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EFFECTS OF APPLYING CALCIUM SALTS TO COASTAL SALINE SOILS ON GROWTH AND MINERAL NUTRITION OF RICE VARIETIES

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ABSTRACT

A greenhouse experiment was conducted with 3 coastal saline soils, viz. Ramgati (Aeric Fluvaquent), Nalchiti (Aeric Haplaquept), and Jhalakati (Typic Haplaquept), representing 3 salinity levels. Calcium (Ca) salts in the form of nitrate, chloride, sulfate, and phosphate (dibasic) were added to maintain the ratio of 1 : 5 for Na : Ca on the basis of the content of sodium (Na) and Ca in all soils. Two varieties of rice (*Oryza sativa* L.) (BR-11 and Pokkali) with varying salt tolerance were grown on the soils under submergence for 30 days. Salt injury symptoms such as chlorosis and necrosis on leaves of plants receiving no additional Ca (control) were observed and the severity of symptoms

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varied among the soils. Pokkali was less affected by salinity than BR-11 and produced greater dry matter yield on all soils. In comparison to control plants, application of calcium phosphate (CP) and calcium sulfate (CS) to soils tended to ameliorate the detrimental effects of salinity stress on dry matter yield. On the other hand, a decrease in dry matter yield was obtained with calcium chloride (CC) and calcium nitrate (CN). This suggests that maintaining a constant Na:Ca in the growth medium with Ca salts (CP and CS) having lower solubility seems to be effective in the amelioration of salinity stress regardless of its level. Concentrations of nitrogen (N), phosphorus (P), potassium (K), and Ca in shoots and roots of two varieties of rice plants decreased with increasing salinity levels, while results obtained with Na and magnesium (Mg) were opposite. Application of CP and CS increased N, P, K, and Ca and decreased Na and Mg concentrations when compared to control plants grown on all soils. The decrease in Na and Mg concentrations was less pronounced in BR-11 as compared to Pokkali. In general, CP was more effective than CS in the acquisition of essential macronutrient elements (except Mg), which was higher in Pokkali than BR-11.

INTRODUCTION

Salt-affected soils make up a substantial portion of the world's land area, including approximately 33% of the irrigated soils (1). Soil salinization does not only mean a simple increase in the amount of salt in the soil, but it also entails catastrophic changes in the soil properties which render the soil useless for agriculture. Salt stress may reduce plant growth by water deficit, ion toxicity, ion imbalance, or a combination of these factors (2). However, the mechanism by which salinity inhibits growth is poorly understood.

In Bangladesh, there are approximately 0.91 million hectares of coastal saline soils and these areas are still increasing rapidly (3). Of many reasons, crop intensification in the coastal areas of Bangladesh is not possible due to i) non-introduction of salt tolerant or adapted varieties of crops, and ii) lack of sound soil-fertilizer-crop-water management program (4). Efforts have been made to control salinity by technological means such as reclamation, drainage, irrigation with high quality and quantity water, and application of soil amendments. These activities should be continued and even expanded in regions where irrigation is meant to provide food, fiber, and other usable biomass on a permanent basis, but reclamation costs generally increase production costs and the process of reclamation is time consuming. In addition, economically feasible engineering schemes cannot eliminate salt from saline environments but they can only minimize it. These considerations have generated interest among soil scientists to other alternatives, such as growing salt tolerant crops and some management practices, which may serve as effective tools combating the catastrophe of salinity. Epstein et al. (1) suggested that the development of salt tolerant plants is necessary for possible improved utilization of saline soils and water.

Rice is a popular crop for reclaiming salt-affected soils and is grown extensively where climate is favorable even though high salinity may be a constraint (5). Rice is the staple food in Bangladesh; it is necessary to increase rice production to meet the demand associated with the rapid population increase in recent years. Research for tolerant and adapted varieties of rice for adaptation to the coastal saline soils needs to be accomplished.

It is well known that a sufficient amount of calcium (Ca) in salt-affected soils alleviates the inhibitory effect of salinity on plant growth (6,7,8,9). One of the major roles of Ca in plant metabolic processes is the stabilization of the cell wall, particularly of the cementing substance, Ca-pectate (10), and stabilization of cell membranes by bridging phosphate and carboxylate groups of phospholipids (11) and proteins, preferentially at membrane surfaces (12). An exchange takes place between Ca^{2+} at these binding sites and other cations such as K^+, Na^+, or H^+, but these cations cannot replace Ca^{2+} from the membrane (13).

Sodium (Na) ions usually compete with Ca^{2+} for uptake (14) and/or change intracellular levels of Ca^{2+} (15). Sodium also plays a crucial role in increasing membrane porosity (8), and results in membrane depolarization (16). Therefore, a sufficient amount of Ca must be present in the external growth medium to maintain membrane stabilization. The presence of Ca^{2+} at the plasma membrane prevents solute leakage from the cytoplasm and it regulates the selectivity of ion uptake (17).

The objectives of this study were to evaluate the salt tolerance of two varieties of rice, namely BR-11 and Pokkali, and the possibility of ameliorating the toxic effects of salinity by maintaining a constant Na:Ca ratio in the growth media with varying salinity levels.

