Influence of Manganese on Nutrient Uptake in Rice Plants under Saline Conditions

Abstract: Salinity-induced nutritional disorders adversely affect the performance of crops. The consequence of salinity disorders may result on nutrient availability, competitive uptake, transport or partitioning within the plants. Present study was aimed to investigate the effects of Mn application on nutrient uptake contributing to the salinity tolerance of the rice. A hydroponic experiment was carried out in National Agriculture Research Centre, Islamabad, Pakistan, on two rice varieties. Three NaCl salt concentrations, namely 0, 25, 50 mmol were used. Manganese sulphate was used for foliar and root application with four concentrations (0, 2, 4, 8 mg Mn L^{-1}). Salinity decreased the uptake of P, K, Ca, Mg, Mn and Zn in both applications methods while application of Mn increased the uptake of almost all the investigated macro and micronutrients. Mn root applications and foliar application methods were compared where root application method was found better for most of the nutrient uptake. Interactive effect i.e salinity×Mn treatment×methods of application was significant. The results showed that Mn application can improve the nutrient uptake capability contributing to the salinity tolerance in rice.

Keywords: Manganese, Salinity, Nutrient uptake, Rice.

INTRODUCTION

During growth and development, plants may face many stresses such as heat, drought, cold anaerobiosis and salt. salinity is considered a major stress disturbing agricultural productivity damagingly especially in arid land, as many major crops show relatively less salt tolerant (Greenway, 1980). Salinity can be described as the occurrence of excessive number of soluble salts in the root zone or soil. The key contributory cations of salinity are Na^+, Ca^+, Mg^+, K^+ and anions are Cl^-, SO_4^{-2}, NO_3^{-2}. Existence of trace ions such as B, Sr, Li, Rb, F, Mo, Ba, and Al also contribute toward salinity. This excessive amount of soluble salts in root zone weaken plant growth because salinity negatively affect the ability of plants to extract water (Tanji, 1990).

Ions present in the soil solution needed to be transported into the root, crossing both cellular and organellar membranes and distributed all over in the plant parts, (Abd El-Hady, 2007). Crop performance may be adversely affected by salinity-induced nutritional disorders. These disorders may result from the effect of salinity on nutrient availability, competitive uptake, transport or partitioning within the plant. For example, soil salinity reduces phosphate uptake and accumulation in crops primarily by reducing phosphate availability but in solution cultures ion imbalances may primarily result from competitive interactions. Salinity dominated by Na^+ salts not only reduces Ca^{2+} availability but reduces Ca^{2+} transport and mobility to growing regions of the plant, which affects the quality of both vegetative and reproductive organs. Salinity can directly affect nutrient uptake, such as Na^+ reducing K^+ uptake or by Cl^- reducing NO^-_3 uptake. Salinity can also cause a combination of complex interactions that affect plant metabolism, susceptibility to injury or internal nutrient requirement (Grattan and Grieve, 1999)

Micronutrients play many complex roles in plant nutrition and plant production. For example, Zinc and manganese function in many plant enzyme systems as bridges to connect the enzyme to the substrate upon which it is meant to act (Abd El-Hady, 2007). Manganese (Mn) is an important micronutrient for plant growth and development and sustains metabolic roles within different plant cell compartments. The metal is an essential cofactor for the oxygen-evolving complex (OEC) of the photosynthetic machinery, catalyzing the water-splitting reaction in photosystem II (PSII). Despite the importance of Mn for photosynthesis and other processes, the physiological relevance of Mn uptake and compartmentation in plants has been underrated (Alejandro *et al.*, 2020). The most-well-studied function in plant metabolism that depends on Mn is the water-splitting reaction in PSII, which is the first step of photosynthesis. This process requires the tetra-Mn cluster Mn4O5Ca to split two water molecules into four electrons, four protons, and molecular O2 (Bricker et al.,2012). The quantity of the Mn in the plant tissues is related to the growth rate (Cramer *et al*., 1991).

In saline and sodic soils, the availability of micronutrients is particularly low, and the plants grown in the soils often experience deficiencies in these elements (Page *et al*., 1990). Salinity reduces the uptake of manganese (Mn) and induces a Mn deficiency in shoots of plants, which reduces the growth (Pandaya *et al*., 2004). Mn deficiency can be a serious plant nutritional disorder in soils with high pH and high partial pressure of O2 (pO_2) where the bio-availability of Mn can decrease far below the level that is required for normal plant growth (Broadley et al., 2012). Several studies also revealed that supplemental Mn plays an important role in the adaptive responses of plants under various environmental stresses (Rahman et al., 2016).

