SCAP
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Soil water tension and rice grain quality

Tensão de água no solo e qualidade do grão de arroz

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A B S T R A C T

Due to the high water use in rice irrigation at the main producing regions of Brazil, it is necessary to test and develop new water-saving cropping systems. The alternate wetting and drying (AWD) system is promising in terms of maintaining productivity levels and water savings. In addition to grain yield, grain quality should be considered, as it is important for commercialization. This study aimed to evaluate the effect of moderate soil water deficiency at different phenological stages of three rice cultivars, on rice grain quality. The experiment was installed in randomized blocks design, with splitplots and four replications. Treatments consisted on the following soil water levels (Factor B): (1) flooding; (2) saturated (0 kPa) but no flooding; (3) water tension up to 10 kPa; and (4) water tension up to 40 kPa. The crop developmental stage in which these water levels were applied was subdivided into three stages (Factor A): vegetative; reproductive initial and reproductive final. The whole, broken and streaked grains, chalky kernels and chalkiness were analyzed. There are no negative effects of water deficits up to 40 kPa applied to soil, at any phenological stage of rice, on grain quality of rice cultivar developed for continuous flood irrigation.

Keywords: water tension; phenological stage; irrigated rice.

R E S U M O

Com o elevado uso de água utilizada na irrigação do arroz, se faz necessário testar e desenvolver sistemas que poupem recursos hídricos. O sistema de inundação intermitente mostra-se promissor em termos de manutenção dos níveis de produtividade e economia de água. Além do rendimento de grãos, a qualidade do grão deve ser considerada, pois é um fator importante na comercialização. O trabalho teve como objetivo avaliar o efeito de moderada deficiência hídrica no solo em diferentes fases fenológicas sobre a qualidade de grãos em três cultivares de arroz. O delineamento experimental foi de blocos casualizados, com parcelas subdivididas com quatro repetições. Os tratamentos de deficiência hídrica foram (fator B): lâmina de água; saturado e as tensões de água no solo até 10 e até 40 kPa. O ciclo da cultura em que estes estresses foram aplicados foi subdividido em três fases (Fator A): vegetativa; reprodutiva inicial e reprodutiva final. As variáveis analisadas foram grãos inteiros, quebrados, gessados, barriga branca e rajados. Não há efeitos negativos dos déficits hídricos de até 40 kPa, em qualquer fase fenológica do arroz, sobre a qualidade de grãos de cultivares desenvolvidas para irrigação por inundação contínua.

Palavras-chave: Tensão de Água no Solo, Fase Fisiológica, Arroz-Irrigado.

INTRODUCTION

Rice is one of the most important food crops in the world, being consumed by more than 3 billion people (Fageria, 2007). Brazil occupies the ninth position among the rice producing countries, with a production of 10,602.9 tons in the 2015/16 cropping season (CONAB, 2016), and the state of Rio

Grande do Sul (RS) contributes with about 70% of this total (SOSBAI, 2016).

The Brazilian state of Rio Grande do Sul grows more than one million hectares of rice, almost entirely by continuous flooding irrigation, which demand in many situations more than 1,000 mm/ crop cycle, for an irrigation period of 80 to 100 days (SOSBAI, 2016). This high demand for water in rice has been a priority issue in discussions in the rice sector, in search for management alternatives aiming to save water, reduce production costs and minimize the environmental impacts (SOSBAI, 2014). The current irrigation management system uses a continuous water layer and connections between neighboring paddies, which potentiates water losses along the soil profile (Walker, 1999; Watanabe *et al*., 2006, 2007) and does not allow the rainfall water to be used, although during the irrigation period, rainfall in the rice regions represents, on average, 46% of total rice evapotranspiration, which is around 650 mm per crop cycle (Mota *et al*., 1990).

