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Evapotranspiration and grain yield of upland rice as affected by water deficit

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Oryza sativa L.
growth stages
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A B S T R A C T

To achieve an accurate phenotyping for drought tolerance, it is important to control water stress levels and timing. This study aimed to determine water use by upland rice plants during periods of irrigation withholding and its relationship with grain yield in order to increase the efficiency of this phenotyping. Two experiments were carried out in a randomized block design in which six water treatments (irrigation withholding for periods of 2, 4, 6, 8, 10 and 12 days) were compared, with four replicates. In the first experiment, treatments were applied at the R3 stage (panicle exsertion) and, in the second, at the R5 stage (beginning of grain filling). The amount of water evapotranspired was determined by the difference between the soil water storage at the beginning and at the end of irrigation withholding periods, from the surface to 80-cm depth. Evapotranspiration of upland rice from R3 stage was higher compared to that observed from R5 stage, when subjected to similar irrigation withholding periods in both growth stages. Rice grain yield is more sensitive to irrigation withholding imposed from R5 stage than from R3 stage.

Palavras-chave:
Oryza sativa L.
estádios de desenvolvimento
supressão da irrigação

Evapotranspiração e produtividade do arroz de terras altas afetadas pela deficiência hídrica

R E S U M O

Para se obter fenotipagem acurada para tolerância à deficiência hídrica, é importante controlar o nível de estresse hídrico e a época de sua aplicação. Este trabalho objetivou determinar o uso de água pelas plantas de arroz de terras altas durante períodos de supressão da irrigação e sua relação com a produtividade de grãos, para aumentar a eficácia desta fenotipagem. Foram conduzidos dois experimentos no delineamento de blocos ao acaso e comparados seis tratamentos hídricos (supressão da irrigação por períodos de 2, 4, 6, 8, 10 e 12 dias) com quatro repetições. No primeiro experimento os tratamentos foram aplicados no estádio R3 (emissão das panículas) e no segundo, no estádio R5 (início do enchimento de grãos). A água evapotranspirada foi determinada pela diferença entre o armazenamento de água no solo no início e no fim dos períodos de supressão da irrigação, da superfície até 80 cm de profundidade. A evapotranspiração do arroz no estádio R3 foi mais alta comparada com a observada no estádio R5, quando submetida a período similar de supressão da irrigação em ambos os estádios. A produtividade do arroz foi mais sensível à supressão da irrigação imposta a partir do estádio R5 do que do estádio R3.

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Introduction

Most of the Brazilian upland rice production occurs in the Cerrado region, where soils are characterized by having low water-storage capacity, low natural fertility and elevated acidity, factors that limit grain yield of crops other than rice. Rice tolerates these soil limitations, allowing the exploitation of large areas (Guimarães et al., 2013). This region mostly presents uneven distribution of rainfall, with the occurrence of "dry spells", which are periods without rain during the rainy season (Crusciol et al., 2006).

According to Pinheiro (2003), during these periods negative water balance occurs in the soil, causing plant water stress and, therefore, compromising its growth, transpiration, photosynthesis, carbohydrate remobilization and grain yield.

Plant response to the effects of water stress is related to the duration, intensity and growth stage in which it occurs. Yambao & Ingram (1988) observed that water stress imposed for 15 days at panicle initiation, flowering and early grain filling reduced rice yields by 70, 88 and 52%, respectively. Zain et al. (2014) found that 15-day water stress cycle reduced rice transpiration rate by 42% and, as it has positive correlation with net photosynthesis rate, reduced grain yield. Rice evapotranspiration also decreases with water stress (Alberto et al., 2011) and is linearly related to grain yield (Cruz & O'Toole, 1982).

Due to climate change, it is clear the increase in temperature and in the irregularity of rainfall distribution, thus restricting the areas for the upland rice production. The development of cultivars tolerant to water stress can be a solution. However, the development of drought-tolerant cultivars has been slow for upland rice and this reflects the lack of a specific method for screening the large number of genotypes required in breeding for drought (Kamoshita et al., 2008).

Capacity for precise phenotyping under reliable conditions probably represents the most limiting factor for the progress of genomic studies on drought tolerance. There is a need for a high precision because the differences may be small and subtle, and detailed physiological measurements are difficult when a large number of genotypes are involved (Araus & Cairns, 2014). To achieve an accurate phenotyping, it is important to control stress levels and timing (Cattivelli et al., 2008).

