TOLERANCE OF RICE CULTIVARS TO SALINITY[1]

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ABSTRACT - Salinity is a serious growth-limiting factor for rice production in arid and semi-arid regions of the world. Data related to the reaction of rice cultivars to salinity are limited, especially for large numbers of cultivars. Forty rice cultivars were grown in a greenhouse in soil adjusted to different levels of salinity by applying 0.34 mol l^{-1} of NaCl solution. The resulting salinity levels were: 0.39 (control), 5, and 10 dS m^{-1} saturation extract conductivity. Significant varietal differences were found in relation to salinity tolerance. Based on relative dry matter yield of shoots at growth depressing salinity levels, rice cultivars were classified as tolerant, moderately tolerant, or moderately susceptible, and susceptible. The effect of salinity on concentrations and uptake of nutrients was observed. The sensitive and tolerant cultivars/lines identified may be beneficial in future breeding and physiological studies.

Index terms: electrical conductivity, nutrient uptake, *Oryza sativa*.

TOLERÂNCIA DE CULTIVARES DE ARROZ À SALINIDADE

RESUMO - A salinidade é um fator nocivo, por limitar a produção de arroz em regiões áridas e semi-áridas do mundo. Dados relacionados à reação de cultivares de arroz à salinidade são limitados, especialmente para grande número de cultivares. Quarenta cultivares de arroz foram testadas em casa de vegetação, em solo ajustado aos diferentes níveis de salinidade criados pela aplicação de solução de 0,34 mol l^{-1} de NaCl. Os níveis de salinidade foram: 0,39 (testemunha), 5 e 10 dS m^{-1} condutividade elétrica do extrato saturado do solo. Diferença significativa foi obtida em relação à tolerância de cultivares à salinidade. Baseado na redução de matéria seca da parte aérea com os altos níveis de salinidade, as cultivares foram classificadas como tolerante, ou moderadamente susceptível, e susceptível. Foi observado o efeito de salinidade na concentração de nutrientes. As cultivares/linhagens identificadas como tolerantes e sensíveis podem ser usadas nos estudos de fisiologia e melhoramento.

Termos para indexação: condutividade elétrica, absorção de nutrientes, *Oryza sativa*.

INTRODUCTION

Saline soils occupy about 380 million hectares of the earth's surface (Mahrous et al. 1983). Salt-affected soils are common in arid and semi-arid regions of many parts of the world where evaporation is higher than precipitation (Allison 1964, United States Salinity Laboratory Staff 1954). As a result, salts are not leached from the soil and accumulate in amounts or types detrimental to plant growth. Soils are also salinized in coastal areas due to tides. Salts generally originate from native soil and irrigation water. Successful crop production on these soils depends on the way the three components, i.e. soil, water and plants are managed.

Rice varieties differ widely in their salinity tolerance (Fageria et al. 1981, Fageria 1985). Therefore, selection for varietal tolerance to salinity is an important aspect of rice breeding programs in arid and semi-arid regions. A greenhouse experiment was conducted with the objective of evaluating rice cultivars/lines for tolerance to salinity. Promising materials may be used either directly after field testing or in breeding programs.

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MATERIALS AND METHODS

The greenhouse experiment was conduted at Brazil's National Rice and Bean Research Center, in Goiânia Goiás. The test soil was a hydromorphic (humic gley), having an initial pH of 5.1, organic matter content of 7.8%, extractable P-14.9 and K-115 mg kg^{-1}, and Ca-9.5, Mg-4.1 and Al0.2 cmol kg^{-1}. Phosphorus and K were extracted with the Mehlich I solution (0.05 mol l^{-1} HCL + 0.0125 mol l^{-1} H_2SO_4). Phosphorus was determined by colorimetry and K by flame photometry. Aluminum, Ca and Mg were extracted with 1 M KCl determined by titration with NaOH and EDTA, respectively.

Five-kg lots of air-dried soils were put in 6 kg plastic pots. Three levels of salinity were induced by treating the soil with a 0.34 mol l^{-1} solution of NaCl. The salinity levels included: 0.34 (unsalinized control), 5 and 10 dS m^{-1} electrical conductivity (EC_e at 25°C). These levels were based upon a calibration curve (Fig. 1) developed on the same soil before starting the experiment. This methodology is that recommended by the International Rice Research Institute in the Philippines for rice (Ponnamperuma 1976). Electrical conductivity of the saturated extract was determined by way of the method prepared by the US Salinity Laboratory (United States Salinity Laboratory Staff 1954).

