Research Article

Yield and profitability of flooded rice genotypes in relation to nitrogen doses and phosphorus and potassium application[1]

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ABSTRACT

The use of hybrid genotypes is a good alternative for increasing the flooded rice yield. However, there is a need for validation of the fertilizer management under different edaphoclimatic conditions and its greater profitability. This study aimed to evaluate the grain yield and profitability of rice hybrids in relation to N doses and fertilization with P and K. Five hybrid cultivars and the conventional IRGA 424 CL cultivar combined with four N doses (0, 100, 150 and 200 kg ha^{-1}) were evaluated, all with fixed doses of 90 kg ha^{-1} of P_2O_5 and 150 kg ha^{-1} of K_2O, besides an additional treatment without the addition of fertilizers. The N application increases, on average, by 10 and 35 % the flooded rice yield in years with favorable and unfavorable climatic conditions, respectively. Regardless of the year and genotype, the highest yields are obtained with doses of N between 106 and 200 kg ha^{-1}, with the most profitable dose being the 150 kg ha^{-1} one (22 % higher than for the absence of N). The hybrids produce an average of 20 % more grains than the IRGA 424 CL cultivar, increasing the profitability by 18 %. In soil with adequate P and K availability, there is no increase in yield due to the application of these nutrients. However, in deficient soil, the fertilization with P and K increases the grain yield by 21 %.

KEYWORDS: *Oryza sativa*, hybrid seed, fertilization response curve, plant nutrition.

RESUMO

Produtividade e rentabilidade de genótipos de arroz irrigado em função de doses de nitrogênio e aplicação de fósforo e potássio

O uso de genótipos híbridos é uma boa alternativa para aumentar a produtividade do arroz irrigado. Há, no entanto, a necessidade de validação do manejo da adubação em diferentes condições edafoclimáticas e de sua maior rentabilidade. Objetivou-se avaliar a produtividade de grãos e a rentabilidade de híbridos de arroz relacionadas a doses de N e à adubação com P e K. Avaliaram-se cinco cultivares híbridas e a cultivar convencional IRGA 424 CL combinadas com quatro doses de N (0; 100; 150; e 200 kg ha^{-1}), todas com doses fixas de 90 kg ha^{-1} de P_2O_5 e 150 kg ha^{-1} de K_2O, além de um tratamento adicional, sem o uso de fertilizantes. A aplicação de N incrementa, em média, em 10 e 35 % a produtividade do arroz irrigado em anos com condições climáticas favoráveis e desfavoráveis, respectivamente. Independentemente do ano e genótipo, as maiores produtividades são obtidas com doses de N entre 106 e 200 kg ha^{-1}, sendo a dose de maior rentabilidade a de 150 kg ha^{-1} (22 % superior à ausência de aplicação de N). Os híbridos produzem 20 % a mais de grãos, em média, que a cultivar IRGA 424 CL, incrementando a rentabilidade em 18 %. Em solo com disponibilidade de P e K adequada, não há incrementos em produtividade pela aplicação desses nutrientes. Porém, em solo deficiente, a fertilização com P e K incrementa em 21 % a produtividade de grãos.

PALAVRAS-CHAVE: *Oryza sativa*, semente híbrida, curva de resposta à adubação, nutrição de plantas.

INTRODUCTION

Rice (*Oryza sativa* L.) is a strategic cereal to food security, especially in developing countries, as it has a relatively low price, when compared to other cereals (Sosbai 2018). It is in the Rio Grande do Sul state that 75 % of the Brazilian rice cultivated area is concentrated, with about one million hectares and average yield of 7.5 Mg ha^{-1}, in the 2018/2019 season (Conab 2020a).

The correct fertilization management has been one of the main factors for the increase in

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yield of the rice crop in the last decades (Menezes et al. 2012). Thus, the selection of genotypes with high yield potential and high efficiency in the use of nutrients is an excellent strategy for reducing costs and increasing profitability (Fageria & Barbosa Filho 1982). The performance of rice, in relation to the nitrogen (N) application, is directly related to meteorological and management factors. In 31 experiments evaluating the effect of N doses on rice crop yield, Scivittaro & Machado (2004) observed a decrease in yield in five of them, absence of response in six and increase in twenty.

Although phosphorus (P) and potassium (K) have historically been neglected in flooded crops, due to the increase in their availability after flooding (Meurer 2012), they are essential for maximizing the crop yield. Fageria et al. (2013) demonstrated an increase in grain yield for flooded rice with fertilization with P and K, mainly in soils deficient in these nutrients.

On the market, there is a large amount of flooded rice genotypes available to rice farmers. One of the current limitations for the proper positioning of these genotypes is the knowledge of the yield behavior of these materials in different environments, with variations in the soil type and fertility, climatic conditions, technological level, etc. (Suhre et al. 2008). Hybrid rice seeds have a 20-30 % higher yield potential, as compared to the conventional ones (Coimbra et al. 2006), in addition to saving 60 % in the amount of seeds needed for the crop implantation. The production of these seeds consists of sowing interleaved tracks of male and female lineage, with the hybrid seed being the result of the crossing between the lineages. Female strains are male-sterile, that is, they do not self-fertilize. Pollen from anthers of the male strain migrates to the stigma of the female strain, with cross-pollination occurring. The male-sterile female strain receives pollen from the male and produces the hybrid seed (Bragantini et al. 2001). Its introduction in Brazil took place in 2003, when the first commercial hybrid was launched (AVAXI by RiceTec Sementes Ltda.) (Sosbai 2018). Currently, among the ten most sown genotypes in Rio Grande do Sul, there is only one hybrid (Inov CL) occupying approximately 9.7 thousand hectares of the total sown area in 2019/2020 (IRGA 2020a). In this scenario, the IRGA 424 CL cultivar prevails, occupying approximately 54 % of the area of the state in the 2019/2020 season (IRGA 2020a). The main limiting factors for the expansion of rice hybrids are the costs of seed production (Goulart 2012) and the use of non-certified conventional seeds, produced by the farmers themselves.

