Sumário

Revista Ciência Agronômica, v. 44, n. 3, p. 594-603, jul-set, 2013
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Artigo Científico
ISSN 1806-6690

Agronomic performance of rice to the use of urease inhibitor in two cropping systems[1]

Desempenho agronômico do arroz irrigado ao uso de inibidor de urease em dois sistemas de cultivo

Enio Marchesan[2]*, Mara Grohs[2], Melissa Walter[3], Leandro Souza da Silva[4] e Tiago Constante Formentini[2]

ABSTRACT - The use of urea coated with urease inhibitor may become a useful tool for increasing the efficiency of nitrogen top-dressing in rice crop, thereby reducing nutrient losses through volatilization of NH_3 (ammonia). Thus, the aim of this study was to evaluate the volatilization of NH_3 and the response of rice to the use of urea coated with urease inhibitor in two cropping systems, no-tillage and conventional. For this purpose, field experiments were developed in the agricultural years 2007/2008 and 2008/2009, in UFSM in Santa Maria-RS. The design was randomized blocks in bifactorial scheme (2x5) with two sources, urea and urea + NBPT and five intervals of water intake (0; 3; 6; 9; 12 days) after application of nitrogen sources. The results of two seasons show that the urease inhibitor present in urea slows and decrease the conversion of N to NH_3, reducing the losses by volatilization, compared to urea without inhibitor. Among the systems, the losses are magnified in the no-tillage cropping system. The behavior of the response variable in relation to productivity is variable in two cropping systems used in this study and the stress caused to the rice plant by the late start of the irrigation is more damaging than the losses caused by the volatilization of NH_3.

Key words: Rice cultivation. Urease inhibitor. Use straw in agriculture.

RESUMO - A utilização de uréia recoberta com inibidor de urease pode tornar-se uma ferramenta útil para aumentar a eficiência da adubação nitrogenada em cobertura na cultura do arroz irrigado, diminuindo assim perdas do nutriente por volatilização de NH_3 (amônia). Com isso, o objetivo desse trabalho foi avaliar a volatilização de NH_3 e a resposta do arroz irrigado ao uso de uréia recoberta com inibidor de urease em dois sistemas de cultivo, direto e convencional. Para tanto, conduziram-se experimentos em campo, nos anos agrícolas 2007/2008 e 2008/2009, na UFSM em Santa Maria-RS. O delineamento utilizado foi o delineamento experimental blocos completos casualizados em esquema bifatorial (2x5), com duas fontes, uréia e uréia+NBPT e cinco intervalos de início da irrigação (0; 3; 6; 9; 12 dias) após a aplicação das fontes de N. Os resultados das duas safras demonstram que o inibidor de urease presente na uréia retarda e diminui a conversão de N para NH_3, reduzindo as perdas por volatilização, comparativamente à uréia sem inibidor. Entre os sistemas, as perdas são potencializadas no sistema plantio direto. O comportamento da variável resposta em relação à produtividade é variável nos dois sistemas de cultivo utilizados e o estresse causado na planta de arroz pelo atraso no início da irrigação é mais prejudicial do que as perdas causadas pela volatilização de NH_3.

Palavras-chave: Cultivo de arroz. Inibidor de urease. Utilização de palha na agricultura.

*Autor para correspondência
[1]Recebido para publicação em 07/10/2011; aprovado 04/02/2013
Trabalho de Graduação realizado com financiamento de bolsa pela instituiçao FAPERGS
[2]Departamento de Fitotecnia, Centro de Ciência Rurais, Universidade Federal de Santa Maria, Santa Maria-RS, Brasil, emarchezan@terra.com.br, maragrohs@yahoo.com.br, tiagoformentini@hotmail.com
[3]Instituto Federal de Educação, Ciência e Tecnologia Farroupilha, Santa Rosa-RS, Brasil, melmelissaw@hotmail.com
[4]Departamento de Solos, Centro de Ciências Rurais, Universidade Federal de Santa Maria, Santa Maria-RS, Brasil, leandrosolos@ufsm.br

INTRODUCTION

In irrigated rice growing, the product most used in the supply of nitrogen (N) is urea due to its high level of N and lower cost per unit of element (XU *et al*., 2005). On the other hand, is a source that presents the greatest losses of N by processes such as volatilization of ammonia (NH_3), reaching up to 80% of the fertilizer applied (LARA CABEZAS; SOUZA, 2008; MARTHA JÚNIOR *et al*., 2004).

The directions of the research for the first top-dressing application of N in rice say that this shall be done preferably at tillering, preceding the intake of water at a maximum interval of three days between application and initiation of irrigation (SOCIEDADE SUL-BRASILEIRA DE ARROZ INTEGRADO, 2007). This recommendation is based on the fact that urea can be converted into ammonia (NH_3) and lost or, following with aerobic conditions, transformed into nitrate (NO_3-), which can then be lost as N_2 or N_2O when the soil is flooded. Thus, with flooding being performed immediately after application of urea, the probability of loss by evaporation, and, subsequently by denitrification, decreases, enhancing the efficiency of the fertilizer applied.

However, due to farming operational factors (farm size, irrigation capacity), this interval of time often cannot be met, reflecting on the efficiency of the fertilizer applied and consequently, on the productivity. One possibility to control or reduce the losses of N is to inhibit the rate of urea hydrolysis in soil by using an enzyme inhibitor, such as N-(n-butyl) thiophosphoric triamide (NBPT), currently considered the most promising urease inhibitor and is already being marketed in the U.S.A since 1996 (WATSON, 2000), reducing in 83% the losses by volatilization in rice (SCIVITTARO *et al*., 2010).

This study aimed to evaluate the N losses by volatilization and the response of irrigated rice using urea coated with urease inhibitor (NBPT) compared to urea, at different intervals of water intake after applying fertilizer in conventional and no-tillage cropping systems in two different seasons.

MATERIAL AND METHODS

Experiments were carried out in the seasons of 2007/2008 and 2008/2009 at the Universidade Federal de Santa Maria, in soil classified as typical albaqualf, belonging to the mapping unit of Vacacaí (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 1999), with the following characteristics: pH_{water}(1:1) = 5.0; $P_{(Mehlich-1)}$ = 11.8 mg dm^{-3}; $K_{(Mehlich-1)}$ = 76 mg dm^{-3}; M.O. = 2.4 m/v; Ca = 4.8 $cmol_c$ dm^{-3}; Mg = 1.6 $cmol_c$ dm^{-3}; Al = 0.5 $cmol_c$ dm^{-3} and clay = 25%. Each year two experiments were conducted simultaneously, allocated side by side, differing only in the cropping system (conventional system (CS) or no-tillage (NT)). To obtain the straw in no-tillage system, ryegrass (*Lolium multiflorum* Lam.) was sown at a density of 40 kg ha^{-1} of seeds. The climatic conditions of the years 2007/2008 and 2008/2009 were, respectively: 30 mm and 40 mm of precipitation, minimum temperature of 28 ºC and 27 ºC, in NT and CS, respectively, and maximum temperature of 30 ºC and 40 ºC, in NT and CS, for two years.

The experimental design was randomized blocks in bifactorial scheme (2x5) with four replications. The factor A (qualitative) was represented to sources of nitrogen (N), common urea and urea coated with NBPT (urea + NBPT) (Super N®), and the factor B (quantitative) five intervals of water intake, represented by: 0; 3; 6; 9 and 12 days after the application of the nitrogen source. Sowings occurred on 10/26/2007 and 11/10/2008, using cultivar IRGA 417 on the density of 90 kg ha^{-1} of seeds in both seasons. Fertilization, at the time of sowing, was 60 kg ha^{-1} of P_2O_5 and 90 kg ha^{-1} of K_2O of formula 05-20-30, using the total amount of 120 kg ha^{-1} of N, divided into 15 kg ha^{-1} at sowing in the form of urea, 75 kg ha^{-1} N before the final irrigation in the form of different sources and 30 kg ha^{-1} of N at panicle initiation, for both urea and urea + NBPT. The experimental units were 4.0 x 2.87 m (11.48 m^2) and floor area to estimate the yield was 3.0 x 1.19 m (3.57 m^2). The remaining practices were performed as recommended by the search for rice production (SOCIEDADE SUL-BRASILEIRA DE ARROZ INTEGRADO, 2007).

The variables analyzed were N losses for 288 hours, N accumulation in shoots of rice plants, SPAD readings in shoots, mineral N in the soil and yield of rice. The variables were subjected to analysis of variance by the F test, and the means of qualitative factors were compared by the Tukey test ($P \leq 0.05$), whereas the quantitative factors were represented by regression analysis and equations adjusted for the water intake intervals on the variables analyzed. Regression analysis was aimed at identifying the effect of delaying the entry of water onto the rice agronomic performance. A confidence interval (upper and lower limit) at 95% probability was used to express the difference between the sources, and those were significantly different when, in comparison, their intervals did not overlap. The dates were analyzed in software Sisvar, version 5.3.

Evaluations of N losses through volatilization of NH_3 were performed with collectors and procedures according to Araújo *et al*. (2009). Evaluations were performed at 10; 24; 34; 48; 72; 96; 144; 216 and 288 hours after application of nitrogen source in the soil, determining NH_3 later, according to Tedesco (1995).

The evaluation of N accumulated in shoots of rice plants was determined by collecting whole plants at 0.5 m^2 of each plot at the last application of N, at panicle initiation, 43 days after emergence (DAE), using the methodology described by Tedesco (1995). On the other hand, for the second crop, plants were also collected at the time of full flowering, 93 DAE. The samples were dried at 70 °C in an oven of forced air and they were grounded right after that. To assess the mineral N in the soil, at the time of collecting the plants, a soil auger was used, taking a sample of 0;10 cm deep in each plot, subsequently freezing it at -5 °C until determining the content of mineral forms of nitrogen (ammonium and nitrate + nitrite), following the methodology described by Tedesco (1995).

In order to estimate the nutritional level of N in the culture, at the time of soil and plant sampling, SPAD readings (chorophyll meter SPAD 502) were also performed on the last fully expanded leaf, in three different positions of the leaf, in three plants per plot.

Grain yield was determined by manually harvesting the panicles of the useful area of the plots when the grains reached the average moisture of 20%. These were threshed and later, the grain weight was determined and the moisture was corrected to 13%.

RESULTS AND DISCUSSION

N losses by ammonia volatilization

The NH_3 volatilization flows varied with the source of nitrogen (N) and cropping system in both years (Figure 1). For the season of 2007/2008, no-tillage system (NT), the amount of NH_3 volatilized during the period of 288 hours, was approximately 28% of the applied amount (the total amount applied corresponded to 75 kg N ha^{-1}), while the loss of urea + NBPT was 18%. The amount of NH_3 volatilization was lower in the conventional system (CS) compared to the NT in which the losses were 11% and 7% of the nitrogen applied to the common urea and urea + NBPT, respectively. In the NT system, NBPT delayed the conversion of nitrogen amidic (urea) into NH_3, delaying the maximum emission of NH_3 from 34 to 72 hours (2-3 days), occurred with common urea to 144 hours (six days) in the treatment urea + NBPT, agreement with the results of Scivittaro *et al*. (2010) in similar work.

For the 2008/2009 crop, the results of NH_3 volatilization were similar to the previous season, showing different losses between sources and cropping systems.

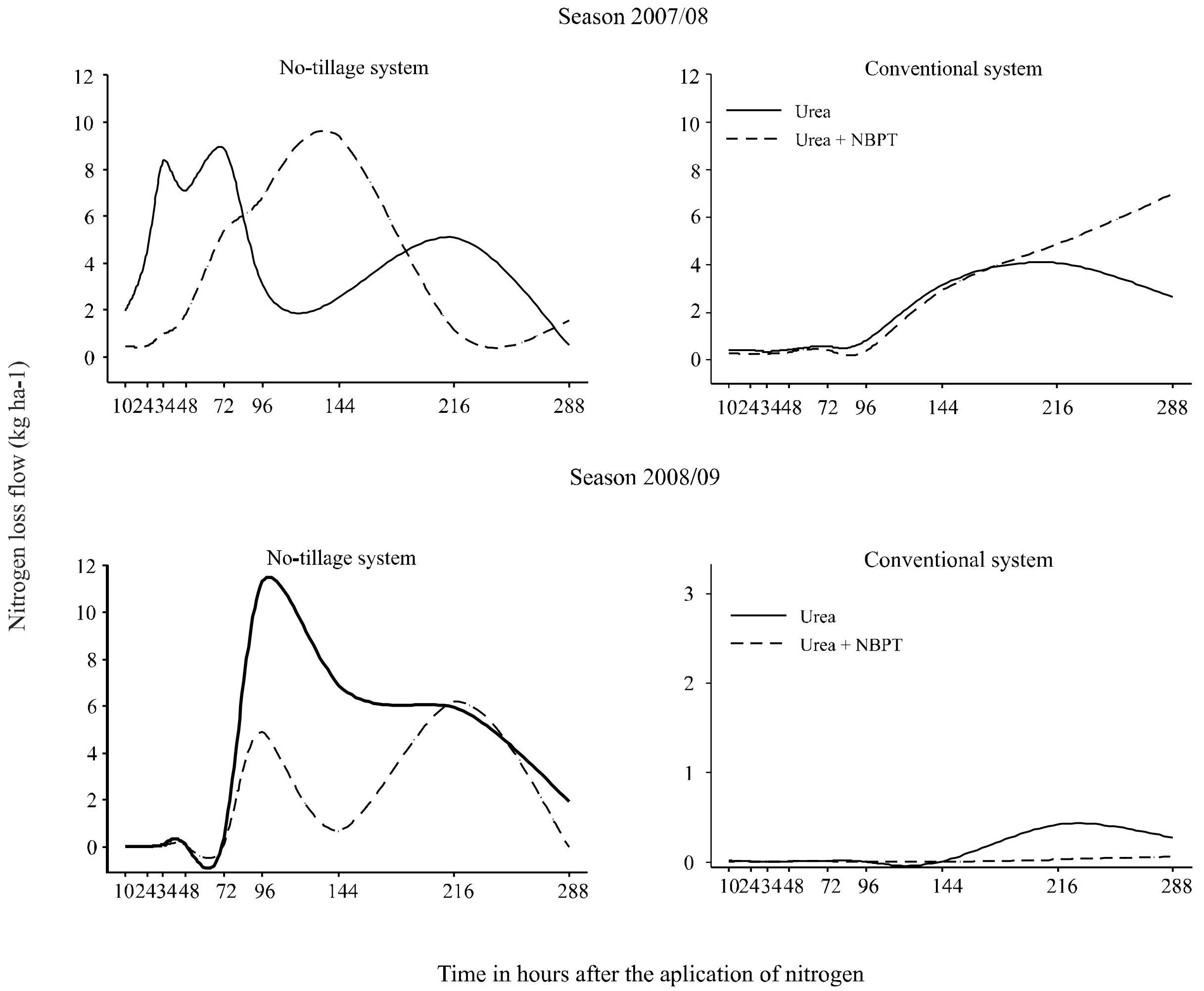
In the NT system, the initiation of a significant flow of NH_3 losses began after 72 hours, regardless of the source, and urea showed the greatest losses, reaching a maximum volatilization after 96 hours, a total cumulative loss of 47% of N applied during 288 hours. Urea coated with NBPT had lower losses of N, with maximums between 96 and 216 hours after application on the soil and accumulated losses of 20% of total N applied in top-dressing. In the NT system, NBPT delayed most part of the conversion of urea into NH_3 for 216 hours, whereas for the urea without inhibitor, most fertilizer was hydrolyzed between 72 to 96 hours. Similar to the first harvest, the urease inhibitor has not completely inhibited the hydrolysis and the loss of NH_3, and its efficiency decreased gradually with time.