The use of managed water stress, where water stress can be imposed at specific periods, has been shown to increase the heritability of yield under stress to values similar to those obtained for yield in well-watered conditions (Bernier et al., 2008).

Thus, the objectives of the study were to determine water use by plants during periods of withholding irrigation and its relationship with grain yield to increase the efficiency of rice phenotyping for the conditions of water stress.

Material and Methods

Two field experiments were conducted at the EMBRAPA's Phenotyping Site, located at the Experimental Station of EMATER, in the municipality of Porangatu, Goiás State, Brazil (13° 18 S, 49° 07 W, altitude: 391 m). According to the Köppen's classification system, the site has an "Aw" (tropical savannah, megathermal) climate. The rainfall regime is well-defined, with the rainy season from October to April and the dry season from May to September. The average annual rainfall is 1685 mm. The climatic variables during the experimental period are shown in Table 1.

The local soil is classified as a Dystrophic Red Latosol, with sandy clay texture from surface until 60-cm depth and clayey texture in the 60-80-cm layer. Chemical analysis of the 0-20-cm layer showed the following results: pH (H_2O) = 5.4, Ca = 11 mmol dm^{-3}, Mg = 5 mmol dm^{-3}, Al = 1 mmol dm^{-3}, P = 2.1 mg dm^{-3}, K = 75 mg dm^{-3}, Cu = 2 mg dm^{-3}, Zn = 3 mg dm^{-3}, Fe = 48 mg dm^{-3}, Mn = 33 mg dm^{-3}, and organic matter = 13 g dm^{-3}. The micronutrients, P and K were extracted by Mehlich 1 solution (0.5 N HCl + 0.025 N H_2SO_4), and Ca, Mg and Al by 1.0 N KCl. All determinations followed the methodologies presented in EMBRAPA (1997).

The experiments were carried out during the dry season of 2011, when the rainfall is usually zero (Table 1), so it is possible to control all the water used by plants. The plots had four rows, which were 4-m long and spaced by 0.40 m, with 18 seeds per meter. 400 kg ha^{-1} of the commercial formula 4-30-16 were applied at sowing. The top-dressing fertilization was performed with 40 kg ha^{-1} of N, in floral differentiation, approximately 50 days after emergence, in the form of ammonium sulfate. The weed control was performed with oxadiazon at a dose of 1000 g a.i. ha^{-1} in pre-emergence. It was used the upland rice variety 'BRS Sertaneja'. In the first experiment, six water treatments were applied at the R3 stage (panicle exsertion) and, in the second, the same treatments were applied at the R5 stage (beginning of grain filling), in a randomized block design with four replicates. The water treatments were irrigation withholding periods of 2, 4, 6, 8, 10 and 12 days, which induced different levels of water stress in the plants. Before and after the application of water treatments, the experiments were properly irrigated using a self-propelled irrigation bar. For this, approximately 25 mm of water were applied when the soil water potential at 0.15-m depth, measured with tensiometer, reached -0.025 MPa (Stone et al., 1986). Twenty-four vacuum gauge tensiometers were used per experiment, one in each treatment. After the end of each water treatment, it was applied to the soil the amount of water evapotranspired during the period of irrigation withholding through a hose connected to a tractor water tanker and the soil water potential was raised to -0.025 MPa from the surface to 80-cm depth. The amount of water evapotranspired was determined by the difference between the soil water storage at the beginning and at the end of irrigation withholding periods. The water storage was calculated by layers of 20 cm from the surface to 80-cm depth, by multiplying the gravimetric moisture by the bulk density and

Table 1. Climatic variables during the experimental period

Month	R (mm)	T (°C)	SR (MJ m^{-2})	RH (%)	WS (m s^{-1})
May	4.75	25.6	14.4	58.3	2.6
June	0	25.0	14.0	49.6	2.8
July	0	25.2	15.4	38.7	3.3
August	0	28.0	18.1	29.2	3.3
September	1.5	28.8	20.3	27.0	4.0

R - Rainfall; T - Mean temperature; SR - Mean solar radiation; RH - Mean relative humidity; WS - Mean wind speed by the thickness of the soil layer. In order to obtain gravimetric moisture, disturbed samples were collect at the desired depth of the soil profile, using a soil auger. The samples were stored in a metallic can with a lid, and kept closed and sealed with adhesive tape until taken to the laboratory to be weighed. After weighing, the samples were dried in an oven at 105-110 ºC until constant weight. The differential weights were used to calculate the soil water content.

