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Growth, Yield and Mineral Composition of Three Rice Varieties Cultivated under Salt-Affected Conditions

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A pot experiment was conducted to study the relative performance of IR 6,KS 282 and IR 10198-66-2 rice varieties cultivated under salt-affected conditions at EC of 6.0,9.0 12.0 dS m^{-1} in a sandy clay loam soil having ECe of 1.6 dS m^{-1} treated as control. Six seedlings of 39-day old were transplanted to each pot having 12 kg soil. The fertilizer as nitrophos and potassium sulphate at the rate of 57.0, 25.0 and 50.0 mg N,P and K kg $^{-1}$ soil respectively was applied at the time of transplanting while zinc sulphate at the rate of 5 mg Zn kg $^{-1}$ soil and 43.0 mg N kg $^{-1}$ of soil as additional dose were applied 19 and 30 days after transplanting respectively. Normal plant protection measures were also adopted. The data on growth and yield components like number of tillers, panicles, paddy grains, filled and unfilled grains, yield per plant and sterility were recorded and shoot and straw samples were analysed for sodium, potassium, calcium and chloride contents. It was observed that growth and yield of all the varieties

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were reduced significantly with increasing soil salinity. Na/K and Na/Ca ratios in shoot and straw increased significantly with increasing soil salinity. It was also observed that higher values of Na/K and Na/Ca ratios in shoots affected growth parameters while higher values of these ratios in straw affected yield components and grain yield. However, IR 6 having relatively lower values of Na/K and Na/Ca ratios proved to be the most salt-tolerant rice among the three varieties studied.

Key Words: soil salinity, growth and yield, mineral composition, rice varieties.

1. INTRODUCTION

Salinity, being the serious constraint in obtaining the increased crop yield, is among the most important problems affecting the irrigated agriculture in the world. Out of 230 million hectare total irrigated land in the world, one third is believed to be salt-affected (Mass and Hoffman,1977)and salinity is seriously limiting crop production on 20 million hectares in the world(El-Ashry et al.,1985). As climatic conditions of Pakistan are characterised by short winter and long summer seasons, high evapotranspiration and low rainfall are responsible for inadequate leaching and consequently the accumulation of salts in the soil profile and sodium becomes a dominant cation in soil solution and on the exchange complex due to precipitation of calcium and magnesium. Moreover, secondary salinization related to canal irrigated area, is the result of insufficient and unequal application of irrigation water, poor drainage, use of poor quality ground water, re-distribution of salts in soil profile due to high water table and lack of proper management of water and soil.

It is believed that harmful effects of high sodium concentration in the medium on plant growth can be categorised as, (a) inhibition of water uptake due to low osmotic potential of the culture solution/soil (Lea-Cox and Syvertsen, 1993), (b) disturbance of normal metabolism caused by high sodium concentration in plant tissues (Cramer et al.,1990), (c) inhibition of the absorption of other essential cations by plants (Cachorro et al.1994). Due to inhibition of the absorption of essential nutrients by plants, especially potassium and calcium, by higher concentrations of sodium in growth medium (Song and Fujiyama,1996), the ratios of different nutrients in shoots and straw of different varieties is disturbed and as a result higher concentrations of some nutrients cause toxicity while lower concentration of other nutrients cause deficiency, leading to poor plant growth and ultimately low yield. The specific ratios of different nutrients especially sodium, potassium and calcium play an important role in determining the salt tolerance of different varieties of a crop.

In this study, the effect of increasing soil salinity on growth, yield, mineral composition and cation ratios and the role of these ratios in determining the salt tolerance of rice varieties was studied to find out salt-tolerant rice variety capable of giving high yields under salt-affected conditions for the utilisation of these soils for increased agricultural production.

2. MATERIALS AND METHODS

These studies were carried out at Faisalabad (Pakistan) in a pot experiment using sandy clay loam soil having the following characteristics (Table 1) to check the performance of three varieties cultivated under salt-affected conditions and to find out relatively more salt-tolerant rice variety for better utilisation of salt-affected soils.

