Pak. J. Sci. Ind. Res. 2010 **53** (3) 164-168

Effect of Calcium on Nitrogen Utilization by Rice in Saline Soils

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(received March 10, 2009; revised February 19, 2010; accepted February 24, 2010)

Abstract. In the study of the effect of $CaSO_4$ application and soaking of rice seedlings in 2% $CaSO_4$ on N use efficiency of rice (var. Shaheen) in 3 sample soils (ECe=0.4, 4.8 and 8.7 dS/m, SAR=1.05, 14.86 and 21.43, pH=7.7, 8.3 and 9.20, respectively), a considerable reduction was observed in tillering (about 26% and 46%), plant height (about 20% and 46%) and yield (about 33% and 53%) of paddy grown in the saline soil (ECe=4.8 and 8.7 dS/m, respectively), as compared to the non-saline soil (ECe=0.4 dS/m), while soaking of seedlings in $CaSO_4$ and N application with or without $CaSO_4$ nutrition, significantly improved plant growth and paddy yield in all types of soil; overall, 26% increase in plant growth and 48% gain in paddy yield over the control was observed due to N and $CaSO_4$ application, respectively, with soaking of seedlings in high salinity soil. Interestingly, seedlings soaked in 2% $CaSO_4$ and with N application but with or without Ca supplementation performed statistically equal. Tissue Na^+ significantly decreased, while K^+ and Ca^{+2} concentrations were high due to N application along with Ca nutrition and soaking of seedlings in all types of soil. Maximum N uptake and apparent N recovery were detected in treatments, where N was applied supplemented with $CaSO_4$.

Keywords: soil salinity; rice; seedling soaking; N efficiency; $CaSO_4$ application

Introduction

Rice is the most important summer cereal crop of rice growing areas of Pakistan and is among the major export commodities. It accounts for 5.7% of the total value added in agriculture and 1.3% to GDP. Rice is cultivated in Pakistan on an area of 2581.2 thousand hectares with a total production of approximately 5438.4 thousand tons (GOP, 2007a). Soil salinity is a serious problem in the country, posing major threat to the sustainable production of agriculture sector. It is estimated that about 6.63 m ha area of Pakistan is salt-affected (GOP, 2007b). The problem soils can be successfully made cultivable by removing excessive soluble salts and exchangeable sodium from root zone. Other approach for utilization of moderately salt-affected lands is the growing of salt tolerant crop varieties alongwith optimum use of plant nutrients, particularly N fertilizers; other management practices can also reduce the chances of N loss and enhance its use. A high proportion of the applied N is lost (Shah *et al*., 1993; Smith and Whitefield, 1990) due to which the efficiency of N fertilizers does not exceed 45% (Zia *et al*., 1997; Craswell, 1987). Supplemental Ca^{2+} is shown to prevent NaCl induced breakdown of the pH tonoplast in mungbean roots exposed to 100 mM NaCl (Colmer *et al*., 1994). A proportion of Ca^{2+} becomes inadequate under saline sodic conditions and may result in reduced yields mainly due to ion imbalance (Davitt *et al*., 1981). Hence, attention has been focused on developing methods for reducing N loss and maximizings its utilization by plants grown under saline environment. The present study was planned with the objective of increasing N use efficiency by rice in different types of salt-affected soils.

Materials and Methods

An experiment was conducted to study the effect of soaking of rice seedlings in 2% $CaSO_4$ solution and $CaSO_4$ application (25 mg/ kg of soil) on N use efficiency of rice (var. Shaheen) in three different types of naturally salt-affected soils (ECe = 0.4, 4.8, 8.7 dS/m, SAR=1.05, 14.86, 21.43 and pH = 8.1, 8.8, 9.2) in glass house at National Agricultural Research Centre, Islamabad during Kharif season 2007. Naturally salt-affected soils, having different physico-chemical properties (Table 1), were collected from Hafizabad and Sheikhupura districts. The experiment was planned according to completely randomized design (factorial) with three replications. Treatments were as:

T_1 = control (without seedling soaking)
T_2 = seedling soaking in 2% $CaSO_4$
T_3 = N fertilization without seedling soaking

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T_4 = N fertilization with seedling soaking in 2% $CaSO_4$
T_5 = N and Ca fertilization without seedling soaking
T_6 = N and Ca fertilization with seedling soaking in 2% $CaSO_4$

