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CROP PROTECTION

Environmental conditions affect herbicide selectivity on paddy rice in Southern Brazil

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ABSTRACT: *Rice yield in Southern Brazil has increased linearly over the years. Early season sowing is the primary contributor to rice yield increase in Southern Brazil. However, that practice might expose rice seedlings to the risk of low-temperature stress, which can enhance herbicide injury and reduce rice yield. This research evaluated the effect of sowing dates on herbicide selectivity and agronomical rice traits. We conducted field experiments during the 2010/11 and 2011/12 growing seasons in Capão do Leão, RS, Brazil. The experimental design was a complete randomized block with a factorial arrangement. Factor A was early-sowed (in September) and late-sowed (in November); factor B was herbicide treatment (bispyribac-sodium, cyhalofop-butyl penoxsulam, metsulfuron-methyl, and nontreated check). Rice response to herbicide treatments differed between years. In 2010/11, bispyribac-sodium, penoxsulam, and metsulfuron-methyl injured rice only on early-sowed. In both years, early sowing rice promoted higher yield potential despite herbicide injury. The injury caused by the herbicides bispyribac-sodium, penoxsulam and metsulfurom-methyl was transient did not lead to yield losses. Cold temperature close the application increases the injury of ALS herbicides.*
Key words: *bispyribac-sodium, penoxulam, metsulfuron-methyl, injury, sowing date.*

Condições ambientais que afetam a seletividade de herbicidas em arroz irrigado no Sul do Brasil

RESUMO: *A produtividade do arroz no Sul do Brasil aumentou linearmente ao longo dos anos. A semeadura no início da janela é o principal contribuinte para o aumento da produtividade do arroz no sul do Brasil. No entanto, essa prática pode expor as plântulas de arroz ao estresse por baixa temperatura, aumentando os danos do herbicida e reduzindo a produtividade do arroz. Este trabalho teve como objetivo avaliar o efeito de épocas de semeadura na seletividade de herbicidas em caracteres agronômicos do arroz. Conduzimos experimentos de campo durante as safras 2010/11 e 2011/12 em Capão do Leão, RS, Brasil. O delineamento experimental foi em blocos casualizados completos com arranjo fatorial. O fator A foram a semeadura-precoce (em setembro) e a semeadura-tardia (em novembro); o fator B foram os tratamentos com herbicidas (bispyribac-sodium, cyhalofop-butyl, penoxsulam, metsulfuron-methyl e controle - sem herbicida). A resposta do arroz aos tratamentos com herbicidas diferiu entre os anos. Em 2010/11, o bispyribac-sodium, o penoxsulam e o metsulfuron-methyl prejudicaram o arroz apenas na semeadura-precoce. Em ambos os anos, a semeadura precoce do arroz promoveu maior potencial de rendimento, apesar dos danos dos herbicidas. As injúrias causadas pelos herbicidas bispyribac-sodium, penoxsulam e metsulfuron-methyl foram transitórias, não acarretando em perdas de produtividade. A temperatura fria próxima a aplicação aumenta a injúria dos herbicidas ALS.*
Palavras-chave: *bispyribac-sodium, penoxsulam, metsulfuron-methyl, injúria, data de semeadura.*

INTRODUCTION

Rice is one of the main cereals grown in Brazil, with an area of 1.70 million ha, and 11.16 million tons of it (CONAB, 2020). The largest rice producer in Brazil is the Rio Grande do Sul (RS) state, accounting for 70% of total production. RS is located at a latitude 32º02'06" south, characterized by having well-defined climatic seasons, with a high radiation and temperature period (January) and a low radiation and temperature (July) with photoperiod ranging from 10-14 hours and temperature ranging from 9.2 to 27.8 °C (INMET, 2022). These characteristics significantly influence growing seasons and rice development (FERRARI et al., 2018).