Nursery of two salt-tolerant rice varieties(IR 6 and KS 282) and a salt-tolerant experimental line(IR 10198-66-2) was raised in glazed pots. The experiment was laid out in completely randomised design with four salinity levels including control (ECe 1.6, 6.0, 9.0 and 12.0 dS m^{-1}) and three replications. The glazed pots were filled with 12 kg air dried soil and a basal dose of fertilizer at the rate of 57.0, 25.0 and 50.0 mg of N, P and K kg $^{-1}$ soil respectively as nitrophos and potassium sulphate was applied at the time of filling of pots. Six seedlings of 39-day old were transplanted to each pot. Later on ECe of 6.0, 9.0 and 12.0 dS m^{-1} was developed 13, 16 and 19 days after transplanting (DAT) respectively by adding mixture of salts. The mixture of salt contained, on equivalent basis, magnesium sulphate, sodium chloride, calcium chloride and sodium sulphate in the ratio of 1:4:5:10 having Na : Ca : Mg ratio of 14 : 5 : 1 and Cl : SO_4 ratio of 9 : 11. Zinc sulphate at the rate of 5 mg Zn kg^{-1} soil was added to pots 19 DAT and 43.0 mg N kg^{-1} soil was applied as additional dose 30 DAT. Normal plant protection measures were also adopted to control insect attack. The data regarding number of tillers, panicles, paddy grains, straw and paddy yield per plant and sterility was recorded. After harvesting the crop, a representative air-dried soil sample was collected from each pot and was analysed for pHs, ECe,

Table 1. Physical and chemical properties of soil studied.

Soil type	Saturation (%)*	pHs**	ECe (dS m^{-1})	Saturation Extract: Cations ($me\ l^{-1}$)		Anions ($me\ l^{-1}$)	
Sandy clay loam	26	8.0	1.6	i.Ca+Mg	10.2	i. CO_3	0.0
				ii.Na	1.7	ii. HCO_3	2.8
				iii.K	0.3	iii. Cl	5.0
						iv. SO_4	8.7

* Water held by soil at saturation(=wt. of water/wt of soil*100)

**pH of saturated soil paste

soluble cations and anions. The shoot and straw samples were analysed for N, P, K, Ca, Mg, Na, Zn and Cl. Analysis of soil, shoot and straw was carried out according to the methods described by the U. S. Salinity Laboratory Staff (1954). At the end of the experiment, the salinity levels were observed as ECe of 2.1, 6.0, 9.1 and 11.9 dS m^{-1} in place of 1.6, 6.0, 9.0 and 12.0 dS m^{-1} which will be used in later discussions.

3. RESULTS

3.1. Effect of salinity on growth, yield components and grain yield.

The number of tillers per plant decreased with increasing soil salinity (Table 2). It was observed that number of tillers per plant at maximum tillering stage were reduced significantly as compared to control but the decrease was non-significant among higher salinity levels. The effect of salinity on decrease in tillers was more significant during early growth stage i.e. maximum tillering stage (47 DAT) but the effect became non-significant during later stages of growth i.e. near maturity. All the three rice varieties were significantly different from each other in number of tillers at 47 DAT but KS 282 and IR 10198-66-2 were statistically alike at maturity whereas IR 6 was significantly different from them. Maximum tillers were observed in IR 6 followed by IR 10198-66-2 and minimum in KS 282 at all growth stages. At maturity, IR 6 and IR 10198-66-2 showed the same number of tillers per plant at EC of 11.9 dS m^{-1} to their respective lower salinity level of 9.1 dS m^{-1} but KS 282 exhibited a decrease (Table 2).

The number of panicles per plant were decreased with increasing levels of soil salinity (Table 2). The decrease was highly significant at all salinity levels in all the three rice varieties. Maximum number of panicles per plant were recorded in IR 6 followed by IR 10198-66-2 and minimum in KS 282. IR 6 and IR 10198-66-2 were statistically alike for number of panicles but both

Table 2. Effect of soil salinity on physical parameters of different rice varieties.

