ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Journal of Agronomy 3 (1): 1-10, 2004
ISSN 1680-8207

Effect of Salinity on Growth of Some Modern Rice Cultivars

[1]M.Z. Alam, [2]T. Stuchbury, [2]R.E.L. Naylor and [1]M.A. Rashid
[1]Adaptive Research Division, Bangladesh Rice Research Institute, Gazipur 1701, Bangladesh
[2]Department of Agriculture and Forestry, University of Aberdeen, UK

Abstract: Ten rice cultivars (*Oryza sativa* L.) were tested for their salt tolerance at three levels of salinity, 4.5, 8.5 and 12.5 dS m^{-1} electrical conductivity (EC) and tap water as control. A 4x10 factorial experiment in split-plot design was used with three replications. Data taken 6 weeks after salt application were reported. Severe effects of salt on rice plant growth were seen even at 4.5 dSm^{-1}. Growth was arrested immediately after application of 12.5 dS m^{-1} salt but not in other lower salt treatments (8.5 and 4.5 dS m^{-1}). However, with time, salt injury symptoms were clearly visible in all plants growing in all levels of salt and showing different symptoms. The degree of injury was greater in the highest salt concentration (12.5 dS m^{-1}). The symptoms appeared mostly in older leaves and the upper portion of the leaves rolled in and withered away. The emerging leaf blades were tightly rolled; the tips were severely withered and necrotic. However, the younger leaves of the affected plant remained succulent and looked darker green. The affected plants looked stunted and most of the young tillers gradually died. Salt injury symptoms varied with concentration of salt and between cultivars. The relative salt sensitivity of cultivars was not consistent across salt levels indicating cultivar differences in threshold levels of salt tolerance. All plant parameters decreased significantly in all cultivars with increasing salinity. However, leaf area, shoot and root fresh weight were relatively more affected and the magnitude of reduction varied between cultivars. Limited differences between cultivars for salt tolerance were seen during vegetative growth. An index combining all plant parameters measured, suggested that V2, V3, V5 and BR23 were relatively tolerant of salinity than others. Neither reduced photosynthetic capacity nor reduced turgor appeared to be the major reason for the reduced growth. Rather, reduced growth may be the result of disturbed mineral nutrition. There was no correlation between sensitivity at germination and later growth stages. The results suggested that screening of rice cultivars for salt tolerance should be at salt sensitive stages.

Key words: Salinity, growth, rice

INTRODUCTION

Salinity has been an important historical factor influencing the life spans of agricultural systems and destroying ancient agrarian societies[1]. Despite the advanced management technologies available today, salinization of millions of hectares of land continues to reduce crop production severely world-wide. It is one of the leading processes contributing to a future world wide biological catastrophe[2]. Since a technological improvement in the situation is improbable in near future traditional means of ameliorating salt affected soils through reclamation, drainage and use of excess irrigation water to leach salts below the root zone have to be complemented with a biological approach to the problem. Sustained and profitable production of crops on salt affected soil is possible if appropriate farm management decisions are made.

There are about 95 million ha of saline soils in south and Southeast Asia[3]. Of those, 27 million ha are coastal saline soils (Akbar and Ponnamperuma, 1982). Growing rice is the most suitable use for coastal saline soils in the humid tropics because:

- they are located in areas climatically, physiographically and hydrologically suited to rice;
- rainfall is adequate for leaching the salt and growing at least one crop of rice;
- the lands are located close to densely populated areas where the demand for both land and food is high[4].

With small reclamation inputs, these soils can be cropped with modern, salt tolerant rice cultivars. Promising results have been obtained in field trials on the performance of modern salt tolerant, disease and insect

Corresponding Author: Dr. Md. Zahidul Alam, Senior Scientific Officer, Adaptive Research Division, Bangladesh Rice Research Institute, Gazipur 1701, Bangladesh E-mail: ardbrri@dhka.net

pest resistant rice cultivars on saline soils in different countries of south and south east Asia. Some recent developments in the fields of characterizing saline soils[5] and breeding of salt tolerant rice[6] suggest that slightly to moderately saline coastal soils have good prospects for modern rice production especially during the rainy season when salinity levels drop below the critical limit of 4 dS m^{-1}. Breeding programmes at the Bangladesh Rice Research Institute have produced a number of varieties and elite breeding lines which show promise in different saline areas of Bangladesh, giving almost double the yields of local varieties.

The basis of successful rice production on salt affected soil lies in identifying the cultivars most tolerant of specific problem situation. In addition to the development of salt tolerant cultivars, growers require an understanding of how plants respond to salinity, the relative tolerance of different crop cultivars and their sensitivity at different stages of growth to soil and environmental conditions. During vegetative growth, plant height, shoot weight, numbers of tillers per plant, dry weight of roots, root elongation and number of days from transplanting to flowering are all affected by salinity. But not all growth parameters are similarly affected by salinity[4]. Strategic responses involve the selection of salt tolerant lines. In addition to the selection of salt tolerant cultivars, a better understanding of the suppression of growth parameters in rice plants by salinity may suggest other strategies for plant breeders and growers so as to ameliorate the impact of salinity. There have been few such studies available on rice.

This research was initiated with the long-term aim of extending the cultivation of modern rice cultivars in the coastal saline soils. The main objective was to evaluate the salt tolerance at vegetative growth stages of some proposed salt tolerant rice cultivars and identification of salt tolerant ones.

