herbicide mixture, which aims to increase action spectrum and efficiency of weed control, such as red rice (*Oryza sativa*), *Echinochloa crus-galli*, *Sesbania exaltata*, *Ipomoea hederacea*, *Alternanthera philoxeroides* (PELLERIN et al., 2003; PELLERIN et al., 2004; CARLSON et al., 2011; MONTGOMERY et al., 2015; FISH et al., 2016). The herbicides mixtures can result in three different types of interactions, which can be an additive, synergistic or antagonistic interaction. These interactions can occur due to mechanisms such as changes in the amount of an herbicide that reaches its sites of action through molecules absorption, translocation or metabolism changes, also can be due interaction at the site action between the herbicides, where one herbicide affects the binding of the other at its site of action. In addition, the interaction of herbicides mixture can produce opposite effects on the same physiological process of the plant or synergizes the overall effect (COLBY, 1967; DAMALAS, 2004; KUDSK & MATHIASSEN, 2004).

The tank mixture has low cost since it requires a single application; besides, it reduces possible mechanical damages to the crop (PETTER et al., 2012). Thus, it has been a usual practice in the face of its recent regularization in Brazil. However, its use requires specific knowledge about the products applied and the final result of chemical reactions during mixing. Several possibilities of herbicide mixtures have emerged to aid in the control of resistant species, including the increasing use of herbicides that are unusual in rice farming, like the saflufenacil (CAMARGO et al., 2012a).

Saflufenacil is an herbicide belonging to the chemical group of pyrimidinediones, acting in the inhibition of the Protoporphyrinogen IX oxidase (Protox). Among its characteristics are the absorption both by roots and leaves, translocation via xylem and phloem (LIEBLE et al., 2008; SOLTANI et al., 2009; KNEZEVIC et al., 2010), and efficiency in the control of wide range dicot weeds, such as *Solanum nigrum*, and *Ipomoea purpurea* (GROSSMANN et al., 2011), *Amaranthus retroflexus*, *Abutilon theophrasti*, and *Polygonum persicaria* (SOLTANI et al., 2009), *Conyza canadensis* (KUMAR et al., 2017), *Conyza sumatrensis* and *Bidens pilosa* (VARGAS et al., 2019). The registration of this herbicide is recent, and it has been indicated for pre and post-emergence applications in irrigated rice crops (MONTGOMERY et al., 2014). In this context, saflufenacil allows controlling a higher number of

weed species, for which the herbicides belonging to the Clearfield® technology are not efficient, such as, for example biotypes *Sagittaria montevidensis* resistant to imidazolinone herbicides (MOURA et al., 2015), and *Aeschynomene* spp. a problematic weed, less responsive to most herbicides labeled in rice (LAZAROTO et al., 2008; CONCENÇO et al., 2018; MILLER & NORSWORTHY, 2018). However, there is little information in the literature on the effects of the interaction between these herbicides (CAMARGO et al., 2012b; MONTGOMERY et al., 2015; WALSH et al., 2015).

The antagonistic effect between ALS and Protox-inhibiting herbicides, more specifically for diphenyl ether group, is known. The combination of imazamox with fomesafen, lactofen, or acifluorfen reduced the control of *Ipomoea hederacea* and *Abutilon theophrasti* (UNLAND et al., 1999). The control of *Setaria faberi* was reduced 14 and 33% when lactofen was mixed with imazamox and imazethapyr, respectively, in comparison to the herbicides applied alone. Similar results were obtained when acifluorfen or fomesafen with imazamox and imazethapyr were mixed (NELSON et al., 1998). The antagonism was due to reduced absorption and translocation of the herbicides imazamox and imazethapyr in the plants, due to the activity of the diphenyl ethers which limited this effect (NELSON et al., 1998; UNLAND et al., 1999). These results may be explained by the difference in the time of phytotoxic action of the two classes of herbicides. The PPO inhibitor herbicides act quickly, resulting in the loss of integrity of cell membranes, caused by the peroxidation of the plasma membrane (DAYAN & WATSON, 2011). Therefore, the destruction of epidermal cells reduced the absorption and translocation of systemic herbicides, such as imidazolinones.