Rice, the most important cereal crop in many parts of the world, is considered to be salt sensitive. Sensitivity of rice to salinity stress varies with the growth stage. In general, rice plants are very sensitive to salinity stress at young seedling stages and less at reproduction (Walia et al., 2005). In contrast, rice is more salt tolerant at germination stage (Hu and Schmidhalter, 2001). As Mn plays very important role in photosynthetic activity and other enzyme systems, the foliar application of this nutrient may reduce the adverse effect of stress conditions, influencing root growth and nutrient uptake capacity. Hence the objective of the study was, to explore the effect of Mn application through root as well as foliar on nutrient uptake contributing to the salinity tolerance in rice.

MATERIALS AND METHODS

A Hydroponic experiment was conducted at Land Resources Research Institute, NARC, Islamabad, to explore the effect of Mn application on nutrient uptake. Seeds of rice varieties Pakhal and KS-282 were surface-sterilized with 0.1% NaOCl for five minutes, washed thoroughly with several changes of distilled water. The seeds were soaked for 24 hours in a beaker of distilled water and then spread on trays containing sand thoroughly washed with distilled water. For growth, two weeks old, four seedlings per pot in triplicate were transplanted to 2 cm plugged holes in black painted pots containing nutrient solution without any sodium and manganese contents. All the pots and solution culture studies were conducted in a glass house having exhaust fans and no any other environmental control. Inside the glass house, maximum temperature range from 35-45 ^{0}C, minimum temperature 15-20 ^{0}C and bright sunlight, with active photoperiod of 7-9 hours. Yoshida nutrient solution (Yoshida *et al*., 1976) at pH 5.0 was used. Applied manganese levels were 0, 2, 4, 8 mg Mn L^{-1} solution as $MnS0_4$ for root application as well as foliar spray. The pH was adjusted every second day with 1 N KOH or 1 N HCl and nutrient solution was changed once a week. After two weeks salt stress was applied at the rate of 0, 25, 50 mmol NaCl with three increments. Plants were harvested after 36 days of transplantation and washed first with running tape water then with distilled water, blotted and air dried. Nutrients in the plant samples were analyzed by using wet digestion method. Digested samples were determined for Zn, Fe, Cu, Mn, Ca and Mg by using Atomic Absorption Spectrophotometer and Na and K by flame photometer. Phosphorus in the digested samples was determined according to the ammonium-vanadomolybdate method (Ryan *et al.*, 2001).

RESULTS AND DISCUSSION

It is difficult to understand the salinity-mineral nutrient interaction because results obtained in experiments conducted in the field and in solution culture are reconciling. In the field, the concentrations of some nutrients in the soil solution, particularly P, K and the micronutrients, are controlled by the solid phase and concentrations are much lower than those in nutrient solutions. In addition, certain nutrients in soil systems undergo transformations such as nitrification (ammonium to nitrate) which may be affected by salinity. To complicate matters further, field studies must contend with extreme variability in salinity, soil moisture, soil texture and soil nutritional status. These factors vary with change in location, depth and time. In solution cultures, concentrations of salts and nutrients are easily controlled over the course of an experiment. Nutrient ratios, however, are much different from those found in soil solutions and root development and architecture are entirely different from that found in soils. It is obvious that plant responses and interactions observed in artificial media may not necessarily occur as they would under natural conditions (Grattan and Grieve, 1999).

Manganese transport to the shoot can be inhibited by salinity, keeping in view this factor a study was carried to determine if increased application of Mn through root as well as foliar under saline conditions can improve nutrient uptake of rice. These two methods of Mn application (foliar and Root) were compared to investigate our hypothesis that under saline condition efficacy of foliar application is better as compared to root application.

As salinity is dominated by Na ions, Na contents increased with the increase of salinity levels but Mn application did not show any significance impact on Na concentration in rice plants. Increasing salinity decreased K and Ca contents however Mn application did not significantly influence K or Ca uptake. It seems that salinity decreased the Mg contents but it was non-significant decrease, Mn application did not show any significant difference in the Mg concentration of the plants.

Phosphorus uptake

Increasing salinity significantly decreased the uptake of P in both the methods of application in both varieties of rice but increase in Mn application showed significant increase in P uptake with maximum uptake in 2mg Mn L^{-1} treatment in Pakal while in 4mg Mn L^{-1} for KS-282. Two methods of application also showed significant difference in both varieties where Root application was found better. Interaction of salinity×Mn treatment×methods of application also presented a significant effect on P uptake with maximum uptake was recorded in 2 mg Mn L^{-1} at 0 mmol salinity level of root application for Pakahal while in KS-282 it was 8 mg Mn L^{-1} at 0 mmol salinity level of root application (Table 1).

