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Nutritional Role of Calcium in Improving Rice Growth and Yield under Adverse Conditions

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ABSTRACT

Investigations on the nutritional aspects of Ca in improving rice growth and yield were conducted in solution and soil cultures and in naturally salt-affected field. In the case of solution culture, Ca at the rate of 5, 10, 20, 40, 80 and 160 µg Ca mL^{-1} was applied in the presence (80 mol m^{-3}) and absence (0 mol m^{-3}) of NaCl salinity; whereas, in case of soil culture, Ca at the rate of 0, 50, 100 and 200 kg ha^{-1} was applied to artificially prepared saline (EC_e 9 dS m^{-1}, SAR 5.46, pH_s 7.8), saline sodic (EC_e 9 dS m^{-1}, SAR 28.2, pH_s 8.2) soils and in naturally salt affected field (EC_e 6 dS m^{-1}, SAR 16.1, pH_s 8.2). Three cultivars of differential salinity tolerance used to investigate the ameliorative nutritional aspects of Ca were: KS-282 (salt tolerant), BG 402-4 (mixed behavior) and IR-28 (salt sensitive). Application of Ca improved all growth characteristics (tillering capacity, shoot and root lengths, shoot and root weights) because of external Ca supply @ 20-40 µg Ca mL^{-1} in solution culture in the presence of NaCl salinity. Shoot Na^+ and Cl^- decreased; whereas, K^+ concentration and K^+: Na^+ ratio improved because of Ca supply to saline medium. Paddy and straw yields, plant height and panicle length were significantly higher in saline as compared to saline sodic soil. Application of 200 kg Ca ha^{-1} proved statistically superior to control in respect of panicle length, number of tillers, paddy and straw yield under both saline and saline sodic soils as well as in naturally salt affected field. The ameliorative effect of Ca was due to reduced shoot Na^+ and Cl^- concentration and better ratio of K^+ to Na^+ in shoot. Seed setting was improved in all the three cultivars because of external Ca supply to saline and saline sodic soils.

Key Words: Calcium; Rice; Solution culture; Saline soil; Saline sodic soil

INTRODUCTION

Elevated levels of external Ca^{2+} can increase both growth and Na^+ exclusion of plant roots exposed to NaCl stress (LaHaye & Epstein, 1971). In addition, roots supplied with elevated levels of external Ca^{2+} (5-10 mM) are often to maintain their K^+-concentration; whereas, roots supplied with low Ca^{2+} (0.2-0.5 mM) frequently cannot (Lauchli, 1990). Thus adequate Ca^{2+} is required in the external medium to maintain the selectivity and integrity of cell membrane (Aslam *et al*., 2000). Supplemental Ca^{2+} may also have effects on intracellular membranes of root cells exposed to NaCl stress (Lynch & Lauchli, 1988) and may decrease NaCl induced vacuolar alkalization in root tissues by a Ca^{2+} effect on Na^+ efflux at the plasma membrane (Martinez & Lauchli, 1993). Besides, 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).

Proportion of Ca^{2+} in the external solution that is adequate under non-saline conditions becomes inadequate under saline-sodic conditions and may result in reduced yields due mainly to ion imbalance (Davitt *et al*., 1981). The use of gypsum ($CaSO_4.2H_2O$) as a source of Ca^{2+} is a well-established practice for the amelioration and management of Na^+ saturated waters/soils (Muhammad, 1998). This paper deals with the studies conducted to investigate the effect of calcium supply under salt stress environment on the growth, yield and ionic composition of three rice cultivars differing in their salinity tolerance behavior.

MATERIALS AND METHODS

1. Solution culture experiment. Fourteen-day old seedlings of three rice cultivars i.e. KS-282 (salt-tolerant), IR-28 (salt sensitive) and BG-402-4 (mixed behavior) raised in Ca free medium were transplanted to foam-plugged holes in polystyrene sheets floating over 25 liters of calcium free Yoshida nutrient solution (Yoshida *et al*., 1976) in plastic tubs (52 x 35.5 x 17.5 cm) during mid May 1994. There were nine equidistant holes in each sheet; three holes were used randomly for each cultivar. Two seedlings were transplanted per hole. In 18 tubs, NaCl salinity of 80 mol m^{-3} was developed in three splits while other 18 were without salt. Calcium concentrations of 5, 10, 20, 40, 80 and 160 µg Ca^{2+} mL^{-1} were developed with $Ca(NO_3)_2$ in the growth tubs with and without salt. In total, there were 36 treatments (3 cultivars, 2 salinity levels, 6 Ca^{2+} levels). Plants were harvested 20 days after salt stress (DASS), tillering capacity and shoot and root dry weights were recorded.

