

Performance of four irrigated rice varieties under different levels of salinity stress

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Abstract

An experiment was carried out at the research field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh with the objective of verifying the effects of different salinity levels on the germination, growth and yield of four irrigated rice (*Oryza sativa* L.) cultivars. The experiment was performed with 6 NaCl concentrations viz. 0, 30, 60, 90, 120 and 150 mM. It was observed that seed germination, plant height, tiller number and leaf area index are negatively influenced by different salinity levels in all the rice varieties. All the yield components that is number of panicles, panicle length, spikelets per panicle, filled grain and grain weight also significantly decrease with the increased salinity stress. An increase of NaCl concentration up to 150 mM decreased 36-50% of the grain yield of all the four rice varieties. Among the varieties BRRI dhan41 showed better performance at salinity stress up to a certain level.

Keywords: Salinity, Rice, Stress, Growth, Yield.

INTRODUCTION

Rice (*Oryza sativa* L.) is the principal source of food for more than one third of the world's population. It is the second most important crop in the world after wheat, more than 90 per cent of which is grown in Asia. Rice is one of the most widely grown crops in coastal areas inundated with sea water during high tidal period, although it is usually considered moderately susceptible to salinity (Akbar *et al.*, 1972; Korbe and Abdel-Aal, 1974; Mori and Kinoshita, 1987). Rice (*Oryza sativa* L.) is rated as one of the major food crops in the world, but is also considered extremely salt-sensitive (Maas and Hoffman, 1977).

Among the various factors limiting rice yield, salinity is one of the oldest and most serious environmental problems in the world (McWilliam, 1986). In Bangladesh, over thirty percent of the net cultivable area is in the coastal region. Out of 2.85 million

hectares of the coastal and off-shore areas, about 0.833 million hectares are arable lands, which constitute about 52.8 percent of the net cultivable area in 13 districts (Karim *et al.*, 1990). Since rice is recognized as a salt-sensitive crop, there is a serious concern that plant stand (i.e., seedling survival) and the development of yield components are affected by water salinity.

The effects of salinity on plants are complex. The general effects of salinity are the results of both osmotic and ionic stresses (Greenway and Munns, 1980). Yield components related to final grain yield are also severely affected by root-zone salinity. Primary branches per panicle, panicle length, spikelets per panicle, number of filled spikelets, and seed weight per panicle are significantly reduced by salinity (Sajjad 1984; Heenan *et al.*, 1988; Khatun *et al.*, 1995). Adverse effects of salinity on seed germination and seedling growth as well as some physiological activities of cultivated plant species have been extensively investigated (Ashraf, *et al.*, 1991; Khan, *et al.*, 1995). The strongest salinity effects on yield are observed around panicle initiation (PI), whereas plants recovered best from stress at the seedling stage (Asch and Wopereis, 2001). Due to a number of environmental factors the coastal soils are slightly to moderately saline on the surface, and highly saline in sub-surface layers

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and substrata. Saline soil contains an excess of soluble salts, especially sodium chloride. In other words, soil salinity develops under the influence of the electrolytes of sodium salts, with a nearly neutral reaction.

Study on the response of rice to salinity stress may be helpful in breeding salt tolerant cultivars by identifying physiological features. The aim of the present investigation is to provide information on the effect of salinity on seed germination, growth, yield components and yield of four popular rice varieties to see if there is any correlation between these variables.

MATERIALS AND METHODS

The experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, during Aman season (August to December, 2008). Geographically, the experimental area is located at 24°75' N latitude and 90°50' E longitude at the elevation of above 18 m of sea level. The soil of the experimental pot was silty-loam having noncalcareous properties.

Earthen pots were used in this experiment. The size of the pot was 30 × 20 cm. The soil was collected from 0-15 cm depth. The collected soil was well pulverized and dried in the sun and decomposed cowdung was mixed with the soil. A basal dose of triple super phosphate (TSP), muriate of potash (MP) and gypsum were used as the source of phosphorus, potassium and sulphur applied at the rate of 180 kg ha⁻¹, 100 kg ha⁻¹ and 20 kg ha⁻¹, respectively (1ha = 3×10⁶ kg fresh soil) at the time of final pot preparation. Urea @ 150 kg ha⁻¹ was applied as 3 equal splits.