In this context, the hypotheses of this study are: i) hybrids have a greater yield potential and profitability when compared to conventional cultivars; ii) rice genotypes respond differently to N fertilization; iii) the application of P and K in the sowing row increases the rice crop yield. Thus, this study aimed to evaluate the grain yield and profitability of hybrid and conventional rice cultivars, in relation to N doses and fertilization with P and K, in a flood-irrigated area.

MATERIAL AND METHODS

Two trials with flooded rice were conducted in the 2017/2018 season, in Triunfo, and in the 2018/2019 season, in Capivari do Sul, both cities in the Rio Grande do Sul state, Brazil. In both locations, a randomized block design, in a $4 \times 4 + 1$ factorial scheme (genotypes $\times$ N doses + absence of NPK), was used, with four replications. The first factor was composed of four genotypes, three being hybrids, all recently launched, and the IRGA 424 CL conventional cultivar. The hybrids XP 113, XP 118 and Lexus CL were tested in Triunfo, and XP 113, XP 117 and XP 119 in Capivari do Sul. To choose the hybrids in the second trial, their response in the first trial was considered, selecting the XP 113 to be repeated and compared to two other hybrids from the same company. All genotypes are blast tolerant and moderate to tolerant to bedding. The genotypes cycle varies from 120 to 130 days. The second variation factor was the N doses (0, 100, 150 and 200 kg ha^{-1}), which were based on the recommendation of 150 kg ha^{-1} for soil with a low organic matter content and high yield expectation (Sosbai 2018), adding one dose above and two below this value. The additional treatment consisted of the absence of NPK fertilization (0-0-0). Except for the additional treatment, the others received 90 kg ha^{-1} of P$_2$O$_5$ and 150 kg ha^{-1} of K$_2$O.

In Triunfo (29º56'33"S, 51º26'08"W and average altitude of 23 m), the climate is humid subtropical, according to the Köppen classification, with average air temperature of 9.8 and 31.6 ºC, respectively in the coldest and hottest months. The soil of the area is classified as Albaqualf (USDA 2014) and Planossolo Háplico (Santos et al. 2018).

The area was under a minimum cultivation system (advance soil preparation), with a production record of soy cultivation in the 2016/2017 season, and flooded rice in previous years.

In Capivari do Sul (30º09'58"S, 50º29'36"W and 10 m above the sea level), the soil is classified as an Entisol (USDA 2014) and Gleissolo Háplico (Santos et al. 2018). The area had been conducted under a minimum cultivation system and had as a production record two consecutive soybean crops after successive rice crops. The main attributes of the soil (0-20 cm layer), before the implementation of the trials, presented the following values in Triunfo: organic matter (low): 14 g dm^{-3}; clay: 220 g kg^{-1}; pH (H$_2$O): 5.0; CEC (pH$_7$): 7.5 cmol$_c$ dm^{-3}; Al^{3+}: 0.3 cmol$_c$ dm^{-3}; available P (medium): 4.5 mg dm^{-3}; available K (high): 61 mg dm^{-3}. In Capivari do Sul, the following values were obtained for the physical and chemical characteristics: organic matter (low): 18 g dm^{-3}; clay: 150 g kg^{-1}; pH (H$_2$O): 4.3; CEC (pH$_7$): 12 cmol$_c$ dm^{-3}; exchangeable Al^{3+}: 1.2 cmol$_c$ dm^{-3}; available P (very low): 1.6 mg dm^{-3}; available K (medium): 82 mg dm^{-3}.

The precipitation and temperature data during the experiment (Figure 1) were obtained from the weather stations of Porto Alegre and Tramandaí, the nearest ones to Triunfo and Capivari do Sul, respectively.

The experimental units had a size of 10.0 × 1.53 m, totaling an area of 15.3 m^2, corresponding to 9 rows of rice. Sowing was carried out mechanically in a row on dry soil, with a plot seeder, at the densities

of 40 and 100 kg ha^{-1} of seeds, when using the rice hybrid and conventional cultivars, respectively. The sources of P and K were triple superphosphate (45 % of P$_2$O$_5$) and potassium chloride (58 % of K$_2$O), respectively. P was applied to the planting rows and K at the surface two days after sowing. The N doses were applied manually, using urea (45 % of N) as a N source. The N doses were fractionated: 60 % of the total applied at V$_3$-V$_4$ and 40 % at the R0 stage (Sosbai 2016).

For both trials, the sowing took place in the second half of October and the harvest in the first two weeks of March. Phytosanitary management was carried out in accordance with the recommendations of Sosbai (2018) for integrated crop management. The plots were manually harvested, disregarding the lateral rows (border). The grains produced in each plot were crushed, weighed, had their humidity corrected to 13 % and the values were extrapolated to Mg ha^{-1}.