In this way, water management methods in rice, alternatives to continuous flooding, are being developed in Brazil and in several regions of the world, in order to reduce water demand while keeping productivity levels. Flood irrigation with periods in which the soil remains aerated, i.e. AWD (alternate wetting and drying) irrigation, is one of the most promising alternatives, and this assumes that rice tolerates periods of aerated soil. In this sense, works such as those by Massey *et al*. (2014), Yang *et al*. (2017) and Dasgupta *et al*. (2015) show that intermittent flood irrigation in rice allows crop grain yields similar or close to those provided by continuous flood irrigation, since the water deficits in the aeration cycles are moderate and adequate for the phenological stage of rice development. In addition to productivity, grain quality should be considered, since it is important for commercialization – whole grains which are free of defects present higher market value (Canellas *et al*., 1997; Ferreira *et al*., 2005).

The concept of grain quality of rice varies from country to country, however it can be stated that, in general terms, the industry defines that grain quality is mostly represented by the yield of whole and broken grains at the end of the processing. As for consumers, they are interested in the appearance, shape and size of grains, cooking behavior, texture and taste (Pandey *et al*., 2014). Most studies (Jennings *et al*., 1979; Cheng *et al*., 2003; Cai *et al*., 2006; Fofana *et al*., 2010) indicate that water stress, especially in the reproductive stage, may be negatively correlated to grain quality; however, there are controversies in this subject (Pan *et al*., 2009; Pandey *et al*., 2014). This study aimed to evaluate the effect of moderate soil water deficiency at different phenological stages of BRS Sinuelo CL, Puitá INTA CL and BRS Pampa rice cultivars, on the yield of whole grains and physical indicators of rice grain quality.

MATERIAL AND METHODS

Three field experiments were carried out at Embrapa Clima Temperado Experimental Station, located in Capão do Leão, RS, Brazil, Lat. 31° 48' 55" S; Lon. 52°28'09"W. The rice cultivars BRS Sinuelo CL (2014/15), Puitá INTA CL (2015/16) and BRS Pampa (2016/17) were used, all originally developed in flood-irrigated rice breeding programs, and recommended for the state of Rio Grande do Sul. The soil of the experimental area is classified as Typic Albaqualf (Soil Survey Staff, 2010) (in Brazilian classification, *Planossolo Háplico* (Streck *et al*., 2008) and the climate as subtropical humid with hot summers, according to Köppen classification (Peel *et al*., 2007), with average annual temperature of 17.8°C and precipitation of 1366.9 mm (averages for 1971 2000) (EMBRAPA, 2016). The sowing dates were respectively on 11/ Nov./2014, 16/Nov./2015 and 09/Nov./2016.

The experiments were installed in soil under conventional tillage system, after plowing and harrowing. Rice was sowed with a drill at density of 100 kg ha^{1} in the three years, with rows spaced in 17.5 cm. Base fertilization was applied to the sowing furrow (300 kg ha^{1} of the formulas 52030, 52020 and 52525, respectively for the years), based on soil analysis and considering the expectation for high response of the crop to fertilization (SOSBAI, 2014). Nitrogen topdressing was divided into two applications: the first in dry soil, preceding the water entry, in the four-leaf stage (V4) and the second, on a non-circulating water layer at panicle initiation (R0). Urea (45% N) was used as the source of nitrogen. The other cultural treatments followed the technical indications for the irrigated rice crop in RS (SOSBAI, 2016).

Treatments consisted in subjecting the plants to distinct soil water levels imposed at different phenological stages of the crop cycle (Table 1). The experiment was installed in randomized blocks design, with splitplots and four replications, in the three years. The phenological stage was attributed to main plots (20 m x 4.6 m each plot), and soil water tension was applied to subplots (4.6 m x 3.5 m each subplot).

Thus, there were two periods in which the crop remained with water layer: V4 V5 and R0 R1, which corresponds to the period between topdressing with N +4 days after each application, thus avoiding possible influence of interaction between soil water tension and N uptake by plants.

