Research Article

Deleterious Impact of Sodium Chloride (NaCl) Toxicity on Chemical Properties of Soil and Ionic Composition of Rice

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Abstract | This experiment was conducted to assess the deleterious impact of NaCl salinity on rice growth parameters. Selection of soil with customary characteristics was done. Various levels of salinity; < 4, 4, 6, 8, 10, 12 and 14 dS m^{-1} were established precisely using NaCl salt. Soil was left for appropriate period (30 days) for the accomplishment of salinity. Completely Randomized Design (CRD) was used for layout of the experiment. Transplantation of seedlings was performed in all pots. Application of mineral fertilizers @ recommended rates was done. Crop was grown till maturity and plant samples were collected from each pot for chemical analysis (Na and K). Soil samples were also collected from all treatment pots and subjected to laboratory for determination of various chemical properties (pH, EC and SAR). To calculate SAR values of soil, concentration of Ca^{2+}, Mg^{2+} and Na^{+} were also determined from all soil samples. It was observed from the results that addition of NaCl proved toxic for different chemical properties of soil as values of pH (7.23 to 8.44), EC (2.96 to 13.54) and SAR (2.45 to 11.57) were impaired negatively and in systematic manner with the increase of NaCl concentration in soil and in all treatments when compared with control. Same trend was observed for various cations like Ca^{2+}, Mg^{2+} and Na^{+} when analyzed in soil samples. In plant samples of rice, concentration of Na was enhanced in all treatments when compared with control while trend of K was in contrast to Na which decreased with the increasing level of Na. Injurious impact of NaCl was more pronounced as the concentration of salt increased in the treatments. All the data were subjected to statistical analysis for the assessment of significance level of various treatments.

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Keywords | NaCl, Salinity, pH, EC, SAR, Na, K and rice plants

Introduction

Rice (*Oryza sativa* L.) belongs to family Oryzeae. Rice is a food crop with prime importance in world. In Asia, over a half of the world's population rice is a principal food. It is extremely valued cash crop and earns large amount of foreign exchange. Generally, depending on climate circumstances average life span of rice is 3-7 months. Rice is not a plant of water but it requires a large amount of water for growing. With extreme protein contents, rice is core food crop and commonly used in serving common people but actual yield per acre of Pakistan is very low. Rice agronomically and nutritionally is a significant crop around the globe. Rice is essential food and feed above three million people in the world on everyday calorie consumption from 50 to 80 % (Khush, 2005). Particularly in Asia, rice is among top five main carbohydrate food crops for the world population. In the world more populated areas i.e., Asia, it is a staple food for over 2 million people and millions of people in Latin America and Africa (Khush and Virk, 2000). Growth pattern, productivity and growth period of rice crop is seriously impacted by temperature regimes (Darwin *et al*., 2005). It is assessed that salt-affected soils of all irrigated lands are at least 20 % (Pitman and Läuchli, 2002). In the world, the major cropping scheme is wheat-Rice. In the Indo gigantic plains of South Asia, almost 85 % of the wheat-rice zone is covering Pakistan, India, Bangladesh and Nepal (Timsina and Connor, 2001).

When rice genotypes are exposed to salt stress, K^+ (potassium) in the tissues evidently decreased (Basu *et al*., 2002). The concentration of Cl^- (chloride) and Na^+ (sodium) ions were improved with the expansion in salinity yet K^+, Mg^{2+} (magnesium) and Ca^{2+} (calcium) concentration of base (root) and shoot diminished with the increase in salinity. A pot study was conducted to check the impact of saline water, gypsum and potassium on storage of these supplements in grain protein contents and plants in cereal (*Triticum aestivum* L.). It was noted that as water saltiness expanded, Na^+ concentration increased in grain protein substance roots, leaves and K^+ substance and K^+/Na^+ (potassium to sodium) ratio diminished in roots of plants and leaves. Application of K^+ improved K^+ and K^+ to Na^+ ratio and gypsum application improved Ca^{2+} and brought down Na^+/Ca^{2+} in roots and plant leaves. K^+ and salt stress on the whole expanded protein of grain, K^+ and ratio of K^+ to Na^+ while K^+ and gypsum together expanded ($K^+ + Ca^{2+}$) buildup in plant leaves and diminished Na^+ in plant roots. Protein content of grains expanded in lower K^+ treatment and brought down with expanding potassium (Bahmaniar, 2006).