MATERIALS AND METHODS

A pot experiment was conducted in a greenhouse with 3 soils, viz. Ramgati (Aeric Fluvaquent), Nalchiti (Aeric Haplaquept), and Jhalakati (Typic Haplaquept). The coastal saline soils were taken from the top 15-cm layer of crop fields at Barguna, Bangladesh. Selected properties of these soils are given in Table 1. Two varieties of rice were used, BR-11 (bred by Bangladesh Rice Research Institute) and Pokkali (local variety) with varying salt tolerance. Each plastic pot

Table 1. General Properties of Saline Soils Used in Greenhouse Studies

Soil	pH	EC_e dS/m	CEC, meq $(100\ g)^{-1}$	Total N %	O.C %	O. M %	Texture	ESP	SAR	SCAR*
Ramgati	6.5	1.85 (S_1)	11.45	0.10	0.92	1.58	SiCL	13.19	9.68	1.85
Nalchiti	7.3	3.59 (S_2)	15.46	0.11	1.10	1.90	SiC	16.05	13.30	2.10
Jhalakati	7.7	6.60 (S_3)	23.00	0.10	1.23	2.12	SiC	27.70	17.95	2.11

*Sodium to calcium activity ratio = $\sqrt{(Na/Ca)}$.

contained 1.0 kg air-dried soil, and Ca was added to adjust a ratio of 1 : 5 for Na : Ca on the basis of the content of Na and Ca in the soils (18). Sources of Ca used were nitrate, chloride, sulfate, and phosphate (dibasic). Soils and salts were mixed thoroughly. The pots were placed in a greenhouse and watered to flooding for 7 days. The pH of flooded soils was adjusted to 5.5 with 1 N HCl.

Seeds of BR-11 and Pokkali were germinated on quartz sand soaked in distilled water. Three seedlings were transplanted per pot 14 days after sowing and were allowed to grow under submergence for 30 days. The whole plants were harvested, washed with distilled water carefully, dried in an oven at 65°C for 24 h, separated into shoots and roots, weighed, and stored in plastic pots. Dried samples were digested in an $HNO_3 - HClO_4 - H_2SO_4$ solution and extracts were analyzed for K, Na, Ca, and Mg by atomic absorption spectrophotometry and for P colorimetrically with the vanadomolybdate yellow assay. The N concentration was determined by digestion with H_2SO_4 according to the Micro-Kjeldahl method (19).

RESULTS AND DISCUSSION

Visual Symptoms

Salt injury symptoms such as chlorosis and necrosis on leaves of control plants were observed, and the severity of the symptoms varied among the soils. Pokkali was less sensitive to salinity than BR-11 in terms of the time of appearance and the severity of the symptoms. Chlorosis and necrosis are well known nutrient deficiency symptoms. Rice plants under salinity stress will be deficient in certain essential nutrient elements. Plants looked most vigorous in Ramgati soils followed by Nalchiti soils and Jhalakati soils when CP and CS were added. On the other hand, application of CC and CN to soils aggravated salt injury symptoms and the plants were almost dead at the time of harvest.

Dry Matter Yield

Dry matter yield of shoots and roots differed between the two varieties and was affected by the levels of salinity (Fig. 1). Pokkali produced greater dry matter yield than BR-11 in all soils. Salinity suppressed the shoot more than the root in both varieties. Munns and Termaat (20) suggested that leaf growth is more sensitive to salinity than root growth; once the older leaves start to die of excessive salt build-up the photosynthetic area of the plant will eventually decline to such a low level that it can no longer produce enough carbohydrate to support continued growth. Our results support this view. Compared to control plants, application of CP and CS increased dry matter yield, whereas CC and CN decreased dry matter yield.

The increase in dry matter yield of plants on all soils with added CP and CS was almost similar when compared to control plants, indicating that maintaining a constant Na : Ca ratio in the growth medium with Ca salts (CP and CS) having lower solubility is effective in the amelioration of salinity stress regardless of its level. Singh et al. (21) reported that the increase in dry matter yield due to phosphate application was due to the reducing effect of P on salinity stress condition of the soils or due to the abundance of P in root zones.

Although the concentrations of micronutrients in soils and plants were not determined in this study, it is possible that the application of CS increased their concentrations, and higher levels of these micronutrients may have increased the dry matter yield. Kuwajima and Kawai (22) reported that the release of phytosiderophore (PS), plant-borne iron (Fe) carrier, from roots of barley increased progressively with increase in sulfur (S) concentration in the growth media. Treeby et al. (23) reported that the PS is effective in solubilizing metal micronutrients from soils. It is possible that the increase in S (from CaSO4 used as a source of Ca) promoted the release of PS, thereby leading to a higher metal supply in the rhizosphere as well as in the root apoplasm. Panaullah (24) reported that the increase in soil fertility mitigates the harmful effect of salinity on dry matter yield of rice plants and saline soils are deficient in metal micronutrients. The decrease in dry matter yield due to CN addition would be related to the fact that nitrogenous fertilizers are generally soluble and therefore tend to increase the level of soil salinity (25). It has already been reported that the higher salt concentration counteracts the favorable effect of added nitrate (26). Application of CC increased the chloride concentration of soils, thereby decreasing the dry matter yield probably due to either osmotic imbalances or inhibiting levels of toxic chloride (Cl) ions.

