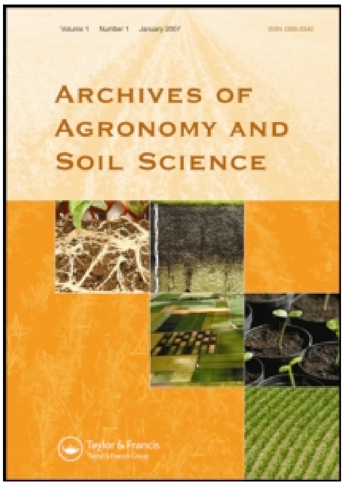

Archives of Agronomy and Soil Science
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453776

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Online publication date: 07 February 2011

To cite this Article Razzaque, Md. Abdur , Talukder, Nur Mohammad , Islam, Md. Tofazzal and Dutta, R. Kumar(2011) 'Salinity effect on mineral nutrient distribution along roots and shoots of rice (*Oryza sativa* L.) genotypes differing in salt tolerance', Archives of Agronomy and Soil Science, 57: 1, 33 — 45

To link to this Article: DOI: 10.1080/03650340903207923

URL: http://dx.doi.org/10.1080/03650340903207923

Archives of Agronomy and Soil Science
Vol. 57, No. 1, February 2011, 33–45

Salinity effect on mineral nutrient distribution along roots and shoots of rice (*Oryza sativa* L.) genotypes differing in salt tolerance

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(*Received 30 January 2009; final version received 24 July 2009*)

The aim of this study was to investigate the effects of salinity on mineral nutrient distribution along roots and shoots of seven selected rice (*Oryza sativa* L.) genotypes, namely Pokkali, PVSB9, PVSB19, PNR381, PNR519, NS15 and Iratom24 differing in salt tolerance. The rice plants were grown in pots and subjected to varying levels of salinity stress (0, 3, 6, 9, 12 and 15 dS m^{-1}). Mineral nutrients distribution in shoots and roots was measured after harvesting the plants at 95 days after transplanting. The responses of salt stress on mineral nutrient uptake and distribution along plant organs significantly differed among the rice genotypes. The contents of Na^+ and Cl^- in the roots and shoots of resistant genotypes (PVSB9, PNR381 and Pokkali) were significantly lower than the susceptible rice genotype (NS15). The concentrations of Na^+ and Na^+/K^+ in shoots of sensitive rice genotype (NS15) sharply increased with increasing salinity above 6 dS m^{-1} than those of tolerant genotypes. The highest concentration of K^+ was obtained in shoots of resistant genotype PVSB9 and this K^+ content decreased more slowly with increasing salinity than those of other genotypes.

Keywords: rice genotypes; salinity; mineral elements; mutant variety; Na^+/K^+

Introduction

Rice is the principal food in densely-populated Bangladesh. The alarming growth of population and loss of arable land due to urbanization are the main causes of concern for finding ways and means for augmenting food production, particularly rice in Bangladesh. The possibility of increasing food production by increasing land area is out of the question in Bangladesh. Furthermore, soil salinity is a major threat to crop productivity in the southern and south-western part of Bangladesh where approximately 2.85 million hectare of coastal soils have different degrees of salinity (from 2 to >12 dS m^{-1}) (Ponnamperuma 1977, Soil Resource Development Institute [SRDI] 2000). The only feasible alternative is to increase the cultivable land areas by bringing salt-affected soils under cultivation with high yielding salt-tolerant rice cultivars. Salinity in soil or water is one of the major stresses that severely limit crop production. The deleterious effects of salinity on plant growth are associated

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ISSN 0365-0340 print/ISSN 1476-3567 online

DOI: 10.1080/03650340903207923
http://www.informaworld.com

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 1994; Juan et al. 2005; Hu et al. 2007). In fact, under saline conditions, soils contain extreme ratios of Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+}, and Cl^-/NO_3^-, leading to specific ion toxicities (e.g. Na^+ and Cl^-) and ionic imbalance (Grattan and Grieve 1999).

Plant growth is seriously affected due to high salinity, which reduces turgor in expanding tissues and osmoregulation (Silva et al. 2008). Salinity reduces plant shoot growth and development, and in grasses this effect is conspicuous on the leaves (de Lacerda et al. 2003). The lack of an effective evaluation method for salt tolerance in the screening of genotypes is one of the reasons for the limited success in conventional salt tolerant breeding. 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 1994; Hu et al. 2007). 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). 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 the H^+ electrochemical potential gradients generated across the plasma membrane and tonoplast (Hasegawa et al. 2000).

Breeding salt-tolerant rice varieties suitable for a vast area of saline soils is needed urgently for food security for the rapidly increasing population of Bangladesh. In the last three decades, plant breeders in Bangladesh have achieved little success in developing salinity-tolerant rice varieties through conventional breeding techniques. The understanding of mineral nutrients uptake patterns and their translocation from root to shoot of rice genotypes contrasting to salinity tolerance is important for designing a breeding program for development of salt-tolerant rice varieties. In order to identify potential salt-tolerant mutants/lines/genotypes, we screened the salt tolerance of 30 genotypes of rice collected from Bangladesh Rice Research Institute and Bangladesh Institute for Nuclear Agriculture and one international salt-tolerant rice variety 'Pokkali' by evaluating their seed germination and growth of seedlings under varying levels of salinity. Among them, four (PVSB9, PVSB19, PNR381 and PNR519) salt-tolerant lines, one moderately salt-tolerant mutant variety (Iratom24) and one highly salt-sensitive genotype (NS15) were considered for further investigation to better understand their tolerance mechanism. Therefore, this study aimed to assess the effect of salt stress on mineral nutrient uptake and distribution along roots and shoots of rice genotypes differing in salt tolerance.

