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Research Article

INFLUENCE OF WATER STRESS ON MORPHOLOGY, PHYSIOLOGY AND YIELD CONTRIBUTING CHARACTERISTICS OF RICE

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ABSTRACT

Water stress or drought is one of the main reasons behind the lower productivity of rice–a widely popular nutritious cereal crop and the staple food for a large portion of the world's population. A pot experiment was conducted to investigate the effect of water stress on three rice varieties e.g. *Banglamoti, Vittiatash* and *Atash balam* in a silty clay soil. To identify whether less water affects rice production, rice plants were cultivated under five different water treatments, T_1: flooding at 5 cm depth, T_2: flooding at 3 cm depth, T_3: saturated water condition, T_4: water content@75% saturation, and T_5: water content @50% saturation, and were arranged in a completely randomized design with three replications. Morphology, yield and physiological parameters of the rice plants were evaluated. Treatment below saturation did not produce any yield for all the rice varieties studied. All the morphological parameters and yields (e.g. dry weight of plants, plant height, tiller number, panicle number, grain number, grain weight, 1000 seed weight, and harvest index) showed a lower value under water deficient condition. Relative water content and water use efficiency declined with declining water content which represented the variations in their physiological responses to water stress. The grain content per panicle as well as 1000 grain weight of the rice varieties was maximum at saturation condition. Highest harvest index was observed for *Vittiatash* rice variety at saturated condition. Flooding the soil with either 5 cm or 3 cm depth did not produce any significant change in the studied parameters which indicated that approximately 2 cm water can easily be curtailed which may not affect the production of rice.

Keywords: Rice, Water Stress, Morphology, Physiology, Yield

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INTRODUCTION

The scarcity of water, commonly known as water stress or drought, is an alarming global problem and one of the major constraints that severely limits the sustainable production of agricultural crops. Increasing the food demand with increasing population would have consequent impact on the yield index due to water deficit. Rice (*Oryza sativa* L.) is one of the most important cereal crops in the world and contributes 90-91% among the total food grain production in Asia (IRRI, 2012). It is the staple food crop in Bangladesh and more than 80 % of the total agricultural lands are under rice cultivation (BBS, 2002). The shortage of irrigation water at the growing season or reproductive stage results in serious deterioration of rice yield (Suriyan et al., 2010). When plant is subjected to water stress, a varieties of physiological changes are occurred such as- reduction of transpiration rate, chlorophyll content in leaves, photosynthetic rate, pigment degradation, stomatal conductance, relative water content (RWC), water use efficiency (WUE) and resulting in decrease of plant growth (Tuna et al., 2010; Jahan et al., 2014). Moreover, under acute water stressed situation, toxic materials like reactive oxygen species (ROS) is produced at the time of photosynthesis and respiration, and combines with fats, nucleic acids, proteins resulting in damage of plant cells, protein denaturation, lipid peroxidation, DNA mutation. Response of water stress by rice plant largely depends on several factors, includes- the genotype of plant, duration and severity of stress, growth stage. In the period of early vegetative growth and flowering, if plants unable to receive sufficient water, it drastically inhibits floret initiation, plant height, tiller number, leaf area, grain filling and ultimately low grain production (Zhang et al., 2018; Yang, et al., 2019). Proper irrigation is the pre-requisite of rice production and in Asian developing countries, over 80% of freshwater is used for irrigational purpose (IRRI, 2012). Currently about 1900 to 5000 liters of water is required to produce 1 kg of rice grain and it is speculated that, almost 10% of irrigated rice will face water scarcity by 2025 (Tuong et al., 2005).

For this reason, researches are conducting numerous experiments and have taken it as a challenge to find out the proper management techniques, appropriate or optimum quantity of water to irrigate a particular rice variety to avoid the use of excess water in rice cultivation. Such initiatives will ensure efficient use of water and help to achieve the motto of grow more crops per drop of water (Akram, 2013; Materu et al., 2018). Therefore, the objectives of this study were to investigate the effect of water stress on morphological, physiological characteristics and yield of three rice varieties, and a systematic evaluation was carried out to identify the rice variety which performs best under low irrigation condition that will help to minimize loss of excess water for rice cultivation.