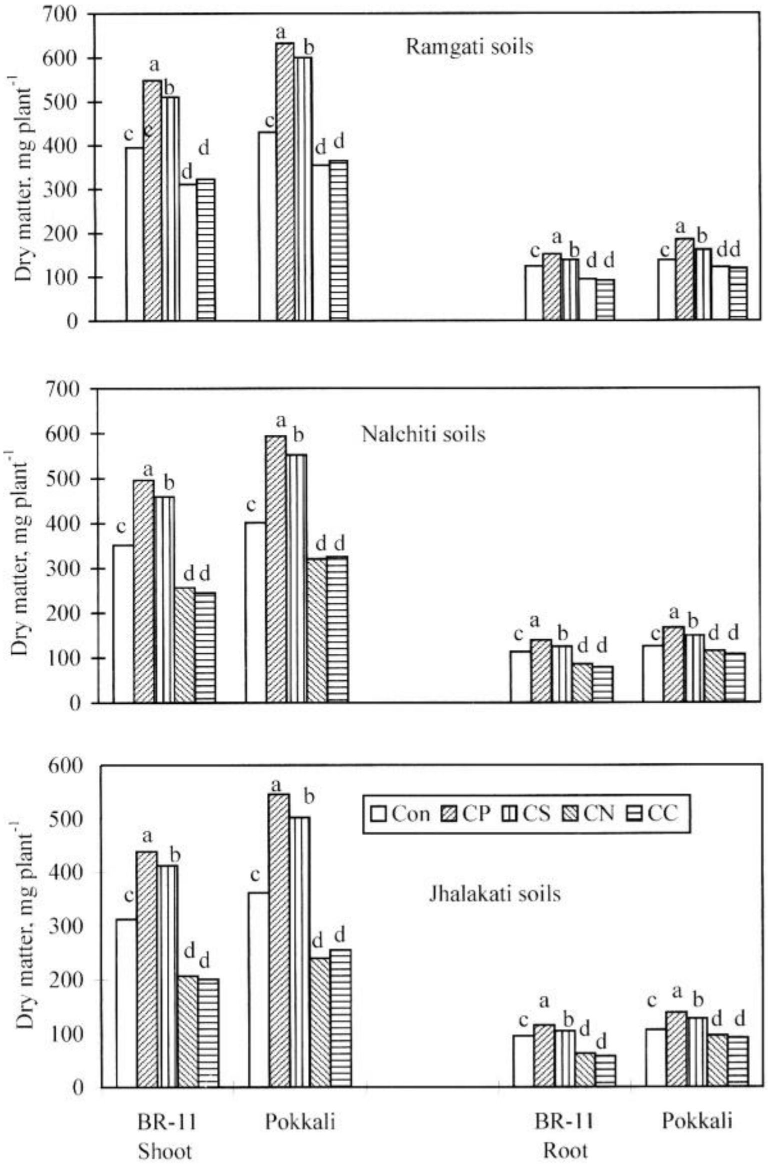

Figure 1. Effects of applying Ca salts to coastal saline soils with different levels of salinity on the dry matter yield of rice plants. Bars followed by same letter are not significantly different according to LSD ($p < 0.05$).

Mineral Nutrition

Concentrations of both N and P in shoots and roots of the two varieties of rice decreased with increasing levels of EC_e in soil saturation extracts, an indicator of soil salinity (Tables 1 and 2). Plant energy metabolism and protein synthesis could be inhibited with the decrease in these two plant macronutrients and could account for some of the yield losses observed with increasing salinity. The relative increase in P concentration compared to control was found in shoots and roots of both varieties as a response to P supplied as CP to soils. Singh et al. (21) reported that P concentration in shoots and roots of plants increased with an increase in P concentration in saline soils. For N an opposite trend was noted,

Table 2. Effects of Applying Ca Salts to Coastal Saline Soils with Different Levels of Salinity on the Concentration of N and P in Shoots and Roots of Rice Varieties

	N, mg kg^{-1} DW				P, mg kg^{-1} DW			
	Shoot		Root		Shoot		Root	
Treatment	BR-11	Pokkali	BR-11	Pokkali	BR-11	Pokkali	BR-11	Pokkali
				Ramgati soils (S_1)				
Control	4125b	4589b	1914b	2113b	3125c	3358c	1378c	1589c
CP	4456a	4782a	2219a	2301a	3826a	4112a	1989a	2145a
CS	4509a	4677a	2188a	2257a	3379b	3548b	1501b	1702b
CN	3874c	4213c	1666c	1887c	2546d	2854d	1154d	1253d
CC	3901c	4199c	1716c	1902c	2499d	2812d	1102d	1189d
				Nalchiti soils (S_2)				
Control	3494b	3775b	1655b	1812b	2589c	2887c	1221c	1342c
CP	3789a	4012a	1874a	2014a	3145a	3427a	1863a	1923a
CS	3657a	4100a	1789a	1963a	2658b	3089b	1459b	1557b
CN	3214c	3412c	1426c	1515c	2145d	2531d	1025d	1185d
CC	3169c	3477c	1473c	1477c	2187d	2499d	1101d	1212d
				Jhalakati soils (S_3)				
Control	2504b	2887b	1187b	1323b	2078c	2256c	1023c	1147c
CP	2654a	3125a	1412a	1496a	2654a	2947a	1536a	1769a
CS	2712a	3211a	1357a	1501a	2285b	2478b	1219b	1336b
CN	2136c	2564c	1123b	1259c	1897d	1986d	963d	1025d
CC	2089c	2612c	1086b	1315c	1842d	1952d	912d	1023d

CP = calcium phosphate, CS = calcium sulfate, CN = calcium nitrate, CC = calcium chloride. Data are means of 3 replicates.
Values within a column followed by the same letter are not significantly different according to LSD test ($p<0.05$).

with decrease in concentration of the element in plants grown in soils containing CN with increasing salinity.

