Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1679-9275
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v34i3.13687

Growth, photosynthetic activity, and potassium and sodium concentration in rice plants under salt stress

Soledad García Morales, Libia Iris Trejo-Téllez*, Fernando Carlos Gómez Merino, Camila Caldana, David Espinosa-Victoria and Braulio Edgar Herrera Cabrera

*Colegio de Postgraduados en Ciencias Agrícolas, Km 36.5, Carretera México-Texcoco, 56230, Montecillo, Texcoco, México.*Author for correspondence. E-mail: tlibia@colpos.mx*

ABSTRACT. Salt stress affects crop growth and productivity. In this study, we determined the growth, yield of photosystem II (PSII), and K^+ and Na^+ concentration in root, stem, old leaves, and young leaves of two Mexican varieties of rice, Tres Ríos and Cotaxtla. In addition, the K^+/Na^+ ratio in stem and root of both varieties was determined. The experiment was conducted in a growth chamber under controlled conditions, under a completely randomized distribution, with a 2 x 2 (Variety x Salinity) factorial arrangement and 12 replications. Plants were grown in a hydroponic solution for 15 days and then some of them were treated with 100 mM NaCl; control plants (without NaCI treatment) were grown in parallel. Salt stress caused 20 and 15% reductions in stem and root length, respectively, in the variety Tres Ríos, while in the variety Cotaxtla no significant differences were observed in these variables compared to the control. Dry matter weight decreased by 24% in the variety Tres Ríos. The quantum yield of PSII decreased by 30% the third day of treatment application, in both varieties. Na^+ concentration was significantly ($p \leq 0.05$) higher in NaCI-treated plants. In the variety Tres Ríos, the yield of PSII was completely eradicated six days after treatment implementation, while the K+ concentration in stem and older leaves also decreased and the lowest K^+/ Na^+ ratio in stem was recorded, which could indicate that it is more susceptible to salinity than the variety Cotaxtla.

Keywords: *Oryza sativa*, yield of photosystem II, K^+/Na^+ ratio, salinity.

Crescimento, atividade fotossintética, concentração de K^+ e Na^+ em plantas de arroz em condições de estresse salino

RESUMO. O estresse salino afeta o crescimento e a produtividade das culturas. Neste ensaio determinou-se o crescimento, o rendimento do fotossistema II (PSII) e a concentração de K^+ e Na^+ nas raízes, caules, folhas velhas e jovens das variedades mexicanas de arroz: Tres Ríos e Cotaxtla. Ademais, estudou-se a relação K^+/Na^+ na parte aérea e raízes de ambas variedades. O experimento foi conduzido em uma câmara de crescimento, sob condições controladas, em delineamento inteiramente ao acaso, com arranjo fatorial 2 x 2 (Variedade x Salinidade) e 12 repetições. As plantas foram crescidas em solução hidropônica durante 15 dias e posteriormente, uma parte foi tratada com 100 mM de NaCl; e o restante como plantas controle (sem tratamento com NaCl), as quais foram crescidas paralelamente. O estresse salino provocou reduções de 20 e 15% na longitude dos brotos e raízes, respectivamente na variedade Tres Ríos; entretanto, na variedade Cotaxtla não apresentaram diferenças significativas nestas variaveis com relação ao tratamento controle. O peso da matéria seca reduziu-se 24% na variedade Tres Ríos. O rendimento quântico do PSII diminuiu 30% ao terceiro dia da aplicação dos tratamentos em ambas variedades. A concentração de Na^+ foi significativamente maior ($p \leq 0,05$) nas plantas tratadas com NaCl. No entanto, na variedade Tres Ríos, o rendimento do PSII diminuiu completamente depois de seis dias da aplicação dos tratamentos, a concentração de K^+ nos talos e folhas velhas também foi diminuída e registrou-se a menor relação K^+/Na^+ nos brotos, o que poderia indicar que se trata de uma variedade mais suscetível à salinidade com relação a variedade Cotaxtla.

Palavras chave: *Oryza sativa*, rendimento do fotossistema II, relação K^+/Na^+, salinidade.

Introduction

Salinity is a major problem in irrigated and rain-fed agriculture. The irrigated farming system provides about a third of the world's food (MUNNS, 2002) and it is estimated that about 20% of the irrigated area (45 million ha) is affected by salinity (FAO, 2008). Salt stress is also a problem in rain-fed agriculture, especially in coastal areas as salt water enters them during high tide (WALIA et al., 2005). It is estimated that 2% of the rain-fed agriculture area (32 million ha) is affected by salinity (FAO, 2008). The salinity problem has been addressed through improvements in production practices and the introduction of tolerant varieties.

However, the implementation of proper irrigation management in areas affected by salinity has been economically unviable and difficult to implement on a large-scale basis (WALIA et al., 2005).

Osmotic stress and ion toxicity are effects caused by salinity. Osmotic stress is the result of the salt in the growth solution reducing the capacity of the plant to absorb water, while ion toxicity is caused by an excessive amount of salts entering the transpiration flow and damaging leaf cells. Reduced growth and photosynthesis are the main effects of salt stress (MUNNS et al., 2006). The ability of plants to grow under salinity is a feature that determines crop distribution and productivity in many areas; therefore, it is important to understand the mechanisms that confer tolerance in saline environments (PATTANAGUL; THITISAKSAKUL, 2008).