Interaction between salinity and phosphorus (P) nutrition of plants is complex. Salt concentration adversely affected the uptake of phosphorus by plants (Pandya, *et al.*, 2004), shoot P reduced at elevating salinity level (Shiyab *et al.*, 2003). In most cases, salinity decreases the concentration of P in plant tissue but the results of some studies indicate salinity either increased or had no effect on P uptake. Plant-growing conditions, plant type and even cultivar play a large role in P accumulation. Most studies demonstrated that salinity increased tissue-P concentration in sand or solution cultures (Grattan and Grieve, 1999), not in soils. Phosphate concentration in solution cultures are often orders of magnitude higher than that in soil solutions (e.g. 2 mM vs. 2 mM). Phosphate availability is reduced in saline soils not only because of ionic strength effects that reduce the activity of phosphate but also because phosphate concentrations in soil solution are tightly controlled by sorption processes and by the low-solubility of Ca-P minerals. Therefore, it is understandable that phosphate concentrations in field-grown agronomic crops decreased as salinity (NaCl or $CaCl_2$) increased (Sharpley *et al*., 1992). Robert *et al*. (1984) reported that in maize salinity stimulated P uptake; its translocation from the root to shoot, and accumulation in root tip cytoplasm. In rice plants, Mn application either through root or shoot enhanced the uptake of phosphorus which is an essential macronutrient and had positive effects on growth parameters.

Potassium uptake

Data regarding K uptake of both rice varieties (Table 2) revealed a significant decrease with salinity increase in foliar as well as root application. Minimum K uptake was recorded at 50 mmol salinity level. Manganese application by root as well as foliar significantly increased the K uptake in both rice varieties with maximum uptake at 2 µg ml^{-1} in Pakhal and at 8 µg ml^{-1} Mn level in KS-282. Statistically significant difference in K uptake was observed between foliar and root application in Pakhal where maximum value was presented in foliar application but for KS-282 it was non-significant. Interactive effect (salinity×Mn treatment×method of application) was statistically significant where maximum K uptake was recorded at 2 µg ml^{-1} in root application of Pakhal and at 8 µg ml^{-1} Mn level in foliar application of KS-282 at 0 mmol salinity level. Maintenance of adequate levels of K is essential for plant survival in saline habitats. K nutrition is known to be disturbed under salt stress. The transcript level of several K transporter genes is changed, the deposition rate into growing cells is reduced, the concentration of K in the xylem, shoot and expanding tissue of the leaf reduced and K efflux from the root increased (Neves-Piestun and Bernstein, 2005). Potassium concentration in plant tissue, expressed on a dry mass basis, declines as the Na-salinity or as the Na/Ca in the root media is increased. Sodium-induced K deficiency has been implicated in growth and yield reductions of various crops (Grattan and Grieve, 1999). A significant decrease in K uptake was observed with increasing salinity level (Sangwan *et al.*, 2003); shoot K decreased with elevating salinity level (Shiyab *et al.*, 2003). Subbarao *et al.* (1990), Sultana *et al.* (2002), Salama (2001) and Othman *et al.* (2006) also reported that K concentration in the plant tissue was reduced as the Na salinity in the root media was increased.

Sodium uptake

Increase in salinity levels significantly elevated the sodium uptake in both varieties of rice through Mn foliar as well as root application. Although the sodium uptake was higher compared to control in Mn treatments but it deceased while increasing Mn concentration in Pakhal however in KS-282, the trend although was significant compared to control but it was non-significant among Mn treatments. Two rice varieties showed non-significant difference while interactive effect between salinity, Mn treatment and method of application was found significant in both rice varieties (Table 3). In plants, concentration of Na increases with the increase of salinity levels (AbdEl-Hady, 2007; Amer, 1999). Under saline conditions, Na in the growth medium might compete with other cations such as K, Ca and Mg, among others, resulting in the low absorption of the latter by the roots, and significant increases in the Na concentration in the leaves (Hu *et al.*, 2006). Salinization induced increases in Na ion contents in shoot and root of rice seedling (Hassanein, 1999). Haq *et al* (2003) reported that Na concentration increased significantly with an increase in salinity from 1.2 to 15 dSm^{-1} and this increase was 13.3-fold as compared to Na in plants grown under non-saline conditions.