The yield data were initially submitted to analysis of variance by the F test at 5 % of probability. The rice genotypes were subjected to multiple comparison of means by the Tukey test at 5 % of probability. For the N doses effect, polynomial regressions were adjusted to 5 % of probability. To calculate the maximum technical efficiency of N doses, the following formula was used: $x = -\Delta_1/2\Delta_2$, where Δ_1 and Δ_2 are the values estimated by the polynomial regression equation (Stork et al. 2006). All statistical analyses were performed using the Sisvar 5.6 software (Ferreira 2011). The effect of P and K application was evaluated by comparing the
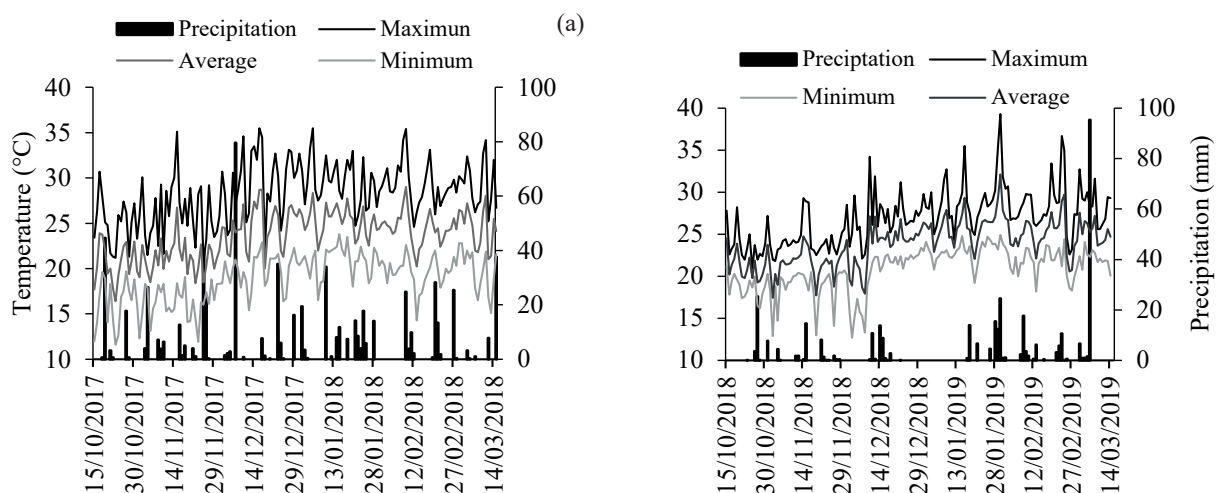

Figure 1. Precipitation and minimum, average and maximum air temperature, between October and March of 2017/2018 in Triunfo (a) and 2018/2019 in Capivari do Sul (b).

treatment with 0 kg ha⁻¹ of N with the additional treatment (0-0-0) by the randomization test of means from the bootstraping procedure with 4,999 iteractions (Lock et al. 2017).

For the simplified economic analysis of the treatments, the cost for implanting the crop was calculated considering only the acquisition values of seeds and fertilizers for each treatment (variation factors). The gross income was obtained by multiplying the grain yield by the price of the ton of produced grains. By subtracting the simplified production cost from the gross income, the simplified net profitability was obtained. Fertilizer prices were obtained in the month of implementation of each agricultural year (Conab 2020b). For the values of hybrid seeds and cultivar, quotations were sought in the study regions at input resellers. To price the rice, data from the harvest months of each crop (IRGA 2020b) were used.

RESULTS AND DISCUSSION

For both trials (Triunfo and Capivari do Sul), there was a significant interaction between the variation factors N doses and rice genotypes, thus demonstrating that the genotypes responded differently to the N doses (Table 1).

In Triunfo, at doses of 0 kg ha⁻¹ (Figure 2a) and 200 kg ha⁻¹ (Figure 2d) of N, there was no significant difference between the studied hybrids. At the dose of 100 kg ha⁻¹ of N (Figure 2b), XP 113 was superior to Lexus CL, with XP 118 showing an intermediate yield between the two. At 150 kg ha⁻¹ of N (Figure 2c), it was possible to verify the inferiority of Lexus CL, when compared to XP 113 and XP 118, which showed a higher yield and did not differ from each other. In Capivari do Sul, the hybrids showed no statistical difference among themselves at doses of 100, 150 and 200 kg ha⁻¹ of N (Figures 2b, 2c and 2d). Only at the dose of 0 kg ha⁻¹ of N (Figure 2a) XP 113 produced 37.5 % more, on average, than the other hybrids.

The yield inferiority of IRGA 424 CL, in relation to the hybrids, in the average of all N doses, varied from 16.9 to 21.8 % in Triunfo and from 19.1 to 32.7 % in Capivari do Sul (Figure 2). This result corroborates Ribas et al. (2016), who observed that hybrids had a 28 % higher production potential than conventional genotypes. The results obtained in the present study, mainly in Triunfo, showed that the hybrids present a high yield even in areas with low fertilization level (0 kg ha⁻¹ of N), where one could expect a greater rusticity of the conventional cultivar.