In this cropping, for the CS, the losses by volatilization have not exceeded 1.2%, and the maximum of losses occurred after 216 hours. In the treatment with urease inhibitor, total NH_3 loss was 0.014% of the total N applied. The urease inhibitor was effective in delaying and reducing the volatilization of NH_3 in the two systems because the product is an indirect inhibitor that, in aerobic conditions, is converted into a direct inhibitor, its oxygen analogue compound, N-(n-butyl) phosphoric triamide (NBPTO), within minutes or hours (DOMINGUEZ *et al*., 2008). However, under anaerobic conditions, this transformation can take several days (WATSON, 2000).

Despite the potential to inhibit the volatilization, the product had reduced its efficiency in the NT system, probably due to the presence of plant residue on the soil surface, since straw reduces the contact of fertilizer with the soil and may present significant activity of urease. This layer of straw covering the soil acts as a barrier between the nitrogen of the fertilizer and the soil, causing the NH_3, hydrolysis product, to remain on the surface of the debris, reducing its adsorption to organic and inorganic colloids, thus facilitating the volatilization (CANTARELLA *et al*., 2008; LARA CABEZAS; SOUZA, 2008; TRIVELIN; VITTI, 2006). Moreover, the presence of plant residues on the soil surface concentrates great amounts of urease enzyme, which has its activity related to the presence of organic matter on the soil, promoting microbial activity and greater enzyme production, which shall accelerate the nitrogen fertilizer hydrolysis, resulting in the formation of NH_3.

The pattern of N released from NBPT depends on the thickness and quality of the treatment. Urea passes from the interior of the granule into the soil by micro-pores, cracks or imperfections of granules or after the microbial degradation of the polymer coating covering the urea (CANTARELLA, 2007). With this, in the NT system, there is the possibility of a combination of higher concentration of urease have occurred coupled to the permanence of nitrogen on the surface, which may have jeopardized its efficiency, compared to its behavior in the CS. In CS, the volatilization losses were substantially lower, since the absence of plant residue provided greater contact between fertilizer and soil. Losses present in this system occurred due to a likely increase in temperature and decrease in moisture in the soil with no straw, which enhanced the volatilization

Figure 1 - Flow of NH_3 losses in kg ha^{-1} according to the fertilizer used in the no-tillage and conventional cropping systems in the seasons of 2007/2008 and 2008/2009 of irrigated rice, Santa Maria. 2011



Mineral N in soil, plants and chlorophyll meter reading

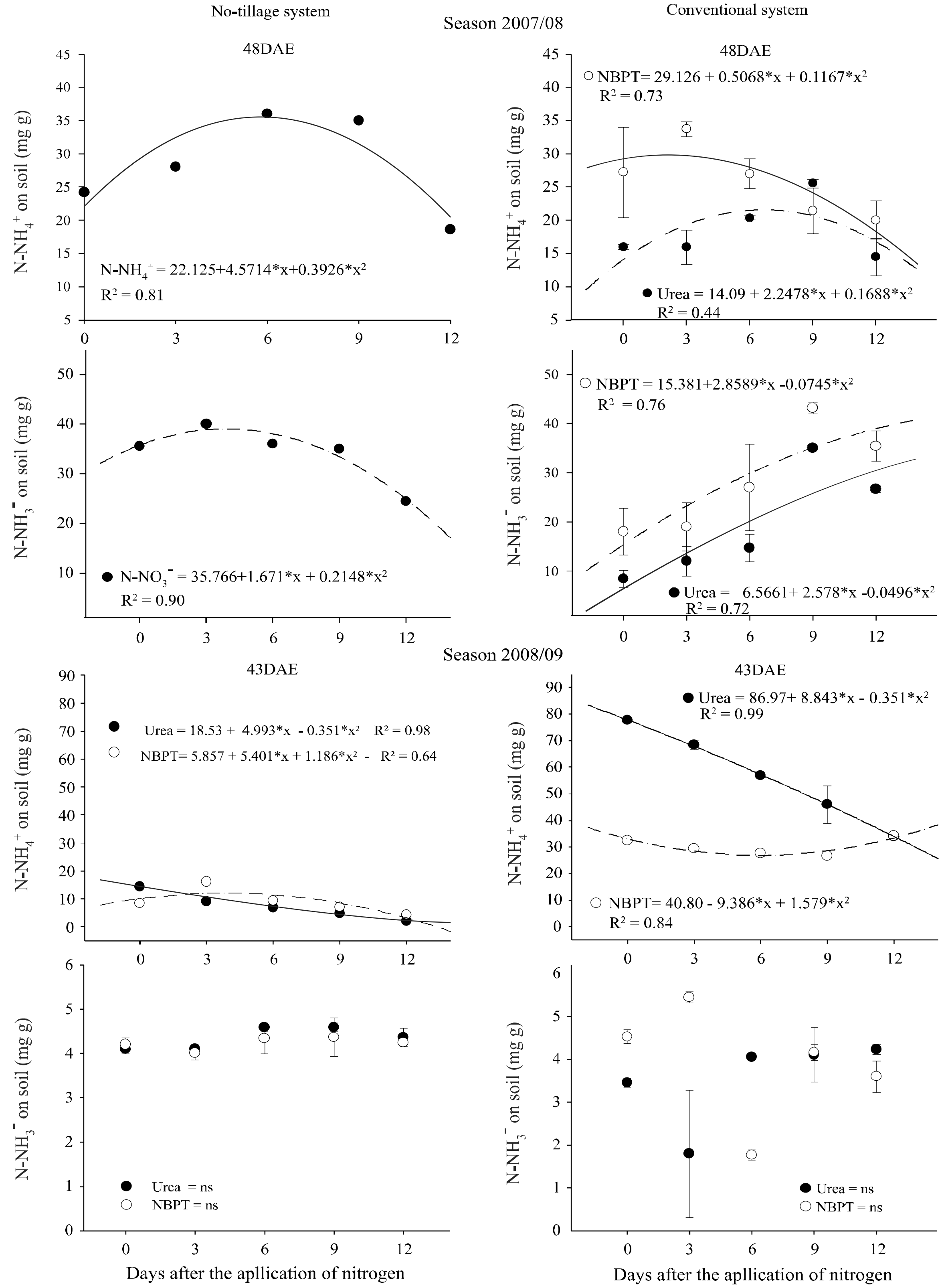
process due to the increase in the rate of reactions linked to the urease activity, as well as facilitated the NH_3 upward diffusion to the atmosphere together with water evaporation from the soil (DA ROS *et al*., 2005; SANGOI *et al*., 2003).

For the season of 2007/08 in the NT system, there was no difference in behavior between urea and urea + NBPT on the levels of N-NH_4^+ in the soil (Figure 2). The difference occurred in relation to the intervals of water intake, demonstrating that the maximum concentration of N-NH_4^+, occurred on the sixth day after the application of N. The behavior of N-NO_3^- fraction was similar, with gradual reductions in the delay of irrigation. Unlike the NT system, the CS, the treatments differed in the evaluation of N-NH_4^+ in mineral soil. Urea + NBPT showed higher contents of mineral N- NH_4^+ in soil in the first six days after application, compared with common urea. This was reflected in the concentration of N-NO_3^-, since the greatest levels were in urea + NBPT and they increased with the time interval until the irrigation input, indicating that N, in the form of N-NH_4^+, oxidized to NO_3^- overtime (over the time).

For the season of 2008/2009, the behavior of N-NH_4^+ was similar to the first season, demonstrating a decrease in the content as it delayed the start of irrigation in both cropping systems. However, there was no increase in the concentration of N-NO_3^- with the reduction of N-NH_4^+, because the sources and the intervals of water intake did not differ significantly in both cropping systems.

In general, the tendency of the N-NH_4^+ level in these past two years was to decrease as it delayed the water intake, because the behavior of the ammonium fertilizer tends to, when applied in soil, undergo hydrolysis and can

Figure 2 - Levels of N-$NH_4^+$and N-NO_3^- on soil according to the fertilizer applied at the no-tillage and conventional cropping systems, during the seasons of 2007/2008 and 2008/2009. Santa Maria, 2011. The bars on the chart indicate the confidence interval (upper and lower limit) at 95% of probability to express the difference between the sources, and they were significantly different when, at comparison, their intervals did not overlap



*Mathematical models regression significant at 5% for Test F be volatilized, forming N-NH_4^+, be absorbed by plants and ultimately be converted into N-NO_3^- (CARRASCO *et al*., 2004). Increasing the concentration of N-NO_3^- over the reduction of N-NH_4^+ occurred due to the fact of the N-NH_4^+ released on hydrolysis of fertilizer reaching the form of N-NO_3^- by nitrification process, depending on the availability of oxygen for this transformation to occur (HOLZSCHUH *et al*., 2009).

Although the sources used did not express differences in the levels of mineral N in soil at the NT system, the evaluation performed in rice plants showed significant differences between treatments (Figure 3) in 2007/08. The concentration of total N in the plant decreased in treatments with urea as it delayed the beginning of irrigation, while urea + NBPT had the highest concentration of total nitrogen, up to 12 days of delay, between the beginning of fertilization and irrigation. Unlike the NT system, in the CS, some significant differences were detected in relation to the levels of mineral nitrogen in soil, without, however, response in relation to the total N level of the rice plant, because the evaluation did not show significant differences, what is completely opposite to what was found in the NT system. Added to this, chlorophyll meter readings (Table 1) were carried out on the same day of the determination of total N content of plants (43DAE). In this evaluation, there were no significant differences between N sources and the intervals of water intake into the CS, as well as into the NT system.

In the second season, 2008/2009, the total N content, determined at panicle initiation (48 DAE) (Figure 3), in shoots of rice at NT system differed between the sources and intervals of water intake, in which urea was the best treatment in almost all time intervals. However, these differences were detected only in a first moment, because, at the flowering stage, the behavior of sources was opposite to the first evaluation. In the case of CS, there were no significant differences in both evaluations, as found in the previous harvest. However, chlorophyll meter readings (Table 1) in the NT system showed different results, indicating that the first evaluation performed at 48 DAE, urea +NBPT behaved similar to the common urea, but there

Table 1 - Chlorophyll meter readings (CR) at 43 and 77 DAE in the cropping of 2007/08 and at 48 and 93DAE in the cropping of 2008/2009 according to the source of nitrogen and the interval of time between the nitrogen fertilization at the tillering and the water intake into the no-tillage and conventional cropping systems. Santa Maria, 2011

Treatment	Chlorophyll meter readings (SPAD Index)				Chlorophyll meter readings (SPAD Index)			
	43 DAE	77 DAE	43 DAE	77 DAE	48 DAE	93 DAE	48 DAE	93 DAE
	No-tillage System		Conventional System		No-tillage System		Conventional System	
	Season 2007/2008				Season 2008/2009			
A1D1	35.3	34.6	35.8	33.8	38.5	34.5	39.6	32.9
A2D1	34.0	33.1	35.4	34.1	41.3	33.8	40.7	32.5
A1D2	32.6	33.2	38.9	34.2	40.3	34.2	39.7	33.0
A2D2	34.1	33.6	37.0	33.7	40.2	33.6	37.1	32.4
A1D3	32.5	33.1	37.1	33.6	40.7	32.7	37.4	31.1
A2D3	32.7	32.4	36.6	34.6	39.9	33.8	40.4	33.1
A1D4	32.5	32.1	37.3	33.1	40.2	33.5	40.3	33.3
A2D4	33.1	33.2	37.3	34.4	40.6	34.6	40.3	32.7
A1D5	31.5	32.5	35.4	34.3	39.8	32.2	39.6	32.5
A2D5	32.7	33.2	35.3	33.4	38.3	34.9	39.3	32.7
**A*D	0.06	0.078	0.98	0.74	0.68	0.00	0.00	0.45
A	0.55	0.066	0.67	0.99	*R^2 = 0.94	*R^2 = 0.93	*R^2 = 0.70	0.34
D	0.45	0.67	0.076	0.56	0.48	*R^2 = 0.96	*R^2 = 0.64	0.062
Mean	33.1	33.1	36.6	33.9	40	33.8	39.4	32.6
C.V. (%)	5.5	3.0	6.0	2.3	9.1	4.3	15.5	13.2

A1: Urea; A2: Urea + NBPT; D1: water intake at the moment of nitrogen sources application; D2: water intake 3 days after the nitrogen sources application; D3: water intake 6 days after the nitrogen sources application; D4: water intake 9 days after the nitrogen sources application; D5: water intake 12 days after the nitrogen sources application; [ns] Not significant in $P \leq 0.05$ level; * Quadratic equations adjusted to express the response of the treatments; ** Interaction among the factors studied and significance level of 5% to Test T

leaf. For this experiment, all the shoot area of the plant was used to determine the total nitrogen, including those already senescent, which should dilute the total N content, rather than the chlorophyll meter which estimates the level of N directly in the assessed leaf.

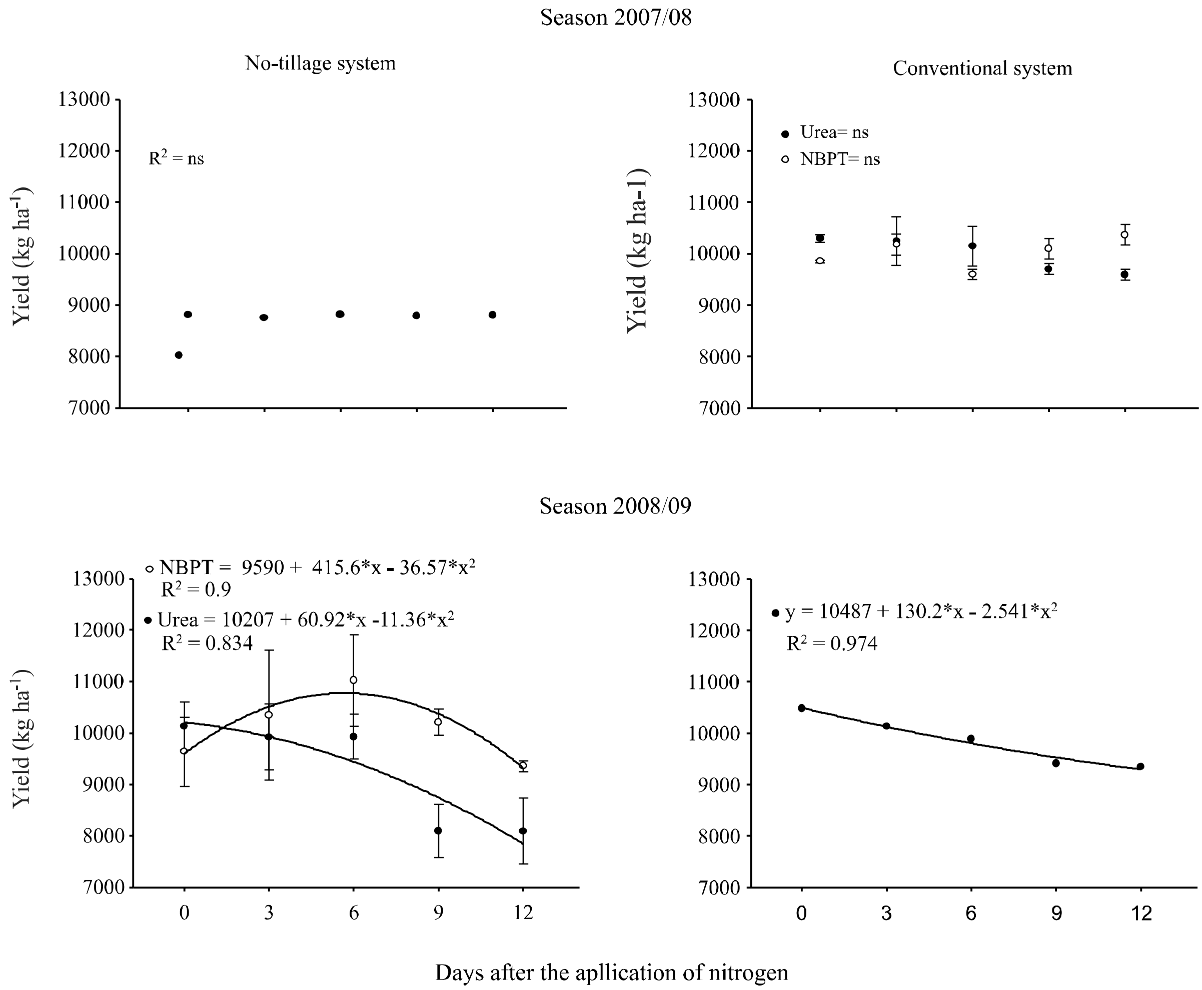
Response of irrigated rice to the sources of N

At the first cropping (2007/2008), the yield of the grains for the NT system did not show significant differences between the intervals of water intake and the sources of N used in the experiment (Figure 4). In the case of CS, there were some differences in the yield of grains between the intervals of water intake and the sources of N. When the water intake occurred right after the application of nitrogen fertilizer; the best behavior was presented by the common urea (4.5% higher). However, when the beginning of the irrigation was delayed for more than nine days, the urea + NBPT presented more grain yield.