Saflufenacil has physicochemical properties, such as weak acid character, pK_a , and K_{ow} of 4.4 and 2.6, respectively, that provide a higher capacity in plant mobility than the herbicides of the diphenyl ether group. The metabolic stability of saflufenacil in the weeds may also explain its systemic mobility behavior (GROSSMANN et al., 2011), facts that can differentiate the results commonly reported in the literature of the mixture of Protox inhibitors with imidazolinones. Contrasting the findings of the interaction between Protox inhibitors and the imidazolinone group, recent studies have shown a synergistic effect in the mixture of imazethapyr and saflufenacil, which resulted in increased control of barnyardgrass and red rice in 15% and 18%, respectively, when compared with the separate

application of imazethapyr (CAMARGO et al., 2012a; MONTGOMERY et al., 2015). The synergistic effect was related to the increase of 30% in absorption and 35% in the translocation of this herbicide mix in the weedy rice plants when compared to the application of imazethapyr alone (CAMARGO et al., 2012b). However, this mixture injured rice crops; although, no reduction in yield was observed (CAMARGO et al., 2012a). It is important to emphasize that the studies mentioned above were conducted with imazethapyr and not with the commercial mixture of imazapyr+imazapic.

Through the regularization of herbicide tank mixtures and the increasing use of this new Protox-inhibiting herbicide in rice crops, there is a need to understand the interaction between saflufenacil and imidazolinone herbicides. Thus, this research aimed to evaluate the interaction effects of the imazapyr+imazapic and saflufenacil herbicides in the post-emergence of weedy rice and barnyardgrass, and to investigate their impacts on the Puitá INTA CL irrigated rice cultivar.

MATERIALS AND METHODS

Greenhouse and field conditions were evaluated in this study. For the greenhouse experiment,

sensitive weedy rice (*Oryza sativa*) seeds were used as an indicator species for imazapyr+imazapic. The seeds were sown in 750 mL plastic pots, with Albaquafsoil, sandy-loam texture class. After emergence, six plants were maintained per pot. The basic fertilization was performed using 20, 75, and 75 kg ha⁻¹ of nitrogen (N), phosphorus pentoxide (P₂O₅), and potassium oxide (K₂O), respectively. The N cover and fertilization were carried out one day before the beginning of flooding irrigation (V3-V4 stages), at the rate of 40 kg N ha⁻¹ (COUNCE et al., 2000). The experiment was conducted in a completely randomized design with four replicates, with each pot corresponding to a replicate.

The treatments consisted of imazapyr+imazapic and saflufenacil combinations (Table 1). One isolated dose of each herbicide and a mixture with two sub-doses of the two herbicides were used. This procedure was conducted to investigate the interaction effect without the overlap of symptoms in plants. A nonionic adjuvant (0.5% v/v) was added to the herbicides. The treatments were applied in post-emergence at the V4 stage (SOSBAI, 2014). Herbicides were applied with a CO₂-pressurized backpack sprayer using TeeJet XR 110 015 at 1.4 bar pressure, resulting in an output of 150 L ha⁻¹.

Table 1 - Doses of the herbicide treatments with imazapyr+imazapic and saflufenacil applied alone and mixture in the greenhouse experiment.

		-----Saflufenacil (g ha ⁻¹)-----		
		0	3.06	6.12
Imazapyr+Imazapic (g ha ⁻¹)	0	0	0	0
	9.2+3.06	9.2+3.06	9.2+3.06	9.2+3.06
	18.4+6.12	18.4+6.12	18.4+6.12	18.4+6.12
	36.75+12.25	36.75+12.25	36.75+12.25	36.75+12.25
	73.5+24.5	73.5+24.5	73.5+24.5	73.5+24.5
	147+49	147+49	147+49	147+49
	294+98	294+98	294+98	294+98
	588+196	588+196	588+196	588+196
			-----Imazapyr+Imazapic (g ha ⁻¹)-----	
		0	9.2+3.06	18.4+6.12
Saflufenacil (g ha ⁻¹)	0	0	0	0
	3.06	3.06	3.06	3.06
	6.12	6.12	6.12	6.12
	12.25	12.25	12.25	12.25
	24.5	24.5	24.5	24.5
	49	49	49	49
	98	98	98	98
	196	196	196	196

The pots were flooded on the first day after herbicide application (DAA).

