EFFECT OF POTASSIUM IN MITIGATING ADVERSE EFFECT OF SALT STRESS ON GROWTH, DEVELOPMENT AND YIELD OF RICE PLANT (*Oryza sativa* L.)

A THESIS

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SHER-E-BANGLA AGRICULTURAL UNIVERSITY
DHAKA -1207
June, 2018

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Registration No. : 12-04936

A Thesis

Submitted to the Department of Agricultural Botany
Sher-e-Bangla Agricultural University, Dhaka, in partial
fulfillment of the requirements
for the degree
of

MASTER OF SCIENCE
IN
AGRICULTURAL BOTANY

SEMESTER: JANUARY-JUNE/2018

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CERTIFICATE

*This is to certify that the thesis entitled, **"EFFECT OF POTASSIUM IN MITIGATING ADVERSE EFFECT OF SALT STRESS ON GROWTH, DEVELOPMENT AND YIELD OF RICE PLANT (Oryza sativa l.)"** submitted to the Department of Agricultural Botany, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURAL BOTANY,** embodies the results of a piece of bonafide research work carried out by **RIPON KUMAR ROY** Registration No.* **12-04936** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

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ACKNOWLEDGEMENTS

All praises to Almightly and Kindfull trust on to "Omnipotent Creator" for his never-ending blessing, it is a great pleasure to express profound thankfulness to my respected parents, who entitled much hardship inspiring for prosecuting my studies, thereby receiving proper education.

I would like to express my heartiest respect,deep sense of gratitude, sincere and profound appreciation to my supervisor, **Associate Prof. Dr. Kamrun Nahar,** *Chairman, Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka for her sincere guidance, scholastic supervision, constructive criticism and constant inspiration throughout the course and in preparation of the manuscript of the thesis.*

*I would like to express my heartiest respect and profound appreciation to my Co-supervisor,***Dr. Md. Sazzadur Rahman***, Senior Scientific Officer Plant physiology Division, BRRI, Gazipur for his constructive suggestions for the preparation of the thesis.*

I express my sincere respect to all the teachers of Department of Agricultural Botany, Sher-e-Bangla Agricultural University,Dhaka for providing the facilities to conduct the experiment and for their valuable advice and sympathetic consideration in connection with the study.

I would like to thank all of my roommates and friends specially and senior brother to help me in my research work.

Mere diction is not enough to express my profound gratitude and deepest appreciation to my father, mother, brothers, sisters, and friends for their ever ending prayer, encouragement, sacrifice and dedicated efforts to educate me to this level.

June, 2018 **The Author**
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ABSTRACT

A pot experiment was conducted at the net house of the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka-1207, during *Boro* rice cropping season of the year of 2017-18 to observe the effect of potassium in mitigating adverse effect of salt stress on growth, development and yield of rice plant (*Oryza sativa* L.). The experiment was conducted using two salinity levels with potassium viz. S_0 = Control, S_1= 4dSm^{-1} salt, S_1K_1= 4dSm^{-1} salt + 80 ppm potassium, S_1K_2 = 4dSm^{-1} salt + 160 ppm potassium, S_2= 6 dSm^{-1}, S_2K_1 = 6 dSm^{-1} + 80 ppm potassium, S_2K_2 = 6 dSm^{-1} + 160 ppm potassium. The experiment was conducted in Randomized Complete Block Design (RCBD) having one factor with three replications. The results and the effect on morphological characters indicated that all parameter were influenced by salinity and potassium. Among 3 salinity level (0, 4 & 6 dSm^{-1}), the damaging effect was found more in higher stress (6 dSm^{-1}).But potassium supplementation along with salt greatly reduced the damaging effect of salt. Out of the 2 levels of potassium 160 ppm potassium significantly reduced the damaging effect of salt. Therefore, for cultivation of BRRI dhan67 under saline condition 160 ppm potassium application could be a better practice for getting higher yield.

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LIST OF ABBREVIATIONS

AEZ = Agro-Ecological Zone
BARI = Bangladesh Agricultural Research Institute
BBS = Bangladesh Bureau of Statistics
LAI = Leaf area index
ppm = Parts per million
et al. = And others
N = Nitrogen
TSP = Triple Super Phosphate
MP = Muriate of Potash
RCBD = Randomized complete block design
DAS = Days after sowing
ha^{-1} = Per hectare
g = gram (s)
Kg = Kilogram
µg = Micro gram
SAU = Sher-e-Bangla Agricultural University
SRDI = Soil Resources and Development Institute
HI = Harvest Index
No. = Number
Wt. = Weight
LSD = Least Significant Difference
^{0}C = Degree Celsius
mm = Millimeter
Max = Maximum
Min = Minimum
% = Percent
cv. = Cultivar
NPK = Nitrogen, Phosphorus and Potassium
CV% = Percentage of coefficient of variance
Hr = Hour
T = Ton
viz. = Videlicet (namely)

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) is a cereal food crop of the grass family Gramineae, extensively cultivated in warm climates, especially in East Asia, producing seeds that are cooked and used as food. About 90 percent of the population of Bangladesh is rice eaters. The Food Department of the Government of Bangladesh recommends 410 gms of rice /head/day. Rice is rich in carbohydrates. The protein content is about 8.5 percent. The Thiamin and Riboflavin contents are 0.27 and 0.12 micrograms per gm of rice, respectively. In Bangladesh total cultivable land is 90,98,460 hectare and near about 70 per cent of this land is under rice cultivation. In the year 2017-18, total production of rice was 3,62,793 metric tons (DAE, 2019).Soil salinization adversely affects crop production worldwide and about 831 million hectares of lands are affected by salt stress (FAO 2005). The agricultural land is decreasing constantly due to population pressure, adverse environmental condition, continuously increasing natural calamities, and global climate change (Hasanuzzaman *et al.*, 2013). In Bangladesh, there are approximately 2.85 million ha of coastal soils which occur in the southern parts of the Ganges tidal floodplain, in the young Meghna estuarine floodplain and in tidal areas of the Chittagong coastal plain and offshore islands (Brammer, 1978). About one million ha of land of these coastal and offshore areas are affected by varying degrees of salinity. These coastal saline soils are distributed unevenly in 64 thanas of 13 coastal districts covering 8 Agroecological zones (AEZ) of the country. The majority of the saline land (0.65 million ha) exists in the districts of Satkhira, Khulna, Bagerhat, Barguna, Patuakhali, Pirojpur and Bhola on the western coast and a smaller portion (0.18 million ha) in the districts of Chittagong, Cox's Bazar, Noakhali, Lakshmipur, Feni and Chandpur. According to the report of Soil Resource Development Institute (SRDI, 2010) of Bangladesh, about 0.203 million ha of land is very slightly (2-4 dSm^{-1}), 0.492 million ha is slightly (4-8 dSm^{-1}), 0.461 million ha is moderately (8-12 dSm^{-1}) and 0.490 million ha is strongly (>12 dSm^{-1}) salt affected soils in southwestern part of the coastal area of Bangladesh. Large fluctuations in salinity levels over time are also observed at almost all sites in these regions. The common trend is an increase in salinity with time, from November- December to March-April, until the onset of the monsoon rains.

Salinity in soil or water is one of the major stresses, can severely limit crop production (Shannon, 1998). The deleterious effects of salinity on plant growth are associated with (i) low osmotic potential of soil solution (water stress), (ii) nutritional imbalance, (iii) specific ion effect, or (iv) a combination of these factors (Ashraf, 1994b; Marschner, 1995). All these cause adverse pleiotropic effects on plant growth and development at physiological and biochemical levels (Munns, 2002) and at molecular level (Mansour, 2000). It is often not possible to assess the relative contribution of these major constraints to growth inhibition at high substrate salinity, as many factors are involved. These include ion concentration, duration of exposure, plant species, cultivar, root stock (excluder and includer), and stage of plant development, plant organ and environmental conditions. So, to cope with the above constraints, salt stressed plants mainly adopt three mechanisms for salt tolerance such as (i) osmotic adjustment, (ii) salt inclusion/ exclusion and (iii) ion discrimination (Volkmar *et al.*, 1998).Salt-induced osmotic stress, ion toxicity and nutrient deficiency primarily affect plant and causes growth reduction (Luo *et al*., 2005; Bhattacharjee, 2008). Salt stress decreases K^+ content and increase Na^+ uptake as Na^+ causes K^+ efflux and triggers K^+ leakage from plant cells. Na^+ displaces Ca from membranes, which also increases intracellular Na^+ (Cramer *et al*., 1985; Shabala *et al*., 2006; Wu and Wang, 2012). Generally, salinity affects the growth of rice plant at all stages of its life cycle. But reproductive stage is more sensitive than vegetative stage which has direct effect on grain yield (Afridi *et al*., 1988). Salt stress reduces the efficiency of water uptake by crop plants. Plant height, total number of tillers, panicle length, grain weight per panicle, 1000-seed weight and quantity of grains decreased progressively with increase in salinity levels (Abdullah *et al*., 2001). Rice is moderately susceptible to salinity, since most rice plants are severely injured at an EC 8-10 dSm^{-1}. Yield loss due to salinity was recorded 30-50% and in Bangladesh farmers generally or often grow local rice varieties due to unavailability of suitable salt tolerant high yielding varieties (Islam *et al*., 2007).

Potassium (K) is a major plant macro-nutrient that plays important roles related to stomatal behavior, osmoregulation, enzyme activity, cell expansion, neutralization of non-diffusible negatively charged ions, and membrane polarization. Metabolic toxicity of Na is largely due to its ability to compete with K for binding site essential for cellular function (Bhandal and Malik 1988). Effects of salt stress and role of K in salt stressed rice plants were studied. Potassium application significantly increased potential photosynthetic activity, percentage of filled spikelets, yield and K concentration in straw. At the same time, it also significantly reduced Na and Mg concentrations and consequently improved the K/Na, K/Mg and K/Ca ratios. Under saline conditions, the mineral nutrition of most plants can be expected to be detrimentally affected. The interactions between K and Na may be emphasized under such conditions and ultimately decrease plant growth (Noaman, 2004). In saline soils and other similar soils the unfavorable conditions as well as inadequate and imbalance use of plant nutrients causes a considerable decline in paddy yield. Potassium is a macronutrient for plants that is required for physiological processes such as the maintenance of membrane potential and turgor, activation of enzymes, regulation of osmotic pressure, stomata movement and tropisms (Golldack, 2003). Nelson (1978) believed that potassium has a positive role in plant growth under saline conditions, because this element plays an essential role in photosynthesis, osmoregulatory adaptations of plant to water stress. Adequate potassium supply is also desirable for the efficient use of Fe, while higher potassium application results in competition with Fe (Celik *et al.,* 2010). Saqib *et al.* (2000) reported a significant reduction in all growth parameters considered and an increased concentration of Na and Cl, decreased K^+:Na^+ ratio.