In general, rice shows variability in its sensitivity to excessive salinity at different stages of growth. It is considered a relatively saline-tolerant species in the germination stage, whereas the vegetative and early reproduction stages are the most sensitive to salinity, directly affecting yield (ZENG, 2004).

Several studies have been conducted to identify responses of rice to salinity. Walia et al. (2005) compared phenotypic responses of two *indica* rice genotypes, salt-tolerant FL478 and salt-sensitive IR29, under salinity stress during the vegetative stage of growth. Their results demonstrate that FL478 is salt tolerant and maintains a low Na^+-to-K^+ ratio in shoot tissue, and may be relatively less stressed at the cellular level compared to IR29. Moreover, Moradi and Ismail (2007) evaluated three rice varieties (IR651, IR632 and IR29) during vegetative stage under culture solution and three electrical conductivities (0, 6 and 12 dS m^{-1}). They found that tolerant rice varieties maintained a relatively higher photosynthetic function after a brief period of acclimation following exposure to salt stress. Results of three *indica* rice (Pokkali, Java and IR20) grown under 0, 50 or 100 mM NaCl in hydroponic culture, suggest that differences in the amount of Na^+ entering in shoot, and as a consequence the ability of a rice variety to withstand saline stress, are influenced by the location, amount and chemical composition of apoplastic barriers in the roots (KRISHNAMURTHY et al., 2009).

The aim of this study was to determine the effect of salt stress on the growth and photosynthetic activity of two Mexican rice plant varieties (Tres Ríos and Cotaxtla) during the vegetative stage (tillering), as well as evaluate the K^+ and Na^+ concentration in root, stem, old leaves and young leaves in plants grown under controlled conditions, and also the K^+/Na^+ ratio in shoot and root in order to identify their salinity-tolerance level.

Material and methods

We used two varieties of rice (*Oryza sativa* L. ssp. *indica*), Cotaxtla and Tres Ríos, obtained from the germplasm bank at the experimental field operated by the National Institute of Forestry, Agricultural and Livestock Research in Zacatepec, Morelos. The experiment was conducted at the Max Planck Institute of Molecular Plant Physiology in Golm, Germany, between January and February 2010.

The seeds of both varieties were surface sterilized with 70% ethanol for 5 min. and then disinfected with a solution of 3% sodium hypochlorite and a drop of Tween 20 for 30 min., then washed with sterile water five times and dried in filter paper. The dried embryos were placed in a glass bottle containing MS medium (MURASHIGE; SKOOG, 1962), supplemented with 3% (w/v) sucrose and solidified with 0.8% agar.

For germination, the glass bottles were subjected to darkness for five days at 28°C. Then the germinated seeds were transferred to a tissue culture room under controlled conditions (16h light at 140 μmol m^{-2} s^{-1}, 22°C, 8h dark and 70% relative humidity) for seven days. Twelve days after seeding, the plants were transplanted to hydroponic tanks containing 10 L of nutrient solution containing 1.43 mM NH_4NO_3, 1.00 mM $CaCl_2$ $2H_2O$, 1.64 mM $MgSO_4$ $7H_2O$, 0.13 mM K_2SO_4, 0.32 mM NaH_2PO_4 $2H_2O$, 1.00 Fe-EDTA, 7.99 μM $MnCl_2$ $4H_2O$, 0.15 μM $ZnSO_4$ $7H_2O$, 0.15 μM $CuSO_4$ $5H_2O$, 0.075 μM $(NH_4)_6Mo_7O_{24}$ $4H_2O$ and 1.39 μM H_3BO_3 (YANG et al., 1994). The pH of the nutrient solution was kept between 5.5 and 6.0. The nutrient solution was renewed every 5 d.

Two NaCI concentrations, 0 mM (control) and 100 mM, and two rice varieties (Tres Ríos and Cotaxtla) were evaluated. Salt stress was applied 15 days after transferring plants into hydroponic tanks by adding 100 mM NaCl. Non-stressed plants (control) were grown in parallel.

Photosynthetic activity was determined with the PAM-2000 portable fluorometer (Walz, Germany), without dark adaptation. The measurements were made in the second fully expanded leaf before applying the treatments, 1, 3, 5 and 6 days after initiation of salt stress. Six days after treatment application, plants were harvested and separated into shoot and root to determine their length, fresh weight and dry weight. The roots were rinsed twice to remove excess salts from the nutrient solution.

The dry weight was determined 48h after drying the samples at 70°C in an oven with forced air circulation. To determine the concentration of potassium (K^+) and sodium (Na^+), plants were divided into root, stem, old leaves and young leaves. The dry samples were subjected to wet digestion with a mixture of perchloric and nitric acids (ALCÁNTAR; SANDOVAL, 1999). The extracts obtained were read on a VARIAN™ Liberty Series II inductively coupled plasma-atomic emission spectrometer (ICP-AES), while the K^+/Na^+ ratio was obtained from the content of these ions in shoot and root, based on the concentration and dry matter weight.

The data were analyzed with SAS statistical analysis software ver. 9.0 (SAS INSTITUTE, 1990) under a completely randomized design in a 2 x 2 (variety x concentration) factorial arrangement, resulting from the combination of four treatment levels with 12 replications each. A plant was considered an experimental unit. To determine statistical differences, we performed an analysis of variance and a means comparison using Tukey's test with a significance level of 95%.