The visual control was accomplished on the 35th DAA, using a percentage rate that ranged from 0 (no symptoms) to 100% (all plants dead). Subsequently, the shoot dry mass (SDM) was obtained by drying the plant material with forced air circulation at 65 °C.

Field experiments were carried out at the Weed Science Center (Ceherb), Federal University of Pelotas, Capão do Leão, Rio Grande do Sul, Brazil, in the 2014/15 and 2015/16 growing seasons. The soil was classified as Albaquaf, sandy-loam textural class, with the following characteristics: $\text{pH}_{\text{water}} (1:1) = 5.1$; $3.4 \text{ cmol c dm}^{-3}$ calcium; $1.8 \text{ cmol c dm}^{-3}$ magnesium; $0.5 \text{ cmol c dm}^{-3}$ aluminium; 11.7 mg dm^{-3} phosphorus; 43 mg dm^{-3} potassium; cation exchange capacity - $\text{CEC}_{\text{pH7}} 9.2$, V 57.6%; 24% clay content; 0.7% organic matter content.

In this experiment, rice seeds of the cultivar Puitá INTA CL were used, with sowing density of 120 kg ha^{-1} in 0.17m spaced rows, employing a mechanical seed drill. The infestation of barnyardgrass was carried out with spontaneous seed germination in the soil seed bank. The fertilization was performed in a row using 20, 75, and 75 kg ha^{-1} of N, P_2O_5 , and K_2O , respectively. Nitrogen cover and fertilization were done another two times at the beginning of irrigation (V4) at the rate of 40 kg N ha^{-1} , and at the panicle initiation stage (R0) at the rate of 80 kg N ha^{-1} (COUNCE et al., 2000).

The experimental plots of $1.53 \times 5 \text{ m}$ (7.65 m^2) were arranged in a randomized block scheme with four replicates. The herbicide treatments consisted of the doses 21 and 42 g ha^{-1} of saflufenacil, corresponding 30 and 60 g ha^{-1} of commercial formulation Heat[®] WG (BASF); and the doses 36.75+12.25; 73.5+24.5; 110.25+36.75; 147+49 g ha^{-1} of imazapyr+imazapic, corresponding to the commercial formulation Kifix[®] WG (BASF); moreover, a mix application of two herbicides in the doses cited and an untreated control (herbicide-free) were also considered. The nonionic adjuvant Dash[®] at 0.5% v/v was added to the herbicides. The application of herbicides was performed as previously mentioned. The experimental area was flooded on the 1st DAA. The disease and insect control were performed according to local research recommendations (SOSBAI, 2014).

The visual barnyardgrass control was conducted on the 14th and 28th DAA, as previously mentioned. For determination of grain yield in the maturity stage of the crop, manual harvesting was performed in 3.4 m^2 of each plot. Then, the grain

moisture was adjusted to 13%, with grain yield expressed in Kg ha^{-1} .

Data analysis

For the experiment in the greenhouse, the data were initially tested for normality and homogeneity of variance and then subjected to analysis of variance (ANOVA). Regressions were performed by adjusting linear or non-linear models to the mean data of treatments, using Sigma Plot 12.5 (Systat Software, Inc., San Jose, CA – USA). For the regression analysis, the herbicide dose was considered as an independent factor, and the variables evaluated as dependent factors. The doses required to control 50% of weedy rice (D_{50}) and growth reduction in 50% (GR_{50}) were estimated using the regression curves of the control and SDM.