Calcium uptake

Calcium plays an essential role in processes that preserve the structural and functional integrity of plant membranes, stabilize cell wall structures, regulate ion transport and selectivity, and control ion-exchange behavior as well as cell wall enzyme activities (Rengel, 1992; Marschner, 1995). Increase in salinity levels significantly decreased the Ca uptake by Mn foliar application aa well root application in both rice varieties. Manganese treatments responded positively by significantly increasing the Ca uptake against control with maximum uptake at 2 μg ml^{-1} in Pakhal and at 8 μg ml^{-1} Mn level in KS-282. Both methods of Mn application behaved significantly different and root application was better in Pakahl and foliar application in KS-282. Interactive effect (salinity×Mn treatment×methods of application) was statistically significant where maximum Ca uptake was recorded at 2 μg ml^{-1} in Pakhal in root application and at 8 μg ml^{-1} Mn level in KS-282 in foliar application at 0 mmol salinity level (Table 4). Salinity dominated by Na salts not only reduces Ca availability but reduces its transport and mobility to growing regions of plant, affecting the quality of both vegetative and reproductive organs. Sodium chloride induce Ca-deficiency symptoms in several plant species, reduce Ca contents in plant tissues including leaves, leaf primordia and growing tissues of the leaf (Neves-Piestun and Bernstein, 2005). Under high levels of NaCl-salinity, calcium uptake and transport to all organs was significantly reduced (Ho and Adams, 1994 a, b). Salinity reduced Ca uptake and concentration in barley (Cramer et al., 1991), rice (Sultana et al., 2002). The hazard to crops, which are susceptible to Ca-related disorders even in the absence of salinity, becomes greater under saline conditions. As the salt concentration in the root zone increases, plant requirement for Ca also increases. At the same time, the uptake of Ca from the substrate may be depressed because of ion interactions, precipitation, and increases in ionic strength. These factors reduce the activity of Ca in solution there by decreasing Ca availability to the plant. Severity of the calcium disorder depends on the kinds of ions that contribute to salinity and environmental conditions (Grattan and Grieve, 1999).

Magnesium uptake

A significant decrease in Mg uptake with increase in salinity levels by both methods of Mn application in both varieties of rice is evident in table 5. Increasing Mn concentration significantly increased the Mg uptake with maximum value at 2 µg ml^{-1} level in both rice varieties. Methods of Mn application were significantly different from each other where in rice variety Pakhal, root application was found better and in KS-282 foliar application methods presented higher Mg uptake. Interactive effect between salinity, Mn treatment and methods of application was significant in Pakhal while non-significant in KS-282. Calcium is strongly competitive with Mg and the binding sites on the root plasma membrane appear to have less affinity for the highly hydrated Mg than for Ca (Marschner, 1995). Salinity declined Mg concentration in barley ((Cramer et al., 1991) maize and barley (Salama, 2001). According to Ruiz et al. (1997) NaCl salinity reduced leaf Mg concentrations in citrus. However, increases in salinity are not always associated with decreases in leaf Mg. Neves-Piestun and Bernstein (2005) found that increases in salinity ($NaCl+CaCl_2$) only reduced leaf Mg concentration in beet and had little or no effect in leaves from five other vegetable crops that they examined.

Micronutrients status under saline conditions

The relationship between salinity and trace element nutrition is complex and salinity may increase, decrease, or have no effect on the micronutrient concentration in plant shoots. In saline and sodic soils, the solubility of micronutrients (e.g. Cu, Fe, Mn, Mo and Zn) is particularly low, and plants grown in these soils often experience deficiencies in these elements (Page *et al*., 1990).

Manganese uptake

Main objective in this hydroponic study was to investigate the effect of Mn by different method of application under saline conditions. Manganese is involved in the oxidation reduction process in the photosynthetic transport system. Biochemical research shows that this element plays a structural role in the chloroplast membrane system, and also activates numerous enzymes. As availability of micronutrient is low under saline conditions, Mn uptake significantly decreased with increasing salinity levels, however increasing Mn application significantly elevated the Mn uptake and maximum value was recorded at 8 mg Mn L^{-1} in application methods in both rice varieties (Table 6). Significant difference was observed between two methods of application where root application presented better Mn uptake compared to foliar application. Significant interaction between salinity, Mn treatment and methods of application was observed where maximum Mn uptake was observed in root application method at 0 mmol salinity in both rice varieties. It was observed that salinity reduced the Mn uptake in shoots (Pandya *et al.*, 2004) as well as in roots of plants. Examples of decrease in Mn concentration under saline conditions include rice (Sultana *et al*., 2002) barley (Cramer *et al.*, 1991) maize (Salama, 2001), bean (Doering *et al*., 1984), corn (Izzo *et al*.,1991; Rahman *et al*., 1993) pea (Dahiya and Singh, 1976), squash, *Cucurbita pepo* L. (Maas *et al*., 1972), wheat (Sangwan *et al.*, 2003) cucumber, *Cucumis sativus* L. (Soyergin and Moltay, 2002) and tomato (Alam *et al*., 1989). According to Cramer and Nowak (1992) supplemental Mn improves the growth and Mn concentration of salt stress plant.