Rice sowing time in RS is from September to November, with an average temperature ranging between 20.0 and 25.2 °C (INMET, 2022; SOSBAI,

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2018). Many producers opt to sow rice in September to synchronize the reproductive period of the culture in the period of greatest solar radiation and temperature (JALOTA et al., 2009; YOSHIDA, 1981). This synchronization with higher solar radiation improves nitrogen assimilation efficiency promoting rice-yield increase (FREITAS et al., 2008; YOSHIDA, 1981). However, the anticipation of rice sowing exposes rice seedlings to cold stress (< 15 °C), which can reduce germination and delay crop establishment (MERTZ et al., 2009). Another problem of low temperatures in the early stages of rice plants is the reduction of herbicide selectivity, such as inhibitors of acetate lactate synthase (ALS) and acetyl-CoA carboxylase (ACCase), which can cause injury and reduce yield (MARTINI et al., 2021; MARTINI et al., 2015). Problems can be accentuated in crops with non-Clearfield™ cultivars (tolerant to ALS-inhibiting herbicides from the imidazolinone group), resulting in the use of herbicides that need to be metabolized to be selective to rice, such as penoxsulam, cyhalofop-butyl, byspiribac-sodium and metsulfuron-methyl (AGOSTINETTO et al., 2021; AHMED et al., 2021; HOYOS et al., 2021).

Herbicide selectivity is dependent on crops and is highly dependent on environmental conditions, especially temperature (XIMENEZ et al., 2019). The cold stress can impair or affect the whole plant metabolism, harming the plant protection mechanisms indirectly against biotic and abiotic stresses (THEOCHARIS et al., 2012). The primary mechanism involved in crop tolerance to ALS and ACCase inhibitor herbicides is through the process called metabolization (YU & POWLES, 2014).

The mechanisms of herbicide metabolism in plants involve three phases, phase I - oxidation, phase II – conjugation, and phase III – compartmentation and/or degradation (HATZIOS & BURGOS, 2004). Phase I is performed primarily by enzymes from the family of the cytochrome P_{450} monooxygenases (P_{450}s), known to detoxify various ALS and ACCase inhibitor herbicides, such as bensulfuron-methyl and bispyribac-sodium in rice (DENG & HATZIOS, 2002; MARTINI et al., 2015), sulfosulfuron in wheat (OLSON et al., 2000), rimsulfuron in maize (KOEPPE et al., 2000), ACCase and ALS herbicides in ryegrass (*Lolium rigidum*) (PRADO et al., 2005; YU et al., 2009). Therefore, changes in temperature, which affect the activity of P_{450} enzymes, can reduce crop selectivity to herbicides (XIMENEZ et al., 2019). Thus, one of the first plant responses to cold stress comprises changes in membrane fluidity (KRATSCH & WISE, 2000), which, by turn, affects the activity of the membrane-bounded proteins such as P_{450s} (MURATA & LOS, 1997). In this context, OLSON et al. (2000) reported that cold stress impairs the metabolism of herbicides ALS in spring wheat and three grass species; in maize, when the temperature was below the range of 25 to 30 °C, the rimsulfuron metabolism was reduced (KOEPPE et al., 2000).

To increase productivity with early sowing of rice, it is necessary to understand the climatic effects of the use of selective herbicides for the crop. Thus, this study evaluated the environmental effects on herbicide selectivity and agronomical traits in paddy rice.

MATERIALS AND METHODS

Plant material and treatments

Field experiments were performed at Crop Protection Department, the Federal University of Pelotas, Brazil, in 2010/11 and repeated in 2011/12 growing season. The soil was classified as Albaquaf, sandy-loam textural class, with the following characteristics: pH_{water} (1:1) = 5.1, clay content = 21 %, organic matter content = 1.9 %, P = 18 mg dm^{-3}, K = 36 mg dm^{-3}, Ca = 4.8 cmol c dm^{-3}, Mg = 1.8 cmol c dm^{-3} and Al = 1.7 cmol c dm^{-3}. The cold-tolerant rice cultivar IRGA 424 (MARTINI et al., 2021) was sowed at 120 kg ha^{-1} in 0.17 m spaced rows, using the minimum-tillage system. The fertilization was performed in a row using NPK 5-20-30 at the rate of 350 kg ha^{-1}. Nitrogen was applied one day before the beginning of irrigation (V_3-V_4) at the rate of 70 kg N ha^{-1} and at the panicle initiation stage (R_0) at 45 kg N ha^{-1}.