The distribution of Na in Pokkali differed from that in BR-11 (Table 3). Shoot Na concentration of BR-11 was higher than root, indicating that the salt-sensitive rice plant translocates more Na from their roots to shoots. The opposite pattern was observed in Pokkali. Our results are in agreement with those of Dionisio-Sese and Tobita (27), who reported that salt tolerance in rice was associated with decreased shoot Na accumulation. Salinity increased the concentration of Na in shoots and roots of both varieties. This increase was accompanied by a decrease in the K concentration (Table 3), indicating an apparent antagonism between K and Na. This antagonism may be due to the

Table 3. Effects of Applying Ca Salts to Coastal Saline Soils with Different Levels of Salinity on the Concentration of Na and K in Shoots and Roots of Rice Varieties

	Na, mg kg^{-1} DW				K, mg kg^{-1} DW			
	Shoot		Root		Shoot		Root	
Treatment	BR-11	Pokkali	BR-11	Pokkali	BR-11	Pokkali	BR-11	Pokkali
				Ramgati soils (S_1)				
Control	5561a	2889a	1878d	3498c	5489c	7736c	2295c	4535c
CP	3180c	2315c	2480b	4385a	7369a	9981a	3369a	6158a
CS	3397b	2563b	2685a	4119b	7031b	9661b	3053b	5893b
CN	5169a	2935a	2192c	3465c	4985d	5063d	2075d	3973d
CC	5235a	2973a	2270c	3489c	4879d	5134d	2068d	3958d
				Nalchiti soils (S_2)				
Control	6983a	3456b	2747c	4797c	4289c	6147c	1756c	3998c
CP	4775d	3025d	3356b	5792a	5662a	7892a	2823a	4999a
CS	5012c	3258c	3539a	5135b	5410b	7163b	2496b	4652b
CN	6021b	3654a	2963c	4665c	2381d	3869d	1487d	2965d
CC	6248b	3589a	2865c	4575c	2409d	3641d	1381d	2947d
				Jhalakati soils (S_3)				
Control	8796a	4235b	4365c	6818a	2827c	4569c	2015a	3293b
CP	5492d	3681d	4965b	6793a	3890a	6497a	2256a	4289a
CS	6784c	3849c	5210a	6479b	3497b	5749b	2114a	4196a
CN	7896b	4592a	3826d	5132d	1246d	3145d	1039b	1597c
CC	7985b	4687a	3814d	5897c	1279d	3025d	1047b	1623c

CP = calcium phosphate, CS = calcium sulfate, CN = calcium nitrate, CC = calcium chloride. Data are means of 3 replicates.
Values within a column followed by the same letter are not significantly different according to LSD test ($p<0.05$).

direct competition between K and Na at the site of ion uptake in the plasmalemma of roots (28,29). Sodium was found to accumulate mainly in roots of plants and may also enhance the efflux of K into the growth medium, because of membrane integrity (30). Imamul Huq and Larher (18) reported that the presence of high Na in the external media increased the Na:Ca ratio, and such a situation gave rise to the passive accumulation of Na, ultimately causing 'ion excess' (31). It has been reported that salt-tolerant plants accumulate Na in their roots since the accumulation of Na in the roots allows more Ca to reach the shoots (32). A high concentration of Na may block the transport of K and Ca that interferes with the growth of a number of plant species (33). The application of CP and CS to soils increased K concentration in shoots and roots of plants. This was probably due to interchange from cation exchange sites with added Ca leading to higher K supply in the rhizosphere as well as in the root apoplasm. Kent and Laüchli (34) reported that K concentration in roots of cotton was reduced by salinity, but was restored to adequate levels by an additional Ca supply. Cramer et al. (30) showed the displacement of membrane-associated Ca by Na, thereby inducing K to leak out of the cytoplasm across the plasmalemma. Jeschke (35) emphasized that the inhibitory effect of Na can be mediated through interactions with cations, mainly K and Ca. Leopold and Willing (36) reported that high concentrations of Na affect intracellular accumulation of K, thus K deficiency can be regarded as a detrimental effect of the exposure to NaCl. The decrease in shoot Na concentration and concomitant increase in roots indicated that the translocation of Na from roots to shoots was inhibited by the application of CP and CS.

Calcium concentration in shoots was higher than in roots (Table 4). Calcium concentration in shoots and roots of plants decreased with increasing salinity levels of soils (Table 1). The decrease in Ca concentration was less pronounced in Pokkali than in BR-11. Under conditions of high external NaCl, the Ca deficiency of shoots is a common symptom of salt stress (37). Calcium concentration in shoots and roots was increased by the application of CP and CS and decreased with CC and CN, and the effect was more pronounced in Pokkali than in BR-11. Lunin and Gallatin (25) reported that the Ca concentration in leaves of beans decreases where N is applied and P fertilization increases the Ca concentration. Clarkson and Hanson (38) reported that Ca is required to protect the roots of plants from the deleterious effects of salinity and ion imbalance. Barnabas et al. (9) showed that at high salinity a high external supply of Ca was necessary to maintain membrane integrity and protect epidermis cells from salt stress. Application of supplemental Ca has been successful in improving crop quality such as the correction of Na-induced Ca deficiency (29).