There were 4 different rice varieties used in the experiment - BR11, BRRI dhan41, BRRI dhan44 and BRRI dhan46 which were collected from Bangladesh Rice Research Institute (BRRI). Seeds and rice plant were subjected to exposure in different salinity concentration of 0, 30, 60, 90, 120 and 150 mM NaCl. The experiment was carried out in a Randomized Complete Block Design (RCBD) with 3 replications as factorial arrangement.

Seeds were allowed for germination in petri dishes having the different salinity concentration. Pregerminated seeds were sown in wet nursery bed and care was taken to raise the seedlings in seedbed. Each thirty- day-old seedling was transplanted in a separate puddled pot with different salinity concentration. Seedling in some hills died off, and these were replaced by gap filling after one week of transplanting with the seedling from the same source. Intercultural operations were done as required. About 5-6 cm water layer was maintained in the pot until the crop attained maturity.

Water was added regularly as per assigned salinity concentrations.

After providing an exposure of salinity treatment for a period of one and two weeks, number of dead leaves per plant, were counted and percent increase in mortality of leaves were calculated comparing the plants growing under non-saline conditions (0 mM NaCl). Relative water content in shoot was determined with following equation:

$$RWC = \frac{(\text{Fresh weight} - \text{Dry weight})}{(\text{Turgid weight} - \text{Dry weight})} \times 100$$

Fresh weight of the plants were measured and the plants were dried at 105°C for 24 h until they reached constant weight for the determination of dry weight. To determine the turgid weight, samples were soaked in distilled water for 4 h at room temperature (approximately 20°C) and then turgid weight was measured (Fletcher *et al.*, 2006).

Leaf area was measured at maximum tillering stages. The leaf area was measured with an automatic leaf area meter (Model AAM, Hayshi Denkoh Co., Tokyo, Japan). Leaf area index was measured as follows:

$$LAI = \frac{\text{Total leaf area}}{\text{Ground area}}$$

Different yield components were recorded at maturity. Grain yield was recorded from each plant and then converted to tons per hectare. Grains were weighed at 14% moisture. Data were analyzed following Analysis of Variance (ANOVA) technique and mean differences were adjusted by the multiple comparison test (Gomez and Gomez, 1984) using the statistical computer based programme MSTAT-C v.2.1. (Russell, 1994) Means were compared by using DMRT test.

RESULTS

Seed germination

Germination of rice seeds of different varieties was significantly influenced by different salinity levels (Table 1 [Supplementary data]). In this experiment, germination percentage decreased with the increase of salinity levels. Among the 4 rice varieties, BRRI dhan41 showed better performance against salinity levels up to 90 mM NaCl. The lowest germination rate was observed at 150 mM NaCl salinity level which was statistically similar with 120 mM NaCl salinity. Seed germination rate was reduced by soil salinity due to the enzyme inhibition. Flowers (1972) reported that malic dehydrogenase and glucose-6-phosphate dehydrogenase were inhibited by elevated NaCl levels.

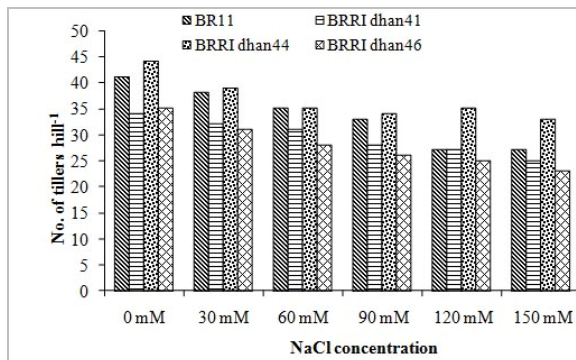


Figure 1: Total no. of tillers hill⁻¹ of rice varieties under different levels of salinity.

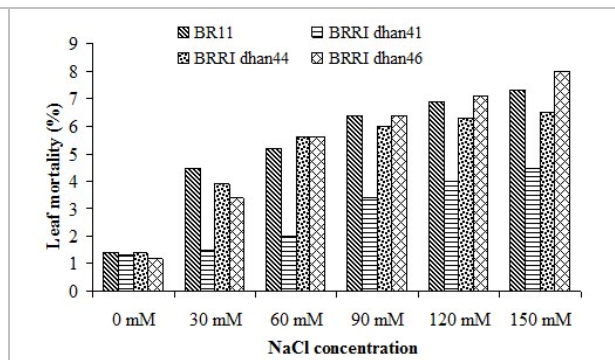


Figure 2: Leaf mortality (%) of rice varieties under different levels of salinity.

