WATER SUPPLIED BY SPRINKLER IRRIGATION SYSTEM FOR UPLAND RICE SEED PRODUCTION

FORNECIMENTO DE ÁGUA POR MEIO DE IRRIGAÇÃO POR ASPERSÃO PARA PRODUÇÃO DE SEMENTES DE ARROZ DE TERRAS ALTAS

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ABSTRACT: Physiological quality of rice seeds may be influenced by water deficiency at seed development and filling stages, which is often reported in upland cropping system. This study had the objective of evaluating the effects of sprinkler irrigation system on the improvement of physiological quality of rice seeds produced under upland conditions. Two experiments were carried out in Selvíria-MS, Brazil, Ilha Solteira College of Engineering, UNESP, in 1994/1995 and 1995/1996, with the upland rice cultivars 'IAC 201' and 'Carajás'. In both years, rice plants were grown under rainfed and sprinkler-irrigation conditions. Based on the rice crop coefficient (Kc), the following water levels were obtained: L1: 0.5 times the Kc, L2: Kc, L3: 1.5 times the Kc, L4: Kc = 1.95. Weight, germination and vigor of rice seeds were evaluated right after harvest. The experimental design was the completely randomized with four replications. Data was submitted to analysis of variance and means were compared by Tukey's test ($P \leq 0.05$) separately for each cultivar. It was concluded that levels of water varying from 0.5 to 1.5 times the rice crop coefficient, supplied through sprinkler-irrigation system, provide better conditions to produce rice seeds of upland cultivars with higher physiological quality.

KEYWORDS: *Oryza sativa*. Germination. Vigor. Rainfall. Water availability.

INTRODUCTION

Rice (*Oryza sativa* L.) crops are cultivated in Brazil in two ecosystems: lowland, in which the crop is irrigated by surface water flows or by water-table elevation, and upland, with no irrigation, or with sprinkler irrigation (GUIMARÃES; SANT'ANA, 1999). The predominant rice ecosystem in Brazil is upland, representing about 61% of the total area used to grow rice, and being responsible for 35% of unhulled rice production (VIEIRA et al., 1991).

Whenever rice plants are not affected by water stress, seed formation is continuous, increasing the number of seeds per panicle, seed weight (GIÚDICE et al., 1974; PINHEIRO et al., 1985) and physiological quality. Therefore, the most likely reason for obtaining low yield and rice seeds of upland cultivars with poor quality is the dependence on rainfall for crop water supply (VIEIRA et al., 1991). The practice of sprinkler irrigation has been demonstrated to be a viable method for solving the water supply problem (McCAULEY, 1990). Additionally, the improvements through the use of sprinkler irrigation may also vary according to genetic characteristics of rice cultivars, besides the influence of precipitation in the cropping season (ARF et al., 2001).

The effects of drought on the rice crop vary. It may decrease nutrient uptake, such as nitrogen and potassium (TANGUILIG et al., 1987), influencing seed formation and development. Water availability may also influence export and distribution of assimilates to seeds. Seed weight may be affected if the amount of water is not sufficient in the maturation stage (STONE et al., 1986; DABNEY; HOFF, 1989), mainly within the first 14 days after flowering. As reported by Carvalho and Nakagawa (2000), bigger and heavier seeds have well formed embryos and thus show higher vigor. Consequently, quality of rice seeds may be indirectly influenced by water availability.

In soybean, seed germination and vigor decrease in drought conditions (KEIGLEY; MULLEN, 1986; DORNBOS et al., 1989; SMICIKLAS et al., 1989). As for grasses, Ghassemi-Golezani et al. (1997) did not observe differences in maize and sorghum. Crusciol et al. (2001) observed that drought decreased quality of rice seeds cultivar 'Caiapó' produced under rainfed conditions compared to a sprinkler-irrigation system.

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This study had the objective of evaluating the effects of sprinkler irrigation system on the improvement of physiological quality of rice seeds cultivars ‘IAC 201’ and ‘Carajás’ produced under upland conditions.

MATERIAL AND METHODS

This study was conducted in Selvíria-MS, Brazil, Ilha Solteira College of Engineering, UNESP, located at 51º 22' W longitude and 20º 22' S latitude, altitude 335 m asl in two growing seasons, 1994/1995 and 1995/1996. Annual rainfall is 1,232 mm. Soil of the experimental area was a Rhodic Hapludox (FAO, 2006). Average annual temperature and relative humidity are 24.5ºC and 70-80%, respectively.