At the second cropping (2008/2009), in the NT system, the sources and the interval of water intake had an influenced the grain yield. In this assessment, urea +NBPT presented an increase in relation to urea when the beginning of irrigation took place at the ninth day after the application of fertilizer. On the other hand, in the CS, there were no significant differences between the sources and, as water intake was delayed, there was a decrease of 12% in the yield from the first in relation to the last interval of water intake.

The response in relation to grain yield differed between the systems evaluated for two years. In the first year, there were no significant differences between intervals of water intake and sources of N. This can be attributed to minor

Figure 4 - Grain yield in the seasons of 2007/2008 and 2008/2009 according to the fertilizer applied in the no-tillage and conventional cropping systems, Santa Maria. 2011. The bars on the chart indicate the confidence interval (upper and lower limit) at 95% probability to express the difference between sources, and they were significantly different when, at comparison, their intervals did not overlap



*Mathematical models regression significant at 5% for Test F differences in N losses through volatilization between sources and the possibility of a greater immobilization of part of the available nitrogen due to the implementation of the NT system after the cultivation of ryegrass, with consequent lower initial availability of nutrients to plants (MULVANEY *et al*., 2010). However, in the CS, there were differences in yield between periods of water intake and sources of urea, where common urea showed the best behavior when water intake occurred soon after the application. This behavior can be explained by the fact that N is readily available, since urea has a high solubility in water (SILVA *et al*., 2008), whereas urea coated with urease inhibitor has its gradual release, especially in anaerobic environments (CUNHA *et al*., 2011) and the immediate use by the crop can be jeopardized. When the beginning of irrigation was delayed for more than nine days, the urea + NBPT showed higher productivity, demonstrating that this source is important for the handling of areas with difficulties in establishing the amount of water immediately after the application of N.

The result of productivity in the second year was different from the first, since in this season, the NT system productivity was directly influenced by the sources of urea. In this case, the differences in N losses through volatilization of N between sources were higher, but lower for urea with urease inhibitor. In CS there were no significant differences for any of the factors studied. This result can be explained by lower N losses between sources, with little influence of sources and delayed irrigation on grain yield. Thus, it is possible to consider that the response of irrigated rice to urea coated with urease inhibitor depends on the risks of loss through volatilization of NH_3, which are associated to the soil conditions, climate and management on site. Furthermore, on average, the coefficient of variation of the analyzes were approximately 15%, giving an average precision of the results obtained according to the classification of Pimental-Gomez (1990).

CONCLUSIONS

1. The use of urea coated with NBPT slows and reduces losses by ammonia volatilization compared with urea, but the magnitude of the effectiveness of adding NBPT into urea is associated with soil and climate conditions, influenced by the year of cropping and the rice cultivation system, which are not always expressed in productivity;
2. In no-till and conventional systems, the best performance of the urease inhibitor occurs as the establishment of the amount of water for irrigation is delayed after the fertilizer application. When the interval between the nitrogen application and the irrigation is within the recommended levels, there is no advantage in adding the product compared to isolated use of urea.

ACKNOWLEDGMENT

To the of Research Support of the State of Rio Grande do Sul - Fundação de Apoio à Pesquisa do Estado do Rio Grande do Sul (FAPERGS) - for the Research Productivity Program of Rio Grande do Sul to Mara Grohs, to the National Council of Scientific and Technological Development - Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) -for the financial aid and research productivity grants to Enio Marchesan and to Leandro Souza da Silva.

REFERENCES

ARAÚJO, E. da S. *et al*. Calibration of a semi-opened static chamber for the quantification of volatilized ammonia from soil. **Pesquisa Agropecuária Brasileira**, v. 44, n. 7, p. 769-776, 2009.

CANTARELLA, H. Nitrogênio. *In*: NOVAIS, R. F. **Fertilidade dos solos**. Viçosa, MG, 2007. p. 376-470.

CANTARELLA, H. *et al*. Ammonia volatilisation from urease inhibitor-treated urea applied to sugarcane trash blankets. **Scientia Agricola,** v. 65, n. 4, p. 397-401, 2008.

CARRASCO, D. *et al*. Measurement of coupled nitrification-denitrification in paddy fields affected by Terrazole, a nitrification inhibitor. **Biology Fertily of Soils,** v. 39, n. 3, p. 186-192, 2004.

CUNHA, P. C .R. *et al*. Fontes, formas de aplicação e doses de nitrogênio em feijoeiro irrigado sob plantio direto. **Pesquisa Agropecuária Tropical**, v. 41, n. 1, p. 80-86, 2011.

DA ROS, C. O. *et al*. Volatilização de amônia com aplicação de uréia na superfície do solo, no sistema plantio direto. **Ciência Rural**, v. 35, n. 2, p. 799-805, 2005.

DOMINGUEZ, M. J. *et al*. Desing, synthesis, and biological evaluation of phosphoramide derivatives as urease inhibitors. **Journal Agricultura Food Chemical**, v. 56, n. 10, p. 3721-3731, 2008.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. Centro Nacional de Pesquisa de Solos. **Sistema brasileiro de classificação dos solos**. Brasília: Embrapa-SPI, 1999. 412 p.

HOLZSCHUH, M. J. *et al*. Resposta do arroz irrigado ao suprimento de amônio e nitrato. **Revista Brasileira de Ciência do Solo**, v. 33, n. 5, p. 1323-1331, 2009.

LARA CABEZAS, W. A. R; SOUZA, M. A. Volatilização de amônia, lixiviação de nitrogênio e produtividade de milho em resposta à aplicação de misturas de uréia com sulfato de amônio ou com gesso agrícola. **Revista Brasileira de Ciência do Solo**, v. 32, n. 6, p. 2331-2342, 2008.

MARTHA JÚNIOR G. *et al*. Perda de amônia por volatilização em pastagem de capim-tanzânia adubada com uréia no verão. **Revista Brasileira de Zootecnia**, v. 33, n. 6, p. 2240-224, 2004.

MULVANEY, M. J. *et al*. Carbon and nitrogen mineralization and persistence of organic residues under conservation and conventional tillage. **Agronomy Journal**, v. 102, n. 5, p. 1425-1433, 2010.

PIMENTEL-GOMES, F. **Curso de estatística experimental**. 13. ed. Piracicaba: Nobel, 1990. 468 p.

SILVA, E. C. *et al*. Utilização do nitrogênio da palha de milho e de adubos verdes pela cultura do milho. **Revista Brasileira de Ciência do Solo**, v. 32, p. 2853-2861, 2008.

SANGOI, S. *et al*. Volatilização de NH_3 em decorrência da forma de aplicação de uréia, manejo de resíduos e tipo de solo, em laboratório. **Ciência Rural**, v. 33, n. 4, p.687-692, 2003.

SCIVITTARO, W. B. *et al*. Perdas de nitrogênio por volatilização de amônia e resposta do arroz irrigado à aplicação de ureia tratada com o inibidor de urease NBPT. **Ciência Rural**, v. 40, n. 6, p. 1283-1289, 2010.

SOCIEDADE SUL-BRASILEIRA DE ARROZ IRRIGADO. **Arroz Irrigado**: Recomendações Técnicas da Pesquisa para o Sul do Brasil. Santa Maria, RS: SOSBAI, 2007. 159 p.

TEDESCO, M. J. **Análise de solo, plantas e outros materiais**. Porto Alegre: UFRGS, 1995. 174 p.

TRIVELIN P. C. O; VITTI A. C. **Manejo do Nitrogênio e Enxofre na nutrição e adubação da cana-de-açúcar**. CENA/ USP, 2006. 47 p. Available at: <http: www.ppi-ppic.org/ ppiweb>. Accessed: 22 mar. 2007.

WATSON, C. J. **Urease activity and inhibition - principles and practice**. London: The International Fertilizers Society, 2000. 40 p.

XU, X. *et al*. Mineral nitrogen in a rhizosphere soil and in standing water during rice (*Oryza sativa* L.) growth: effect of hydroquinone and dicyandiamide. **Agriculture, Ecosystems and Environment**, v. 109, n. 1/2, p. 107-117, 2005.

Effects of Irrigated Rice Sowing Season and Imazapyr + Imazapic Time of Application on Rice Grain Yield and Red Rice Management[1]

Efeito da Época de semeadura de Arroz Irrigado e do Momento de Aplicação de Imazapyr+Imazapic no Rendimento de Grãos de Arroz e no Manejo do Arroz-Vermelho

SARTORI, G.M.S.[2], MARCHESAN, E.[3], AZEVEDO, C.F.[4], FILHO, A.C.[5], ROSO, R.[6], COELHO, L.L.[7], and OLIVEIRA, M.L.[8]

ABSTRACT - Irrigated rice sowing season and red rice competition are among the main factors affecting grain yield. The objective of this work was to evaluate the sowing date of irrigated rice and moments of application of the herbicide imazapyr + imazapic to control red rice management and irrigated rice grain yield. Eight experiments were performed at the following dates (09/30, 10/19, 11/08 and 12/01) for the 2010/2011 harvest season and (09/27, 10/17, 11/08 and 12/05) for the 2011/2012 harvest season. The treatments were: application of the herbicide imazapyr + imazapic at doses of 105+35 g ha^{-1} in pre-emergence (PRE); 52.5+17.5 g ha^{-1} in pre-emergence and 52.5+17.5 g ha^{-1} in post-emergence (PRE + POST); and 105+35 g ha^{-1} in post- emergence (POST), and a control without application and no weeding. The cultivar Puitá Inta CL was used and a randomized block design with four replicates. A joint analysis of the experiments was carried out. There was less emergence of red rice and higher grain yield of the irrigated rice at the early periods (09/30/10 and 09/27/11), with 10,578 and 8,653 kg ha^{-1}, respectively. At the end of the season (12/01/10 and 12/05/11), there was greater reduction of the red rice seed bank. Sowing at the beginning of the recommended period provided more irrigated rice grain yield. The application of imazapyr + imazapic at a dose of 52.5+17.5 g ha^{-1} in PRE + 52.5+17.5 g ha^{-1} POST, and 105+35 g ha^{-1} only in PRE and POST was effective in the control of red rice.

Keywords: weed, herbicide, chemical control, temperature, solar radiation, *Oryza sativa*.

RESUMO - A época de semeadura de arroz irrigado e a competição com arroz-vermelho estão entre os principais fatores que alteram o rendimento de grãos da cultura. O objetivo deste estudo foi avaliar épocas de semeadura do arroz irrigado e dos momentos de aplicação do herbicida imazapyr+imazapic no controle de arroz-vermelho e no rendimento de grãos de arroz irrigado. Realizaram-se oito experimentos nas seguintes épocas: (30/09, 19/10, 08/11 e 01/12) safra 2010/11 e (27/09, 17/10, 08/11 e 05/12) safra 2011/12. Os tratamentos avaliados foram: aplicação do herbicida imazapyr+imazapic nas doses de 105+35 g ha^{-1} em pré-emergência (PRE); 52,5+17,5 g ha^{-1} em pré-emergência e 52,5+17,5 g ha^{-1} em pós-emergência (PRE+POS); e 105+35 g ha^{-1} em pós-emergência (POS), além de uma testemunha sem aplicação e sem capina. O cultivar utilizado foi Puitá Inta CL, e o delineamento utilizado foi blocos ao acaso em quatro repetições. Realizou-se análise conjunta dos experimentos em cada safra. Ocorreu menor emergência de arroz-vermelho e maior rendimento de grãos de arroz irrigado no início da época (30/09/10 e 27/09/11), com 10.578 e 8.653 kg ha^{-1}, respectivamente. No final da época (01/12/10 e 05/12/11), houve maior redução do banco de sementes

---

[1] Recebido para publicação em 15.8.2012 e aprovado em 24.12.2012.

[2] Agricultural Engineer, Master's student in Crop Sciences, Department of Plant Science, Center of Agricultural Sciences (CCR - Centro de Ciências Rurais), Universidade Federal de Santa Maria – UFSM, <gersonmss@yahoo.com.br>; [3] Dr. Professor, Department of Plant Science, CCR, UFSM, <eniomarchesan@gmail.com>; [4] Undergraduate in Agronomy, Department of Plant Science, CCR, UFSM, <cristian.az@hotmail.com>; [5] Dr. Professor, Department of Plant Science, CCR, UFSM, <alberto.cargnelutti.filho@gmail.com>; [6] Undergraduate in Agronomy, Department of Plant Science, CCR,UFSM, <rodrigoroso@yahoo.com.br>; [7] Undergraduate in Agronomy, Department of Plant Science, CCR, UFSM,< lucas_l_c@hotmail.com>; [8] Undergraduate in Agronomy, Department of Plant Science, CCR,UFSM, <mauriciodeoliveira8@hotmail.com>.

SBCPD

do arroz-vermelho. A semeadura no início da época recomendada proporciona maior rendimento de grãos de arroz irrigado. A aplicação de imazapyr+imazapic nas doses de 52,5+17,5 g ha^{-1} em PRE + 52,5+17,5 g ha^{-1} POS e de 105+35 g ha^{-1} somente em PRE e POS foi eficiente no controle do arroz-vermelho.

Palavras-chave: planta daninha, herbicida, controle químico, temperatura, radiação solar, *Oryza sativa*.

INTRODUCTION

Rice sowing season plays a significant role in crop yield potential, since it affects the response of other management practices. According to Freitas et al. (2008), the intersection of rice flowering and grain filling time with the period of highest solar radiation availability is what determines when rice sowing season will occur, once optimal conditions of temperature and solar radiation are key to raising grain yield potential. According to Junior et al. (1995), the optimal values of air temperature and radiation around flowering are 25 °C and 475 cal cm^{-2} day^{-1}, respectively.

However, low temperatures at microsporogenesis or high temperatures at anthesis can cause spikelet sterility, affecting crop yield (Farrell et al., 2006). According to Jagadish et al. (2007), temperatures above 35 °C at anthesis for more than one hour may reduce the fertility of spikelets on rice. Rang et al. (2011) have reported that rice response to elevated temperature differs according to its stage of development, with greater sensitivity in the reproductive phase.

According to Slaton et al. (2003) and Freitas et al. (2008), the highest grain yields of irrigated rice are found when sowing is carried out early in the recommended season and they tend to decrease when sowing is performed at the end of the season. Sowing time delay causes reduction in the number of panicles per square meter (Freitas et al., 2008). Moreover, when sowing time is anticipated, emergence and early establishment may be negatively impacted, mainly due to suboptimal air temperatures during this period (Slaton et al., 2003).