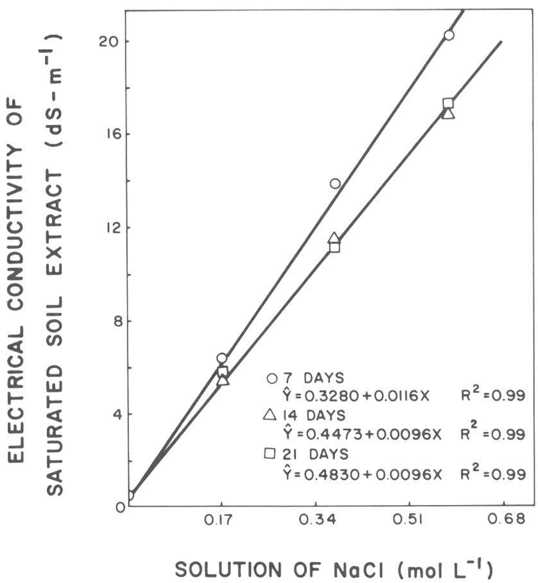

FIG. 1. Relation between NaCl solution and electrical conductivity.

Seeds of 40 rice cultivars were germinated in nutrient solution contained in 2 liter plastic pots. The composition of the nutrient solution was similar to that developed by the International Rice Research Institute for solution culture experiments (Yoshida et al. 1976). When seedlings attained an age of 15 days, 5 seedlings were transplanted into the pots of soil with different salinity levels. The salinity treatments were applied to the soil 14 days before transplanting, when an equilibrium was attained (Fig. 1). Each treatment was replicated two times.

To maintain a uniform distribution of salt, the soil layer in the pots was kept submerged to a depth of approximately 1 cm with distilled water.

Thirty-seven days after transplanting, the seedlings in the treated pots were harvested. Plant material was dried to constant weight in a forced-draft oven at 70 to 75°C and ground. Ground material was digested with a 2:1 mixture of nitric and perchloric acids. Composite samples per treatment of 9 randomly selected cultivars were analyzed for N, P, K, Ca, Mg, Na, Fe, Mn, Zn and Cu. The P concentration in the digest was determined colorimetrically, while K and Na were determined by way of flame photometry. Total N was determined with a Tecator 1016 digestor and 1004 distilling unit and the remaining elements were determined by way of atomic absorption spectroscopy. An analysis of variance of the data was made and Statistical Analysis System (SAS) programs were used to calculate correlation coefficients and regression equations relating growth parameters and plant nutrients status.

RESULTS AND DISCUSSION

Analysis of variance indicated a highly significant difference between cultivars and salinity levels of plant height, tillers and dry shoot weight (Table 1). The cultivars x salinity interaction was also significant for plant height and tillers, but nonsignificant for shoot dry weight.

Influences of salinity on plant height, tiller number, and shoot dry weight of 9 rice cultivars are illustrated in Table 2. Within cultivars, differences existed in the reduction of growth parameters at excess salt concentrations. On an average basis, all growth parameters were reduced with increasing salinity levels. At the 10 dS m^{-1} level of salinity, plant height, tiller number, and shoot dry weight were reduced by 13, 15, and 27%, respectively, as compared to the control. This means shoot dry weight is more sensitive to salinity than plant height and tiller number.

The results of Munns et al. (1982) with barley suggest that the primary cause of reduced shoot growth under NaCl salinity is located in the growing tissues and not in the mature photosynthetic tissues. The inhibition by salt of cell division or enlargement (or both) in the growing region may be indirect or direct (Maas & Nieman 1978, Setter et al. 1983). Salt may affect growth indirectly by decreasing the amount of photosynthates, water, or growth factors reaching the growing region (Maas & Nieman 1978). The amount of photosynthate reaching the growing region may decrease because of inhibition of photosynthesis due to stomal closure (Shoe & Gale 1983) or by direct effects of salt on the photosynthetic apparatus. In addition, transport of photosynthates in the phloem may be inhibited (Maas & Nieman 1978). Water deficits in the growing region may occur by insufficient osmotic adjustment or increased resistance to water flow (Ownbey & Mahall 1983). According to Kawasaki et al. (1983), salinity hazards to plant growth are mainly because of competition in uptake between nutritional and saline ions, rather than due to high osmotic pressure.

Influences of soil salinity on dry matter production and the relative yield of 40 rice cultivars is shown in Table 3. Rice cultivars differed greatly in their growth response to

TABLE 1. F values for analysis of variance of growth parameters of 9 rice cultivars.