MATERIAL AND METHODS

The experiment was conducted in front of the net house of field laboratory of Soil, Water and Environment Discipline, Khulna University, Bangladesh which is geographically located at N: 22˚10′ north latitude and 89˚20' east latitude. The experimental site has silty clay texture. Surface soil (0-15 cm) was collected from this site and the characteristics of experimental soil are given in Table 1.

Table 1: General properties of experimental soil

Properties	Values
Soil moisture content (%)	25
Sand	12.05
Silt	54.12
Clay	33.83
Soil Textural Class	Silty clay
Particle density (gcm^{-3})	2.5
Bulk density (gcm^{-3})	1.15
Porosity (%)	55
pH	7.80
EC (dSm^{-1})	0.13

The collected soil was dried under the sun followed by crushing, mixed thoroughly and 8 kg soil was put in each of the 12L plastic pots. The pot soil was fertilized with urea, Triple Super Phosphate (TSP), Muriate of Potash (MOP) and gypsum as sources of N, P, K and S at the rate of 100 kg N, 60 kg P_2O_5, 75 kg K_2O and 20 kg S ha^{-1}, respectively (BARC, 2012). The whole amount of TSP, MOP, gypsum and $1/3^{rd}$ of urea was applied prior to final preparation of the pots. The remaining $2/3^{rd}$ urea was top dressed in two equal installments at 25 and 50 days after transplanting. Irrigation was done very carefully when needed to maintain the water stress according to the treatments and weeding was done regularly.

Plant materials and plant growth

To simulate the conditions of the local farming in Khulna region, 27 days old rice seedlings in regular cultivation *Banglamoti* (BRRI *dhan* 50), *Vittiatash* (BRRI *dhan* 28 selected) and *Atash balam* (BRRI *dhan* 28) were selected for transplanting into the pots. Three seedlings were transplanted in each pot which were arranged according to completely randomized design (CRD).

Treatments

In growth experiment, plants were subjected to five degrees of water stresses: T_1 = pots containing soil are ponded with water up to 5 cm above the soil surface, T_2 = pots containing soil are ponded with water up to 3 cm above the soil surface, T_3 = pots containing soil are saturated with water, T_4 = soils in the pot contain water @ of 75% of saturation, T_5 = soils in the pot contain water @ of 50% of saturation. Each treatment was replicated three times.

Measurement of agronomic yield and yield components

Data on some morphological parameters such as plant height, tiller number, panicle number, and dry weight; yield attributes such as grain panicle^{-1}, grain weight panicle^{-1}, 1000 grain weight, and harvest index were measured according to standard methods (Jahan et al., 2013). Two physiological characteristics like Water Use Efficiency (WUE), Relative Water Content (RWC) were recorded by following methods.

Relative Water Content (RWC) estimation

After collecting the leaves from the top, the RWC was calculated according to the following formula:

$$RWC = \frac{FW-DW}{TW-DW} \text{ x } 100$$

Where, FW = fresh weight of leaves, TW = turgid weight of leaves, DW = dry weight of leaves

To avoid moisture loss from the leaves, the FW was taken as soon as possible after leaf collection. For obtaining the TW, the leaves were kept into a container filled with distilled water for 12 hours until the leaves reach a constant weight which was considered as 100% hydration. The TW was determined immediately after removing the leaves from water. The DW was taken after oven drying of fully turgid leaves for 48 hours at 70^0C (Turner, 1986).

Water Use Efficiency (WUE) estimation

WUE was calculated as total dry weight divided by total amount of transpiration for each water treatment. WUE was calculated by using the following formula after observing the amount of water loss from the potson daily basis.

$$WUE = \frac{W_2 - W_1}{\Sigma Transpiration}$$

Where, $W_2$and W_1 are the total plant dry weights after 2nd and 1st harvest respectively. Water stresses were imposed by simply weighing the soil added to the pot (dry weight), the amount of water started with and all other objects (weight of pot, etc.). Finally, weighing each pot once a week to measure evaporation and add evaporated water.