Salinity level	No. of tillers per plant(47 DAT)*			No. of tillers per plant(at maturity)		
EC(dS m-1)	KS 282	IR 6	IR 10198-66-2	KS 282	IR 6	IR 10198-66-2
2.1	13.4	16.9	15.4	14.1	17.2	15.1
6	10.8	14.6	13.1	13.3	16.4	13.8
9.1	10.2	13.5	12.5	13.5	14.9	14
11.9	8.9	12.5	11.8	12	14.9	14

Salinity level	No. of panicles per plant			No. of paddy grains per plant		
EC(dS m-1)	KS 282	IR 6	IR 10198-66-2	KS 282	IR 6	IR 10198-66-2
2.1	10.1	13.3	12	694.7	775	669.7
6	7.8	10.8	9	649.7	725.3	619
9.1	6.7	8.5	7.4	623	679.3	589.3
11.9	5.2	6.8	7.6	607.3	675	615.3

Salinity level	Sterility(%)			Paddy yield (g plant-1)		
EC(dS m-1)	KS 282	IR 6	IR 10198-66-2	KS 282	IR 6	IR 10198-66-2
2.1	14.7	13	15.8	15.1	15.9	14.1
6	17.2	16.4	20.6	12.6	13.5	12
9.1	18.8	19	29.2	11.7	12.8	10.6
11.9	23.5	23.7	29.8	11.3	12.6	12.4

* = Days after transplanting.

had significantly higher number of panicles than KS 282. IR 10198-66-2 produced higher number of panicles at the highest salinity level (EC 11.9 dS m^{-1}) than at EC of 9.1 dS m^{-1} and showed the highest number of panicles among all the rice varieties at this salinity level.

The number of paddy grains per plant were decreased significantly with soil salinity but the decrease was non-significant among higher salinity levels(Table 2). The decrease in paddy grains was consistent with salinity increase at all salinity levels in KS 282 and IR 6 whereas IR 10198-66-2 showed higher number of paddy grains at EC of 11.9 dS m^{-1} than at EC of 9.1 dS m^{-1}. Maximum number of paddy grains were observed in IR 6 at all salinity levels while minimum in IR 10198-66-2. Moreover, KS 282 and IR 10198-66 were statistically alike in number of paddy grains while IR 6 had significantly higher number of paddy grains.

There was a significant increase in grain sterility with increasing soil salinity at all salinity levels (Table 2). KS 282 and IR 6 were statistically alike for grain sterility whereas IR 10198-66-2 showed significantly higher grain sterility. It was also observed that there was a gradual increase in grain sterility at all salinity levels in KS 282 and IR 6 but IR 10198-66-2 showed more or less same sterility percentage at EC of 9.1 and 11.9 dS m^{-1}.

The grain yield was decreased with increasing soil salinity in all the three rice varieties (Table 2). The decrease was highly significant as compared to control but was non-significant among higher salinity levels. KS 282 and IR 10198-66-2 were statistically alike for paddy yield but IR 6 was having significantly higher grain yield than both other varieties. The grain yield of all the three rice varieties decreased gradually with increasing soil salinity except in IR 10198-66-2 which interestingly produced higher grain yield at EC of 11.9 dS m^{-1} than at EC of 9.1 dS m^{-1} .

The number of panicles per plant were decreased with increasing levels of soil salinity (Table 2). The decrease was highly significant at all salinity levels in all the three rice varieties. Maximum number of panicles per plant were recorded in IR 6 followed by IR 10198-66-2 and minimum in KS 282. IR 6 and IR 10198-66-2 were statistically alike for number of panicles but both had significantly higher number of panicles than KS 282. IR 10198-66-2 produced higher number of panicles at the highest salinity level (EC 11.9 dS m^{-1}) than at EC of 9.1 dS m^{-1} and showed the highest number of panicles among all the rice varieties at this salinity level.

3.2. Effect of salinity on mineral composition.

There was an increase in Na and Ca contents whereas a decrease in K content in straw with increasing soil salinity (Fig. 1). The increase was highly significant among all salinity levels in case of Na and Ca contents in straw of different rice varieties. All the three rice varieties were significantly different from each other for Na content in straw. Maximum Na content was observed in straw of IR 10198-66-2 while minimum in IR 6 at all salinity levels.