Besides influencing the yield potential of rice, sowing time, if considered independently, may contribute to a more efficient control of red rice, one of the most relevant weeds found in irrigated rice areas. According to Marchesan et al. (2010) and Marchesan et al. (2011), red rice affects grain yield, the quality of the final product, and the price paid for the product (Gealy et al. 2000).

There are options for the chemical control of red rice, which include the use of cultivars that are tolerant to herbicides from the imidazolinone group. However, due to the diversity of biotypes, red rice and cultivated rice crossing, seed dormancy (Burgos et al., 2008), differences in emergence onset, and speed and duration of emergence (Shivrain et al., 2009), it is difficult to control red rice.

Accordingly, sowing time may be a significant crop practice for the control of red rice, since early in the recommended season (September/October), air and soil temperatures are lower compared to late in the recommended season (November/December). Lower temperature conditions maintain red rice seed dormancy, reducing germination and plant emergence (Gianinetti & Cohn, 2008; Young-Son Cho, 2010).

Shivrain et al. (2009) have reported that, in sowing conducted early in the recommended season, red rice competition is reduced when compared to sowing conducted late in the recommended season. According to Norsworthy & Oliveira (2007), at the end of the recommended season, red rice emergence rate is increased due to higher temperatures, which provide rapid seedling emergence and establishment. Thus, there is a need to know the impact of sowing time, when associated with weather conditions such as temperature and solar radiation, on the dynamics of red rice and rice grain yield, in order to have a more efficient control of red rice. There is also a need to know the best time to apply these herbicides (imazapyr and imazapic) taking into account the time of sowing, because some works on this subject, for instance those of Santos et al. (2007) and Marchesan et al. (2011), have assessed herbicide application time in a single sowing period. However, it is important to assess the behavior of such application times at different sowing periods.

The hypothesis of this work is that in sowing carried out early in the recommended season, there is lower emergency of red rice and greater rice grain yield; and in sowing carried out late in the recommended season, there is great seed bank reduction. Thus, this study aimed to assess irrigated rice sowing periods and imazapic + imazapyr moments of application on the control of red rice and on irrigated rice grain yield.

MATERIAL AND METHODS

Eight experiments were conducted on growing seasons 2010/11 and 2011/12. The area was located in the physiographic region of the Central Region of the State of Rio Grande do Sul (RS), in the city of Santa Maria, where climate is characterized, according to the Köppen classification, as humid subtropical (Cfa), with no dry season, with mean temperature of the warmest month above 22 ºC (Moreno, 1961).

The experiments were performed on soil classified as Eutrophic Haplic Planossolo Hapludalf belonging to the mapping unit of Vacacaí (Embrapa, 2006), which exhibited the following physicochemical characteristics: clay = 18%, pH_{water} (1:1) = 5.8, P = 7.6 mg dm^{-3}, K = 40 mg dm^{-3}, Ca = 6.1 $cmol_c$ dm^{-3}, Mg = 1.8 $cmol_c$ dm^{-3}, and MO = 2.1%.

The experiments consisted of the following sowing dates for Puitá Inta-CL rice: (09/30, 10/19, 11/08 and 12/01) for the 2010/11 harvest, and (09/27, 10/17, 11/08 and 12/05) for the 2011/12 harvest. The sowing period, according to the agricultural zoning Puitá Inta-CL in Santa Maria, goes from September 1 to November 20. However, the choice of sowing dates in this study aimed to represent the sowing period for the state of RS, which is from early September to mid-December, varying according to the cycle of each cultivar and to the cultivation region. The treatments examined were: Kifix ® (imazapic + imazapyr) application at doses 105+35 g ha^{-1} in pre-emergence (PRE), 52.5 +17.5 g ha^{-1} in pre-emergence, and 52.5 +17.5 g ha^{-1} in post-emergence (PRE + POS) and 105 + 35 g ha^{-1} in post-emergence (POS), in addition to control with no herbicide and weed free. The experimental design was randomized blocks with four replications. The PRE application was held in stage S_3 (emergence of prophyll from coleoptile) of rice, and the POS application was conducted one day before final irrigation in stage V_3/V_4, according to the scale of Counce et al. (2000). Also in stage S3 of irrigated rice, we applied glyphosate at 1.08 kg ha^{-1} in all treatments, with the purpose of controlling all the red rice plants that had emerged in the period between sowing and grain formation.

We used irrigated rice cultivar Puitá Inta-CL, which has a mean cycle of 125 days, with 90 kg ha^{-1} seed, sown in row spacing of 0.17 m, in minimum tillage system in the 2010/11 harvest and in direct sowing in the 2011/12 harvest. Base fertilizer was 15 kg ha^{-1} nitrogen (N), 45 kg ha^{-1} P_2O_5 and 90 kg ha^{-1} K_2O, and the N dose was divided in quantities of 15 kg ha^{-1} at sowing, 70 kg ha^{-1} at tillering (V_3/V_4) and 35 kg ha^{-1} at panicle iniciation (R0).

The following evaluations were performed: red rice seed bank, determined before sowing to sowing times, by counting the number of red rice seeds in two subsamples of 0.2 x 0.2 m in each portion at a depth of 7 cm; number of red rice plants emerged in the range from PRE application to POS application, determined by counting emerged plants in two subsamples of 0.2 x 0.2 m in each plot, later transformed into percentage in relation to seed bank; total number of desiccated plants up to the moment of each sowing date, determined by counting the number of red rice plants in 0.5 x 0.5 m per plot of 5 m x 1.53 m.

Desiccations were conducted with glyphosate at 1.08 kg ha^{-1}, when red rice plants were in stage V_3/V_4. Seed bank reduction was determined by summing emerged plants from PRE to POS application with the total number of plants desiccated up to the moment of each sowing date, and transformed in percentage in relation to the seed bank.

Furthermore, was assessed the control of red rice by counting the number of red rice panicles in each plot, and transforming in percentage in relation to control.

Grain yield was estimated by manual harvesting of 4.16 m^2 on crop area, when they reached mean moisture of 22%. After sorting, cleaning and weighing of grain with shell, data were corrected to 13% moisture and converted to kg ha^{-1}. The number of panicles m^{-2} was determined by counting the panicles in a row meter, and in that same area we collected 15 panicles at harvest to estimate the number of grains per panicle, thousand grain weight and spikelet sterility.

The values of global solar radiation and air temperature were obtained from the meteorological station of the University of Santa Maria, available at the National Institute of Meteorology (INMET). Soil temperature was obtained using temperature sensor (model L34-108-EN) at a depth of 3 cm and recorded in data logger CR1000.

Results were submitted to analysis of variance, comparing in each crop the sowing dates of irrigated rice. Means were compared by Tukey test at 5% probability.

Data that referred to red rice seed bank reduction, red rice desiccated plants m^{-2}, and red rice emergence were transformed to $yt = \sqrt{(y)+0.5}$.

RESULTS AND DISCUSSION

2010/11 Harvest

There was interaction between sowing dates and times of herbicide application for all variables except for thousand grain weight and spikelet sterility (Table 1). The area where the experiment was conducted showed variation in red rice seed bank from 237 to 2533 seeds m^{-2}, the largest seed bank noted in the area of the first and third sowing times: 09/30 and 11/08, respectively (Table 2).

At the beginning of the recommended sowing period (09/30 and 10/19) there was lower emergence of red rice when compared to late sowing period (11/08 and 12/01) (Table 2), indicating that sowing time plays a key role in the management of red rice, by having lower emergency of red rice early in the sowing period, thus, there is less competition and damage to irrigated rice.

This response may be related to the seed dormancy of red rice, due to the physiological immaturity of the embryo, once it is detached from the mother plant, and it may also present impermeability to gas cover and/or imbalance of substances that promote and inhibit germination induced during the accumulation of dry seed weight (Filio, 2005), associated with lower air temperature (average temperature around 16 °C) and soil (average temperature around 18 °C) during the beginning of the recommended period (Figure 1A), which may have contributed to inhibit germination and emergence of large population of red rice in this area.

Young-Son Cho (2010) evaluated the effect of different temperatures in the day and night, represented by 15/10, 20/15, 25/20 and 30/25 °C, and found on average a lower percentage of red rice germination in lower temperatures, with 25/20 °C as one in which there was best germination. According to this author, the percentage and speed of germination increase with increasing temperature. Gianinetti & Cohn (2008), have observed greater red rice mean germination at 20 to 35 °C, compared to 1 to 15 °C, and optimum temperature for rice development from 25 °C to 30 °C (Yoshida, 1981). According to Marcos Filho (2005), rice seeds overcome dormancy when exposed to high temperatures, and response speed is directly related to the increase in temperature.

Temperatures lower than this range (25 to 30 °C) can cause cold stress, which is considered one of the most important abiotic stresses in rice, causing changes in germination, percentage of normal seedlings, coleoptile length, among other factors, mainly affecting the expression of isozymes, such as esterase and dehydrogenase enzyme, involved in seed germination (Mertz et al., 2009).

In sowings conducted at the end of the recommended period, the emergence rate of red rice was increased due to higher temperatures, which provide rapid seedling emergence (Norsworthy & Oliveira, 2007). This emergence speed is very similar to rice, implying rapid establishment of biotopes

Table 1 - Source of variation (SV), number of degrees of freedom (DF) and mean square estimates of the red rice seed bank (RRSB), red rice emergence (RRE), red rice desiccated plants (RRDP), red rice seed bank reduction (RRBR), control of red rice (CRR), grain yield (GY), number of panicles (NP), number of grains per panicle (NGP), thousand grain weight (TGW) and spikelet sterility (S) in the 2010/11 and 2011/12 harvests. Santa Maria, RS. 2012

SV	DF	2010/11 harvest				
		QM				
		RRSB	RRE	RRDP	RRBR	CRR
B(A)	12	141240.67*	0.67	19.11*	1.27	1.19
A	3	11277164.81*	90.68*	705.95*	92.16*	64.45*
D	3	614714.40*	1.64*	17.03*	2.52*	72.95*
A*D	9	415739.59*	2.71*	23.24*	3.81*	66.08*
error	36	59242.46	0.38	4.29	0.85	1.27
CV%		22.5	17.8	14.2	16.7	1.1
		GY	NP	NGP	TGW	S
B(A)	12	395115.84	12980.50*	20.82	0.73	2.66
A	3	24700262.50*	214106.87*	192.99*	7.49*	25.30*
D	3	11866878.34*	11438.39*	98.82*	3.02*	11.76*
A*D	9	2657118.27*	22793.99*	125.66*	1.30ns	5.29ns
error	36	324184.36	3488.36	28.61	0.94	2.68
CV%		6.3	11.89	6.2	3.8	29.4
		2011/12 harvest				
		RRSB	RRE	RRDP	RRBR	CRR
B(A)	12	56.48	2.38	1.12	1.96	1.66
A	3	1792.70*	28.02*	244.21*	129.87*	1.45ns
D	3	405.20*	3.44ns	23.51*	1.62ns	1.88ns
A*D	9	73.07*	3.85*	6.48*	2.48ns	1.58ns
error	36	33.79	1.58	3.21	1.96	1.65
CV%		28.1	30.4	26.4	33.2	1.2
		GY	NP	NGP	TGW	S
B(A)	12	315332.68	4011.78	67.96	1.11	2.66
A	3	4913070.01*	40796.55*	2677.80*	13.45*	36.61*
D	3	6829406.68*	11385.75*	109.12ns	2.64*	2.78ns
A*D	9	2095265.29*	6284.66*	105.79ns	1.07ns	1.95ns
error	36	240082.29	2630.85	77.23	0.82	2.82
CV%		5.9	10.2	13.9	3.8	22.4

* Significant at 5% probability. ns Non-significant. B = block; A = sowing seasons; D = times of application.

(Shivrain et al., 2009), which increases the potential for competition and damage to irrigated rice.

The greatest emergence of red rice at the end of the recommended period (11/08 and 12/01) provided high reduction of seed bank (Table 2): 54 to 91.6% in the last sowing date. This reduction of seed bank was due to longer time to perform desiccations of red rice seedlings that emerged in the area, with a higher number of seedlings desiccated: 553 and 289 seedlings m^{-2} at end of period (11/8 and 12/01), respectively, compared with 109 and 71 seedlings m^{-2} in the early period 09/30 and 10/19 respectively (Table 2).

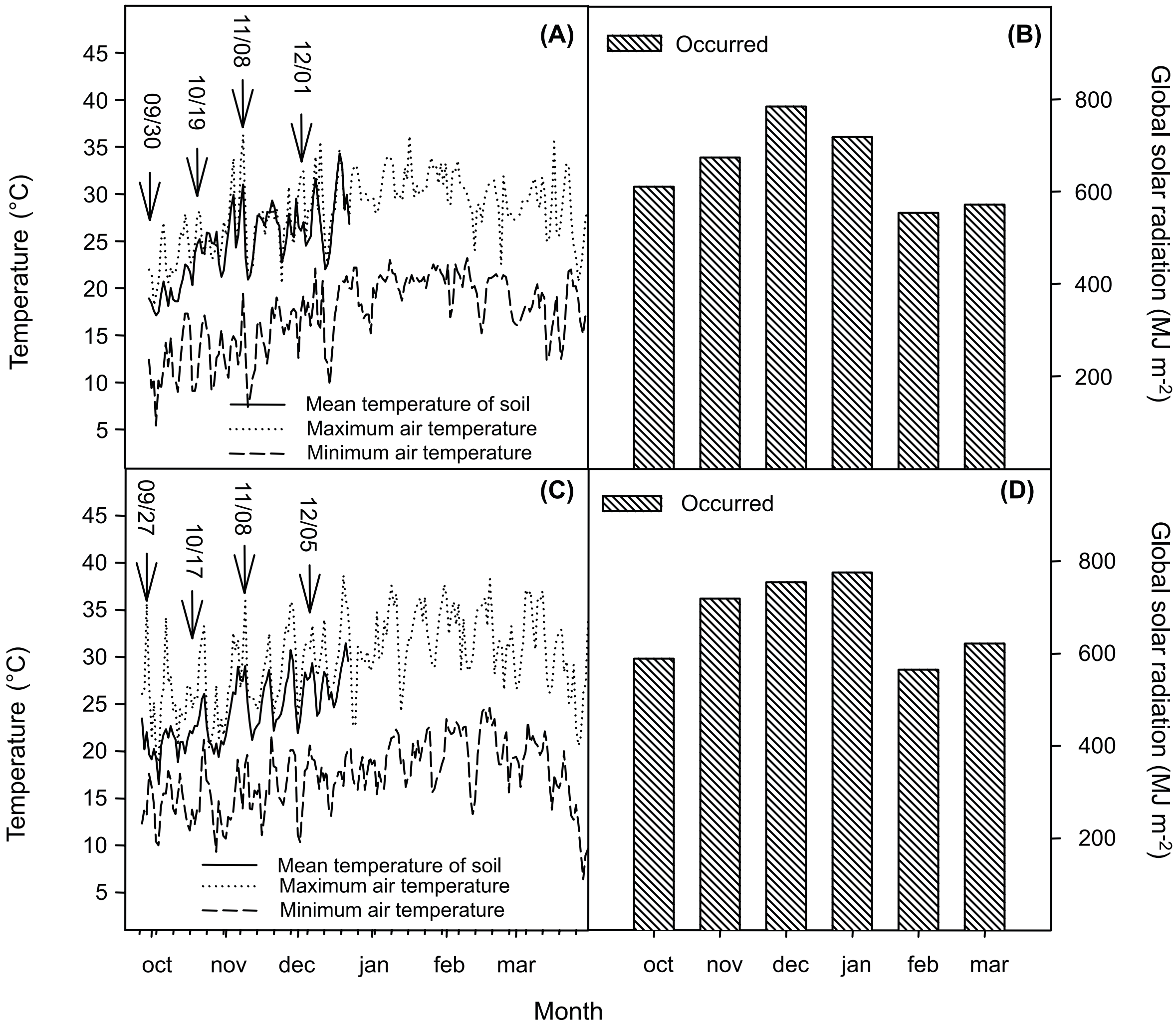
Such sowing practice at the end of the recommended period may be an important alternative to guide decision-making when you want to use the strategy to reduce seed bank in areas infested with red rice.

