Rice Ecophysiology: Climatic Variables and Yield at Uruguay

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1. Introduction

In the last 20 years the national rice yield has increased at a rate of approx. 150 kg/ha/year, explained by the adoption of high yielding cultivars, improved cultural practices and favorable environmental conditions; average national yields in Uruguay at the last six rice seasons was in the range 8.1-8.6 t/ha (Carracelas et al. 2017). In turn, in the same period the experimental yield for the main group of check varieties has increased 104 kg/ha/year (Macedo 2014). In this paper we study, for a series of 20 rice seasons, the productive performance of commercial varieties under experimental conditions in relation to climatic factors, with the aim of understanding the interaction between genotypes and environment; this allows the generation of new working hypotheses in genetic improvement as well as guidance in general crop management guidelines.

2. Materials and Methods

Data from 20 years of the Final Evaluation stage of advanced and elite cultivars of the Rice Breeding Program (PMGA) of INIA Treinta y Tres at the Paso de la Laguna Experimental Unit (UEPL) are analyzed. The management of these experiments is done as standard for rice practices in the country, including direct seeding at rates of 130-150 kg/ha, complete chemical weeds control, split fertilization of 70-100 kg total N/ha, approx. 50 kg/ha of P2O5 at sowing, full irrigation from 30-40 days post-emergency and without fungicide either insecticides applications. At least two seeding time were accomplished every season. The climatic information was extracted from the agroclimatic data bank of the INIA GRAS Portal, collected at the INIA Treinta y Tres station (33S, 54W). For this work, we collected daily data of maximum (TMAX) and minimum (TMIN) temperatures, number of days with a minimal temperature below 15 °C (DIAS T <15) and solar radiation (RAD [cal/cm2/day]) from the rice seasons of 1996-1997 to 2015-2016. The averages of these variables were estimated for four periods (0-3, Table 1), defined to assess the climatic impact on rice Yield and its components. The day recorded as "50% flowering" was taken as the "zero" day (heading), from which the reference periods were estimated and linked to the yield components that are mainly defined in each of them.

Table 1: Defined periods for evaluation of climatic factors on yield and yield components.

Period	Days	Yield Components
0	40-20 pre-heading days	Pan/m2, TotGr
1	20 pre-heading days	Pan/m2, TotGr
2	10 pre and 10 pos-heading days	%Ster, 1000GW
3	20 pos-heading days	1000GW

Pan/m2=number of panicles per square meter; TotGr=Total grains number per panicle; %Ster= percentage of unfiled grains; 1000GW= 1000 grains weight (grs)

Four cultivars were included as they were present on most of the serie: El Paso 144 (EP144) and INIA Olimar (Olimar), Indica subtype; INIA Tacuarí (Tacuarí) and Parao, Tropical Japónica subtype. The analysis was carried out with JMP 14.0 software (FTV), from SAS Institute Inc. To analyze the effects of components and climate on yield performance, an average of the repetitions of each experimental unit was used, then using Path Analysis. For its preparation, a model that estimates yield from registered yield components was adjusted, from which the standardized "beta" and the coefficient of determination R2 were obtained. The regression model used is: Y = a + bx + Ɛ; being: Y = yield, a =

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independent or intercept term, b = parameter (pending), being x = Pan/m2, TotGr, % Ster, 1000GW, Ɛ = experimental error.

On the other hand, a multiple regression model was first carried out using the Stepwise method for yield components based on climatic variables. The mixed methodology was used. This method selects some variables of all possible for all periods under consideration. The regression model used was: Y = a + bx + Ɛ; being Y = Pan/m2, TotGr, % Ster, P1000, a = independent term or intercept; b = parameter (pending); x = TMIN, TMAX, RAD, DAYS; Ɛ = experimental error. A model was also adjusted for Yield based on climatic variables, with the same methodology as for yield components based on climatic variables.

3. Results

Under the conditions of the East region of Uruguay, rice crop yield varies according to seeding time (ST) (Figure 1) as reported by Pèrez de Vida (2010); likewise, in this series, it results a significant interaction with the rice subtype. In "early" ST (defined until October 15) there are no statistical differences between the subtypes, although the average of the Indica was 400 kg/ha greater. In "intermediate" ST (October 15-November 15) the differences are not significant, with means differing by only 200 kg/ha. The yield in the set of sowings until "15-Nov" is maximized with Indica genotypes. In contrast, the difference between subtypes is significant in "late" ST (after November 15), in which the Japonica subtype significantly over yields (as by 600 kg/ha) the Indica subtype (Figure 1).