Results and discussion

Root and stem growth

Based on the variety factor, there were no significant ($p > 0.05$) differences in stem length; however, due to NaCI concentration and its interaction with the variety, there were highly significant ($p \leq 0.01$) differences. In the case of root length, the three sources of variation presented significant differences (Table 1).

Table 1. Results of analysis of variance (ANOVA) of variety, NaCl concentration (NaCl) and their interaction (Variety x NaCl) for shoot length and root length of rice plants.

Source of variation	DF	Length	
		Shoot	Root
Variety	1	ns	**
NaCl concentration	1	**	**
Variety x NaCl	1	**	*

ns = Not significant; * = Significant at 5% level; ** = Significant at 1% level.

Application of 100 mM NaCl significantly ($p \leq 0.05$) reduced shoot and root length in the variety Tres Ríos (20 and 15% respectively, compared to the control) as shown in Figure 1, while in the variety Cotaxtla there were no significant ($p > 0.05$) reductions in shoot and root length in the presence of NaCl. Similar results have been obtained in other rice varieties, namely BR11, BR23, BR29 and BR 31 (ALAM et al., 2004) treated with 0.0, 4.5, 8.5 or 12.5 dS m^{-1} (approximately equivalent to 0, 45, 85 and 125 mM NaCl, respectively). In the variety IR36, 14-days-old seedlings treated with 50 mM NaCl for 7 days showed damage symptoms caused by salinity mainly in old leaves, including rolled leaves with tips withered and necrosis(GONG et al., 2006), similar to those observed in Figure 2, which is explained by accumulation of toxic concentrations of Na^+ in older leaves (MUNNS; TESTER, 2008).

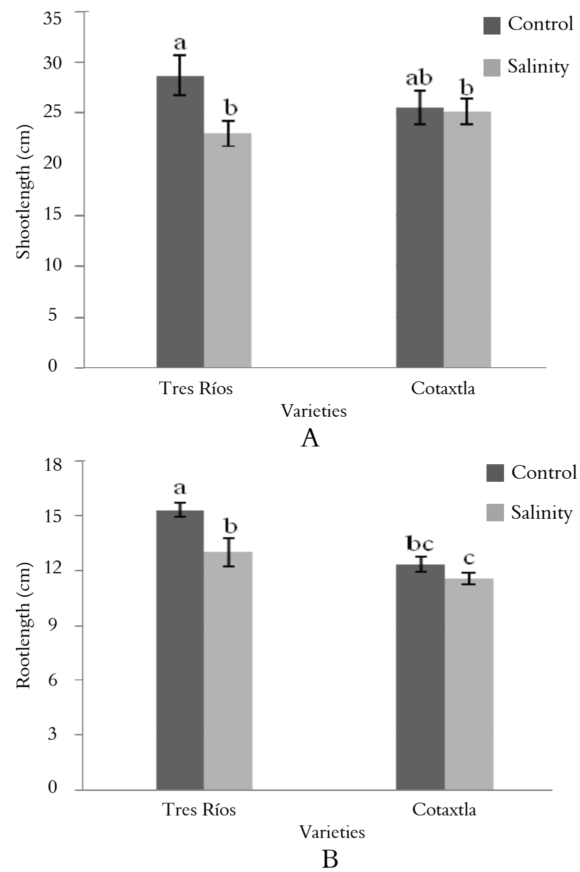

Figure 1. Effect of salinity (100 mM NaCl) on the shoot length (A) and root length (B) of rice plants of Mexican varieties (Tres Ríos and Cotaxtla), after six days of treatment.

Means with different letters, in each subfigure, are significantly different (Tukey, 0.05). Vertical bars represent standard errors (n=12).

Figure 2. Rice plants of two Mexican varieties Tres Ríos and Cotaxtla, 30 days after germination and six days after the start of salt treatment (100 mM de NaCl).

Jamil et al. (2006) found a direct relationship between reduced shoot and root length with increased salt concentration in the growth medium, which was also observed in the variety Tres Ríos in our experiments. They suggest that the above-mentioned variables are important indicators of salt stress tolerance because the root is in direct contact with the growth medium and absorbs water and other components of the media, making them available to the rest of the plant. Therefore, shoot and root length is an indicator of plant response to salinity. Furthermore, salinity problems are generally related to the presence of high concentration of Na^+ and Cl^-, and excessive salt in soil or nutrient solution causes a decrease in nutrient uptake by plant such as N by bean (CHAKRABARTI; MUKHERJI, 2003) and rice (ABDELGADIR et al., 2005). Also, ionic imbalance is an effect of salt stress, which occurs in the cells due to excessive Na^+ and Cl^- and reduces the absorption of other mineral nutrients, such as K^+, Ca^{2+} and Mn^{2+} (HASEGAWA et al., 2000; SUDHIR; MURTHY, 2004).

Biomass production

In shoot and root fresh weight, highly significant ($p \leq 0.01$) effects were found based on the source of variation, variety and NaCI concentration. Similar results were obtained in root fresh weight with the effect of the variety x NaCI interaction, contrary to that recorded in shoot where no significant difference was found (Table 2).

Table 2. Analysis of variance of variety, NaCl concentration (NaCl) and their interactions (variety x NaCl) for the shoot and root fresh weight in rice plants.