The IRGA 424 CL cultivar showed a quadratic response to increasing N doses, with maximum technical efficiency doses of 201 kg ha⁻¹ and 152 kg ha⁻¹, respectively in Triunfo and in Capivari do Sul (Figures 3a and 3c). Although the maximum technical efficiency doses are high, it is possible to observe a low increase in grain yield with the use of doses above 100 kg ha⁻¹ of N. The Lexus CL hybrid (Figure 3c), in Triunfo, did not respond to the addition of N, an unusual condition, due to the high yield potential of this hybrid that had an average yield of 14.2 Mg ha⁻¹. The lack of response of this hybrid to N may be related to the hybrid's good ability to use the N available on the soil organic matter and organic

Table 1. Analysis of variance (Anova) of grain yield from rice genotypes submitted to N doses, in two trial locations.

Variation factors	Degrees of freedom	Sum of squares	Mean square	F value	F statistic (5 %)
		Triunfo			
Genotype (G)	3	71.0	23.7	47.1	2.8*
Dose (D)	3	26.9	9.0	17.8	2.8*
G X D	9	10.7	1.2	2.4	2.1*
Block	3	4.9	1.6	3.3	2.8*
Error	45	22.6	0.5	-	-
		Capivari do Sul			
Genotype (G)	3	61.3	20.4	25.2	2.8*
Dose (D)	3	89.2	29.7	36.7	2.8*
G X D	9	16.5	1.8	2.3	2.1*
Block	3	25.4	8.5	10.5	2.8*
Error	45	36.5	-	-	-

* Significant at 5 % of probability.

a) 0 kg N ha⁻¹

b) 100 kg N ha⁻¹

c) 150 kg N ha⁻¹
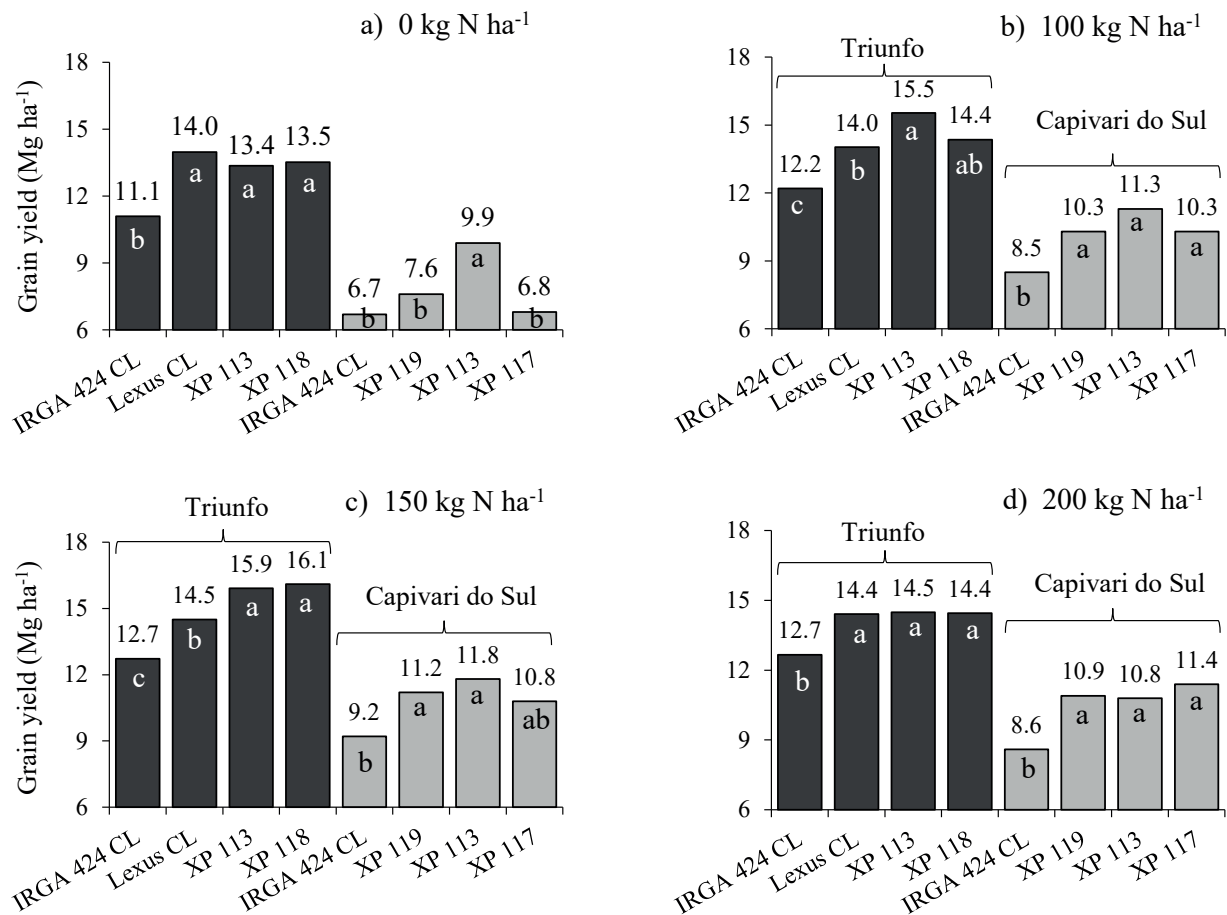

d) 200 kg N ha⁻¹

Figure 2. Average grain yield of flooded rice genotypes submitted to 0 (a), 100 (b), 150 (c) and 200 (d) kg ha⁻¹ of N, in Triunfo (2017/2018) and Capivari do Sul (2018/2019). Averages followed by the same letter in each location do not differ, according to the Tukey test at 5 % of probability.

waste. The other hybrids evaluated in Triunfo, XP 113 and XP 118 (Figures 3a and 3b), showed quadratic responses to the addition of N doses, with a greater yield obtained with 106 and 131 kg ha⁻¹ of N, respectively, and with a significant decrease in yield in the treatment with 200 kg ha⁻¹ of N.