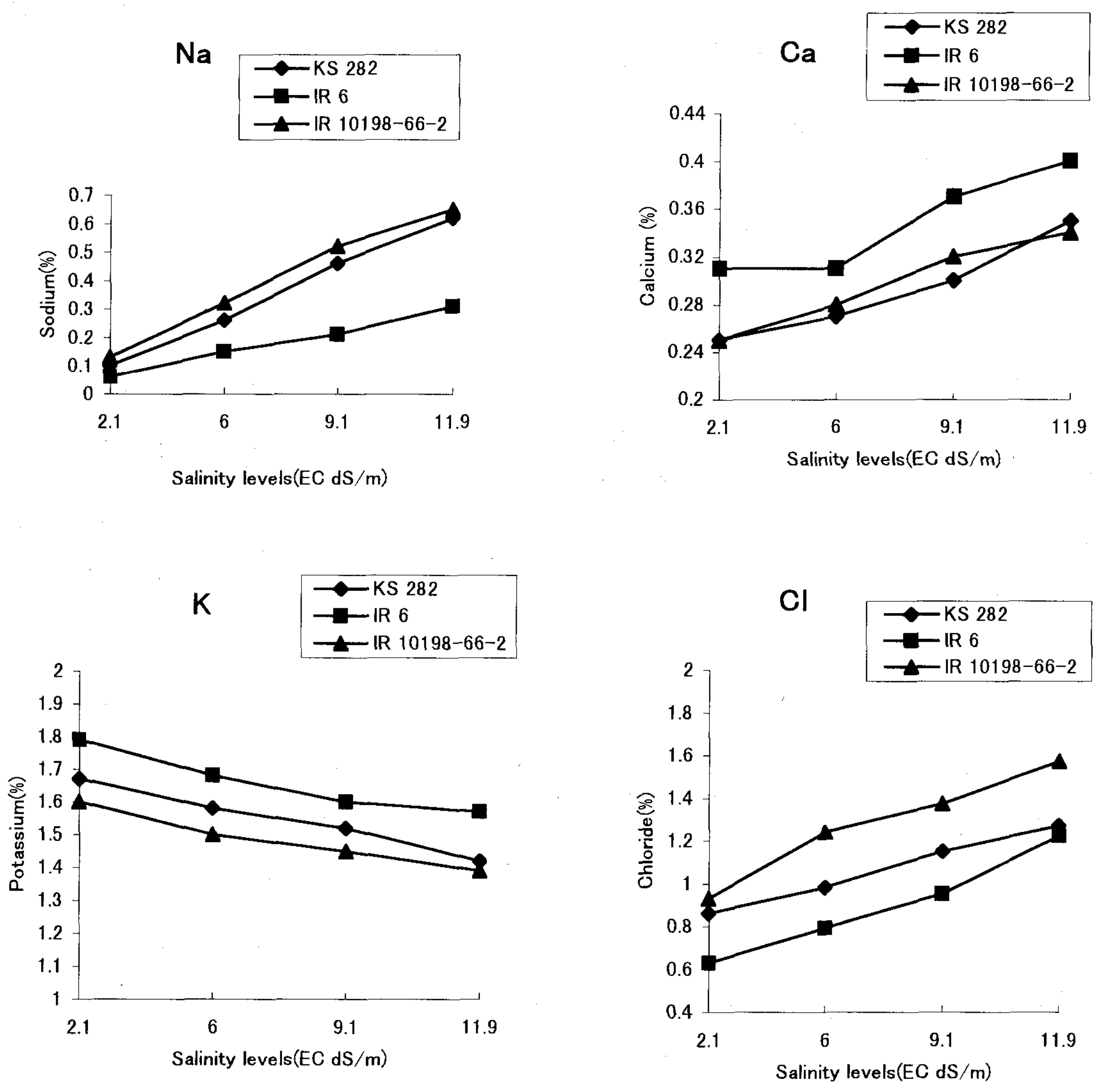

Fig. 1. Effect of salinity on Na, Ca, K and Cl concentrations in straw of rice varieties.

KS 282 and IR 10198-66-2 were statistically alike for Ca content in straw whereas IR 6 had significantly higher Ca content at all salinity levels than the both other varieties (Fig. 1). The lowest Ca content was recorded in straw of KS 282 at lower salinity levels but IR 10198-66-2 exhibited the lowest Ca content in straw at EC of 11.9 dS m^{-1}.

There was a significant decrease in K content in straw of all the rice varieties at all salinity levels (Fig. 1). Maximum K content was observed in straw of IR 6 at all salinity levels followed by KS 282 and minimum in IR 10198-66-2. Moreover all the varieties were significantly different from each other for K content in straw.

There was an increase in Cl content in straw of all the rice varieties with increasing soil salinity (Fig. 1). The increase was non-significant up to EC of 9.1 dS m^{-1} but a significant increase was observed at EC of 11.9 dS m^{-1} . All the three rice varieties were significantly different from each other. IR 6 had the lowest Cl content in straw followed by KS 282 and highest in IR 10198-66-2.