Materials and methods

Plant materials and growth conditions

Rice seedlings were grown in a nursery bed until six weeks. The experiment was conducted in plastic pots at the glasshouse of Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, during the period from December 2003 to June

2004. The experiment was laid out in two factorials CRD (Completely Randomized Design) with four replications. Factor 1: Rice genotype (7) and Factor 2: Salinity level (6) – 0, 3, 6, 9, 12 and 15 dS m^{-1}. Among the seven rice genotypes, five of them were of mutants/lines (PVSB19, PVSB9, PNR519, PNR381 and NS15) of which NS15 represented as salt-sensitive and four were salt-tolerant genotypes. Pokkali was included as an internationally salt-tolerant check and Iratom24 was a modern mutant variety developed by BINA. Soil for this pot experiment was collected from the field of BINA Farm, which was non-calcareous Dark Grey Floodplain having loamy texture and belonging to the Agro-Ecological-Zone of Old Brahmaputra Floodplain. The soil was dried under the sun followed by crushing and mixed thoroughly. Eight kg of this soil was put in each pot. The pot soil was fertilized with urea, triple super phosphate (TSP), muriate of potash (MOP) and gypsum as sources of nitrogen (N), phosphorus (P), potassium (K) and suplhur (S) at the rate of 100 kg N, 60 kg P_2O_5, 75 kg K_2O and 20 kg S ha^{-1}, respectively. The whole amount of TSP, MOP, gypsum and $^1/_3$ of urea were applied prior to final preparation of the pots. The soil in pots was moistened with water and commercial NaCl salt was added to salinize treated pots to develop salinity up to the level of 3 dS m^{-1}. Six-week-old single seedlings of selected rice genotypes per hill and three hills per pot were transplanted in the respective pot. Two weeks after transplanting, the remaining salt solutions were applied in each pot according to the treatments. The appropriate amount of NaCl solution was directly added to the pots (based on estimated moisture contents) and then mixed with a glass rod to raise salinity up to the expected level (Shannon et al. 1998). To avoid osmotic shock, salt solutions were added in three equal installments on alternate days until the expected conductivity was reached. Salt solutions were collected every 24 h from each pot and electric conductivity (EC) was measured with a conductivity meter and necessary adjustments were made. The remaining $^2/_3$ urea were top dressed in two equal installments at 25 and 50 days after transplanting. Weeds grown in the pots and visible insects were removed time to time manually in order to keep the pots neat and clean. Watering was done in each pot to hold the soil water level and salt concentration constant when needed.

Analysis of mineral nutrients in rice plants

After maturity, the harvested rice plants were separated into roots and shoots and rinsed repeatedly with tap water and finally with distilled water and then oven-dried at 70°C to obtain constant weight. The oven-dried samples were ground in a Wiley Hammer Mill, passed through 40-mesh screens, mixed well and stored in plastic vials.

Plant samples were analyzed to determine the amount of sodium (Na), potassium (K), calcium (Ca), magnesium (Mg) and chlorine (Cl). All elemental analyses were conducted on acid digested material through micro-Kjeldahl digestion system (Thomas et al. 1967). The content of Na^+, K^+, Ca^{2+} and Mg^{2+} ions were measured by Atomic Absorption Spectrophotometer (AAS) and Cl^- was determined by argentometric method of titration according to the methods outlined by Clesceri et al. (1988) and expressed in percentage of dry weight basis. The Na^+/K^+ ratio was calculated from concentrations of Na^+ and K^+ in the plant tissues.

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 Least Significance Differences (LSD), Duncan's Multiple Range test (DMRT) where necessary.

Results and discussion

Growth and dry matter production

The root dry weight (RDW), shoot dry weight (SDW) and total dry matter (TDM) $hill^{-1}$ were decreased as the salinity level was increased irrespective of rice genotypes (data not shown). The highest percentage of relative RDW (50.63), SDW (55.08) and TDM (54.75) $hill^{-1}$ were found in Pokkali followed by PVSB9 (RDW, SDW and TDM were 48.24, 50.91 and 50.59, respectively), whereas the lowest values were recorded in the susceptible genotype NS15 (RDW, SDW and TDM were 26.82, 29.43 and 29.21, respectively).

After control treatment, the highest relative root and shoot dry weight and TDM were recorded in PVSB9 at 3 dS m^{-1} level, which were lowest in NS15 at all the salinity levels compared to other genotypes. The percentage relative RDW, SDW and TDM $hill^{-1}$ in susceptible genotype NS15 decreased very sharply from 3 dS m^{-1} salinity level compared to other genotypes, whereas the dry weight was reduced gradually and reached a minimum at 15 dS m^{-1} level of salinity in genotypes PVSB9 and Pokkali (Figure 1). These results indicated that PVSB9 and Pokkali were more resistant than the other rice genotypes. The results further showed that under salinity stress, the least reduction in root and shoot dry weight and total dry matter were obtained in Pokkali, PVSB9, PVSB19, Iratom24, PNR519 and PNR381; and very sharp reductions were in NS15 (Figure 1). Asch et al. (2000) reported that the salt-tolerant genotype had the smallest reduction in dry matter and the susceptible genotype had the greatest reduction in dry matter, which corroborate our results.