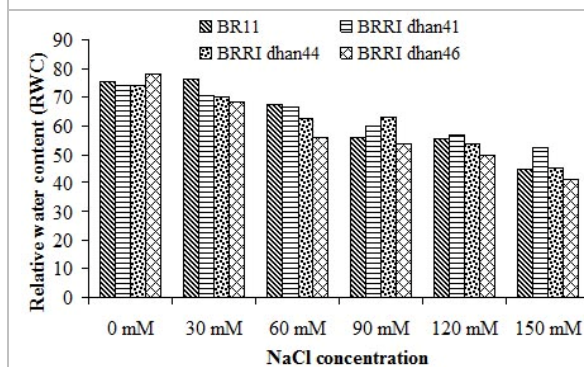


Figure 3: Relative water content (RWC) in shoots of rice varieties under different levels of salinity.

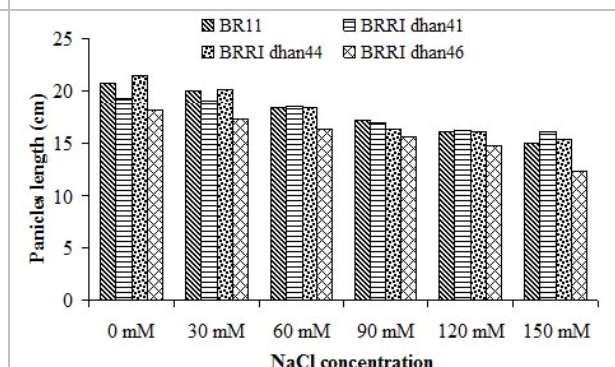


Figure 4: Panicle length of rice varieties under different levels of salinity.

High ion content in plant cells can induce changes in protein hydration and their precipitation, causing an inhibition of enzyme activity (Waisel, 1972). In this experiment BRR1 dhan 44 showed maximum susceptibility to salinity stress in terms of germination (Table 1).

Plant height

Plant heights of different rice varieties were significantly affected by different salinity levels except BRR1 dhan41. In case of all the varieties, plant height decreased with increase in salinity levels. BRR1 dhan44 showed maximum susceptibility to salinity stress. A decrease of plant height of BR11, BRR1 dhan41, BRR1 dhan44 and BRR1 dhan46 with 150mM salinity levels was 10.21%, 7.49%, 16.71% and 11.07%, respectively compared to fresh water (Table 2 [Supplementary data]). The results indicate the effect of salinity on plant elongation of different varieties were different, which might be due to genetic potentiality of the varieties. Shalhevet (1995) reported that salinity generally reduces shoot growth of crops more than root growth, based on dry weight rather than length measurements. Islam *et al.* (2007) also observed the differences in plant height of rice varieties with different salinity levels.

Number of tillers

Rice grain yields are highly dependent upon the number of panicle-bearing tillers produced per plant. Salinity stresses greatly affected the development and viability of tillers in this experiment (Fig. 1). All the rice varieties in this experiment are significantly influenced by salinity levels in terms of effective tiller production. Tiller production gradually decreases with the increased levels of salinity. In case of BR11 more than 30% reduction of effective tillers was observed with 150mM NaCl treatment compared to control (no salinity). BRR1 dhan41 shows a tolerance to salinity stress up to a certain level (60 mM NaCl). BRR1 dhan 44 and BRR1 dhan 46 also showed similar performance like BR11 to produce effective tillers. This result is supported by Zeng and Shannon (2000).

Leaf mortality

Fig. 2 reveals that leaf mortality greatly influences salinity stress. In this study leaf mortality increases in all rice varieties due to the increase of salinity levels. Maximum differences in leaf mortality are observed between 0 mM NaCl and 30 mM NaCl treatments. The differences in leaf mortality with 90, 120 and 150 mM NaCl salinity is not statistically significant in rice

varieties. In this study BRR1 dhan46 showed greater leaf mortality due to salinity stress while BRR1 dhan41 is slightly tolerant. Leaf senescence rate increases and the leaf's physiologically active period is shortened under salinity. This result is supported by Ullah *et al.* (2007) who reported that early seedling stage and huge plant mortality is found under saline field conditions. Salinity reduces the growth of plant through osmotic effects, reduces the ability of plants to take up water and this causes reduction in growth. There may be salt specific effects. If excessive amount of salt enters the plant, the concentration of salt eventually rises to a toxic level in older transpiring leaves causing premature senescence and reduces the photosynthetic leaf area of a plant to a level that cannot sustain growth (Munns, 2002).