Na/K ratio was increased in straw of all the rice varieties with increasing soil salinity (Fig. 2). Higher values of Na/K ratio were observed in IR 10198-66-2 while IR 6 showed the lowest values. KS 282 and IR 10198-66-2 showed

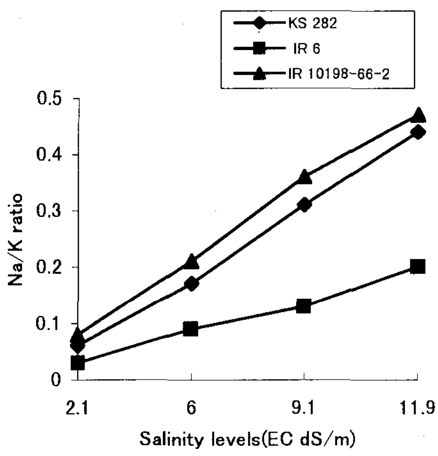

Fig.2.Na/K ratio in straw of rice varieties.

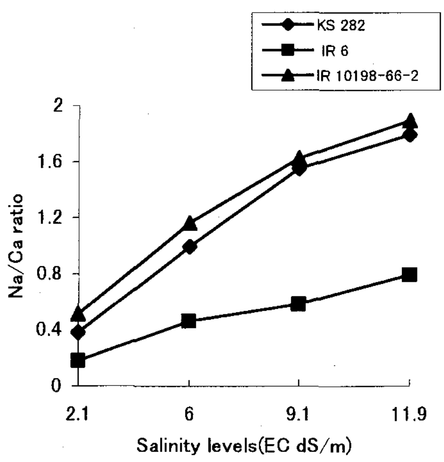

Fig.3.Na/Ca ratio in straw of rice varieties.

more or less similar pattern of increase in Na/K ratio at all salinity levels with a greater increase at each salinity level whereas the corresponding increase was very little in IR 6. It was also observed that IR 10198-66-2 exhibited relatively smaller increase in Na/K ratio at the highest salinity level than the corresponding increase in other varieties.

Na/Ca ratio was also increased in straw of all the rice varieties with increasing soil salinity (Fig. 3). The pattern of increase in Na/Ca ratio in straw of all the varieties and the increase in Na/Ca ratio at the highest salinity level was more or less similar as in case of Na/K ratio in straw.

4. DISCUSSION

The number of tillers were reduced with increasing soil salinity. The decrease in tillers might be due to result of decreased membrane permeability or enzyme activity under saline conditions and metabolic limitations caused by ion toxicity due to accumulation of saline ions for osmotic adjustment. Moreover plant cells may be energy deficient due to biosynthesis processes required for maintenance of salinity tolerance i.e. osmoregulation, compartmentation etc. as reported by Wyn Jones (1985). Similar decrease in tillers with salinity has also been reported by Verma and Neue (1984). The effect of salinity on decrease in tillers was significant at maximum tillering stage (47 days after transplanting) but became non-significant at maturity due to the fact that salt tolerance of plants increases with age as reported by Francois et al. (1994). Among all the three rice varieties, IR 6 was able to produce highest number of tillers per plant at all salinity levels and at all growth stages having some better mechanism to cope with limitations caused by saline conditions.

Soil salinity decreased the number of panicles per plant by adversely affecting the tillering capacity, delaying the tillering and thus decreasing the productive tillers as reported by Verma and Neue (1984). The decrease in number of panicles might be due to sodium and chloride toxicity as also reported by Muhammed (1986). IR 6 produced the highest number of panicles per plant at all salinity levels having the lowest sodium and chloride contents in straw except at the highest salinity level where IR 10198-66-2 was able to produce the highest number of panicles among all rice varieties probably due to the reason that it maintained the lowest Ca contents in straw at this salinity level (Fig. 1) to improve the nutritional balance and to lower the osmotic potential of the tissue to improve water uptake as reported by Song and Fujiyama (1996) or its higher salt tolerance at maturity.