Before the beginning of the experiment, samples were taken at random for soil chemical analysis, according to Raij et al. (2001) (Table 1). Afterwards, soil was tilled with plowing and two diskings.

During the experiment, minimum and maximum temperatures were daily recorded. Rainfall was also monitored (Figure 1).

Table 1. Soil chemical attributes.

Year	Organic matter ($g\ kg^{-1}$)	pH ($CaCl_2$)	P_{resin} mg dm^{-3}	K	Ca	Mg	H+Al	SB	CEC	Base saturation (%)
				$mmol_c\ dm^{-3}$						
1994/1995	26	5.4	24	1.3	24.0	15.2	29.2	40.5	69.7	58
1995/1996	23	5.1	26	1.9	28.0	8.0	28.0	37.9	65.9	58

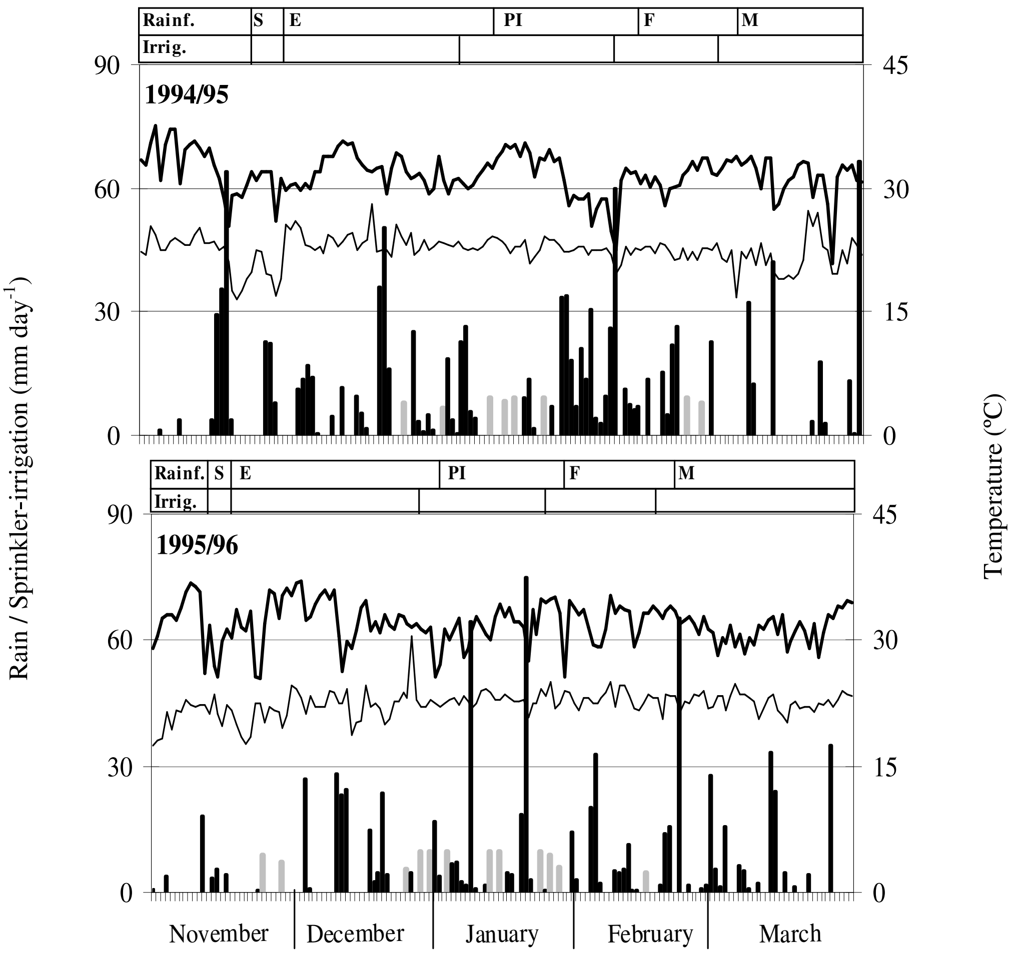

Figure 1. Rain ( ), sprinkler-irrigation ( ), maximum ( ) and minimum ( ) temperatures from November to March of 1994/1995 and 1995/1996 in Selvíria-MS, Brazil. Rainf.: treatment without irrigation, with only natural precipitation; Irrig.: sprinkler-irrigation system; S: sowing; E: emergence; PI: panicle initiation; F: flowering and M: maturation.