The experimental plots 2 x 5 m (10 m^2) were arranged in a complete randomized block design with a factorial arrangement and four replications. Factor A (main plot) consisted of two sowing dates: early - sowed in 17th and 28th September and late - sowed in 12th and 1st November, in growing season 2010/11 and 2011/12, respectively; factor B (subplot) – herbicides: penoxsulam (240 g a.i. L^{-1}), bispyribac-sodium (400 g a.i. L^{-1}), cyhalofop-p-butyl (180 g a.i. L^{-1}) and metsulfuron-methyl (600 g a.i. kg^{-1}) at rates of 0.25 L ha^{-1}, 0.125 L ha^{-1}, 1.75 L ha^{-1} and 3.3 g ha^{-1}, respectively and a nontreated (no herbicide) weed-free check.

The weed control consisted of a pre-emergence application of glyphosate at 1.440 g a.i. ha^{-1} ten days before sowing the crop, and the post-emergent herbicides treatments mentioned above when seedlings reached the 3–4-leaf stage. Disease and insect control were performed according to the local research recommendations (SOSBAI, 2018). The experimental area was flooded one day after applied herbicides treatments. Herbicides were applied with a CO_2 pressurized backpack sprayer using TeeJet XR 110 015 at 1.4 bar pressure, resulting in a volume of 150 L ha^{-1}.

Evaluations

Crop injury was evaluated visually at 7, 14, 21, and 28 days after herbicide application (DAA), using the percentual rate ranging from 0 (no symptoms) to 100% (all plants dead). The injury symptoms observed include the overall visible negative effect of herbicides on rice plants, including stunting and chlorosis. Also, it was evaluated the agronomical traits such as the number of tillers m^{-2} at 7, 14, 21, and 28 DAA. The number of culms and panicles m^{-2}; plant height at flowering stage (10 plants per plot); flowering measured in days from emergence to 50% of heading; number of spikelets, number of grains per panicle and spikelet sterility (10 panicles/plot) and grain yield.

Data analysis

Data were initially tested for normality and homogeneity of variance. The injury data were transformed using the function:

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

where "yt" and "y" are transformed and untransformed injuries, respectively. All data 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. A test for the interaction among sowing date (factor A) and herbicides (factor B) was also performed. Moreover, it was also tested the difference among growing seasons.

There was no interaction among growing seasons, sowing dates and herbicides for tillering, plant height, number of culms and panicles m^{-2}, grain mass, number of spikelets, number of grains per panicle, and grain yield. In these cases, the data were pooled across the growing seasons, sowing dates, and herbicides. Statistical analyses were performed using SPSS (Statistical Analysis for Social Sciences) (JAYAKUMAR, 2015).

RESULTS AND DISCUSSION

Cold stress enhances herbicide damage and leads to a decreasing in selectivity

Regarding crop injury, at 7 and 28 DAA evaluations, the data were omitted because the first one was considered too early to have a good contrast among, treatments and at 28 DAA, in general, rice plants showed a considerable recovering from injury effects from the herbicides. Because of similar responses between evaluations at 14 and 21 DAA, the later analysis was chosen, and a three-way interaction was observed among growing seasons, sowing dates, and herbicides. In this case, growing seasons as a random factor were separately analyzed. Two-way interaction between sowing dates and herbicides for the 2010/11 growing season was observed. When ALS herbicides were applied at early-sown time in rice, there was higher injury compared to cyhalofop and the nontreated check (Table 1). Conversely, on the late sowing date, there was no differences on rice injury by herbicide treatments.