Source of variation	DF	Fresh weight	
		Shoot	Root
Variety	1	**	**
NaCl concentration	1	**	**
Variety x NaCl	1	ns	**

ns = Not significant; * = Significant at 5% level; ** = Significant at 1% level.

Salt stress (100 mM NaCl) significantly reduced shoot fresh weight in both varieties (Figure 3A). The variety Tres Ríos had 31% less shoot fresh weight and the variety Cotaxtla had 22% less, in both cases compared to the control. With respect to the variable root fresh weight (Figure 3B), only the variety Tres Ríos was affected, showing a significant ($p \leq 0.05$) decrease of 27% compared with the control.

The variety Tres Ríos had a significant reduction in shoot and root dry matter weight (Figure 4). The decrease was 24% in both variables compared with the control. This was due to the variety x concentration interaction, since no significant ($p > 0.05$) differences were found as a result of variety factor or the NaCl concentration. Similar results have been obtained in other rice varieties, BR11, BR23, BR29 and BR31 (ALAM et al., 2004), wheat (SAQIB et al., 2005) and sweet sorghum (ALMODARES et al., 2007). In the case of sweet sorghum, differences in salinity tolerance in the vegetative state are due to genetic diversity and inherited differences among varieties. It was also observed that by increasing the concentration of sodium, the fresh and dry matter weight of the plants decreased. Some species are sensitive to salinity, especially in the vegetative phase, because the mechanisms of stress tolerance have not been fully developed. However, other species may show tolerance to salinity during the vegetative phase of development (ROY et al., 2005).

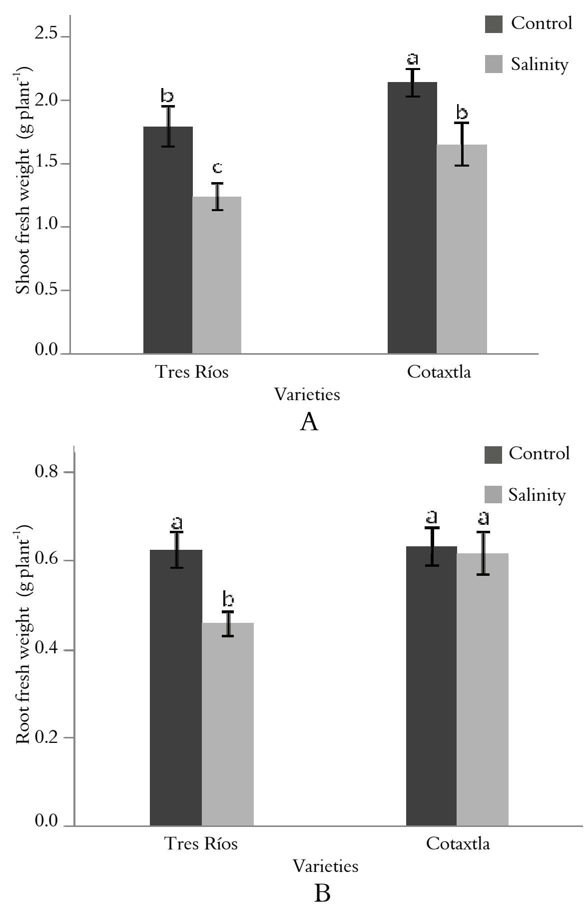

Figure 3. Shoot fresh weight (A) and root fresh weight of rice plants of two Mexican varieties (Tres Ríos and Cotaxtla), growing under salinity (100 mM NaCl) for six days.

Means with different letters, in each subfigure, are significantly different (Tukey, 0.05). Vertical bars represent standard errors (n=12).

The variety Cotaxtla showed no differences with respect to shoot and root dry matter weight, six days after the application of 0 and 100 mM NaCl. This response has been reported in other rice varieties (IR632, IR651 and IR29) in experiments in which plants subjected to salt stress for one week show no negative effects. However, after two weeks of treatment with salts, growth was significantly reduced in the three varieties (MORADI; ISMAIL, 2007).

Kumar et al. (2009) evaluated 11 varieties of rice under saline conditions and found that tolerant varieties have greater plant height and dry matter weight. In this context, the variety Cotaxtla neither had the highest shoot and root length values, nor exhibited significant ($p > 0.05$) reductions in plant length, root fresh weight, shoot dry weight and root weight, which could indicate that it is a salt-tolerant variety.