In Capivari do Sul, all genotypes showed a quadratic response to the increasing N doses (Figures 2c and 2d). The maximum technical efficiency doses of the XP 119, XP 113 and XP 117 hybrids (Figures 2c and 2d) were 201, 142 and 217 kg ha⁻¹ of N, respectively. When compared to the control (0 kg ha⁻¹ of N), the dose of 100 kg ha⁻¹ of N increased the genotype yield by 32 %, on average. Between 100 and 150 kg ha⁻¹ of N, the increments were more modest, averaging 7 %. In general, the dose of 200 kg ha⁻¹ caused the genotypes in both places to show a yield decrease, which can be explained by the excessive biomass production, causing the plant to have a high energy expenditure with the maintenance

of its leaf structure, consequently converting less energy into grain yield (Fabre et al. 2011). In addition, the excessive height growth and biomass production make plants more susceptible to lodging (Menezes et al. 2004), a fact that was visually observed in the trials at the highest dose, but not quantified.

At the N dose (150 kg ha⁻¹) in which the highest yields were obtained for the average of the four cultivars, in their respective place and year, the grain yield was close to 14 Mg ha⁻¹ in Triunfo and 9.8 Mg ha⁻¹ in Capivari do Sul. In both tests, the yields were higher than the average obtained in Rio Grande do Sul, which is approximately 7.5 Mg ha⁻¹ (Conab 2020a). The yield variation evidenced between the tests in this study is based on meteorological variations (temperature and solar radiation) and soil chemical attributes, because there was a greater availability of nutrients in Triunfo, in relation to Capivari do Sul.

Rice has a high susceptibility to spikelet sterility in the reproductive phase, due to sudden

● Irga 424 CL y = 11.074 + 0.016x - 0.0001x² R² = 0.62
▲ XP 113 y = 13.3250 + 0.0422x − 0.0002x² R² = 0.63

a)

● XP 118 y = 13.4 + 0.0262x − 0.001x2 R² = 0.38
▲ LEXUS CL y = 14.23

b)

● Irga 424 CL y = 6.654 + 0.0303x − 0.0001x² R² = 0.61
▲ XP 113 y = 9.8734 + 0.0284x − 0.0001x² R² = 0.33

c)

● XP 117 y = 6.8367 + 0.0434x − 0.0001x² R² = 0.70
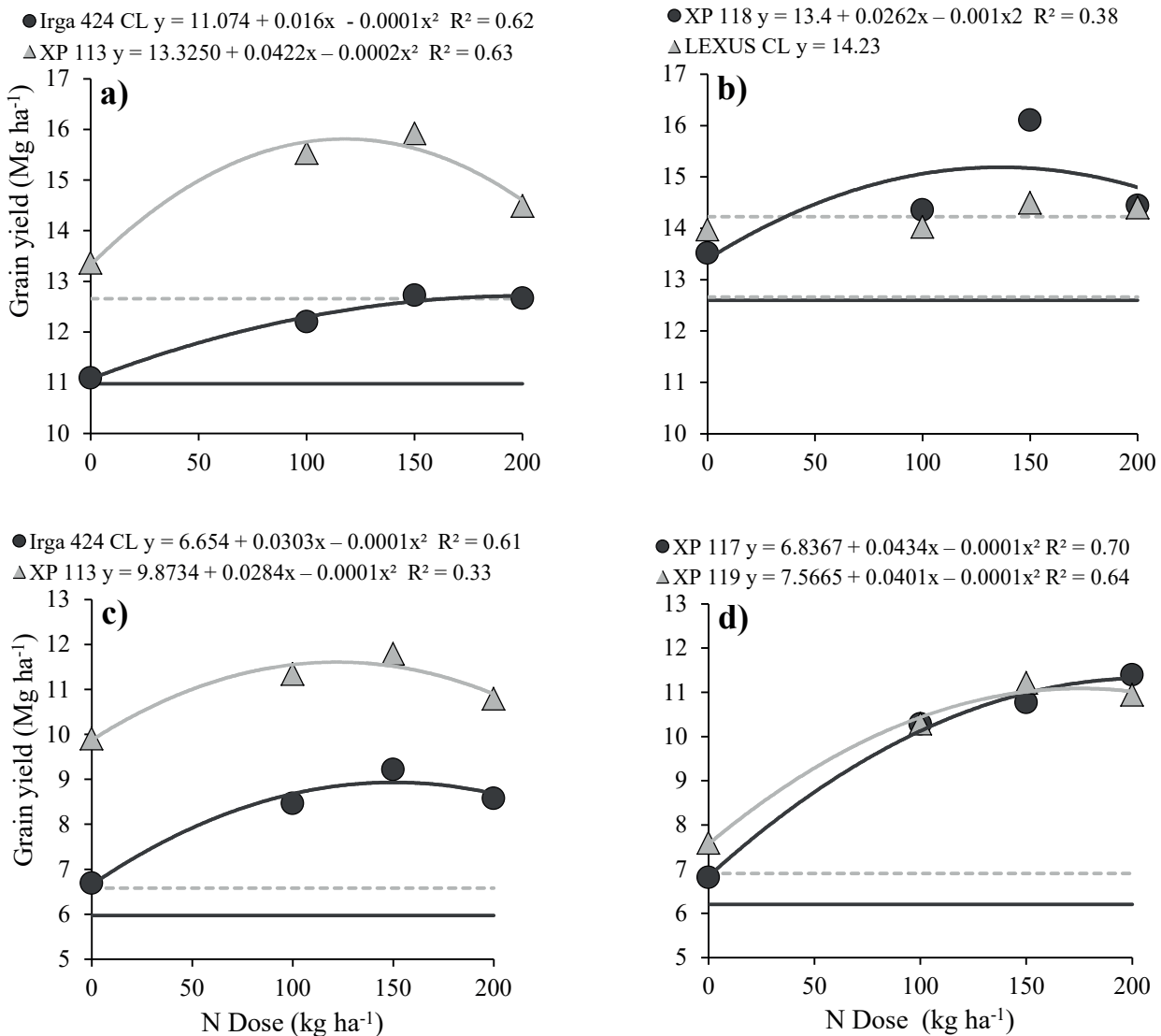▲ XP 119 y = 7.5665 + 0.0401x − 0.0001x² R² = 0.64