MATERIALS AND METHODS

Ten rice cultivars (*Oryza sativa* L.) were assessed in this experiment at four levels of salinity (0, 4.5, 8.5 or 12.5 dS m^{-1}) (Table 1). All but one (IR8) was developed by BRRI. Six have been advanced salt tolerant breeding lines (V1-V6). Two are popular MVs (BR29 and BR31) but their reaction to salt is not known. BR23 was included as a salt tolerant check as it is popularly being grown in salt prone areas of Bangladesh and IR8 is a known salt sensitive IRRI variety. A 4x10 factorial experiment in split plot design was used with three replications.

Raising of seedlings: Sterilised seeds were imbibed in distilled water for 36 h. Then they were placed singly in module trays (65x27x5 cm, 210 modules) containing Q4 multipurpose compost (Ben Reid Garden Centre, Aberdeen, UK), seeds were covered by compost and well moistened. The module trays containing the seeds were maintained in a growth chamber at 26°C and were irrigated at regular intervals. After 3 days the young seedlings were transferred to the glass house where the temperature varied between 36 and 17°C.

Soil collection and preparation: Soil was collected from Craibstone Estate, Aberdeen (Scottish Agricultural College). The texture of the soil was sandy loam. Physical properties and nutrient status of the soil are shown in Table 2. The soil was air dried for 10 days and then sieved through a 2 mm sieve.

Growing of plants/salt application/sample collection: Nine 3 week-old seedlings (4th leaf unfolded) were transplanted in 12.5x12.5x11 cm deep pots containing 1.5 kg of sieved soil pre-moistened with 500 ml of half strength Hoagland solution. Ten pots were placed in 65x27x10 cm trays. Each tray was considered as a main plot and each pot as a sub-plot. Two weeks after transplanting (when plants had recovered from any transplanting shock) salt solutions were applied in each tray according to the treatments. To avoid osmotic shock salt solutions were added in three equal increments over a 6 day period until the expected conductivity (4.5, 8.5 and 12.5 dS m^{-1}) was reached. Each tray contained about 8 liters of either salt solution or tap water. Management and sampling dates were as follows:

Time (d)	7 14 21	28 35	42 49	56 63	70 77	84 91	
Activity	Seeding	Trans-planting	Salt initiation	1st sampling	2nd sampling	3rd sampling	4th sampling

Table 1: List of rice cultivars used in the study with 1000 seed weight and salt reaction

Rice cultivars	Designated as	Germination (%) at 200 mM salt	Salt reaction
BR1192-2B-35*	V1	18	Advanced salt tolerant breeding lines
BR5331-93-2-8-3	V2	63	-do-
BR5331-93-2-8-4	V3	84	-do-
BR5778-156-1-3	V4	97	-do-
BR5828-11-1-4	V5	88	-do-
BR5842-15-4-8	V6	69	-do-
BR23	BR23	95	Tolerant (check)
BR29	BR29	36	Not known
BR31	BR31	58	Not known
IR8**	IR8	23	Sensitive (check)

* BR = Bangladesh Rice ** IR = International Rice

Table 2: Soil physical properties and nutrient status (at 24% moisture content and at 1.25 Mg m^{-3} bulk densities)

Physical properties			Nutrient status								
PR MPa	VSS KPa	PVW (%)	PVA (%)	N (%)	P (%)	K (%)	Na (%)	Ca (%)	Mg (%)	Mn (ppm)	Zn (ppm)
1.7	6.3	30.0	21.9	0.27	0.33	0.37	0.13	0.39	0.27	459	65

PR = Penetration resistance, VSS = Vane shear strength, PVW = Porosity volume filled with water, PVA = Porosity volume filled with air. Source (physical properties): M.H. Ghali, University of Aberdeen, UK. (personal communication); Chemical properties: myself (M.Z. Alam), by chemical analysis

After completion of second sampling (63 d) about 250 ml of half strength Hoagland solution were added to each pot to ensure a sufficient supply of essential nutrients for the plants. Salt solutions were collected every 24 h from each tray and electric conductivity (EC) values were measured with a conductivity meter (Jenway 4010, UK) and necessary adjustments were made.

Plant samples were harvested first 14 days after salt initiation (i.e. 49 days from seeding) and then three further times each at 14 d interval. Leaf area, shoot height, tillers per plant, root length and fresh and dry weights of shoot and roots were measured.

Measurement of different growth parameters: Shoot height was measured from the root base to the tip of the longest leaf, excluding any dead portion. Root lengths were measured from the root-shoot junction to the tip of the longest root. Leaf area (green portion only) was measured by a leaf area meter (model MK2, DELTA-T DEVICES, Burwell, England). Plant samples were dried at 70°C for 72 h for dry weight measurements. The data were analysed using analysis of variance in GENSTAT. The statistical significance of differences between pairs of treatments was determined by Student's t-test.

RESULTS

Ten rice cultivars were tested for their salt tolerance at three levels of salinity, 4.5, 8.5 and 12.5 dS m^{-1} electrical conductivity (EC) and tap water as control. Plant samples were harvested at regular intervals of 2 weeks for 56 days. It was observed that at times after 6 weeks of 12.5 dS m^{-1} salt imposition, most of the cultivars were almost dead and at all salinity levels the deleterious effects of salt increased with time for all the parameters measured. Therefore, data taken 6 weeks after salt application are presented here. All the plant parameters varied greatly between cultivars under even non saline control conditions. The differences were statistically significant due to inter cultivar (genetic) differences. As salinity increased, differences between cultivars decreased and significant salinity and cultivar differences were observed.