Leaf Area Index (LAI)

Table 3 [Supplementary data] indicates that leaf area index of different rice varieties decreases with the increase of salinity levels. Leaf area index of all the four rice varieties is significantly affected by salinity stress. Highest LAI is observed with control treatment (fresh water) while the lowest LAI is observed with 150 mM NaCl treatment. Maximum reduction of LAI due to salinity is observed in BR11 rice variety, while the BRR1 dhan41 has better performance. Decrease in LAI might have been due to decrease in leaf expansion in salinity stress condition. This result corroborates with Bal and Dutt (1984). Mahmood and Quarine (1993) reported that the growth of wheat in terms of leaf area and dry weight are reduced by salt treatment.

Relative Water Content (RWC)

Relative water content in shoot is greatly influenced by salinity levels (Fig. 3). In this experiment leaf relative water content of all 4 varieties shows decreased RWC after salt stress. But, this reduction is more visible from 30mM NaCl and higher salinity levels. Among the varieties BRR1 dhan46 is most susceptible to salinity in terms of RWC while BRR1 dhan41 shows better performance. In case of BR11 150 mM NaCl reduced the RWC to 30.7%. In case BRR1 dhan41, BRR1 dhan44 and BRR1 dhan46 the reduction of RWC are 21.5%, 28.8% and 36.9%, respectively. The maximum differences in RWC are observed between 30 mM NaCl and 60 mM NaCl salinity. Rodriguez *et al.* (1997) reported that leaf relative water content values decreased more rapidly in the treated plants than in control plants.

Numbers of panicles

It is evident from Table 4 [Supplementary data] that number of panicles per hill in rice plants decrease with increase in salinity levels. In this experiment BR11 rice varieties produced almost half of the panicles per hill

when salinity level reached to 150 mM NaCl. In case of BRR1 dhan41 the reduction of panicle number is less which might be due to its tolerance to salinity. A gradual decrease of panicle number is also observed in BRR1 dhan44 where 42.41% reduction is observed with 150 mM NaCl compared to control. In case of BRR1 dhan46 the effect is significant up to 120 mM NaCl and after that the reduction is insignificant. The lower panicle yield in high salinity can be due to lower accumulation of photosynthate to the reproductive parts. When the plants are continuously exposed to saline media, salinity affects the panicle initiation. Grattan *et al.* (2002) observed that salinity has profound effects on panicle yield. Sajjad (1984) and Heenan *et al.* (1988) also reported that salinity stress reduce the number of panicles.

Panicle length

Fig. 4 reveals that panicle length of different rice varieties is also affected by various salinity levels. In control condition the maximum length of panicle is observed in BRR1 dhan44 and minimum length is observed in BRR1 dhan46. The significant reduction of panicle length is observed after 30mM NaCl level and onwards. Maximum reduction in panicle length is observed in BR11 and BRR1 dhan44 varieties. BRR1 dhan41 shows lower response to salinity stress regarding panicle length. The number of panicles per unit area depend on tillering ability of plants which is also affected by salinity. Similar results are earlier reported by Marassi *et al.* (1989) in rice.

Filled spikelets per panicle

Significant influence of salinity on filled spikelets is also observed in this experiment (Table 5 [Supplementary data]). Filled spikelets or grains per panicle decrease significantly on increase of salinity. The highest filled grain per panicle is recorded at control condition and the number of lowest filled grain per panicle is recorded at 150 mM NaCl level of salinity. Except BRR1 dhan41 a gradual decrease in filled spikelets is observed with the increase in salinity concentration. Zaibunnisa *et al.* (2002) and Zaman *et al.* (1997) reported that filled grain per panicle decreased by salinity.