Statistical Analysis

The collected data were taken under the analysis of variance (ANOVA) using Minitab's ANOVA (version 17.0) and Duncan's New Multiple Range Test (DNMRT) was used to compare treatments.

RESULTS AND DISCUSSION

Effect of water stress on morphological parameters

The morphological characteristics of three rice varieties were tested at different water stressed condition are presented in Fig. 1. All the morphological results of tested rice varieties reduced significantly ($p<0.001$) due to water stress except plant height. Fig. 1(a) represents that plant height was almost similar regardless of the water stress as well as three rice varieties. In this case, *Banglamoti* showed highest plant height (66.33±1.26 cm) under T_3 and the lowest (45.17±4.25 cm) under T_5 treatment. Plant dry weight reduced progressively with the increment of stressed condition Fig. 1(b).

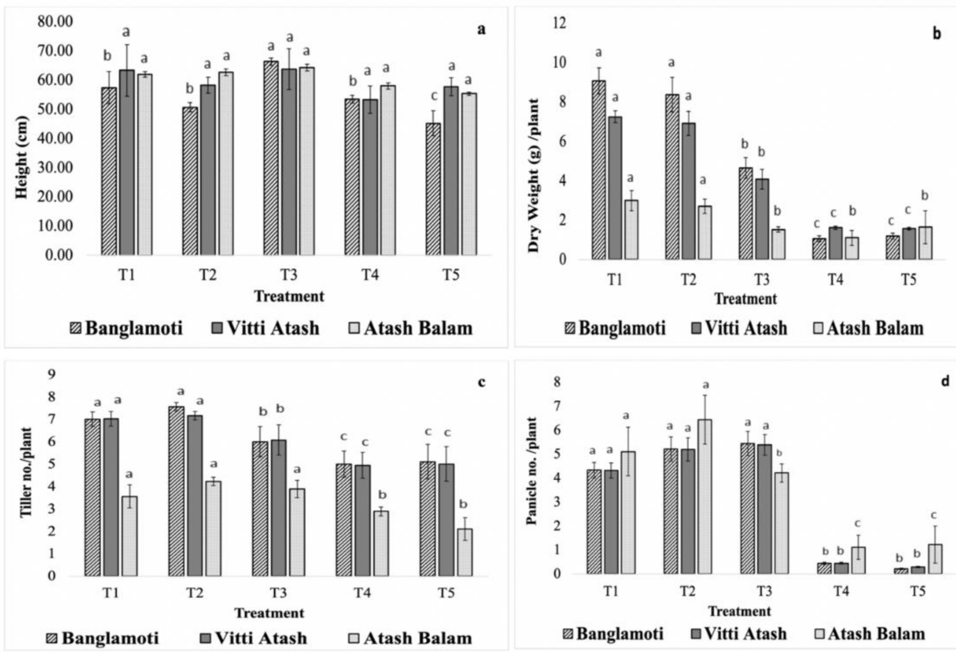

Fig. 1. Effects of water stress on (a) plant height, (b) dry weight, (c) tiller number, (d) panicle number (Each bar represents the average value of three replication, vertical lines above each bar indicates standard deviations, and different letters above the bars indicate the significant differences ($p=0.05$). Here, T_1=5 cm standing water; T_2= 3 cm standing water; T3= saturated condition; T_4= 75% and T_5= 50% of saturation)

Banglamoti showed the maximum dry weight (9.07±0.66g plant^{-1}) with T_1 treatment though it is not significantly higher than *Vittiatash* and on the other hand, in case of *Atash balam* plant dry weight was comparatively very low under T_1, T_2 and T_3 treatments than the other two varieties. Water stress did not produce any significant change in tiller number plant^{-1} in case of each rice variety (Fig. 1c) but tiller numbers of *Banglamoti* and *Vittiatash* were almost similar and quite higher than that of *Atash balam* in every treatment. (Fig. 1d) shows that the maximum panicle number (6.44±1.02 plant^{-1}) was found in Atash balam rice under T_2 whereas *Banglamoti* and *Vittiatash* did not show any significant change in panicle number up to saturation. Panicle initiation was drastically reduced at severe water stress irrespective of the rice varieties studied.