Table 3: Effect of salinity on plant height (cm) of different rice cultivars 6 weeks after salt application

	Salinity level			
Cultivars	0 dS m^{-1}	4.5 dS m^{-1}	8.5 dS m^{-1}	12.5 dS m^{-1}
V1	47.83	34.77 (73)	30.87 (65)	22.18 (46)
V2	48.50	38.23 (79)	37.25 (77)	24.88 (51)
V3	57.45	45.60 (79)	35.77 (62)	17.35 (30)
V4	55.27	40.77 (74)	31.98 (58)	25.83 (47)
V5	47.43	47.30 (100)	33.28 (70)	12.03 (25)
V6	71.02	51.10 (72)	42.27 (60)	29.23 (41)
BR11	47.05	37.57 (80)	29.63 (63)	25.58 (54)
BR23	50.03	42.72 (85)	43.85 (88)	26.38 (53)
BR29	48.83	36.48 (75)	28.58 (59)	22.92 (47)
BR31	52.78	42.32 (80)	37.25 (71)	25.52 (48)
Mean	52.62	41.69 (80)	35.07 (67)	23.19 (44)

LSD values for salinity = 1.70, cultivar = 2.42, salinity*cultivar = 4.83
Values in parentheses indicate percent relative the control

Table 4: Effect of salinity on tiller number (per plant) of different rice cultivars 6 weeks after salt application

	Salinity level			
Cultivars	0 dS m^{-1}	4.5 dS m^{-1}	8.5 dS m^{-1}	12.5 dS m^{-1}
V1	1.83	1.67 (91)	1.00 (55)	0.33 (18)
V2	1.50	0.83 (56)	0.67 (44)	0.50 (33)
V3	1.83	2.13 (118)	1.17 (64)	0.83 (45)
V4	1.67	2.33 (140)	0.67 (40)	0.67 (40)
V5	2.33	2.50 (107)	1.33 (43)	0.50 (21)
V6	0.33	0.00 (0)	0.00 (0)	0.00 (0)
BR11	2.33	1.50 (64)	1.00 (43)	0.67 (29)
BR23	2.17	1.50 (69)	1.33 (62)	1.17 (54)
BR29	2.17	2.00 (92)	0.67 (31)	0.67 (31)
BR31	2.00	1.17 (58)	0.67 (33)	0.50 (25)
Mean	1.82	1.57 (80)	0.82 (41)	0.58 (30)

LSD values for salinity = 0.21, cultivar = 0.29, salinity*cultivar = 0.58
Values in parentheses indicate percent relative the control

Table 5: Effect of salinity on leaf area (cm^2) of different rice cultivars 6 weeks after salt application

Cultivars	Salinity level 0 dS m^{-1}	4.5 dS m^{-1}	8.5 dS m^{-1}	12.5 dS m^{-1}
V1	105.83	45.82 (43)	25.83 (24)	8.05 (8)
V2	100.62	38.67 (38)	39.37 (39)	21.72 (22)
V3	198.42	130.13 (66)	50.30 (25)	15.43 (8)
V4	133.12	62.68 (47)	26.75 (20)	12.25 (9)
V5	110.82	88.15 (80)	24.60 (22)	4.92 (4)
V6	111.27	61.27 (55)	28.88 (26)	9.87 (9)
BR11	121.63	50.12 (41)	22.72 (19)	16.07 (13)
BR23	99.30	74.07 (75)	59.17 (60)	18.28 (18)
BR29	138.02	86.93 (63)	30.12 (22)	17.65 (13)
BR31	147.60	50.08 (34)	32.78 (22)	16.12 (11)
Mean	126.66	68.79 (54)	34.09 (28)	14.04 (11)

LSD values for salinity = 6.66, cultivar = 9.46, salinity*cultivar = 18.93
Values in parentheses indicate percent relative the control

Table 6: Effect of salinity on root fresh weight (g/plant) of different rice cultivars 6 weeks after salt application

Cultivars	Salinity level 0 dS m^{-1}	4.5 dS m^{-1}	8.5 dS m^{-1}	12.5 dS m^{-1}
V1	0.87	0.49 (57)	0.23 (26)	0.17 (20)
V2	0.60	0.25 (42)	0.33 (55)	0.25 (42)
V3	1.32	0.87 (66)	0.35 (27)	0.21 (16)
V4	1.02	0.57 (56)	0.24 (24)	0.21 (21)
V5	0.44	0.66 (151)	0.26 (60)	0.11 (25)
V6	0.83	0.39 (46)	0.37 (44)	0.24 (29)
BR11	0.75	0.33 (44)	0.21 (28)	0.16 (22)
BR23	0.50	0.58 (116)	0.49 (98)	0.23 (47)
BR29	0.99	0.63 (63)	0.32 (32)	0.24 (24)
BR31	1.19	0.41 (34)	0.37 (31)	0.22 (18)
Mean	0.85	0.52 (68)	0.32 (43)	0.20 (26)

LSD values for salinity = 0.07, cultivar = 0.09, salinity*cultivar = 0.19
Values in parentheses indicate percent relative the control

Table 7: Effect of salinity on shoot fresh weight (g/plant) of different rice cultivars 6 weeks after salt application