The present work has therefore, been designed and planned with the following objectives:

- To study the growth, development, yield contributing characters and yield of rice plant under salt stress
- To observe the roles of K in alleviating adverse effect on vegetative stage of salt stress in rice plant
- To study the roles of K in improving reproductive and yield performance of salt affected rice plant.

CHAPTER II

REVIEW OF LITERATURE

Saline soil contains sufficient water-soluble salts on the root zone to impair the growth of crop plants. Salt injury depends on species, variety, growth stage, environmental factors, and characteristics of the soil. Soil characteristics included salt source, nature and content of salts, distribution of salts (lateral, vertical, and seasonal), p^H, organic matter content, nutrient status, water regime,other soil-related toxicities and deficiencies. Hence, it is difficult to define saline soil precisely. The following section describes some of the findings observed and reported by other researchers.

Ebrahimi *et al.* (2012) carried out pot experiment in 2011 in Rice Research Institute of Iran to examine the effects of potassium application methods on rice (*Oryza sativa* L.) under different soil salinity levels. Four methods of potassium application: K_0: spraying with distilled water every 10 days interval (control); K_1: the use of 65mg K Kg^{-1} soil; K_2: spraying 5% K_2SO_4 solution in every 10 days interval; K_3: the use of 65mg K Kg^{-1} soil plus spraying with 5% K_2SO_4 solution every 10 days interval and four levels of irrigation water salinity (tap water and salinities 2, 4 and 6 dSm^{-1}) were investigated in complete randomized block design with three replications. Results showed that soil salinity affected growth and yield components in most of the cases. Potassium application alleviated the stress condition and significantly improved dry matter yield and yield components in rice. Grain, straw, total biological yield, harvest index, 100 grains weight, root dry weight and total tillers significantly decreased with increasing salinity. The interaction between salinity levels and methods of potassium application was significant only for root dry weight. Based on the results use of 65 mg K Kg^{-1} soil plus spraying with 5% K_2SO_4 solution every 10 days interval was most effective in increasing the above features.

Kandil *et al.* (2010) conducted three field experiments at El-Sirw Agricultural Research Station, Damietta during 1999, 2000 and 2001 under saline soil. The field experiments were laid out in split-split plot design with four replications. The main plots were devoted to four irrigation treatments *i.e.* continuous flooding (I1), water withholding for 12 days at 15 days after transplanting (DAT) (I2), at 25 DAT (I3) and at 35 DAT (I4). The sub plots were allocated to the three rice cultivars viz. Sakha 101, Sakha 102 and Giza 178. Three K rates 0, 48 and 46 kg K_2O ha^{-1} was randomized in the sub-sub-plots. The growth characteristic like leaf area index (LAI), dry matter productions (DM) g/m^2, chlorophyll content, heading date were studied along with the chemical traits i. e Na and K contents of shoot as well as Na/K ratio. It was observed that water stress at any growth stage significantly decreased LAI, DM and chlorophyll content and delayed the heading date. Similarly water stress increased Na and K contents (%) in shoots while it had no effect on Na/K ratio. Varietal differences were found significant in all studied characters. Giza 178 had the superiority in this concern as compared to other varieties while Sakha 102 was found inferior in all parameters under these conditions. K rates significantly increased LAI, DM, chlorophyll content and K% up to 48 kg K_2O ha^{-1} while lessen Na% and Na/K ratio and hastened the heading date. The interaction between irrigation treatments and varieties affected LAI, DM, chlorophyll content and heading date while the interactive effects of irrigation and K rates had significant effect on LAI, while cultivars and K rates significantly affected DM and chlorophyll content.

Ashraf *et al.* (2010) conducted a hydroponics experiment to evaluate the role of potassium (K) and silicon (Si) in mitigating the deleterious effects of NaCl on rice cultivars differing in salt tolerance. Two salt-sensitive (CPF 243 and SPF 213) and two salt-tolerant (HSF 240 and CP 77-400) rice cultivars were grown for six weeks in ½ strength Johnson's nutrient solution. The nutrient solution was salinized by two NaCl levels (0 and 100 mmol L^{-1} NaCl) and supplied with two levels of K (0 and 3 mmol L^{-1}) and Si (0 and 2 mmol L^{-1}). Applied NaCl enhanced Na^+ concentration in plant tissues and significantly ($P \leq 0.05$) reduced shoot and root dry matter in four rice cultivars. However, the magnitude of reduction was much greater in salt-sensitive cultivars than salt-tolerant cultivars. The salt interfered with the absorption of K^+ and Ca^{2+} and significantly ($P \leq 0.05$) decreased their uptake in rice cultivars. Addition of K and Si either alone or in combination significantly ($P \leq 0.05$) inhibited the uptake and transport of Na^+ from roots to shoots and improved dry matter yields under NaCl conditions. Potassium uptake, K^+/Na^+ ratios,Ca^{2+} and Si uptake were also significantly ($P \leq 0.05$) increased by the addition of K and/or Si to the root medium. In this study, K and Si-enhanced salt tolerance in rice cultivars was ascribed to decreased Na^+ concentration and increased K^+ with a resultant improvement in K^+/Na^+ ratio, which is a good indicator to assess plant tolerance to salt stress.Zayed *et al*. (2007) conducted two field experiments at the experimental farm of El Sirw Agriculture Research Dammiatta prefecture, Egypt during 2005 and 2006 seasons. The study aimed to investigate the effect of various potassium rates; Zero, 24, 48 and 72 Kg K_2O ha^{-1}, on growth, sodium, potassium leaf content and their ratio at heading, grain yield and yield components of three hybrids: SK2034H, SK2046H, SK2058H and three varieties**;** Giza 177, Giza 178 and Sakha 104. The economic values were also estimated. The experimental soil was clayey with salinity levels of 8.5 and 8.7 dSm^{-1} in the first and second seasons, respectively. The experiments were performed in a split plot design with four replications. The main plots were devoted to the tested rice varieties, while potassium rates were distributed in the sub plots. The studied varieties varied significantly in their growth parameters, Na^+ and K^+ leaf content at heading as well as ratio, yield components and their economic values. SK2034H surpassed the rest varieties without any significant differences with SK2046H. SK2058H didn't show advantage over Giza 178 or Sakha 104. Giza 177 was the worst under such conditions. Increasing potassium rate significantly improved all studied traits leading to high grain yield. Furthermore, potassium succeeded to reduce Na^+, lower Na^+ /K^+ ratio and raised K^+ resulted in considerable salinity withstanding. The hybrids of SK2034H and SK2046H as well as the salt sensitive rice variety Giza 177 were the most responsive cultivars to potassium fertilizer up to 72 kg K_2O ha^{-1}. Consequently, the economic estimates SK2034H had the higher net return and the high potassium level of 72 kg K_2O ha^{-1} gave the highest values of economic parameters under the tested saline soil conditions.

Mehdi *et al.* (2007) conducted a field experiment to evaluate the response of rice crop to potassium fertilization in saline-sodic soil during 2005. Soil samples were collected before transplanting of rice crop and analyzed for physical and chemical properties of the soil. In this experiment five rates of K_2O (0, 25, 50, 75 and 100 kg ha^{-1}) were applied in the presence of basal doses of N and P_2O_5 i.e., 110 and 90 kg ha^{-1}, respectively. Whole of P, K and ½ of N were applied at the time of rice transplanting. Twelve and half kg ha^{-1} $ZnSO_4$ was also applied 15 days after rice transplanting. The remaining half of N was applied 30 days after rice transplanting. The system of layout was Randomized Complete Block Design with four replications. The net plot size was 6x4 m. Fertilizer sources of NPK were urea, TSP and SOP, respectively. Rice salt tolerant line PB-95 was used as test crops. The data of growth parameters and yield was recorded and samples of paddy and straw were collected treatment-wise and analyzed for N, P and K contents. Soil samples after harvesting the crop were also collected, processed and analyzed for the changes in the extractable soil K. The results showed that increasing rates of potassium fertilizer increased the number of tillers m^{-2}, plant height (cm), 1000-paddy weight and paddy as well as straw yield significantly. Maximum paddy (3.24 t ha^{-1}) and straw (3.92 t ha^{-1}) yields were obtained in T_5 (100 kg K_2O ha^{-1}) which was at par with T_4 (75 kg K_2O ha^{-1}). With increasing rates of potassium fertilizer, concentration of potassium in paddy and straw increased significantly. After harvesting the crop, the extractable potassium contents of soil increased from that of the original soil. It was concluded from the results that there was an increase of 30.65% in paddy over control by applying potassium (100 kg K_2O ha^{-1}) in saline-sodic soil.Cha-um *et al.* (2005) conducted an investigation with an objective to evaluate the effective salt-tolerance defense mechanisms in aromatic rice varieties. Pathumthani 1 (PT1), Jasmine (KDML105), and Homjan (HJ) aromatic rice varieties were chosen as plant materials. Rice seedlings photoautotrophically grown *in-vitro* were treated with 0, 85, 171, 256, 342, and 427 mM NaCl in the media. Data, including sodium ion (Na^+) and potassium ion (K^+) accumulation, osmolarity, chlorophyll pigment concentration, and the fresh and dry weights of seedlings were collected after salt-treatment for 5 days. Na^+ in salt-stressed seedlings gradually accumulated, while K^+ decreased, especially in the 342-427 mM NaCl salt treatments. The Na^+ accumulation in both salt-stressed root and leaf tissues was positively related to osmolarity, leading to chlorophyll degradation. In case of the different rice varieties, the results showed that the HJ variety was identified as being salt-tolerant, maintaining root and shoot osmolarities as well as pigment stabilization when exposed to salt stress or Na^+ enriched cells. On the other hand, PT1 and KDML105 varieties were classified as salt-sensitive, determined by chlorophyll degradation using Hierarchical cluster analysis. In conclusion, the HJ-salt tolerant variety should be further utilized as a parental line or genetic resource in breeding programs because of the osmoregulation defensive response to salt-stress.

Zafar *et al.* (2004) investigated the response of rice cultivars Basmati-370 (salt-sensitive) and IR6 (salt-tolerant) to 2 salinity levels (4.0 (control) and 10 dSm^{-1}) in a pot experiment in a wire-house. They took four harvests at an interval of 10 days each after imposition of salinity treatment,growth and chemical analyses of plant samples were carried out. Plant biomass showed an inverse relationship with increasing salinity levels. A general trend of decrease in dry weight of plant with salinity was noted in both cultivars. The mean values for dry weight were higher in Basmati-370 in the control condition. Analysis of variance showed a significant increase in Na^+ and Cl^- uptake with increasing salinity. Varietal means were highly significant and the maximum increase in Na^+ uptake (18.69%) was recorded in Basmati-370. Harvest means showed that Na^+ uptake increased with the passage of time. However, at maturity there was a decline in Na^+ content in both cultivars. Cl^- increased with increasing salinity levels. Cultivar x treatment interaction revealed an increase in Na^+ and Cl^- uptake over the control in both cultivars. However, it was less in IR6. The cultivars differed significantly for K^+, Ca^{2+}, P and N uptake. K^+ and Ca^{2+} uptake increased with the passage of time. Basmati-370 and IR6 showed 45.20 and 15.55% decrease in Ca^{2+} over the control. P and N uptake increased with increasing salinity levels. An increase of 23.21% P uptake was recorded in Basmati-370 compared to IR-6. However, IR-6 accumulated higher (22.16%) N compared to Basmati-370 under the control and saline conditions.