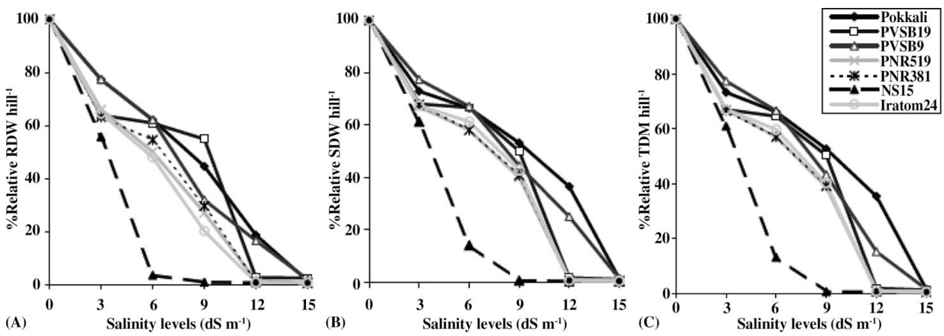

Figure 1. Effect of different salinity levels on (A) relative root dry weight (RDW); (B) relative shoot dry weight (SDW); and (C) relative total dry matter (TDM) of the seven selected rice genotypes.

Contents of Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^- in roots and shoots

The contents of Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^- in roots and shoots of selected rice genotypes significantly differed due to increasing salinity levels (Table 1). Irrespective of genotypes, Na^+ content in rice roots increased gradually up to 12 dS m^{-1} and at further higher level of salinity (15 dS m^{-1}) it started decreasing. At the highest salt

Table 1. The effect of different salinity levels on Na^{+}, K^{+}, Ca^{2+}, Mg^{2+} and Cl^{-} concentration (mmol g^{-1}DW) and Na^{+}/K^{+} mol ratio in roots and shoots of seven selected rice genotypes (each value is a mean of the 7 genotypes).

	Root						Shoot					
Salinity level (dS m^{-1})	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Cl^{-}	Na^{+}/K^{+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Cl^{-}	Na^{+}/K^{+}
0	0.150 d	0.053 b	0.080 c	0.088 c	0.067 f	3.07 d	0.123 d	0.379 a	0.025 d	0.079 f	0.142 f	0.33 c
3	0.156 d	0.035 cd	0.075 d	0.085 d	0.179 e	4.63 c	0.231cd	0.348 b	0.027 d	0.087 e	0.280 e	0.66 c
6	0.166 d	0.031 d	0.068 e	0.081 f	0.309 d	5.67 b	0.392 c	0.290 c	0.036 c	0.092 d	0.510 d	1.35 c
9	0.320 c	0.042 c	0.077 cd	0.084 e	0.505 c	7.44 a	0.826 b	0.240 d	0.040 c	0.110 c	0.718 c	4.25 b
12	0.650 a	0.092 a	0.095 b	0.096 b	0.940 b	7.22 a	1.707 a	0.167 e	0.085 b	0.137 b	1.087 a	14.19 a
15	0.558 b	0.094 a	0.104 a	0.098 a	1.165 a	6.86 a	1.748 a	0.115 f	0.112 a	0.162 a	0.952 b	13.82 a
Significance level	**	**	**	**	**	**	**	**	**	**	**	**
$LSD_{0.05}$	0.024	0.007	0.005	0.001	0.047	0.916	0.209	0.014	0.005	0.001	0.055	2.87
CV (%)	11.85	21.41	9.42	7.02	14.72	25.72	35.43	9.22	17.80	6.93	14.75	65.55

Values having same letter(s) in a column do not differ significantly at 5% level of probability; **Significant at 0.01 level of probability.

level, the death of the rice plants was observed within a very short time after the application of the full-strength salt solution of 15 dS m^{-1} due to high osmotic shock. The highest amount of Na^+ in the roots (0.650 mmol g^{-1}DW) was recorded at 12 dS m^{-1} while the lowest (0.150 mmol g^{-1}DW) was at control. The content of K^+, Ca^{2+} and Mg^{2+} in roots of selected rice genotypes decreased up to 6 dS m^{-1}, and then the ions content increased at higher salinity levels. According to Figure 2C, we observed that the concentration of K^+ increased very sharply in the roots of susceptible genotype NS15 with increasing salinity after 6 dS m^{-1}. In the case of other genotypes, at 12 and 15 dS m^{-1} levels of salinity the concentration of K^+ in roots was also slightly higher than in control treatment (Figure 2C). These results might have occurred due to the osmotic adjustment in the roots (Claussen et al. 1997) and translocation of K^+ from root to shoot was countered by Na^+. The contents of K^+, Ca^{2+} and Mg^{2+} in rice roots was highest (0.094, 0.104 and 0.098 mmol g^{-1}DW, respectively) at 15 dS m^{-1}, while the lowest contents of all these three nutrients were (K^+ 0.031 mmol g^{-1}DW, Ca^{2+} 0.068 mmol g^{-1}DW and Mg^{2+} 0.081 mmol g^{-1}DW) at 6 dS m^{-1}. The accumulation of Cl^- in rice roots maintained the increasing pattern with an increase in salinity levels, where the highest Cl^- content (1.165 mmol g^{-1}DW) was obtained at 15 dS m^{-1} while the lowest (0.067 mmol g^{-1}DW) was at control. In the case of shoots, the results in Table 1 show that the content of Na^+, Ca^{2+}, Mg^{2+} and Cl^- increased progressively with the increase in salinity levels, ranging from 0.123, 0.025 and 0.079 mmol g^{-1}DW (control) to 1.748, 0.112 and 0.162 mmol g^{-1}DW (15 dS m^{-1}), respectively. Conversely, the content of K^+ in shoots decreased with the increase in the salinity levels (from 0.379–0.115 mmol g^{-1}DW).