2. Soil culture experiment. The experiment was conducted in a net house in glazed pots (20 cm deep, 27 cm dia) during July-November 1994 to study the effect of Ca^{2+} supply on growth and yield of rice in salt affected soils. Each pot was filled with 8 kg pre-treated soil. A non saline soil (EC_e 2.5 dS m^{-1}, pH 7.8 and SAR 1.21) was collected and passed through 2 mm sieve after drying. The saline soil (EC_e 10.0 dS m^{-1}) was developed by adding mixture of salts (Na_2SO_4+NaCl+$CaCl_2$+$MgSO_4$) commonly present in salt affected soils of Pakistan in the ratio of 9:5:5:1 (equivalent basis). Saline-sodic soil (EC_e 10.0 dS m^{-1}; SAR 22.8) was developed by using above-mentioned salts and by spraying $NaHCO_3$ solution, and allowing the soil to go through wet and dry cycles to attain equilibrium. The soils were puddled before the transplantation of rice seedlings. Nitrogen was applied as urea at the rate of 150 kg ha^{-1} in three equal splits i.e. at transplanting, 20 days after transplanting (DAT) and 45 DAT. A basal dose of P (18 kg P_2O_5), K (50 kg K_2O) was also applied as single super phosphate and sulphate of potash, respectively on per hectare basis during puddling. Calcium was applied as $Ca(NO_3)_2$ at the rates of 50, 100 and 200 kg Ca ha^{-1}. Nitrogen added through $Ca(NO_3)_2$ was taken into account while adding basal N as urea. The experiment was laid out in completely randomized design. Six (30-day-old) seedlings of each cultivar were transplanted in each pot and thinned to three seedlings per pot after a week interval. Soil was kept submerged by adding canal water daily. At panicle initiation stage, mother shoot was sampled for analysis of Na, K and Cl. At maturity, data on different agronomic parameters were recorded.

3. Field experiment. The experiment was conducted in a naturally salt-affected field (EC_e 6.0 dS m^{-1}; SAR 16.0), to study the effect of Ca on the yield of salt-tolerant rice cultivar (KS-282) during June–November, 1996. The field was prepared with three ploughings and two planking and was puddled before transplanting of seedlings. A basal dose of N, P and K at the rates of 150, 18 and 50 kg ha^{-1}, respectively was applied all at transplanting except N which was applied in three equal splits i.e. at transplanting, 20 and 45 DAT as urea, single super phosphate and sulphate of potash, respectively. Calcium as $Ca(NO_3)_2$ was applied at the rates of 0, 50, 100 and 200 kg ha^{-1}. Nitrogen applied through $Ca(NO_3)_2$ was taken into account while adding basal N as urea. The experiment was laid out in completely randomized block design with four replications. Three seedlings (30-day-old) were transplanted per hill. At maturity, data on paddy and straw yield were recorded.

RESULTS AND DISCUSSION

Solution Culture

Tillering capacity. Data indicate that tillering capacity was reduced significantly under 80 than 0 mol m^{-3} NaCl salinity (Table I). On the other hand, calcium supply significantly improved this character both in the presence and absence of salt. Under non-saline condition, the maximum mean tillering was observed at external 40 μg Ca^{2+} mL^{-1}; whereas, under saline condition Ca concentration of 40-80 μg Ca^{2+} mL^{-1} produced statistically similar number of tillers. Tillering was less both at the lowest and the highest external Ca concentration in all cases (saline and non saline). Interaction between cultivars x Ca levels and salinity x cultivars x Ca supply was also significant. In case of KS-282 and BG-402-4, 40 μg Ca^{2+} mL^{-1}under 0 mol m^{-3} NaCl salinity produced significantly higher number of tillers compared with the lowest and the highest rates of external Ca; whereas, in IR-28, all external concentrations of Ca had no differences in this respect except the lowest and the highest rates of external Ca. Under 80 mol m^{-3}, NaCl salinity, increasing Ca concentration significantly improved the tillering, however the response was statistically the same between 20 to 80 μg Ca^{2+} mL^{-1} in the case of all the three cultivars. At this salinity, on overall basis, KS-282 produced significantly higher number of mean tillers than IR-28; whereas, the difference between KS-282 and BG-402-4 was statistically non-significant. However, under non saline conditions, all the cultivars differed significantly from one another. The higher number of tillers was found in BG-402-4 while lowest in IR-28; whereas, under saline conditions KS-282 and BG-402-4 had similar number of tillers whereas IR-28 produced significantly less number of tillers.