Table 1. Physicochemical analysis of the soils

Parameters	Unit	Soil 1 (S-I)	Soil 2 (S-II)	Soil 3 (S-III)
pH	–	7.7	8.3	9.2
ECe	dS/m	0.4	4.8	8.7
SAR	–	1.72	14.86	21.43
$CaCO_3$	%	1.42	1.23	1.31
OM	%	0.70	0.30	0.29
Total N	%	0.034	0.031	0.026
Extractable P	mg/kg	4.12	3.47	2.10
Extractable K	mg/kg	54.6	33.5	15.4
Sand	%	42.7	22.1	12.5
Silt	%	37.2	35.6	34.2
Clay	%	20.1	42.3	53.3
Textural class	–	sandy loam	clay loam	clayey

Basal dose of P, K and Zn @ 30, 25 and 10 mg/kg of soil, respectively, and half of the N @ 50 mg N/kg of soil were applied to all treatments at transplanting, while the remaining half dose of N was applied at tillering stage. Before transplanting, rice seedlings were soaked in 2% $CaSO_4$ solution for 24 h. Eight seedlings were transplanted in the pots having 8 kg of soil. After seedling establishment, thinning was carried out at the rate of four healthy plants per pot. The crop was allowed to stand till maturity and data on tillering, shoot elongation, straw and paddy yields were recorded at the time of plant harvest. Pre-sowing soil samples were analyzed for particle size distribution by hydrometer method (Bouyoucos, 1962). Calcium carbonate was estimated by acid neutralization method and soil organic matter by oxidation with potassium dichromate in sulphuric acid medium under standardized conditions by Walkley and Black procedure (Ryan *et al.*, 2001). Soil pH was determined in water (soil water ratio, 1:1). Electrical conductivity of the soil suspension was measured using conductivity meter. P and K were determined using AB-DTPA method (Soltanpour and Workman, 1979). Total N was measured through sulphuric acid digestion. For distillation Micro-Kjeldahl method (AOAC, 1990) was used. Plant samples were dried in oven at 60 ºC till constant weight and the dry matter yield was recorded. Ground plant samples were digested in perchloric-nitric acid (2:1 1N) mixture (Rhoades, 1982) and Na, K, Ca and Mg were estimated using atomic absorption spectrophotometer. For N determination, plant samples were digested with sulphuric acid, using auto-analyzer. Total N uptake by rice was calculated based on dry matter yield data. Apparent N recovery was determined by the proportion of the applied N taken up and expressed in terms of percentage. The data thus obtained were subjected to statistical analysis according to Gomez and Gomez (1984).

Results and Discussion

Growth and yield. It was observed that tillering and growth of rice were significantly reduced in different salt-affected soils while N fertilization with Ca application and soaking of seedlings in 2% $CaSO_4$ significantly improved tillering and plant growth (Table 2). Adverse effects of increasing root medium salinity on plant growth and yield has been documented by Hussain and Illahi (1995) and Grattan and Grieve (1992). Among the treatments, N application to plants from the soaked seedlings, showed better performance in all salt-affected soils whereas in high salinity soil, about 36% increase in plant growth and 48% gain in paddy yield over the control were observed. It was interesting to note that N fertilization with or without Ca nutrition to the rice plants from soaked seedlings produced statistically equal straw and paddy yields (Table 3). Improvement in the growth and the yield with N fertilization alone to 2% $CaSO_4$ treated rice plants is presumably due to maximum N utilization because of better Ca^{2+}/Na^+ ratio which minimized the adverse effect of Na^+.

Calcium has been reported to have a definite impact on plant establishment in saline environment because of increased nutrient availability to the plants. Roots supplied with external Ca^{2+} often maintain their K^+ concentration and healthy crop stand. Calcium supply can increase N use efficiency and hence plant growth as well as Na^+ exclusion of plant roots exposed to NaCl stress (Aslam *et al.*, 2001; LaHaye and Epstein, 1971). Supplemental Ca^{2+} may also affect intracellular membranes of root cells exposed to salinity stress (Lynch and Lauchli,

Table 2. Tillering and growth of rice as affected by N application with Ca nutrition in different salt-affected soils (average of three repeats)

Treatments	No. of tillers/hill			Plant height (cm)		
	S-I	S-II	S-III	S-I	S-II	S-III
T_1	9.33^d	6.01^d	3.50^d	72.55^d	51.23^d	36.52^d
T_2	10.88^c	7.62^c	5.03^c	78.60^c	62.89^c	42.85^c
T_3	11.33^{bc}	9.66^b	6.77^{ab}	83.69^b	69.51^b	45.90^b
T_4	13.66^a	11.33^a	8.01^a	92.33^a	73.44^a	49.33^a
T_5	11.66^b	9.84^b	6.83^{ab}	87.79^{ab}	68.13^b	47.69^{ab}
T_6	13.00^{ab}	10.98^a	7.96^a	88.34^{ab}	75.24^a	49.63^a
LSD	1.01	1.09	1.20	3.52	5.44	2.82

Means followed by different letter(s) within the columns differ significantly at 5 % level of significance.