Zinc uptake

Different behavior was observed in both rice varieties related to Zn uptake where increasing salinity increase Zn uptake in foliar application as well as root application in Pakhal while in KS-282 increasing salinity decreased Zn uptake (Table 7). Increasing Mn levels increased Zn uptake in both rice varieties with maximum uptake at 2mg Mn L^{-1} in Pakhal and 4mg Mn L^{-1} in Ks-282. Methods of Mn application showed significant difference in Pakhal while it was non-significant in KS-282. Interactive effect between salinity, Mn treatment and methods of applications was significant in both varieties of rice where maximum uptake was observed at 2mg Mn L^{-1} in root application of Pakhal and at 4mg Mn L^{-1} in root application method of Ks-282 at 0 mml salinity. The majority of studies in the literature have shown salinity increased Zn concentration in shoot tissue such as in bean (Doering *et al*., 1984), citrus (Ruiz *et al.*, 1997), maize (Rahman *et al*., 1993) and tomato (Maas *et al.*, 1972; Niazi and Ahmed, 1984; Knight *et al*., 1992), but in other studies it has not affected (Izzo *et al.*, 1991) or actually decreased Zn concentration as in cucumber leaves (Al-Harbi, 1995). Mn application enhanced the uptake of Zn which affected the growth parameters positively, because according to Fox and Guerinot (1998) Zn is an essential catalytic component of over 300 enzymes, including alkaline phosphatase, alcohol dehydrogenase, Cu-Zn superoxide dismutase, and carbonic anhydrase. Zn also plays a critical structural role in many proteins.

Copper uptake

As evident in table 8, increasing saline conditions did not impact uniformly in foliar application although the difference was significant but in root application, increase in salinity levels significantly decreased Cu uptake. Increasing Mn treatments presented significant positive response on Cu uptake with in Pakhal the maximum uptake was at 2mg Mn L^{-1} and 8mg Mn L^{-1} in KS-282. Root application method was found significantly better compared to foliar. Interactive effect i.e salinity× Mn treatment× methods of applications was also significant in both varieties of rice where maximum uptake was recorded at 2mg Mn L^{-1} of root application in Pakhal and 8mg Mn L^{-1} of foliar application in KS-282. Leaf and shoot Cu concentration decreased in salt-stressed maize grown in soil (Rahman et al., 1993) and solution cultures (Izzo *et al.*, 1991) but NaCl-salinity substantially increased leaf Cu in hydroponically-grown tomatoes.

As Cu is an essential redox component required for a wide variety of processes, including the electron transfer reactions of respiration (cytochrome *c* oxidase, alternate oxidase) and photosynthesis (plastocyanin), the detoxification of superoxide radicals (Cu-Zn superoxide dismutase) and lignification of plant cell walls (laccase) (Fox and Guerinot, 1998).

Iron

Table 9 presents the significant difference in the Fe uptake in the rice in relation to salinity and Mn treatment. Increasing salt level increased Fe uptake in foliar application but it decreased in root application. Increasing Mn application levels significantly enhanced Fe uptake with maximum value at 2mg Mn L^{-1} level in Pakhal and at 4mg Mn L^{-1} in KS-282. Root Mn application method was found significantly better compared to foliar application in both rice varieties. Interaction between salinity, Mn treatment and methods of applications was also significant in both varieties where maximum Fe uptake was recorded at 2mg Mn L^{-1} level for Pakhal and 4mg Mn L^{-1} level in KS-282 at 0 mmol salinity level. Reports on the influence of salinity on the iron (Fe) concentration in plants are as inconsistent as those that concern Zn and Cu concentration. Salinity was demonstrated to increase, decrease or have no effect on leaf Fe contents under conditions which have reduced leaf growth (Grattan and Grieve, 1999). Salinity increased the Fe concentration in the shoots of pea (Dahiya and Singh, 1976), tomato, soybean, Glycine max (L.) Merrill, squash (Maas *et al*., 1972), maize (Neves-Piestun and Bernstein. 2005) and decreased its concentration in the shoots of barley and corn (Hassan *et al*., 1970).

CONCLUSION

Rice is the most important but salt sensitive cereal crop in the world. Salinity reduces the uptake of essential nutrients for the growth. As Mn plays very important role in photosynthetic activity and other enzyme systems, its application reduces the adverse effect of stress conditions and enhance the nutrient uptake capacity contributing to the salinity tolerance in rice.

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Table 1: **Response of Mn application through different methods on P (mg pot^{-1}) uptake in different rice varieties**