Cultivars	Salinity level 0 dS m^{-1}	4.5 dS m^{-1}	8.5 dS m^{-1}	12.5 dS m^{-1}
V1	3.44	2.23 (65)	1.61 (47)	1.14 (33)
V2	2.85	1.61 (56)	1.82 (64)	1.28 (45)
V3	5.27	4.31 (82)	2.55 (48)	1.52 (29)
V4	4.08	2.93 (72)	1.78 (44)	1.45 (36)
V5	3.29	3.50 (106)	1.77 (54)	0.86 (26)
V6	3.76	2.43 (65)	1.74 (46)	1.19 (32)
BR11	3.43	1.93 (56)	1.59 (46)	1.33 (39)
BR23	3.29	2.81 (85)	2.51 (76)	1.70 (52)
BR29	3.59	2.55 (71)	1.53 (43)	1.30 (36)
BR31	4.28	2.21 (52)	2..25 (53)	1.38 (32)
Mean	3.73	2.65 (71)	1.91 (52)	1.32 (36)

LSD values for salinity = 0.20, cultivar = 0.28, salinity*cultivar = 0.56
Values in parentheses indicate percent relative the control

Table 8: Effect of salinity on root dry weight (g/plant) of different rice cultivars 6 weeks after salt application

Cultivars	Salinity level 0 dS m^{-1}	4.5 dS m^{-1}	8.5 dS m^{-1}	12.5 dS m^{-1}
V1	0.12	0.05 (41)	0.04 (36)	0.04 (29)
V2	0.09	0.04 (48)	0.06 (64)	0.04 (51)
V3	0.21	0.14 (67)	0.07 (34)	0.05 (22)
V4	0.16	0.10 (60)	0.05 (29)	0.05 (30)
V5	0.08	0.11 (131)	0.05 (60)	0.03 (30)
V6	0.15	0.07 (48)	0.06 (40)	0.05 (30)
BR11	0.11	0.06 (53)	0.04 (36)	0.04 (32)
BR23	0.10	0.10 (99)	0.08 (81)	0.06 (55)
BR29	0.17	0.10 (59)	0.06 (35)	0.05 (28)
BR31	0.19	0.08 (42)	0.07 (39)	0.05 (27)
Mean	0.14	0.08 (65)	0.06 (45)	0.04 (33)

LSD values for salinity = 0.01, cultivar = 0.01, salinity*cultivar = 0.03
Values in parentheses indicate percent relative the control

Table 9: Effect of salinity on shoot dry weight (g/plant) of different rice cultivars 6 weeks after salt application

Cultivars	Salinity level 0 dS m^{-1}	4.5 dS m^{-1}	8.5 dS m^{-1}	12.5 dS m^{-1}
V1	0.55	0.40 (74)	0.33 (60)	0.28 (51)
V2	0.49	0.34 (69)	0.40 (81)	0.31 (64)
V3	1.04	0.92 (88)	0.57 (55)	0.35 (33)
V4	0.70	0.56 (81)	0.38 (54)	0.32 (47)
V5	0.59	0.69 (117)	0.39 (65)	0.21 (35)
V6	0.83	0.57 (69)	0.42 (50)	0.29 (35)
BR11	0.58	0.43 (73)	0.35 (59)	0.31 (54)
BR23	0.70	0.61 (87)	0.55 (79)	0.43 (62)
BR29	0.60	0.48 (81)	0.34 (56)	0.30 (50)
BR31	0.80	0.49 (61)	0.53 (66)	0.36 (45)
Mean	0.69	0.55 (80)	0.42 (63)	0.32 (48)

LSD values for salinity = 0.04, cultivar = 0.05, salinity*cultivar = 0.10
Values in parentheses indicate percent relative the control

Table 10: Effect of salinity on shoot dry weight/shoot fresh weight ratio of different rice cultivars 6 weeks after salt application

Cultivars	Salinity level 0 dS m^{-1}	4.5 dS m^{-1}	8.5 dS m^{-1}	12.5 dS m^{-1}
V1	0.16	0.18 (114)	0.20 (127)	0.24 (153)
V2	0.17	0.21 (123)	0.22 (128)	0.25 (144)
V3	0.20	0.22 (108)	0.23 (114)	0.23 (117)
V4	0.17	0.19 (113)	0.21 (124)	0.23 (132)
V5	0.18	0.20 (110)	0.22 (121)	0.25 (137)
V6	0.23	0.23 (103)	0.24 (106)	0.25 (111)
BR11	0.17	0.22 (131)	0.22 (128)	0.24 (139)
BR23	0.21	0.22 (101)	0.22 (103)	0.25 (119)
BR29	0.17	0.19 (114)	0.22 (132)	0.23 (140)
BR31	0.19	0.22 (117)	0.24 (125)	0.26 (138)
Mean	0.18	0.21 (113)	0.22 (121)	0.24 (133)

LSD values for salinity = 0.005, cultivar = 0.007, salinity*cultivar = 0.014
Values in parentheses indicate percent relative the control