The experimental design was the completely randomized with four replications. Treatments consisted of upland rice cultivars 'IAC 201' and 'Carajás' grown under rainfed and four different sprinkler-irrigated conditions. The sprinkler levels were calculated based on the rice crop coefficient (Kc) reported by Reichardt (1987), although some modifications had been made to obtain water level 2 (L2), which was considered as reference to obtain the others. Level 1 (L1) consisted of half the crop coefficient used to calculate level 2. Level 3 (L3) was obtained by multiplying L2 by 1.5 times. As for level 4 (L4), a Kc of 1.95 was used during all the experiment (Table 2).

Table 2. Irrigation levels (L) and respective crop coefficients (Kc).

Irrigation levels	E*	BD			MS	
	Vegetative stage	Reproductive stage				Maturation
	P1**	P2	P3	P4	P5	P6
	-30	-19	-11	-3	+5	+12
	---------- valores de Kc ----------					
Natural rainfall	-	-	-	-	-	-
L1	0.20	0.35	0.50	0.65	0.50	0.35
L2	0.40	0.70	1.00	1.30	1.00	0.70
L3	0.60	1.05	1.50	1.95	1.50	1.05
L4	1.95	1.95	1.95	1.95	1.95	1.95

* E: emergence; BD: bud differentiation; MS: maturation stage;** Days, in relation to flowering, for the use of crop coefficients. P1: period between seedling emergence and 30 days before flowering; P2: period between 30 and 19 days before flowering; P3: period between 19 and 11 days before flowering; P4: period between 11 and 3 days before flowering; P5: period between 3 days before and 5 days after flowering; P6: period between 5 and 12 days after flowering.

Soil water retention capacity was determined according to Grohmann (1960), Richards and Fireman (1943) and Richards (1947) for the ranges 0.002 to 0.01 MPa, 0.033 to 0.101 MPa and 0.101 to 1.520 MPa, respectively. Table 3 shows the tensions used to obtain the water retention curve from the amounts of water in the depths 0-15 cm and 15-30 cm.

Table 3. Water tensions and moisture contents (%).

Layer (cm)	Tension (MPa)							
	1.520	0.507	0.101	0.033	0.010	0.006	0.004	0.002
	Moisture (%)							
0-15	14.58	15.15	16.95	18.51	20.50	26.24	27.78	44.22
15-30	16.94	17.88	19.49	20.35	22.55	27.61	31.45	47.80

The water retention curve in the depth 0-15 cm showed that moisture was 0.2050 and 0.1458 g g^{-1}, at field capacity and permanent wilting point, respectively. Soil bulk density was 1.25 g cm^{-3} and effective root depth was down to 20 cm.

Available water capacity (AWC, mm) was calculated by the expression **AWC = (µfc - µpwp) x δa x ERD**, which means: **µfc** = moisture at field capacity (g g^{-1}); **µpwp** = moisture at permanent wilting point (g g^{-1}); **δa** = bulk density (g cm^{-3}); **ERD** = effective root depth (cm). Therefore, AWC was considered 14.80 mm.

Application rate per sprinkler was 3.3 mm h^{-1}, whenever maximum evapotranspiration reached 8.25 mm.

Each experimental unity consisted of six rows of plants 6 m long and spaced 0.40 m. The useful area was the four central rows, except 0.50 m of each extremity.

Sowing took place on November, 24th of 1994 and November, 13th of 1995, using 100 seeds per m^2 treated with carbofuran (1.5 kg ha^{-1} of the active ingredient). Seedling emergence was on December, 2nd of 1994 and November, 21st of 1995. Weed was controlled with the herbicides oxadiazon and 2.4D (1 kg ha^{-1} and 670 g ha^{-1} of the active ingredient, respectively). Side dressing fertilization consisted of 30 kg ha^{-1} of urea applied at tillering. Panicles were manually harvested and threshed.

Seeds were stored under environmental conditions while evaluated by the following germination and vigor tests:

Weight of 1,000 seeds: it was obtained by weighing two replications of 1,000 seeds from each treatment (BRASIL, 1992). The results were expressed in grams.

Germination: four replications of 50 seeds per lot were distributed on towel paper moistened with water equivalent to 2.5 times the weight of the dry paper. Rolls were made and placed into plastic bags and left for germination at 25ºC. Evaluation took place 5 and 14 days after sowing (BRASIL, 1992) and results were expressed as mean percentage of normal seedlings.

