

Effect of Water Deficit Stress on Grain Yield of Rice

Munnujan Khanam^{1,*} and A. Hamid²

¹ Bangladesh Rice Research Institute, Gazipur, Bangladesh

² Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur, Bangladesh

*Corresponding author, Email: munnujan_khanam@yahoo.com

Manuscript Received: 25 May 2015 Accepted: 19 February 2018

Abstract

We tested whether exposing rice plants to water stress during reproductive growth affects the rice grain yield, yield components and grain growth, which is one of the most important traits for rice growing in a rainfed condition. A field experiment was conducted in the rainout shelter at the farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur, Bangladesh, during wet season. One locally popular high yielding rice variety BRRI dhan49 grown at three levels of moisture regime- irrigation stop at 1st heading to maturity (WS1), irrigation stop at 15 days after heading to maturity (WS2) and optimum irrigation or well watered (WW) condition. Water stress during the reproductive stage reduced grain yield but the magnitude was greater when water stress imposed at 1st heading. Grain yield reduced 44% and 9% by WS1 and WS2 respectively compared to well watered condition. The increased spikelet sterility caused by water stress was closely related to the reduction of the total spikelet number per panicle.

Keywords: Water deficit stress, well-watered condition, grain yield, yield components

Introduction

Rice grown in the most diverse range of environments (Wade et al., 1999) and yield is usually low in rainfed lowland systems because of drought and drought-associated problems (Mackill et al., 1996). In Bangladesh drought is a major problem in rainfed lowland rice. Low water demanding varieties are preferable from the point of our environmental safety. The rainfed lowland rice usually suffers from water stress mainly at their reproductive and ripening stages when rainfall is minimal or none during October or November. Late season drought stress, due to an abrupt finish of the annual rainfall, is common and grain yield can drastically reduced if drought occurs during flowering time (Hsiao, 1982; O'Toole, 1982; Boonjung and Fukai, 1996).

The critical period for rice, when drought stress most severely affects yield, is in the panicle development-to-anthesis stage (Matsushima, 1966; Cruz and O'Toole, 1984). Stress soon after panicle initiation reduces the number of spikelet primordial that develop. If drought stress occurs later during meiotic division or at anthesis, then sterility of florets is increased and consequently there is a lower percentage of filled grains. The reproductive stage therefore, represents a series of sensitive developmental events with little flexibility or compensatory capacity (O'Toole and Chang, 1979). Water stress adversely impacts many aspects of the physiology of plants, especially photosynthetic capacity; if the stress is prolonged, plant growth, and productivity are severely diminished (Osakabe et al., 2014). Exposure of plants to abiotic stresses such as temperature fluctuations, water supply, and salinity,

result in the formation of ROS (Gill and Tuteja, 2010; Suzuki et al., 2012; Zinta et al., 2014).

After monsoon rains, the conditions prevailing in the country can be classified as drought and severe drought. Growth regulation in proportion to soil water content is thus an important plant morphological response to water deficit. Drought affects every aspects of plant life and inhibits growth, development and productivity. Some developmental stages, such as development of reproductive organs are more sensitive to abiotic stress than other stages of growth. As success of plant reproductive development is directly correlated with grain yield, stresses coinciding with reproductive phase results in the higher yield losses (Zinta et al., 2016). However, there has been no systematic field work in our country to examine the effect of drought occurring at different growth stages on growth during the drought and subsequent recovery and grain yield. It is important to combine the ability to produce high yield under no water limitation and the ability to tolerate drought in one variety. The present study was conducted to determine how drought affects grain yield and the process of grain filling in one popular rice variety BRR1 dhan49.

This study investigated how water stress affect grain yield, yield components of a popular transplanted Aman variety BRR1 dhan49.

Materials and Methods

A field experiment was conducted in the rainout shelter at the farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur, Bangladesh during Aman season, 2009. Seedlings were raised in plastic tray. Pre-germinated seeds (1 day soaking and 1 day incubation) were sown on the tray on August 3, 2009. The methods of raising seedling have been described in earlier section. The experiment was laid out in a randomized complete block design with four replications. Ten days old single seedling was transplanted at 25×15 cm² apart. A fertilizer dose of 20 kg P, 35 kg K, 10 kg S, 3.6 kg Zn ha⁻¹ was applied in the form of triple super phosphate, muriate

of potash, gypsum and zinc sulphate respectively during final land preparation. Nitrogen was top dressed at 80 kg ha⁻¹ as urea in three equal splits – 26 days after transplanting (DAT), 46 DAT and 76 DAT. The unit plots were 2 m × 1.5 m in size. High raised dikes were made surrounding each plot and the dikes were covered with polyethylene sheet to avoid seepage. Plots were clean weeded by hand, and insect pests were controlled with insecticides as necessary. At ripening stage grains were infected by false smut disease. Water stress treatment was imposed at 1st heading (WS1), 15 days after heading (DAH) (WS2) and another treatment is optimum irrigation (WW). Heading was determined when the first panicle exerted out from the sheath of the flag leaf of the main shoot. One of the water stress treatment was imposed at this stage (WS1) and another 15 days after first heading (WS2).