Table 3. Straw and paddy yields as affected by N application with Ca nutrition in different salt-affected soils (average of three repeats)

Treatments	Straw yield (g/pot)			Paddy yield (g/pot)		
	S-I	S-II	S-III	S-I	S-II	S-III
T_1	21.60[d]	17.13[e]	10.54[d]	18.34[c]	14.05[c]	9.45[c]
T_2	32.56[c]	23.01[d]	17.99[c]	23.59[b]	16.58[b]	11.82[b]
T_3	47.42[b]	29.35[c]	21.35[b]	26.31[b]	16.47[b]	12.35[b]
T_4	53.29[a]	42.56[a]	28.75[a]	31.46[a]	20.95[ab]	13.54[a]
T_5	48.51[ab]	34.03[b]	22.13[b]	28.79[ab]	17.13[b]	13.23[ab]
T_6	52.34[a]	40.11[a]	29.42[a]	30.84[a]	21.74[a]	13.98[a]
LSD	3.79	4.02	3.25	2.78	4.23	1.93

Means followed by different letter(s) within the columns differ significantly at 5 % level of significance.

1988a;1988b) and may decrease NaCl induced vacuolar alkalization in root tissues by Ca^{2+} effect on Na^+ efflux at the plasma membrane (Martinez and Lauchli, 1993) to withstand salt stress. Furthermore, calcium improves K^+/Na^+ selectivity of membranes and prevents the soil from invasion of toxic ion (Cramer *et al*., 1990).

Ionic composition. High Na^+ and low K^+ and Ca^{2+} concentrations in tissues were noted in plants grown in salt-sadic soils while the effect of Ca nutrition on Mg contents in plant tissues was statistically non-significant (Table 4 and 5). Maximum Na^+ concentration was found in higher salinity soil while K^+ and Ca^{2+} contents decreased due to increase in salinity. The results conform to the findings of Kupier (1984) and Ali *et al*. (2003) who reported interference of the root medium salinity with the absorption and translocation of K^+ and Ca^{2+} by plants. Nitrogen application, particularly with Ca nutrition, decreased significantly Na^+ contents and increased K^+ and Ca^{2+} concentrations in plant tissues. The data indicate that N application to the soaked seedlings performed statistically equal to that of N application supplemented with Ca nutrition in all salinity soils. K^+ was transported preferentially to Na^+ in the presence of the Ca supply and selectivity became more pronounced in the presence of Ca concentration in the root medium. This might be due to perfect nutrition which resulted in less Na^+ and more K^+ contents in plant tissues. External Ca supply in saline root medium presumably enhanced Na^+ exclusion ability of plants to suppress Na^+ transport. Ali *et al.* (2001) documented that at relatively higher concentration of Ca, plants absorbed and translocated relatively more K^+ and less Na^+ than at lower concentration of Ca^{2+}, demonstrating the positive role of Ca in alleviating the hazardous effects of salinity of sunflower growth.

Table 4. Ionic concentration in rice tissues as affected by N application with Ca nutrition in different salt-affected soils

Treatments	Na^+ (mg/kg)			K^+ (%)		
	S-I	S-II	S-III	S-I	S-II	S-III
T_1	45.21[a]	72.33[a]	96.28[a]	5.26	4.44	3.71
T_2	36.78[b]	68.57[a]	84.00[b]	7.14	6.67	4.58
T_3	33.56[b]	58.41[b]	74.74[bc]	6.55	6.04	4.94
T_4	30.54[bc]	54.25[c]	69.85[c]	6.72	6.32	4.79
T_5	28.66[bc]	56.54[c]	68.09[c]	7.36	6.48	5.68
T_6	24.35[c]	52.13[c]	67.64[c]	6.76	6.56	5.59
LSD	8.56	3.21	10.44			

Means followed by different letter(s) within the columns differ significantly at 5 % level of significance.