Magnesium concentration in shoots and roots of plants increased with increasing salinity (Table 4). This was expected, as the soil salinity was characterized by Na-Mg type of salinity (4,39) where Na and Mg concentrations

Table 4. Effects of Applying Ca Salts to Coastal Saline Soils with Different Levels of Salinity on the Concentration of Ca and Mg in Shoots and Roots of Rice Varieties

	Ca, mg kg^{-1} DW				Mg, mg kg^{-1} DW			
	Shoot		Root		Shoot		Root	
Treatment	BR-11	Pokkali	BR-11	Pokkali	BR-11	Pokkali	BR-11	Pokkali
Ramgati soils (S_1)								
Control	351c	512c	312c	356c	1442a	1089a	754a	523a
CP	563a	732a	379a	519a	1145c	802c	503c	345c
CS	456b	661b	335b	481b	1355b	907b	612b	461b
CN	221d	284d	185d	202d	1101d	689d	756a	556a
CC	212d	292d	178d	212d	1072d	674d	766a	587a
Nalchiti soils (S_2)								
Control	301c	369c	218c	221c	1709a	1250a	910a	741a
CP	636a	773a	323a	489a	1365c	902c	665c	547c
CS	498b	539b	281b	379b	1559b	1065b	778b	656b
CN	158d	245d	134d	189d	1227d	898d	665d	702a
CC	152d	225d	135d	191d	1219d	874d	648d	714a
Jhalakati soils (S_3)								
Control	285c	324c	175b	201b	1978a	1626a	999a	862a
CP	436a	502b	211a	259a	1524c	1345c	754c	612c
CS	389b	546a	220a	254a	1745b	1502b	865b	725b
CN	116d	148d	152b	156c	1256d	984d	645d	801a
CC	124d	156d	142b	149c	1248d	965d	673d	809a

CP = calcium phosphate, CS = calcium sulfate, CN = calcium nitrate, CC = calcium chloride. Data are means of 3 replicates.
Values within a column followed by the same letter are not significantly different according to LSD test ($p < 0.05$).

in plant tissues increased consistently. The application of CP and CS decreased Mg concentration and the effect was more pronounced in roots than in shoots. Grattan and Maas (40) reported that the increased Ca/Na ratio decreased the Mg content in soybean, presumably because of competition from increased substrate Ca. This competition is in agreement with observations of Mg deficiency induced in crop plants by extensive application of Ca (41).

The concentration of essential macronutrient elements was higher in Pokkali than in BR-11 grown in all soils. This may be related to the fact that Pokkali had higher root dry matter yield than BR-11, and subsequently had larger surface area for absorption of nutrients. Clarkson (42) reported that the uptake of ions depends not only on the capacity of the uptake system, but also on the size of