Source of variance	Plant height	Tillers	Shoot dry weight
Cultivars	7.16**	3.73**	3.96**
Salinity	24.55**	15.49**	29.65**
CV x Salinity	2.40*	3.82**	1.73NS

*, ** Significant at P = 0.05 and 0.01, respectively.
NS = Not Significant.

TABLE 2. Influence of salinity on growth parameters of 9 rice cultivars.

Cultivar	Salinity level (dS m^{-1} at 25°C)								
	0,34 control			5			10		
	Plant height (cm)	Tillers per 5 plants	Shoot dry weight (g/5 plants)	Plant height (cm)	Tillers per 5 plants	Shoot dry weight (g/5 plants)	Plant height (cm)	Tillers per 5 plants	Shoot dry weight (g/5 plants)
GA 4223	66.5a	15.0d	6.20a	65.2ab	14.5b	6.19ab	63.2a	14.0b	5.52ab
CNA 3525	63.8a	15.5d	5.34a	63.4ab	15.5b	5.17b	58.8b	15.0ab	5.18a-c
CNA 4909	68.2a	15.5cd	6.37a	65.6ab	20.0a	6.98a	59.2b	18.0a	5.78a
CICA 8	66.4a	19.5ab	6.63a	68.8a	17.5ab	5.97ab	58.2b	15.5ab	14.4b-d
METICA 1	65.0a	15.5cd	5.65a	65.8ab	17.0ab	5.94ab	60.0ab	15.0ab	4.28cd
CNA 4982	56.6a	18.5bc	6.75a	56.6b	16.0ab	6.06ab	52.2c	15.5ab	5.19a-c
CNA 3949	61.2a	16.5b-d	5.57a	59.0ab	17.0ab	5.09b	59.4b	15.5ab	4.25cd
CNA 4900	66.9a	22.0a	6.15a	55.2b	18.0ab	5.39ab	39.0d	12.0b	2.52e
CNA 4988	62.2a	18.5bc	6.36a	62.0ab	16.0ab	6.39ab	54.3c	12.0b	3.71d

Means in the same column followed by the same letter are not significantly different at P = 0.05 by Duncan's Multiple Range Test.

TABLE 3. Influence of soil salinity on dry matter production of 40 rice cultivars.

Cultivar	Electrical conductivity (dS m^{-1})			Relative yield	
	0.34 control	5	10	5	10
CICA 8	6.63 a-d	5.97a-e	4.44c-f	91a-e	68c-i
METICA 1	5.65b-h	5.94a-e	4.28d-g	106a-c	77a-f
FJ 10	5.98a-g	5.41b-j	3.96e-g	91a-e	68c-i
GA 3922	6.22a-f	5.72a-g	5.34a-c	92a-e	87a-c
GA 3879	6.05a-g	5.67a-h	4.55b-e	94a-e	75a-f
GA 3852	5.80b-g	6.72ab	1.86j	116a	32kl
CNA 4	5.61b-h	5.34c-k	-	95a-e	-
CNA 796019	6.84ab	5.17c-k	0.88k	77c-f	131m
GA 3630	5.59b-h	6.40a-c	0.98k	115a	181m
GA 3947	4.86f-h	5.66a-i	0.39k	117a	8m
GA 3891	5.26d-h	5.90af	-	112a	-
GA 3762	5.50b-h	5.24c-k	0.37k	96a-e	7m
GA 3815	4.19h	4.42g-l	-	105a-c	-
GA 3771	5.21d-h	5.51b-j	-	106a-c	-
GA 3755	5.80b-g	5.94a-e	-	103a-d	-
GA 3949	5.79b-g	6.29a-c	4.02e-g	107ab	70b-h
GA 3955	5.15d-h	4.93d-k	0.35k	96a-e	7m
GA 3887	5.08e-h	4.74e-k	0.54k	93a-e	11l-m
GA 3894	5.60b-h	5.38c-j	0.79k	97a-e	14lm
GA 4223	6.20a-f	6.19a-d	5.52ab	100a-d	89a-c
GA 3886	4.30a-f	4.09a-d	3.65ab	100a-d	90a-c
CNA 810230	4.20h	4.87d-k	3.53f-h	115a	85a-d
CNA 4911	6.17a-f	5.97a-d	5.57a	101a-d	90a-c
CNA 3525	5.34c-h	5.17c-k	5.18a-d	97a-e	97a
CNA 4925	5.61b-h	4.32i-l	4.50c-f	78c-f	81a-e
CNA 4892	6.00a-g	4.38h-l	3.37g-i	74df	57f-i
CNA 3949	5.57b-h	5.09c-k	4.25d-g	92a-e	77a-f
CNA 4897	5.12e-h	4.04kl	4.08e-g	79b-f	80a-f
CNA 4917	4.99e-h	5.59b-i	4.42c-f	115a	92ab
CNA 4918	5.74b-f	4.57f-k	4.55b-e	80b-f	80a-f
CNA 4891	5.52b-h	5.57b-g	5.28a-c	101a-d	96a
CNA 4900	6.15a-f	5.39b-j	2.52ij	89a-e	67jk
CNA 4191	7.39a	4.17j-l	3.34g-i	57f	45i-k
CNA 4922	5.81b-g	5.29c-k	2.77h-j	92a-e	47h-k
CNA 4898	6.06a-g	6.08a-e	3.76e-g	101a-d	62d-j
CNA 4942	4.62gh	3.161	2.27j	69ef	50g-k
CNA 4981	5.16d-h	4.52g-k	3.69e-h	88a-e	72b-g
CNA 4982	6.75a-c	6.60a-e	5.19a-d	91a-e	78a-f
CNA 4988	6.36a-e	6.39a-c	3.71e-h	101a-d	58e-j
CNA 4909	6.37a-e	6.98a	5.98a	105a	93ab