From the results in Table 2 it appeared that the content of Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^- in roots and shoots of the tested rice genotypes varied significantly due to the mean effect of the salinity levels employed. The results indicated that roots of rice genotype NS15 contained the highest amount of Na^+, K^+, Ca^{2+} and Cl^- (0.678, 0.110, 0.098 and 0.792 mmol g^{-1}DW, respectively) and the highest amount of Mg^{2+} was in Iratom24. The lowest concentration of Na^+, K^+ and Ca^{2+} were found in Pokkali; whereas PVSB9 showed the minimum amounts of Mg^{2+} and Cl^-. The content of these ions in shoots did not maintain the same pattern. In shoots, the highest amounts of Na^+, Ca^{2+}, Mg^{2+} and Cl^- (1.327, 0.083, 0.136 and 0.723 mmol g^{-1}DW, respectively) were in the susceptible genotype NS15, K^+ (0.326 mmol g^{-1}DW) in PVSB9 while the lowest amounts of Na^+, Ca^{2+} and Mg^{2+} (0.598, 0.033 and 0.088 mmol g^{-1}DW, respectively) were in Pokkali and K^+ and Cl^- concentrations were lowest in NS15 (0.216 mmol g^{-1}DW) and PNR381 (0.507 mmol g^{-1}DW), respectively.

The content of Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^- in the roots and shoots of the seven selected rice genotypes differed significantly due to the effect of different salinity levels. The content of Na^+, Ca^{2+}, Mg^{2+} and Cl^- was found to increase in the roots and shoots of all the genotypes due to the increase in salinity levels, although the increase in Ca^{2+} and Mg^{2+} content in roots did not maintain a regular pattern (Figures 2 and 3). The concentration of K^+ showed a slight increase in the roots of all genotypes after 9 dS m^{-1} level of salinity except in the susceptible genotype NS15, where K^+ content increased very sharply after 6 dS m^{-1} level of salinity. However, a considerable decreasing pattern of K^+ content was found in the shoots of all the genotypes at different salinity levels where a very sharp decreasing pattern was found in the susceptible genotype NS15 after 6 dS m^{-1} level of salinity (Figure 2C and 2D).