Irrigation started at V4, after the first N topdressing. For the implementation of the water deficit treatments, drainage was performed at the beginning of each period predicted for the imposition of the soil water tension (treatment), and the plot was irrigated again when it reached the threshold water tension for the treatment, by establishing a 10 cm water layer for 24 hours. In order to monitor soil water tension, two Watermark® sensors were installed per subplot at a depth of 10 cm, connected to a datalogger. Thus, the water tension was controlled independently for each subplot. During the periods when the crop was not under the water tension established for the respective treatment, subplots were kept flooded at approximately 7 cm depth.

For the monitoring of the phenological stages of rice, the scale of Counce *et al*. (2000) was adopted. The panicle initiation (R0) was considered to occur four days before panicle differentiation (Carli *et al*., 2014). Soon after harvest, threshing and pre-cleaning were carried out, then the samples were subjected to drying at a controlled temperature of 30°C until 13% humidity.

The procedure for obtaining the milling yield was performed in a Suzuki type test machine with operation time of one minute to remove the husk and grain polishing, followed by 30 seconds in the trieur to separate the whole, broken and streaked grains, and the chalky kernels. Chalkiness was later determined by visual evaluations. For cv. Sinuelo, only whole and broken grains were determined, since no trieur was available in the 2014/15 cropping season.

Data were submitted to statistical analysis, which consisted in the regression adjustment between mean water tensions (real observed tensions) which occurred in the period of soil water deficiency, and rice grain quality indicators, by using the statistical environment "R" (R CORE TEAM, 2016).

RESULTS AND DISCUSSION

The mean (real) soil water tensions for treatments were as follows (means for all development periods): *saturated*: 3-5 kPa; 2-7 kPa; 2-8 kPa, respectively to Sinuelo, Puitá and Pampa; *up to 10 kPa*: 7-9 kPa; 6-7 kPa; 5-8 kPa, respectively to Sinuelo, Puitá and Pampa; and *up to 40 kPa*: 15-21 kPa; 14-15 kPa; 11-17 kPa, respectively to Sinuelo, Puitá and Pampa. This variation was mainly attributed to differential rainfall occurrence among years. Obviously, the treatment with flooding was continuously at zero tension.

Results from whole and broken grains for cv. Sinuelo are shown in Table 2. Tables 3 and 4 show the results for whole and broken grains and

Table 1 - Soil water levels and crop stages where these water levels were applied at the three field experiments

Factor A (3 levels) - Phenological crop stage *	**Factor B (4 levels) -** Soil water tension / moisture level
(1) Vegetative (**Veg** – 5-leaf (V5) to panicle initiation (R0))	(1) flooded;
(2) Reproductive initial (**RI** - panicle differentiation (R1) to flowering (R4) + 10 days)	(2) saturated (0 kPa) but no flooding;
(3) Reproductive final (**RF** - R4 + 10 days to grain dry down (R7))	(3) up to 10 kPa of water tension
	(4) up to 40 kPa of water tension

* Rice growth scale by Counce et al. (2000).

other physical grain quality indicators for cv. Puitá and cv. Pampa. Mean values for whole grains for cv. Sinuelo, were 64.5%, 64.3% and 64.3%, respectively for Veg, RI and RF; and broken grains were 5.39%, 5.64 % and 5.58%, also respectively for Veg, RI and RF (Table 1).

Table 2 - Mean values for whole and broken grains (%) for cv. BRS Sinuelo CL, as function of water tension in soil, and phenological stage. Embrapa Clima Temperado, Capão do Leão, RS, Brazil, 2017

Phenological stage	Treatment	Whole Grains (%)	Broken Grains (%)
Vegetative	Flooding	64.3[NS*]	5.78[NS]
	Saturated	63.7	5.58
	10 kPa	64.7	5.18
	40 kPa	65.5	5.05
	Mean	64.5	5.39
Reproductive initial	Flooding	65.3[NS]	5.35[NS]
	Saturated	63.8	5.45
	10 kPa	64.6	5.78
	40 kPa	63.6	6.00
	Mean	64.3	5.64
Reproductive final	Flooding	64.5[NS]	5.73[NS]
	Saturated	64.2	5.78
	10 kPa	64.1	5.48
	40 kPa	64.4	5.33
	Mean	64.3	5.58

*Regression analysis was non-significant (no adjustment) between mean water tensions in the period under stress and the grain quality indicators.