Table 5. Ca^{2+} and Mg concentration in rice tissues as affected by N application with Ca nutrition in different salt-affected soils

Treatments	Ca^{2+} (%)			Mg (%)		
	S-I	S-II	S-III	S-I	S-II	S-III
T_1	0.70[b]	0.57[b]	0.33[d]	0.308	0.307	0.312
T_2	1.51[a]	1.12[a]	0.53[c]	0.319	0.318	0.314
T_3	1.01[ab]	0.87[ab]	0.66[b]	0.327	0.311	0.309
T_4	1.57[a]	1.14[a]	0.78[a]	0.317	0.318	0.321
T_5	1.56[a]	1.11[a]	0.75[ab]	0.331	0.317	0.313
T_6	1.55[a]	1.21[a]	0.84[a]	0.319	0.317	0.324
LSD	0.92	0.53	0.10			

Means followed by different letter(s) within the columns differ significantly at 5 % level of significance.

Apparent N recovery. It is obvious from the data in Table 6 that maximum apparent N recovery (82.40 %) was detected with N application to the plants from soaked seedlings (T4) in high salinity soil (ECe= 8.7 dS/m). Further application of $CaSO_4$ was not significant and showed statistically the same apparent N recovery (82.02 %) as that of T4 closely followed by N application supplemented with $CaSO_4$ to the plants from unsoaked seedlings (T5). Similar trend was noted in lower salinity soils (ECe=0.4 and 4.8 dS/m). This means that soaking of seedlings improved apparent N recovery.

As it has been discussed earlier that roots supplied with external Ca^{2+} often maintain their K^+ concentration and healthy crop stand due to selectivity and integrity of cell membrane of plants grown in saline environment (Aslam *et al.*, 1999; Kinraide, 1999). Supplemental Ca^{2+} may also have effects on intracellular membranes of root cells exposed to salinity stress (Lynch and Lauchli, 1988a; 1988b) and may decrease NaCl induced vacuolar alkalization in root tissues by a Ca^{2+} effect on Na^+ efflux at the plasma membrane (Martinez and Lauchli, 1993). Proportion of Ca^{2+} becomes inadequate in saline soils and may result in reduced yields mainly due to ion imbalance (Davitt *et al*., 1981).

The average apparent N recovery in rice was significantly higher in all types of soils with the treatment of N fertilization to the soaked seedlings either with or without Ca nutrition. Comparatively lower efficiency of simple application of N compared with supplemented Ca is understandable, because the major part of N in saline soils might have volatilized (Mahmood and Qureshi, 2000; Hamid and Ahmed, 1988; 1987; Vlek and Craswell, 1981), however on the other hand, through blended fertilization, improvement in apparent N recovery could be due to suppression of N losses. Since it is clear from the data (Table 6) that maximum N uptake by the plants was detected where N was applied supplemented with Ca treatment, which conclusively resulted in enhancing apparent N recovery. Zia *et al*. (2000; 1997; 1992), Haq *et al*. (2001), Fiez *et al*. (1995) and Hamid *et al.* (1998)have reported similar elucidations.

Table 6. Total N uptake and apparent N recovery of rice* as affected by N application with Ca nutrition in different salt-affected soils

Treatments	N uptake (g/pot)			Apparent N recovery (%)		
	S-I	S-II	S-III	S-I	S-II	S-III
T_1	17.57[d]	11.85[e]	6.40[d]	–	–	–
T_2	28.64[c]	22.57[d]	18.78[c]	38.65[b]	47.50[b]	65.92[b]
T_3	45.71[b]	27.95[c]	26.62[b]	61.56[ab]	57.60[b]	75.96[b]
T_4	54.24[a]	43.19[a]	36.37[a]	67.61[a]	72.56[a]	82.40[a]
T_5	44.83[b]	34.27[b]	27.93[b]	60.81[b]	65.42[ab]	77.09[ab]
T_6	53.24[a]	43.91[a]	35.59[a]	67.00[a]	73.01[a]	82.02[a]
LSD	5.23	5.18	7.52	6.13	9.29	5.64

* = average of three readings; means followed by different letter(s) within the columns differ significantly at 5 % level of significance.

Conclusion

Nitrogen fertilizer loss is the hot issue with the scientists for quite a long time. Cultural practices reducing nitrogen losses are very important for controlling this problem. The present experiment was conducted to optimize Ca^{+2} nutrition for optimum N utilization in rice crop in salt affected soils. It could thus be concluded from this experiment that the efficiency of N fertilization can be improved through Ca supplementation and/ or with soaking of seedlings in 2 % $CaSO_4$ solution before transplanting in moderately salt-affected soils. However, the results should be reconfirmed with other crops to reach a generalized condusion.

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