Regulation of ion transport is one of the important factors responsible for salt tolerance in plants. Membrane proteins play a significant role in selective distribution of ions within the plant or cell (Ashraf and Harris, 2004). According to Du-Pont (1992) the membrane proteins involved in cation selectivity and redistribution of Na^+ and K^+. These proteins are: (a) primary H^+-ATPases which generate the H^+ electrochemical gradient that drives ion transport, (b) Na^+/H^+ antiports in the plasma membrane for pumping excess Na^+ out of the cell, (c) Na^+/H^+ antiports in the tonoplast for extruding Na^+ into the vacuole and (d) cation channels with high selectivity for K^+ over Na^+. It is well established that Na^+ moves passively through a general cation channel from the saline growth medium into the cytoplasm of plant cells (Marschner, 1995; Jacoby, 1999; Mansour *et al.*, 2003) and the active transport of Na^+ through Na^+/H^+ antiports in plant cells is also evident (Shi *et al.*, 2003). Salt tolerance in plants is generally associated with low uptake and accumulation of Na^+, which is mediated through the control of influx and/ or by active efflux from the cytoplasm to the vacuoles and also back to the growth medium (Jacoby, 1999). Energy-dependent transport of Na^+ and Cl^- into the apoplast and vacuole can occur along with the H^+ electrochemical potential gradients generated across the plasma membrane and tonoplast (Hasegawa *et al.*, 2000). The tonoplast H^+ pumps (H^+-ATPase and H^+-pyrophosphatase) also play a significant role in the transport of H^+ into the vacuole and generation of proton (H^+) which operates the Na^+/H^+ antiporters (Mansour *et al.*, 2003; Blumwald, 2000).

Choi *et al.* (2003) observed that the plant height decreased in the 0.5% saline water in the soil. Khan *et al.* (1997) conducted a pot experiment with three rice cultivars and reported that plant height was seriously decreased by salinity. Similar opinion was also postulated by Saleque *et al*. (2005). During vegetative period, the most common salinity effect was stunting of plant growth, whereas leaf withering was less apparent (Alam *et al.*, 2001). The mutant variety maintained its superiority in various characteristics such as plant height, higher number of fertile panicles per plant and high plant yield (Baloch *et al*., 2003).

Baba and Fujiyama (2003) investigated short-term (72 h) responses of the water and nutritional status to Na-salinization in rice (*Oryza sativa* L. cv. Koshihikari) and tomato (*Lycopersicon esculentum* Mill cv. Saturn) using pot experiments. The short-term effect of supplemental K and Ca to the nutrient solution on the water status absorption and transportation of ions in the plants was also investigated. In both species, Na salinity resulted in the deterioration of the water status of tops and in nutritional imbalance. However, in rice, it was possible to prevent the deterioration of the nutrient status by enhancing the transport of cations, especially K, while tomato could maintain an adequate water status by inhibiting the water loss associated with transpiration. On the other hand, the water status in rice and the nutritional status in tomato markedly deteriorated by high Na level in the solution. Supplemental K and Ca could not ameliorate the water status in both species, and even worsened the status in rice. In rice, a close relationship was observed between the osmotic potential (OP) of the solution, water uptake and water content. The water status of rice, therefore, seemed to depend on OP of the solution. Supplemental K and Ca, on the other hand, were effective in the amelioration of the nutritional status. In tomato, supplemental Ca could improve the nutritional balance by suppressing the transport of Na and enhancing that of the other cations in avoidable deterioration of the water status. Thus, the differences in the responses of the water and nutritional status of rice and tomato to high Na salinization and to supplemental K and Ca were evident in a short-term study and supported a similar tendency observed in a long-term study.

Fageria (2003) evaluated the dry matter production and the concentration of nutrients in rice (*Oryza sativa* L.) cultivars from soil adjusted to different levels of salinity under a greenhouse condition. Soil salinity levels were produced by applying 0.34 mol L^{-1} solution of NaCl which resulted in the following levels, control (0.29), 5, 10 and

15dSm^{-1} conductivity of saturation extract. The effect of salinity on dry matter production varied from cultivar to cultivar. The concentrations of P and K in the top of rice cultivars decreased with increasing soil salinity but the concentrations of Na, Zn, Cu and Mn increased. Significant varietal differences were found in relation to salinity tolerance.

Many scientists have suggested that selection is more convenient and practicable if the plant species possesses distinctive indicators of salt tolerance at the whole plant, tissue or cellular level (Ashraf, 2002; Epstein and Rains, 1987; Jacoby, 1999; Munns, 2002). Physiological criteria are able to supply more objective information than agronomic parameters or visual assessment while screening for component traits of complex characters (Yeo, 1994). There are no well-defined plant indicators for salinity tolerance that could practically be used by plant breeders for improvement of salinity tolerance in a number of important agricultural crops. This is partly due to the fact that the mechanism of salt tolerance is so complex that variation occurs not only among the species but, in many cases, also among cultivars within a single species (Ashraf, 1994a; 2002). During the course of plant growth, the form and functions of various organs undergo significant change and the ability of the plant to react to salinity stress depend on those genes that are expressed at the stage of development during which the stress is imposed (Epstein and Rains, 1987). The mechanism of salinity tolerance becomes even more complicated when the response of a plant also varies with the concentration of saline medium and the environmental conditions in which the plant is grown. Considerable improvements in salinity tolerance have been made in crop species in recent times through conventional selection and breeding techniques

(Shannon, 1998; Ashraf, 1994a; 2002). Most of the selection procedures have been based on differences in agronomic characters, which represent the combined genetic and environmental effects on plant growth and include the integration of the physiological mechanisms conferring salinity tolerance. Typical agronomic selection parameters for salinity tolerance are yield, biomass, plant survivality, plant height, leaf area, leaf injury, relative growth rate and relative growth reduction.

Din *et al.* (2001) used artificially salinized soils to see the effect of foliar and soil application of K on rice. Results indicated that the number of tillers plant^{-1}, paddy and straw yield and grains to straw ratio significantly decreased with the increase in salinity. All K application methods increased the above parameters significantly at all salinity levels over distilled water spray. Increasing levels of salinity decreased K concentration in shoots and straw, which was increased significantly by foliar and soil application. Both methods of K application remained at par with each other. Sodium concentration increased the with increase in salinity in both shoots and straw and decreased by foliar and soil application of K. Foliar application of K proved better than soil application in this respect. The K/Na ratio decreased significantly by the increase of salinity, while this ratio increased significantly by the foliar and soil application of K.

Alam *el al*. (2001) stated that the critical EC level of salinity for seedling growth was about 5 dSm^{-1}. They observed that dry matter, seedling height, root length and emergence of new roots of rice decreased significantly at an electrical conductivity value of 5-6 dSm^{-1} and during the early seedling stage, higher salinity caused rolling and withering of leaves, browning of leaf tips and ultimately death of seedlings. They especulated that both osmotic imbalance and Cl^- was responsible for suppressing the growth. These authors showed that the shoot growth was more suppressed than that of root and salt injury was more severe at high temperature (35°C) and low humidity (64%) due to increased transpiration and uptake of water and salt by rice plants. At the reproductive stage, salinity depressed grain yield much more than that at the vegetative growth stage. These authors found that at critical salinity levels straw yield was normal but produced little or no grain. The decrease in grain yield was found proportional to the salt concentration and the duration of the saline treatment. When the plants were continuously exposed to saline media, salinity affected the panicle initiation, spikelet formation, fertilization of florets and germination of pollen grains hence caused an increase in the number of sterile florets. The greatest injurious effect was on the panicle. Salinity severely reduced the panicle length, number of primary branches per panicle, number of spikelet per panicle, seed setting percentage, panicle weight and reduced the grain yield. The weight of 1000-grain was also reduced. Salt injury resulted in the production of small grains in grain length, width and thickness. Most rice cultivars were severely injured in submerged soil cultures at EC of 8-10 dSm^{-1} at 25° C; sensitive ones were hurt even at 2 dSm^{-1}. At comparable EC's injury was less in sea water than in solutions of common salt, in neutral and alkaline soils than in acid soils, at 20°C than at 35°C and in 2-week old seedling than in 1-week old seedlings. Since rice plant is susceptible to salinity at transplanting and gains tolerance with age, they advised that aged seedlings (6 weeks old) be planted in saline fields.

Abdullah *et al.* (2001) performed an experiment on the effect of salinity stress (50 mM) on floral characteristics, yield components,biochemical and physiological attributes of the sensitive rice variety IR-28. The results showed significant decrease in panicle weight, panicle length, primary branches per panicle, filled and unfilled grain, total grains and grain weight per panicle, 1000-grain weight and total grain weight per hill. They further observed significant reduction in both chlorophyll a and chlorophyll b content in different parts of the rice leaves at saline condition. In another experiment, Abdullah *et al*. (2002) studied the effect of salinity on photosynthate translocation in panicle branches and developing spikelets, carbohydrate content of different vegetative parts and suggested that reduction in grain number and grain weight in salinized panicles were not merely due to reduction in pollen viability and higher accumulation of Na^+ and less K^+ in different floral parts but also due to higher accumulation of photosynthates (sugar) in primary and secondary panicle branches, panicle main stalk and panicle stem coupled with reduced activity of starch synthetase in developing grains.

Several salt-induced proteins have been identified in plant species and have been classified into two distinct groups such as (i) salt stress proteins, which accumulate only due to salt stress and (ii) stress associated proteins, which also accumulate in response to heat, cold, drought, water-logging and high and low mineral nutrients (Pareek *et al.*, 1997; Ali *et al.*, 1999; Mansour, 2000). Proteins that accumulate in plants grown under saline conditions may provide a storage form of nitrogen that is neutralized when stress is over and may play a role in osmotic adjustment (Singh *et al.*, 1987). A higher content of soluble proteins has been observed in salt tolerant than in salt sensitive cultivars of barley, sunflower (Ashraf and Tufail, 1995) and rice (Lutts *et al.*, 1996; Pareek *et al.*, 1997). Pareek *et al.* (1997) also suggested that stress proteins could be used as important molecular markers for improvement of salt tolerance using genetic engineering techniques.