Grain yield was determined in two central lines of each plot, leaving a border of 0.50 m at both ends. Regression analyses were performed between the water treatments and the evaluated variables.

Results and Discussion

It was observed that the use of the water stored in the soil surface layer, 0-20 cm depth, during the periods of irrigation withholding was described by an exponential equation in the R3 stage. There was a significant reduction in soil moisture from 2-day to 4-day irrigation withholding treatment and then a moderate reduction was verified with the increase in the number of days without irrigation (Figure 1A). This relationship was linear and negative in the other layers, with decreasing slope coefficients with the deepening of the soil layers. Reductions of 0.0098, 0.0089 and 0.0075 $m^3\ m^{-3}$ in soil moisture were observed in the layers of 20-40, 40-60, and 60-80 cm, respectively, for each day of increase in irrigation withholding.

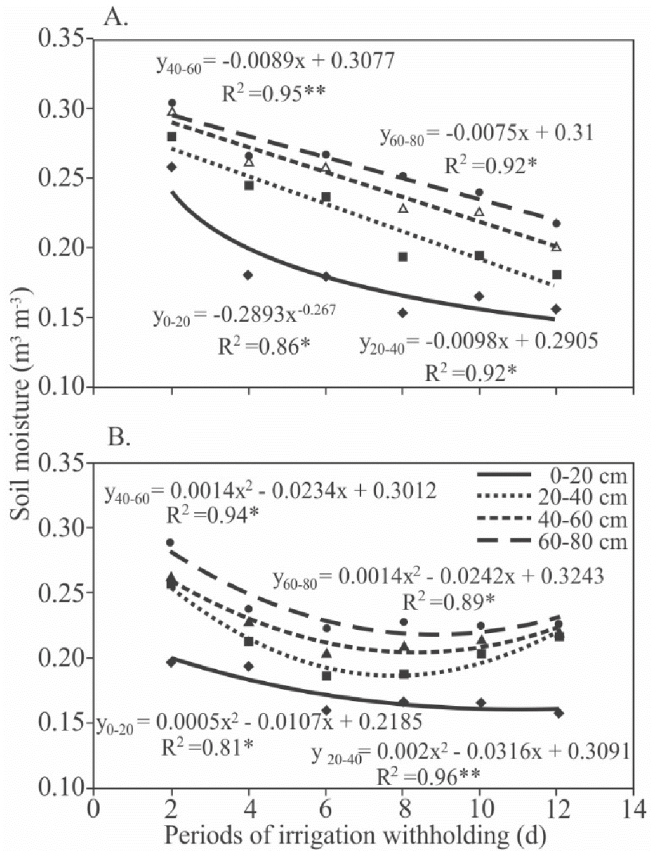

Figure 1. Volumetric soil moisture at 0-20, 20-40, 40-60, and 60-80 cm depth as a function of periods of irrigation withholding at (A) R3 (panicle exsertion) and (B) R5 (beginning of grain filling) growth stages

Regarding the use of soil water by plants during the R5 stage, in 0-20 cm soil layer, water depletion occurred with the increase in the number of days without irrigation, as in R3 stage. This relationship was described by a quadratic equation (Figure 1B) and with maximum water uptake in the treatment of 12 days without watering. The dynamics of water use in the other layers was also described by quadratic equations. Additionally, it was observed that the minimum soil moisture contents, 0.184, 0.203 and 0.220 $m^3\ m^{-3}$, in the 20-40, 40-60 and 60-80 cm soil layers, respectively, were observed in the treatment with eight days without watering. From this, there was moderate use of soil water (Figure 1B), probably due to the maturation of the plant and the nearest senescence phase. Root weight density peaks at around flowering and its decrease is accentuated after this stage, specially bellow 0.15 m (Kato & Okami, 2010), due to root degeneration. Additionally, likely upward flow of ground water may explain the trend of increased soil moisture from deeper layers. During this period, water usage by plants is reduced initially by the loss of physiological activity of the plant in absorption of water due to stomatal closure, restricting transpiration, and by reducing its leaf area by leaf senescence and leaf rolling (Serraj et al., 2009).