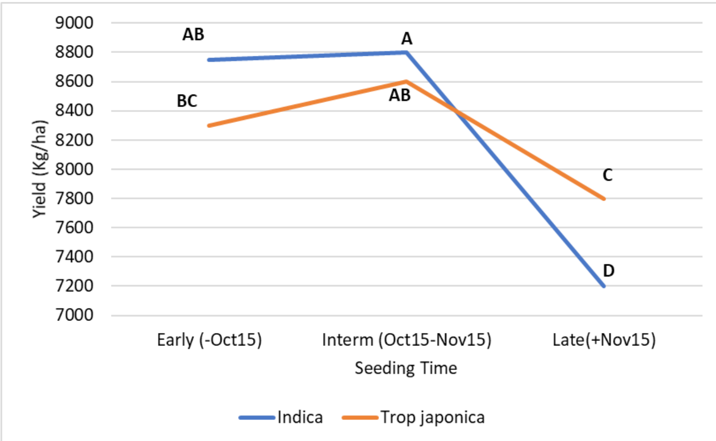

Figure 1: Yield according to seeding time and rice subtype (Indica [cultivars El Paso 144, INIA Olimar], and Tropical japonica [INIA Tacuarí and Parao]) and three seeding times (early, intermediate and late), in 20 years (from 1996/97 to 2015/16) at, Paso de la Laguna Experimental Unit, Treinta y Tres, Uruguay. (Letters indicate separation of means by Student's t-test, levels not connected by the same letter are significantly different α = 0.05).

The variations in yield linked to ST in Fig 1, are a function of the variation in climatic variables associated with the rice life cycle, given the time of planting of the genotypes. The path analysis diagram is shown in Figure 2, explaining grain yield based on climatic factors. The most important factors were selected by stepwise method, thus defining TMIN2 and RAD2 as being causally associated with variations in Yield; sun radiation around flowering (+/- 10 days) is the most important variable (as reported by Stansel (1975), Macedo (2014)).

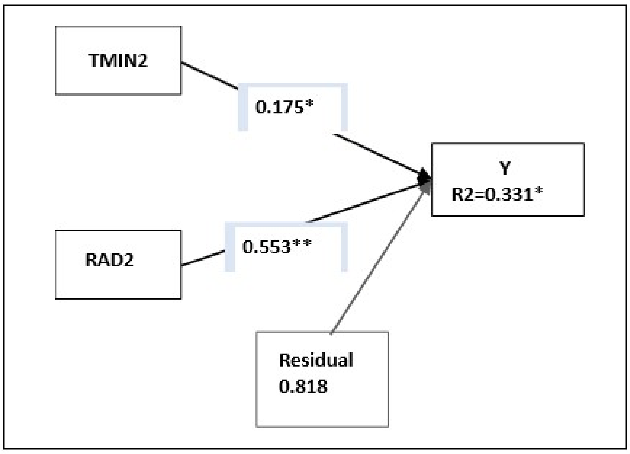

Figure 2: Yield as explained by climatic variables for cultivars Indicas (El Paso 144, INIA Olimar) and Tropical japonicas (INIA Tacuarí and Parao) and three planting times (Early, Intermediate and Late), in 20 years (from 1996/97 to 2015/16) at Paso de la Laguna Experimental Unit, Treinta y Tres Uruguay.
(* and **, represents significant with P = 0.05 and P = 0.01, respectively).

Paths diagrams for grain Yield are presented (Figure 3) according to its components (panicles/m2, total grains per panicle, % grain sterility and weight of 1000 grains), and in turn the model explaining the variations in these components based on climatic variables (only a significant one is showed). These considered climatic variables were those relevant at the definition time of the components (e.g. weight of 1000 grains would be mainly influenced by post-flowering environmental conditions); in table 2 are presented the direct and indirect effects of the components on Yield.