Amino acids have been reported to have accumulated in higher plants under salinity stress (Ashraf, 1994b; Mansour, 2000). The important amino acids are alanine, arginine, glycine, serine, leucine and valine, together with the imino acid - proline and the non-protein amino acids- citrulline and ornithine (Mansour, 2000). Lutts *et al.* (1996) found that proline did not take part in osmotic adjustment in salt stressed rice and its accumulation seemed to be a symptom of injury rather than an indicator of salt tolerance. On the contrary, Garcia *et al.* (1997) reported that exogenously applied proline exacerbated the deleterious effects of salt on rice. The salt tolerant rice cultivars Nona Bokra and IR 4630 accumulated less proline in their leaves than the salt sensitive Kong Pao and IR 31785 (Lutts *et al.*,1996). These contrasting reports on the role of proline in salt tolerance and its use as selection criterion for salt tolerance in rice has been questioned.

Franco *et al*. (1999) studied the effect of supplemental $CaCl_2$ on growth and osmoregulation in NaCl stressed cowpea seedlings. They found that salinity inhibited the length of root and shoot of cowpea but the inhibitory effect could be ameliorated by the addition of Ca^{2+}. The concentration of organic osmoregulators (proline, soluble carbohydrates, soluble amino-nitrogen, and soluble proteins) increased in root tips of seedlings grown in salt-stressed condition with supplemental Ca. They indicated that Ca^{2+} could have a protective effect in root tips, which is of fundamental importance for the maintenance of root elongation in NaCl stressed cowpea seedlings.Osmotic adjustment in plants subjected to salt stress can occur by the accumulation of high concentration of either inorganic ions or low molecular weight organic solutes. Although both of these play a crucial role in higher plants grown under saline conditions, their relative contribution varies among species, among cultivars and even between different compartments within the same plant (Ashraf, 1994a). The compatible osmolytes generally found in higher plants are of low molecular weight sugars, organic acids, amino acids, proteins and quaternary ammonium compounds.

Salinity affected rice during pollination, decreased seed setting and grain yield (Maloo, 1993). Finck (1977) suggested that deficiency of K and Ca elements might play a significant role in plant growth depression in many saline soils. Girdhar (1988) observed that salinity delayed germination, but did not affect the final germination up to the EC of 8 dSm^{-1} by evaluating the performance of rice under saline water irrigation. In normal conditions, the Na^+ concentration in the cytoplasm of plant cells was low in comparison to the K^+ content, frequently 10^{-2} versus 10^{-1} and even in conditions of toxicity, most of the cellular Na^+ content was confined into the vacuole (Apse *et al*., 1999).

Bohra and Doerffling (1993) grown a salt-tolerant (Pokkali) and a salt-sensitive (IR28) variety of rice (*Oryza sativa* L.) in a phytotron to investigate the effect of K (0, 25, 50 and 75 mg K kg^{-1} soil) application on their salt tolerance. Potassium application significantly increased potential photosynthetic activity (Rfd value), percentage of filled spikelets, yield and K concentration in straw. At the same time, it also significantly reduced Na and Mg concentrations and consequently improved the K/Na, K/Mg and K/Ca ratios. IR28 responded better to K application than Pokkali. Split application of K failed to exert any beneficial effect over basal application.

According to Cram (1976), of the various organic osmotica, sugars contribute up to 50% of the total osmotic potential in glycophytes subject to saline conditions. The accumulation of soluble carbohydrates in plants has been widely reported as response to salinity or drought, despite a significant decrease in net CO_2 assimilation rate (Popp and Smirnoff, 1995; Murakeozy *et al.*, 2003). Ashraf and Tufail (1995) determined the total soluble sugars content in five sunflower accessions differing in salt tolerance. They found that the salt tolerant lines had generally greater soluble sugars than the salt sensitive ones. Ashraf and Harris (2004) suggested that considerable variations in the accumulation of soluble sugars in response to salt stress were evident at both inter specific and/or intra-specific levels and even among all lines which were salt tolerant.

CHAPTER III

MATERIALS AND METHODS

This chapter presents a brief description about experiment period, site description, climate condition, crop or planting materials, treatments, experimental design and layout, crop growing procedure, fertilizer application, intercultural operation, data collection and statistical analysis.

3.1 Experimental location

To study the morpho-physiological and yield responses of rice, this experiment was conducted at the experimental shed of the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka during the period from Dccember-2017 to April-2018

3.2 Soil condition

The soil of experimental area situated at the Modhupur Tract (UNDP, 1988) under the AEZ no. 28 and Tejgoan soil series (FAO, 1988). The soil was sandy loam in texture with pH 5.47 - 5.63. The physical and chemical characteristics of the soil have been presented in Appendix I.

3.3 Climatic condition

The experimental area is under the sub-tropical climate that is characterized by less rainfall associated with moderately low temperature during rabi season, (October-March) and high temperature, high humidity and heavy rainfall with occasional gusty winds during kharif season (April-September).

3.4 Selection of cultivars

BRRI dhan67 is a salt tolerant variety which was, used as the test crop in this experiment. This variety was released in 2014 by Bangladesh Rice Research Institute (BRRI), Gazipur. It can tolerte salinity 12-14 dSm^{-1} (upto 3 weeks) during seedling stage and 8 dSm^{-1} during reproductive stage. Grain is medium fine. Its plant height is 100 cm and yield is 3.8-7.4 t ha^{-1}. Life cycle of this variety ranges from 140 to 150 days.

3.5 Experimental design

The experiment was set in Randomized Complete Block Design **(**RCBD) having one factor with three replications. The treatment combination of the experiment was assigned at random into 21 pots of each at 3 replications.

3.6 Treatments

The experiment consisted of one factors salinity level and potassium concentration

1. S_0 = Control
2. S_1= 4dSm^{-1} Salt
3. S_1K_1= 4 dSm^{-1} Salt + 80 ppm potassium
4. S_1K_2 = 4 dSm^{-1} Salt + 160 ppm potassium
5. S_2= 6 dSm^{-1} Salt
6. S_2K_1 = 6 dSm^{-1} Salt + 80 ppm potassium
7. S_2K_2 = 6 dSm^{-1} Salt + 160 ppm potassium

3.7 Collection and preparation of soil

The soil of the experiment was collected from Sher-e-Bangla Agricultural University (SAU) farm. The soil was non-calcarious Red Brown Terrace soil with loamy texture belonging to the AEZ Madhupur Tract. The collected soil was pulverized and inert materials, visible insect pest and plant propagules were removed. The soil was dried in the sun, crushed carefully and thoroughly mixed.

3.8 Sterilization of seed

Prior to germination, seeds were surface sterilized with 1% sodium hypochlorite solution. The glass vials containing distilled water for seed rinsing was sterilized for 20 minutes.

3.9 Sowing of seeds in seed bed

The sterilized seed were soaked with water for 24 hours, washed thoroughly in clean water, and incubated for sprouting, which were sown in the wet seed bed. Required amount of fertilizers were applied one day before sowing seeds in the seed bed.

3.10 Raising of seedlings

The seedlings were grown in pots and the soil was used as growth medium. Chemical fertilizers namely urea, Triple Super Phosphate (TSP) and Muriate of Potash (MoP) were used for N, P and K at the rate of 120, 100 and 75 $kgha^{-1}$ respectively before final preparation of the seed bed. The fertilizers were applied one day before sowing seeds in the seed bed. Sterilized seeds were imbibed in distilled water for 24 hours and then washed thoroughly in fresh water and the seeds were incubated for sprouting. After sprouting, they were placed in the pots.

3.11 Seedling transplant in the pots and application of salinity stress:

The chemical fertilizers *i.e.*, Urea, Triple Super Phosphate (TSP) and Gypsum were added for N, P and S in all the pot soils at the rate of 100 kg N, 60 kg P_2O_5, and 20 kg S ha^{-1}, respectively. Potassium Sulphate used as per requirement. The whole amount of TSP,Gypsum and 1/3rd of urea were applied before the final preparation of the pots. Thereafter,the pots containing soil were moistened with water. Five weeks old seedlings of selected rice cultivars were transplanted in the respective pots. There were two hills in each pot.Two weeks after transplanting, the salt solutions were applied in each pot according to the treatments. To avoid osmotic shock, salt solutions were added in three equal installments on alternate days until the expected conductivity was reached. The electrical conductivity (EC) of each pot was measured everyday with a EC meter and necessary adjustments were made by adding water. The remaining 2/3rd urea were top dressed at two equal divisions after 25 and 50 days of transplanting.

3.12 Collection of data

3.12.1 Plant height

The plant height (cm) was measured from the surface level of the growth media to the tip of the longest panicle at harvesting by taking the average value of ten random samples,but before headingit was measured from base to tallest leaf tip.

3.12.2 Total tiller hill^{-1}

Total tiller number hill^{-1} was counted at maximum tillering stages. At the final harvest, the data on yield components like number of effective tillers hill^{-1}, filled grains panicle^{-1}, unfilled grains panicle^{-1} and grain yield hill^{-1} were recorded.

3.12.3 Length and breadth of leaf

Length and breadth of the leaf of each sample plant was recorded and sum total of them were divided by the total number of leaves of the sample plant. Leaf breadth was measured at the middle (widest part of the leaf) of each leaf.

3.12.4 SPAD value

Three leaves were randomly selected from each pot. The top and bottom of each leaves were measured with as at LEAF value. Then,it was averaged and total chlorophyll content was measured by the conversion of at LEAF value into SPAD units.

3.12.5 Number of effective tillers

Effective tiller number hill^{-1} was counted at harvesting. There were two hills in each pot. The effective tiller number hill^{-1} was counted from the pot.

3.12.6 Number of non effective tillers

Number of sterile tillers was also counted by subtracting the number of effective tillers from the total tiller number hill^{-1}.

3.12.7 Total dry matter:

The total dry matter was recorded by drying the plants at 80 ± 2^{o}C for 48 hours and calculated from summation of leaves, stem, roots and panicle weight as observed in an electronic balance.

3.12.8 Panicle length

Average panicle length (cm) was calculated by taking the lengths of all the panicles hill^{-1}.

3.12.9 1000-seed weight

1000-seed were counted, which were taken from the seed sample of each plot separately, then weighed in an electrical balance and data were recorded.

3.12.10 Grain yield

The grain yield of the hill which had effective tiller were recorded.

3.12.11 1000- seed weight

1000-seed were counted, which were taken from the seed sample of each pot separately,then weighed in an electrical balance and data were recorded.

3.12.12 Grain yield

The grain yield of each hill was measured for those hills which had effective tiller were recorded.

3.13 Statistical analysis

The collected data were analyzed statistically following CRD design by MSTAT-C computer package programme developed by Russel (1986). The treatment means were compared by Duncan's Multiple Range Test (DMRT) and regression analysis were performed as and where necessary.