For experiments in the field, the data were initially tested for normality and homogeneity of variance. The control data were transformed using the function:

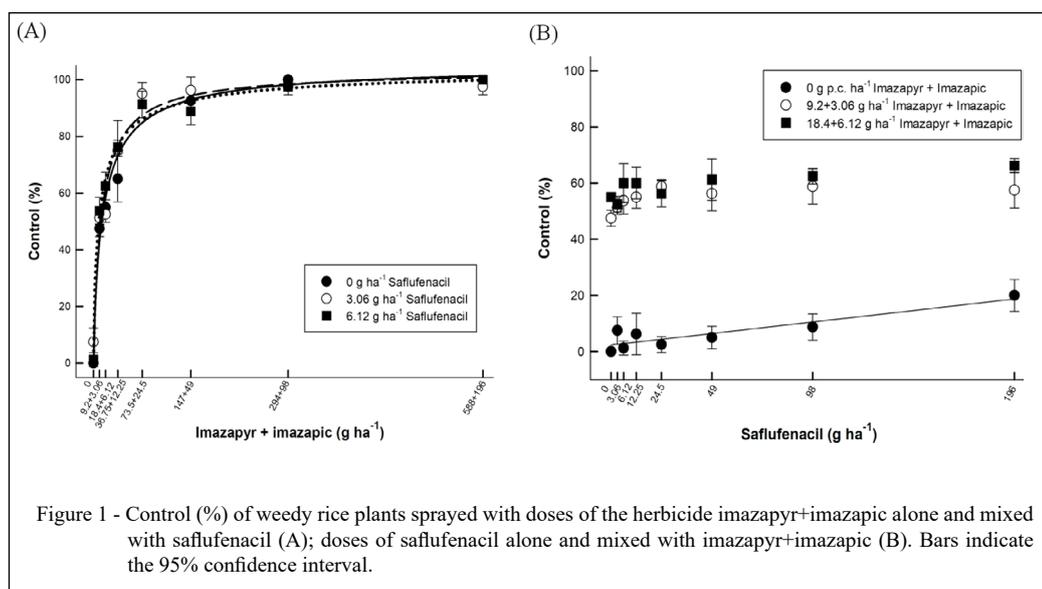
$$yt = \text{asin} \sqrt{(y + 0.5)/100},$$

where “yt” and “y” is the transformed and untransformed control, respectively. The control and grain yield variables for each year (2014/15 and 2015/16) were subjected to analysis of variance and, in case of significant differences among herbicide treatments, Tukey’s test ($P \leq 0.05$) was performed to separate means. This process was performed with the statistical program SAS[®] (Statistical Analysis Systems, Software 9.2, SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

In the greenhouse experiment, the increment doses of imazapyr+imazapic resulted in increased weedy rice control (Figure 1A), regardless of the mixture with saflufenacil. The D_{50} values of imazapyr+imazapic obtained for control were $14.5 \pm 5.0 \text{ g ha}^{-1}$, for isolated application, and $9.1 \pm 3.0 \text{ g ha}^{-1}$, and $12.5 \pm 4.2 \text{ g ha}^{-1}$ of imazapyr+imazapic in combination with 3.06 and 6.12 g ha^{-1} of saflufenacil, respectively (Table 2). These findings evidenced that, under these conditions, adding saflufenacil in the mixture did not interfere in the action of imazapyr+imazapic in controlling weedy rice.

The isolated saflufenacil did not result in adequate weedy rice control since the highest isolated dose applied (196 g ha^{-1}) led to a control of only 20% (Figure 1B). The addition of imazapyr+imazapic sub-doses in the mix with saflufenacil resulted in a control higher than 50%, with no adjustment of regression equations. However, the increment of combined



doses of saflufenacil did not represent an increase in weedy rice control (Figure 1B).

Regarding the SDM, when the plants were sprayed with imazapyr+imazapic doses (Figure 2A), regardless of the mixture with saflufenacil, there was a reduction in the SDM of weedy rice plants.