First count of germination: it was performed along with the germination test; the percentage of normal seedlings was recorded on the 5th day after sowing.

Speed of germination-index (SGI): the number of normal seedlings from the germination test was daily recorded until de 14th day and then, the formula established by Maguire (1962) was applied.

Accelerated aging: according to Marcos Filho (1999), four replications of 50 seeds were arranged on accelerated aging trays. These were placed into plastic boxes (11.0 x 11.0 x 3.5 cm) with 40 mL of water at the bottom. The boxes remained at 42ºC for 96 hours. Afterwards, the seeds from each treatment were analyzed through the germination test. The percentage of normal seedlings was recorded on the 5th day after sowing.

Electrical conductivity: fifty seeds of each replication were weighed and soaked into 200-mL plastic cups containing 75 mL of deionized water, for 24h at 25ºC (VIEIRA; KRZYZANOWSKI, 1999); afterwards, the electrical conductivity of the solution was determined through reading in a conductivimeter and the mean values obtained for each lot were expressed as μS cm^{-1} g^{-1}.

For statistical analysis, data was submitted to analysis of variance and means for each seed quality evaluation were compared by Tukey's test at a probability level of 5%. Data from both years were analyzed separately.

RESULTS AND DISCUSSION

In both growing seasons, the amount of water applied in the reproductive stage of the rice crop was higher than in the vegetative stage for levels 1, 2 and 3, except for level 4, considering that higher Kc was continuously adopted during all the cycle (Table 4). In 1994/1995, the differences in the total amount of water applied in each treatment were not proportional to the crop coefficients due to rainfall distribution and intensity. As for the growing season 1995/1996, the differences in the total amount of water applied in each growth stage was closer to the Kc values previously established, considering all periods within each stage (Table 2). At maturation, there was no water application in level 1 because the least required limit was not reached for replacement.

Table 4. Water levels in the vegetative (V), reproductive (R) and maturation (M) stages of rice plants.

Stages	Water level (mm)								
	Irrigation				Total amount of water				
	L1(1)	L2	L3	L4	Natural rainfall	L1	L2	L3	L4
1994/1995									
V	-	14.4	38.5	148.7	333.7	333.7	293.3	294.9	329.5
R	18.7	42.5	68.7	137.5	328.2	343.9	322.6	361.3	415.4
M	18.7	17.0	26.0	32.1	180.6	135.4	233.6	252.6	349.0
Total	37.4	73.9	133.2	318.3	842.5	813.0	849.5	908.8	1093.9
1995/1996									
V	2.2	21.3	30.4	151.4	245.2	242.3	251.4	260.5	381.5
R	26.7	59.2	96.2	120.0	228.4	245.2	277.3	314.3	338.1
M	-	19.5	57.3	110.3	124.2	139.2	159.1	185.7	231.9
Total	28.9	100.0	183.9	381.7	598.8	626.7	687.8	760.5	951.5

(1) L1 – Kc*0.5; L2 – Kc (rice crop coefficient); L3 – Kc*1.5; L4 – Kc=1.95

Seed weight of the cultivar 'IAC 201' was significantly influenced by the treatments in 1994/1995 (Table 5). All water levels supplied by sprinkler-irrigation system increased seed weight compared to the production under rainfed conditions.

Seed weight is usually a non-variable characteristic. It depends on seed coat (YOSHIDA, 1981) and caryopsis (MATSUSHIMA, 1970) development, which occur two weeks before anthesis and after flowering, respectively. Therefore, the accumulation of reserve substances is affected by carbohydrate distribution (MACHADO, 1994). According to Figure 1, there was a 6-day drought period during reserve accumulation, and thus rice seeds produced with no additional irrigation showed lower weight. Similar results were found by Giúdice et al. (1974) and Pinheiro et al. (1985) who reported that water availability is essential in the filling stage.

Table 5. Seed weight (SW, g), germination (G, %) and vigor (first count of germination, FC, %; speed of germination-index, SGI; accelerated aging, AA, % and electrical conductivity, EC, μS cm^{-1} g^{-1}) of rice cultivars as affected by sprinkler irrigation levels in 1994/1995.