On the 2010/11 growing season, ALS herbicides applied at the early sowing date caused significant injury to rice seedlings. No effect of sowing date on the injury evaluation in 2011/12 was detected. In general, when compared to cyhalofop, ALS herbicides were more phytotoxic to rice seedlings. This distinct response observed among growing seasons can be correlated with the environmental conditions of each year. For instance, the difference observed between sowing dates in 2010/11 might be explained by the contrast in solar radiation and mean air temperature (Figure 1A). Following the herbicide application, the air temperature and solar radiation during the early sowing date were lower than observed during the late sowing date. The average temperature was 15 °C on the early sowing date until four DAA, while on the late sowing date, it was 24.5 °C. This difference in temperature between the sowing dates in the 2010/11 growing season may have affected rice plants, reducing herbicides' selectivity.

That difference was not consistent in 2011/12 (Figure 1B). In this season, the average temperature of the four DAA was 20 °C on the early sowing date, while on the late sowing date, it was 21.5 °C. The differences in 1.5 °C between early and late sowing were enough to distinguish between injuries to rice plants; however, the damage was less than observed in the 2010/11 season. The temperature increase in the 2010/11 season's early sowing date from 15 to 20 °C in 2011/12 probably led to a reduction in rice injury by herbicides. These results demonstrate that the temperature is influencing the selectivity of rice. Previous research has shown that low temperatures decrease rice selectivity to bispyribac-sodium, causing stunting and chlorosis (MARTINI et al., 2021; MARTINI et al., 2015). Bispyribac-sodium injury in cold-

Table 1 - Crop injury (%) at 21 DAA caused by herbicide treatments sowing date in 2010/11 and 2011/12 growing seasons.

Herbicides	--------------------------------2010/11----------------------------------		2011/12
	Early sowing	Late sowing	
Nontreated check	0.00 Ac[1]	0.00 Aa	0.00 b
Bispyribac-sodium	16.25 Aab	0.00 Ba	18.12 a
Cyhalofop-butyl	0.00 Ac	0.00 Aa	1.00 b
Penoxsulam	25.00 Aa	5.00 Ba	18.12 a
Metsulfuron-methyl	11.25 Ab	5.00 Ba	19.37 a
Early sowing main effect			12.65 *
Late sowing main effect			10.00

[1]Means not followed by same uppercase (sowing dates) and lowercase letters (herbicides) differ by Tukey's test ($P \leq 0.05$); * the two means are significantly different between sowing dates in 2011/12 growing season, according to F test ($P \leq 0.05$). DAA: Days after application.

weathered rice plants was due to lower herbicide metabolism (MARTINI et al., 2021; MARTINI et al., 2015). When plants are exposed to low temperatures, membranes become less fluid, decreasing membrane-bound Cyt-P_{450}s enzyme activity (UEMURA et al., 1995), reducing its ability to metabolize herbicides.

In addition to that, even being selective to the crops, herbicides promote biochemical and physiological alterations as a secondary effect, causing metabolism disorders in plants (DAYAN et al., 2019), increasing their toxicity and decreasing their selectivity (XIMENEZ et al., 2019). According to previous studies, reactive oxygen species (ROS) generation comprises one of the most common secondary effects promoted by herbicides (FIPKE et al., 2022; LUO et al., 2017). These molecules are generated during the peroxisome metabolism and are induced by environmental stimuli to which the plants are exposed (GUO et al., 2006). Generally, ROS causes lipid peroxidation, membrane senescence, damage to proteins, and nucleic acids (FOYER & NOCTOR, 2016), common effects observed in plants submitted to cold stress (MORSY et al., 2007). Thus, having the same consequences, the cold stress can enhance herbicides' damage, decreasing their selectivity.