d)

Figure 3. Grain yield of flooded rice genotypes, as a function of N doses, in Triunfo (2017/2018; a and b) and Capivari do Sul (2018/2019; c and d). The line drawn in parallel to the x axis (N dose) represents the yield of the additional treatment, without the addition of NPK fertilizer (0-0-0).

temperature variations. According to Yoshida (1981), the critical temperature ranges from 15-20 to 38 °C for panicle emergence and 22 to 35 °C for anthesis. By observing the period between the second half of December and the entire month of January (Figure 1), which coincided with the reproductive phase in both years of the experiment, it is possible to notice significant differences. In Triunfo (2017/2018), temperatures followed a constant, not varying beyond the critical ranges (Figure 1a); but, in Capivari do Sul (2018/2019), maximum temperature peaks that exceeded the appropriate development range (Figure 1b) occurred. In addition, in Capivari do Sul, there was a long rainy period (81 mm in 16 days) after high temperature peaks,

with a reduction in the available light (Figure 1b). According to Berlato & Fontana (2003), in years of high precipitation levels, there is a decrease in the incident solar radiation and, consequently, a tendency to obtain a lower yield for flooded rice.

It is also possible to verify the great importance of N fertilization especially in years with the occurrence of stresses. The results showed that, in the average of the three doses, and regardless of the genotype, in relation to the control treatment, the yield increase was only 10 %, in a year of favorable climate with absence of temperature peaks and low radiation due to excessive precipitation (2017/2018), and approximately 35 % in a year less conducive to high rice yield (2018/2019) (Figure 3).

In Triunfo, the average yield of the genotypes (0 kg ha^{-1} of N) that received fertilization with P and K was 12.8 Mg ha^{-1}; while, in the additional treatment without the addition of NPK fertilizers, the yield was 12.3 Mg ha^{-1}, with no statistical difference between the treatments. This is due to the soil medium initial level of available P and high initial level of available K, resulting in a lower response potential to the addition of these nutrients (Sosbai 2018). The absence of rice response to the application of P and K was also observed by Lopes et al. (2016) and Reis et al. (2018), testing K doses and P and K combined doses, respectively, in soils with high levels of these nutrients. Besides, it is important to note that redox reactions, after flooding the soil, result in an increase of the available P levels in the solution, due to the release of the fraction adsorbed to Fe oxides, and also an increase in the available K content in the solution due to the Fe^{2+} and Mn^{2+} competition by the exchange sites of the soil solid phase (Sousa et al. 2015).

In Capivari do Sul, where the available P and K contents were below critical levels, the application of P and K fertilizers increased the average genotype yield by 1.35 Mg ha^{-1}, from 6.4 to 7.8 Mg ha^{-1}. Thus, the fertilizer application benefited the plant mainly until the increase of the availability of P and K for the crop, due to the soil reduction effect, which takes around 15-30 days after the flooding, when the plants are already in the V_4 stage onwards (Meurer 2012).

Hybrid genotypes have a high cost, in relation to cultivars, and fertilization represents around 10.9 % of the production cost in the rice crop (IRGA 2020c). Thus, we evaluated which was the effect of these factors on the profitability of the crop for the different managements carried out. The simplified economic analysis (Figure 4) proved the superiority of the hybrids, since, both in Triunfo and Capivari do Sul, there was a greater profitability in all treatments, in relation to the cultivar. In addition, for the average of the hybrids and the cultivar in both trials, the N dose in which the highest gross and net income were obtained was 150 kg ha^{-1}. In Triunfo, IRGA 424 CL, at 150 kg ha^{-1} of N, provided a net income of US$ 1,912.00 ha^{-1} and, to the average of hybrids, the gross income was US$ 2,282.00 ha^{-1} (19 % higher). In Capivari do Sul, at the same dose, the net income was US$ 1,549.00 ha^{-1} for the cultivar and US$ 1,857.00 ha^{-1} for the average of hybrids (20 % higher).