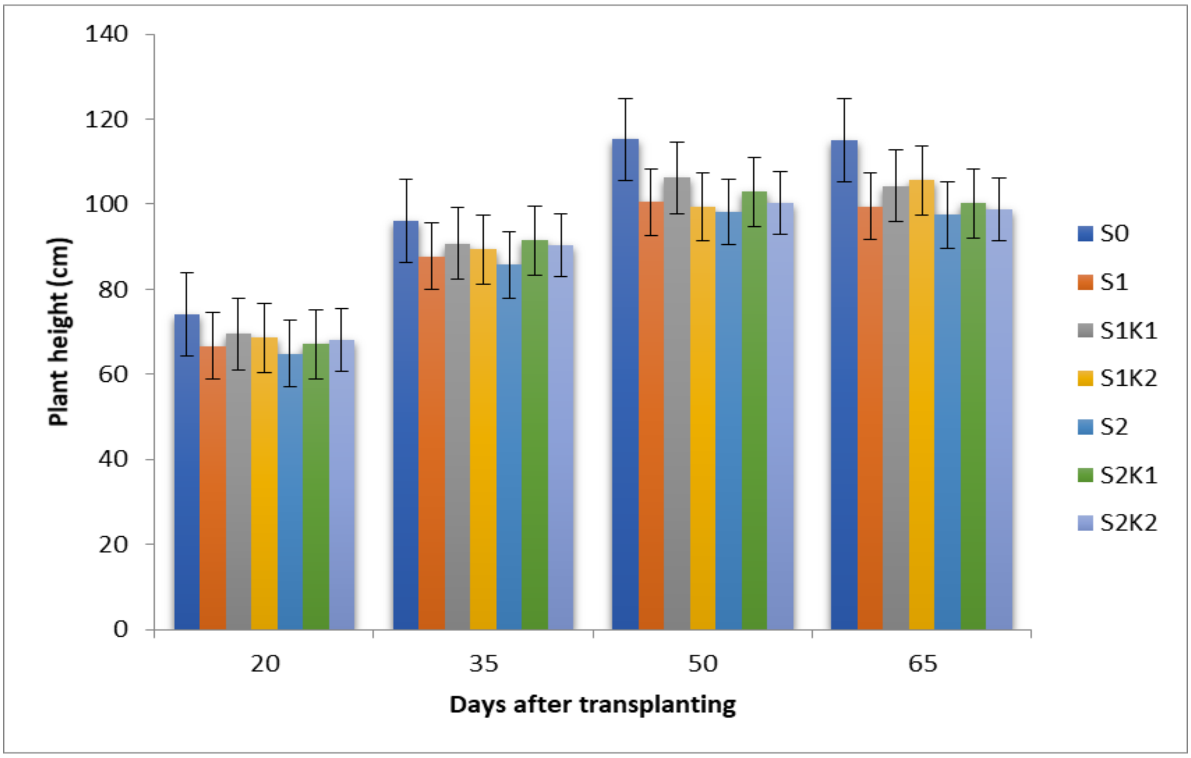
CHAPTER IV

RESULTS AND DISCUSSION

Result obtained from the present study have been presented and discussed in this chapter. The data have been presented in different tables and figures. The results have been presented and discussed, and possible interpretations are given under the following headings.

4.1 Plant height

The height of the plant was significantly influenced by salinity and potassium at 20, 35, 50 and 65 DAT (Days after Transplanting) (Figure1).At 20 DAT, the highest plant height (74.07 cm) was observed at control (S_0) treatment and the lowest plant height (64.80 cm) was observed at S_2 (6 dSm^{-1} salt) treatment. The tallest plant height (96.00 cm) was obtained at control (S_0) treatment which was followed by S_2K_1, S_1K_1, and S_2K_2 while the shortest plant height (85.77 cm) was obtained by S_2 (6 dSm^{-1} salt) treatment at 35 DAT. At 50 DAT, the tallest plant height (115.20 cm) was obtained by at control (S_0) treatment which was followed by S_1K_1, and by S_2K_1 while the shortest plant height (98.20 cm) was obtained by at S_2 (6 dSm^{-1} salt) treatment. At 65 DAT, the tallest plant height (115.00 cm) was obtained at control (S_0) treatment which was followed by S_1K_2, S_1K_1, and by S_2K_1 while the shortest plant height (97.50 cm) was obtained by S_2 (6 dSm^{-1} salt) treatment.Choi *et al.* (2003) observed that the plant height decreased in the 0.5% saline water in the soil. Khan *et al.* (1997) conducting a pot experiment with three rice cultivars reported that plant height was seriously decreased by salinity. Similar opinion was also postulated by Saleque *et al.* (2005).



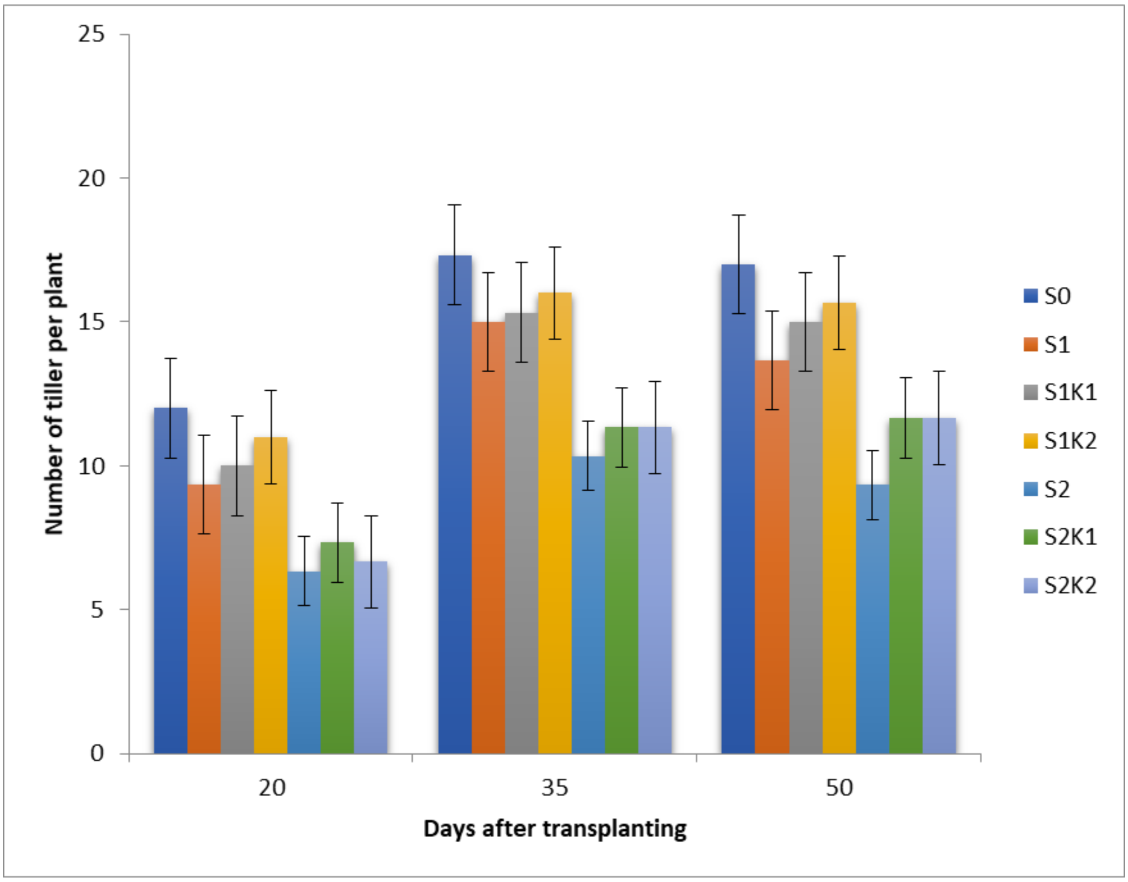
S_0 = Control, S_1= 4dSm^{-1} Salt, S_1K_1= 4 dSm^{-1} Salt + 80 ppm potassium, S_1K_2 = 4 dSm^{-1} Salt + 160 ppm potassium, S_2= 6 dSm^{-1} Salt, S_2K_1 = 6 dSm^{-1} Salt + 80 ppm potassium, S_2K_2 = 6 dSm^{-1} Salt + 160 ppm potassium

Figure1. Effect of different levels of salinity and potassium on the plant height of rice at different days after transplanting

4. 2 Number of total tiller hill^{-1}

Total number of tiller hill^{-1} was statistically influenced by different salinity level with potassium at 20, 35 and 50 DAT (Figure2). The maximum number of tiller hill^{-1} (12.00) was produced from control treatment (S_0) and the minimum number of tiller hill^{-1} (6.33) was produced form S_2 treatments at 20 DAT. At 35 DAT, the maximum number of tiller hill^{-1} (17.33) was produced from control treatment (S_0), which was followed by S_1K_2 (16.00) and the minimum number of tiller hill^{-1} (10.33) was produced form S_2 treatments. At 50 DAT, the maximum number of tiller hill^{-1} (17.00) was produced from control treatment (S_0), which was followed by S_1K_2 (15.67) and S_1K_1 and the minimum number of tiller hill^{-1} (9.33) was produced form S_2 treatments.

Zeng and Shannon (2000) stated that tiller number hill^{-1} and spikelet number per panicle contributed the most variation in grain yield hill^{-1} under salinity.Choi *et al.* (2003) observed that tiller number of rice decreased in 0.5% saline water in the soil with low salinity level. Zeng *et al*. (2001) observed that reduction in tiller number per plant was significant only when plants were salinized for 20 days duration before panicle initiation (PI) of rice. The tiller number decreased significantly at 15.62 dSm^{-1} salinity level in BR11 rice (Gain *et al.*, 2004). Grattan *et al*. (2002) reported that salinity threshold for rice yield was at the EC of 3.0 dSm^{-1} and tiller densities reduced by 40% as compared to control (0.4 dSm^{-1}).



S_0 = Control, S_1= 4dSm^{-1} Salt, S_1K_1= 4 dSm^{-1} Salt + 80 ppm potassium, S_1K_2 = 4 dSm^{-1} Salt + 160 ppm potassium, S_2= 6 dSm^{-1} Salt, S_2K_1 = 6 dSm^{-1} Salt + 80 ppm potassium, S_2K_2 = 6 dSm^{-1} Salt + 160 ppm potassium

Figure2. Effect of different salinity with potassiumon the number of tiller of riceat different days after transplanting

4.3 Leaf length

Length of leaf showed statistically significant differences due to different levels of salinity with potassium. The longest leaf (43.11 cm) was found at control (S_0)treatment, which was followed by S_1K_2, S_2K_1, S_1K_1, S_2K_2 and S_1 and the lowest leaf length (37.94 cm) was recorded at S_2 treatment (Table 1).

4.4 Leaf breath

Breath of leaf showed statistically significant differences due to the different levels of salinity with potassium. The maximum leaf breath (1.62 cm) was obtained at control treatment(S_0), which was followed by S_1K_1, S_2K_1 and S_1K_2 and the minimum leaf breath (1.22 cm) was recorded at S_2 treatment, which was followed by S_1 and S_2K_2 (Table 1).