Recording of data: Visual observations on the phenological events were recorded over time. Time to first flowering, termination of flowering and date of maturity were recorded for each treatment. The plants were considered mature when more than 90% of the filled spikelets had turned yellow and hard.

Soil moisture: To measure the soil water content during the time of first water stress treatment imposition soil samples were collected by an auger from the three surface layer 0-5, 5-10 and 10-15 cm depth and Soil sample was dried at 105°C for over 80 hrs. Gravimetric moisture content (gg⁻¹) of the soil samples was calculated on oven dry weight basis and moisture percent was determined and was repeated at 3 days interval and continued till maturity of the crop.

Yield and yield components: Plants from a 0.6 m² site (excluding border plants) in each plot were harvested at maturity for the determination of grain yield. Grain yield was adjusted at 14% moisture content (MC) as follows:

$$\text{Grain yield at 14\% MC} \times \frac{\text{fresh weight of grains at harvest}}{\text{harvest}}$$

Yield components, i.e., panicles per square meter, spikelets per panicle, the percentage of ripened grains, and grain weight, were determined from 20 panicles sampled randomly from each plot. Panicle length was measured from the panicle node to the tip of the top most grain. After measuring the panicle length grains were separated from rachis. Number of total filled and unfilled grains and 1000 grain weight were determined. 1000 grain weight was adjusted at 14% moisture content. Ripening% was calculated as filled grains to total grain number expressed in percent.

The results were analyzed for variance using ANOVA. Data from each sampling date were analyzed separately. Means were tested by least significant difference at $P=0.05$ (LSD0.05) and interrelationships among parameters were worked out employing regression analysis.

Results and Discussion

Soil moisture

The amount of moisture stored in the profile to a soil depth of 15 cm was significantly greater under well watered condition. Nevertheless, expressing soil water depletion is a useful metric for assessing the severity of crop water deficit stress. Soil moisture depletion period coincided with heading and flowering stage when stress imposed at 1st heading (Figure 1).

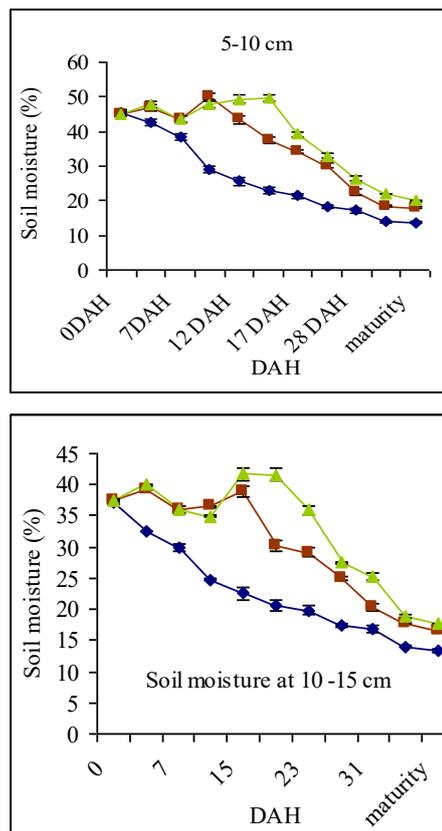
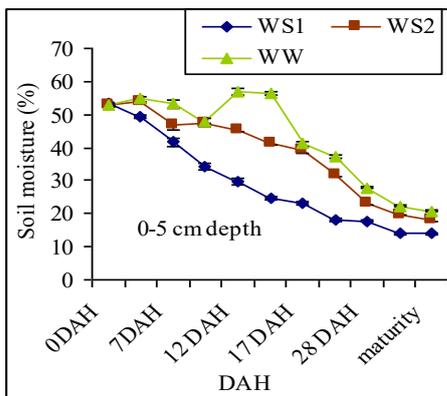


Figure 1 Depletion of soil moisture due to water deficit treatment imposition.