As previously seen, the maximum technical efficiency doses differed among the evaluated genotypes; however, if we consider the cultivar and the average of the hybrids, the dose with the greatest profitability was 150 kg ha^{-1} of N, which is identical to the recommendation made by Sosbai (2016), considering a soil with low organic matter content linked to a very high expectation of response to the addition of this fertilizer. Therefore, although there are differences in the responses of the genotypes to the fertilization with N, on average, the current recommendations are adequate for a high profitability, contributing to food security and maintenance of the production system.
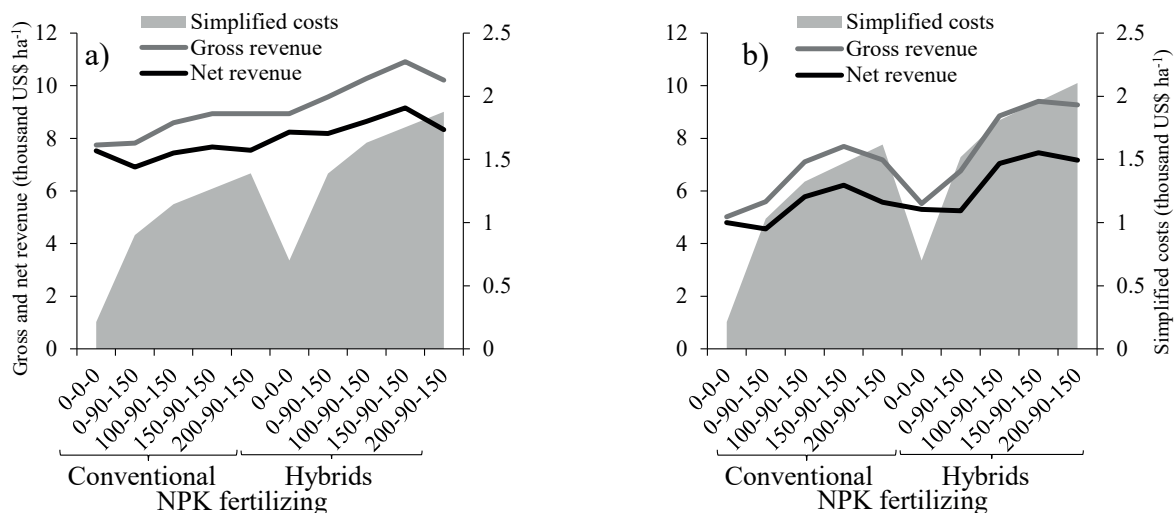

Figure 4. Simplified economic analysis of costs (conventional and hybrid seed and NPK fertilization) for implanting rice crops, gross revenue and net revenue in crops carried out in Triunfo (2017/2018; a) and Capivari do Sul (2018/2019; b).

CONCLUSIONS

1. The highest yields of the evaluated genotypes are obtained with N doses ranging from 106 to 200 kg ha^{-1}. However, the highest profitability occurs at the dose of 150 kg ha^{-1} (22 % higher than for the absence of N application);

2. The application of N increases, on average, by 10 and 35 % the yield of flooded rice, in years with favorable and unfavorable climatic conditions (peaks with high temperature and low solar radiation) for the development of the plants, respectively;

3. The hybrids have a yield approximately 20 % higher than the IRGA 424 CL conventional cultivar, with the profitability increased by 18 %;

4. In soil with P and K levels in medium to high availability, there is no increase in yield due to the application of these nutrients. However, in soil with very low levels of P and average levels of K, fertilization increases the grain yield by 21 %.

REFERENCES

BERLATO, M. O.; FONTANA, D. C. *El niño e la niña*. Porto Alegre: Ed. da UFRGS, 2003.

BRAGANTINI, C.; GUIMARÃES, E. P.; CUTRIM, V. dos A. Produção de sementes macho-estéreis em arroz. *Pesquisa Agropecuária Brasileira*, v. 36, n. 2, p. 273-277, 2001.

COIMBRA, J. L. M.; OLIVEIRA, A. C. de; CARVALHO, I. F. F. de; MAGALHÃES JUNIOR, A. M. de; FAGUNDES, P. R. R.; KOPP, M. M. Heterose em arroz híbrido. *Revista Brasileira de Agrociência*, v. 12, n. 3, p. 257-264, 2006.

COMPANHIA NACIONAL DE ABASTECIMENTO (Conab). *Insumos agropecuários*. 2018. Disponível em: https://bit.ly/2vSpOVl. Acesso em: 16 abr. 2020b.

COMPANHIA NACIONAL DE ABASTECIMENTO (Conab). *Série histórica das safras*. 2018. Disponível em: https://bit.ly/2ViIW99. Acesso em: 11 abr. 2020a.

FABRE, D. V. O.; CORDEIRO, A. C. C.; FERREIRA, G. B.; VILARINHO, A. A.; MEDEIROS, R. D. de. Doses e épocas de aplicação de nitrogênio em arroz de várzea. *Pesquisa Agropecuária Tropical*, v. 41, n. 1, p. 29-38, 2011.

FAGERIA, N. K.; BARBOSA FILHO, M. P. Avaliação preliminar de cultivares de arroz irrigado para maior eficiência de utilização de nitrogênio. *Pesquisa Agropecuária Brasileira*, v. 17, n. 12, p. 1709-1712, 1982.

FAGERIA, N. K.; KNUPP, A. M.; MORAES, M. F. Phosphorus nutrition of lowland rice in tropical lowland soil. *Communications in Soil Science and Plant Analysis*, v. 44, n. 20, p. 2932-2940, 2013.

FERREIRA, D. F. Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia*, v. 35, n. 6, p. 1039-1042, 2011.