The decrease in soil moisture affected the average daily evapotranspiration (ET). It decreased linearly with increasing periods of irrigation withholding in both growth stages, R3 and R5 (Figure 2A). Additionally, it was observed that ET was higher in the R3 than in the R5 stage. ET varied from 13.0 to 7.1 mm d^{-1} in R3 and from 9.9 to 3.5 mm d^{-1} in R5 with the suppression of irrigation from 2 to 12 days, corresponding to a reduction of 46 and 65%, respectively.

The higher ET values in shorter periods of irrigation withholding may contain an error due to the calculation methodology. It is possible that part of the reduction in soil water storage at the end of these irrigation withholding periods is due to internal drainage. However, Shih et al. (1982) also observed high rice ET values during the summer, reaching values of 11.7 mm d^{-1}, and Rowshon et al. (2014) reported values of 9 mm d^{-1}.

The reduction in evapotranspiration with increasing irrigation withholding period is due to the reduction in soil evaporation by soil surface drying and by reduced transpiration. Plants exposed to water stress closed their stomata to maintain their inner moisture content and, consequently, their transpiration and photosynthetic rates, and productivity decreased (Hirayama et al., 2006). Parent et al. (2010) found that under well-watered conditions, stomatal conductance of seven rice cultivars ranged from 0.21 to 0.30 mol $m^{-2}\ s^{-1}$ and was reduced in all cultivars with soil water deficit (0.07-0.145 mol $m^{-2}\ s^{-1}$). As in the evaluated stages the main component of evapotranspiration is transpiration, the observed reduction in evapotranspiration is consistent with the reduction of 42% in rice transpiration rate found by Zain et al. (2014) for 15-day water stress cycle.

The amount of water transpired during the early reproductive stage (R3) was higher due to the higher plant leaf area during the period. The lowest ET during the final stage of plant development (R5) was due to loss of leaf area with the start of plant senescence and the reduction of its cellular activity.

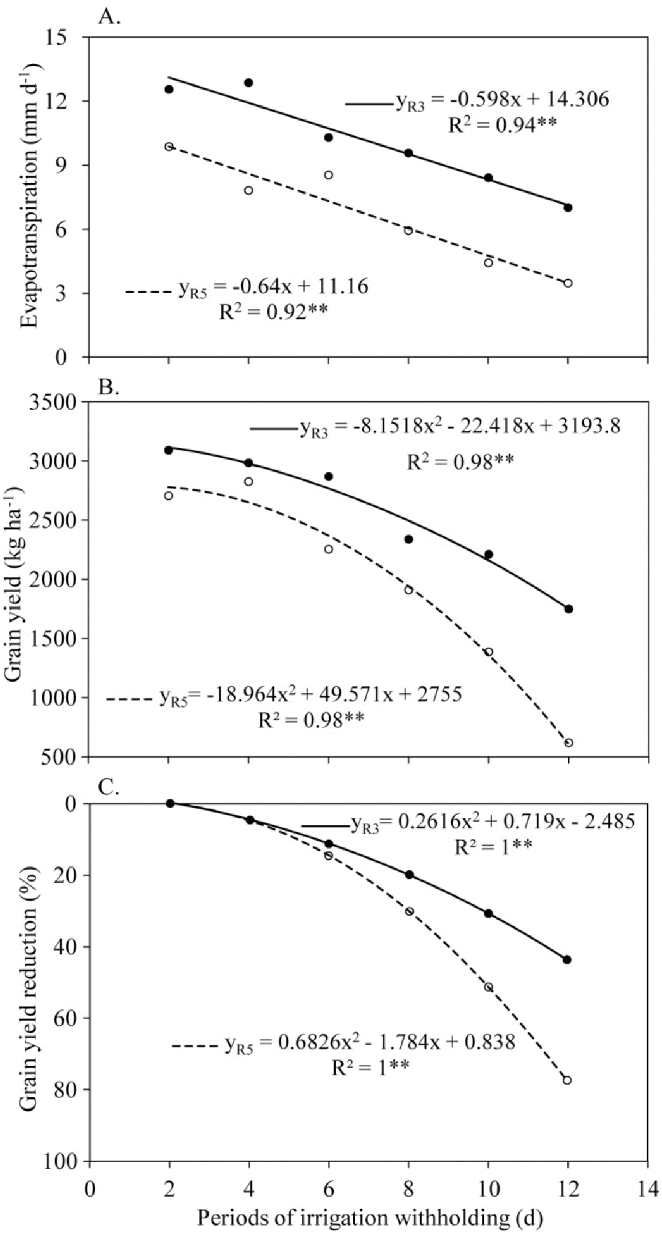

Figure 2. Average daily evapotranspiration (A), grain yield (B) and grain yield reduction (C) as a function of periods of irrigation withholding at R3 (panicle exsertion) and R5 (beginning of grain filling) growth stages