4.5 SPAD value of leaf

Analysis of variance indicated that the effect of salinity with potassium on rice on the SPAD value of leaf was varied significantly (Table.1). The maximum SPAD value (62.63) was found in S_2 treatment. The minimum SPAD value (48.42) was found from S_0 (control) treatment.

4.6 Total dry mater plant^{-1}

Salinity with potassium had a significant influence on the total dry matter plant^{-1}. The highest total dry matter plant^{-1} (23.99 g) was recorded in S_0 (control), which was followed by S_1K_2,$S_1K_{1,}$$S_2K_{2,}$$S_2K_1$ and S_1 The lowest total dry mater per plant (11.56g) was recorded in S_2(Table 1).

Table 1. Effect of salinity with potassium on leaf length, leaf breath, SPAD value and total dry matter weight on rice

Treatment	Leaf length (cm)		Leaf breath (cm)		SPAD value		Total dry matter weight (g)	
S_0	43.11	a	1.62	A	48.42	d	23.99	a
S_1	39.29	ab	1.277	cd	53.57	bc	14.32	c
S_1K_1	41.64	ab	1.533	B	54.5	b	17.15	b
S_1K_2	42.36	ab	1.34	C	51.8	bcd	18.11	b
S_2	37.94	b	1.217	D	62.63	a	11.56	d
S_2K_1	42.29	ab	1.357	C	50.04	cd	14.44	c
S_2K_2	41.41	ab	1.287	cd	59.87	a	16.79	bc
LSD $_{(0.05)}$	4.12		0.08		3.7		2.512	
CV (%)	5.63		6.86		8.5		10.83	

S_0 = Control, S_1= 4dSm^{-1} Salt, S_1K_1= 4 dSm^{-1} Salt + 80 ppm potassium, S_1K_2 = 4 dSm^{-1} Salt + 160 ppm potassium, S_2= 6 dSm^{-1} Salt, S_2K_1 = 6 dSm^{-1} Salt + 80 ppm potassium, S_2K_2 = 6 dSm^{-1} Salt + 160 ppm potassium

In a column figures having similar letter do not differ significantly whereas figures with dissimilar letter differ significantly as per LSD.

4.7 Number of effective tillers hill^{-1}

The number of effective tillers hill^{-1} of rice was significantly influenced by different levels of salinity with Potassium (Table2). The highest number of effective tillers hill^{-1} (15.00) was recorded at control treatment and the lowest (8.33) was found at S_2 treatment.Bohra and Doerffling (1993) observed that plant height, number of tillers and shoot dry weight reduced under salinity stress in both salt tolerant and salt sensitive rice cultivars. They observed that salinity stress wasted more energy in salt sensitive rice cultivars than that of salt tolerant ones. Khatun *et al*. (1995) found that salinity delayed flowering, reduced the number of productive tillers, the number of fertile florets panicle^{-1}. Salt tolerance indexes in terms of seed yield, seed weight panicle^{-1}, spikelet number panicle^{-1}and tiller number plant^{-1} were reduced with increasing salinity (Zeng *et al*., 2002). Our results also indicate that the percent effective tiller hill^{-1} was badly affected at higher salinity levels. However, Potassium supplementation has mitigated to some extent by increasing effective tiller hill^{-1} .In both salinity treatment (4 dSm^{-1}& 6 dSm^{-1}) addition of 80 and 160 ppm Potassium has increased 1-3 effective tiller hill^{-1} (Table 2)

Table 2. Effect of salinity with potassium on number of effective tiller and non effective tiller hill^{-1} on rice

Treatment	Number of effective tiller hill^{-1}		Non effective tiller hill^{-1}	
S_0	15.00	a	0.67	b
S_1	11.33	bc	1.33	ab
S_1K_1	11.67	abc	1.33	ab
S_1K_2	12.67	ab	1.33	ab
S_2	8.33	c	2.33	a
S_2K_1	10.00	bc	0.67	b
S_2K_2	11.33	bc	0.67	b
LSD (0.05)	3.23		1.03	
CV (%)	5.81		6.65	

S_0 = Control, S_1= 4dSm^{-1} Salt, S_1K_1= 4 dSm^{-1} Salt + 80 ppm potassium, S_1K_2 = 4 dSm^{-1} Salt + 160 ppm potassium, S_2= 6 dSm^{-1} Salt, S_2K_1 = 6 dSm^{-1} Salt + 80 ppm potassium, S_2K_2 = 6 dSm^{-1} Salt + 160 ppm potassium

In a column figures having similar letter do not differ significantly whereas figures with dissimilar letter differ significantly as per LSD.

4.8 Number of non-effective tillers hill^{-1}

The mean effect of different salinity levels with potassium influenced the number of non-effective tillers hill^{-1}(Table 2). The highest number of non-effective tillers hill^{-1}(2.33) was observed in S_2 treatment and it was least in control treatment (0.67) Potassium supplementation enhanced panicle growth through minimizing toxicity effect of salinity. Alam *et al*., (2001) stated that the salinity at reproductive stage of rice depressed grain yield much more than that at the vegetative growth stage and at critical salinity levels it might give normal straw yield of rice but produced little or no grain. They also observed that when the plants were continuously exposed to saline media, salinity affected the panicle initiation, spikelet formation, fertilization of florets and germination of pollen grains and hence caused an increase in number of sterile florets. The mutant variety maintained its superiority in various characteristics such as plant height, higher number of fertile panicles plant^{-1} (Baloch *et al*., 2003).

4.9 Panicle length

Length of panicle showed statistically significant differences due to different levels of salinity with potassium (Table 3). The longest panicle (25. cm) was found at control treatment and the lowest panicle length (18.33 cm) was recorded at S_2 treatment.Khatun *et al*. (1995) and Alam *et al*. (2001) reported thatsalinity severely reduced the panicle length, seed setting percentage and panicle weight. Similar to panicle bearing tillering in potassium supplemented salinity treatment, panicle length also recovered by K supplementation. But the effect was more prominent in higher salinity level (6 dSm^{-1} salt) (Table 3)

4.10 Number of primary branch panicle^{-1}

The number of primary branch panicle^{-1} was significantly influenced by different salinity levels with potassim (Table 3). The highest number of primary branch panicle^{-1} (10.78) was recorded at control treatment and the lowest (9.22) was found at S_2 treatment. Primary branches panicle^{-1} was greatly affected in high salinity stress (Table 3). However, the mitigation effect of Potassium was found better for low salinity level (4 dSm^{-1}).

4.11 Thousand seed weight

A highly significant variation in thousand seed weight of rice cultivars was observed due to different salinity levels with potassium (Table 3**).** The highest thousand grain weight (21.75g hill^{-1}) was recorded at control treatment and it was lowest (16.99 g hill^{-1}) at S_2 treatment.Similar affect was observed for thousand grain weight ie. More reduction of 1000- grain weight was observed for higher salinity level but mitigation of reduction in 1000-grain weight was least in 4dSm^{-1} salinity with 80 ppm potassium. Grain yield is the function of number of panicles hill^{-1}, number of filled grain panicle^{-1} and 1000-grain weight. All the yield contributing characters contributed for the yield reduction hill^{-1} under saline conditions; contribution of the number of unfilled grains panicle^{-1} was the highest (Grattan *et al*., 2002). Baloch *et al*. (2003) observed that the mutant variety of rice "Shua-92" maintained its superiority to other varieties in various characteristics such as plant height, higher number of fertile panicles plant^{-1}, more fertile grains panicle^{-1}, heavy grain size and high plant yield at 7.11- 8.0 dSm^{-1} level of salinity.

Table 3. Effect of salinity with potassium on yield and yield contributing characters of rice

Treatment	Length of panicle (cm)		Primary branch per panicle		Thousand seed weight (g)		Yield (g)	
S_0	25.00	a	10.78	a	21.75	A	25.17	a
S_1	21.33	ab	9.33	bc	18.79	C	15.24	d
S_1K_1	21.67	ab	10.11	abc	20.38	B	22.30	b
S_1K_2	22.67	ab	10.33	ab	19.11	Bc	24.01	ab
S_2	18.33	b	9.22	c	16.99	D	13.27	e
S_2K_1	20.00	b	9.34	bc	18.36	Cd	17.19	c
S_2K_2	21.67	ab	9.56	bc	18.03	Cd	17.92	c
LSD $_{(0.05)}$	4.43		0.95		1.31		2.03	
CV (%)	8.75		5.44		5.87		12.89	

S_0 = Control, S_1= 4dSm^{-1} Salt, S_1K_1= 4 dSm^{-1} Salt + 80 ppm potassium, S_1K_2 = 4 dSm^{-1} Salt + 160 ppm potassium, S_2= 6 dSm^{-1} Salt, S_2K_1 = 6 dSm^{-1} Salt + 80 ppm potassium, S_2K_2 = 6 dSm^{-1} Salt + 160 ppm potassium

In a column figures having similar letter do not differ significantly whereas figures with dissimilar letter differ significantly as per LSD.

4.12 Grain yield hill^{-1}

A highly significant variation in grain yield hill^{-1} of rice cultivars (BRRI dhan67) was observed due to different salinity levels with potassium (Table 3)**.** The highest grain yield (25.17 g) was recorded at control treatment, which was followed by S_1K_1 and $S_1K_{2,}$and it was lowest (13.27 g hill^{-1}) at S_2 treatment. Incomparision to control (without salt), the reduction of grain yield was highest in S_2 (6 dSm^{-1} salt) treatment (47.28%) followed by S_1(4 dSm^{-1} salt) treatment (39.45%) (Table 3). But in both of the salt treatment, Potassium supplementation greatly mitigated. The damaging effect of salinity thereby reducing grain yield reduction. However, the mitigation effect was more in less salinity stress (4 dSm^{-1} salt), where yield reduction was 11.4% and 4.61% for 80 and 160 ppm potassium, respectively. Grain yield is the function of number of panicles hill^{-1}, number of filled grain panicle^{-1} and 1000-grain weight. All the yield contributing characters contributed for the yield reduction hill^{-1} under saline conditions; contribution of the seriously affected number of unfilled grains panicle^{-1} was the highest (Grattan *et al*., 2002). Baloch *et al*. (2003) observed that the mutant variety of rice “Shua-92” maintained its superiority over other varieties in various characteristics such as plant height, higher number of fertile panicles plant^{-1}, more fertile grains panicle^{-1}, heavy grain size and high plant yield at 7.11- 8.0 dSm^{-1} salinity.