Shoot and root dry weights. Shoot dry weight was reduced significantly because of salinity (Table I) while it improved consistently both under saline and non-saline conditions because of external Ca supply. The improvement in the mean shoot dry weight was the highest at 40 μg Ca^{2+} mL^{-1} under both the set of conditions. The cultivars KS-282 and IR-28 yielded maximum shoot dry weights at 40 μg Ca^{2+} mL^{-1} under non saline and saline conditions. BG-402-4, however, yielded the maximum shoot dry weight at 20 μg Ca^{2+} mL^{-1} and a decline in shoot dry weight was observed beyond this point.

Similar to shoot dry weight, rood dry weight also improved because of external Ca supply both under 0 and 80 mol m^{-3} NaCl salinity (Table I) and the increase was the maximum at 40 μg Ca^{2+} mL^{-1}. Under 80 mol m-3 NaCl salinity, the mean root dry weight although increased consistently up to 40 μg Ca^{2+} mL^{-1}, statistical improvement was the same from 10 to 40 μg Ca^{2+} mL^{-1}. The lowest and the highest external concentration of Ca i.e. 5 and 160 μg Ca^{2+} mL^{-1} produced statistically the same root dry weight.

Pot Culture

Panicle length. Panicle length reduced significantly in saline sodic soil than saline soil (Table II). In saline soil, external Ca supply did not improve panicle length at 50 kg Ca ha^{-1}, however, its higher rates (100 to 200 kg Ca ha^{-1} improved panicle length statistically at the same rate. Under saline sodic soil, although external Ca supply improved mean panicle length over control, the differences among various Ca rates (from 50 to 200 kg Ca ha^{-1}) were statistically not sharp. In case of saline soil, KS-282 panicle length improved significantly over control at all rates of external Ca supply but this improvement was statistically not sharp at 100 to 200 kg Ca ha^{-1}. In case of BG-402-4, panicle length improved significantly only at 200 kg Ca ha^{-1} ; whereas, IR-28 showed no response to all rates of external Ca over control for improving panicle length. Under saline sodic soil, KS-282 produced significantly higher panicle length only at the highest rate of external Ca supply (200 kg Ca ha^{-1}) while Ca rates below this did not cause any significant improvement in panicle length.

Table I. Effect of Calcium supply and NaCl salinity on tillering capacity, shoot dry weight, and root dry weight of three rice cultivars