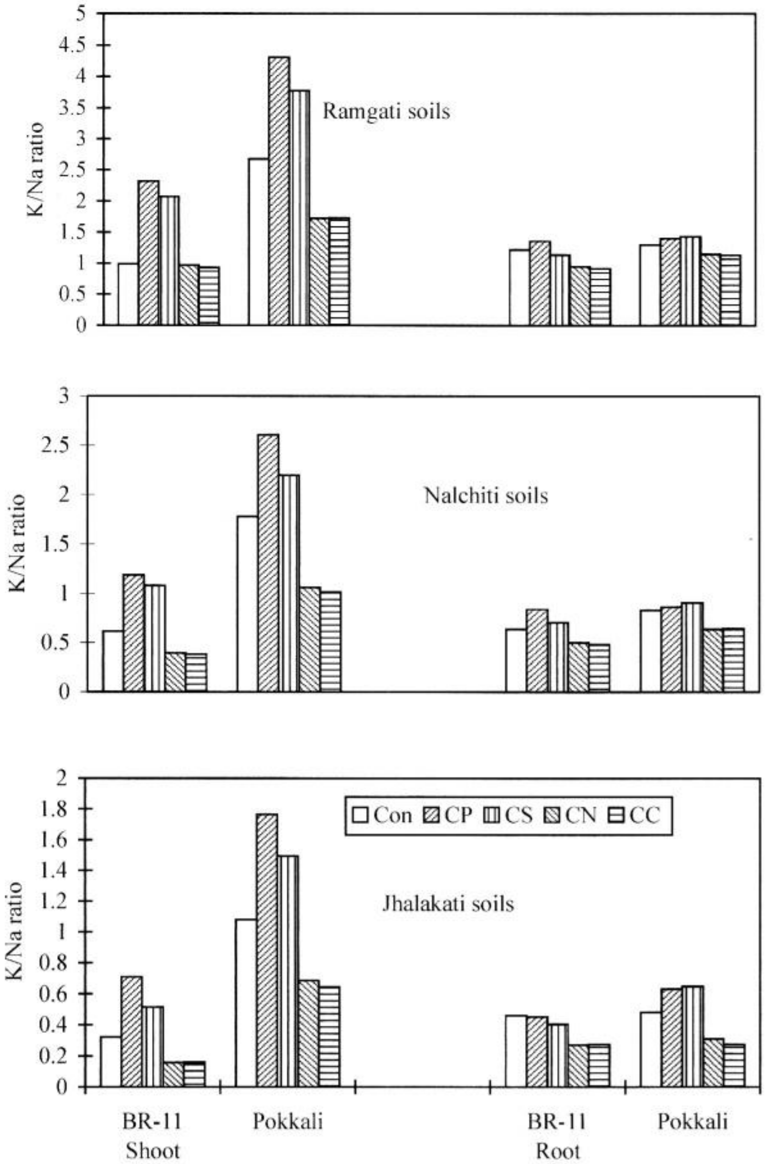

Figure 2. Effects of applying Ca salts to coastal saline soils with different levels of salinity on the K/Na ratios in shoots and roots of rice plants.

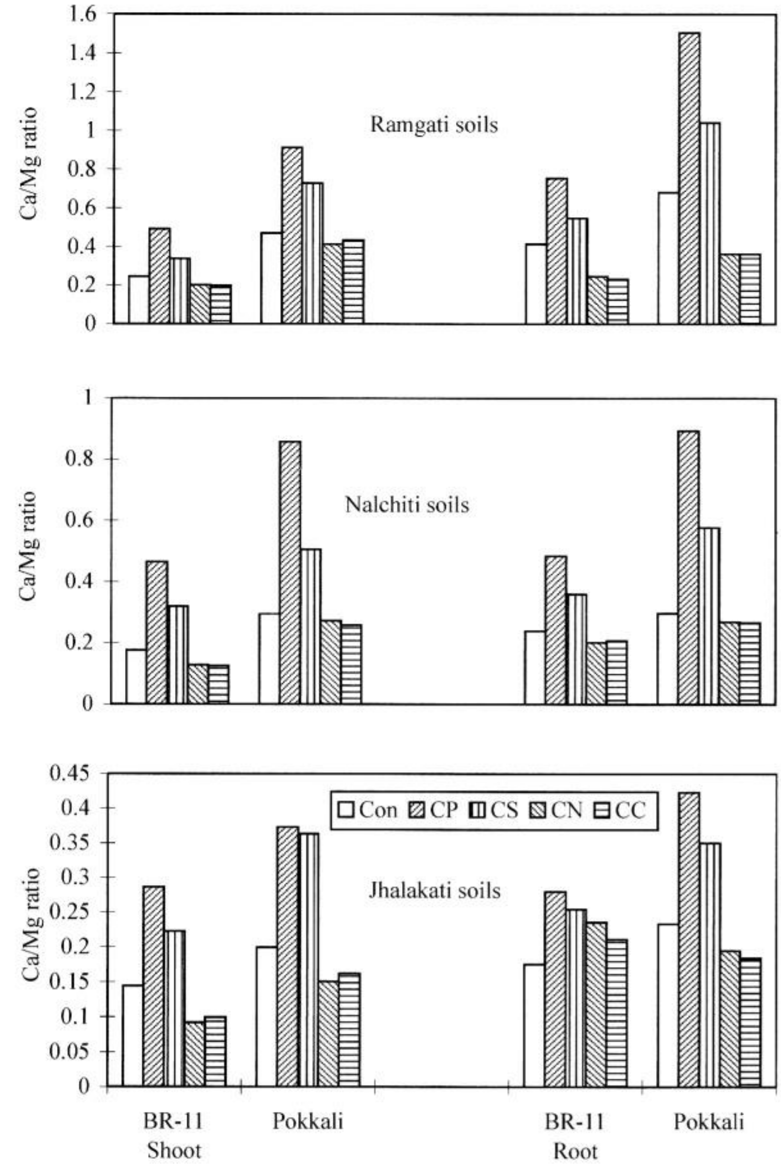

Figure 3. Effects of applying Ca salts to coastal saline soils with different levels of salinity on the Ca/Mg ratios in shoots and roots of rice plants.

the absorbing surface. Intracellular absorption of ions is an important component of osmotic adjustment, which is necessary for the plant adaptation to salinity (31).

Soil salinity decreased K/Na ratio in shoots and roots of plants (Fig. 2). Pokkali had higher K/Na ratio in shoots and roots than BR-11, indicating that the tolerant rice plant translocates less Na from roots to shoots and maintains a high K/Na ratio in its tissue. This may have been one of the reasons for relatively better growth of Pokkali under saline conditions, since it is evident that maintenance of high K/Na ratio in plants growing under saline habitats is considered one of the effective factors for normal growth (43,44). Increased K/Na ratios in shoots and roots of plants grown in soils with CP and CS were also observed when compared to control plants. Grattan and Grieve (29) reported that the presence of adequate Ca in the substrate influences the K/Na selectivity by shifting the uptake ratio in favor of K at the expense of Na.

The Ca/Mg ratios in shoots and roots of plants were higher in Pokkali than in BR-11 (Fig. 3). Application of CP and CS increased the Ca/Mg ratio, which coincided with increased plant growth. Thus, a nutritional Ca/Mg imbalance may be another factor, apart from Na toxicity, in the reduction of plant growth under low Ca and saline conditions.