Our experimental results revealed that, water stress had no effects on the height of rice varieties and the observed results can be compared with Khairi et al. (2015) who run an experiment on rice under different water level and found the similar results. On the other hand, Zubaer et al. (2007) stated an inverse relation between plant height and water stress. Dry weight of three rice varieties decreased almost sequentially with increasing water stress (Fig. 1b). The process of oxidative deterioration due to water stress causes cell damage and reduction of nutrient uptake, photosynthesis rate and leaf area which might be responsible for the decrease in plant dry matter under lower soil moisture. The finding was also in accordance with Zubaer et al. (2007), who observed a decrease in shoot dry matter of Aman rice with increasing water stress. The soil moisture deficiency at a severe rate caused a reduction of tillers production and panicle number regardless of the three genotypes which may be caused by the reduction of assimilates production under water stress and our findings were similar with Sokoto and Muhammad, (2014). Akram et al. (2013) also found a decrease in panicle number in three *basmati* rice cultivars under water deficit stress.

Effect of water stress on yield of three rice varieties

The yields of three rice varieties influenced by different water level are presented in Fig. 2. The observed yield characteristics insignificantly differed with different water level among the rice varieties but it was noticeable that there were no yields below the saturation level in all varieties tested. The maximum grain plant^{-1} (49.67±7.95) and grain weight plant^{-1} (0.96±0.17g) were observed under T_3 in *Vittiatash*. *Banglamoti* and *Atash balam* were in the second and third position, respectively, in both the cases Fig. 2(a, b).

From Fig. 2(c) it is seen that *Vittiatash* rice variety had the highest 1000 grain weight (18.70±4.32g) at T_3 and the lowest (16.19±2.73g) at T_1 but the values did not differ significantly from *Banglamoti* and *Atash balam*. The maximum 1000 grain weight of *Banglamoti* and *Aatshbalam* was calculated under T_1 and T_2, respectively. Fig 2(d) represents the effects of water stress on harvest index (HI) of three rice varieties. Among the rice varieties studied, the *Vittiatash* rice showed the highest HI than the other varieties of rice with T_3 which was (0.50 ±0.06) and *Atash balam* was in the lowest position in all the treatments. However, treatment did not show any significant effect on the specific rice variety.

The yield parameters were adversely affected under water stressed condition in such an extent that, no yields were observed below the saturation level. Several researches on rice plant also explained the decrease of grain number panicle^{-1}, grain weight panicle^{-1},1000 grain weight with increasing moisture stress (Sokoto and Muhammad, 2014; Khairi et al., 2015; Yang, et al.,2019). In some cases, the drastic reduction of grain number (up to 50%) was also found (Sarvestani et al., 2008). The reason of decrement of grain production can be narrated as, water stress reduced the starch accumulation capacity of endosperm into grain by inhibiting photosynthesis rate and