Table 2 - Red rice seed bank (RRSB), red rice emergence (RRE), number of red rice desiccated plants (RRDP), red rice seed bank reduction (RRBR), and control of red rice (CRR) as a function of sowing time and time of Kifix ® (imazapic + imazapyr) application in cultivar Puitá Inta-CL. 2010/11 harvest. Santa Maria, RS. 2012

Times of sowing	Times of application			
	Control group with no application	PRE#	PRE + POS	POS
Red rice seed bank (RRSB) (seeds m^{-2})				
09/30/2010	2533 Aa	2179ABa	1653 Cb	1842 BCa
10/19/2010	237 NSd	342 c	247 c	269 c
11/8/2010	1704 Ab	1159 Bb	2137 Aa	1017 Bb
12/1/2010	779 Ac	422 ABc	525 ABc	262 Bc
Mean	1313	1025	1140	847
CV%	22.5			
Red rice emergence (RRE) (%)1/				
9/30/2010	1.1(0.8)* NSc	1.1(0.8) c	2.0(3.6) c	1.6(2.2) c
10/19/2010	1.5(2.6) Bbc	1.8(3.2) Bc	3.1(10.3) Abc	2.1(5.1) ABc
11/8/2010	7.9(63.8) Aa	6.5(41.6) BCa	5.6(30.6) Ca	7.3(53.9) ABa
12/1/2010	2.5(5.9) Bb	3.3(11.1) ABb	3.4(11.8) ABb	4.5(19.8) Ab
Mean	18.2	14.1	14.0	20.2
CV%	17.8			
Red rice desiccated plants (RRDP) (plantas m^{-2})2/				
9/30/2010	8.9(83) NSb	9.8(97) b	10.9(121) c	11.4(133) c
10/19/2010	8.3(72) NSb	7.6(57) b	10.4(108) c	6.9(48) d
11/8/2010	19.7(399) Ba	19.4(393) Ba	27.0(765) Aa	25.5(654) Aa
12/1/2010	18.7(355) NSa	17.7(315) a	15.3(244) b	15.4(241) b
Mean	227	215	309	269
CV%	14.2			
Red rice seed bank reduction (RRBR) (%)3/				
9/30/2010	2.2(4.4) NSc	2.3(4.9) c	2.8(7.3) b	2.6(6.4) c
10/19/2010	5.7(33.8) ABb	4.8(23.6) Bb	6.7(44.9) Aa	4.3(19.1) Bc
11/8/2010	4.6(22.2) Bb	5.7(33.0) ABb	5.9(35.3) ABa	7.3(54.7) Ab
12/1/2010	7.6(59.0) Ba	8.7(77.3) ABa	7.4(54.0) Ba	9.6(91.6) Aa
Mean	30	35	35	43
CV%	16.7			
Control of red rice (CRR) (%)				
9/30/2010	-	99 NSa	100 ns	100 ns
10/19/2010	-	100 NSa	100	100
11/8/2010	-	86 Bb	100 A	100 A
12/1/2010	-	100 NSa	100	100
Mean		96	100	100
CV%	1.1			

Variables with values †in parentheses indicate original values †, averages not followed by the same letter, lowercase in column and uppercase in row, differ by Tukey test at 5% probability; NS not significant in row; ns not significant in column ; [1]percentage of red rice emergence in relation to seed bank in PRE to POS application; [2]number of red rice desiccated plants from 09/23/2010 to the sowing date of each season, [3] seed bank reduction in relation to red rice seed bank. * Doses of imazapic + imazapyr were: 105+35 g ha^{-1} (PRE), 52.5+17.5 g ha^{-1} and 52.5+17.5 g ha^{-1} (PRE+POS) and 105+35 g ha^{-1} (POS).

With respect to the chemical control of red rice (Table 2), the POS application and the PRE + POS application were efficient, resulting in 100% control. The PRE application alone showed lower efficiency in 11/08, with 86% control, which can be explained by the greater



[1/] Times of sowing.

Figure 1 - Mean temperature at 3 cm soil depth, maximum and minimum air temperature (Figure 1A, 2010/11 harvest) and (Figure 1B, 2011/12 harvest) and global solar radiation occurred in the 2010 / 11 harvest (Figure 1C) and in the 2011/12 harvest (Figure 1D). Santa Maria, RS. 2012.

seed bank (more seeds for the same amount of herbicide) in comparison to the areas that were performed in 10/19 and 12/01, in which seed bank was smaller. Moreover, at 11/08, the conditions of air temperature and soil were greater (Figure 1A), which improved germination and emergence of red rice. This control efficiency of treatment in POS and PRE + POS is related to the fact that in the area where the experiment was conducted there are no biotypes resistant to the imidazolinone chemical group, plus it has perfect leveling of surface area and the proper management of irrigation. Furthermore, high efficiency in the control provided by the PRE + POS application or POS only, is due to the fact that the POS applications were performed on a day before the final irrigation. Thus, with the establishment of water depth, an anaerobic environment was formed, reducing one of the main mechanisms of dissipation of these herbicides from the imidazolinone group, which is the microbial degradation (Flint & Witt, 1997; Madani et al. 2003; Alister & Kogan 2005).

Machesan et al. (2010) have also reported that the POS application may decrease the biodegradation of herbicides due to anaerobic condition, which occurs with the establishment of irrigation after herbicide application. Another very important factor that may have contributed to greater efficiency in the control treatments that were applied in POS is auto-liming (soil chemical changes resulting from the reduction process), which occurs 15 to 20 days after the formation of water depth, raising the pH of acidic soils favoring dissociation of herbicides, making herbicides molecules available for plant uptake (Avila et al. 2006), since, with the presence of the carboxylic acid and the basic functional group of pyridine, imazapyr has three pKa values (1.9, 3.6 and 11.4), which is one of the characteristics that make the behavior of this herbicide in soil pH dependent (Firmino et al., 2008). Also, a study with imazaquin conducted by Oliveira et al. (2004) showed that with increasing pH reduction occurs Kd values (soil water partition coefficient) in all levels (2-6%) of organic matter studied, with it, the adsorption is reduced due to the dominance of their shape anionic, becoming more available in the soil solution.

However, the herbicides of the chemical group of imidazolinones, when applied in PRE, may have a reduced efficiency because they can be degraded by microorganisms in greater quantities compared to POS application, whereas the application to the soil remains PRE for a longer period of time in aerobic condition, which is favorable to biodegradation. Thus, there can be reduction in the concentration of herbicide in the soil and therefore it can provide lower efficiency of control. One of the factors considered most important - responsible for the lower efficiency of herbicides when applied in PRE - that is, in conditions of lower pH of the soil, there may be adsorption of these herbicides to soil colloids (Bresnaham et al., 2000; Madani et al. 2003; Alister & Kogan, 2005; Kraemer et al. 2009), which decreases the efficiency of control.

Corroborating the study, Marchesan et al. (2011), when assessing the control of red rice using chemical herbicides of the imidazolinone group imazethapyr (75 g L^{-1}) + imazapic (25 g L^{-1}) (ready mix) at the recommended dose in Brazil, found no differences between application in PRE + POS and POS application only. Villa et al. (2006) have also evaluated the control of red rice in two rice varieties using imidazolinone herbicides at a dose of 75 g L^{-1} imazethapyr + 25 g L^{-1} of imazapic, and found that the split application of herbicide (PRE + POS) using 75% of the dose in PRE followed by 50% for POS, was the one which provided better control without causing loss of yield.

Santos et al. (2007) evaluated the efficiency of control of red rice provided by the use of formulated mixture (75 g L^{-1} imazethapyr + 25 g L^{-1} of imazapic) and observed that the application of 52.5 g ha^{-1} imazethapyr + 17.5 g ha^{-1} in PRE imazapic followed by the same dose in POS, is more efficient when compared to the application of 75 g ha^{-1} imazethapyr + 25 g ha^{-1} PRE imazapic only, or only in POS.

Sowing dates have also affected the yield of irrigated rice (Table 3), with higher grain yield in the first season (09/30), ranging from 9,752 kg ha^{-1}, with no chemical control of red rice, to 11,258 kg ha^{-1}, when control was performed, and this was (09/30) the best sowing time, to obtain higher yield. The highest grain yield occurred in this sowing season may be related to the coincidence that this was the period of more responsive plant behavior (flowering and grain filling) and the period of highest solar radiation availability in the months of December and January (Figure 1C), which was reflected in a higher number of panicles, higher thousand grain weight and lower spikelet sterility in relation to sowing dates at end of recommended period (Table 3). In sowing at the end of the recommended period (12/01), the yield was 22% lower compared to the sowing of 09/30, equivalent to a reduction of 38 kg ha^{-1} day^{-1} in the mean of treatments PRE, PRE + POS and POS.

These results support the work conducted in the state of Rio Grande do Sul by Freitas et al. (2008) in which they gained greater number of panicles and higher grain yield when rice was sown at the preferred date (11/02) compared to late recommended period (12/09). Besides the sowing date, another factor that affected grain yield was the presence of red rice. Comparing the first sowing date (09/30) with the other, there is a reduction of 11, 52 and 22% yield when chemical control was not performed (Table 3) to the second (10/19), third (11/08) and fourth times (12/01), respectively. This occurred because of greater emergence of red rice in the first sowing date.

The largest reduction in grain yield of the third season of sowing is related to the increased presence of red rice in the area, compared to the second and fourth seasons. These results show the great potential

Table 3 - Grain yield (GY) (kg ha^{-1}), number of panicles (NP), number of grains per panicle (NGP), thousand grain weight (TGW) and spikelet sterility (S) as a function of sowing date and time of Kifix ® (imazapic + imazapyr) applicationfor Puitá Inta-CL. 2010/11 harvest. Santa Maria, RS. 2012

Times of sowing	Times of application			
	Control group with no application	PRE$^{\#}$	PRE + POS	POS
Grain yield (GY) (kg ha^{-1})				
9/30/2010	9752 Ba	10650 ABa	11258 Aa	10654 ABa
10/19/2010	8658 ^{NS}b	8973 b	9469 b	9602 ab
11/8/2010	4689 Bc	8718 Ab	8723 Ab	8786 Abc
12/1/2010	7621 Bb	8219ABb	8881 Ab	8435 ABc
Mean	7680	9140	9583	9369
CV%	6.3			
Number of panicles (NP) (m^{-2})				
9/30/2010	643 ^{NS}a	571 a	671 a	650 a
10/19/2010	528 ABb	569 Aa	448 Bb	482 ABb
11/8/2010	466 Ab	229 Bb	279 Bc	428 Ab
12/1/2010	487 ^{NS}b	565 a	479 b	454 b
Mean	531	483.5	287.9	503
CV%	11.89			
	Number of grains per panicle (NGP)			
9/30/2010	73 Bc	86 Aa	82 AB^{ns}	87 A^{ns}
10/19/2010	94 ^{NS}a	86 a	89	86
11/8/2010	81 ABbc	74 Bb	90 A	89 A
12/1/2010	85 ^{NS}ab	88 a	86	90
Mean	83	83	86	88
CV%	6.2			

Times of sowing	TGW (g)	S %
9/30/2010	26 a	4.1 c
10/19/2010	26 a	4.9 bc
11/8/2010	24 b	6.9 a
12/1/2010	25 b	6.4 ab
Times of application		
Control group with no application	25 ab	5.5 ab
PRE	26 a	4.9 b
PRE + POS	25 ab	5.0 b
POS	24 b	6.8 a
Mean	25	5.5
CV%	3.8	9.4

Averages not followed by the same letter, lowercase in column and uppercase in row, differ by Tukey test at 5% probability; ^{NS} not significant in row; ^{ns} not significant in column * Doses of imazapic + imazapyr were: 105+35 g ha^{-1} (PRE),,52.5+17.5 g ha^{-1} and 52.5+17.5 g ha^{-1} (PRE+POS), and 105+35 g ha^{-1} (POS).

of damage to red rice with cultivated rice, according to Fischer & Ramirez (1993), 24 panicles m^{-2} red rice can cause losses of 50% in grain yield.

Generally, for this harvest, sowing time affected the yield of crop, with higher grain yield when seeding is performed early in the recommended date (09/30), due to better conditions of temperature and solar radiation in the reproductive period of the culture. However, from the second (10/19) until the fourth season (1/12) there was no significant reduction in grain yield, as the average values of minimum air temperature were 25, 23 and 21 °C for the months of January, February and March (reproductive period of culture), respectively, the average maximum for the same months were 26, 24 and 23 °C (Figure 1A), respectively, without compromising spikelet fertility and hence grain yield. Even though the lowest accumulation of solar radiation, during the reproductive period of crop in such sowing dates, may explain the lower yields when compared to the first season (09/30).

2011/12 Harvest

In this season, there was interaction between sowing dates and times of herbicide application with seed bank, emergence of red rice, number of red rice desiccated seedlings, grain yield and number of panicles m^{-2} (Table 1). There was decrease in seed bank of red rice (Table 4) in the area compared to the 2010/11 harvest, with variation from 62 to 1,791 seeds m^{-2}, and the largest seed bank were in the area of the first and third seasons.

In general, except for control with no herbicide application, the results of red rice emergence (Table 4) follow similar behavior to the 2010/11 harvest, with increased emergence of red rice with the delay of sowing time with mean emergence from 4 to 18% at the beginning of the recommended period (09/27 and 10/17), respectively, and 35 and 26% at the end of the emergency period (8/11 and 5/12), respectively. The lowest emergence of red rice early in the recommended period, compared to times at the end of the period can be related to lower temperatures at the beginning of the period (Figure 1B) and the air temperature around 15 °C to average minimum 25 °C and the average maximum around 20 °C, the seed of red rice have been induced to secondary dormancy because in work performed by Gianinetti & Cohn (2008), when evaluating the germination of red rice under different temperature conditions at 15 °C, the population of red rice seed dormancy was induced in secondary. According to these authors, the percentage of seeds that are induced in secondary dormancy decreases with increasing temperature (15-25 °C), in the optimum germination temperature (30 °C) biotypes had minimal dormancy, explaining in part the results. The highest emergence of red rice at late period may be related to higher temperatures occurring during this period (Figure 1B), because with increasing temperature, germination processes occur faster than inducing dormancy (Gianinetti & Cohn, 2008).

As for the control without herbicide, this season there was no difference in emergence of red rice between sowing dates, emergency occurring high even in the beginning of the sowing period recommended (09/27). This may be related to the fact that in the 2010/11 season was not held control of red rice plants in this treatment (control without herbicide and weed free), promoting feedback seedbank red rice. Moreover, this harvest, the seeds of red rice resulting from the 2010/11 season were on the road surface, because, unlike the 2010/11 season, in which the system used was the minimum tillage with tillage after harvest this crop system was used direct seeding, so there is no incorporation of the seeds in the soil profile.

Thus, red rice seeds remained on the soil surface, becoming more exposed to weather conditions such as temperature, moisture, oxygen, and other factors that may have contributed to overcoming dormancy and consequently led to the germination of seeds. Fogliatto et al. (2011), when evaluating the germination of a population of red rice stored under different conditions in the field, observed that the seeds on the soil surface showed rapid release of dormancy and germination. In the United States, Noldin et al. (2006) found a higher percentage of seed dormancy of red rice seeds buried at 12 cm depth, compared to seeds exposed to soil surface.