Visual observations: Adverse effects of salt on normal growth and nutrition of rice were noticeable from the appearance of the plants. Growth was arrested immediately after application of 12.5 dS m^{-1} salt but not in other lower salt treatments (8.5 and 4.5 dS m^{-1}). Young and middle leaves of most of the cultivars were rolled, withered and droopy within 48 h of salt imposition. Within 72 h from the start of treatment some signs of leaf chlorosis were observed starting from just below the leaf tip and gradually extending towards the leaf base. However, with time, although plants seemed to be recovering from the initial shock, salt injury symptoms were clearly visible in all plants growing in all levels of salt and showing different symptoms. The degree of injury was greater in the highest salt concentration (12.5 dS m^{-1}). The symptoms appeared in older leaves as whitish spots along the middle of the leaf blade, which coalesced with time and gradually enlarged upwards. Finally the

Table 11: Salt concentration needed for 30% reduction in different growth parameters, R^2 values, position of the cultivars and total score

		Tiller /plant		Leaf area per plant		Root FW per plant		Shoot FW per plant		Plant height		Root DW per plant		Shoot DW per plant	
Cultivar	Sensitivity	$dS\ m^{-1}$	R^2	$dS\ m^{-1}$	R^2	$dS\ m^{-1}$	R^2	$dS\ m^{-1}$	R^2	$dS\ m^{-1}$	R^2	$dS\ m^{-1}$	R^2	$dS\ m^{-1}$	R^2
V1	tolerant	5.77	0.93	2.74	0.92	3.44	0.93	4.73	0.96	6.60	0.97	2.93	0.77	6.68	0.95
V2	tolerant	4.11	0.89	2.86	0.80	3.78	0.59	5.41	0.75	8.27	0.92	5.02	0.53	10.07	0.61
V3	tolerant	8.62	0.70	3.72	0.98	3.83	0.96	5.49	0.98	6.00	0.98	4.17	0.97	6.23	0.96
V4	tolerant	7.92	0.50	2.81	0.92	3.35	0.91	5.02	0.96	6.28	0.97	3.77	0.88	6.48	0.97
V5	tolerant	5.78	0.82	4.14	0.95	8.28	0.54	6.62	0.83	7.01	0.84	7.97	0.64	8.06	0.73
V6	tolerant	0.29	0.63	3.30	0.97	3.49	0.82	4.65	0.97	5.97	0.98	3.49	0.84	5.11	0.98
BR11	tolerant	4.43	0.97	2.50	0.87	2.86	0.85	4.33	0.85	7.52	0.98	3.66	0.86	6.82	0.93
BR23	tolerant	6.70	0.89	5.28	0.96	11.26	0.55	8.60	0.96	9.78	0.79	10.12	0.86	10.48	0.98
BR29	tolerant	5.36	0.84	3.56	0.95	3.97	0.95	4.96	0.95	6.39	0.98	3.88	0.93	6.77	0.96
BR31	tolerant	3.76	0.93	2.23	0.84	2.40	0.79	4.15	0.84	7.57	0.98	3.05	0.79	5.90	0.81
Position of the cultivars according to their salt tolerance															Total
BR31		2		1		1		1		8		2		2	17
V6		1		6		5		3		1		3		1	20
V1		6		3		4		4		5		1		5	28
BR11		4		2		2		2		7		4		7	28
V4		9		4		3		6		3		5		4	34
BR29		5		7		8		5		4		6		6	41
V3		10		8		7		8		2		7		3	45
V2		3		5		6		7		9		8		9	47
V5		7		9		9		9		6		9		8	57
BR23		8		10		10		10		10		10		10	68

Table 12: Slope, intercept, R^2 values and significance of the relationship between germination percent and growth parameters at later growth stages

Plant parameters			Slope	Intercept	R^2	Significance
Germination	Vs	plumule length	0.139	11.85	0.629	**
		radicle length	0.078	21.60	0.215	ns
		plant height	-0.008	48.93	0.073	ns
		leaf area	-0.007	11.80	0.001	ns
		root fresh weight	-0.095	20.61	0.067	ns
		shoot fresh weight	-0.037	33.21	0.018	ns
		root dry weight	-0.098	27.06	0.064	ns
		shoot dry weight	-0.069	51.46	0.032	ns
		overall growth	0.252	22.99	0.193	ns

upper portion of the leaves rolled in and withered away. The emerging leaf blades were tightly rolled; the tips were severely withered and necrotic. This was probably a manifestation of Ca deficiency[7]. However, the younger leaves of the affected plant remained succulent and looked darker green than the leaves of healthy plants. The affected plants looked stunted and most of the young tillers gradually died. Salt affected plants began to show N deficiency symptoms, which became more severe with time. Salt injury symptoms varied with concentration of salt and between cultivars. V3 looked more affected initially, but with time little difference was observed between cultivars.

Growth parameters

Plant height: Salinity decreased plant height of all the cultivars. Even at the lowest salinity treatment (4.5 $dS\ m^{-1}$), plant heights after 6 weeks of salinization were significantly reduced with respect to the controls, except for V5. The average plant height of cultivars at 4.5, 8.5 and 12.5 $dS\ m^{-1}$ salinity was reduced to about 80, 65 and 45% of controls (Table 3). There was a negative correlation ($r = -0.995$, $P< 0.001$) between salt concentration and plant height. There were also significant differences between cultivars at different salt levels. However, the differences were not pronounced at salt concentrations below 12.5 $dS\ m^{-1}$ except for V5 at 4.5 $dS\ m^{-1}$ in which plant height was not affected. The height reduction of V5 was the greatest (75%) at 12.5 $dS\ m^{-1}$, other cultivars showed at least 46% reduction in height at 12.5 $dS\ m^{-1}$ salinity. The lowest reductions were observed in V2, BR11 and BR23.