Treatment Mn **(µg ml^{-1})**	**Pakhal**							**KS-282**						
	Foliar application			**Root application**			**Mean**	**Foliar application**			**Root application**			**Mean**
	Salinity level (mmol)							**Salinity level** (mmol)						
	0	25	50	0	25	50		0	25	50	0	25	50	
Control	08.67j	06.72k	07.14k	09.07 j	06.66k	09.25j	07.92 D	9.13i-k	8.63jk	10.55hi	8.96jk	10.12h-j	10.73h	9.69C
2	13.98fg	17.05d	12.79g-i	27.18a	18.55c	12.18i	16.96 A	18.10bc	13.15g	15.89de	14.95ef	14.34fg	13.71fg	15.02B
4	12.50hi	15.25e	14.08ef	19.51c	16.57d	14.01e-g	15.32 B	18.77b	15.89de	13.67fg	17.07cd	13.54fg	14.55e-g	15.58B
8	09.41j	12.60hi	14.22ef	22.54b	14.49ef	13.56e-h	14.47 C	16.57d	18.87b	16.66cd	26.09a	13.10g	8.56k	16.64A
Mean		12,04*			15.30*				14.66*			13.81*		
Mean	11.14E	12.91 C	12.06D	19.58A	14.07B	12.25D		15.64B	14.14C	14.19C	16.77A	12.77D	11.89E	
LSD (0.05)	Applcation=0.36; Trt=0.51: Application*trt=0.72; Applicatio*Salinity*trt=1.25							Applcation=0.44; Trt=0.631: Application*trt=0.77; Applicatio*Salinity*trt= 1.25						

Table 2: **Response of Mn application through different methods on K (mg pot^{-1}) uptake in different rice varieties**

Treatment Mn **(µg ml^{-1})**	**Pakhal**							**KS-282**						
	Foliar application			**Root application**			**Mean**	**Foliar application**			**Root application**			**Mean**
	Salinity level (mmol)							**Salinity level** (mmol)						
	0	25	50	0	25	50		0	25	50	0	25	50	
Control	66.13gh	37.50kl	33.01l	66.40gh	33.74l	31.16l	44.66D	64.04e-g	57.77e-g	41.14h-j	55.53f-h	49.05g-i	39.69ij	51.20B
2	105.61c	85.69de	54.25i	152.32a	110.04c	38.89kl	91.13A	87.77cd	72.01e	52.43g-i	103.15bc	69.58ef	57.46eg	73.73A
4	93.68d	66.49gh	53.91i	128.03b	81.51ef	52.88ij	79.41B	96.30c	68.72ef	55.87f-h	116.50b	72.37de	48.50g-i	76.38A
8	74.81fg	65.55h	56.23i	123.84b	74.60fg	44.19jk	73.20C	134.61a	64.09e-g	29.82j	99.50c	88.40c	51.98g-i	78.07A
Mean		66.07 B			78.13 A				70.97			68.71		
Mean	85.05B	63.81D	49.35E	117.65A	74.97C	41.78F		93.67A	69.85B	49.41C	95.68A	65.65B	49.41C	
LSD (0.05)	**Method =1.25; Trt=1.54: Method*sal=1.77; Method *Sal*trt=6.14**							**Method =4.54; Trt=6.42: Method*sal=7.86; Method *Sal*trt=15.72**						

Table 3: **Response of Mn application through different methods on Na (mg pot^{-1}) uptake in different rice varieties**

Treatment Mn (µg ml^{-1})	Pakhal: Foliar application, Salinity level (mmol) 0	25	50	Pakhal: Root application, Salinity level (mmol) 0	25	50	Mean
Control	04.98m	08.30jk	14.23h	04.88m	07.57k	10.27ij	08.37C
2	08.62jk	19.00fg	28.34b	11.42i	34.79a	14.96h	19.52A
4	07.02kl	20.52e-g	22.81cd	07.86k	20.68e-g	20.84d-f	16.62B
8	05.53lm	21.30de	23.87c	08.91jk	23.97c	18.74g	17.05B
Mean		15.38			15.41		
Mean	06.54A	17.28B	22.31A	08.26D	21.75A	16.20C	
LSD (0.05)	Method =0.58; Trt=0.82: Method*sal=1.00; Method *Sal*trt=2.00						

Treatment Mn (µg ml^{-1})	KS-282: Foliar application, Salinity level (mmol) 0	25	50	KS-282: Root application, Salinity level (mmol) 0	25	50	Mean
Control	7.70^{gh}	15.60^{fg}	21.14^{c}	6.96^{h}	19.02^{c-e}	31.80^{ab}	16.54B
2	7.55^{gh}	15.07^{ef}	27.64^{b}	6.15^{h}	20.43^{cd}	32.26^{a}	18.68A
4	8.00^{gh}	15.76^{d-f}	30.25^{ab}	6.18^{h}	16.48^{c-f}	33.46^{a}	18.35AB
8	7.84^{gh}	18.81^{ce}	30.42^{ab}	8.18g^{h}	17.10^{c-f}	32.89^{a}	19.21A
Mean		16.90			19.49		
Mean	7.77^{E}	15.56^{D}	27.36^{B}	6.87^{E}	18.25^{C}	33.35^{A}	
LSD (0.05)	Method =1.47; Trt=2.07: Method*sal=2.54; Method *Sal*trt=5.08						