Table 4 - Red rice seed bank (RRSB), red rice emergence (RRE), number of red rice desiccated plants (RRDP), red rice seed bank reduction (RRBR), and control of red rice (CRR) as a function of sowing time and time of Kifix ® (imazapic + imazapyr) application in cultivar Puitá Inta-CL. 2011/12 harvest. Santa Maria, RS. 2012

Times of sowing	Times of application			
	Control group with no application	PRE[#]	PRE + POS	POS
Red rice seed bank (RRSB) (seeds m^{-2})				
9/27/2011	1787 Aa	906 Ba	956 ABa	853 Ba
10/17/2011	275 ^{NS}b	269 bc	112 bc	200 b
11/8/2011	1791 Aa	687 Bab	384 Bb	462 Bab
12/5/2011	159 ^{NS}b	100 c	62 c	97 b
Mean	1003	490	378	403
CV%	28.1			
Red rice emergence (RRE) (%)[1/]				
9/27/2011	3.9(16.7)^{*NSns}	1.8(3.5) b	2.5(4.8) b	1.8(3.2) b
10/17/2011	3.1(10.7) ^{NS}	2.6(6.6) b	4.8(23.5) a	4.7(25.1) a
11/8/2011	5.0(24.6) ^{NS}	6.2(39.5) a	5.7(34.6) a	5.4(31.0) a
12/5/2011	3.9(16.0) AB	3.6(16.6) Bb	6.0(36.5) Aa	4.9(25.4) ABa
Mean	17.0	16.5	24.8	21
CV%	30.4			
Red rice desiccated plants (RRDP) (plantas m^{-2})[2/]				
9/27/2011	4.8(24) ^{NS}b	3.6(10) c	3.3(12) b	3.9(15) b
10/17/2011	3.9(15) ^{NS}b	3.0(10) c	3.7(13) b	2.0(3) b
11/8/2011	14.2(214) Aa	12.0(152) Aa	8.1(67) Ba	11.0(124) ABa
12/5/2011	11.3(129) Aa	7.2(51) Bb	8.4(71) ABa	7.7(60) Ba
Mean	95	55	40	50
CV%	26.4			

Times of sowing	RRBR (%)[3/]	CRR (%)
9/27/2011	1.3(1.5) d	99.8 ^{ns}
10/17/2011	2.7(9.7) c	99.2
11/8/2011	4.8(26.3) b	99.9
12/5/2011	7.9(63.4) a	100
Times of application		
Control group with no application	3.9(22.5) ^{ns}	-
PRE	4.2(23.5)	99.3 ^{ns}
PRE + POS	4.7(25.6)	100
POS	4.0(29.4)	100
Mean	25.2	99.7
CV%	33.2	1.2

Variables with values †in parentheses indicate original values †, averages not followed by the same letter, lowercase in column and uppercase in row, differ by Tukey test at 5% probability; ^{NS} not significant in row; ns not significant in column ; [1/] percentage of red rice emergence in relation to seed bank in PRE to POS application; [2/] number of red rice desiccated plants from 9/20/2011 to the sowing date of each season, [3/] seed bank reduction in relation to red rice seed bank. * Doses of imazapic + imazapyr were: 105+35 g ha^{-1} (PRE), 2.5+17.5g ha^{-1} and 52.5+17.5 g ha^{-1} (PRE+POS), and 105+35 g ha^{-1} (POS).

For the variables red rice seed bank reduction and red rice control, there was no interaction between sowing dates and times of herbicide application (Table 1). At all times sowing decreased red rice seed bank (Table 4), which was lower in sowing dates performed at the beginning of the recommended period and higher at late period. This behavior is similar to what happened in the 2010/11 harvest. This further reduction of the seed bank of red rice in the late recommended period is due primarily to the longer period of time to control the seedlings that emerged during the period. In sowing dates early in the period, (09/27 and 10/17) in the average of treatments, 15 and 10 seedlings m^{-2} were desiccated, respectively, while in late period (11/08 and 12/05) that number was 139 and 78 seedlings m^{-2}, respectively, which contributed to further reduction of seed bank (Table 4).

As for chemical control (Table 4) there was no significant control difference among PRE, PRE + POS and POS applications, with control average of 99.7% in the dates of application. As in the 2010/11 harvest, this control efficiency is due to appropriate irrigation management and the fact that the red rice biotypes present in the area are not resistant to the imidazolinone group of herbicides. In addition, this season had fewer red rice seeds in the seed bank compared to the 2010/11 season for the same amount of herbicide, explaining in part the efficiency of control at the time of application only in PRE. However, in absolute terms, was observed reduced control at the time of PRE application, which may in part be related to the adsorption

Table 5 - Grain yield (GY) (kg ha^{-1}), number of panicles (NP), number of grains per panicle (NGP), thousand grain weight (TGW) and spikelet sterility (S) as a function of sowing date and time of Kifix ® (imazapic + imazapyr) applicationfor Puitá Inta-CL. 2011/12 harvest. Santa Maria, RS. 2012

Times of sowing	Times of application			
	Control group with no application	PRE#	PRE + POS	POS
Grain yield (GY) (kg ha^{-1})				
9/27/2011	6973 Bbc	9237 Aa	9268 Aa	9135 Aa
10/17/2011	8625 ABa	8031 Bbc	8451 ABa	9091 Aa
11/8/2011	6228 Bc	8761 Aab	8996 Aa	8805 Aa
12/5/2011	7168 NSb	7538 c	7196 b	7814 b
Mean				
CV%	5.9			
Number of panicles (NP) (m^{-2})				
9/27/2011	494 NSa	498 ab	508 ab	507 b
10/17/2011	531 ABa	507 Ba	565 ABa	623 Aa
11/8/2011	372 Bb	407 Bb	425 Bb	529 Aab
12/5/2011	529 NSa	505 a	486 ab	488 b
Mean	482	479	496	537
CV%	10.2			
Times of sowing		NGP	TGW (g)	S (%)
9/27/2011		74 a	24 a	7 bc
10/17/2011		51 b	25 a	8 ab
11/8/2011		75 a	24 a	6 c
12/5/2011		53 b	22 b	9 a
Times of application				
Control group with no application		60ns	24 ab	7ns
PRE		62	24 a	7
PRE + POS		63	23 b	7
POS		66	24 ab	8
Mean		63	24	7
CV %		13.9	3.8	22.4

Averages not followed by the same letter, lowercase in column and uppercase in row, differ by Tukey test at 5% probability; NS not significant in row; ns not significant in column * Doses of imazapic + imazapyr were: 105+35 g ha^{-1} (PRE),,52.5+17.5 g ha^{-1} and 52.5+17.5 g ha^{-1} (PRE+POS), and 105+35 g ha^{-1} (POS).

portion of herbicide to the soil. Thus, part of the herbicides may have been adsorbed on the soil and is not available for uptake by plants (Oliveira et al. 2004).

Corroborating the results of the 2010/11 harvest, sowing date affected grain yield (Table 5), which was higher in the sowing of 09/27, this being the best time of sowing, and lower on 12/05, with an average grain yield of treatments PRE, PRE + POS and POS of 9,213 and 7,516 kg ha^{-1}, respectively - a decrease of 18.4%, equivalent to 25 kg ha^{-1} day^{-1}. These results indicate a larger number of grains per panicle, greater thousand grain weight and lower spikelet sterility occurred at 09/27 (Table 5), due to better conditions of temperature and solar radiation during the reproductive period (Figure 1B, D) compared to the climate conditions of the last date (12/05).

In the Philippines, Yang et al. (2008) evaluated the effect of temperature and solar radiation on the weight of grain filling rate and duration of grain filling in different rice genotypes and found a linear increase in yield with increasing temperature and solar radiation accumulated. In Bangladesh, Islam & Morison (1992) also evaluated the influence of solar radiation and temperature on the yield of rice, and found a positive relationship between grain yield and solar radiation during the reproductive and maturing stages. According to Katsura et al. (2008), high yield is a result of high accumulation of biomass and nitrogen that occurs with high solar radiation availability. Lack et al. (2012) also associated highest yield with grain filling in appropriate temperature conditions.

Thus, sowing date is one of the most important management practices in irrigated rice. However, the isolated use of this practice may not be an important strategy in controlling red rice, and one should then associate sowing time with temperature conditions that hinder the emergence of red rice at the time of sowing to the final irrigation of rice, thus enabling lower emergence of red rice, in addition to matching the reproductive period of the plant with the best weather conditions.

Sowing early in the recommended season provides higher grain yield of rice. The application of imazapic + imazapyr at doses of 52.5 +17.5 g ha^{-1} in PRE + 52.5 +17.5 g ha^{-1} in POS and 105 +35 g ha^{-1} only in PRE and POS was effective in controlling red rice, but irrigation management must be adequate and with no presence of red rice biotypes resistant to these herbicides.

ACKNOWLEDGEMENTS

We thank the National Council for Scientific and Technological Development (CNPq), for granting master's scholarship to the first author and for the exchange of research productivity for the second author. The Foundation for Research Support of the State of Rio Grande do Sul (FAPERGS), for granting Scientific Initiation scholarship to the third author. We give thanks to CNPq and FAPERGS for their financial support on the research.

LITERATURE CITED

ALISTER, C.; KOGAN, M. Efficacy of imidazolinone herbicides applied to imidazolinone-resistant maize and their carryover effect on rotational crops. **Crop Protec.**, v. 24, n. 4, p. 375-379, 2005.

AVILA, L. A. et al. Imazethapyr aqueous photolysis, reaction quantum yield, and hydroxyl radical rate constant. **J. Agric. Food Chem.**, v. 54, n. 7, p. 2635-2639, 2006.

BRESNAHAN, G. A. et al. Influence of Soil pH-Sorption Interactions on Imazethapyr Carry-over. **J. Agric. Food Chem.**, v. 48, n. 5, p 1929-1934, 2000.

BURGOS, N. R. et al. Red Rice (*Oryza sativa*) Status after 5 Years of Imidazolinone-Resistant Rice Technology in Arkansas. **Weed Technol.**, v. 22, n. 1, p. 200-208, 2008.

COUNCE, P. A.; KEISLING, T. C.; MITCHELL, A. J. A uniform, objective and adaptive system for expressing Rice development. **Crop Sci. Soc. Am.**, v. 40, n. 2, p. 436-443, 2000.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. Centro Nacional de Pesquisa de Solos. **Sistema brasileiro de classificação dos solos**. Brasília: Embrapa-SPI, 2006. 412 p.

FIRMINO, L. E. et al. Sorcão do imazapyr em solos com diferentes texturas. **Planta Daninha**, v. 26, n. 2, p. 395-402, 2008.

FISCHER, A. J.; RAMIREZ, A. Red Rice (*Oriza sativa*): competition studies for management decisions. **Intern. J. Pest Manag.**, v. 39, n. 2, p. 133-138, 1993.

FOGLIATTO, S.; VIDOTTO, F.; FERRERO, A. Germination of weedy rice in response to field conditions during winter. **Weed Technol.**, v. 25, n. 2, p. 252-261, 2011.

FREITAS, T. F. S. et al. Produtividade de arroz irrigado e eficiência da adubação nitrogenada influenciadas pela época da semeadura. **R. Bras. Ci. Solo**, v. 32, n. 6, p. 2397-2405, 2008.

GEALY, D. R. Emergence of red rice (Oryza sativa) ecotypes under dry-seeded rice (*Oryza sativa*) culture. **Weed Technol.**, v. 14, n. 2, p. 406-412, 2000.

GIANINETTI, A.; COHN, M. A. Seed dormancy in red rice. XIII: Interaction of dry-afterripening and hydration temperature. **Seed Sci. Res.**, v. 18, n. 3, p. 151-159, 2008.

INSTITUTO NACIONAL DE METEOROLOGIA – INMET. Capturado em 01 out. 2010 a 01 abr. 2012. Online. Disponível em: http://www.inmet.gov.br/sonabra/dspDadosCodigo.php?QTgwMw==

ISLAM, M. S.; MORISON, J. I. L. Influence of solar radiation and temperature on irrigated rice grain yield in Bangladesh. **Field Crops Res.**, v. 30, n. 1-2, p. 13-28, 1992.

JAGADISH, S. V. K.; CRAUFURD, P. Q.; WHEELER, T. R. High temperature stress and spikelet fertility in rice (*Oryza sativa* L.). **J. Exper. Bot.**, v. 58, n. 7, p. 1627-1635, 2007.

KATSURA, K. The high yield of irrigated rice in Yunnan, China ‘A cross-location analysis. **Field Crops Res.**, v. 107, n. 1, p. 1-11, 2008.

KRAEMER, A. F. et al. Persistência dos herbicidas imazethapyr e imazapic em solo de várzea sob diferentes sistemas de manejo. **Planta Daninha**, v. 27, n. 3, p. 581-588, 2009.

LACK, S.; MARANI, N. M; MOMBENI, M. The effects of planting date on grain yield and yield components of rice cultivars. **Adv. Environ. Biol.**, v. 6, n. 1, p. 406-413, 2012.

MADANI, M. E. et al. pH effect and kinetic studies of the binding behaviour of imazethapyr herbicide on some Moroccan soils. **Fresenius Environ. B.**, v. 12, n. 9, p. 1114-1119, 2003.

MARCHESAN, E. et al. Carryover of imazethapyr and imazapic to notolerant rice. **Weed Technol.**, v. 24, n. 1, p. 6-10, 2010.

MARCHESAN, E. et al. Produtividade, fitotoxicidade e controle de arroz-vermelho na sucessão de cultivo de arroz irrigado no Sistema CLEARFIELD®. **Ci. Rural**, v. 41, n. 1, p. 17-24, 2011.

MARCOS FILHO, J. **Fisiologia de sementes de plantas cultivadas**. Piracicaba: Fealq, 2005. 495 p.

MERTZ, L. M. et al. Alterações fisiológicas em sementes de arroz expostas ao frio na fase de germinação. **R. Bras. Sementes**, v. 31, n. 2, p. 254-262, 2009.

MORENO, J. A. **Clima do Rio Grande do Sul**. Porto Alegre: Secretaria da Agricultura, 1961. p. 41.

NOLDIN, J. A.; CHANDLER, J. M.; MCCAULEY, G. N. Seed longevity of red Rice ecotypes buried in soil. **Planta Daninha**, v. 24, n. 4, p. 611-620, 2006.

NORSWORTHY, J. K.; OLIVEIRA, M. J. A model for predicting common cocklebur (*Xanthium strumarium*) emergence in soybean. **Weed Sci.**, v. 55, n. 4, p. 341-345, 2007.

OLIVEIRA, M. F. et al. Sorção do herbicida imazaquin em Latossolo sob plantio direto e convencional. **Pesq. Agropec. Bras.**, v. 39, n. 8, p. 787-793, 2004.

RANG, Z. W. et al. Effect of high temperature and water stress on pollen germination and spikelet fertility in rice. **Environ. Exper. Bot.**, v. 70, n. 1, p. 58-65, 2011.

SANTOS, F. M. et al. Controle químico de arroz-vermelho na cultura do arroz irrigado. **Planta Daninha**, v. 25, n. 2, p. 405-412, 2007.

SHIVRAIN, V. K. et al. Red rice (Oryza sativa) emergence characteristics and influence on rice yield at different planting dates. **Weed Sci.**, v. 57, n. 1, p. 94-102, 2009.

SLATON, N. A. et al. Seeding date effect on rice grain yields in Arkansas and Louisiana. **Agron. J.**, v. 95, n. 1, p. 218-223, 2003.

VILLA, S. C. C. et al. Controle de arroz-vermelho em dois genótipos de arroz (*oryza sativa*) tolerantes a herbicidas do grupo das imidazolinonas. **Planta Daninha**, v. 24, n. 3, p. 549-555, 2006.