For cv. Puitá, the mean values for whole and broken grains in the phenological stages Veg, RI and RF were, respectively 65.5%, 65.1% 65.0% and 4.82%, 5.66% and 5.93%. For cv. Pampa, the values were 58.0%, 59.2%, 58.2% for whole grains and 8.3%, 8.1% and 8.8% for broken grains, respectively for the phenological stages.

The cultivars Sinuelo and Puitá presented similar values (Tables 2 and 3). However, although still with good results, cv. Pampa (Table 4) yielded a lower proportion of whole grains and a higher proportion of broken grains compared to the other two cultivars. According to Magalhães *et al*. (2010), the industrial yield of whole rice grains under normal conditions of crop and milling management is higher than 61% of whole grains, with total milling yield of 69%; thus, it is verified that values obtained in the present study, even under soil water levels below the ideal, were satisfactory.

It can also be verified that the moderate water deficit (Parfitt *et al*., 2017) did not affect the percentage of whole and broken grains in the distinct phenological stages of each cultivar, that is, there were no differences in milling yield, independently of the crop stage in which the treatment was imposed. Xie *et al*. (2001), on the other hand, verified that water deficit was most preponderant for rice grain quality when imposed at grain filling stage.

Concerning the physical indicators of grain quality, such as chalkiness, chalky and streaked kernels, for Puitá and Pampa it can be verified that both presented very low values for these indicators. Only the values of streaked grains for cv. Puitá exceeded 1% of the total grains.

According to Fornasieri Filho and Fornasieri (2006), the Brazilian legislation establishes a minimum of 40% for whole grains and a maximum of 28% for broken grains; thus, the results of this study fit both parameters. According to MAPA (1988), for chalkiness and streaked grains, the mean data obtained are within the values considered ideal for human consumption, since the maximum limit for these variables is 15% and 10%, respectively.

The regression analyses between the mean soil water tensions and the grain quality indicators within each subplot, for both the three cultivars and the three phenological stages, show that the soil water level did not affect grain quality (Tables 2, 3 and 4). It is important to mention that the maximum water tensions in these experiments were slightly higher than 40 kPa due to the water replenishment schedule, which was performed daily in the early hours of the morning. Tensions around 40 kPa can still be considered as moderate, since in practical terms, for rice in the reproductive stage at this type of soil, this water tension would be reached between 3 and 5 days after saturation, with no rains.

Water stress in rice crop reduces productivity, and this grain yield reduction is proportional to the level of stress (Arf *et al*., 2002; Huang *et al*., 2008). According to O'Toole (1982), grain productivity response to water stress varies with the growth stage of the plant, being the most sensitive stages the flowering followed by booting and grain filling. Parfitt *et al*. (2017) found rice grain yield reductions

Table 3 - Mean values for whole, broken and streaked grains, chalky kernels and chalkyness for cv. Puitá Inta CL, as function of water tension in soil, and phenological stage. Embrapa Clima Temperado, Capão do Leão, RS, Brazil, 2017

Phenological stage	Treatment	Whole Grains (%)	Broken Grains (%)	Chalky Kernel (%)	Chalkiness (%)	Streaked Grains (%)
Vegetative	Flooding	64.7 NS*	5.19 NS	0.82 NS	0.01 NS	2.48 NS
	Saturated	66.1	4.70	0.61	0.03	2.95
	10 kPa	65.5	4.27	0.55	0.00	2.45
	40 kPa	65.5	5.12	0.49	0.04	2.37
	Mean	65.5	4.82	0.62	0.02	2.56
Reproductive initial	Flooding	64.8 NS	5.76 NS	0.53 NS	0.08 NS	1.59 NS
	Saturated	65.1	5.67	1.07	0.06	2.22
	10 kPa	65.2	5.40	1.05	0.05	1.64
	40 kPa	65.6	5.81	0.60	0.03	2.01
	Mean	65.1	5.66	0.81	0.05	1.87
Reproductive final	Flooding	63.9 NS	6.05 NS	0.98 NS	0.05 NS	0.95 NS
	Saturated	65.2	6.18	0.37	0.01	0.96
	10 kPa	66.2	4.96	0.79	0.07	1.14
	40 kPa	64.9	6.51	0.78	0.04	1.38
	Mean	65.0	5.93	0.73	0.04	1.11