The highest evapotranspirations observed in R3 in relation to those observed in the R5 stage suggest that plants, even subjected to similar water stress periods in both growth stages, kept better water conditions in R3 than in the R5 stage. This can be explained by the reduction in effectiveness of the root system during the grain filling stage, which occurs from the R5 stage on (Kato & Okami, 2010), when the competition between plant organs for carbohydrates favors the grains over the other storage sites, such as the root system. In addition, the remobilization of carbohydrates in the plant to the grains, although little intense in rice, compromises the root system. In this case, the replacement of the fine roots and the root hair decreases and, therefore, the root system gets older and its efficiency in water uptake is reduced. Water stress during the grain-filling period reduces photosynthesis, induces early senescence and shortens the grain-filling period, but increases the remobilization of assimilates from the straw to the grains (Barnabás et al., 2008). In addition, it should be considered if the aging of the transpiration apparatus, which occurs with plant maturity, reduces the plant water use.

The decrease in evapotranspiration, as consequence of the increase in the period of irrigation withholding, caused linear reduction in grain yield at both growth stages considered (Figure 3).

The reduction was more intense in the R5 stage compared to that observed in R3, since the slope of the equation that describes the variation of yield with change in ET is larger in R5 than in R3. There were reductions of about 218 kg ha^{-1} per each 1 mm reduction of ET caused by reduced availability of water in the soil during the R3 stage, and of 309 kg ha^{-1} in the R5 stage.

Grain yields were quadratically reduced by water deficit induced by irrigation withholding, in both growth stages (Figure 2B). There were grain yields of 3116, 2974, 2766, 2493, 2154 and 1751 kg ha^{-1} in the R3 stage in treatments with 2, 4, 6, 8, 10 and 12 days of irrigation withholding, respectively, and of 2778, 2650, 2370, 1938, 1354 and 619 kg ha^{-1} in the R5 stage, for the same treatments.

Arf et al. (2001; 2002) and Centritto et al. (2009) also observed reduction in grain yield as the intensity of water deficit increased. The authors reported that this performance is attributed to genetic factors of the evaluated germplasm, the stage of development in which plant is and the intensity of water deficit. This affects all physiological processes and, therefore, has a marked effect on the production of biomass and grain yield. Among the physiological processes affected by water deficit, growth is the most sensitive, while CO_2 assimilation and respiration are less sensitive and, therefore, affected later in a water deficit cycle (Pinheiro, 2006).

Compared to the 2-day treatment, the periods of irrigation withholding from 4 to 12 days caused reductions in grain yield that varied from 4.6 to 43.8% and from 4.6 to 77.7%, in the R3 and R5 stages, respectively (Figure 2C). Davatgar et al. (2009) also concluded that rice is very sensitive to mild and severe drought stress during reproductive stage. Rodrigues et al. (2004) and Guimarães et al. (2009) reported that inadequate replacement of water transpired by the plant during the period of crop development causes water stress and its grain yield is compromised.

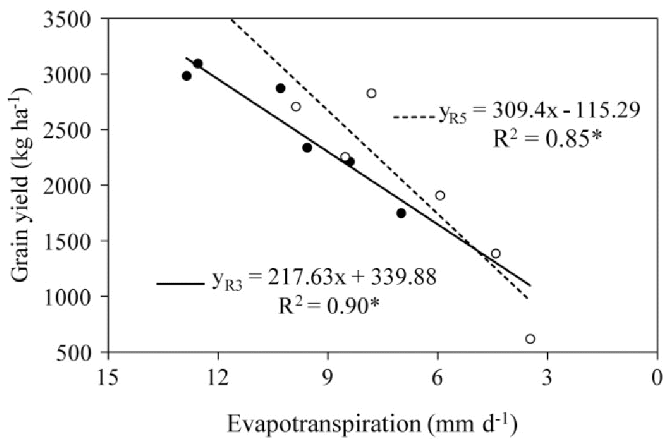

Figure 3. Grain yield as a function of average daily evapotranspiration at R3 (panicle exsertion) and R5 (beginning of grain filling) growth stages

Considering the conditions of the experimental area, irrigation withholding should not surpass 12 days at the R3 stage and 9 days at the R5 stage, in order not to exceed the threshold of 50% of reduction in grain yield (Figure 2C). According to Jongdee et al. (2006), water stress is considered moderate below this value and allows the selection of genotypes for drought tolerance.