Means in the same column followed by the same letter are not significantly different at P = 0.05 by Duncan's Multiple Range Test.

$$\text{Relative yield} = \frac{\text{Yield at 5 or 10 salinity level}}{\text{Yield at control}} \times 100$$

salinity. Some cultivars produced good dry matter yields at the highest salinity level, while others could not survive.

Relative yield (percent of control) of plant species or cultivars can be used as a parameter for classification as salt tolerant or susceptible (Maas & Hoffman 1977). One group of the cultivars having relative yield approaching 90% or more may be considered as tolerant. The other group, having relative yield in the range of 0 - 50, may be considered as susceptible, and the third group of cultivars falling between these two ranges may be considered as moderately tolerant or susceptible. Based on these criteria, almost all cultivars were tolerant and/or moderately tolerant or susceptible at the 5 dS m^{-1} salinity level (Table 3). At the 10 dS ms^{-1} salinity level, tolerant cultivars were: GA 3922, GA 4223, GA 3886, CNA 4911, CNA 3525, CNA 4917, CNA 4891, and CNA 4909. The most susceptible cultivars at the highest salinity levels were: GA 3852, CNA 4, CNA 796019, GA 3630, GA 3947, GA 3891, GA 3762, GA 3815, GA 3771, GA 3755, GA 3887, GA 3894, CNA 4191, CNA 4922, and CNA 4942. All other cultivars were moderately tolerant or susceptible. These results showed that the best genotypes at low salt concentration may not be best at higher concentration. This means salinity screening should be done at least at three salinity levels (low, medium, and high) to fit cultivars under variable salt concentrations that normally exist under field conditions.

Macro - and micronutrient concentrations and contents in the shoots of 9 randomly selected cultivars are presented in Tables 4 and 5. Across all the cultivars, nitrogen concentration decreased at 5 dS m^{-1}, then increased.

TABLE 4. Influence of salinity on the concentration and uptake of macronutrients in the shoots of 9 rice cultivars.