Rice Cultivars	NaCl salinity mol m^{-3}													
	0							80						
	Ca Concentration (μg mL^{-1})							Ca Concentration (μg mL^{-1})						
	1	10	20	40	80	160	Mean	5	10	20	40	80	160	Mean
	Number of tillers ($Plant^{-1}$)													
KS-282	10.08 g	13.08 f	15.17 d	18.67 a	16.51 bc	14.08 e	14.60 B	2.94 mn	3.89 kl	4.44 jk	5.11 ij	5.11 ij	3.17 lm	4.11 D
BG-402-4	13.00 f	13.67 ef	13.67 ef	18.42 a	16.92 b	15.75 cd	15.24 A	2.78 mn	3.06 l-n	4.33 jk	4.98 ij	4.89 j	3.02 l-n	3.84 D
IR-28	5.83 I	6.75 h	7.08 h	7.08 h	6.90 h	5.25 ij	6.48 C	1.17 o	2.17 n	2.37 mn	2.87 mn	2.23 m	- p	1.80 E
Mean	9.64 E	11.17 D	11.97 C	14.72 A	13.4 B	11.69 CD		2.96 I	3.04 H	3.71 G	4.32 F	4.078 FG	2.06 I	
Salinity Mean	**12.11 A**							**3.25 B**						
	Shoot Dry Weight (g $Plant^{-1}$)													
KS-282	2.81 ef	2.85 ef	2.89 d-f	3.94 a	3.32 b	2.17 g	3.00 A	0.55 no	1.10 kl	1.33 jk	1.34 jk	1.14 kl	0.97 lm	1.07 C
BG-402-4	3.01 b-e	3.06 b-e	2.89 d-f	3.94 a	3.32 b	2.17 g	3.02 A	0.64 n	0.97 lm	1.06 k-m	1.03 k-m	1.07 k-m	0.76 mn	0.93 D
IR-28	1.52 I-j	1.67 h-I	1.90 gh	2.14 g	1.52 ij	1.36 I-k	1.69 B	0.06 p	0.22 p	0.38 op	0.31 op	0.06 p	- p	0.16 E
Mean	2.45 C	2.53 BC	2.68 B	3.09 A	2.60 BC	2.05 D		0.42 G	0.76 EF	0.90 E	0.91 E	0.76 EF	0.59 FG	
Salinity Mean	**2.57 A**							**0.72 B**						
	Root Dry Weight (μg $Plant^{-1}$)													
KS-282	560 ef	643 cd	811 ab	871 a	574 de	485 fg	657 B	181 jk	205 j	217 j	318 I	190 jk	98 Lm	202 D
BG-402-4	678 bc	733 b	849 a	862 a	604 cd	543 ef	711 A	118 k-m	211 j	223 j	347 I	189 jk	189 jk	213 D
IR-28	539 ef	543 ef	675 bc	729 b	444 gh	380 hi	552 C	58 mn	73 L-n	114 k-m	153 j-I	50 mn	- o	75 E
Mean	592 BC	639 B	778 A	821 A	541 C	469 D		119 FG	163 FG	185 F	273 E	143 FG	96 G	
Salinity Mean	**640 A**							**163 B**						

Means with different letter(s) differ significantly according to Duncan's Multiple Range Test (P=0.05); Extra letter(s) have been omitted except first and the last one to simplify the table. (-) Plant died.

Paddy yield (g pot^{-1}). Data on paddy yield are presented in Table II. Paddy yield improved because of Ca application to salt affected soil. Although application of Ca had a consistent and positive effect on mean paddy yield under salt affected soil conditions, the results were significant only at 100 and 200 kg Ca ha^{-1}. When cultivars and soils were separately considered, KS-282 produced significantly higher paddy yield than BG-402-4 followed by IR-28 in both soils and overall mean paddy yield was significantly higher in saline than saline sodic soil. Among Ca levels, 200 kg Ca ha^{-1} resulted in the harvest of the highest paddy yield compared with all the other levels of Ca.

Paddy : straw ratio. Like paddy and straw yields, Ca did not affect paddy: straw ratio significantly under salt affected soils (Table II). Increasing Ca supply significantly improved paddy: straw ratio at 100 and 200 kg Ca ha^{-1} in saline soil in all cultivars. In saline-sodic soil, improvement in the paddy: straw ratio for KS-282 was upto 100 kg Ca ha^{-1} later it decreased significantly at higher rates of Ca while the paddy: straw ratio in BG-402-4 and IR-28 at 100 to 200 kg Ca ha^{-1} was statistically non significant. Overall cultivar mean showed that KS-282 was superior to the other cultivar in respect of paddy: straw ratio in salt affected soils.

Na^+ concentration. Mean Na concentration in shoot decreased significantly because of supply of Ca to salt-affected soil (Table III). Sodium concentration decreased consistently in all the three cultivars in both the soils except in the case of BG-402-4 for saline soil where tissue Na concentration was statistically the same when Ca was applied at the rate of 100 to 200 kg Ca ha^{-1}. The maximum decrease in mean Na concentration was observed at 200 kg Ca ha^{-1} under both the soils. In both the salt affected soils, cultivar KS-282 had the lowest tissue Na^+ concentration but statistically this was similar to the leaf Na concentration of BG-402-4. However, IR-28 had significantly higher Na concentration compared to both the other cultivars in both the soils. The effect of Ca in lowering the leaf Na concentration was significant whether the soil was saline or saline sodic.