Spikelet fertility

Fertile grain is an important contributory factor to grain yield. In this study spikelet fertility is greatly influenced by salinity level (Fig. 5). Among the rice varieties BR11 shows maximum response to salinity in decreasing spikelet fertility. In BR11 39.1% reduction of spikelet fertility is observed due to the salinity level of 150mM NaCl compared to control. BRR1 dhan 41 gives better performance to salinity stress in terms of fertile grain production. A drastic decline in spikelet

fertility is observed with increase in salinity level for all rice varieties under investigation. Maximum reduction of spikelet fertility is observed between 90 and 120 mM NaCl treatment. The reduced spikelet fertility might be due to failure of grain formation in rice grain which could be caused by lack of pollen viability. Khatun *et al.* (1995) earlier reported that salinity reduces pollen viability and seed set.

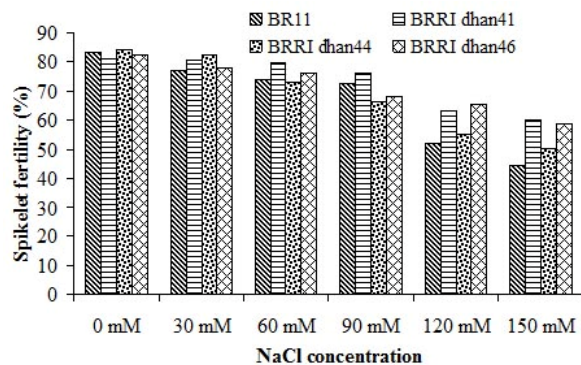


Figure 5: Spikelet fertility of rice varieties under different levels of salinity.

1000 grain weight

Among the 4 rice varieties significant differences are observed in 1000-grain weight (23.2 g) due to salinity stress (Table 6 [Supplementary data]). In BR11 variety the maximum 1000-grain weight is observed with control plot whereas lowest weight of 1000 grains (19.1 g) is observed from 150 mM NaCl. In BRR1 dhan41 the effect of salinity is clearly visible after the treatment of 60mM NaCl which is due to high salt tolerance. In case of BRR1 dhan44 44.79% reduction of grain weight is observed in 150 mM NaCl salinity. BRR1 dhan46 also shows similar results. This might be due to lower accumulation of carbohydrates and other food materials due to salt stress. Khatun and Flowers (1995) reported that 1000-grain weight decreases with increase in levels of salinity.

Grain yield

Grain yield of rice is the ultimate product of yield components which is greatly influenced by salinity levels. All the rice varieties in this study are inversely influenced by salinity levels (Table 7 [Supplementary data]). In control condition, maximum grain yield is obtained from BR11 while the lowest yield is obtained from BRR1 dhan46. But with the increase of salinity levels the yield of these varieties decreases (Table 7 [Supplementary data]). Maximum differences in grain yield are observed between the salinity levels of 30 and 60 mM salinity. The loss of grain yield due to 150 mM salinity are 50%, 37.5%, 44.44% and 36.17% over control for BR11, BRR1 dhan41, BRR1 dhan44 and BRR1 dhan46, respectively. Under continuous salinity stress, the loss of grain yield results from a combination

of reductions in plant stand, spikelet number per panicle, fertility, and harvest index. Among all these contributing components studied, the fertility of grain is found most severely affected and thus causes significant reduction in total yield of grain. In addition to fertility, panicle length and panicle numbers are two important affected characters that contribute to grain yield. The magnitude of salt induced yield losses could not be attributed to a single factor. Different physiological, and biochemical factors at different stages of rice plants might be involved. One factor may be the overall control mechanism (before flowering) of sodium uptake through root properties and its subsequent distribution in different vegetative and floral parts especially in leaves where it causes leaf mortality thereby reducing transportation of total assimilates to the growing region (Munns 2002). The severe inhibitory effects of salts on fertility may be due to the differential competition in carbohydrate supply between vegetative growth and constrained supply of these to the developing panicles (Murty and Murty, 1982). Also reduced viability of pollen under stress condition, could result in failure of seed set (Abdullah *et al.*, 2001). Grain yield reduction of rice varieties due to salt stress is also reported by Linghe *et al.* (2000) and Gain *et al.* (2004).

From the results it can be concluded that different levels of salinity significantly affect the performance of different rice varieties. With the increase of salinity levels the growth, yield components and yield decrease which render the lower yield. The effect of salinity stress also differs among the varieties. The difference is more prominent at higher salinity. It is revealed from the current investigation that among the four rice varieties BRR1 dhan41 performs better at certain levels of salinity stress.

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