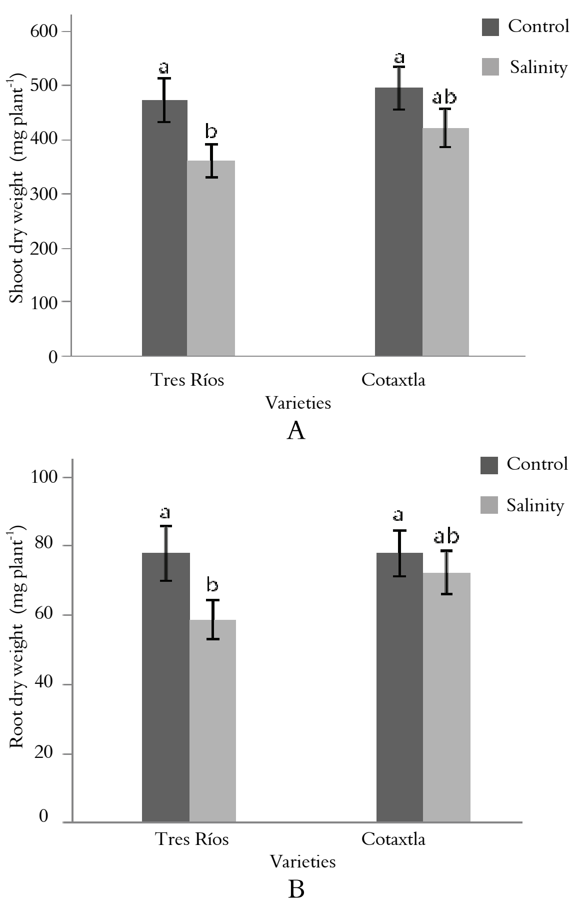

Figure 4. Effect of salinity on shoot dry weight (A) y root dry weight (B) of plant of the Mexican rice varieties (Tres Ríos and Cotaxtla), growing in the presence of 100 mM NaCl for six days. Means with different letters, in each subfigure, are significantly different (Tukey, 0.05). Vertical bars represent standard errors (n=12).

Photosynthetic activity

Plants subjected to salt stress have reduced photosynthetic efficiency, which seems to be associated with the complex of photosystem II (PSII) (MUNNS et al., 2006). Salinity reduces PSII activity and promotes the destruction of chlorophyll pigments by the accumulation of ions that may inhibit the quantum yield of electron transport in PSII (SUDHIR; MURTHY, 2004).

The above is seen in Figure 5, which shows the quantum yield of PSII in the second fully expanded leaf. When plants grew in the absence of salinity, both varieties had a high yield of PSII. However, when plants were subjected to salt stress (100 mM NaCl), a reduction of photosynthetic yield was observed three days after application of treatments in both varieties. Six days after application of treatments, the variety Tres Ríos showed no yield of PSII, while the variety Cotaxtla had a 90% reduction compared with the control.

These results differ from those reported in other rice varieties (IR651 and IR632) tolerant to salinity (MORADI; ISMAIL, 2007), and those obtained in sorghum (NETONDO et al., 2004). In both cases, there were no significant changes in the quantum yield of PSII under saline conditions, which may indicate that salinity does not severely affect the transport of electrons in sorghum (NETONDO et al., 2004). Rice varieties IR651 and IR632 can serve as an indirect way of determining the effect of salinity on the photosynthetic apparatus (MORADI; ISMAIL, 2007).

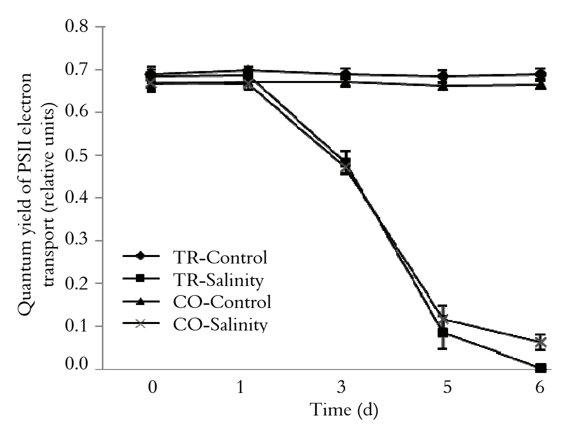

Figure 5. Changes in the quantum yield of PSII electron transport on the second fully expanded leaves of Mexican rice varieties (Tres Ríos and Cotaxtla) growing with 100 mM NaCl. Vertical bars represent standard errors (n=12).

Table 3 presents the simple effects and interaction of the factors evaluated on the quantum yield of PS II. For the variety factor, significant differences were observed on days 0, 1, 5 and 6 after the application of treatments, whereas for NaCl concentration, effects were significant at 1% on days 3, 5 and 6. Finally, the variety x NaCl concentration interaction was highly significant during the fifth and sixth days of salt stress.

Table 3. Results of analysis of variance (ANOVA) of variety, NaCl concentration (NaCl) and their interaction (Cultivar) for quantum yield of PSII in lives of rice plants.

Source of variation	DF	Time days				
		0	1	3	5	6
Variety	1	**	**	*	ns	**
NaCl concentration	1	ns	ns	**	**	**
Variety x NaCl	1	ns	ns	ns	**	**

ns = Not significant; * = Significant at 5% level; ** = Significant at 1% level.

Sodium and potassium concentration

K^+ concentration in different rice plant organs was significantly different due to the variety x NaCl concentration interaction (Table 4). In root, there were differences due to the variety factor, with Tres Ríos having a higher K^+ concentration than Cotaxtla, with and without the application of NaCl in the growth medium. In stem, the statistical differences observed are due to the NaCl concentration factor, i.e. the presence of salts significantly reduced K^+ concentration in stem. Differences were also caused by the variety x NaCl interaction, since while in the variety Tres Ríos the K^+ concentration in stem decreased significantly, it increased in the Cotaxtla variety. The same behavior was obtained in the concentration of old leaves in both varieties.

Table 4. K^+ concentration (mg kg^{-1} dry weight) on root, stem and leaves of two Mexican varieties Tres Ríos and Cotaxtla, six days after the start of salt stress (100 mM NaCl).