Table II. Effect of Ca supply on the growth of three rice cultivars grown in salt affected soils (Average of three repeats)

Ca^{2+} kg ha^{-1}	Saline Soil				Saline-sodic Soil			
	KS-282	BG-402-4	IR-28	Mean	KS-282	BG-402-4	IR-28	Mean
				Panicle Length (cm)				
Control 0	23.1 c-e	22.4 d-f	19.5 hi	21.7 BC	20.1 g-I	19.0 I	19.0 I	19.4 D
50	25.3 b	23.0 de	20.3 f-I	22.9 B	21.3 e-h	22.5 d-f	19.4 hi	21.1 C
100	27.4 a	24.5 b-d	20.6 f-I	22.2 A	22.1 e-g	22.5 d-f	19.8 hi	21.5 C
200	28.3 a	25.1 bc	20.6 f-I	22.7 A	22.6 d-f	22.6 d-f	20.1 g-I	21.7 BC
Mean	26.0 A	23.8 B	20.3 D		21.5 C	21.6 C	18.6 D	
		23.4 A				**20.6 B**		
				Paddy yield (g $plant^{-1}$)				
Control 0	9.63 g	6.81 ij	4.85 k	7.10 D	7.06 ij	4.85 k	3.71 I	5.21 E
50	9.90 g	7.06 ij	5.31 k	7.42 D	7.49 I	5.31 k	3.80 I	5.53 E
100	18.98 b	13.23 e	11.00 f	14.40 B	16.51 c	11.30 f	9.90 g	12.57 C
200	23.21 a	16.15 c	13.15 e	17.50 A	19.03 b	13.29 e	10.80 f	14.37 B
Mean	15.43 A	10.81 C	8.58 D		12.52 B	8.69 D	7.05 E	
		11.61 A				**9.42 B**		
				Paddy:straw ratio				
Control 0	0.70 h-j	0.44 n	0.48 m	0.54 E	0.73 g-j	0.47 mn	0.58 kI	0.59 D
50	0.68 ij	0.45 n	0.51 lm	0.55 E	0.73 g-j	0.49 m	0.58 kl	0.59 D
100	0.95 bc	0.74 g-j	0.75 gh	0.82 C	1.16 a	0.76 gh	0.92 d	0.95 A
200	1.00 b	0.80 f-g	0.83 e-g	0.88 B	0.90 cd	0.77 gh	0.89 c-e	0.88 B
Mean	0.83 B	0.61 E	0.64 D		0.88 A	0.62 E	0.74 C	
		0.70 B				**0.75 A**		

Means with different letter(s) differ significantly according to Duncan's Multiple Range Test (P=0.05); Extra letter(s) have been omitted except first and the last one to simplify the table.

Table III. Effect of calcium supply on Na^+, K^+ concentration in the shoot of three rice cultivars grown in salt-affected soils

Ca^{2+} kg ha^{-1}	Saline Soil				Saline-sodic Soil			
	KS-282	BG-402-4	IR-28	Mean	KS-282	BG-402-4	IR-28	Mean
				Na^+ concentration (µM g^{-1} d.wt)				
Control	206.0 no	200.6 o	338.4 I	248.3 E	435.3 e	407.5 f	690.8 a	511.2 A
50	157.2 p	158.8 p	243.2 m	186.4 F	365.4 h	385.6 g	616.0 b	455.7 B
100	140.2 q	131.2 qr	216.2 n	162.5 G	291.6 k	310.4 j	567.6 c	389.9 C
200	104.4 s	122.8 r	193.2 o	140.1 H	248.8 lm	262.4 l	518.0 d	343.1 D
Mean	152.0 D	153.4 D	247.8 C		335.3 B	341.5 B	598.1 A	
		184.4 B				**425.0 A**		
				K^+ concentration (µM g^{-1} d.wt)				
Control	315.7 j	338.7 I	308.0 j	320.8 E	223.0 m	242.0 l	206.3 n	230.8 G
50	432.2 e	411.3 f	360.0 h	401.2 C	350.0 hi	338.7 I	250.6 l	313.1 F
100	482.4 c	447.1 d	395.2 g	441.6 B	399.1 fg	398.0 g	289.0 k	362.0 D
200	534.2 a	519.6 b	407.0 fg	468.9 A	455.0 d	424.0 e	320.1 j	399.7 C
Mean	441.1 A	429.2 B	367.5 C		356.8 D	350.7 E	266.5 F	
		412.6 A				**324.7 B**		

Means with different letter(s) differ significantly according to Duncan's Multiple Range Test (P=0.05); Extra letter(s) have been omitted except first and the last one to simplify the table.