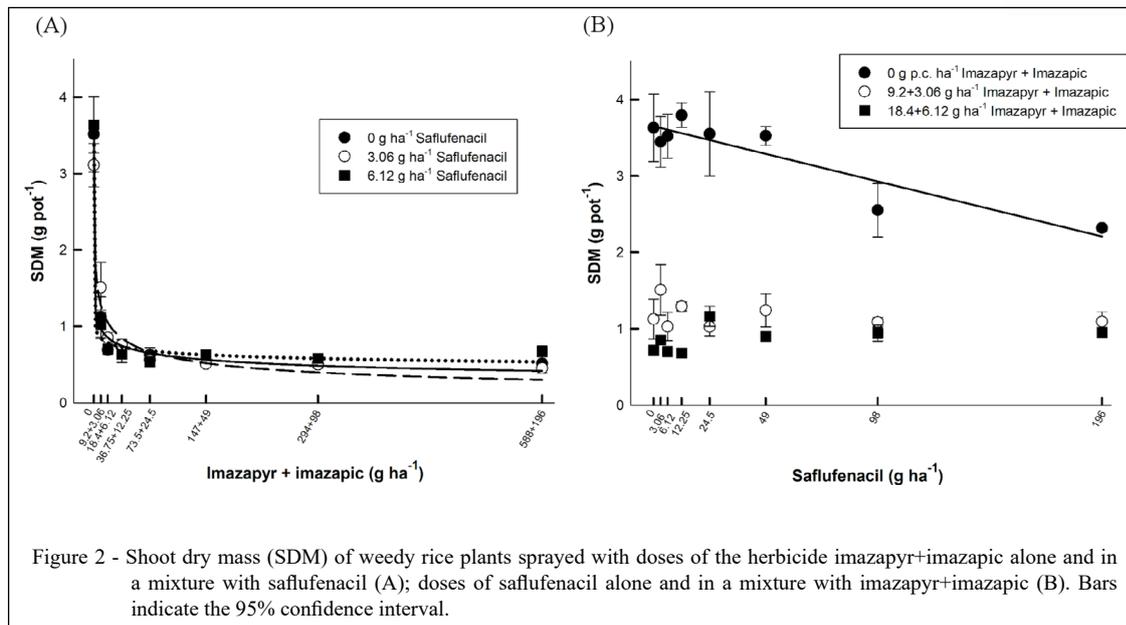
The association with saflufenacil did not change the SDM of weedy rice plants and showed that, under these conditions, the Protox inhibitor does not reduce the action of imidazolinones. All the GR₅₀ estimated values for this variable 0.2+0.06, 4.1+1.3, and 0.001+0.0001 g ha⁻¹ imazapyr+imazapic (doses

Table 2 - Regression equations used to determine the effects of herbicides on weedy rice plants in mixed and isolated in tank in the 2015/16 growing season.

¹ Her	² Mix	Parameters of the equation (PE)##					
		A	b	D50-GR50###	R ²	P##	Equation
-----Control-----							
I+I	Isolated	107.6(9.8)**	-0.82(0.26)*	14.9+5.0*	96.6	<0.01	y=a/1+(x/D50)b
I+I	3.06 g SA	104.3(5.4)**	-0.74(0.16)**	9.1+3.0**	98.9	<0.01	y=a/1+(x/D50)b
I+I	6.12 g SA	105.0(8.5)**	-0.91(0.31)*	12.5+4.2*	95.5	<0.01	y=a/1+(x/D50)b
SA	Isolated	2.3(1.2)ns	0.08(0.01)**	-	78.5	<0.01	y=a+b*x
SA	9.2 I+I	-	-	-	-	-	-
SA	18.4 I+I	-	-	-	-	-	-
-----Shoot dry mass-----							
I+I	Isolated	3.52(0.11)**	0.24(0.06)**	0.2+0.06ns	98.7	<0.01	y=a/1+(x/ D50)b
I+I	3.06 g SA	3.11(0.17)**	0.45(0.10)**	4.1+1.3ns	96.4	<0.01	y=a/1+(x/ D50)b
I+I	6.12 g SA	3.63(0.13)**	0.13(0.06)ns	0.001+0.0ns	98.4	<0.01	y=a/1+(x/ D50)b
SA	Isolated	3.65(0.10)**	-0.007(0.0)**	-	82.3	<0.01	y=a+b*x
SA	9.2 I+I	-	-	-	-	-	-
SA	18.4 I+I	-	-	-	-	-	-

PE = standard error of estimate; * indicates P<0.05; ** indicates P<0.01; ns = not significant. ## P indicates the probability of the model. ### D50 and GR50 indicate the dose required to promote control 50% or growth reduction in 50% in weedy rice, respectively.