Tillers per plant: Tiller production of rice plants was more sensitive to salt than plant height and cultivar differences were pronounced at all levels of salinity. On average over all the cultivars at 4.5, 8.5 and 12.5 $dS\ m^{-1}$ salinity tiller production per plant was about 80, 40 and 30%, respectively of control (Table 4). Tiller production was inversely related to salt concentration ($r = -0.972$, $P<0.001$). The average number of tillers per plant ranged from 0.22 to 3.37 under non-saline conditions. With increasing salinity, tillers per plant decreased by 50-100% in all cultivars except in V3, V4 and V5 at 4.5 $dS\ m^{-1}$ in which it increased by 18, 40 and 7%, respectively relative to the control. BR23 and V3 consistently had greater number of tillers at all salinity levels while V6 did not produce any tillers at any salt level. The salt tolerance of rice cultivars regarding tiller production was not consistent between salt levels. V1 and BR11 performed better up to 8.5 dS m^{-1} but poorly at 12.5 dS m^{-1}.

Leaf area (LA): LA was highly sensitive to salt with about 50% reduction even at the lowest concentration of 4.5 dS m^{-1} (Table 5). With increasing salinity, LA decreased progressively and there was a negative correlation (r = -0.981, P <0.001) between salt concentration and LA. On average over all the cultivars at 4.5, 8.5 and 12.5 dS m^{-1} salinity, LAs were about 55, 30 and 10% of the control. However, there were differences between cultivars.

The average LA per plant of the cultivars ranged from about 100 to 200 cm^2 under non saline control conditions. Cultivar performances were not consistent with increasing salinity except BR23. Although BR23 had the smallest LA (100 cm^2) in control, it maintained consistently higher LAs than other cultivars with further increase in salt. In contrast, V3 had the greatest LA in control and at 4.5 dS m^{-1} (about 200 and 80 cm^2, respectively) but LA was reduced greatly with further increase in salt.

Root fresh weight (RFW): RFW also was inversely related to the salt concentration (r = -0.983, P<0.001). On average over all cultivars at 4.5, 8.5 and 12.5 dS m^{-1} salinity RFWs were about 70, 40 and 25% of the control (Table 6). There were differences between cultivars in response to salinity. At the lowest salt concentration (4.5 dS m^{-1}) RFWs of all the cultivars were reduced to about 40-70% to the control, whilst in the proposed salt tolerant line V5 and salt tolerant check BR23, RFWs increased by about 15 and 50%, respectively. V5 and BR23 also showed better root growth at 8.5 and 12.5 dS m^{-1} salt. The root growth of V2 did not appear to be as adversely affected by increasing salt as other cultivars.

Shoot fresh weight (SFW): SFW was relatively less sensitive to salt than RFW especially at higher salt concentrations. On average over all cultivars at 4.5, 8.5 and 12.5 dS m^{-1} salinity SFWs were about 70, 50 and 30%, respectively of the control (Table 7). A negative correlation was found between SFW and salt concentration (r = 0.992, P<0.001). Cultivars also differed in the response of SFW to salt. Shoot fresh weight of V5 was not adversely affected at 4.5 dS m^{-1}, whilst in all other cultivars, SFW was reduced and ranged from 52 to 85% relative to the control. BR23 consistently maintained higher SFW at all salt levels. Shoot fresh weight at 12.5 dS m^{-1} ranged from 26 to 52% relative to the control. Higher SFWs were observed in V2 and BR23 (more than 45% of the control) and lower SFWs were observed in V1, V3, V5, V6 and BR31 (less than 35%). However, V5 maintained a higher SFW up to 8.5 dS m^{-1} (54%) and had the lowest SFW (26% relative to the control) at 12.5 dS m^{-1}.

Root dry weight (RDW): RDW was also inversely related to salt concentration (r = 0.970, P <0.001). On average over all cultivars at 4.5, 8.5 and 12.5 dS m^{-1} salinity, RDWs were about 65, 45 and 30%, respectively relative to the control (Table 8). The RDW of BR23 was similar to control and that of V5 increased about 30% at 4.5 dS m^{-1} salinity. In contrast, RDW reduced to about 42 to 67% in other cultivars. BR23 again performed consistently better at all salt levels. The performance of V5 was better up to 8.5 dS m^{-1}, but at 12.5 dS m^{-1} it performed poorly. The RDW of V2 did not appear to be as adversely affected as other cultivars at 8.5 and 12.5 dS m^{-1}.

Shoot dry weight (SDW): Shoot dry weight was relatively less affected than RDW (Table 9). A deleterious effect of salt on SDW was observed at all salt concentrations on all the cultivars except V5 at 4.5 dS m^{-1}. However, on average over all cultivars at 4.5, 8.5 and 12.5 dS m^{-1} salinity SDWs were reduced to about 80, 65 and 50%, respectively of the control. A negative linear correlation (r = -0.999, P<0.001) was obtained between salt concentration and SDW. There were also differences between the cultivars. At the lowest salt concentration (4.5 dS m^{-1}) the greatest reduction in SFW was observed in BR31 (34%) and the lowest in V3 and BR23 (about 13%). However, at this level of salinity, the SDW of V5 was increased about 17% relative to the control. At 8.5 dS m^{-1}, cultivar differences were not pronounced; V2, V5 and BR23 had about 20-30% reductions and other cultivars had 40-50% reductions. At 12.5 dS m^{-1}, reductions in SDW ranged from 36-65%. The smallest reductions were observed in V2 and BR23 (about 40%) and the greatest in V3, V4 and V5 (about 65%).