Salt stress is the most common and serious problem of agriculture. According to Ashraf *et al*. (2008) due to salinity 40,000 ha area of arable land in Pakistan has been lost and is increasing quickly each year. Due to high salinity toxicity, soil water potential is decreased, so plants become incapable to absorb water to sufficient amount from soil, ultimately reduction in plant growth rate (Tester and Davenport, 2003). Wilting occurs by constant salinity stress alike to drought symptoms, with waxed and thickened leaves and with a greenish blue color (Fraga *et al*., 2010). By osmotic effects salt stress shortens plant growth, shrinks water up takes capacity of crops that causes decline in growth. If salts pass in the crops in dangerous extent, ultimately salt concentration rise to affect senescence and photosynthetic leaf zone of plant abridged to a level that growth of plant cannot continue (Shereen *et al*., 2005). NaCl salts are quickly dissolved in the water and cause ionic effects in rice crop including higher plant (Nishimura *et al*., 2011). Cell organelles and membrane systems directly damages due to surplus Na^+ concentration in plant cells, causing abnormal development and plant growth decrease, before decay of plant (Davenport *et al*., 2005; Quintero *et al*., 2007).

Salinity persuade some injurious effects include lessened seedling growth and germination (Zeng and Shannon, 2000; Ashraf, 2010) and repressed leaf expansion which ultimately reduces production of dry matter and photosynthetic area (Mansour and Salama, 2004). In response to salinity stress, plants also show high deprivation of chlorophyll by showing symptom as yellowing of leaves. Many reports showed that decline in photosynthetic pigments happen due to salinity in several rice species (Chaum *et al*., 2007). Salinity stress together with photo inhibition causes serious injury to several physiological and cellular progressions including, cellular metabolism, photosynthesis, root growth, nutrient uptake and water absorption which all clearly lead to yield deterioration (Zeng and Shannon, 2000; Zhu, 2001; Darwish *et al*., 2009). Potential of growth of sensitive crops is restricted by soil sodicity and salinity. High salinity might lead to no yield and finally plant death. On yield of crops, the effects of salinity were shown with 5 conductivity levels (0-2, 2-4, 4-8, 8-16, >16 dS m^{-1} individually), a scale of growth and yield limitation (Eynard *et al*., 2005).

The current research work is very significant keeping in view the vast area of Pakistan having NaCl toxicity (salinity problem). This study will help to assess the limit of sodium chloride toxicity at which rice plants can grow. Furthermore, an estimate of deterioration of chemical properties of soil will also be monitored with the usage of sodium chloride in varying concentration. In the nutshell, this study will be helpful for making future policy about the utilization of saline soils in the country. The overall objective of this study was to appraise the effects of salt stress on the growth of rice as well as to judge the toxicity effects of salinity on yield of rice.

Materials and Methods

A pot experiment was carried out at College of Agriculture, University of Sargodha (UOS), to appraise NaCl toxicity on soil chemical characteristics and rice plant's ionic composition. Soil samples were obtained and laboratory analysis was done for important parameters/characteristics (Table 1). After analysis 10 kg of such soil was filled in all pots. NaCl salt was added to all the respective pots after calculations as per treatment plan and 30 days' time was given to complete chemical reactions on exchange site of the clay. Super basmati nursery of rice was transplanted in all pots. The experiment comprised of seven treatments replicated thrice with Completely Randomized Design (CRD). At maturity, plant samples of rice were collected from each pot of the experiment for the analysis of Na^+ and K^+ concentration. Soil samples were also collected from all experimental pots and shifted to the laboratory for the determination of Ca^{2+}, Mg^{2+}, Na^+, pH, EC and SAR values as affected by the addition of NaCl. Analytical methods of Handbook 60 were applied for laboratory analysis (USDA, 1969).

Table 1: *Soil characteristics used for experimentation.*

Sr. No.	Soil Characteristic	Unit	Value
1	Soil Reaction (pH)	-	7.92
2	Electrical Conductivity (EC)	dS m^{-1}	1.78
3	Sodium Adsorption Ratio (SAR)	-	10.15
4	Sodium (Na)	$mmol_c.L^{-1}$	14.0
5	Ca + Mg	$mmol_c.L^{-1}$	3.80
6	Available K	mg kg^{-1}	349.0
7	Sand	%	45.10
8	Silt	%	26.80
9	Clay	%	28.10
10	Textural Class	-	Sandy clay loam

Treatments contain; T_1= Control (normal soil); T_2 = EC 4 dS m^{-1}; T_3 = EC 6 dS m^{-1}; T_4 = EC 8 dS m^{-1}; T_5 = EC 10 dS m^{-1}; T_6 = EC 12 dS m^{-1} and T_7 = EC 14 dS m^{-1}. Statistical analysis regarding ANOVA calculation was made by means of Statistics 8.1 (Steel *et al*., 1997).