CHAPTER V

SUMMARY AND CONCLUSION

A pot experiment was conducted at the net house of the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka-1207. During *Boro* rice growing season (December to April) of the year of 2017- 18 to know the effect of potassium in mitigating adverse effect of salt stress on growth, development and yield of rice plant (*Oryza sativa* L.). The experiment was conducted using seven salinity levels with potassium viz. S_0 = Control, S_1= 4 dSm^{-1} Salt, S_1K_1= 4 dSm^{-1} Salt + 80 ppm potassium, S_1K_2 = 4 dSm^{-1} Salt + 160 ppm potassium, S_2= 6dSm^{-1} Salt, S_2K_1 = 6 dSm^{-1} Salt + 80 ppm potassium, S_2K_2 = 6 dSm^{-1} Salt + 160 ppm potassium. The experiment was carried out following Randomized Complete Block Design **(**RCBD) having one factor with three replications.

The results on the effect of morphological characters indicated that plant height; number of tillers, leaf length, leaf breath, and SPAD value, effective tiller, number of non effective tiller, total dry matter weight, panicle length , thousand seed weight and grain yield were significantly influenced by salinity and potassium. All the measured morphological parameters were found highest in non saline control treatment. But the parameters gradually declined in 4 and 6 dSm^{-1} salt treatment .However, potassium supplementation greatly mitigated the damaging effect of salt for the growth, development and yield of BRRI dhan67.But the mitigation effect was more prominent at low salinity stress (4 dSm^{-1}) compared to the higher stress (6 dSm^{-1}).Moreover, application of 160 ppm potassium showed better recovery compared to 80 ppm potassium to the 4 dSm^{-1} salt stress.

Considering above facts, it can be concluded that application of potassium under salt stress condition can be a good option for obtaining better yield of salt tolerant varieties like BRRI dhan67.Further research is needed to get a concrete recommendation considering more varieties and varying number of salt stress and potassium level

REFERENCES

Abdullah, Z., Khan, M.A., and Flowers, T.J. (2001). Causes of sterility in seed set of rice under salinity stress. *J. Agron Crop Sci*. **187**(1): 25-32.

Abdullah, Z., Khan, M.A., Flowers, T.J., Ahmad, R. and Malik, K.A. (2002). Causes of sterility in rice under salinity stress. *Pros. Saline Agric*. 177-187.

Afridi, M.R.K., Ali, R.S. and Dwivedi. (1988). Effect of salinity and sodicity on growth and ionic composition of *Oryza sativa* and *Diplachne fusca*. *Indian J. Bot. Soc*., **67**(1-2): 166-172.

Alam, S.M., Ansari, R., Mujtaba, S.M. and Shereen, A. (2001). Salinization of millions of hectares of land continues to reduce crop productivity severely worldwide. ***In*:** Saline Lands and Rice: Industry & Economy. *Pakistan Economist*. **17**: 60-71.

Ali, G., Srivastava, P.S. and Iqbal, M. (1999). Proline accumulation, protein pattern and photosynthesis in regenerants grown under NaCl stress. *Biol. Plant*. **42**: 89-95.

Apse, M.P., Aharon, G.S., Snedden, W.A. and Blumwald, E. (1999). Salt tolerance conferred by overexpression of a vacuolar Na^+/H^+ antiport in *Arabidopsis*. *Sci*. **285**: 1256-1258.

Ashraf, M. (1994a). Breeding for salinity tolerance in plants. *Crit. Rev. Plant Sci.* **13**: 17-42.

Ashraf, M. (1994b). Organic substances responsible for salt tolerance in *Eruca sativa*. Biol. Plant. **36**: 255-259.

Ashraf, M. (2002). Salt tolerance of cotton: some new advances. *Crit. Rev. Plant Sci.* 21: 1-30.

Ashraf, M. and Harris, P.J.C. (2004). Potential biochemical indicators of salinity tolerance in plants. *Plant Sci*. **166**: 3-16.

Ashraf, M. and Tufail, M. (1995). Variation in salinity tolerance in sunflower (*Helianthus annuus* L.). *J. Agron. Soil Sci*. **174**: 351-362.

Ashraf, M., Rahmatullah, A.R., Bhatti, A.S., Afzal, M., Sarwar, A., Maqsood, M.A. and Kanwal, S. (2010). Amelioration of salt stress in rice (*Oryza sativa* L.) by supplying potassium and silicon in hydroponics. *Pedosphere*. **20**(2): 153–162

Baba, T and Fujiyama, H. (2003). Differences in short-term responses of rice and tomato to sodium salinization and supplemental potassium and Calcium. *Soil Sci. Plant Nutr.* **49**(5): 669-675.

Baloch, A.W., Soomro, A.M., Javed, M.A., Bughio, H.R., Alam, S.M., Bughio, M.S., Mohammed, T.and Mastoi, N.N. (2003). Induction of salt tolerance in rice through mutation breeding. *Asian J. Plant Sci.* **2**(3): 273-276.

BBS (Bangladesh Bureau of Statistics). (2011). Statistical Year Book of Bangladesh Bureau of Statistics. Bangladesh Rice Knowledge Bank (BRKB). Available at the following web site: http://www.knowledgebank-brri.org.

Bhandal, I.S., Malik, C.P. (1988): Potassium estimation, uptake, and its role in the physiology and metabolism of flowering plants. Int. Rev of Cytol. **110**: 205–254.

Bhattacharjee, S. (2008). Triadimefon pretreatment protects newly assembled membrane system and causes up-regulation of stress proteins in salinity stressed *Amaranthus lividus* L. during early germination. *J. Environ. Biol.* **29**: 805-810.

Blumwald, E. (2000). Sodium transport and salt tolerance in plants. *Curr. Opin. Cell Biol.* **12**: 431-434.

Bohra, J.S. and Doerffling , K. (1993). Potassium nutrition of rice (*Oryza sativa* L.) varieties under NaCl salinity. *Plant soil*. **152**(2): 299-303.

Brammer, H., (1978). Rice soils of Bangladesh. *In*: Soils and Rice. IRRI, Philippines: 35-54.

Celik, H., Asik, B.B., Gurel, S., and Katkat, A.V. (2010). Potassium as an intensifying factor for iron chlorosis. *Int. J. Agric. Biol.*,**12**: 359-364.

Cha-um, S., Vejchasarn, P. and Kirdmanee, C. (2005). An Effective Defensive Response in Thai Aromatic Rice Varieties (*Oryza sativa* L. spp. *indiK*) to Salinity. *J. Crop Sci. Biotech.***10**(4): 257 – 264.

Choi, W.Y., Lee, K.S., Ko, J.C., Choi, S.Y. and Choi, D.H. (2003). Critical saline concentration of soil and water for rice cultivation on a reclaimed saline soil. *Korean J. Crop Sci.* **48**(3): 238-242.

Cram, W.J. (1976). Negative feedback regulation of transport in cells. The maintenance of turgor, volume and nutrient supply. ***In*****:** Luttge, U. and Pitman, M. G.(eds.), Encyclopaedia of Plant Physiology. New Series, Vol. 2, Springer-Verlag, Berlin. pp. 284-316.

Cramer, G.R., Läuchli, A., and Polito, V.S. (1985). Displacement of Ca^{2+} and Na^{+} form the plasma lemma of root cells. Plant Physiol. **79**: 207–211.

Din, C., Mehdi, S.M., Sarfraz, M., Hassan, G. and Sadiq, M. (2001). Comparative Efficiency of Foliar and Soil Application of K on Salt Tolerance in Rice. *Pakistan J. of Biological Sci.* **4**(7): 815 – 817.

Ebrahimi, R.F., Rahdari, P., Vahed, H.S., Shahinrokhsar, P. and Babazadeh, S. (2012). Rice Response to Different Methods of PotassiumApplication under Salinity Stress Condition. American-Eurasian J. Agric. Environ. Sci., **12**(11): 1441-1445.

Epstein, E. and Rains, D.W. (1987). Advances in salt tolerance. ***In:*** Gableman, H. W. and Loughman, B. C. (eds.), Genetic Aspects of Plant Mineral Nutrition. Martinus Nijhoff, Boston. pp. 113-125.

Fageria, N.K. (2003). Salt tolerance of rice cultivars. *Plant Soil*. **88**(2): 237-243.

FAO (Food and Agricultural Organization). (2005). Global Network on Integrated Soil Management for Sustainable use of Salt-affected Soils. Rome, Italy: FAO Land and Plant Nutrition Management Service. http://www.fao.org/ag/agl/agll/ spush

Finck, A. (1977). Soil salinity and plant nutritional status. ***In:*** Managing Saline Water. Proceedings of the International Conference. Texas Tech. Univ., Lubbock, Texas. pp. 199-210.

Franco, O.L., Filho, J.E., Prisco, J.T. and Filho, E.G. (1999). Effects of $CaCl_2$ on growth and osmoregulator accumulation in NaCl stressed cowpea seedlings. *R. Bras. Fisiol. Veg.* **11**(3): 145-151.

Gain, P., Mannan, M.A., Pal, P.S., Hossain, M.M. and Parvin, S. (2004). Effect of salinity on some yield attributes of rice. Pakistan J. Biol. Sci., **7**: 760-762.

Garcia, A.B., Almeida-Engler, J., Lyer, S., Gerats, T., Montagu, M.V. and Caplan, A.B. (1997). Effects of osmoprotectants upon NaCl stress in rice. *Plant Physiol.* **115**: 159-169.

Girdhar, I.K. (1988). Effect of saline irrigation water in the growth, yield and chemical composition of the rice crop grown in a saline soil. *J. Indian Soc. Soil Sci.* **36**: 324-329.

Golldack, D.,Quigley, F.,Michalowski, C.B.,Kamasani, U.R. and Bohnert, H.J.(2003). Salinity stress-tolerant and sensitive rice (*Oryza sativa* L.) regulate AKT1- type potassium channel transcripts differently. Pl. Mol. Biol., **51**: 71-81

Hasanuzzaman, M., Nahar, K., and Fujita, M. (2013). Plant response to salt stress and role of exogenous protectants to mitigate salt-induced damages,In: Ahmed,P., Azooz, M.M. and Prasad, M.N.V.(eds) Ecophysiology and Responses of Plants Under Salt Stress, (New York, NY: Springer), 25–87. doi: 10.1007/978-1-4614-4747-4_2

Hasegawa, P.H., Bressan, R.A., Zhu, J.K. and Bohnert, H.J. (2000). Plant cellular and molecular responses to high salinity. Annu. Rev. *Plant Physiol. Plant Mol. Biol.* **51**: 463-499.

Islam, K.R., Ahmed, I.U., Faizz, B. and Mohiuddin, A.S.M. (1998). Growth, yield and N, P, K and Na contents of paddy (*Oryza sativa* L.) under saline water irrigation. *Int. J. Trop. Agric.* **16**(1-4): 25-32.

Islam, M.Z., Mia, M.A.B., Islam, M.R., and Akter, A. (2007) Effect of different saline levels on growth and yield attributes of mutant rice. J. Soil. Nature. **1**: 18-22

Jacoby, B. (1999). Mechanisms involved in salt tolerance of plants. ***In:*** Pessarakli, M. (ed.), Handbook of Plant and Crop Stress,. Marcel Dekker, New York. pp. 97-123.