Conclusions

1. Evapotranspiration of upland rice from the panicle exsertion stage is higher compared to that observed from the beginning of grain filling, when subjected to similar irrigation withholding periods in both growth stages.

2. Rice grain yield is more sensitive to irrigation withholding imposed from the beginning of grain filling than from the panicle exsertion.

Literature Cited

Alberto, M. C. R.; Wassmanna, R.; Hirano, T.; Miyata, A.; Hatano, R.; Kumar, A.; Padre, A.; Amante, M. Comparisons of energy balance and evapotranspiration between flooded and aerobic rice fields in the Philippines. Agricultural Water Management, v.98, p.1417-1430, 2011. http://dx.doi.org/10.1016/j.agwat.2011.04.011

Araus, J. L.; Cairns, J. E. Field high-throughput phenotyping: the new crop breeding frontier. Trends in Plant Science, v.19, p.52-61, 2014. http://dx.doi.org/10.1016/j.tplants.2013.09.008

Arf, O.; Rodrigues, R. A. F.; Sá, M. E. de; Crusciol, C. A. C. Resposta de genótipos de arroz de sequeiro ao preparo do solo e à irrigação por aspersão. Pesquisa Agropecuária Brasileira, v.36, p.871-879, 2001. http://dx.doi.org/10.1590/S0100-204X2001000600004

Arf, O.; Rodrigues, R. A. F.; Sá, M. E.; Crusciol, C. A. C.; Pereira, J. C. R. Preparo do solo, irrigação por aspersão e rendimento de engenho do arroz de terras altas. Scientia Agrícola, v.59, p.321-326, 2002. http://dx.doi.org/10.1590/S0103-90162002000200018

Barnabás, B.; Jäger, K.; Fehér, A. The effect of drought and heat stress on reproductive processes in cereals. Plant, Cell and Environment, v.31, p.11-38, 2008.

Bernier, J.; Atlin, G. N.; Serraj, R.; Kumar, A.; Spaner, D. Breeding upland rice for drought resistance. Journal of the Science of Food and Agriculture, v.88, p.927-939, 2008. http://dx.doi.org/10.1002/jsfa.3153

Cattivelli, L.; Rizza, F.; Badeck, F. W.; Mazzucotelli, E.; Mastrangelo, A. M.; Francia, E.; Marè, C.; Tondelli, A.; Stanca, A. M. Drought tolerance improvement in crop plants: An integrated view from breeding to genomics. Field Crops Research, v.105, p.1-14, 2008. http://dx.doi.org/10.1016/j.fcr.2007.07.004

Centritto, M.; Lauteri, M.; Monteverdi, M. C.; Serraj, R. Leaf gas exchange, carbon isotope discrimination, and grain yield in contrasting rice genotypes subjected to water deficits during the reproductive stage. Journal of Experimental Botany, v.60, p.2325-2339, 2009. http://dx.doi.org/10.1093/jxb/erp123

Crusciol, C. A. C.; Soratto, R. P.; Arf, O.; Mateus, G. P. Yield of upland rice cultivars in rainfed and sprinkler-irrigated systems in the Cerrado region of Brazil. Australian Journal of Experimental Agriculture, v.46, p.1515-1520, 2006. http://dx.doi.org/10.1071/EA04035

Cruz, R. T.; O'Toole, J. C. Dryland rice response to an irrigation gradient at flowering stage. Agronomy Journal, v.76, p.178-183, 1982. http://dx.doi.org/10.2134/agronj1984.00021962007600020003x

Davatgar, N.; Neishabouri, M. R.; Sepaskhah, A. R.; Soltani, A. Physiological and morphological responses of rice (*Oryza sativa* L.) to varying water stress management strategies. International Journal of Plant Production, v.3, p.19-32, 2009.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Centro Nacional de Pesquisa de Solos. Manual de métodos de análise de solos. 2.ed. Rio de Janeiro: Embrapa CNPS, 1997. 212p. Documentos, 1.