Yield and yield components

There were significant differences ($*P < 0.05$) between the timing of stress (WS1, WS2) on yield and yield components. Both water deficit treatments had lower yields. Water deficit stress in the 1st heading resulted the lowest yield followed by that produced in water stress treatment at 15 DAH compared to control (Table 1). Water deficit during 1st heading and 15 days after heading reduced mean grain yield by 44%, 9% on average in comparison to well watered condition respectively.

Table 1 Yield and yield attributes of BRR1 dhan49 as affected by water deficit

Treatment	Yield (gm ⁻²)	Panicle m ⁻² (no.)	Filled grain panicle ⁻¹ (no)	Spikelet panicle ⁻¹ (no.)	Ripening %	1000 grain wt (g)	Panicle length (cm)	Grain filling duration (days)
WS1	369.94 (44.14%)	298	139	199	69.93	18.985	23.07	30
WS2	603.07 (8.93%)	314	199	239	82.53	18.962	22.96	34
WW	662.21	324	231	261	88.18	19.36	23.673	39
LSD _(0.05)	42.07	12.08	49	47.85	4.755	ns	ns	

Figures in the parentheses indicate the percent yield reduction.

The number of panicle varied significantly among the treatments. The number of panicle varied between 298 to 324m⁻² across the treatments. The lowest number of panicle was observed from the plant when stressed imposed at 1st heading because panicle did not exert fully due to water deficit. Because water deficit stress (WS1) developed during the elongation of internodes, the retarded panicle exertion may be a consequence of a failure in maintenance of internal plant water potential. Hsiao et al. (1973) showed that elongation rate of sorghum declined in association with decreased leaf water potential during the period of soil water deficit. Similarly in rice O'Toole and Namuco (1980) found that reduction in panicle exertion rate and the fraction length of exerted panicle was due to a reduction in leaf water potential under drought stress condition. When stress imposed at 15 DAH the most of the panicle exerted before the imposition of water deficit stress caused similar panicle number per unit area with well watered treatment.

The number of fertile grains, total spikelet per panicle decreased significantly when plants were subjected to prolonged water-deficit conditions. Water deficit stress might decrease current photosynthesis which caused reduce translocation of assimilates to the grains and increased the unfilled grains. The low yield obtained for the water stress at 1st heading treatment was due to the small number of panicles per unit area, lower number of spikelet per panicle and higher percentage of sterility.

Water deficit immediately reduced fertility of rice plants at the time of exposure (Nguyen and Sutton, 2009). Grain yield reductions ranging from 20 % to 70 % of the control have been observed in rice under water-deficit treatment during the reproductive stage (Lilley and Fukai, 1994). Sheoran and Saini (1996) reported a serious decline in grain set from 92 to 22 % by withholding water for 4 days during the meiotic stage of pollen mother cells.

There was no effect of water deficits on panicle length (Table 1). Influence of water deficits on the percentage of ripened grains varied among the treatments. Water deficits reduced significantly the percentage of ripened grains. Changes in the percentage of ripened grains under water deficit treatments were mainly attributed to changes in the number of unfilled grains because the percentage of sterile or unfertilized grain was highly affected by water deficit. This might be due to the fact that water stress slowed down current carbohydrate synthesis and / or weakened the sink strength at reproductive stages and abortion of fertilized ovaries. This result is in agreement with those reported by Kumar et al. (2006) who showed that percentage of unfilled grains were significantly higher in sites that were affected by drought at reproductive stage. Water stress at flowering causes flower abortion, grain abscission and increasing of percentage of unfilled grain (Hsiao et al., 1976). Grain size was fairly constant across the treatments. A water deficit during any stage of grain development may caused the premature cessation of grain filling. Kernel moisture content and its direct impact on metabolism

appear to be key regulatory factors in shortening the duration of grain filling (Table 1)

Conclusion

Results of this experiment suggested that the genotype had no capability in expressing their genetic yield potential under water stress conditions. It appears that the yield advantage observed under favorable conditions was not maintained under water-limiting conditions. From the above results and discussion it may be concluded that cultivars required for rainfed conditions, where frequent drought develop, are those with appropriate phenological development to escape late drought and ability to maintain growth during drought that may develop late in the season. Consideration of these characters in plant-breeding programs should increase the efficiency of plant improvement in the drought prone environment. Grain yield was greatly reduced by water deficit stress that commenced before flowering and continued until maturity. The water stress treatment increased the grain filling rate and shortened the grain filling period