Cultivar	Irrigation levels	SW	G	FC	SGI	AA	EC
IAC 201	Natural rainfall	19.9 b [2]	87	83	8.42	39 bc	69.04 b
	L1[1]	23.5 a	94	80	8.50	50 abc	42.08 a
	L2	23.2 a	91	88	8.90	55 ab	45.46 a
	L3	22.6 a	93	82	8.57	66 a	47.20 a
	L4	22.8 a	89	87	8.77	33 c	47.12 a
	C.V. (%)	4.46	4.76	5.70	5.08	17.54	10.88
Carajás	Natural rainfall	29.2	88	84	8.49	55	37.60 b
	L1	31.3	88	83	8.48	67	31.01 a
	L2	31.4	89	87	8.72	66	26.96 a
	L3	31.3	96	91	9.23	75	26.97 a
	L4	31.9	90	88	8.82	55	26.96 a
	C.V. (%)	8.64	5.14	6.46	5.73	14.15	6.98

[1] L1 – Kc*0.5; L2 – Kc (rice crop coefficient); L3 – Kc*1.5; L4 – Kc=1.95; [2] Means followed by the same letter in the column do not differ significantly by the Tukey test (P≤0.05) for each rice cultivar

Conversely, there was no effect of any of the treatments on seed weight of the cultivar 'Carajás', probably because this material is better adapted to drought situations.

Seed germination and vigor evaluated by the first count and speed of germination-index did not vary with any of the irrigation conditions for neither of the cultivars (Table 5). Ghassemi-Golezani et al. (1997) also did not observe any negative effects of drought on germination and vigor of maize and sorghum seeds. Conversely, Crusciol et al. (2001) evaluated final percentage and speed of germination of rice seeds cultivar 'Caiapó' affected by different levels of irrigation and found that seeds produced under rainfed conditions were of lower quality.

In this study, it was not observed any effects of water availability on seed germination. However, seed vigor was significantly influenced by the treatments, as shown by the evaluations of accelerated aging and electrical conductivity (Table 5).

The accelerated aging test was efficient to establish different vigor levels of rice seeds cultivar 'IAC 201'. Seed vigor decreased either under rainfed conditions or water excess (L4). Better results were obtained for intermediary water levels (L1, L2 and L3). Seed vigor was probably affected by the dry periods reported in the vegetative stage of the crop (Figure 1), although seed germination was not influenced. Seeds from different treatments may have similar germination values they can differ in the extent of deterioration and so exhibit differences in their ability to establish vigorous seedlings.

As already mentioned, seed weight of the cultivar 'Carajás' was not affected by water levels, which may directly influence seed vigor, especially evaluated by the accelerated aging test. Therefore, no differences among the treatments were detected, once heavier seeds are more vigorous (CARVALHO; NAKAGAWA, 2000). In addition, seed formation and reserve accumulation depend on the efficiency with which the plants can use the limited available water (PASSIOURA, 1994), which can vary among genotypes. Comparing both studied materials, cultivar 'Carajás' is better adapted to drought situations.

For both cultivars, rice seeds produced under rainfed conditions showed higher values of electrical conductivity. Lower values were observed for all water levels supplied by the sprinkler irrigation system, which did not differ from each other. Low conductivities are considered to be an indication of high vigor because it is thought to represent a low level of cell membrane system disorganization (MARCOS FILHO, 2005). Considering that the membranes are the last structures to become fully organized before the maturation stage (HEYDECKER, 1974), the 6-day drought that occurred during the reserve accumulation period could have increased leaching of essential metabolites.

Seed weight of the cultivar IAC 201 was positively affected by the higher amount of water applied through a sprinkler irrigation system (L4) in 1995/1996 (Table 6). Also, the lower the amount of water the lower the seed weight. Therefore, the lower value was obtained when rice was cropped under rainfed conditions. Seed weight decreased because seed filling was harmed by short drought periods (Figure 1) during the maturation stage in both years, mainly 14 days after flowering (MATSUSHIMA, 1970) and two weeks before anthesis (YOSHIDA, 1981). Similar results were reported by Giúdice et al. (1974) and Pinheiro et al. (1985). The same effects were observed for this material in the previous year. Seed weight of the cultivar 'Carajás' was influenced similarly to the results reported by Crusciol et al. (2003) on grain yield. The authors observed that either rainfed conditions and the lower water level (L1) sprinkled resulted in lower values compared to higher water supply (L2, L3 and L4), once drought periods were reported from November to March of 1995/1996 (Figure 1).