Varieties	NaCl (mM)	K^+ concentration (mg kg^{-1} dry weight)			
		Root	Stem	Old leaves	Young leaves
Tres Ríos	0	66.57 a	50.86 a	56.59 a	30.65 b
Tres Ríos	100	67.41 a	11.81 d	27.22 b	55.62 a
Cotaxtla	0	28.09 b	18.92 c	18.63 b	28.65 b
Cotaxtla	100	22.22 b	41.87 b	50.72 a	54.12 a
Varieties					
Tres Ríos		66.99 a	31.34 a	41.91a	43.14 a
Cotaxtla		25.16 b	30.39 a	34.67 a	41.39 a
NaCl (mM)					
0		47.33 a	34.89 a	37.61 a	29.65 b
100		44.82 a	26.84 b	38.97 a	54.87 a
$LSD_{0.05}$					
Variety (V)		4.55	22.74	23.75	8.07
NaCl		29.77	22.03	24.27	3.11
V x NaCl		7.87	6.38	22.08	6.47
CV		6.54	7.90	22.06	5.85

Means with different letters, in each column, are significantly different (Tukey, 0.05).

The reduction in the K^+ concentration obtained in the variety Tres Ríos is similar to that obtained in other rice varieties (WALIA et al., 2005) and wheat (SAQIB et al., 2005; SHARMA et al., 2005). This is due to the presence of NaCl in the growth medium, which can interfere with the absorption of cations like K^+, Ca^{2+} or Mg^{2+}, or as the result of the substitution of K^+ by Na^+ (TESTER; DAVENPORT, 2003). K^+ concentration in young leaves increased significantly by applying salinity, in both varieties, as an effect of NaCl concentration and its interaction with the variety factor.

As a result of the variety x NaCI concentration interaction (Table 5), by applying 100 mM NaCl in the hydroponic solution, Na^+ concentration was significantly higher in root, stem and leaves of both varieties, compared with the control. These results are consistent with those obtained in other rice varieties, FL478 and IR29 (WALIA et al., 2005), wheat (SAQIB et al., 2005; SHARMA et al., 2005), soybean and cucumber (DABUXILATU; IKEDA, 2005), where there was a positive relationship between salt concentration and Na^+ concentration in root and stem.

Table 5. Na^+ concentration (mg kg^{-1} dry weight) on root, stem and leaves of two Mexican rice varieties Tres Ríos and Cotaxtla, six days after the start of salt treatment.

Varieties	NaCl (mM)	Na^+ concentration (mg kg^{-1} dry weight)			
		Root	Stem	Old leaves	Young leaves
Tres Ríos	0	3.56 b	3.50 c	3.45 b	2.77 c
	100	26.37 a	13.88 b	17.15 a	9.87 b
Cotaxtla	0	2.88 b	1.41 c	1.84 b	2.17 c
	100	21.25 a	37.14 a	27.25 a	16.65 a
Varieties					
Tres Ríos		14.97 a	8.69 b	10.30 a	6.32 b
Cotaxtla		12.07 a	19.28 a	14.55 a	9.41 a
NaCl (mM)					
0		3.22 b	2.46 b	2.65 b	2.47 b
100		23.81 a	25.51 a	22.20 a	13.26 a
$LSD_{0.05}$					
Variety (V)		15.35	18.58	15.07	17.99
NaCl		5.40	11.70	6.81	3.48
V x NaCl		10.79	2.65	10.25	1.76
CV		30.54	7.25	31.56	8.55

Means with different letters, in each column, are significantly different (Tukey, 0.05).

Tester and Davenport (2003) indicate that many plants can tolerate salt stress by excluding Na^+ from the stem, or at least from the leaves, and maintaining high levels of K^+. This could be happening in the variety Cotaxtla, since in saline conditions, it had a higher concentration of Na^+ in stem than Tres Ríos, perhaps as a mechanism for excluding Na^+ from the leaves. In addition, under the same conditions, this variety had a significant increase in the K^+ concentration (Table 4) in old leaves and stem, while Tres Ríos showed reductions.

Na^+ concentration was higher in young leaves treated with salinity in both varieties. However, the variety Cotaxtla recorded a higher Na^+ concentration in young leaves compared with the variety Tres Ríos. Under some conditions, a high Na^+ concentration in stem may be beneficial in helping the plant to maintain its turgor, since the ions are sequestered in the vacuole and can thus reduce the toxicity of Na^+ (MUNNS; TESTER, 2008).

The ability of plants to discriminate between Na^+ and K^+ can be determined by an index, the K^+/Na^+ ratio (FLOWERS, 2004). Figure 6 shows the K^+/Na^+ content ratio in shoot and root of the two rice varieties studied. In general, it was found that by applying 100 mM NaCl in the hydroponic solution, the K^+/Na^+ ratio was significantly ($p \leq 0.05$)

reduced in both varieties. Similar results have been obtained in other rice varieties, FL478 and IR29 (WALIA et al., 2005) and IR36 (GONG et al., 2006), and in wheat (SAQIB et al., 2005), Sesbania rostrata and beans (JUNGKLANG et al., 2003). In shoot, the variety Tres Ríos had the lowest K^+/Na^+ ratio when the plants were subjected to stress. The information presented here is similar to that reported for other rice varieties that differ in salt tolerance (MORADI; ISMAIL, 2007). These authors found that the saline-susceptible variety IR29 had a K^+/Na^+ ratio in leaves significantly less than the IR632 and IR651 varieties (tolerant).