The number of paddy grains were reduced with increasing soil salinity as also reported by Girdhar (1988). This decrease can be attributed to sodium and chloride toxicity by interference with the production of proteins which reduce productive tillers (panicles) per plant and ultimately less paddy grains, limited supply of metabolites to young growing tissues and damage to enzymic proteins exposed to low water potential as reported by Wyn Jones, (1985). IR 6 produced higher number of paddy grains due to its ability to have higher number of tillers and panicles under saline conditions than other two varieties (Table 2). Moreover, IR 6 showed relatively lower decrease in the contents of essential cation i.e. K in addition to the lower increase in Na content with increasing soil salinity while KS 282 and IR 10198-66-2 were statistically alike having relatively higher contents of Na along with greater decrease in the contents of essential cation due to suppression of uptake of the essential nutrients by Na which adversely affected growth. IR 10198-66-2 showed relatively higher number of paddy grains at EC of 11.9 dS m^{-1} than at EC of 9.1 dS m^{-1} probably due to relatively small increase in Na and Ca contents in straw at this salinity level than lower salinity levels resulting in lower increase in Na/K and Na/Ca ratios in straw and thus improving the energy balance of plant cells as reported by Wyn Jones (1985).

There was an increase in grain sterility with increasing soil salinity. Similar results have also been reported by Muhammed et al. (1986). The increase in grain sterility might be due to same reasons as discussed in case of decrease in tillers per plant with increasing soil salinity and as a consequence plant cell might become energy deficient resulting in increased infertile grains as reported by Wyn Jones (1985). IR 10198-66-2 showed negligible increase in grain sterility at EC of 11.9 dS m^{-1} probably due to its higher salt tolerance at maturity and relatively lower increase in cation ratios at this salinity level compared to lower salinity levels.

The grain yield was decreased significantly with soil salinity as also reported by Verma and Neue (1984). However, the decrease was non-significant among higher salinity levels which might be due to the fact that salt tolerance increases with age. IR 10198-66-2 produced higher grain yield at EC of 11.9 dS m^{-1} than at EC of 9.1 dS m^{-1} because it was able to produce higher number of panicles per plant and ultimately higher number of grains at the highest salinity level. Moreover, IR10198-66-2 maintained more or less same grain sterility percentage at this salinity level. IR 6 having the lowest contents of sodium and chloride and the highest content of potassium in straw, showed the highest grain yield among all the rice varieties.

There was an increase in contents of sodium and calcium but a decrease in content of potassium as also reported by Song and Fujiyama (1996). The increase in content of Na might be due to increased uptake under salinity (high Na concentration) and reduced growth while increase in content of Ca might be due to excessive uptake and accumulation for osmotic adjustment. However, the decrease in K content may be resulting from competition between Na and K as an antagonism effect and a resultant increase in the uptake of Na at the cost of K as reported by Cachorro (1994). Among all the rice varieties, IR 6 having the lowest contents of Na and Cl and the highest K and Ca contents in straw due to genetic control or selective absorption, proved to be more salt tolerant as reported by Mahmood and Quarrie (1993) and Colmer et al. (1995).

Na/K and Na/Ca ratios in straw of all the rice varieties increased with increasing salinity. It was observed that IR 6, having the lowest Na/K and Na/Ca ratios in straw, was able to produce the higher number of tillers, panicles, grains and grain yield per plant and lower grain sterility among all the rice varieties, therefore, proved to be more salt tolerant as reported by Takai et al. (1987).

It can be concluded that salinity caused accumulation of higher concentrations of saline ions, especially Na, Ca and Cl and increase in Na/K and Na/Ca ratios while decrease in K concentration. Consequently, salinity results in low osmotic potential and causing toxic effects and nutritional imbalances, make the plant cells energy deficient and ultimately result in poor growth exhibited as decrease in number of tillers and low yield resulted from decrease in number of panicles, grains and grain weight while an increase in grains sterility . It was also observed that soil salinity (higher Na concentration) reduces crop growth and ultimately the grain yield through inhibition of water uptake due to low osmotic potential of soil solution as reported by Lea-Cox and Syvertsen (1993), disturbance of normal metabolism caused by high Na content in plant tissues as reported by Cramer et al.(1990) and inhibition of the absorption of other essential cations by plants as reported by Cachorro et al.(1994). It can also be concluded that IR 6 which was capable to maintain lower concentrations of Na and Cl, higher concentration of K and relatively very little increase in Na/K and Na/Ca ratios, proved to be more salt tolerant among the rice varieties studied and thus produced relatively higher number of tillers, productive tillers(panicles), paddy grains and grain yield and possessed lower sterility percentage.

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