¹ Her = Herbicide doses. ² Mix = Herbicide mixture. Isolated = no mixing; 3.06 g SA = mixture with 3.06 g ha⁻¹ saflufenacil; 6.12 g SA = mixture with 6.12 g ha⁻¹ saflufenacil; 9.2 I+I = mixture with 9.2+3.06 g ha⁻¹ imazapyr+imazapic; 18.4 I+I = mixture with 18.4+6.12 g ha⁻¹ imazapyr+imazapic.



corresponding to isolated, plus 3.06, 6.12 g ha⁻¹ saflufenacil, respectively; Table 2) were below the lowest dose of imazapyr+imazapic (9.2+3.06 g ha⁻¹), indicating the herbicide efficiency.

The isolated saflufenacil resulted in a reduction in SDM of the weedy rice (Figure 2B). However, about 40% reduction in the highest dose of this herbicide (196 g ha⁻¹ saflufenacil). When mixed with imazapyr+imazapic, the SDM decline was higher than 70%, regardless of the saflufenacil dose. For this variable, it was not possible to calculate the GR₅₀ values since the separate application of saflufenacil did not cause a reduction of 50% in the plants and, with the mixtures of imazapyr+imazapic, the reduction was higher than 70%, with no differences.

In the field experiments in 2014/15 and 2015/16 growing seasons, the results of the barnyardgrass control for treatments with the isolated application of saflufenacil did not show a difference between evaluation periods (Tables 3 and 4). These results were expected since saflufenacil is recommended for the control of Magnoliopsida weeds (MONTGOMERY et al., 2014; WALSH et al., 2015). TROLOVE et al. (2011) also showed an inefficient control of monocotyledons when saflufenacil was applied at 70 and 105 g ha⁻¹. This behavior is likely related to the ability of weeds to metabolize these herbicides. Studies on the selectivity of saflufenacil in maize crop performed by GROSSMANN et al. (2011) showed that maize seedlings rapidly metabolized

saflufenacil in non-phytotoxic compounds in the roots and shoots tissue, after 16h, in the treated leaf tissues of maize 96% of saflufenacil was metabolized. In pre emergence applications, the low translocation of root-absorbed herbicide into the shoot tissue additionally favors the tolerance to saflufenacil. In addition, in leaf discs from corn treated with saflufenacil slight increases in protoporphyrin IX and hydrogen peroxide were reported, providing selectivity for the species (GROSSMANN et al., 2010).

On the 14th DAA in the 2014/15 growing season, the barnyardgrass control was higher than 80%, both in the isolate application of imazapyr+imazapic and in the mixture with saflufenacil (Table 3). On the 28th DAA, these treatments provided a control equal to or higher than 97%. For this variable in both growing seasons, there was no difference in the barnyardgrass control between the treatments, with satisfactory control (above 80%) at the lowest dose of imazapyr+imazapic (36.75 + 12.25 g ha⁻¹).

For 2015/16 growing season (Table 4) and concerning the barnyardgrass control on the 14th and 28th DAA, only the treatment with a lower dose of imazapyr+imazapic (36.75 + 12.25 g ha⁻¹) differed from the others, indicating a less efficient control. At all evaluation times and treatments, the control levels of barnyardgrass were above 80%. The use of saflufenacil in the mixture with imazapyr+imazapic did not interfere in the barnyardgrass control.

Table 3 – Barnyardgrass (*Echinochloa* spp.) control due to the application of saflufenacil and imazapyr+imazapic herbicides at 14 and 28 days after application (DAA), and grain yield of the cultivar Puitá INTA CL. FAEM/UFPEL. Capão do Leão/RS, in the 2014/15 growing season.