Cultivars	Soil salinity level (ds m^{-1} at 25°C)																	
	0.34 (control)						5						10					
	Concentration (mg.g^{-1})																	
	N	P	K	Ca	Mg	Na	N	P	K	Ca	Mg	Na	N	P	K	Ca	Mg	Na
GA4223	26.9	4.6	37.0	4.0	2.5	1.0	21.5	3.7	33.5	3.4	2.4	2.4	28.1	4.0	22.0	3.5	3.0	10.0
CNA3525	28.3	4.2	38.0	3.4	2.2	1.0	27.7	3.4	36.0	3.6	2.6	3.2	29.0	3.6	28.5	3.4	2.7	6.7
CNA4909	24.0	5.4	33.5	4.3	2.2	0.9	19.2	3.8	30.0	3.8	2.0	3.2	22.6	3.3	30.0	3.3	1.9	5.6
CICA 8	28.0	4.4	37.0	2.8	2.6	1.2	26.1	3.3	34.0	3.2	2.2	2.8	29.6	2.9	31.0	3.5	2.4	6.6
Metical	27.9	5.0	36.0	2.9	2.3	0.6	25.9	3.6	33.0	3.3	2.5	2.1	34.2	3.0	29.5	3.0	2.7	5.1
CNA 4982	27.4	4.3	33.0	3.4	2.0	0.7	27.3	2.9	30.0	4.5	2.2	1.4	28.5	3.3	25.5	3.3	2.0	6.0
CNA 3949	25.4	4.7	40.0	3.6	2.2	0.5	27.6	3.8	33.5	4.4	2.3	3.5	26.8	3.0	26.0	3.8	2.3	5.9
CNA4900	27.8	4.0	36.0	3.7	2.1	0.4	25.5	3.0	34.0	3.5	2.2	4.1	37.3	3.2	30.0	5.1	2.9	9.4
CNA4988	38.0	4.7	35.0	4.0	2.8	0.8	22.5	3.3	34.0	3.5	2.1	1.4	32.4	3.3	28.0	3.9	2.8	6.4
Mean	28.2	4.6	36.2	3.6	2.3	0.8	24.8	3.4	33.1	3.7	2.3	2.7	29.8	3.3	27.8	3.6	2.5	6.7
	Uptake (mg/5 plants)																	
GA4223	167	29	229	25	16	6	133	23	207	21	15	15	155	22	121	19	17	55
CNA3525	155	22	203	18	12	5	143	18	186	19	13	17	150	19	148	18	14	35
CNA4909	151	34	213	27	14	6	134	27	209	27	14	22	131	19	173	19	11	32
CICA 8	186	29	245	19	17	8	156	20	203	19	13	17	131	13	138	16	11	29
Metical	158	28	203	16	13	3	154	21	196	20	15	12	146	13	126	13	12	22
CNA4982	185	29	223	23	14	5	165	18	182	27	13	8	148	17	132	17	10	31
CNA3949	142	26	223	20	12	3	141	19	171	22	12	18	114	13	111	16	10	25
CNA4900	171	25	221	23	13	3	137	16	183	19	12	22	94	8	76	13	7	24
CNA4988	242	30	223	25	17	5	144	21	217	22	13	9	120	12	104	15	10	24
Mean	173	28	220	22	14	5	145	20	195	22	13	16	132	15	125	16	11	31

TABLE 5. Influence of salinity on the concentration and uptake of micronutrients in the shoots of 9 rice cultivars.

Cultivars	Soil salinity level (ds m^{-1} at 25^{o}C)											
	0.34 (control)				5				10			
	Fe	Mn	Zn	Cu	Fe	Mn	Cn	Cu	Fe	Mn	Cn	Cu
	Concentration (mg kg^{-1})											
GA4223	100	1075	24	12	85	1275	25	17	120	1350	36	21
CNA3525	105	600	28	14	125	750	38	20	105	700	36	22
CNA4909	135	650	35	13	110	700	35	15	100	650	35	19
CICA8	120	675	29	18	110	675	33	21	135	650	41	25
Metical	105	975	28	16	125	1000	29	17	130	1150	41	24
CNA4982	120	575	20	13	125	600	36	32	135	725	23	20
CNA3949	95	700	25	16	120	775	36	24	115	950	38	21
CNA4900	100	700	30	14	120	700	36	21	155	625	58	35
CNA4988	130	725	31	17	90	600	26	19	135	900	45	23
Mean	112	742	28	15	123	786	33	21	126	856	39	23
	Uptake (mg/5 plants)											
GA4223	620	6665	149	74	526	7892	155	105	662	7452	199	116
CNA3525	561	3204	149	75	646	3878	196	103	544	3636	187	114
CNA4909	860	4141	223	83	768	4886	244	105	578	3757	202	110
CICA8	796	4475	192	119	657	4029	197	125	599	2886	182	110
Metical	593	5509	158	90	743	5940	172	101	556	4922	175	103
CNA4982	810	3881	135	88	758	3636	218	194	700	3762	119	104
CNA3949	529	3899	139	89	611	3945	183	122	489	4038	162	89
CNA4900	615	4305	185	86	647	3773	194	113	391	1575	146	88
CNA4988	827	4611	197	108	575	3834	166	121	501	3339	167	85
Mean	690	4521	170	90	659	4646	192	121	558	3929	171	102

Uptake decreased with increasing levels of salinity because of sharp declines in dry matter production. Concentration, as well as uptake of P and K decreased with increasing salinity. The decrease in K may be related to and increase in Na availability (Bange 1959, Hassan et al. 1970). Similarly, uptake of Ca and Mg was decreased at the highest salinity level. Tissue concentration and uptake of Na increased with increasing salinity as expected. The concentrations of Fe, Mn, Zn and Cu increased with increasing salinity. With respect to uptake, there were no definite trends. Iron uptake decreased with increasing levels of salinity while Mn, Zn, and Cu increased at 5 dS m^{-1} salinity treatment, but decreased at 10 dS m^{-1} salinity level.