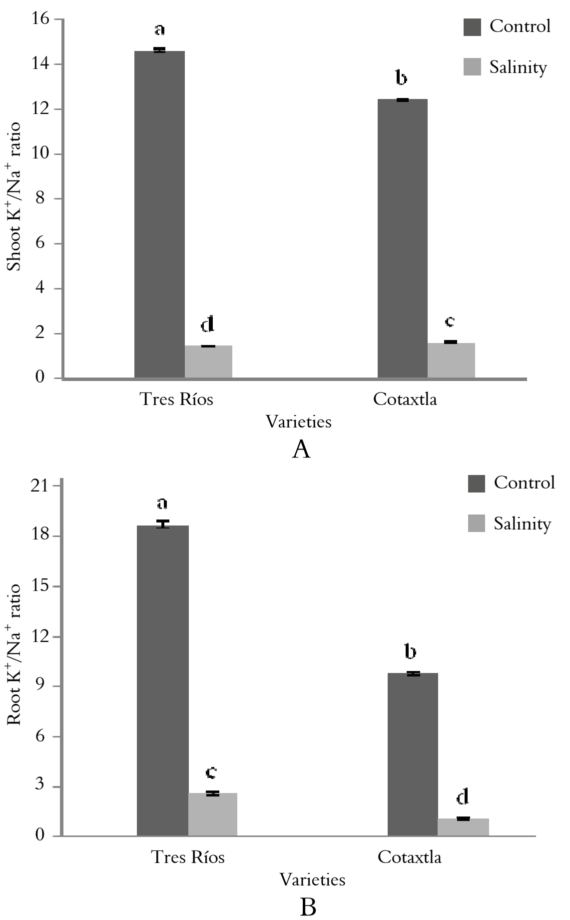

Figure 6. Effect of salinity on K^+/Na^+ ratio in shoot (A) and root (B) of Mexican rice plants Tres Ríos and Cotaxtla. After six days of exposure to 100 mM NaCl.

Means with different letters, in each subfigure, are significantly different (Tukey, 0.05). Vertical bars represent standard errors (n=4).

Conclusion

The application of 100 mM NaCl in growth medium for six days caused significant reductions in the variety Tres Ríos in shoot and root length, and fresh and dry matter weight. Moreover, it led to a significant decrease in the quantum yield of photosystem II, lower K^+ concentration in stem and leaves and, consequently, a lower K^+/Na^+ ratio in the stem, suggesting that this cultivar is more susceptible to salinity than the variety Cotaxtla, which showed greater tolerance to this stress.

Acknowledgements

We thank the National Council of Science and Technology of Mexico (CONACYT) for the award to SGM, and to LPI5 Microbial, Plant and Animal Biotechnology research line from Colegio de Postgraduados for the research facilities.

References

ABDELGADIR, E. M.; OKA, M.; FUJIYAMA, H. Nitrogen nutrition of rice plants under salinity. **Biologia Plantarum**, v. 49, n. 1, p. 99-104, 2005.

ALAM, M. Z.; STUCHBURY, T.; NAYLOR, R. E. L.; RASHID, M. A. Effect of salinity on growth of some modern rice cultivars. **Journal of Agronomy**, v. 3, n. 1, p. 1-10, 2004.

ALCÁNTAR, G. G.; SANDOVAL, V. M. **Manual de análisis químico de tejido vegetal**. Chapingo: Sociedad Mexicana de la Ciencia del Suelo A.C., 1999. (Publicación especial No. 10).

ALMODARES, A.; HADI, M. R.; DOSTI, B. Effects of salt stress on germination percentage and seedling growth in sweet sorghum cultivars. **Journal of Biological Science**, v. 7, n. 8, p. 1492-1495, 2007.

CHAKRABARTI, N.; MUKHERJI, S. Effect of phytohormone pretreatment on nitrogen metabolism in *Vigna radiata* under salt stress. **Biologia Plantarum**, v. 46, n. 1, p. 63-66, 2003.

DABUXILATU, M.; IKEDA, M. Interactive effect of salinity and supplemental calcium application on growth and ionic concentration of soybean and cucumber plants. **Soil Science and Plant Nutrition**, v. 51, n. 4, p. 549-555, 2005.

FAO-Food and Agriculture Organization. **Global network on integrated soil management for sustainable use of salt-effect soils**. Rome: FAO Land and Plant Nutrition Management Service, 2008.

FLOWERS, T. J. Improving crop salt tolerance. **Journal of Experimental Botany**, v. 55, n. 396, p. 307-319, 2004.

GONG, H. J.; RANDALL, D. P.; FLOWERS, T. J. Silicon deposition in the root reduces sodium uptake in rice (*Oryza sativa* L.) seedlings by reducing bypass flow. **Plant, Cell and Environment**, v. 29, n. 10, p. 1970-1979, 2006.

HASEGAWA, P. M.; BRESSAN, R. A.; ZHU, J.-K.; BOHNERT, H. J. Plant cellular and molecular response to high salinity. **Annual Review of Plant Physiology and Plant Molecular Biology**, v. 51, p. 463-499, 2000.