Table 4: **Response of Mn application through different methods on Ca (mg pot^{-1}) uptake in different rice varieties**

Treatment Mn (µg ml^{-1})	Pakhal: Foliar application, Salinity level (mmol) 0	25	50	Pakhal: Root application, Salinity level (mmol) 0	25	50	Mean
Control	08.32f-i	04.49kl	04.67j-l	08.91e-g	04.52j-l	04.36l	05.88C
2	13.03cd	10.33d-f	06.84g-l	20.85a	13.67c	05.38i-l	11.68A
4	11.42c-e	08.57e-h	06.98g-l	18.21ab	10.26d-f	07.00g-l	10.41B
8	09.40e-g	07.57f-j	07.50f-k	17.56b	09.12e-g	05.80h-l	09.49B
Mean		08.26B			10.47A		
Mean	10.54B	07.74C	07.50CD	16.38A	09.39B	05.64D	
LSD (0.05)=	Method =2.00; Trt=0.88: Method*sal=1.25; Method *Sal*trt=2.16						

Treatment Mn (µg ml^{-1})	KS-282: Foliar application, Salinity level (mmol) 0	25	50	KS-282: Root application, Salinity level (mmol) 0	25	50	Mean
Control	6.75ef	5.11hi	4.19i	6.92ef	6.52fg	4.20i	5.62B
2	13.29ab	7.47ef	5.25hi	9.66cd	7.72e	5.13hi	8.09A
4	13.75a	7.35ef	5.04hi	10.49c	7.35ef	5.05hi	8.17A
8	12.54b	8.92d	5.54gh	14.20a	7.04ef	2.86j	8.52A
Mean		7.93A			7.26B		
Mean	11.58A	7.21C	5.00D	10.32B	7.16C	4.31E	
LSD (0.05)	Method =0.34; Trt=0.48: Method*sal=0.58; Method *Sal*trt=1.17						

Table 5: **Response of Mn application through different methods on Mg (mg pot^{-1}) uptake in different rice varieties**

Treatment Mn (µg ml^{-1})	Pakhal							KS-282						
	Foliar application			Root application			Mean	Foliar application			Root application			Mean
	Salinity level (mmol)							Salinity level (mmol)						
	0	25	50	0	25	50		0	25	50	0	25	50	
Control	2.50h-j	1.58l	1.61l	2.42ij	1.50l	1.63l	1.88D	2.85	2.80	2.87	2.90	3.36	2.87	2.92
2	3.84d	3.54e	06.84g-l	5.66a	4.22c	2.01k	3.63A	6.25	3.93	3.97	4.18	3.96	3.57	7.64
4	3.37e	2.81fg	2.52h-j	4.72b	3.34e	2.70f-h	3.24B	5.86	4.02	3.28	4.53	3.78	3.70	4.16
8	2.67gh	2.55hi	2.66gh	4.36c	2.89f	2.32j	2.91D	5.04	4.66	3.71	6.25	3.63	2.03	4.22
Mean		2.68B			3.15A				5.74A			3.73B		
Mean	3.09B	2.62D	2.33E	2.29A	2.99C	2.17F		4.96	3.85B	3.41B	4.47AB	3.68B	3.04B	
LSD (0.05)= Method =3.05; Trt=0.06: Method*sal=0.09; Method *Sal*trt=0.15								Method =3.50; Trt=ns: Method*sal=6.06; Method *Sal*trt=12.12						

Table 6: **Response of Mn application through different methods on Zn (µg pot^{-1}) uptake in different rice varieties**

Treatment Mn (µg ml^{-1})	Pakhal							KS-282						
	Foliar application			Root application			Mean	Foliar application			Root application			Mean
	Salinity level (mmol)							Salinity level (mmol)						
	0	25	50	0	25	50		0	25	50	0	25	50	
Control	38.30l	36.68l	48.75k	38.91l	43.47kl	49.05k	42.52D	49.69i	66.84f-h	63.61g-i	52.49hi	81.12ef	72.12fg	64.31C
2	68.50ij	94.14e	83.62fg	124.07b	145.51a	74.90hi	98.46A	102.71cd	89.55d	101.40cd	95.43de	102.48cd	107.58cd	101.36B
4	60.10j	76.37g-i	79.19gh	113.18cd	125.91b	113.92c	94.78B	150.11a	101.79cd	95.17de	127.10b	97.08d	108.07cd	113.22A
8	48.00k	72.57hi	90.58ef	106.60cd	106.47cd	105.19d	88.24C	127.01b	116.26bc	108.96cd	163.98a	95.29de	58.23g-i	111.62B
Mean		66.40B			95.60A				98.51			96.74		
Mean	53.73F	69.94E	75.53D	95.69B	105.34A	85.77C		107.38	95.86	92.28B	109.75	93.99	86.50	
LSD (0.05)= Method =0.21; Trt=3.05: Method*sal=4.31; Method *Sal*trt=6.12								Method =ns; Trt=6.10: Method*sal=7.48; Method *Sal*trt=14.95						