CONCLUSIONS

The most important findings were i) the salt tolerance capacity of Pokkali was higher than that of BR-11, and ii) maintaining a constant Na:Ca ratio (1:5) in the growth medium with Ca salts having lower solubility was effective in the amelioration of salinity stress regardless of its levels, while Ca salts with high solubility aggravated salinity effects.

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REFERENCES

1. Epstein, E.; Norlyn, J.D.; Rush, D.W.; Kingsberg, R.W.; Kelley, D.B.; Cunningham, G.A.; Wrona, A.F. Saline Culture of Crops: A Genetic Approach. Science **1980**, *210*, 399–404.

2. Cramer, G.R.; Laüchli, A.; Epstein, E. Effects of NaCl and CaCl2 on Ion Activities in Complex Nutrient Solutions and Root Growth of Cotton. Plant Physiol. **1986**, *81*, 792–797.
3. Imamul Huq, S.M.; Iqbal, A. Land Use in Some Coastal Saline Areas of Bangladesh. Oriental Geographer **1992**, *36*, 20–29.
4. Imamul Huq, S.M. *Integrated Research on the Evaluation of the Production Potentials of the Coastal Saline Soils of Bangladesh*, BARC Report; BARC: Farmgate, Dhaka, Bangladesh, 1990.
5. Abrol, I.P.; Bhumbla, D.R.; Meelu, O.P. Influence of Salinity and Alkalinity on Properties and Management of Rice Lands. In *Soil Physics and Rice*; International Rice Research Institute: Metro Manila, The Philippines, 1985; 183–198.
6. Epstein, E. The Essential Role of Calcium in Selective Cation Transport by Plant Cell. Plant Physiol. **1961**, *36*, 437–438.
7. Rains, D.W. Salt Transport by Plants in Relation to Salinity. Annu. Rev. Plant Physiol. **1972**, *23*, 367–388.
8. Rengel, Z. The Role of Calcium in Salt Injury. Plant Cell Environ. **1992**, *15*, 625–632.
9. Barnabas, A.D.; Jagels, R.; Przybylowicz, W.J.; Mesjasz-Przybylowicz, J. Calcium and Salt Tolerance of Leaf Epidermal Cells of *Ruppia maritima*. Proc. Microsc. Soc. South Afr. **1998**, *28*, 59.
10. Gardner, F.P.; Pearce, R.B.; Mitchell, R.L. *Physiology of Crop Plants*; Iowa State University Press: Ames, IA, 1985; 119 pp.
11. Caldwell, C.R.; Haug, A. Temperature Dependence of the Barley Root Plasma Membrane-Bound Ca^{2+} and Mg^{2+}-Dependent ATPase. Physiol. Plant. **1981**, *53*, 117–124.
12. Legge, R.L.; Thompson, J.E.; Baker, J.E.; Lieberman, M. The Effect of Calcium on the Fluidity and Phase Properties of Microsomal Membranes Isolated from Postclimacteric Golden Delicious Apples. Plant Cell Physiol. **1982**, *23*, 161–169.
13. Van Steveninck, R.F.M. The Significance of Calcium on the Apparent Permeability of Cell Membranes and the Effect of Substitutions with Other Divalent Ions. Plant Physiol. **1965**, *18*, 54–69.
14. Lynch, J.; Polito, V.S.; Laüchli, A. Salinity Reduces Membrane Associated Calcium in Root Protoplasts. Plant Physiol. **1987**, *90*, 1271–1274.
15. Lynch, J.; Laüchli, A. Salinity Affects Intracellular Calcium in Corn Root Protoplasts. Plant Physiol. **1988**, *87*, 351–356.
16. Laüchli, A. Calcium Salinity and the Plasma Membrane. In *Calcium in Plant Growth*; Leonard, R.T., Hepler, P.K., Eds.; American Society of Plant Physiologists: Rockville, MD, 1990; 26–35.
17. Kirkby, E.A.; Pilbeam, D.J. Calcium as a Plant Nutrient. Plant Cell Environ. **1984**, *7*, 397–405.