Seed germination and vigor evaluated by the first count and speed of germination-index of the cultivar 'Carajás' was significantly influenced by the irrigation treatments (Table 6). Lower quality was observed for seeds produced under conditions of water excess (L4), although the means did not differ from the lower water level (L1). The other conditions did not differ from each other and all of them increased the percentage and speed of germination. Crusciol et al. (2001) also found that water excess decreased the physiological quality of rice seeds cultivar 'Caiapó'. For that specific situation, the authors explained that the genotype belonged to the landrace group and it was recommended for upland cropping, not adapted to flood conditions.

Table 6. Seed weight (SW, g), germination (G, %) and vigor (first count of germination, FC, %; speed of germination-index, SGI; accelerated aging, AA, % and electrical conductivity, EC, $\mu S\ cm^{-1}\ g^{-1}$) of rice cultivars as affected by sprinkler irrigation levels in 1995/1996.

Cultivar	Irrigation levels	SW	G	FC	SGI	AA	EC
IAC 201	Natural rainfall	21.7 c (2)	75	74	7.48	63	53.77 bc
	L1 (1)	23.2 bc	79	77	7.82	61	56.78 c
	L2	23.8 b	80	79	7.95	77	45.94 ab
	L3	24.4 b	81	80	8.05	79	40.94 a
	L4	26.3 a	80	79	7.89	67	37.00 a
	C.V. (%)	6.49	6.54	7.19	6.45	15.16	13.80
Carajás	Natural rainfall	33.0 b	80 a	76 a	7.87 a	69	41.23
	L1	32.9 b	77 ab	75 ab	7.58 ab	63	37.46
	L2	34.7 a	79 a	78 a	7.83 a	76	36.14
	L3	35.3 a	92 a	81 a	8.10 a	72	33.49
	L4	35.8 a	73 b	72 b	7.20 b	65	34.45
	C.V. (%)	3.62	4.85	5.15	5.04	11.92	11.96

(1) L1 – Kc*0.5; L2 – Kc (rice crop coefficient); L3 – Kc*1.5; L4 – Kc=1.95; (2) Means followed by the same letter in the column do not differ significantly by the Tukey test (P≤0.05) for each rice cultivar

Seeds of the cultivar 'IAC 201' produced under rainfed conditions and with a lower water level (L1) showed higher electrical conductivity (Table 6) and thus lower vigor (MARCOS FILHO, 2005), similarly to the results obtained in 1994/1995. These two treatments had similar effects probably because there was no water application in L1 at maturation stage. Dornbos et al. (1989) also reported an increase by 20% in the electrical conductivity of seeds produced under rainfed conditions.

CONCLUSION

Levels of water varying from 0.5 to 1.5 times the rice crop coefficient, supplied through sprinkler-irrigation system, provide better conditions to produce rice seeds of upland cultivars with higher physiological quality.

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RESUMO: A qualidade fisiológica das sementes de arroz pode ser afetada pela ocorrência de deficiência hídrica durante as fases de desenvolvimento e formação, situação frequente em cultivos de sequeiro. Este trabalho objetivou avaliar os efeitos do sistema de irrigação por aspersão na melhoria da qualidade fisiológica de sementes de arroz produzidas em condições de sequeiro. Dois experimentos foram conduzidos em Selvíria-MS, Brasil, Faculdade de Engenharia de Ilha Solteira, UNESP, em 1994/1995 e 1995/1996, com os cultivares de arroz de sequeiro 'IAC 201' e 'Carajás'. Em ambos os anos, as plantas de arroz foram cultivadas sob condições de sequeiro, sem e com irrigação por aspersão. Quatro níveis de água foram calculados em função do coeficiente da cultura do arroz (Kc): L1: 0,5 x Kc, L2: 1 x Kc, L3: 1,5 x Kc, L4: Kc = 1,95. Logo após a colheita, avaliou-se a massa, a germinação e o vigor das sementes de arroz. O delineamento experimental foi o inteiramente casualizado com quarto repetições. Os dados foram submetidos à análise de variância e as médias comparadas pelo teste de Tukey ($p \leq 0,05$), separadamente para cada cultivar. Concluiu-se que níveis de água variando entre 0,5 e 1,5 vezes o Kc da cultura do arroz, fornecidos pelo sistema de irrigação por aspersão, proporcionam melhores condições para produção de sementes de arroz de cultivares de terras altas com melhor qualidade fisiológica.

PALAVRAS-CHAVE: *Oryza sativa.* Germinação. Vigor. Precipitação pluvial. Disponibilidade hídrica.

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