References

- Cruz, R.T. and J.C. O'Toole. 1984. Dry land rice response to an irrigation gradient at flowering stage. *Agron. J.* 76: 178-183.
- Gill, S.S. and N. Tuteja. 2010. Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiol. Biochem.* 48: 909-930.
- Hsiao, T.C. 1973. Plant responses to water stress. *Ann. Rev. Plant Physiol.* 24: 519-570.
- Hsiao, T.C. 1982. The soil-plant atmospheric continuum in relation to drought and crop production. In: *Drought Resistance in Crop with Emphasis on Rice*. IRRI, Los Banos, Phillipines, pp. 39-52
- Kumar, R., A.K. Sarawgi, C. Ramos, S.T. Amarante, A.M. Ismail and L.J. Wade. 2006. Partitioning of dry matter during drought stress in rainfed lowland rice. *Field Crops Res.* 96: 455-465.
- Lilley, J.M. and S. Fukai. 1994. Effect of timing and severity of water deficit on four diverse rice cultivars III. Phenological development, crop growth and grain yield. *Field Crops Res.* 37: 225-234.
- Mackill, D. J., W.R. Coffman, D.P. Garrity. 1996. *Rainfed Lowland Rice Improvement*. International Rice Research Institute, Manila, Philippines, 242 pp.
- Matsushima, S. 1966. *Crop Science in Rice-Theory of Yield Determination and its Application*. Fuji Publishing Co., Tokyo, 365 pp.
- Michihiro W.J., C.B. Lui and G.C. Garvalho. 1994. Cultivar difference in leaf photosynthesis and grain yield of wheat under soil water deficit conditions. *Jpn. J. Crop Sci.* 63:339-344
- Nguyen, G.N. and B.G. Sutton. 2009. Water Deficit Reduced Fertility of Young Microspores Resulting in a Decline of Viable Mature Pollen and Grain Set in Rice. *J. Agronomy Crop Science.* 195:11-18.
- Osakabe, Y., K. Osakabe, K. Shinozaki and L-S.P. Tran. 2014. Response of plants to water stress. *Front. Plant Sci.* 5:86.
- O'Toole, J.C. 1982. Adaptation of rice to drought prone environment. In: *Drought resistance in crop with emphasis on Rice*. IRRI, Los Banos, Phillipines. pp.195-213.
- O'Toole, J.C. and O.S. Namuco. 1983. Role of panicle exertion in water stress induced sterility. *Crop Sci.* 23: 1093-1097.
- O'Toole, J.C. and T.T. Chang. 1979. Drought resistance in cereals-rice: A case study. In: ed. H. Mussell and R.C. Staples, *Physiology of Crop Plants*. Wiley, New York, pp. 374-405.
- Sheoran, I.S. and H.S. Saini. 1996. Drought-induced male sterility in rice: changes in carbohydrate levels and enzyme activities associated with the inhibition of starch accumulation in pollen. *Sex. Plant Reprod.* 9: 161-169.
- Singh, B.M. and C.F. Jenner. 1982. A modified method for the determination of cell number in wheat endosperm. *Plant Sci. Lett.* 26: 273-278.

- Suzuki, N., S. Koussevitzky, R. Mittler and G. Miller. 2012. ROS and redox signaling in the response of plants to abiotic stress. *Plant Cell Environ.* 35: 259–270.
- Todaka, D., K. Shinozaki and K.Y. Shinozaki. 2015. Recent advances in the dissection of drought-stress regulatory networks and strategies for development of drought-tolerant transgenic rice plants. *Front. Plant Sci.* 6:84.
- Wade, L.J., C.G. McLaren, L. Quintana, Harnpichitvitaya, S. Rajatasereekul, A.K. Sarawgi, A. Kumar, H.U. Ahmed, Sarwoto, A.K. Singh, R. Rodriguez, J. Siopongco and S. Sarkarung. 1999. Genotype by environment interactions across diverse rainfed lowland rice environments. *Field Crops Res.* 64: 35–50.
- Wang, S., Z. Ji, S. Liu, Y. Ding and W. Cao. 2003. Relationships between balance of nitrogen supply-demand and nitrogen translocation and senescence of different position leaves on rice. *Agric. Sci. China* 2(7):747–750.
- Zinta, G., H. Abdelgawad, M.A. Domagalska, L. Vergauwen, D. Knapen, I. Nijs, I.A. Janssen, G.T.A. Beemster and H. Assard. 2014. Physiological, biochemical, and genome-wide transcriptional analysis reveals that elevated CO₂ mitigates the impact of combined heat wave and drought stress in *Arabidopsis thaliana* at multiple organizational levels. *Glob. Chang. Biol.* 20: 3670–3685.
- Zinta, G., A. Khan, H. AbdElgawad, V. Verma and A. K. Srivastava. 2016. Unveiling the Redox Control of Plant Reproductive Development during Abiotic Stress. *Front. Plant Sci.* 7: 700.