Sowing dates affects rice crop

Plant height, culms, and panicles were not affected by herbicide treatments. Differences were detected in plant height and culms concerning growing season and sowing dates (Table 2). Plant height and culms were increased in late sowing than in early sowing. This response may be related to the higher mean air temperature observed during the vegetative stage (Figure 1). Plants exposed to warmer temperatures usually grow taller and develop more tillers, being a positive point concerning weed-crop competition (RADOSEVICH et al., 2007). Likewise, plants in 2010/11 were taller than in the 2011/12 season, and this response was related to the differential rainfall pattern and solar radiation availability in both growing seasons. However, more culm was detected in 2011/12 than in the 2010/11 season. Panicles (m^2) were affected only by the growing season, and a high panicle number was detected in the 2011/12 season. This effect was probably due to the greater number of culms produced per plant, culminating in a greater panicle number.

Flowering was affected by growing seasons, sowing dates, and herbicide treatment

Rice flowering period was also affected by all treatment factors (growing seasons, sowing dates, and herbicides; table 3). Concerning the main effect of sowing date, early sowing resulted in a delay of the booting stage in 2010/11 and 2011/12. It could be related to the difference in temperature observed between sowing dates. Rice is a temperature-responsive crop, and plants need to accumulate hours of above threshold temperature. Therefore, under higher temperatures, faster will be the phyllochron and; consequently, the plant's growth (STRECK et al., 2007). Conversely, plants with a more prolonged vegetative phase neutralize phytotoxic effects promoted by herbicides, a positive aspect of herbicide selectivity on rice plants. Concerning the main herbicide effect, ALS promoted a delay in flowering in 2011/12, different from the observed in 2010/11.

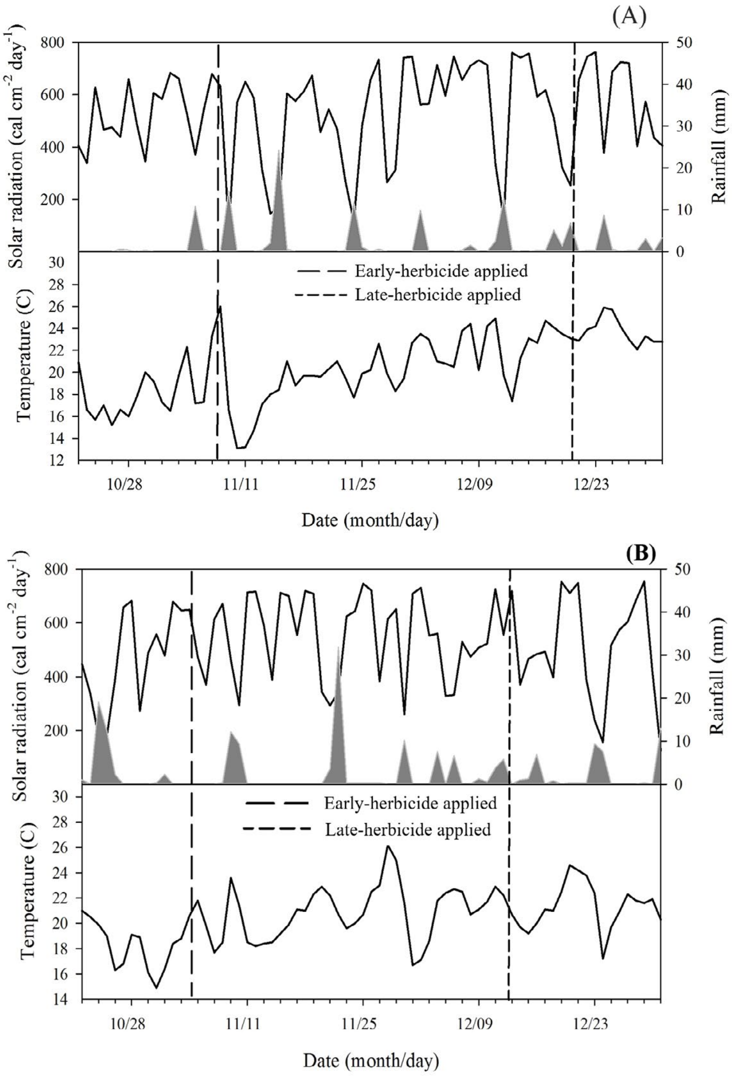

Figure 1 - Daily mean air temperature, solar radiation, and rainfall during the herbicide application period in 2010/2011 (A) and 2011/2012 (B). The vertical dashed lines represent herbicides applied in early sowing (early-herbicide applied) and late sowing (late-herbicide applied).