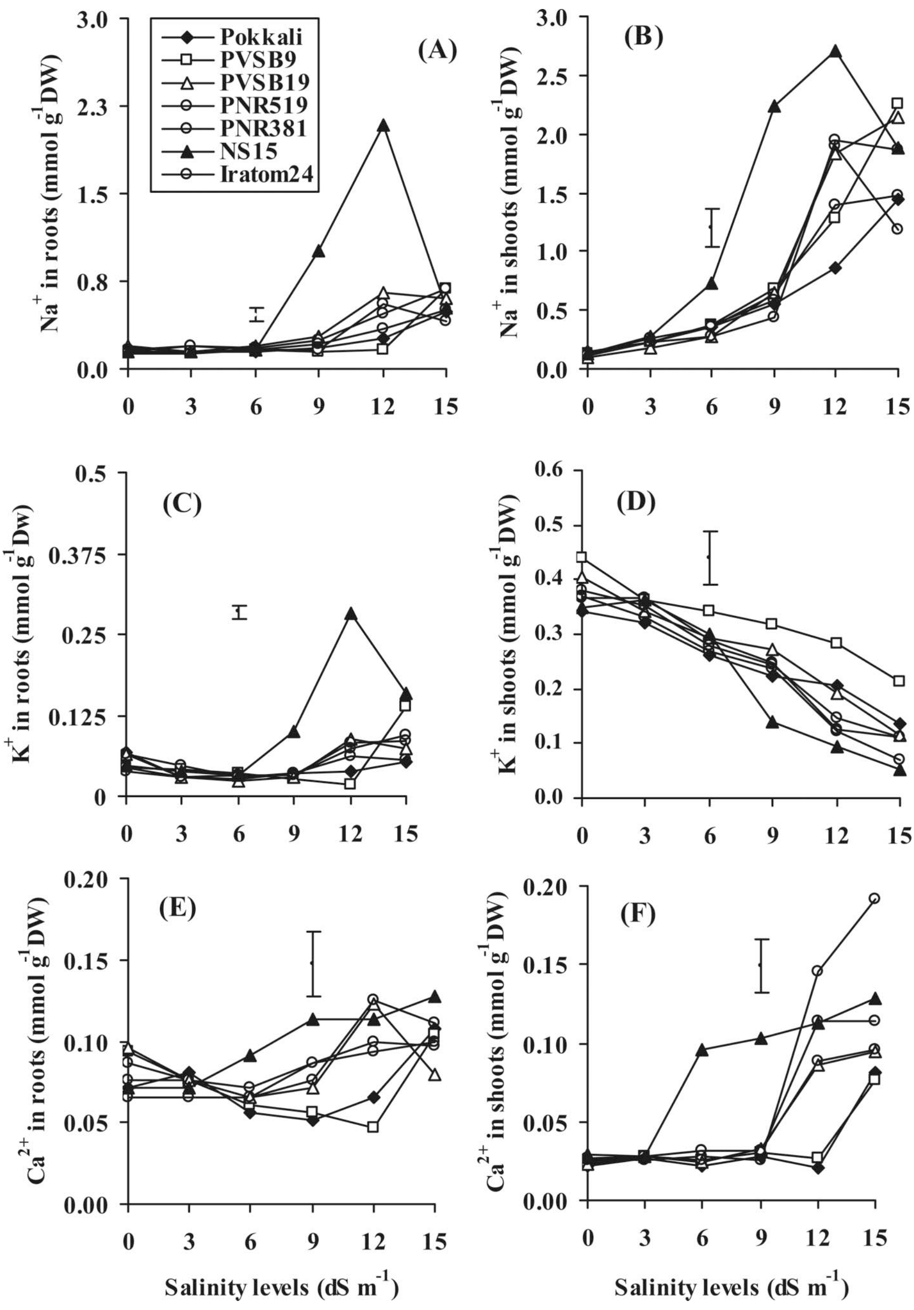

Figure 2. The effect of different salinity levels on Na^+ content in (A) roots and (B) shoots, K^+ content in (C) roots and (D) shoots, Ca^{2+} content in (E) roots and (F) shoots of the selected rice genotypes (vertical bars represent LSD at 0.05 level of significance).

The root of susceptible genotype NS15 contained high amounts of all the ions (Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^-), whereas the root of the genotypes Pokkali and PVSB9 contained a very low amount of all these ions. The shoot of tolerant genotype

Table 2. Genotypic effect on Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^- concentration (mmol g^{-1}DW) and Na^+/K^+ mol ratio in roots and shoots of seven selected rice (each value is a mean of 6 salinity levels [0, 3, 6, 9, 12 and 15 dSm^{-1}]).

	Root						Shoot					
Genotype	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	Na^+/K^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	Na^+/K^+
Pokkali	0.234 d	0.042 c	0.072 d	0.084 e	0.369 e	5.80 bc	0.598 d	0.248 cd	0.033 e	0.088 f	0.665 ab	3.31 bc
PVSB9	0.239 d	0.050 b	0.073 d	0.082 f	0.344 e	5.27 c	0.625 d	0.326 a	0.036 e	0.102 e	0.526 d	3.21 bc
PVSB19	0.348 b	0.052 b	0.086 bc	0.088 c	0.439 d	6.93 a	0.865 b	0.270 b	0.048 d	0.108 d	0.559 cd	5.20 b
PNR519	0.271 c	0.051 b	0.090 b	0.084 e	0.630 b	5.39 c	0.707 c	0.251 c	0.051 d	0.115 c	0.613 bc	5.04 b
PNR381	0.250 cd	0.052 b	0.080 c	0.086 d	0.374 e	4.93 c	0.700 c	0.233 d	0.056 c	0.115 c	0.507 d	5.56 b
NS15	0.678 a	0.110 a	0.098 a	0.090 b	0.792 a	5.79 bc	1.327 a	0.216 e	0.083 a	0.136 a	0.723 a	13.03 a
Iratom24	0.323 b	0.049 bc	0.084 c	0.101 a	0.551 c	6.60 ab	0.810 b	0.252 c	0.074 b	0.125 b	0.711 a	5.04 b
Significance level	**	**	**	**	**	**	**	**	**	**	**	**
$LSD_{0.05}$	0.026	0.007	0.005	0.001	0.051	0.984	0.226	0.016	0.005	0.001	0.059	3.10
CV (%)	11.85	21.41	9.42	7.02	14.72	25.72	35.43	9.22	17.80	6.93	14.75	65.55

Values having same letter(s) in a column do not differ significantly at 5% level of probability; **Significant at 0.01 level of probability.