Results and Discussion

Soil reaction (pH)

Concentration of salt in soil negatively affects physical and chemical properties of soil. Increasing concentration of salts in soil affected the soil reaction (pH) and indirectly availability of water and nutrients to plants. Data indicated that pH of soil increased with increasing concentration of NaCl. The differences among various treatments regarding soil reaction were significant in terms of statistics (Figure 1). Maximum pH of 8.44 was analyzed in treatment T_7 having maximum NaCl concentration and it was followed by T_6 with value of 8.31. These 2 treatments T_7 and T_6 found non-significant when compared with each other. Lowest pH value (7.23) was determined for control treatment (T_1) and this treatment showed non-significant difference with T_2 (EC level of 4 dSm^{-1}). The determined value for $T_{3,}$ T_4 and T_5 were 7.70, 7.84 and 8.15 respectively. However, treatments T_3 and T_4 were non-significant when compared with each other. Similar difference was noticed between T_4 and T_5 (EC level of 8 and 10 dS m^{-1}).

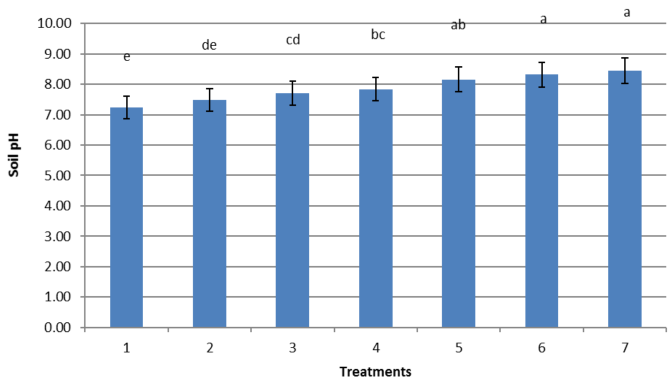

Figure 1: *Impact of NaCl toxicity on soil pH.*

These outcomes are conferring to the universal theoretic tendency (generally accepted theory). An intensification in soil pH was distinguished due to extra absorption of NaCl (EC level). This is normal when additional extent of NaCl will be supplemented in the soil; sodium already existing in this salt will pay in the direction of cumulative soil pH. Judgements of earlier experts are also similar (Brady and Weil, 2010). Likewise, Mahmood (2007) also found the matching inclination of elevation in soil pH with cumulative absorption of soluble salts.

Soil electrical conductivity (EC)

According to this experiment, application of salt (NaCl) disturbs physical and chemical soil properties. Increasing salt concentration in soil by addition of NaCl affected the amount of total soluble salts and eventually availability of water and nutrients to plants. This enhanced quantity of salts in the soil negatively affected plant growth. However, the increasing trend in the concentration of total soluble salts in soil was linear according to addition of NaCl. Results indicated that EC of soil increased with increasing concentration of sodium chloride. The differences among various treatments regarding soil conductivity were significant in terms of statistics (Figure 2). Results showed that maximum value of EC 13.54 dS m^{-1} was analyzed in treatment T_7 (EC = 14 dS m^{-1}) and the lowest value of EC 2.95 dS m^{-1} was analyzed for T_1 (control) and treatments; T_1 (control) and T_2 (EC level of 4 dS m^{-1}) were non-significant when compared with each other statistically. On the other hand, remaining all the treatments like T_3 (6 dS m^{-1}), T_4 (8 dS m^{-1}), T_5 (10 dS m^{-1}) and T_6 (12 dS m^{-1}) were significant to each other statistically having the values of 5.53, 7.76, 9.49, 11.61 dS m^{-1}, respectively.