Rice grain yield was not affected by herbicide treatment but affected by sowing date

No differences ($P \geq 0.05$) for herbicide´s main-effect pooled across sowing dates and growing seasons were detected for rice grain yield (Table 4). The lack of difference in grain yield is probably a result of rice's efficient detoxification mechanism. Despite the initial injury in some treatment at the beginning of the season, plants recovery from herbicides injury along the growing season.

Regarding the sowing date effect, as expected, in 2010/11 and 2011/12 season, early-sowed rice yields more compared to late-sowed rice. The higher yields observed on the early sowing dates are due to the synchrony of the reproductive phase with the higher solar radiation; this synchrony

Table 2 - Plant height, number of culms, and panicles m^{-2} as affected by herbicide treatments on rice plants sowed early and late in 2010/11 and 2011/12 growing seasons.

Treatments	Plant height (cm)	Culms m^{-2}	Panicles m^{-2}
Nontreated check	93.51 a[1]	723.53 a	591.49 a
Bispyribac-sodium	93.07 a	734.68 a	632.35 a
Cyhalofop-butyl	92.63 a	808.82 a	638.60 a
Penoxsulam	91.09 a	737.87 a	587.13 a
Metsulfuron-methyl	93.05 a	767.28 a	644.80 a
Early sowing main effect	89.50 *	795.59 *	596.42 ns
Late sowing main effect	95.73	713.29	641.32
2010/11	98.64 A[2]	714.02 B	563.19 B
2011/12	86.82 B	794.85 A	674.56 A

[1]Means not followed by same lowercase letters (herbicides) differ by Tukey's test ($P \leq 0.05$); [2] means not followed by same uppercase letters (growing seasons) differ by Tukey's test ($P \leq 0.05$); * means are significantly different between sowing dates, according to F test ($P \leq 0.05$). ns not significant by F test ($P \geq 0.05$).

promotes a higher carbon fixation by the plant and higher nitrogen assimilation (FREITAS et al., 2008; YOSHIDA, 1981).

Sowing dates and growing seasons differentially affected rice tillering (Figure 2). Those effects were irrelevant because they did not affect the number of culms m^{-2} (Table 2). Concerning the other yield components, no significant interactions and no main effects were observed in terms of the number of panicles per m^2 (Table 2) and spikelets per panicle (Table 4), meaning that the herbicides and sowing dates did not affect those variables.

Grain weight was higher in rice early sowed (Table 4). Rice sowed early is more exposed to favorable weather conditions as solar radiation and cooler night temperatures, which implies better performance during the grain filling stage (FERRARI et al., 2018). Plants of rice sowed later are exposed to higher night temperatures, increasing plant respiration and reducing grain yield (LACK et al.,

Table 3 - Days from emergence to the flowering of rice plants exposed to different herbicides treatments on rice plants sowed early and late in 2010/11 and 2011/12 growing seasons and sowing time.

Herbicides	----------------------Flowering (days from emergence to heading)--------------------	
	2010/11	2011/12
Untreated check	94.75 a[1]	94.37 c
Bispyribac-sodium	95.25 a	96.87 abc
Cyhalofop-butyl	95.37 a	94.50 bc
Penoxsulam	95.37 a	97.75 ab
Metsulfuron-methyl	95.25 a	98.50 a
Early sowing main effect	103.20 *	98.85 *
Late sowing main effect	87.20	93.95

[1]Means followed by different lowercase letters (herbicides) differs by Tukey's test ($P \leq 0.05$); * means are significantly different between sowing dates, according to F test ($P \leq 0.05$).