K^+ concentration. Potassium concentration increased because of Ca supply to salt affected soils (Table III). Shoot-K concentration increased with increasing external Ca application at the rate of 50 to 200 kg Ca ha^{-1}. The highest K concentration was determined when Ca was applied at the rate of 200 kg Ca ha^{-1} both under saline and saline sodic soils. The differences among all Ca rates for tissue K concentration in both the soils were significant for all the cultivars except in IR-28 at 100 to 200 kg Ca ha^{-1} in saline soil. Overall, plants grown in saline soil had significantly higher tissue-K concentration than those grown in saline sodic soils.

Cl^- concentration. Data on Cl concentration of three rice varieties are presented in Table IV. External supply of Ca significantly reduced shoot Cl concentration in all the rice cultivars included in this study both under saline and saline sodic soils. Overall mean Cl concentration was significantly higher in control and it decreased with increasing supply of Ca. The decrease was significant at 200 kg Ca ha^{-1} in all the cultivars in saline sodic soil. However, in case of saline soil

Table IV. Effect of calcium supply on K^+:Na^+ ratio and Cl^- concentration in the shoot of three rice cultivars grown in salt-affected soils

Ca^{2+} kg ha^{-1}	Saline Soil				Saline-sodic Soil			
	KS-282	BG-402-4	IR-28	Mean	KS-282	BG-402-4	IR-28	Mean
				K^+:Na^+ ratio				
Control 0	1.53 g-l	1.69 f-g	0.91 k	1.38 D	0.51 lm	0.59 lm	0.30 n	0.47 G
50	2.75 d	2.59 d	1.48 hi	2.28 C	0.96 k	0.88 k	0.41 mn	0.75 F
100	3.44 c	3.41 c	1.83 f	2.89 B	1.37 ij	1.28 j	0.51 lm	1.05 E
200	5.12 a	4.23 b	2.11 e	3.83 A	1.83 f	1.62 gh	0.62 l	1.36 D
Mean	3.21 A	2.98 B	1.58 C		1.17 D	1.09 D	0.46 E	
		2.59 A				0.91 B		
				Cl^- concentration (µM g^{-1} d.wt)				
Control 0	314.2 fg	323.3 ef	337.2 de	324.9 B	304.5 f-h	355.9 cd	461.8 a	374.1A
50	251.3 kl	298.0 g-l	269.4 jk	272.9 D	285.4 h-j	297.6 g-l	385.0 b	322.7 B
100	242.2 l-n	266.5 jk	250.4 kl	253.0 E	278.2 ij	289.3 hi	363.2 c	310.2 C
200	230.7 mn	250.1 km	235.01 l-n	238.6 F	224.3 n	266.0 jk	338.9 de	276.4 D
Mean	259.6 E	284.5 C	273.0 D		273.1 D	302.2 B	387.2 A	
		272.4 B				320.8 A		

Means with different letter(s) differ significantly according to Duncan's Multiple Range Test (P=0.05); Extra letter(s) have been omitted except first and the last one to simplify the table.

100 and 200 kg Ca ha^{-1} in the most cases had statistically similar tissue Cl in all rice cultivars. The tissue Cl concentration was statistically different in all cultivars when grown in both saline and saline sodic soils. The cultivar KS-282 had the lowest Cl concentration in its tissues; whereas, IR-28 the highest.

K^+: Na^+ ratio. A steep reduction in shoot K^+: Na^+ ratio of all rice cultivars was observed when grown in saline sodic soils compared with saline soil (Table IV). Calcium supply improves mean K^+: Na^+ ratio significantly in all cultivars because of each incremental supply of calcium from 50 to 200 kg Ca ha^{-1} in both the salt affected soils. The maximum increase in K^+: Na^+ ratio was at 200 kg Ca ha^{-1}. As regards cultivars, KS-282 was significantly superior to other cultivars in maintaining tissue K^+: Na^+ ratio in saline soils. However, in saline-sodic soil although KS-282 had the highest tissue K^+: Na^+ ratio amongst the cultivars, BG-402-4 had statistically similar tissue K^+: Na^+ ratio.

Field Culture

Paddy, straw yield and paddy : straw ratio. Data presented in Table V clearly reveal that calcium application to salt-affected field had positive effect on the yield of rice.