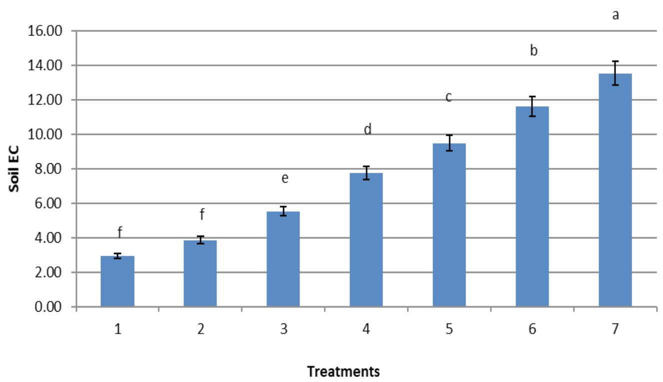

Figure 2: *Impact of NaCl toxicity on soil EC.*

Outcomes of current research exhibited that amplified soil EC was detected due to supplementary addition of NaCl (EC level). It is usual tendency when extra extent of NaCl will be detected in the soil; more will be the absorption of total soluble salts in the soil. Fallouts of former studies are also in the equivalent mode. Mahmood *et al.* (2010) found a cumulative drift in soil EC after saline water of variable EC was added to soil. Likewise, Mahmood (2007) too detected the matching tendency of elevation in soil EC with absorption of soluble salts.

Sodium adsorption ratio (SAR)

Concentration of soluble salts like NaCl in the soil plays an important role in affecting soil physical and chemical properties. With increasing salts concentration in soil, affects its SAR level as Na^+ added in the form of NaCl contributes towards increasing SAR value of the soil. Results revealed that SAR of soil increased with increasing concentration of NaCl. The differences among various treatments regarding soil adsorption ratio were significant in terms of statistics (Figure 3). Maximum value of SAR 11.56 was analyzed in treatment T_7 having NaCl concentration 14 dSm^{-1} and it was followed by T_6 with value of 9.51. These two treatments T_7 and T_6 remained significant when compared each other. The lowest value of SAR 2.44 was determined for control treatment (T_1) and this treatment showed non-significant difference with T_2 (EC level of 4 dS m^{-1}). The observed values for T_3, T_4 and T_5 were 5.36, 5.91 and 7.38 correspondingly. Still, treatments T_3 and T_4 were non-significant after equating with each other whereas T_4 and T_5 (EC 8 and 10 dS m^{-1}) were significant in terms of statistics.

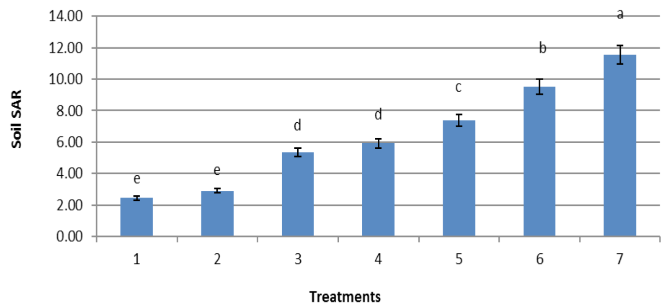

Figure 3: *Impact of NaCl toxicity on soil SAR.*

Owing to collective contribution of NaCl, the worth of SAR amplified with cumulative diverse levels of salinity. Conclusions of preceding researchers are likewise having the equivalent inclination. Mahmood (2007) noticed a rise in soil SAR points with cumulative stages of salinity. Mahmood *et al.* (2010) assessed a growing drift in soil SAR when saline water of variable EC levels was pragmatic to soil.

Concentration of Na in rice plants

The data of plant analysis indicated that concentration of Na in rice plants was significantly affected by various levels of salinity. Results depicted that Na concentration in rice plants increased with increasing concentration of sodium chloride. Variances amongst several treatments about Na concentration were assessed as significant statistically (Figure 4). Highest

Na concentration (7.10 ppm) was analyzed in treatment T_7 (EC level of 14 dS m^{-1}) and it was followed by T_6 with value of 5.86 ppm. However, these two treatments T_6 (EC level of 12 dS m^{-1}) and T_7 (EC level of 14 dS m^{-1}) endured non-significant when equated statistically. The lowest value of Na 2.13 was determined for control (T_1) and this treatment showed non-significant difference when compared with T_2 (EC level of 4 dS m^{-1}). The determined values of sodium for T_3, T_4 and T_5 were 4.4, 5.23 and 5.46 ppm respectively. All these three treatments T_3 (EC level of 6 dS m^{-1}), T_4 (EC level of 8 dS m^{-1}) and T_5 were non-significant when compared with each other.