Guimarães, C. M.; Breseghello, F.; Castro, A. P. de; Stone, L. F.; Morais Júnior, O. P. de. Comportamento produtivo de linhagens de arroz do grupo Indica sob irrigação adequada e sob deficiência hídrica. Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2009. 4p. Comunicado Técnico, 180

Guimarães, C. M.; Stone, L. F.; Rangel, P. H. N.; Silva, A. C. de L. Tolerance of upland rice genotypes to water deficit. Revista Brasileira de Engenharia Agrícola e Ambiental, v.17, p.805-810, 2013. http://dx.doi.org/10.1590/S1415-43662013000800001

Hirayama, M.; Wada, Y.; Nemoto, H. Estimation of drought tolerance based on leaf temperature in upland rice breeding. Breeding Science, v.56, p.47-54, 2006. http://dx.doi.org/10.1270/jsbbs.56.47

Jongdee, B; Pantuwan, G.; Fukai, S; Fischer, K. Improving drought tolerance in rainfed lowland rice: an example from Thailand. Agricultural Water Management, v.80, p.225-240, 2006. http://dx.doi.org/10.1016/j.agwat.2005.07.015

Kamoshita, A.; Babu, R. C.; Boopathi, N. M.; Fukai, S. Phenotypic and genotypic analysis of drought-resistance traits for development of rice cultivars adapted to rainfed environments. Field Crops Research, v.109, p.1-23, 2008. http://dx.doi.org/10.1016/j.fcr.2008.06.010

Kato, Y.; Okami, M. Root growth dynamics and stomatal behaviour of rice (*Oryza sativa* L.) grown under aerobic and flooded conditions. Field Crops Research, v.117, p.9-17, 2010. http://dx.doi.org/10.1016/j.fcr.2009.12.003

Parent, B.; Suard, B.; Serraj, R.; Tardieu, F. Rice leaf growth and water potential are resilient to evaporative demand and soil water deficit once the effects of root system are neutralized. Plant, Cell and Environment, v.33, p.1256-1267, 2010. http://dx.doi.org/10.1111/j.1365-3040.2010.02145.x

Pinheiro, B. da S. Integrating selection for drought tolerance into a breeding program: the Brazilian experience. In: Fisher, K. S.; Lafitte, R.; Fukai, S.; Atlin, G.; Hardy, B. (ed.). Breeding rice for drought-prone environments. Los Baños: IRRI, 2003. p.75-83.

Pinheiro, B. da S. Características morfofisiológicas da planta relacionadas à produtividade. In: Santos, A. B. dos; Stone, L. F.; Vieira, N. R. de A. (ed.). A cultura do arroz no Brasil. 2.ed. rev. ampl. Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2006. p.209-256.

Rodrigues, R. A. F.; Soratto, R. P.; Arf, O. Manejo de água em arroz de terras altas no sistema de plantio direto, usando o tanque classe A. Engenharia Agrícola, v.24, p.546-556, 2004. http://dx.doi.org/10.1590/S0100-69162004000300007

Rowshon, M. K.; Amin, M. S. M.; Mojid, M. A.; Yaji, M. Estimated evapotranspiration of rice based on pan evaporation as a surrogate to lysimeter measurement. Paddy Water Environment, v.12, p.35-41, 2014. http://dx.doi.org/10.1007/s10333-013-0356-4

Serraj, R.; Kumar, A.; Mcnally, K. L; Slamet-Loedin, I.; Bruskiewich, R.; Mauleon, R.; Cairns, J.; Hijmans, R. J. Improvement of drought resistance in rice. Advances in Agronomy, v.103, p.41-99, 2009. http://dx.doi.org/10.1016/S0065-2113(09)03002-8

Shih, S. F.; Rahi, G. S.; Harrison, D. S. Evapotranspiration studies on rice in relation to water use efficiency. Transactions of the ASAE, v.25, p.702-707, 1982. http://dx.doi.org/10.13031/2013.33598

Stone, L. F.; Moreira, J. A. A.; Silva, S. C. da. Tensão da água do solo e produtividade do arroz. Goiânia: Embrapa CNPAF, 1986. 6p. Comunicado Técnico, 19

Yambao, E. B.; Ingram, K. T. Drought stress index for rice. Philippine Journal of Crop Science, v.13, p.105-111, 1988.

Zain, N. A. M; Ismail, M. R.; Puteh, A.; Mahmood, M.; Islam, M. R. Impact of cyclic water stress on growth, physiological responses and yield of rice (*Oryza sativa* L.) grown in tropical environment. Ciência Rural, v.44, p.2136-2141, 2014. http://dx.doi.org/10.1590/0103-8478cr20131154