Kandil, A.A., Sultan, M.S ., Badawi, M.A., El-Rahman, A.A.A. and Zayed, B.A. (2010). Performance of rice cultivars as affected by irrigation and potassium fertilizer under saline soil conditions. 1-Physiological and chemical characteristics. *Crop Environ.* **1**: 35-38.

Khan, H.R., Faiz, S.M.A., Islam, M.N., Adachi, T. and Ahmed, I.U. (1997). Effects of salinity, gypsum and Zn on mineral nutrition of rice. Int. J. Trop. Agric., 10: 147-156.

Luo, Q., Yu, B. and Liu, Y. (2005). Differential sensitivity to chloride and sodium ions in seedlings of *Glycine max* and G. *soja* under NaCl stress. J. Plant Physiol.,**162**:1003-1012.

Lutts, S., Kinet, J.M. and Bouharmont, J. (1996). Effects of salt stress on growth, mineral nutrition and proline accumulation in relation to osmotic adjustment in rice (*Oryza sativa* L.) cultivars differing in salinity tolerance. *Plant Growth Regul.* **19**: 207-218.

Maloo, S.R. (1993). Breeding and screening techniques for salt tolerance in crop plants. ***In:*** Somani, L.L. and Totawat,K.L. (eds.), Management of Salt-Affected Soils and Waters. Agrotech Publishing Academy, Udaipur-313001, India. pp. 321-357.

Mansour, M.M.F. (2000). Nitrogen containing compounds and adaptation of plants to salinity stress. *Biol. Plant*. **43**: 491-500.

Mansour, M.M.F., Salama, K.H.A. and Al-Mutawa, M.M. (2003). Transport proteins and salt tolerance in plants. *Plant Sci.* **164**: 891-90.

Marschner, H. (1995). Adaptation of plants to adverse chemical soil conditions. ***In:*** Mineral Nutrition of Higher Plants. Academic Press, London. pp. 596-680.

Mehdi, S.M., Sarfraz, M. and Hafeez, M. (2007). Response of rice advance line PB-95 to potassium application in saline-sodic soil. *Pak. J. Biol. Sci.* **10**: 2935-2939.

Munns, R. (2002). Comparative physiology of salt and water stress. *Plant Cell Environ.* **25**: 239-250.

Murakeozy, E.P.,Nagy, Z., Duhaze, C., Bouchereau, A. and Tuba, Z. (2003). Seasonal changes in the levels of compatible osmolytes in three halophytic species of inland saline vegetation in Hungary. *J. Plant Physiol.* **160**: 395-401.

Nelson, W.L. (1978). Influence of K on tolerance to stress (North American experience). In: Sekhon GS (eds) Potassium in soils and crops, Potas. Res. Inst. of India. New Delhi, pp: 203-211.

Noaman, M.N. (2004). Effect of potassium and Science, nitrogen fertilizers on the growth and biomass of some halophytes grown under high levels of salinity. J. Agro., **3**: 25-30.

Pareek, A., Singla, S.L. and Grover, A. (1997). Salt responsive proteins/genes in crop plants. ***In*:** Jaiwal, P.K. Singh, R.P. and Gulati, A. (eds), Strategies for Improving Salt Tolerance in Higher Plants. Oxford and IBH Publication Co., New Delhi. pp. 365-391.

Popp, M. and Smirnoff, N. (1995). Polyol accumulation and metabolism during water deficit. ***In:*** Smirnoff, N. (ed.), Environment and Plant Metabolism: Flexibility and Acclimation. Bios Scientific, Oxford. pp. 199-215.

Saleque, M.A., Choudhury, N.N., Rezaul-Karim, S.M. and Panaullah G.M. (2005). Mineral nutrition and yield of four rice genotypes in the farmers' fields of salt affected soils. *J. Plant Nutr.* **28**(5): 865-875.

Saqib, M., Akhtar, J., Qureshi, R.H., Aslam, M. and Nawas, S. (2000). Effect of salinity and sodicity on growth and ionic relations of different wheat genotypes. Pak. J. S. Sci., **18**(1-4): 99-104.

Shabala, S., Demidchick, V., Shabala, L., Cuin, T.A., Smith, S.J., Miller, A.J.(2006).Extracellular Ca^{2+} ameliorates NaCl-induced K^+ loss from Arabidopsis root and leaf cells by controlling plasma membrane K^+ -permeable channels. Plant Physiol. **141**:1653–1665.

Shannon, M.C. (1998). Adaptation of plants to salinity. *Adv. Agron.* **60**: 75-119.

Shi, H., Lee, B.H., Wu, S.J. and Zhu, J.K. (2003). Overexpression of a plasma membrane Na^+/H^+ antiporter gene improves salt tolerance in *Arabidopsis thaliana*. *Nat. Biotechnol.* **21**: 81-85.

Singh, N.K., Bracken, C.A., Hasegawa, P.M., Handa, A.K., Buckel, S., Hermodson, M.A., Pfankoch, F., Regnier, F.E. and Bressan R.A. (1987). Characterization of osmotin: a thaumatin-like protein associated with osmotic adjustment in plant cells. *Plant Physiol.* **85**: 529-536.

SRDI, (2007). Coastal area and water salinity map of Bangladesh (1967 and 1997), Soil Resource Development Institute (SRDI), Dhaka.

Volkmar, K.M., Hu.Y. and Steppuhn, H. (1998). Physiological responses of plants to salinity. *Canadian J. Plant Sci.* **78**: 19-27.

Wu, G.Q. and Wang, S.M. (2012). Calcium regulates $K^{+/}Na^{+}$ homeostasis in rice (*Oryza sativa* L.) under saline conditions. Plant Soil Environ. **58**:121–127.

Yeo, A.R. (1994). Physiological criteria in screening and breeding. ***In:*** Yeo, A.R. and Flowers, T.J. (eds.),Soil Mineral Stresses, Approaches to Crop Improvement. *Springer Verlag, Berlin*. pp. 37-60.

Zafar, S., Ashraf, M.Y., Sarwar, G., Mahmood, S., Kausar, A. and Ali, I. (2004). Variation in growth and ion uptake in salt tolerant and sensitive rice cultivars under NaCl salinity. Asian J. of Plant Sci. **3**(2): 156-158.

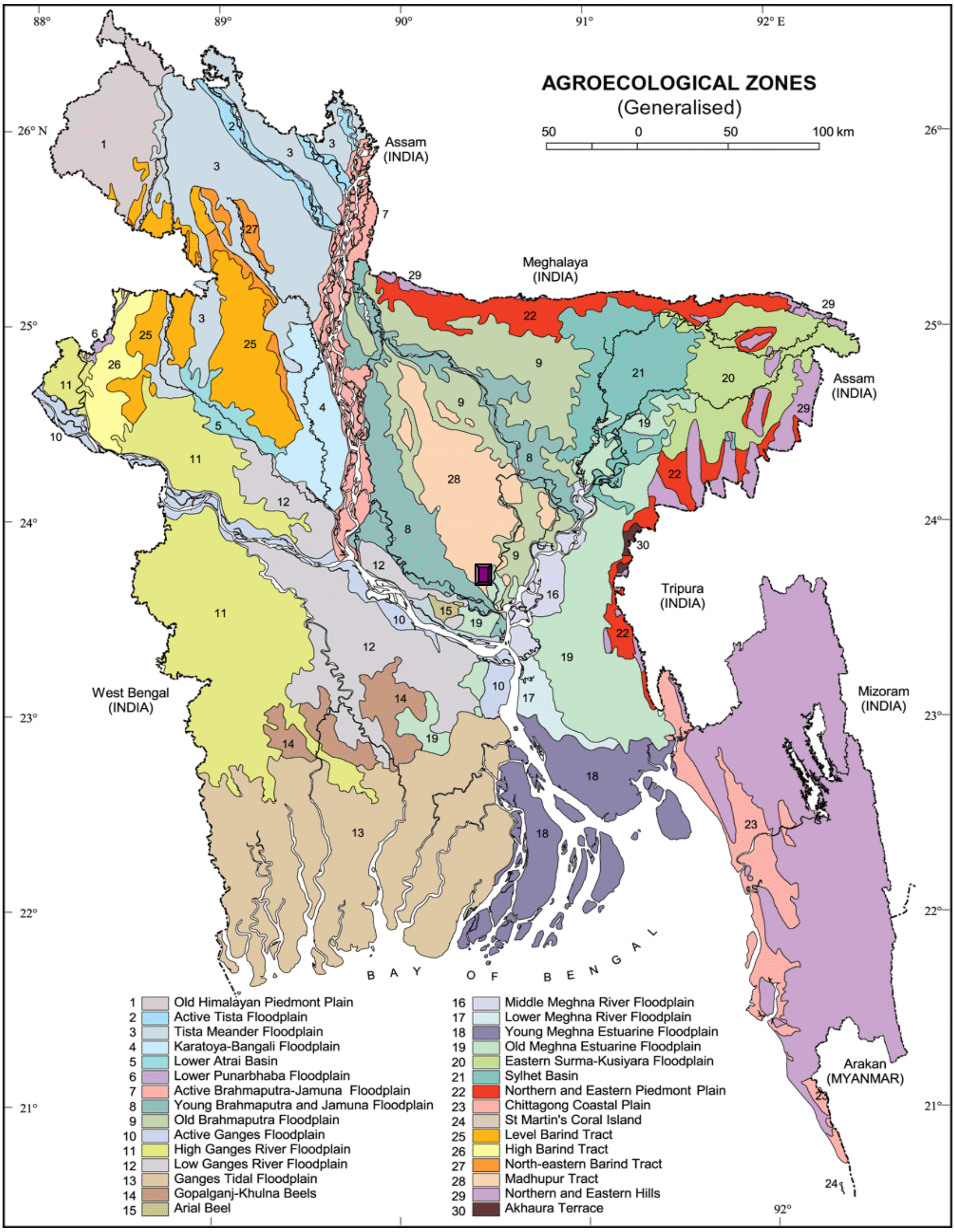
Zayed, B.A., Elkhoby, W.M., Shehata, S.M. and Ammar, M.H. (2007). Role of potassium application on the productivity of some inbred and hybrid rice varieties under newly reclaimed saline soils. Afr. Crop Sci. Con. Proc. **8**: 53-60.

Zeng, L. and Shannon, M.C. (2000). Salinity effects on seedling growth and yield components of rice. Crop Sci., 40: 996-1003.

Zeng, L., Shannon, M.C. and Lesch, S.M. (2001). Timing of salinity stress affects rice growth and yield components. Agril. Water Manage. 48: 191-206.

APPENDICES

Appendix I. Map showing the experimental sites under study



■ **The experimental site under study**