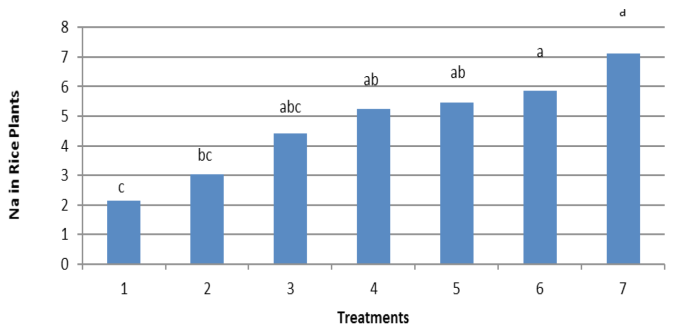

Figure 4: *Impact of NaCl toxicity on Na concentration of rice plants.*

The worth of Na absorption in rice plants with different increasing levels of salinity was enhanced at the end of experiment due to cumulative effect of NaCl. Similar results were reported by Bhatti *et al.* (2004). In the same way, Royo and Abio (2003) also demonstrated that concentration of Na^+ increased with increasing salinity stress.

Concentration of K in rice plants

According to results of this experiment, K was significantly affected by various levels of salinity. Data indicated that K in rice plants decreased with increasing levels of salinity (Figure 5). Highest K concentration (27.53 ppm) was analyzed in treatment T_1 (control) and it was followed by T_2 (EC level of 4 dS m^{-1}) with value of 26.10 ppm. These two treatments T_1 (EC < 4 dS m^{-1}) and T_2 (EC level of 4 dS m^{-1}) persisted non-significant when related in relations of statistics. Minimum worth of K 17.63 ppm was determined for treatment (T_7) and this treatment showed non-significant difference with T_6 (EC level of 12 dS m^{-1}). The determined values for T_3, T_4 and T_5 were 24.47, 23.50 and 22.16 ppm respectively. However, treatments T_3 and T_4 were non-significant when compared with each other. Similar difference was observed between T_4 and T_5 (EC level of 8 and 10 dS m^{-1}).

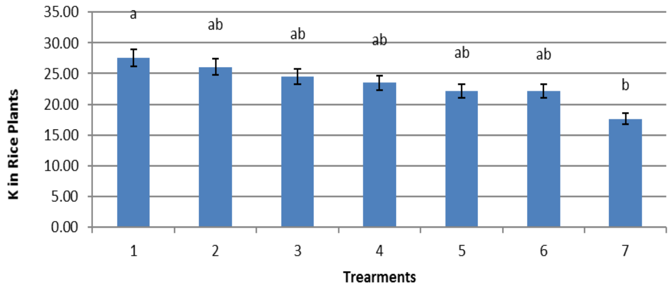

Figure 5: *Impact of NaCl toxicity on K concentration of rice plants.*

These results are in the same direction as reviewed by previous scientists. Similar results were reported by Raza *et al.* (2002) who noted a decline in K^+ aggregation in leaves and stem while the concentration of Na^+ and Cl^- was enhanced with increasing concentration of soluble salts. Results of Mahmood *et al.* (2009) also favoured these findings.

Conclusions and Recommendations

Prominent outcomes of this study indicated that exposure to higher salt levels enhanced soil pH value with increasing salinity levels when compared with control. The same trend was shown with values of soil EC and SAR as both of these also increased with more addition of NaCl in soil. Concentration of Na^+ in rice plants was enhanced by following empirical trend of more salinity levels in all subsequent treatments in contrast to K^+ contents in the rice plants which was decreased with the increasing levels of NaCl salinity in the soil.

Novelty Statement

Excess of Sodium Chloride deteriorated soil properties.

Author's Contribution

Hafiz Muhammad Waseem: Basic Researcher who conducted research.
Ghulam Sarwar: University Supervisor.
Noor-us-Sabah and Mukkram Ali Tahir: Co-Supervisor (Drafting and technical assistance).
Muhammad Aftab and Abid Niaz: Interpretation of data and excel work for graphs making.
Khurshid Ahmad Mufti and Muhammad Arif: Statistical analysis.
Muhammad Zeeshan Manzoor and Ayesha Zafar: Helped in Lab. work and write up.
Imran Shehzad and Aneela Riaz: Proof reading and

final editing.

Conflict of interest

The authors have declared no conflict of interest.

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