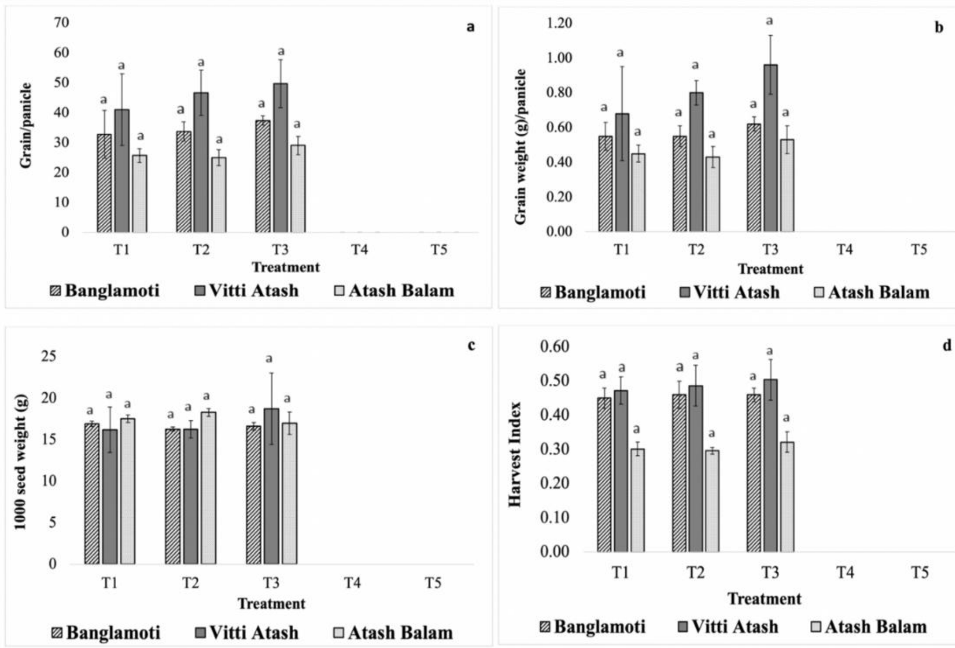

Fig. 2. Effects of water stress on yield and yield contributing characteristics of three rice varieties (a) grain content plant^{-1}(b) grain weight panicle^{-1} (c) 1000 grain weight (d) harvest index at different water stress (Each bar represents the average value of three replication, vertical lines above each bar indicates standard deviations, and different letters above the bars indicate the significant differences (p=0.05). Here, T_1=5 cm standing water; T_2= 3 cm standing water; T_3= saturated condition; T_4= 75% and T_5= 50% of saturation)

nutrient uptake which affected rice yield which was similar with the findings of Zhang et al. (2018). Among the different rice varieties studied, weight of 1000 grain were different in different moisture level and *Vittiatash* performed better in yield than that of *Banglamoti* and *Atash balam*. On the other hand, in spite of being a water loving plant, the highest amount of water level (5 cm) did not show highest production and grain yield increased from T_1 to T_3. So, from the experiment, it was clear that, rice need optimum water for its maximum growth and yield though the need of water depends on varieties. At the water levels below fully saturation (50% and 75% saturation), there were no yield and above saturation (5 cm and 3 cm water level), the yields were lower than that of saturated condition. The principal reasons behind the maximum grain yield were- proper oxidation mechanism, photosynthesis, sufficient nutrient uptake and increase in translocation of assimilates to the grain under saturation level.

The harvest index (HI) value is a very important indicator of production efficiency which indicates the proper translocation of sufficient assimilates to the grain. The reason of decrease in HI value could be explained as water stress inhibit nutrient supply and increase the yield of empty grain. In our experiment, the results suggested that soil water condition above saturation did not affect harvest index as well as yield and it was clear that, the three rice varieties showed different HI values under the experimental water treatments. The result was in agreement with the findings of Zubaer et al. (2007) and Khairi et al. (2015), who observed the highest HI under well irrigated varieties compared to that of grown under water stressed condition. They also stated that, the rate of reduction of HI largely influenced by the tolerance level of rice genotypes and soil moisture level.

Effect of water stress on physiological characteristics of three rice varieties

Relative Water Content (RWC)

The effects of water stress on relative water content (RWC) of three rice varieties are presented in Fig. 3a. From the figure, it is clear that the RWC of three rice varieties followed the similar decreasing trend with the increment of water stress and in each variety T_5 showed the lowest RWC. *Banglamoti*, *Vittiatash* and *Atash balam* showed significantly ($p<0.001$) the maximum RWC (73.62±1.71, 76.45±1.80 and 76.72±4.44% respectively) under T_1 condition than the other water treatments though *Banglamoti* did not produce any significant reduction in RWC until saturation.