Table V. Effect of calcium supply on paddy, straw yield and paddy : straw ratio of rice cultivars KS-282 grown in naturally salt-affected field (Average of four replicates)

Ca^{2+} kg ha^{-1}	Paddy yield kg ha^{-1}	Straw yield kg ha^{-1}	Paddy : straw ratio
0 (Control)	787.32 B	1146.8 B	0.686 B
50	829.74 B	1194.3 B	0.694 B
100	1132.11 A	1375.5 A	0.923 A
200	1167.11 A	1405.4 A	0.830 A

Means with different letter(s) differ significantly according to Duncan's Multiple Range Test (P=0.05); Extra letter(s) have been omitted except first and the last one to simplify the table.

Paddy and straw yield as well as paddy: straw ratio improved consistently with increasing supply of calcium. However, statistically the application of Ca at the rate of 100 and 200 kg Ca ha^{-1} were superior to control and Ca at the rate of 50 kg Ca ha^{-1}. Nevertheless, the calcium application of 100 and 200 kg Ca ha^{-1} resulted in similar yield. The lowest paddy and straw yield and paddy : straw ratio were recorded where no calcium was applied and the values of these yield parameters were the highest at the Ca supply of 200 kg Ca ha^{-1}.

In the present study, salinity at 80 mol m^{-3} NaCl reduced all the growth parameters studied (Table I). Plants grown in saline soils have to face high osmotic stress, high concentration of potentially toxic ions such as Na^+ and Cl^- which ultimately causes reduction in growth (Martinez & Lauchli, 1993). Ion absorption though facilitates osmotic adjustment but may lead to ion toxicity and nutritional imbalance. Growth inhibition because of salt induced nutritional imbalance can be minimized with the judicious supply of plant nutrients (Aslam *et al*., 1996).

High sodium concentration in the growth medium inhibits uptake and transport of Ca and may, therefore, induce Ca deficiency in plants (Lynch & Lauchli, 1985). An adequate supply of Ca along with other nutrients to plants, therefore, may mitigate the deleterious effects of salinity (Aslam *et al*., 2000). Elevated levels of external Ca can increase both growth and Na exclusion of plant root exposed to NaCl stress (LaHaye & Epstein, 1971). Calcium application in the present study improved the growth parameters both in solution and soil cultures. A concentration of 40 µg Ca mL^{-1} produced maximum shoot dry weight under 0 mol m NaCl salinity in solution culture (Table I). However, addition of calcium (20-80 µg Ca mL^{-1}) to saline solution improved shoot and root dry weights. In the case of soil culture studies, application of Ca at the rate of 200 kg Ca ha^{-1} produced maximum paddy yield as compared to its lower rates both in saline and saline-sodic soils (Table II). The improvement in saline and non-saline conditions in solution culture and paddy yield in salt-affected soils may be due to fulfillment of calcium requirements of plants and improvement in Ca^{2+} : Na^{+} ratio of the growth medium because of Ca application over control where it would have been a limiting factor (Aslam *et al*., 2000).

The ratio K^{+}: Na^{+} was improved at 40 µg Ca mL^{-1} and 200 kg Ca ha^{-1} in all rice cultivars under saline environment and in salt-affected soils, respectively. According to Lauchli (1990), roots supplied with elevated Ca are often able to maintain their potassium concentration whereas, roots supplied with low calcium concentration frequently can not. High K concentration and K^{+}: Na^{+} ratio in the tissue of three rice cultivars because of external Ca supply in the present study clearly demonstrates the effects of calcium application to maintain shoot K concentration and root integrity of rice plants (Aslam *et al*., 2000). The improvement in yield thus may be due to the fact the addition of Ca reduced Na binding to cell walls, alleviated membrane leakiness improved ion selectivity and prevented salt-induced decline in cell production and cell elongation (Zidan *et al*., 1990).

Reduction in plant growth at higher Ca rates in solution culture study may be due to antagonism of Ca with NH_4, K, and Mg, and number of micro-nutrients such as Fe, B, Cu, Mo, Mn, and Zn (Schimansky, 1981). Another important reason of declined growth at higher external Ca concentration could be the extra cellular salt (Ca) accumulation i.e. osmotic effect: a primary factor in salinity damage (Flowers *et al*., 1991).

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