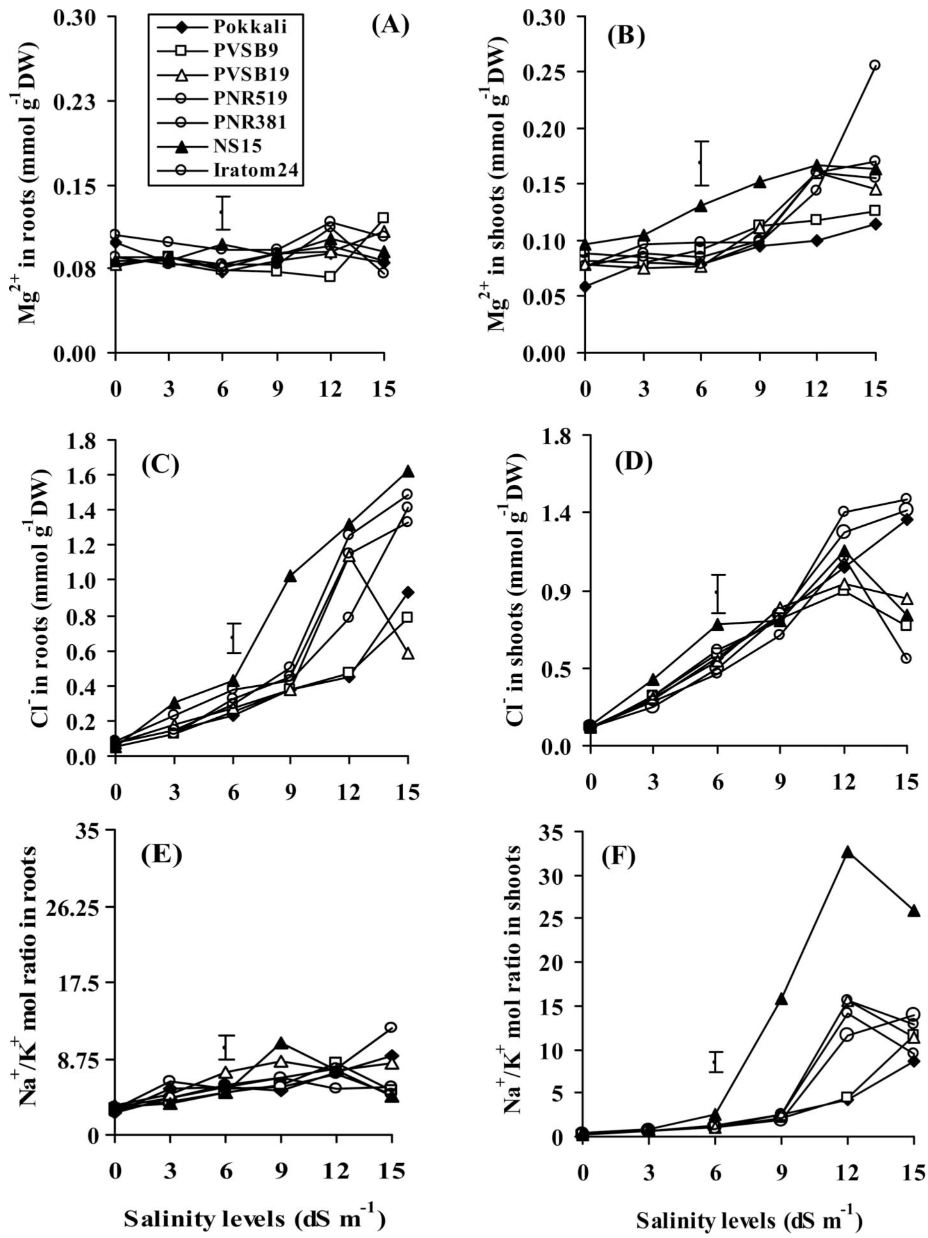

Figure 3. The effect of different salinity levels on Mg^{2+} content in (A) roots and (B) shoots, Cl^- content in (C) roots and (D) shoots, Na^+/K^+ mol ratio in (E) roots and (F) shoots of the selected rice genotypes (vertical bars represent LSD at 0.05 level of significance).

PVSB9 contained the highest amount of K^+ and a very low amount of Na^+ and Cl^-, whereas the shoot of susceptible genotype NS15 contained the highest amount of Na^+, Ca^{2+}, Mg^{2+}, Cl^- and the lowest amount of K^+. The concentration of Na^+ and Ca^{2+} sharply increased with increasing salinity levels in both the roots and shoots of susceptible genotype NS15 as compared to other genotypes (Figure 2A, 2B, 2E and 2F).

The concentration of K^+ sharply decreased in shoots and increased in the roots of NS15 with increasing salinity (above 6 dS m^{-1}) (Figure 2C and 2D). This suggests that the translocation of K^+ from root to shoot might have been countered by Na^+. The Cl^- concentrations increased with increasing salinity at a similar trend in both the roots and shoots of NS15 up to 12 dS m^{-1} (Figure 3C and 3D).

We know that the osmotic shock was more prominent in salt-susceptible plants than that of salt-tolerant plants at higher salinity. As a result, the ions uptake mechanism is regulated through the osmotic adjustment (Claussen et al. 1997). Therefore, to survive in saline conditions, the higher accumulation of all ions by the roots of susceptible genotypes was helpful to maintain osmoregulation to protect the plant cells from osmotic shock caused by higher salinity. In our study, the amount of K^+ in the roots of susceptible rice genotype NS15 (Figure 2C) was higher than those of other genotypes at 9 and 12 dS m^{-1} salinity, which might be associated with disruption of translocation of K^+ from root to shoot by Na^+ (Figure 2D). Velu and Srivastava (2000) found that the plants grew in salinized medium, the Na^+ content increased and K^+ content decreased in plant tissue irrespective of varieties at all stages of growth. They also found that the sensitive variety had higher Na^+ content coupled with lower K^+ content compared to moderately tolerant and tolerant varieties. A similar opinion was stated by Jacoby (1999). Zhu et al. (2001) observed that salt stress induced a decrease of shoot K^+ content, an increase of shoot Cl^- content and higher accumulation of Ca^{2+} in roots. Instead, salt-tolerant cultivars had lower Na^+ and higher K^+ contents due to salinity (Pandey and Sharma 2002). Hussain et al. (2003) observed that Na^+ concentration increased in roots and shoots of rice due to the increase of its concentration in root medium and it significantly increased the Ca^{2+} concentration in root and tissues at higher salinity. They further stated that there was no significant difference in K^+ concentration in root and Mg^{2+} concentration in the shoot at 60 and 90 mM NaCl. The increase of Na^+ content and the decrease of K^+ content in plants due to salinity might be related to the competition and resultant selective uptake between K^+ and Na^+, which caused an increase in the uptake of Na^+ at the cost of K^+ (Kuiper 1984). The accumulation of Mg^{2+} in the leaf of the plant was helpful to maintain osmoregulation to protect the plant cells from osmotic shock caused by salinity (Greenway and Munns 1980).