Table 4 - Number of spikelets and grains per panicle, grain weight, and grain yield of rice as affected by sowing date and herbicide treatments.

Treatments	Spikelets panicle^{-1}	Grains panicle^{-1}	1,000-grain weight (g)	Yield (kg ha^{-1})
Nontreated check	100.92 a[1]	88.59 a	25.42 a	10,742 a
Bispyribac-sodium	98.61 a	80.07 a	25.01 a	10,979 a
Cyhalofop-butyl	96.31 a	84.37 a	25.48 a	11,492 a
Penoxsulam	100.66 a	84.39 a	25.04 a	11,298 a
Metsulfuron-methyl	102.13 a	87.21 a	25.15 a	11,010 a
Early sowing effect	100.27 ^{ns}	83.02 ^{ns}	25.86 *	12,838 *
Late sowing effect	99.18	86.83	24.58	10,526
2010/11	108.14 ^{ns}	95.89 A[2]	25.75 A	12,319 A
2011/12	91.31	73.95 B	24.68 B	11,105 B

[1]Means not followed by same lowercase letters (herbicides) differ by Tukey's test ($P \leq 0.05$); [2] means not followed by same uppercase (growing seasons) letters differ by F test ($P \leq 0.05$); * means are significantly different between sowing dates, according to F test ($P \leq 0.05$). ^{ns} not significant by F test ($P \geq 0.05$).

2012). Likewise, in 2010/11, higher grain weight was observed compared to the 2011/12 season. As mentioned above, environmental conditions guided this plant response, partially explaining the lower yield obtained in the late sowing date and 2011/12 growing season. Also, yield loss can be correlated with the filled grains per panicle, lower than the 2010/11 growing season. However, this yield component was not affected by herbicides and sowing dates.

ALS herbicides and cold-stress caused spikelet sterility

In the 2010/11 growing season, ALS herbicides, especially the treatments with penoxsulam and bispyribac-sodium, resulted in greater spikelet sterility; however, it was not observed in 2011/12, when no difference was detected compared to the nontreated check (Table 5). This response was due to the lower herbicide injury observed in 2011/12. Concerning the sowing date

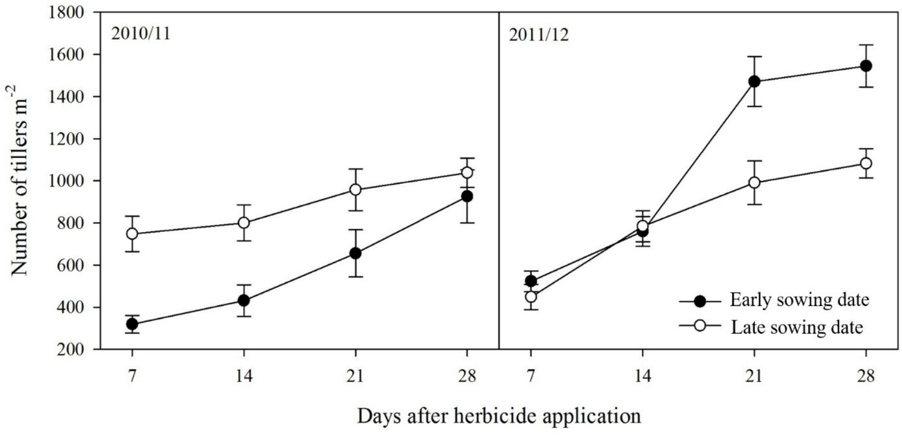

Figure 2 - Tillering of early and late sowing dates in 2010/11 and 2011/12 (95% confidence intervals).

Table 5 - Spikelet sterility of rice as affected by herbicide treatments on rice plants sowed early and late in 2010/11 and 2011/12 growing seasons.