FLINT, J. L.; WITT, W. W. Microbial degradation of imazaquin and imazethapyr. **Weed Sci.**, v. 45, n. 4, p. 586-591, 1997.

YANG, W. et al. Grain filling duration, a crucial determinant of genotypic variation of grain yield in field-grown tropical irrigated rice. **Field Crops Res.**, v. 105, n. 3, p. 221-227, 2008.

YOSHIDA, S. **Fundamental of rice crop science**. Los Baños: International Rice Research Institute, 1981. 269 p.

YOUNG-SON CHO. **Germination characteristics of Korean and Southeast Asian Redrice (*Oryza sativa* L.). Seeds as affected by temperature. Asian J. Plant Sci.**, v. 9, n. 2, p. 104-107, 2010.

Ciência Rural, Santa Maria, v.43, n.3, p.397-403, mar, 2013
ISSN 0103-8478

Rendimento de grãos e eficiência no uso de água de arroz irrigado em função da época de semeadura

Grain yield and water use efficiency in irrigated rice according to sowing date

Gerson Meneghetti Sarzi Sartori[I*] **Enio Marchesan**[I] **Cristian Fernandes Azevedo**[I]
Nereu Augusto Streck[I] **Rodrigo Roso**[I] **Lucas Lopes Coelho**[I] **Maurício Limberger de Oliveira**[I]

RESUMO

Uma das práticas desafiadoras de manejo é aumentar a produção de arroz utilizando menos água. O experimento foi realizado nas safras de 2010/11 e 2011/12 na área experimental da Universidade Federal de Santa Maria, Rio Grande do Sul. O objetivo foi avaliar o rendimento de grãos e a eficiência do uso de água na semeadura no início e final da época recomendada. Os tratamentos foram as épocas de semeadura (01/10/10 e 01/12/10) safra 2010/11, e (27/09/11 e 07/12/11) safra 2011/12, com cinco repetições, e a cultivar utilizada foi a 'IRGA 424'. Não houve diferença no volume de água aplicado entre as épocas de semeadura, com volume médio de 5757 e 8420m^3 ha^{-1}, respectivamente, para safra 2010/11 e 2011/12. A época de semeadura afetou o rendimento de grãos, com rendimento de 13 e 24% a mais nas semeaduras do início da época (01/10/10 e 27/09/11), comparado às semeaduras do final da época (01/12/10 e 07/12/11), respectivamente. A semeadura realizada no início da época recomendada (início de outubro) proporciona maior rendimento de grãos e maior eficiência no uso de água.

Palavras-chave: *precipitação pluvial, radiação solar, potencial produtivo,* ***Oryza sativa***.

ABSTRACT

One of the challenging management practices is to increase rice production using less water. The study was conducted during the harvest of 2010/11 and 2011/12 in the experimental field of Universidade Federal de Santa Maria, Rio Grande do Sul State, Brazil. The objective was to evaluate the yield and water use efficiency at sowing at beginning and end of the recommended time. Treatments were at planting dates (10/01/10 and 12/01/10) 2010/11 harvest, and (9/27/11 and 12/07/11) 2011/12 harvest, with five replicates, the cultivar used was the 'IRGA 424'. There was no difference in the amount of applied water between sowing times, with an average of 5757 and 8420m^3 ha^{-1}, respectively for season 2010/11 and 2011/12. The sowing date affected grain yield, with yields of 13 and 24% more in the beginning of the sowing season (10/01/10 and 9/27/11) compared to the end of the sowing date (12/01/10 and 12/07/11), respectively. Sowing early in the recommended period (early October) provides greater yield and more water use efficiency.

Key words: *rainfall, solar radiation, potential yield,* ***Oryza sativa***.

INTRODUÇÃO

O arroz irrigado é assunto em vários debates envolvendo conservação de água em nível mundial, por estar entre as espécies que mais utilizam irrigação e por ser classificada como muito exigente quanto ao uso de água durante o ciclo de desenvolvimento (NOLDIN et al., 2001; MACHADO et al., 2006). Diante da preocupação com a produção de alimentos e a crise mundial da água, elevar a eficiência de uso de água, é uma meta de extrema importância para a sustentabilidade da produção de arroz.

Estratégias visando à maior eficiência de água em arroz estão sendo estudadas em diversas partes do mundo por diversos pesquisadores (TOESCHER et al., 1997; BOUMAN & TUONG, 2000; MACHADO et al., 2006; AHMAD et al., 2008; JALOTA et al., 2009; MAHAJAN et al., 2009; YAO et al., 2012). Entre as estratégias, está o uso de diferentes sistemas de irrigação (contínuo e intermitente), densidades de plantas, cultivares de

[I]Departamento de Fitotecnia, Centro de Ciências Rurais (CCR), Universidade Federal de Santa Maria (UFSM), 97105-900, Santa Maria, RS, Brasil. E-mail: gersonmss@yahoo.com.br. *Autor para correspondência.

Recebido 23.07.12 Aprovado 22.10.12 Devolvido pelo autor 11.12.12
CR-2012-0578.R1

diferentes ciclos (curto, médio e tardio), híbridas e convencionais, diferentes momentos de supressão da irrigação e épocas de semeadura do arroz. A maioria dessas estratégias são eficazes, porém, algumas delas apresentam certas restrições à sua utilização, pelo aumento de custos e necessidade de precisão no controle da água de irrigação e diminuição no rendimento de grãos. No entanto, é desafio produzir mais alimento com menos água, o que, de acordo com HAEFELE et al. (2009), pode ser alcançado reduzindo as perdas de água por evaporação, percolação e escoamento.

A época de semeadura do arroz irrigado, associada às condições meteorológicas como temperatura e radiação solar, constitui-se num dos fatores relacionados ao rendimento de grãos do arroz (SLATON et al., 2003; LINSCOMBE et al., 2004, FREITAS et al., 2008; AKBAR et al., 2010; MORADPOUR et al., 2011; LACK et al., 2012) e pode trazer benefícios em termos de redução da quantidade e aumento da eficiência do uso de água da lavoura, pois, em semeaduras realizadas no início do período recomendado (outubro), normalmente, as precipitação pluviais são maiores e as perdas de água por evaporação são menores, já que a radiação solar e a temperatura do ar são mais baixas, quando comparado com semeaduras realizadas no final da época recomendada (dezembro). MAHAJAN et al. (2009), avaliando diferentes épocas de semeadura no rendimento de grãos e no uso de água do arroz, no estado de Punjab, noroeste da Índia, em que o clima da região é semi-árido com precipitação média anual de 400 a 700mm, encontraram maior eficiência no uso de água na semeadura realizada no início da época (15 de junho), comparado com 25 de junho e 05 de julho. Como as regiões produtoras de arroz são distintas em termos de disponibilidade climática, há necessidade de se conhecer melhor os efeitos da época de semeadura do arroz, no rendimento de grãos e no uso de água nas condições do Rio Grande do Sul, para que se possa manejar a lavoura de forma sustentável, com menor custo, e mínimo impacto ao ambiente.

Em vista disso, o trabalho teve por objetivo avaliar o rendimento de grãos e a eficiência do uso de água de arroz irrigado na semeadura no início e final da época recomendada para a Depressão Central do Rio Grande do Sul, uma das regiões orizícolas de grande relevância deste estado.

MATERIAL E MÉTODOS

O experimento foi realizado na safra agrícola de 2010/11 e 2011/12 na área experimental de várzea da Universidade Federal de Santa Maria (UFSM), em solo classificado como Planossolo Háplico Eutrófico arênico, pertencente à unidade de mapeamento Vacacaí. Na área em que foi realizado o experimento, o horizonte A variou de 0 a 0,2m e o Bt de 0,2 a 0,4 + m, segundo metodologia proposta por SANTOS et al. (2005). Os tratamentos foram épocas de semeadura (01/10/10 e 01/12/10) safra 2010/11 e (27/09/11 e 07/12/12) safra 2011/12, com cinco repetições.

A cultivar utilizada foi a IRGA 424, a qual possui ciclo de 132 dias. A semeadura foi realizada na quantidade de 90kg ha^{-1} de semente, com espaçamento de 0,17m, no sistema de cultivo mínimo, o qual consistiu de preparo antecipado da área e, após, houve formação de cobertura vegetal, sendo esta dessecada com glyphosate na dose de 1,08kg i.a. ha^{-1}, em área sistematizada. A adubação de base foi de 15kg ha^{-1} de nitrogênio (N), 45kg ha^{-1} de P_2O_5 e 90kg ha^{-1} de K_2O, conforme a indicação da análise de solo. O N foi aplicado na quantidade de 150kg ha^{-1}, dividido nas quantidades de 15kg ha^{-1} por ocasião da semeadura, 90kg ha^{-1} no perfilhamento (V3/V4) e 45kg ha^{-1} na diferenciação da panícula (R0) segundo escala de COUNCE et al. (2000). Os demais tratos culturais foram realizados conforme as recomendações técnicas para a cultura (SOSBAI, 2010).

O volume de água aplicado foi avaliado através de medidor de vazão com diâmetro nominal de 4”. Para quantificar o volume, as parcelas de aproximadamente 28m^2 de área foram isoladas com taipas ronda, de altura média de 0,6m, e a entrada de água foi individualizada para cada parcela. O sistema de irrigação utilizado foi o intermitente, com a irrigação de cada parcela formando lâmina de água de aproximadamente de 0,1m e, após, deixava-se evapotranspirar até aproximadamente 0,02m de lâmina, com objetivo de armazenar a água, em eventuais precipitações. A irrigação foi suspensa aos 15 dias após a floração plena (R2), aproximadamente, 112 dias após a semeadura. Com a finalidade de evitar as perdas de água por infiltração lateral, foi mantida água ao entorno das parcelas através de taipas de contenção, mantendo assim a mesma carga hidráulica em todas as parcelas.

O rendimento de grãos foi avaliado através da colheita de 4,5m^2 de área útil em cada parcela, quando os grãos se encontravam com grau de umidade médio de 22%. Após a trilha, limpeza e pesagem dos grãos com casca, os dados foram corrigidos para 13% de umidade e convertidos em kg ha^{-1}. O número de panículas m^{-2} foi determinado uma semana antes da colheita, através da contagem das panículas em um metro de linha previamente demarcado, sendo nesta mesma área realizada a coleta de quinze panículas por ocasião da colheita para a estimativa do número de grãos por panícula, massa de mil grãos e esterilidade de espiguetas.

A eficiência do uso de água foi obtida pela divisão do rendimento de grãos pelo volume de água aplicado. Avaliou-se também a contribuição de água advinda das precipitações pluviais, através do monitoramento da precipitação com pluviômetro instalado ao lado do experimento. Por ocasião da irrigação definitiva, colocou-se em cada parcela uma estaca com altura de 0,1m acima da superfície do solo, após, regularam-se todas as saídas de água das parcelas (despontes) no mesmo nível da extremidade das estacas (0,1m de altura) para mensuração da lâmina de água antes e após as precipitações, para quantificar a contribuição de água das precipitações pluviais.

Os valores de radiação solar global, precipitação pluvial e temperatura do ar foram obtidos da estação meteorológica automática e os valores de evaporação foram obtidos pelo tanque Classe A da estação meteorológica convencional do 8° DISME/INMET, localizado no Departamento de Fitotecnia da UFSM, a aproximadamente 500m do experimento. Para análise estatística, realizou-se, para cada safra, o teste t bilateral para duas amostras independentes em nível de 5% de probabilidade, para comparar as épocas de semeadura.

RESULTADOS E DISCUSSÃO

O volume de água aplicado não diferiu entre as épocas de semeadura nas safras 2010/11 e 2011/12, com volume médio aplicado para cada safra de, respectivamente, 5.757 e 8.420m^3 ha^{-1}(Tabela 1). Na safra 2010/11, nos meses de outubro e novembro, a precipitação foi de, respectivamente, 62 e 41% a menos que a normal (Figura 1C), provavelmente, devido ao fenômeno La Niña, cujo sinal é de chuvas abaixo da normal na primavera. Por outro lado, nos meses de dezembro, fevereiro e abril, a precipitação foi de, respectivamente, 26, 41 e 39% a mais que a normal. Já em janeiro e março foi de 18 e 60% a menos que a normal. Com isso, a contribuição de água pelas chuvas foi semelhante entre as duas épocas de semeadura, com 4.080m^3 ha^{-1} na semeadura realizada no início do período recomendado (01/10) e 3.792m^3 ha^{-1} para a semeadura realizada no final do período (01/12), explicando, em parte, a semelhança entre as épocas de semeadura quanto ao volume de água aplicado nesta safra.

Na safra 2011/12, o volume de água aplicado foi 32% superior ao volume de água aplicado na safra 2010/11. Embora a contribuição da água das chuvas na semeadura realizada ao final do período recomendado (07/12) foi 37% superior à semeadura realizada no início do período recomendado (27/09), isso não se refletiu em diferença significativa quanto ao volume de água aplicado. Isso pode estar relacionado à maior evaporação ocorrida no estabelecimento inicial da cultura (janeiro), o que demandou maior volume de água, em comparação à semeadura do início do período em que o estabelecimento inicial foi no mês de novembro. O maior volume de água aplicado nessa safra está relacionado à menor precipitação ocorrida principalmente nos meses de novembro, dezembro

Tabela 1 - Volume de água aplicado (VAA), contribuição de água das precipitações pluviais (CP), esterilidade de espiguetas (E), número de panículas m^{-2} (NP), massa de mil grãos (MMG), número de grãos por panícula (NGP), rendimento de grãos (R) e eficiência de uso da água (EUA), na cultivar IRGA 424, em duas épocas de semeadura, na safra 2010/11 e 2011/12. Santa Maria, RS. 2012.

Épocas	VAA m^3 ha^{-1}	CP m^3 ha^{-1}	E %	NP	MMG g	NGP	R kg ha^{-1}	EUA
				safra 2010/11				
01/10/10	5901^{ns}	4080	9 b	761^{ns}	24,8^{ns}	81 b	11334 a	1,92 a
01/12/10	5614	3792	13 a	673	24,7	88 a	9876 b	1,76 b
Média	5757	3936	11	717	24,7	84	10605	1,84
CV %	3,4		18,5	11,6	2,3	2,4	4,8	6,0
				safra 2011/12				
27/09/11	8453^{ns}	2040	12,9^{ns}	801 a	23,7 b	61,9^{ns}	9972 a	1,2 a
07/12/11	8386	3252	12,5	659 b	25 a	68,1	7610 b	0,9 b
Média	8420	2646	13	730	24	65	8791	1
CV %	4,1		13,7	6,9	3,7	9,7	2,6	6,7

^{ns} Não significativo em nível P≤ 0,05;
* Médias não seguidas da mesma letra minúscula na coluna diferem entre si pelo teste t bilateral em nível de 5% de probabilidade.