Treatment	Dose (g ha ⁻¹)	-----Control (%)-----		
		14th DAA	28th DAA	Grain yield (kg ha ⁻¹)
Untreated	-	0 b ¹	0 b	- ²
Saflufenacil	21	0 b	0 b	-
Saflufenacil	42	0 b	0 b	-
I+I	36.75 + 12.25	86 a	98 a	9.377 ^{ns}
I+I	73.5 + 24.5	90 a	100 a	8.757
I+I	110.25 + 36.75	87 a	100 a	7.580
I+I	147 + 49	86 a	100 a	8.244
S+(I+I)	21 + (36.75 + 12.25)	90 a	98 a	7.808
S+(I+I)	21 + (73.5 + 24.5)	89 a	100 a	9.063
S+(I+I)	21 + (110.25 + 36.75)	90 a	100 a	8.763
S+(I+I)	21 + (147 + 49)	86 a	100 a	9.480
S+(I+I)	42 + (36.75 + 12.25)	88 a	97 a	7.870
S+(I+I)	42 + (73.5 + 24.5)	93 a	99 a	8.059
S+(I+I)	42 + (110.25 + 36.75)	88 a	100 a	9.737
S+(I+I)	42 + (147 + 49)	81 a	100 a	9.273
CV (%)		9.1	2.2	10.9

¹Means with different letters in the columns are significantly different according to the Tukey test ($P \leq 0.05$). ²Data not collected due to the lodging of the crop caused by the high level of infestation of weeds that caused severe damage to the growth and development of the crop.

^{ns} F non-significant test ($P \leq 0.05$).

In this study, the control obtained as a function of spraying only imazapyr+imazapic was equivalent to the treatments where these doses were combined with saflufenacil (Figure 1, tables 3 and 4). In these experiments, adding saflufenacil did not alter the weed control when compared to the herbicide imazapyr+imazapic alone, highlighting its neutral effect. These results differ from those of some previously published studies, where there was an antagonistic effect between Protox-inhibiting herbicides and ALS inhibitors (WESTBERG & COBLE, 1992) or, more recently, which showed a synergistic effect between saflufenacil and imidazolinones (CAMARGO et al., 2012a; CAMARGO et al., 2012b; MONTGOMERY et al., 2015). It should be noted that in these studies saflufenacil was applied in a mixture with imazethapyr. Although, imazethapyr, imazapyr, and imazapic belong to the imidazolinone group, these molecules have small differences in their chemical and physical properties (SENSEMAN, 2007) which may explain the differences in results obtained when they are mixed with others herbicides molecules, such as saflufenacil. In addition, CAMARGO et al., 2012b, used a specific ecotype of weedy rice denominated TX4, which has a slight tolerance to imazethapyr, due to differential metabolism, absorption or

translocation. In this ecotype, partial tissue necrosis caused by saflufenacil resulting from the peroxidation of cell membranes, can facilitate the movement of imazethapyr through the epicuticular layers to the cytoplasm by opening pores and channels of the plasma membrane.

Imazethapyr and saflufenacil in combination are synergic in the control of the weedy rice (CAMARGO et al., 2012a). A previous study showed that, in two evaluation periods in two years, there was an increase in the weedy rice control when imazethapyr was mixed with saflufenacil in comparison to imazethapyr applied alone (CAMARGO et al., 2012a). Similar effects were observed in the control of *Echinochloa crus-galli*, *Sesbania herbacea*, *Ipomoea hederacea*, and *Amaranthus palmeri*, where the use of the imazethapyr at 70 g ha⁻¹ mixed with saflufenacil at 50 g ha⁻¹ resulted in increased control of all these weeds, in comparison to imidazolinone alone (MONTGOMERY et al., 2015). Saflufenacil did not control weed grass species when applied alone (ANONYMOUS et al., 2013); however, the authors commented that this herbicide could cause injury to these species and that its emulsifiable concentrate formulation may favor the herbicidal effect (FISH et al., 2014; MONTGOMERY et al., 2015). Besides, when in combination with

Table 4 – Barnyardgrass (*Echinochloa* spp.) control due to the application of saflufenacil and imazapyr+imazapic herbicides at 14 and 28 days after application (DAA), and grain yield of the cultivar Puitá INTA CL. FAEM/UFPel. Capão do Leão/RS in the 2015/16 growing season.