*Regression analysis was non-significant (no adjustment) between mean water tensions in the period under stress and the grain quality indicators.

Table 4 - Mean values for whole, broken and streaked grains, chalky kernels and chalkyness for cv. BRS Pampa, as function of water tension in soil, and phenological stage. Embrapa Clima Temperado, Capão do Leão, RS, Brazil, 2017

Phenological stage	Treatment	Whole Grains (%)	Broken Grains (%)	Chalky Kernel (%)	Chalkiness (%)	Streaked Grains (%)
Vegetative	Flooding	59.3 NS*	8.1 NS	0.23 NS	0.01 NS	0.003 NS
	Saturated	57.5	8.5	0.13	0.02	0.000
	10 kPa	58.5	7.9	0.24	0.01	0.000
	40 kPa	57.9	8.4	0.15	0.02	0.000
	Mean	58.0	8.3	0.172	0.018	0.000
Reproductive initial	Flooding	59.3	8.1	0.23	0.01	0.003
	Saturated	59.6	7.9	0.31	0.02	0.000
	10 kPa	58.4	8.5	0.31	0.02	0.000
	40 kPa	59.7	7.9	0.35	0.00	0.000
	Mean	59.2	8.1	0.325	0.014	0.000
Reproductive final	Flooding	59.3	8.1	0.23	0.01	0.003
	Saturated	58.8	8.6	0.34	0.01	0.007
	10 kPa	57.3	9.2	0.34	0.01	0.000
	40 kPa	58.5	8.7	0.37	0.03	0.000
	Mean	58.2	8.8	0.349	0.016	0.002

*Regression analysis was non-significant (no adjustment) between mean water tensions in the period under stress and the grain quality indicators.

under field conditions when soil water tension was above 10 kPa, with serious grain yield reductions above 30 kPa. Reduction in productivity due to water stress at flowering is a result of reduced panicle fertility and percentage of full grains, by accelerating plant senescence at this stage of the cycle. According to Xie *et al*. (2001), the grain filling pattern has a marked influence on grain quality. However, the effect of water stress in this period may vary with the genotype of each cultivar (Bhattacharya, 1980; Roshan *et al*., 2013). In general, grain quality is influenced by genetic factors and environmental conditions (Krishnan *et al*., 2005).

Although some studies indicate that reduced soil moisture has a marked negative influence on grain quality, especially when the stress occurs at grain filling (Dingkuhn *et al*., 1996), our study with three years and three cultivars, do not corroborate this information. It is assumed that the water deficits which occurred in soil and/or plant in studies that detected effect of water stress on grain quality, were more severe than those verified in the present study.

To illustrate how literature data related to the effect of water stress on grain quality is controversial, Pan *et al*. (2009), for example, demonstrated that rice cultivated in the AWD or raisedbed systems – therefore with periods of stress, presented higher grain quality compared to the obtained in the traditional (continuous) flood irrigation system. It is noteworthy that the maximum water deficiency in the work of Pan *et al*. (2009) corresponds to soil moisture content of about 70-80% of the saturation moisture, which is very similar to the conditions in which the experiments of the present study were performed.

CONCLUSIONS

Soil water deficiency of up to 40 kPa, in any phenological stage of the crop cycle, does not affect grain quality of rice cultivars developed in rice breeding programs for continuous flood irrigation.

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