Shoot dry weight (SDW) /Shoot fresh weight (SFW) ratio: SDW/SFW ratios progressively increased with increasing salinity suggesting plants were less hydrated at higher salinities (Table 10). A positive linear correlation was obtained between them (r = 0.996, P <0.001). On average over all the cultivars at 4.5, 8.5 and 12.5 dS m^{-1} salinity SDW/SFW ratio increased by 13, 21 and 33%, respectively relative to the control. The increment in SDW/SFW ratio was consistently greater in V2, BR11, BR29 and BR31 (mostly salt sensitive cultivars) and consistently lower in V3, V6 and BR23 (salt tolerant cultivars). At 4.5 dS m^{-1} the SDW/SFW ratio increment ranged from 1-23%. Relatively smaller increments were observed in BR23, V3 and V6 (1-8%) and greater increments were observed in V2 and BR11 (about 25%).

V6, BR23 and V3 showed significantly smaller increments also at 8.5 and 12.5 dS m^{-1}. At 12.5 dS m^{-1}, the SDW/SFW ratio increment ranged from 11-53% relative to the control. Greater increments were observed in V1, V2, V5, BR11, BR29 and BR31 (more than 35%) and lower in V3, V6 and BR23 (less than 20%). SDW/SFW ratio also increased with time at all salt levels as well as in control.

Position of cultivars according to their salt tolerance: As the responses of the ten cultivars to salt concentrations differed between plant parameters measured, the salt concentrations needed for 30% reduction in different growth parameters at 6 weeks after salt application were calculated. These were then sorted according to their salt tolerance and were ranked (1 = worst, 10 = best). The ranks were then summed (Table 11). The known salt tolerant check BR23, appeared to be the most salt tolerant cultivar with a score of 68, out of a possible maximum of 70 followed by V5, V2 and V3 (57, 47 and 45, respectively). BR31 appeared to be the most salt sensitive cultivar with a score only 17, followed by V6, V1 and BR11 (20, 28 and 28, respectively). Clearly of the six lines proposed as salt tolerant, three are relatively salt tolerant and three are rather susceptible.

Relationship between germination and later growth stages: Correlations between germination percent at 200 mM salt and other growth parameters at later growth stages were examined and were not significant except in the case of plumule length (Table 12).

DISCUSSION

The result of the present study demonstrate that rice, in common with certain other cereals (e.g. wheat, corn), is highly sensitive to salt with severe effects even at 4.5 dS/m. The disorder was particularly obvious in the leaf blades so much so that at the time of harvest (6 or 8 weeks after salt application) each sample comprised of almost only the physiologically active centres of the plant at 12.5 dS m^{-1} salinity. In response to external salt supply plants also exhibited severe salt injury, Ca and N deficiency symptoms. Similar observations were reported by Grieve and Fujiyama[8] and Khan *et al.* [9] Shannon *et al.* [10] reported that biomass production and plant density of rice decreased with increasing salinity over a range of even 0.5 to 4 dS m^{-1}. At 2.9 dS m^{-1} significant reductions in biomass production of rice occurred after only 14 days of salinization. Although plant height, tiller number, leaf area, root and shoot fresh and dry weight all decreased significantly in all cultivars with increasing salinity, the magnitude of reduction varied between cultivars. Leaf area, shoot and root fresh weight were relatively more affected and cultivar differences were more pronounced. These parameters could form the basis of a screening system.

The relative salt sensitivity of cultivars was not consistent across salt levels. At higher salt levels cultivar differences were not pronounced. Nevertheless, V2, V3, V5 and BR23 were observed to have relatively higher tolerance (on average of all parameters, Table 12) than others. Although cultivars differed, their salt tolerance during vegetative growth was not simple. Some cultivars performed well up to a certain level of salinity (e.g. V5 up to 8.5 dS m^{-1}) but very poorly with further increase in salt concentrations. Some cultivars performed poorly at low salt levels (e.g. V2) but were not much affected by further increases in salt concentrations indicating cultivar differences in threshold levels of salt tolerance. So, additional information are needed of the threshold levels of salinity of those cultivars. If threshold salinity of V2, V3, V5 and BR23 and the interaction between threshold sensitivity and environmental factors were known it would be feasible that appropriate management strategies could be proposed based on monitoring water electrical conductivity of a particular rice growing area. This might include selecting particular varieties for specific low, moderate or highly saline conditions using historical patterns of water electical conductivity of that particular area.

Roots are in direct contact with the surrounding solution. As such they are first to encounter the saline medium and are potentially the first site of damage or of defense under salt stress. Root growth of rice in this study was severely inhibited by high concentrations of NaCl. This has been found by other workers in rice as well as in other crop[11,33]. It was probably because salinity affected final cell size and as well as rate of cell production[12-14] thereby producing shorter roots. However, these results do not agree with those of Cramer *et al.*[15] who reported that roots were less sensitive to salt than shoots. This contrast might be linked to the methodology, particularly whether the work involved transplanting, or application of salt solutions to direct seeded plants. Usually in the case of rice, after transplanting the previous roots die and new roots grow to support the plant[7]. Inhibition of root growth by salinity reduces the volume of the growth media which can be explored by the roots and hence the availability and uptake of water and essential minerals[16]. The diminished supply of nutritional elements to the shoot may also contribute to growth reduction of both root and shoot.