Herbicides	----------Spikelet sterility (%)----------	
	2010/11	2011/12
Nontreated check	8.48 c[1]	16.49 a
Bispyribac-sodium	14.92 a	22.92 a
Cyhalofop-butyl	6.95 c	18.30 a
Penoxsulam	13.77 ab	18.76 a
Metsulfuron-methyl	9.58 bc	19.29 a
Early sowing main effect	12.04 [ns]	21.94 *
Late sowing main effect	9.50	16.36

[1]Means not followed by the same lowercase letters (herbicides) differ by Tukey's test ($P \leq 0.05$); * means are significantly different between sowing dates, according to F test ($P \leq 0.05$). [ns] not significant by F test ($P \geq 0.05$).

effect, no difference was observed in 2010/11; however, early-planted rice showed higher spikelet sterility in 2011/12. This profile was related to the low temperatures that occurred in 2011/12 during the booting stage (Figure 3), considered to be the most sensitive stage to low temperatures, which by turn promotes high spikelet sterility (NAHAR et al., 2009), resulting in yield loss as observed in 2011/12 growing season.

Final remarks

Sowing date is one of the most critical factors to achieve high rice yields because it alters the temperature and solar radiation to which the plants are subjected. Early sowing yielded better than late sowing in both growing seasons because the period of the reproductive stage was coincident with the maximum solar radiation availability, favoring high nitrogen assimilation during that stage.

The herbicide injury was transient and did not promote yield loss, weather conditions by herbicide application timing and sowing date should be carefully observed when applying ALS herbicides. Cold and cloudy days should be avoided based on the forecast because in these conditions the herbicide injury is higher. We attributed these results to the

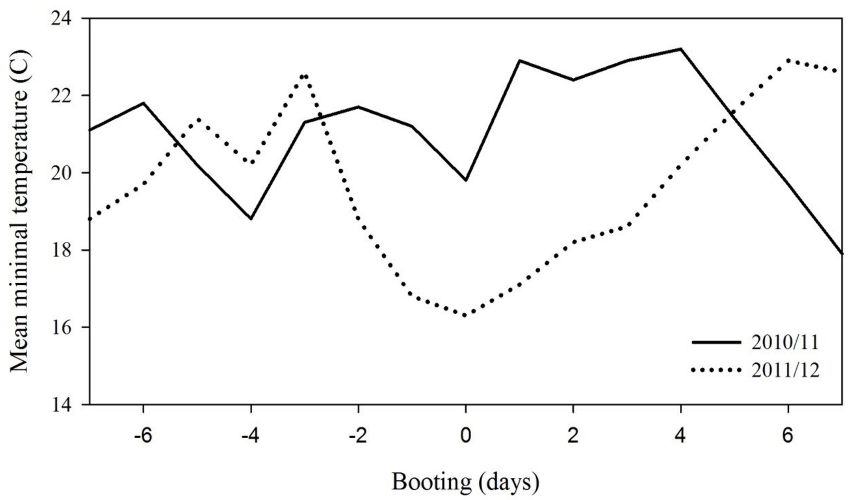

Figure 3 - Mean minimal air temperature during the flowering stage in early-sowed rice.

fact that those chemicals seem to be metabolized by an enzymatic complex that is highly dependent on temperature and solar radiation, which guides the whole plant metabolism; and consequently, the herbicide metabolism. Herbicide metabolism involves several factors that should be revised in future studies; for instance, the proper P_{450} and glutathione-S-transferases activity should be a suitable indicator of herbicide metabolism in rice plants exposed to cold stress.

CONCLUSION

Early sowed rice yielded better than late sowed in both growing seasons, due to the maximum solar radiation in the reproductive stage. The cyhalofop-butyl herbicide did not cause injuries or reduced yield in the crop. The injury caused by the herbicides bispyribac-sodium, penoxsulam and metsulfurom-methyl were transient, did not lead to yield losses. Cold temperature around the application timing increase the injury of ALS herbicides. The weather conditions during the herbicide application timing and sowing date should be carefully observed when applying ALS herbicides.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

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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