JAMIL, M.; DEOG BAE, L.; KWANG YONG, J.; ASHRAF, M.; SHEONG CHUN, L.; EUI SHIK, R. Effect of salt (NaCl) stress on germination and early seedling growth of four vegetables species. **Journal of Central European Agriculture**, v. 7, n. 2, p. 273-282, 2006.

JUNGKLANG, J.; USUI, K.; MATSUMOTO, H. Differences in physiological responses to NaCl between salt-tolerant *Sesbania rostrata* Brem. & Oberm. and non-tolerant *Phaseolus vulgaris* L. **Weed Biology and Management**, v. 3, n. 1, p. 21-27, 2003.

KRISHNAMURTHY, P.; RANATHUNGE, K.; FRANKE, R.; PRAKASH, H. S.; SCHREIBER, L.; MATHEW, M. K. The role of root apoplastic transport barriers in salt tolerance of rice (*Oryza sativa* L.). **Planta**, v. 230, n. 1, p. 119-134, 2009.

KUMAR, B. S.; TITOV, S.; MOFFAZZAL ISLAM, M.; SIDDIKA, A.; SULTANA, S.; SHAHIDUL HAQUE, M. Phenotypic and genotypic screening of rice genotypes at seedling stage for salt tolerance. **Global Journal of Biotechnology and Biochemistry**, v. 4, n. 2, p. 126-131, 2009.

MORADI, F.; ISMAIL, A. M. Responses of photosynthesis, chlorophyll fluorescence and ROS-scavenging systems to salt stress during seedling and reproductive stages in rice. **Annals of Botany**, v. 99, n. 6, p. 1161-1173, 2007.

MUNNS, R. Comparative physiology of salt and water stress. **Plant, Cell and Environment**, v. 25, n. 2, p. 239-250, 2002.

MUNNS, R.; TESTER, M. Mechanisms of salinity tolerance. **Annual Review of Plant Biology**, v. 59, n. 1, p. 651-681, 2008.

MUNNS, R.; JAMES, R. A.; LÄUCHLI, A. Approaches to increasing the salt tolerance of wheat and other cereals. **Journal of Experimental Botany**, v. 57, n. 5, p. 1025-1043, 2006.

MURASHIGE, T.; SKOOG, F. A revised medium for rapid growth and bio assays with tobacco tissue cultures. **Physiologia Plantarum**, v. 15, n. 43, p. 473-497, 1962.

NETONDO, G. W.; ONYANGO, J. C.; BECK, E. Sorghum and salinity II. Gas exchange and chlorophyll fluorescence of sorghum under salt stress. **Crop Science**, v. 44, n. 3, p. 806-811, 2004.

PATTANAGUL, W.; THITISAKSAKUL, M. Effect of salinity stress on growth and carbohydrate metabolism in three rice (*Oryza sativa* L.) cultivars differing in salinity tolerance. **Indian Journal of Experimental Biology**, v. 46, n. 10, p. 736-742, 2008.

ROY, P. K.; NIYOGI, K.; SENGUPTA, D. N.; GHOOSH, B. Spermidine treatment to rice seedlings recovers salinity stress-induced damage of plasma membrane and PM-bound H^+-ATPase in salt-tolerant and salt-sensitive rice cultivars. **Plant Science**, v. 168, n. 3, p. 583-591, 2005.

SAQIB, M.; AKHTAR, J.; QURESHI, R. H. Na^+ exclusion and salt resistance of wheat (*Triticum aestivum*) in saline-waterlogged conditions are improved by the development of adventitious nodal roots and cortical root aerenchyma. **Plant Science**, v. 169, n. 1, p. 125-130, 2005.

SAS INSTITUTE. **SAS/STAT User´s guide**. Cary: SAS Institute, 1990. (Ver. 6.0).

SHARMA, N.; GUPTA, N. K.; GUPTA, S.; HASEGAWA, H. Effect of NaCl salinity on photosynthetic rate, transpiration rate, and oxidative stress tolerance in contrasting wheat genotypes. **Photosynthetica**, v. 43, n. 4, p. 609-613, 2005.

SUDHIR, P.; MURTHY, S. D. S. Effects of salt stress on basic processes of photosynthesis. **Photosynthetica**, v. 42, n. 4, p. 481-486, 2004.

TESTER, M.; DAVENPORT, R. Na^+ transport and Na^+ tolerance in higher plants. **Annals of Botany**, v. 91, n. 5, p. 503-527, 2003.

WALIA, H.; WILSON, C.; CONDAMINE, P.; LIU, X.; ISMAIL, A. M.; ZENG, L.; WANAMAKER, S. I.; MANDAL, J.; XU, J.; CUI, X.; CLOSE, T. J. Comparative transcriptional profiling of two contrasting rice genotypes under salinity stress during the vegetative growth stage. **Plant Physiology**, v. 139, n. 2, p. 822-835, 2005.

YANG, X.; RÔMHELD, V.; MARSCHNER, H. Effect of bicarbonate on root-growth and accumulation of organic-acids in Zn-Inefficient and Zn-efficient rice cultivars (*Oryza* sativa L.). **Plant and Soil**, v. 164, n. 1, p. 1-7, 1994.

ZENG, L. Response and correlated response to salt tolerance selection in rice by yield parameters. **Cereal Research Communications**, v. 32, n. 4, p. 477-484, 2004.

Received on June 9, 2011.
Accepted on November 10, 2011.