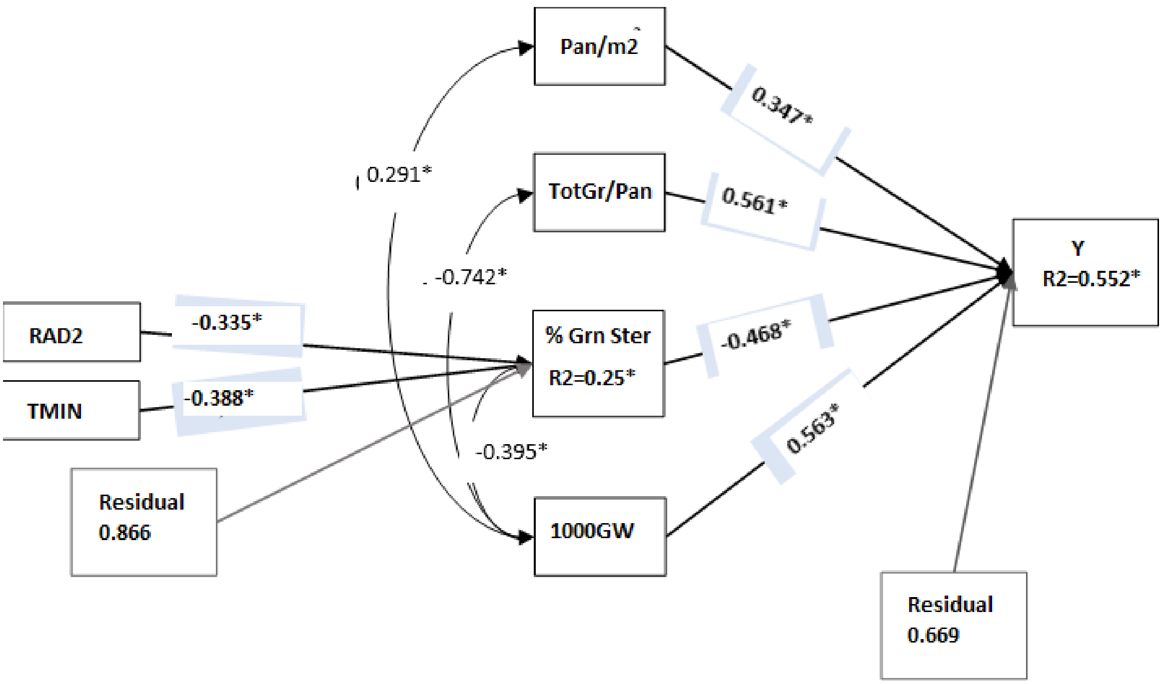

Figure 3. Diagram of path analysis for Yield (Y) as function of yield components, and effects of climatic variables on yield components (only significant at P=0.05 model is showed) for all cultivars (Indicas and Tropical Japonica) and seeding times. (Numbers in boxes of single head-arrows indicates values of path coefficients, numbers on double head-arrows indicates correlations coefficients) (* Significant with P = 0.05)

According to these results, all components have a significant direct effect on grain yield; being the weight of 1000 grains (P1000) and total grains per panicle (TotGr) which have "standardized beta" of greater absolute value. However, when considering the indirect effects, the TotGr component loses that importance, due to the strong indirect effect through 1000GW (high negative correlation between these components). In this balance of direct and indirect effects (those through the variables (components) with which it is correlated, it turns out that the most important component is % of sterile grains, with the highest sum of direct and indirect effects: -0.635. On the other hand, Pan/m2 and 1000GW have a similar overall effect, both positive and relevant, indicating the importance on Yield of high effective tillering and the weight of grains, with little interaction with climatic variables (Table 2). In relation to these, only the component "% grains sterility" is significantly affected. RAD and TMIN variables at period 2 (20 days around heading time), have both a numerically similar "beta" standardized coefficient and of equal sign (negative) (Figure 3).

Table 2: Direct, indirect and total effects of yield components on rice yield.

	Pan/m2	**TotGr/Pan**	**% grn ster**	**1000GW**
Direct	0,347	0,561	-0,468	0,563
Indirect	0,065	-0,500	-0,167	-0,130
Total Efect	**0,412**	0,060	**-0,635**	**0,433**

Conclusions

Rice production is maximized when the crop is sown in early or intermediate dates (1/10 to 15/11), while in late sowing the yield decreases significantly due to worse environmental conditions (temperature and radiation) at times of critical importance for the crop; yield of Tropical Japonica subtype decreases less than of Indica subtype cultivars. However, a greater proportion of yield variations are explained by variations in sun radiation, and less by low temperatures. Considering all ST the % grn ster is the component whose variations explain largely yield; otherwise, % grn ster was explained by variations in minimum temperature and radiation around flowering. Indeed, variables RAD and TMIN at 20 days around flowering were the most important climatic factors associated to the variation of crop yield. ST conditions the expected availability of environmental resources for whole crop; the earlier ST (October) would increase the available radiation in the period of critical importance (approx. 1st half of January), as well as later for grain filling period. Both, early and intermediate ST also decrease the incidence of low temperatures and therefore the % of grains sterility is minimized, resulting on larger crop yields.

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