Ratio of Na^+/K^+ in roots and shoots

The ratio of Na and K ions such as Na^+/K^+ in roots and shoots of the selected rice genotypes significantly differed due to different salinity levels (Table 1). Upon increased salt stress, the Na^+/K^+ molar ratios were raised in both shoots and roots. There were significant differences in the values of Na^+/K^+ molar ratios in roots and shoots of the selected rice genotypes due to the mean effect of different salinity levels (Table 2). The highest value of Na^+/K^+ molar ratio (6.93) was found in root of PVSB19 and the lowest value was found in PNR381, PVSB9 and PNR519. In shoots, the highest value of Na^+/K^+ molar ratio (13.03) was recorded in NS15. The lowest value of Na^+/K^+ molar ratio (3.21) was found in the shoots of PVSB9, which was similar to that of Pokkali (3.31). The molar ratios of Na^+/K^+ in roots and shoots of the seven selected rice genotypes were found to differ significantly due to the application of different salinity levels (Figure 3E and 3F). The results (Figure 3E and 3F) indicated that Na^+/K^+ ratio increased slightly in all genotypes with the increasing salinity levels in roots and it suddenly increased to some extent from 6 dS m^{-1} in shoots of genotype NS15.

Dionisio and Tobita (2000) found a significant increase in Na^+/K^+ content with increasing salinity in salt-sensitive rice cultivars. An increase in salinity level increased the content of Na^+ and Na^+/K^+ ratio in rice cultivars (Labeed et al. 2002). Pandey and Sharma (2002) found that salt-tolerant genotypes such as Kalaratta, Damodar and RPA-5929 had relatively lower Na^+/K^+, Na^+/Ca^{2+} and Na^+/Mg^{2+} ratios, compared to salt-sensitive genotypes having medium to high ratios in their leaves. Salinity resulted in marked imbalance in the Na^+ and K^+ content and Na^+/K^+ ratio of shoots in the rice genotypes, although these changes were relatively more pronounced in sensitive rice varieties (Hussain et al. 2003).

Dobermann and Fairhurst (2000) postulated a relationship between salt tolerance and ion effects in that there were differences among plant species in the degree of toxicity of Na^+ and Cl^- to growth and finally, among genotypes in the capacity to maintain sufficient nutrient concentrations, like K^+ and Ca^{2+} for plant growth under salt stress. Our results show that the concentration of Na^+, Cl^- and the values of Na^+/K^+ ratio in root and shoot tissues of genotypes PVSB9, PNR381, along with Pokkali were lower while NS15 contained the highest amount of Na^+, Ca^{2+}, Mg^{2+} and Cl^- (Table 2). The highest percentage of relative root and shoot dry weight and total dry matter $hill^{-1}$ were recorded in genotype PVSB9 at 3 dS m^{-1} level, whereas the lowest values were recorded in genotype NS15 at all salinity levels compared to other genotypes (Figure 1). The % relative root, shoot and total dry weight (RDW, SDW and TDM) $hill^{-1}$ in susceptible genotype NS15 decreased very sharply from 3 dS m^{-1} salinity level compared to other genotypes. The decrease in dry matter under long-term exposure of rice genotypes to salinity leads to premature leaf senescence thus reduced dry matter production as compared to the control treatment. The higher RDW, SDW and TDM in genotypes Pokkali and PVSB9 might be due to the lower uptake of Na^+ and Cl^- or dilution of Na^+ and Cl^-. This assumption is supported by the higher K^+ content and lowers the Na^+/K^+ ratio in shoots of the tolerant genotypes Pokkali and PVSB9. The concentration of Na^+ and Cl^- in the root and shoot of the tolerant genotypes appeared to be lower than that of NS15 (susceptible). Ions could be preferentially accumulated in certain cells or cellular compartments and these tolerant and susceptible genotypes showed different relative tolerances, which support the argument that ion effects are responsible for the differences in salt tolerance between tolerant and susceptible genotypes (de Lacerda et al. 2003; Hu et al. 2007).

Conclusion

In conclusion, the results showed that the uptake of Na^+, Cl^- increased and the uptake of K^+ decreased in the shoots of rice with increasing salinity irrespective of rice genotypes, where the resistant genotypes contained significantly lower amounts of Na^+, Cl^- and higher amounts of K^+ compared to susceptible genotype NS15. Wide genotypic differences were identified for relative salt tolerance in terms of mineral composition, i.e. Na^+ and K^+ content and Na^+/K^+ ratio in the selected rice genotypes. This study revealed that the genotypes PVSB9, PNR381 along with Pokkali were salt tolerant and NS15 was salt susceptible. Although the salt tolerance mechanism is not clearly understood, our results suggest that the ions uptake by selected rice genotypes under salinity stress may be helpful to know the salt tolerance mechanism in rice plants. Characterization of Na^+, K^+ and Cl^- transport and their regulation under salt stress conditions is needed to elucidate the mechanism of salt tolerance, which will eventually help us to develop a salt-tolerant rice cultivar.