Higher root fresh weights in V5 and BR23 (and also root dry weight in BR23) were observed at 4.5 dS m^{-1} salinity and may have been related to their higher tiller producing ability. These two cultivars had the highest number of tillers per plant (more than two per plant) in control. Increased number of tillers per plant were observed in V3 and V4 at 4.5 dS m^{-1} rather than control. It was due to their reduced vegetative growth at this salinity level. Which checked inter-plant competition and luxury growth as in control thereby facilitating higher tiller production. In fact, although tiller production was influenced by salinity it was a genetically controlled character rather than salinity. V6 had the lowest number of tillers at all salinity levels and in control as well. Most of the cultivars in this study were panicle number type where as V6 was a panicle weight type[17].

It is possible that the decrease in the observed shoot and root growth in salinized plants were due to several reasons. One possibility is that salinity reduced photosenthesis, which in turn limited the supply of carbohydrate needed for growth. A second possibility is that salinity reduced shoot and root growth by reducing turgor in expanding tissues resulting from lowered water potential in root growth medium. A third is that the root response to salinity was to down regulate shoot growth (and root also) via a long distance signal. Fourth, a disturbance in mineral supply, either an excess or deficiency, induced by changes in concentrations of specific ions in the growth medium, might have directly affected growth[18]. Each of these hypotheses has some merit and may contribute in some way towards the long term effects of growth.

The possible reasons for reduced plant growth such as reduced photosynthesis and turgor and a long distance signal might contribute in some way towards reduced growth, but could not be tested in this programme of research. Nevertheless, reductions in net photosynthesis have been found not to occur during the first 5 h of salinization even when the elongation of young leaves was inhibited in the same time period in maize[19]. After 2-3 weeks of salinization, photosynthetic activity per unit leaf area may be little affected but overall rates of photosynthesis were reduced as a result of reduction of the photosynthetically active leaf area[19-21]. Increased starch accumulation has been reported for the whole shoot[22] mature leaves[23] and for expanding leaves[24,25]. Therefore, it seems unlikely that it is reduction in photosynthesis per unit leaf area which leads to reduced shoot growth. In rice, photosynthesis per unit leaf area did decline after 10 days of salinization and the leaf Na content steadily climbed[26], but this was accounted for by accelerated leaf senescence[27]. The present study also showed that salinity greatly reduced leaf area, but the younger leaves of the salt affected plants remained dark green while mainly the older leaves were dead. It appears that the reduction of growth was due to the reduced leaf area and loss of photosynthetic capacity.

In the present and other studies with rice[9-10] the degree of salt injury was greater in older leaves. However, the younger leaves of the salt affected plants remained dark green and suggests that the photosynthetic capacity per unit leaf area is not severely limited by moderate levels of salt. Similar results were reported on barley and maize[19-21].

It also seems unlikely that plant productivity was limited during salinity stress primarily by the reduced turgor and limitations of plants capacity for osmoregulation. Turgor may return to near control levels after a transient decrease[28-30]. During the initial few minutes of exposing roots to moderate salt stress, leaf expansion sharply decreased but recovered within a few to several hours[28,31]. Where changes in turgor have been shown after transfer to salinized medium these have also been rapid, transient and reversible with time[30]. In this study, plants wilted immediately after salt application but recovered with time. Existence of dark green healthy leaves in the present study is also evidence of maintained turgor. On the other hand the root signal hypothesis of reduced growth under salt conditions remains to be thoroughly explored and tested. Indeed there is a similarity between this hypothesis and that of disturbed nutrition, as nutrients themselves might be considered long distance messengers. After all many nutrients have an essential role in the process of cell division and cell extension and those would cease soon after the supply were halted, especially in tissues with little nutrient storage capacity[18]. Therefore, the dominant specific reason for reduced rice plant growth in the present study under salt conditions appears to be that of disturbed/imbalanced nutrition.

In this study, plants wilted immediately after salt application and recovered with time. Other workers have reported transient decreases in turgor[28-30] and in leaf expansion[28,31]. Thus neither reduced photosynthetic capacity nor reduced turgor appear to be the major reason for the reduced growth seen in this work. Rather, the results suggest that reduced growth may be the result of disturbed mineral nutrition.

High salt tolerance of rice seed during germination but great sensitivity during subsequent growth, poses serious questions about screening rice cultivars depending on germination. Rice germination was not affected up to 150 mM NaCl, whereas about 115-135 mM (10.5-12.5 dS m^{-1}) salinity proved to be fatal for leaf developmental stage[32] and also for vegetative growth. This suggests that screening of rice cultivars for salt tolerance should be at salt sensitive stages. The lack of correlation between sensitivity at germination and later growth stages strongly supports this conclusion.

The results reported herein show that the reduced plant growth of rice preferentially accounted for the disturbed nutrition in the growth medium. However, more important questions for the hypothesis of disturbed nutrition in relation to salinity might be:

- whether the levels of a particular nutrient element becomes so low/high as to inhibit growth or metabolism;
- whether any similar disruptions in mineral nutrient supply occur for other nutrients; and
- whether any such disruptions correspond to the locale and time frame of well documented growth inhibitions needs to be investigated. Calcium is a particularly interesting nutrient for evaluating these questions, considering that it is known to be both essential and closely regulated during the process of both cell division and extension.

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