Treatment	Dose (g ha ⁻¹)	-----Control (%)-----		
		14th DAA	28th DAA	Grain yield (kg ha ⁻¹)
Untreated	-	0 c ¹	0 d	- ²
Saflufenacil	21	0 c	0 d	-
Saflufenacil	42	0 c	0 d	-
I+I	36.75 + 12.25	83 b	91 c	7.177 d
I+I	73.5 + 24.5	89 ab	99 ab	9.986 a
I+I	110.25 + 36.75	94 a	96 abc	9.360 ab
I+I	147 + 49	94 a	100 a	8.136 bcd
S+(I+I)	21 + (36.75 + 12.25)	89 ab	94 bc	7.908 cd
S+(I+I)	21 + (73.5 + 24.5)	91 a	99 ab	9.078 abc
S+(I+I)	21 + (110.25 + 36.75)	91 a	100 a	9.831 a
S+(I+I)	21 + (147 + 49)	95 a	100 a	9.881 a
S+(I+I)	42 + (36.75 + 12.25)	88 ab	96 abc	7.727 cd
S+(I+I)	42 + (73.5 + 24.5)	93 a	100 a	9.083 abc
S+(I+I)	42 + (110.25 + 36.75)	93 a	99 ab	9.475 ab
S+(I+I)	42 + (147 + 49)	93 a	99 ab	9.987 a
CV (%)		4.5	3.0	6.3

¹Means with different letters in the columns are significantly different according to the Tukey test ($P \leq 0.05$). ²Data not collected due to the lodging of the crop caused by the high level of infestation of weeds that caused severe damage to the growth and development of the crop.

saflufenacil, imazethapyr had an increase in 30 and 35% the uptake and translocation; respectively, in weedy rice when compared to the herbicide alone, thus increasing weed grass control (CAMARGO et al., 2012b).

Treatments without herbicide (control) and with separate application of 21 and 42 g ha⁻¹ of saflufenacil showed a high level of barnyardgrass infestation in both 2014/15 and 2015/16 crops (Table 3 and 4), leading to a severe lodging of cultivated rice plants, which made it impossible to evaluate these treatments concerning the grain yield parameter. In the 2014/15 growing season (Table 3), there was no significant difference in grain yield for other treatments. The highest absolute yield (9.737 kg ha⁻¹) was provided by the mixture of 42 g ha⁻¹ of saflufenacil + (110.25 + 36.75) g ha⁻¹ of imazapyr+imazapic. In the 2015/16 growing season (Table 4), there were differences in the yield variable between treatments. The lowest grain yields were observed in the treatments with a lower dose of imazapyr+imazapic (36.75 + 12.25 g ha⁻¹), either in the isolated (7.177 kg ha⁻¹) or mixed treatments with saflufenacil (21 and 42 g ha⁻¹) with yields of 7.908 and 7.727 kg ha⁻¹, respectively. In the imazapyr+imazapic isolated at

147 + 49 g ha⁻¹, the grain yield (8.136 kg ha⁻¹) was lower than the intermediate doses of this herbicide (73.5 + 24.5 and 110.25 + 36.75 g ha⁻¹) with 9.986 and 9.360 kg ha⁻¹, respectively. In this research, neither injury (results not shown) nor reduction in the rice yield grain related to the mixture of imazapyr+imazapic with saflufenacil was observed. Previous studies had indicated post-emergence saflufenacil injuries in other Poaceae species, such as wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.), which directly reflected the reduction of 13% and 24% in grain yield, respectively (SIKKEMA et al., 2008). However, studies with rice cultivars showed that there was no reduction in the grain yield when spraying a mix of saflufenacil and imidazolinones (CAMARGO et al., 2012a, MONTGOMERY et al., 2014). In the tested rice cultivars; although, there were injuries of up to 20% with the application of saflufenacil, rapid growth and crop management (such as N fertilization) allowed plant recovery and did not cause grain yield losses.

CONCLUSION

In the mixture with imazapyr+imazapic, the saflufenacil herbicide did not interfere in the action of

imidazolinones in the weedy rice and barnyardgrass control. Saflufenacil did not lead to injury or loss of yield when mixed with imazapyr+imazapic. The Puitá INTA CL rice cultivar was tolerant of the tested herbicides, either alone or in a mixture.

ACKNOWLEDGMENTS

To Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the Research Fellowship of Luis Antonio de Avila/N.Proc. 310538/2015-7 CNPq; "This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001".

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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