GOULART, E. S. *Arranjos de semeadura e desempenho de híbridos de arroz*. 2012. Dissertação (Mestrado em Ciências) - Programa de Pós-Graduação em Ciência e Tecnologia de Sementes, Universidade Federal de Pelotas, Pelotas, 2012.

INSTITUTO RIO GRANDENSE DO ARROZ (IRGA). *Mercado*: Cepea - preços. 2018. Disponível em: https://bit.ly/2E8toPm. Acesso em: 12 maio 2020b.

INSTITUTO RIO GRANDENSE DO ARROZ (IRGA). *Mercado*: custo de produção de arroz 2018/19: revisado. 2018. Disponível em: https://bit.ly/2wwCMYS. Acesso em: 01 abr. 2020c.

INSTITUTO RIO GRANDENSE DO ARROZ (IRGA). *Safras*: cultivares safra 2019/20. 2018. Disponível em: https://irga-admin.rs.gov.br/upload/arquivos/202007/23184000-cultivares-10-safra-2019-20.pdf. Acesso em: 18 out. 2020a.

LOCK, R. H.: LOCK, E. F.: MORGAN, K. L.: LOCK, D. F.: LOCK, P. F. *Statistics*: unlocking the power of data. 2. ed. Nova York: Wiley, 2017.

LOPES, M. B. S.; SILVA, F. R. da; ZELLMER, V. A.; ALVES, P. M.; FIDELIS, R. R. Adubação potássica na cultura do arroz em solos arenosos de várzea tropical. *Applied Research & Agrotechnology*, v. 9, n. 3, p. 27-33, 2016.

MENEZES, V. G.; ANGHINONI, I.; SILVA, P. R. F. da; MACEDO, V. R. M.; PETRY, C.; GROHS, D. S.; FREITAS, T. F. S. de; LEON VALENTE, L. A. de. *Projeto 10*: estratégias de manejo para o aumento da produtividade e da sustentabilidade da lavoura de arroz irrigado no RS: avanços e novos desafios. Cachoeirinha: IRGA, 2012.

MENEZES, V. G.; MACEDO, V. R. M.; ANGHINONI, I. *Projeto 10*: estratégias de manejo para o aumento da produtividade, competitividade e sustentabilidade da lavoura de arroz irrigado no RS. Porto Alegre: IRGA, 2004.

MEURER, E. J. *Fundamentos de química do solo*. 4. ed. Porto Alegre: Evangraf, 2012.

REIS, A. F. de B.; NASCENTE, A. S.; ALMEIDA, R. E. M. de; CHAGAS JUNIOR, A. F. Growth and nutrient contents in lowland rice due to phosphorus and potassium fertilization. *Pesquisa Agropecuária Tropical*, v. 48, n. 2, p. 98-108, 2018.

RIBAS, G. G.; STRECK, N. A.; ISABEL, L.; ZANON, A. J.; WALDOW, D. A. G.; DUARTE JUNIOR, A. J.; NASCIMENTO, M. de F. do; FONTANA, V. Acúmulo de matéria seca e produtividade em híbridos de arroz irrigado simulados com o modelo SimulArroz. *Pesquisa Agropecuária Brasileira*, v. 51, n. 12, p. 1907-1917, 2016.

SANTOS, H. G. dos; JACOMINE, P. K. T.; ANJOS, L. H. C. dos; OLIVEIRA, V. A. de; LUMBRERAS, J. F.; COELHO, M. R.; ALMEIDA, J. A. de; ARAUJO FILHO, J. C. de; OLIVEIRA, J. B. de; CUNHA, T. J. F. *Sistema brasileiro de classificação de solos*. Rio de Janeiro: Embrapa Solos, 2018.

SCIVITTARO, W. B.; MACHADO, M. O. Adubação e calagem para a cultura do arroz irrigado. *In*: GOMES, A. S.; MAGALHÃES JUNIOR, A. M. *Arroz irrigado no sul do Brasil*. Brasília, DF: Embrapa Informação Tecnológica, 2004. p. 259-303.

SOCIEDADE SUL-BRASILEIRA DE ARROZ IRRIGADO (Sosbai). *Arroz irrigado*: recomendações técnicas da pesquisa para o sul do Brasil. Pelotas: Sosbai, 2016.

SOCIEDADE SUL-BRASILEIRA DE ARROZ IRRIGADO (Sosbai). *Arroz irrigado*: recomendações técnicas da pesquisa para o sul do Brasil. Farroupilha: Sosbai, 2018.

SOUSA, R. O.; CAMARGO, F. A. O; VAHL, L. C. Solos alagados (reações de redox). *In*: MEURER, E. J. *Fundamentos de química do solo*. 5. ed. Porto Alegre: Ed. dos Autores, 2015. p. 178-197.

STORK, L.; GARCIA, D. C.; LOPES, S. J.; ESTAFANEL, V. *Experimentação vegetal*. 2. ed. Santa Maria: Ed. UFSM, 2006.

SUHRE, E.; CORDEIRO, A. C. C.; MEDEIROS, R. D. Avaliação de linhagens de arroz em diferentes sistemas de cultivo em várzea de Roraima. *Revista Agro@mbiente On-line*, v. 2, n. 2, p. 1-9, 2008.

UNITED STATES DEPARTMENT OF AGRICULTURE (USDA). Soil Survey Staff. Natural Resources Conservation Service. *Keys to soil taxonomy*. 12. ed. Washington, DC: USDA, 2014.

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