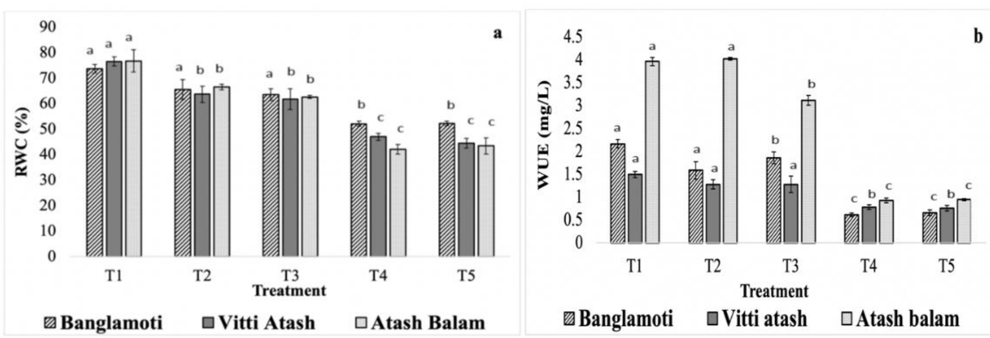

Fig. 3. Effects of water stress on (a) relative water content and (b) water use efficiency of three rice varieties (Each bar represents the average value of three replication, vertical lines above each bar indicates standard deviations, and different letters above the bars indicate the significant differences (p=0.05). Here, T_1=5 cm standing water; T_2= 3 cm standing water; T_3= saturated condition; T_4= 75% and T_5= 50% of saturation)

Water Use Efficiency (WUE)

The results of Fig. 3b represents that the change in WUE varied with water level and rice varieties and decreased with the increasing rate of water stress. The WUE of *Atash balam* was higher in each case and the significantly ($p<0.001$) higher value was observed in *Atash balam* under T_2 (4.03± 0.03 mgl^{-1}) though T_1 and T_2 were statistically similar. The maximum WUE of *Banglamoti* (2.17± 0.09 mgl^{-1}) and *Vittiatash* (1.5± 0.07 mgl^{-1}) were found under T_1 treatment.

RWC is considered as one of the important and easily measurable parameters in agriculture that is very useful to identify the drought tolerance of plants. The high RWC value expressing the withstand capacity of plant under water stressed condition than the drought-sensitive species with low RWC (Boutraa et al., 2010). Our results were in accordance with Zulkarnain et al. (2009) and Akram et al. (2013), who revealed the decreased of RWC in rice grown under water stress treatment. By using RWC value as a criterion for finding out drought tolerance, the three rice varieties might be considered drought-tolerant up to saturated condition as the RWC values are close for T_1, T_2 and T_3 but below this level, a noticeable decrease were observed. This result can be compared with the experimental outcome of Chelah et al. (2011), who did not find out any adverse impact on RWC in rice plant at saturation level.

Water use efficiency (WUE) can be considered as one of the major physiological characteristics of rice plant that is obtained by the ratio of plant dry matter to transpiration rate which determine the yield under limited condition of water (Jaafar et al., 2000; Boutraa et al., 2010). So, it can be said that, *Atash balam* was the most water consuming variety, followed by *Banglamoti* and *Vittiatash*, respectively. Under the most stressed condition i.e. T_4 and T_5 treatments, all varieties showed very low and no significant change in WUE. The result showed that WUE was not affected at higher water content in any one of the studied rice variety. Under water stressed condition, the recession of water is responsible for stress at these treatments and results in low WUE. This inverse relationship between water stressed condition and WUE was also confirmed by earlier research (Shangguan et al., 2000; Boutraa et al., 2010) using wheat as experimental plant, but highly depends on variety. On the other hand, Akram et al. (2013) found opposite results by an experiment on rice plant and stated that, WUE was enhanced significantly under moisture stress.

CONCLUSION

The response of three rice cultivars under different water treatments was investigated and yield reduction was observed in each case under water deficient condition. No yield was found in the soil water level below the saturation for all the rice varieties. The vegetative growth and dry weight of the studied plants were higher under 5 cm standing water level but grain yields and harvest index were found higher under saturated condition. The relative water content and water use efficiency also decreased with decreasing moisture level. Among the varieties, *Vittiatash* can be evaluated as most potential variety with the maximum grain content per panicle, 1000 grain weight and harvest index by consuming minimum quantity of water under saturated water treatment. Finally, it can be concluded that there were no significant differences in yield of rice grown under the soil flooding with 5 cm or 3 cm depth, as a result approximately 2 cm irrigation water can be curtailed easily without any adverse impact on rice production.

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