Table 7: **Response of Mn application through different methods on Cu (µg pot^{-1}) uptake in different rice varieties under saline conditions**

Pakhal

Treatment Mn (µg ml^{-1})	Foliar application			Root application			Mean
	Salinity level (mmol)						
	0	25	50	0	25	50	
Control	23.78kl	28.74jk	38.34hi	25.66kj	20.69l	22.95kl	26.70C
2	47.11fg	52.27ef	52.48ef	76.05b	84.43a	37.36hi	58.28A
4	41.73gh	46.02fg	51.68ef	64.24c	63.41cd	57.10de	54.03B
8	33.95ij	49.60f	49.55f	61.81cd	64.07c	51.84ef	52.14B
Mean		42.94B			52.63A		
Mean	36.64D	44.16C	48.02B	56.94A	58.64A	42.31C	

LSD **(0.05)= Method =8.63; Trt=2.46: Method*sal=2.84; Method *Sal*trt=4.93**

KS-282

Treatment Mn (µg ml^{-1})	Foliar application			Root application			Mean
	Salinity level (mmol)						
	0	25	50	0	25	50	
Control	24.62j	24.05j	25.87ij	25.72ij	28.65g-j	28.37g-j	26.21B
2	48.29b-e	33.50f-j	57.59ab	38.61e-i	36.97e-j	41.61d-g	42.76A
4	62.52a	38.26e-i	52.82a-d	41.69d-g	39.89d-h	43.65c-f	46.47A
8	50.19a-e	48.42b-e	62.14a	56.80a-b	38.85e-i	27.36h-j	47.29A
Mean		44.02A			37.35B		
Mean	46.40AB	36.06C	49.60A	40.70BC	36.09C	35.25C	

Method =3.91; Trt=5.53: Method*sal=6.77; Method *Sal*trt=13.55

Table 8: **Response of Mn application through different methods on Mn (µg pot^{-1}) uptake in different rice varieties**

Pakhal

Treatment Mn (µg ml^{-1})	Foliar application			Root application			Mean
	Salinity level (mmol)						
	0	25	50	0	25	50	
Control	65h	39h	48h	64h	42h	45h	51D
2	128h	109h	111h	6067b	3338d	1245g	1831C
4	148h	120h	124h	6016b	3787c	2359f	2092B
8	133h	127h	138h	6313a	3853c	2516e	2163A
Mean		107B			2962A		
Mean	118D	102D	98D	4615A	2730B	1541C	

LSD **(0.05)= Method =26.97; Trt=47.40: Method*sal=54.74; Method *Sal*trt=94.81**

KS-282

Treatment Mn (µg ml^{-1})	Foliar application			Root application			Mean
	Salinity level (mmol)						
	0	25	50	0	25	50	
Control	88l	95kl	95kl	94kl	110j-l	95kl	98D
2	182ik	152il	159il	2854f	2333g	2354g	1339C
4	202ij	215i	171il	4173b	3142d	3015e	1820B
8	185ik	212i	177il	7463a	3562c	1943h	2257A
Mean		161.3B			2596A		
Mean	165D	167D	150D	3646A	2287B	1855C	

Method =26.81; Trt=37.92: Method*sal=46.44; Method *Sal*trt=92.89

Table 9: **Response of Mn application through different methods on Fe (µg pot^{-1}) uptake in different rice varieties**

Treatment Mn (µg ml^{-1})	Pakhal							KS-282						
	Foliar application			Root application			Mean	Foliar application			Root application			Mean
	Salinity level (mmol)							Salinity level (mmol)						
	0	25	50	0	25	50		0	25	50	0	25	50	
Control	54m	56lm	68jl	53m	51m	62k-m	54 C	71kl	76jl	93j	65l	89jk	92j	81C
2	85i	128de	117e-h	198a	158c	78ij	127 A	127hi	113i	154d-f	170cd	156df	175bc	149B
4	86i	122ef	115f-h	171b	187d-f	120e-g	123 AB	155df	129hi	165c-e	188ab	140f-h	176bc	159A
8	73i-k	106h	108gh	180b	126d-f	135d	121 B	151e-g	204a	114i	195a	135gh	123hi	154AB
Mean	93 B			122 A				129B			142A			
Mean	75D	103C	102C	151 A	116B	99C		126C	131C	131C	154A	130C	142B	

LSD (0.05)= Method =3.72; Trt=5.26: Method*sal=6.43; Method *Sal*trt=12.87 (Pakhal); **Method =5.17; Trt=7.31: Method*sal=8.96; Method *Sal*trt=17.91** (KS-282)