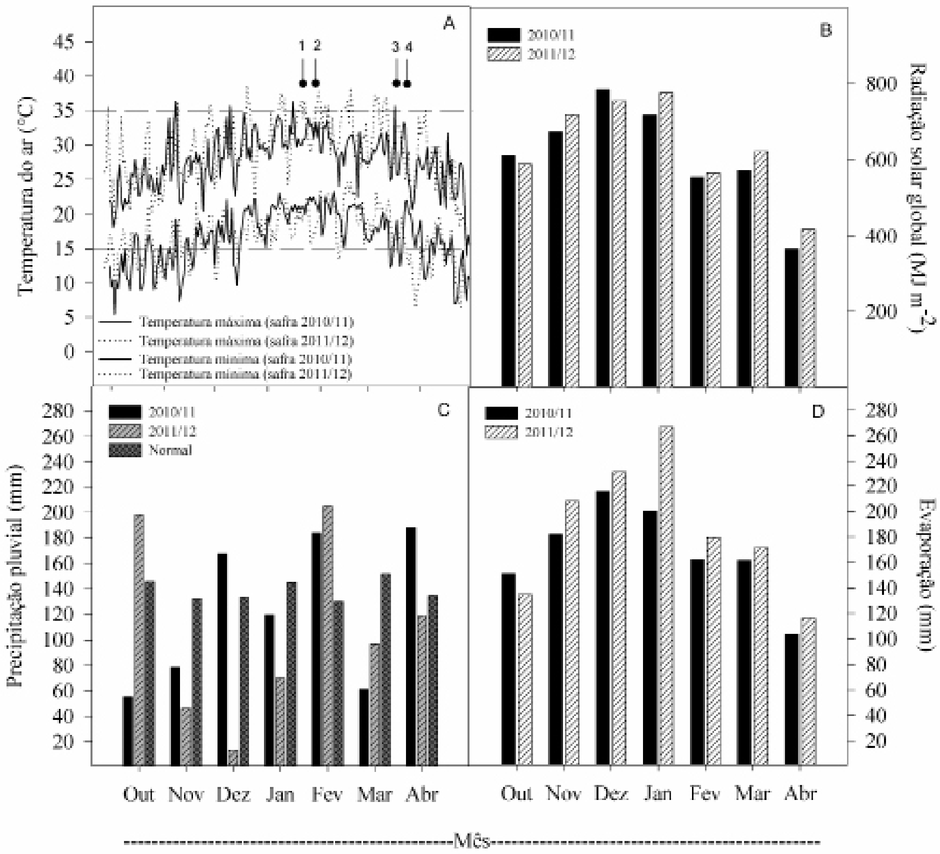


Figura 1 - Temperatura do ar máxima e mínima (A), radiação solar global (B), precipitação pluvial (C) e evaporação (D) durante os meses de outubro a abril nas safras 2010/11 e 2011/12. Na figura 1A, os números 1,2,3 e 4 indicam as datas em que ocorreu a floração plena: 1 = floração ocorrida em 22/01/11; 2 = floração ocorrida em 26/01/11; 3 = floração ocorrida em 16/03/12; 4 = floração ocorrida em 23/03/12, para as épocas de semeadura de 01/10/10, 27/09/11, 01/12/10 e 07/12/11, respectivamente. Santa Maria, RS. 2012.

e janeiro, com precipitação de, respectivamente, 65, 90 e 52% abaixo do normal (Figura 1C). Com isso, houve menor contribuição de água pelas chuvas, com contribuição de, respectivamente, 50 e 14% a menos que a safra de 2010/11 para as épocas de semeadura no início e final do período recomendado.

Além da menor precipitação, outro fator que pode ter contribuído para um maior volume de água aplicado é a maior evaporação ocorrida (Figura 1D). De maneira geral, na safra 2011/12, comparado à safra 2010/11, as temperaturas máximas do ar (Figura 1A) e a radiação solar global (Figura 1B) foram superiores em grande parte do período, o que deve ter contribuído para elevação da evaporação, pois o aumento da temperatura contribui para elevação do déficit de pressão de vapor. MAHAJAN et al. (2009) também associam a exigência de água na cultura do arroz com a demanda evaporativa.

Esses resultados estão próximos aos obtidos por MACHADO et al. (2006), os quais encontraram volumes de água aplicado variando de 5.431 a 6.422 e de 5.374 a 5.852m^3 ha^{-1}, respectivamente, para as safras 2000/01 e 2001/02 em diferentes sistemas de cultivos, na mesma área experimental do presente estudo, com a cultivar ELPASO 144, semeada em 03 de novembro para ambas as safras agrícolas. Já TOESCHER et al. (1997), no sistema de irrigação intermitente, na mesma condição de clima e solo do presente estudo, encontraram volume de água aplicado de 8.764 e 8.579m^3 ha^{-1}, respectivamente, para as cultivares BR-IRGA 409 e IAC-47. O sistema de irrigação intermitente permite grande economia no uso de água, chegando a 24 e 38% nas safras de 2009 e 2010, respectivamente, comparado com a irrigação contínua (YAO et al., 2012), pois ele permite armazenar grande parte da água advinda das precipitações pluviais.

Embora a época de semeadura não tenha influenciado no volume de água aplicado nas duas safras avaliadas, ela interferiu no rendimento de grãos da cultura (Tabela 1). Na safra 2010/11, o maior rendimento de grãos foi 11.334kg ha^{-1} para a semeadura realizada no início do período recomendado, 13% a mais que a semeadura no final do período, uma redução de 24kg $ha^{-1}dia^{-1}$ no rendimento, a partir de 01/10. Comportamento semelhante a essa safra ocorreu na safra 2011/12, em que o maior rendimento de grãos foi na semeadura realizada no início do período recomendado, com rendimento de grãos 24% maior em comparação à época de semeadura no final do período, uma redução de 33kg $ha^{-1}dia^{-1}$, a partir de 27/09.

O maior rendimento de grãos obtido na semeadura realizada no início do período recomendado pode ser explicado em parte pela maior disponibilidade de radiação solar (Figura 1B) e melhores condições de temperatura (Figura 1A), durante o período reprodutivo da cultura (floração e enchimento de grãos), comparado à menor disponibilidade neste período na semeadura realizada no final da época recomendada. Além das condições meteorológicas, o aumento da esterilidade de espiguetas observado na semeadura, no final do período recomendado na safra de 2010/11, e o menor número de panículas produzidos na safra 2011/12 podem ter contribuído para o menor rendimento de grãos.

O aumento da esterilidade de espiguetas pode estar relacionado às temperaturas mais baixas (Figura 1A) durante a formação do grão de pólen, pois FARRELL et al. (2006) relatam que baixa temperatura nessa época pode causar aumento da esterilidade de espigueta. Além disso, outro fator que pode ter contribuído para maior esterilidade de espiguetas foi as temperaturas elevadas na antese, que, de acordo com JAGADISH et al. (2007), temperaturas superiores a 35°C nesse estádio, por mais de uma hora, pode diminuir a fertilidade de espiguetas em arroz. GUNAWARDENA et al. (2003), avaliando 12 horas por dia de temperatura de 21,4/21°C (dia/noite), comparado a 18/13°C (dia/noite) em diferentes alturas de lâmina de irrigação, durante sete dias no desenvolvimento do micrósporo de arroz, encontraram, de forma geral, maior esterilidade de espiguetas na temperatura mais baixa (18/13°C). Em trabalho realizado por PEDRO JÚNIOR et al. (1995), avaliando a relação entre os valores de temperatura média do ar durante o período crítico e a produtividade relativa (%), encontraram a temperatura de 25°C, como temperatura ótima na análise em conjunto de diferentes cultivares de arroz irrigado.

Esses resultados estão de acordo com SLATON et al. (2003) e FREITAS et al. (2008), os quais relatam que os melhores rendimentos de grãos são obtidos quando as semeaduras são realizadas no início da época recomendada e tendem a diminuir quando realizadas no final.

AKBAR et al. (2010), também avaliando diferentes épocas de semeadura na cultura do arroz no Pakistão, encontraram que a época de semeadura afeta o rendimento de grãos da cultura, e associaram o aumento do rendimento às condições meteorológicas favoráveis durante o crescimento e desenvolvimento da cultura, como aumento dos valores médios de temperatura acumulada e horas de radiação solar. Nesse sentido, fazer coincidir o período reprodutivo da cultura do arroz com as melhores condições de temperatura e radiação solar traz resposta positiva em termos de rendimento de grãos (ISLAM & MORISON, 1992; SLATON et al., 2003; FREITAS et al., 2008; KATSURA et al., 2008; SAFDAR et al., 2008; LACK et al., 2012).

A época de semeadura de arroz irrigado, além de influenciar no rendimento de grãos, influenciou na eficiência do uso de água, com uso de água mais eficiente na semeadura, realizada no início do período recomendado em ambas as safras avaliadas (Tabela 1). A maior eficiência no uso de água está relacionada ao maior rendimento de grãos ocorrido na semeadura do início do período, pois aumentar o rendimento de grãos com o mesmo volume de água é uma estratégia que proporciona maior eficiência no uso de água. Esse resultado corroborando MAHAJAN et al. (2009), os quais encontraram maior eficiência no uso de água na semeadura do início da época (15 de junho), associando essa eficiência ao maior rendimento de grãos.

Portanto, a época de semeadura de arroz irrigado é uma prática de manejo importante que afeta o rendimento de grãos da cultura e a eficiência do uso de água. Assim, deve-se priorizar semeaduras no início do período recomendado, visando a um maior rendimento de grãos, que proporciona uso mais eficiente de água.

CONCLUSÃO

A semeadura realizada no início da época recomendada (início de outubro) proporciona maior rendimento de grãos e maior eficiência no uso de água, devido à cultura se desenvolver em condições meteorológicas adequadas como temperatura, radiação solar e precipitação pluvial.

AGRADECIMENTOS

Ao Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), pela bolsa de Mestrado concedida ao primeiro autor e pela bolsa de produtividade em pesquisa para o segundo autor. À Fundação de Apoio à Pesquisa do Estado do Rio Grande do Sul (FAPERGS), pela bolsa de Iniciação Científica concedida ao terceiro autor. Ao CNPq e à FAPERGS, pelo auxílio financeiro para realização da pesquisa.

REFERÊNCIAS

AKBAR, N. et al. Effect of different sowing dates on the yield and yield components of direct seeded fine rice *(Oryza sativa* L.). **Journal of Plant Breeding and Crop Science**, v.22, n.10, p.312-315, 2010.

AHMAD, S. et al. Water and radiation use efficiencies of transplanted rice (***Oryza sativa*** L.) At different plant densities and irrigation regimes under semi-arid environment. **Pakistan Journal of Botany**, v.40, n.1, p.199-209, 2008.

BOUMAN, B.A.M; TUONG, T.P. Field water management to save water and increase its productivity in irrigated lowland Rice. **Agricultural Water Management**, v.1615, p.1-20, 2000. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0378377400001281>. Acesso em: 07 maio, 2012. doi: 10.1016/S0378-3774(00)00128-1.

COUNCE, P.A. et al. A uniform, objective and adaptive system for expressing rice development. **Crop Science Society of America**, v.40, n.2, p.436-443, 2000.

FARREL, T.C. et al. Genotypic variation for cold tolerance during reproductive development in rice: Screening with cold air and cold water. **Field Crops Research**, v.98, p.178-194, 2006. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0378429006000256>. Acesso em: 07 maio, 2012. doi: 10.1016/j.fcr.2006.01.003.

FREITAS, T.F.S. et al. Produtividade de arroz irrigado e eficiência da adubação nitrogenada influenciadas pela época da semeadura. **Revista Brasileira de Ciência do Solo**, v.32, p.2397-2405, 2008. Disponível em: <http://www.scielo.br/scielo.php?pid=S0100-06832008000600018&script=sci_abstract&tlng=pt>. Acesso em: 07 maio, 2012. doi: 10.1590/S0100-06832008000600018.

GUNAWARDENA, T.A. et al. Low temperature induced spikelet sterility in rice. II. Effects of panicle and root temperatures. **Australian Journal of Agricultural Research**, v.54, n.10, p.947-956, 2003.

HAEFELE, S.M. et al. Transpiration efficiency of rice (***Oryza sativa*** L.). **Field Crops Research**, v.111, p.1-10, 2009. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0378429008001901>. Acesso em: 07 maio, 2012. doi: 10.1016/j.fcr.2008.09.008.

ISLAM, M.S.; MORISON, J.I.L. Influence of solar radiation and temperature on irrigated rice grain yield in Bangladesh. **Field Crops Research**, v.30, p.13-28, 1992.

JAGADISH, S.V.K. et al. High temperature stress and spikelet fertility in rice (***Oryza sativa*** L.). **Journal of Experimental Botany**, v.58, n.7, p.1627-1635, 2007. Disponível em: <http://jxb.oxfordjournals.org/content/58/7/1627>. Acesso em: 07 maio, 2012. doi: 10.1093/jxb/erm003.

JALOTA, S.K. et al. Integrated effect of transplanting date, cultivar and irrigation on yield, water saving and water productivity of rice (***Oryza sativa*** L.) in Indian Punjab: field and simulation study. **Agricultural Water Management**, v.96, p.1096-1104, 2009.

KATSURA, K. et al. The high yield of irrigated rice in Yunnan, China. 'A cross-location analysis. **Field Crops Research**, v.107, p.1-11, 2008. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0378429007002596>. Acesso em: 08 maio, 2012. doi: 10.1016/j.fcr.2007.12.007.

LACK, S. et al. The effects of planting date on grain yield and yield components of rice cultivars. **Advances in Environmental Biology**, v.6, n.1, p.406-413, 2012.

LINSCOMBE, S.D. et al. Rice response to planting date differs at two locations in Louisiana. **Crop Management**, 2004. Disponível em: <http://www.plantmanagementnetwork.org/pub/cm/research/2004/rice/>. Acesso em: 08 maio, 2012. doi: 10.1094/CM-2004-0130-01-RS.

MACHADO, S.L.O. et al. Consumo de água e perdas de nutrientes e de sedimentos na água de drenagem inicial de arroz irrigado. **Ciência Rural**, v.36, n.1, p.65-71, 2006. Disponível em: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-84782006000100010>. Acesso em: 08 maio, 2012. doi: 10.1590/S0103-84782006000100010.

MAHAJAN, G. et al. Yield and water productivity of rice as affected by time of transplanting in Punjab, India. **Agricutural Water Management**, v.26, p.525-532, 2009. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0378377408002369>. Acesso em: 08 maio, 2012. doi: 10.1016/j.agwat.2008.09.027.

MORADPOUR, S. et al. Effect of planting date and plant density on yield and yield components of rice. **Ecology, Environment and Conservation**, v.17, n.2, p.251-256, 2011.

NOLDIN, J.A. et al. Persistência do herbicida clomazone no solo e na água quando aplicado na cultura do arroz irrigado, sistema pré-germinado. **Planta Daninha**, v.19, n.3, p.401-408, 2001. Disponível em: <http://www.scielo.br/scielo.php?pid=S0100-83582001000300013&script=sci_abstract&tlng=pt>. Acesso em: 08 maio, 2012. doi: 10.1590/S0100-83582001000300013.

PEDRO JÚNIOR, M.J. et al. Estimativa da produtividade de arroz irrigado por inundação em em função da temperatura do ar e da radiação solar. **Scientia Agricola**, v.52, n.1. p.96 -100, 1995.

SANTOS, R.D. et al. **Manual de descrição e coleta de solo no campo**. 5.ed. Viçosa: SBCS, 2005. 100p.

SAFDAR, M.E. et al. Effect of transplanting dates on paddy yield of fine grain rice genotypes. Pakistan Journal of Botany, v.40, n.6, p.2403-2411, 2008.

SLATON, N.A. et al. Seeding date effect on rice grain yields in Arkansas and Louisiana. **Agronomy journal**, v.95, n.1, p.218-223, 2003.

SOCIEDADE SUL-BRASILEIRA DE ARROZ IRRIGADO (SOSBAI). **Arroz irrigado**: recomendações técnicas da pesquisa para o Sul do Brasil / 28. Reunião Técnica da cultura do Arroz Irrigado, Bento Gonçalves, RS. Porto Alegre, 2010. 188p.

TOESCHER, C.F. et al. Volume de água aplicada e produtividade do arroz sob diferentes métodos de irrigação. **Revista da FZVA**, v.4, n.1, p.49-57, 1997.

YAO, F. et al. Agronomic performance of high-yielding rice variety grown under alternate wetting and drying irrigation. **Field Crops Research**, v.126, p.16-22, 2012. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0378429011003339>. Acesso em: 08 maio, 2012. doi: 10.1016/j.fcr.2011.09.018.