18. Imamul Huq, S.M.; Larher, F. Osmoregulation in Higher Plants—Effect of Maintaining a Constant Na : Ca Ratio on the Growth, Ion Balance and Organic Solute Status of NaCl Stress Cowpea (*Vigna sinesis* L.). Z. Pflazenphysiol. **1984**, *113*, 163–176.
19. Bremner, J.M. Total Nitrogen. In *Methods of Soil Analysis*, Part 2; Black, C.A., Ed.; American Society of Agronomy: Madison, WI, 1965; 1149–1178.
20. Munns, R.; Termaat, A. Whole-Plant Response to Salinity. Aust. J. Plant Physiol. **1986**, *13*, 143–160.
21. Singh, R.K.; Sengupta, M.B.; Goswam, N.N. Role of Phosphate in Saline Soil in Relation to Soil Properties and Crop Growth. J. Indian Soc. Soil Sci. **1988**, *36*, 766–773.
22. Kuwajima, K.; Kawai, S. Relationship Between Sulfur Metabolism and Biosynthesis of Phytosiderophores in Barley Roots. In *Plant Nutrition for Sustainable Food Production and Environment*; Ando, T., Fujita, K., Mae, T., Matsumoto, H., Mori, S., Sekiya, J., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1997; 285–286.
23. Treeby, M.; Marschner, H.; Römheld, V. Mobilization of Iron and Other Micronutrient Cations from a Calcareous Soil By Plant-Borne, Microbial, and Synthetic Metal Chelators. Plant Soil **1989**, *114*, 217–226.
24. Panaullah, G.M. *Characteristics of Six Coastal Saline Soils of the Philippines in Relation to the Growth and Mineral nutrition of Rice*; University of the Philippines: Los Banos, The Philippines; 1984; Ph.D. thesis.
25. Lunin, J.; Gallatin, M.H. Salinity-Fertilizer Interactions in Relation to the Growth and Composition of Beans. I. Effect of N, P and K. Agron. J. **1965**, *57*, 339–342.
26. Shomer-Ilan, A.; Samish, Y.B.; Ipnis, T.; Elmer, D.; Waisel, Y. Effect of Salinity, N-Nutrition and Humidity on Photosynthesis and Protein Metabolism of *Chloris gayana* Kh. Plant Soil **1979**, *53*, 477–486.
27. Dionisio-Sese, M.L.; Tobita, S. Effects of Salinity on Sodium Content and Photosynthetic Responses of Rice Seedlings Differing in Salt Tolerance. J. Plant Physiol. **2000**, *157*, 54–58.
28. Epstein, E. Dual Pattern of Ion Absorption by Plant Cells and by Plants. Nature **1966**, *212*, 1324–1327.
29. Grattan, S.R.; Grieve, C.M. Salinity-Mineral Nutrient Relations in Horticultural Crops. Sci. Hortic. **1999**, *78*, 127–157.
30. Cramer, G.R.; Laüchli, A.; Polito, V.S. Displacement of Ca^{2+} by Na^{+} from Plasmalemma of Root Cells. A Primary Response to Salt Stress? Plant Physiol. **1985**, *79*, 207–211.
31. Greenway, H.; Munns, R. Mechanism of Salt Tolerance in Non-Halophytes. Annu. Rev. Plant Physiol. **1980**, *31*, 149–190.

32. Bar, Y.; Apelbaum, A.; Kafkafi, U.; Goren, R. Relationship Between Chloride and Nitrate and its Effect on Growth and Mineral Composition of Avocado and Citrus Plants. J. Plant Nutr. **1997**, *20*, 715–731.
33. Cramer, G.R.; Lynch, J.; Laüchli, A.; Epstein, E. Influx of Na^+ and Ca^{2+} into Roots of Salt-Stressed Cotton Seedlings. Plant Physiol. **1987**, *83*, 510–516.
34. Kent, L.M.; Laüchli, A. Germination and Seedling Growth of Cotton: Salinity-Calcium Interactions. Plant Cell Environ. **1985**, *8*, 155–159.
35. Jeschke, W.D. K^+-Na^+ Exchange at Cellular Membranes, Intracellular Compartmentation of Cations, and Salt Tolerance. In *Salinity Tolerance in Plants: Strategies for Crop Improvement*; Staples, R.C., Toenniessen, G.H., Eds.; John Wiley & Sons: New York, 1984; 37–66.
36. Leopold, A.C.; Willing, R.P. Evidence for Toxicity Effects of Salt on Membranes. In *Salinity Tolerance in Plants: Strategies for Crop Improvement*; Staples, R.C., Toenniessen, G.H., Eds.; John Wiley & Sons: New York, 1984; 67–76.
37. Ho, L.C.; Belda, R.; Brown, M.; Andrews, J.; Adams, P. Uptake and Transport of Calcium and the Possible Causes of Blossom-End Rot in Tomato. J. Exp. Bot. **1994**, *44*, 509–518.
38. Clarkson, D.T.; Hanson, J.B. The Mineral Nutrition of Higher Plants. Ann. Rev. Plant Physiol. **1980**, *31*, 239–298.
39. Islam, A.; Imamul Huq, S.M.; Alam, S. Chemical, Physico-Chemical and Nutrient Dynamics in Four Saline Soils of Bangladesh. *Reports of the Workshop on Coastal Zone Management in Bangladesh*, Dhaka, Bangladesh, Dec 27–31, 1992; Bangladesh National Commission for UNESCO: Dhaka, Bangladesh; 1–11.
40. Grattan, S.R; Maas, E.V. Effect of Salinity on Phosphate Accumulation and Injury in Soybeans. I. Influence of $CaCl_2$/NaCl Ratios. Plant Soil **1988**, *105*, 25–32.
41. Marschner, H. *Mineral Nutrition of Higher Plants*; Academic Press: London, 1995; 277 pp.
42. Clarkson, D.T. Factors Affecting Mineral Nutrient Acquisition by Plants. Annu. Rev. Plant Physiol. **1985**, *36*, 77–115.
43. Muhammad, S.; Akbar, M.; Neue, U.H. Effect of Na/Ca and Na/K Ratios in Saline Culture Solution on the Growth and Mineral Nutrition of Rice (*Oryza sativa* L.). Plant Soil **1987**, *104*, 57–62.
44. Yeo, A.R.; Flowers, T.J. The Absence of an Effect of the Na/Ca Ratio on Sodium Chloride Uptake by Rice (*Oryza sativa* L.). New Phytol. **1985**, *99*, 81–90.