Coefficients for linear correlations between growth parameters and nutrient concentration, uptake and uptake efficiency are presented in Table 6. Concentrations of all nutrients but P and K were negatively correlated with the growth parameters. Uptake of almost all the macronutrients was highly correlated with all three growth parameters. Among micronutrients, Fe and Mn showed significant correlation. As far as nutrient efficiency is concerned, there was a positive significant correlation with N, Ca, Mg and Na. Correlations of P and K and with all three growth parameters were negative.

The combined influence of nutrient concentrations and uptake of plant growth parameters of rice cultivars were evaluated using

TABLE 6. Coeficient of linear correlation between growth parameters and nutrient concentration, nutrient uptake, and nutrient uptake efficiency by shoots in 9 rice cultivars.

Variables	Plant height	Tillers	Shoot dry weight
Plant ht.	1.00		
Tillers	0.46**	1.00	
Shoot dry wt.	0.75**	0.68**	1.00
Nutrients conc.			
N	-0.51**	-0.33NS	-0.60**
P	0.50**	0.19NS	0.49**
K	0.45*	0.35NS	0.38*
Ca	-0.48**	-0.26NS	-0.33NS
Mg	-0.22NS	0.52**	-0.48*
Na	-0.61**	-0.52**	-0.71**
Fe	-0.57**	-0.30NS	-0.54**
Mn	-0.04NS	-0.08NS	0.03NS
Zn	-0.59**	-0.43*	-0.77**
Cu	-0.74**	-0.44*	-0.69**
Nutrients uptake			
N	0.47*	0.51**	0.64**
P	0.70**	0.48**	0.83**
K	0.73**	0.65**	0.88**
Ca	0.48*	0.49**	0.79**
Mg	0.73**	0.38NS	0.78**
Na	-0.35NS	-0.35NS	-0.42*
Fe	0.46*	0.55**	0.73**
Mn	0.59**	0.05NS	0.46*
Zn	0.35NS	0.37NS	0.33NS
Cu	-0.07NS	0.14NS	0.18NS
Nutrients uptake efficiency			
N	0.46*	0.34NS	0.60**
P	-0.51**	-0.12NS	-0.52**
K	-0.37NS	-0.36NS	-0.36NS
Ca	0.42*	0.23NS	0.27NS
Mg	0.18NS	0.54**	0.49**
Na	0.39*	0.46*	0.46*

Nutrient conc. = Nutrient content per unit of dry matter; Nutrient uptake = nutrient conc. x dry matter; Nutrient uptake efficiency = mg dry matter/mg nutrient absorbed.

*, ** = Significant at the 5% and 1% level of probability, respectively. NS = Not significant.

stepwise multiple regression analysis (Table 7). Plant height was best explained by tissue concentrations of Ca, Na, Ca, and Mn and uptake of Zn.

TABLE 7. Multiple regression equation relating overall height, tillers and shoot weight of rice cultivars with salinity levels and nutrients concentration, nutrients uptake and nutrients uptake efficiency.

Growth parameter	Regression equation	R^2
Plant height	Y = 60.70 - 2.85CaC - 0.70NaC - 0.38 CuC + 0.001 MnC + 0.082 ZnU	0.86**
Tillers	Y = 2.14 + 0.027NU + 0.011KU + + 0.022 ZnU + 0.019 MgUE	0.65**
Shoot dry wt.	Y = 2.34 - 0.12KC + 0.024KU + 0.061 CaU + 0.006NaU + 0.003CaUE + + 0.0005MgUE	0.99**

C = Stands for conc.; U = Stands for uptake; and UE = Stands for uptake efficiency of respective nutrients.

** Significant at 1% probability level.

Tiller numbers were mainly influenced by uptake of N, K, Zn and Mg-uptake efficiency. As far as shoot dry weight is concerned, 99% (R^2 = 0.99**) variation was due to K concentration, uptake of K, Ca, Na and uptake efficiency of Ca and Mg.

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