References

Apse MP, Aharon GS, Snedden WA, Blumwald E. 1999. Salt tolerance conferred by overexpression of a vacuolar Na^+/H^+ antiport in *Arabidopsis*. Science 285:1256–1258.

Asch F, Dingkuhn M, Doerffling K. 2000. Salinity increases CO_2 assimilation but reduces growth in field-grown irrigated rice. Plant Soil. 218(1–2):1–10.

Ashraf M. 1994. Breeding for salinity tolerance in plants. Crit Rev Plant Sci. 13:17–42.

Claussen M, Luthen H, Blatt M, Boltgen M. 1997. Auxin induced growth and its linkage to potassium channels. Planta. 201:227–234.

Clesceri LS, Greenberg AE, Trussel RR. 1988. Standard methods for the examination of water and waste water. 17th ed. Washington (DC): American Public Health Association. p. 100–175.

de Lacerda CF, Cambraia J, Oliva MA, Ruiz HA, Prisco JT. 2003. Solute accumulation and distribution during shoot and leaf development in two sorghum genotypes under salt stress. Environ Exp Bot. 49:107–120.

Dionisio SML, Tobita S. 2000. Effect of salinity on sodium content and photosynthetic response of rice seedling differed in salt tolerance. J Plant Physiol. 157:54–58.

Dobermann A, Fairhurst T. 2000. Rice. Nutrient disorders & nutrient management. Handbook series. Potash & Phosphate Institute (PPI), Potash & Phosphate Institute of Canada (PPIC) and International Rice Research Institute. p. 191.

Grattan SR, Grieve CM. 1999. Salinity mineral nutrient relations in horticultural crops. Sci Hortic. 78:127–157.

Greenway H, Munns R. 1980. Mechanism of salt tolerance in non-halophytes. Annu Rev Plant Physiol. 31:149–190.

Hasegawa PH, Bressan RA, Zhu JK, Bohnert HJ. 2000. Plant cellular and molecular responses to high salinity. Annu Rev Plant Physiol Plant Mol Biol. 51:463–499.

Hu Y, Burucs Z, Tucher SV, Schmidhalter U. 2007. Short-term effects of drought and salinity on mineral nutrient distribution along growing leaves of maize seedlings. Environ Exp Bot. 60:268–275.

Hussain N, Ali A, Khan AG, Rahman O, Tahir M. 2003. Selectivity of ions absorption as mechanism of salt tolerance in rice (Variety Shaheen Basmati). Asian J Plant Sci. 2: 445–448.

Jacoby B. 1999. Mechanisms involved in salt tolerance of plants. In: Pessarakli M, editor. Handbook of plant and crop stress. 2nd ed. New York: Marcel Dekker. p. 97–123.

Juan M, Rivero RM, Romero L, Ruiz JM. 2005. Evaluation of some nutritional and biochemical indicators in selecting salt-resistant tomato cultivars. Environ Exp Bot. 54:193–201.

Kuiper, PJC. 1984. Functioning of plant cell membrane under saline conditions: membrane liqid composition and ATPases. In: Staples RC, Toenniessen AM (eds.), Salinity Tolerance in Plants: Strategres for Crop Improvement. John Wiley and Sons, Inc. New York. pp. 77–91.

Labeed S, Khdhayer A, Hatim J, Hassan M. 2002. Rice plants content of Na, K, Ca and Mg and its relationship with salt tolerance. Dirasat Agric Sci. 29:232–246.

Pandey UK, Sharma AP. 2002. Effect of salinity on potassium, calcium and magnesium content in rice varieties. Indian J Plant Physiol. 7:302–304.

Ponnamperuma FM. 1977. Physiological properties of submerged soils in relation to fertility. IRRI Research Paper Series No.5. Philippines: IRRI. p. 1–32.

Russel DF. 1986. MSTAT-C Package Programme. Michigan State University. USA: Dept. of Crop and Soil Science.

Shannon MC, Rhoades JD, Draper JH, Scardaci SC, Spyres MD. 1998. Assessment of salt tolerance in rice cultivars in response to salinity problems in California. Crop Sci. 38(2):394–398.

Silva EC, Nogueira RJMC, de Araújo FP, de Melo NF, de Azevedo Neto AD. 2008. Physiological responses to salt stress in young umbu plants. Environ Exp Bot. 63:147–157.

Soil Resource Development Institute (SRDI). 2000. Soil salinity in Bangladesh, Khamarbari, Dhaka-1215.

Thomas RL, Sheard RW, Moyer JR. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus and potassium analysis of plant material using a single digestion. Agron J. 59:240–243.

Velu G, Srivastava GC. 2000. Status of sodium-potassium as a basis of salinity tolerance in rice. Indian J Plant Physiol. 5:300–302.

Zhu GY, Kinet JM, Lutts S. 2001. Characterization of rice (*Oryza sativa* L.) F_3 populations selected for salt resistance. I. Physiological behaviour during vegetative growth. Euphytica. 121:251–263.