

## PROPERTIES OF SALT AFFECTED SOIL UNDER *EUCALYPTUS CAMALDULENSIS* PLANTATION IN FIELD CONDITIONS

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Plantation of salt tolerant trees on salt affected land is an environmental friendly and economically viable strategy to live with salinity where ground water is also highly saline. We studied growth response of eucalyptus camaldulensis on salt affected land and its impact on soil pH, EC, SAR, organic matter contents and infiltration rate. Two sites were selected with varying levels of natural salinity. Eucalyptus seedlings were grown on both sites for three years. A wide variation exhibited in growth of eucalyptus plants at each site. Sixteen plants were selected randomly on each site on the basis of visual growth differences. Among these selected trees, eight were categorized as good and other eight as poor plants. Growth parameters, such as plant height, tree girth and numbers of branches were recorded to monitor the effect of salinity on plant growth. Soil samples under the canopy of selected plants were collected up to the depth of 90 cm and analyzed for EC, SAR, pH, organic matter contents and infiltration rate. Growth of *Eucalyptus* plants at both sites was significantly affected by salinity as compared with other plantations grown on other fields (visual observation). All growth parameters were significantly more in good plants at both sites compared to poor plants. Sodium and chloride concentration was significantly more with lower K:Na ratio in poor plants than in good ones. Amelioration of salt affected soil by *Eucalyptus* plantation was assessed by comparing the soil chemical and physical properties before plantation and after three years. The soil pH was quite lower in soil under good trees than in soil under poor trees at all depths and at both sites. Sodium adsorption ratio (SAR) of soil under good plants at both sites was quite lower when sampled under the canopy of poor plants.

**Keywords:** *Eucalyptus* spp, salinity stress, ion imbalance, sodium concentration

### INTRODUCTION

Salinization of soil and water is an important factor for increased desertification in arid and semi-arid regions of the world (Szabolcs, 1992). About 6.3 million hectares of arable land in Pakistan is affected to varying degrees of salinity/sodicity. A number of strategies including use of chemical amendment and engineering approaches had been proposed for reclamation and revegetation of saline waste lands (Ashraf, 1994; Flowers, 2004). The high initial investment to purchase chemical amendment and low salinity tolerance of our major agriculture crops impels to develop and adopt more viable and economical strategies for highly salt affected lands.

Saline agriculture is an environment friendly and economically viable approach to live with salinity as certain crop species and varieties are available with high salt tolerance (Aslam *et al*, 1993). A number of mechanisms have been proposed by which tree plantations can ameliorate the soil salinity and sodicity. These mechanisms include release of organic acids and complex energy sources by roots (Dormaer, 1988) and increase in partial pressure of CO<sub>2</sub> (Qadir *et al.*, 1996) as well as a decrease in soil pH (Mashali, 1991; Qadir *et al.*, 1996). Increased CO<sub>2</sub> concentration in soil releases Ca<sup>2+</sup> from dissolution of CaCO<sub>3</sub>. Physical movement of roots within soil also improves soil aeration and porosity favourable for plant growth on sodic soils.

Under high salinity levels in the soil, many salt tolerant crops even fail to produce economic growth and yield, hence are not economical to grow on highly salt affected lands (Aslam *et al.*, 1997). The development and maintenance of sustainable agro-ecosystem on highly salt-affected lands is an easier and more economical strategy with perennial plant species. The use of trees and shrubs to reclaim saline

lands has been a subject of interest for many years (Qureshi *et al.*, 1993). Growth of trees are very slower than agronomic crops, hence their ameliorative action might be of sustainable nature. Organic matter content of many forest soils is often high because of litter deposition and more decomposition of roots in the soil. In addition, trees also exhibit all of above mentioned mechanisms to control salinity and sodicity, hence can be selected for revegetation of highly salt affected lands (Qureshi *et al.*, 1993; Nasim, 2000).

*Eucalyptus* is one of many tree species that has been planted successfully under a variety of ecological conditions of Pakistan (Siddiqui *et al.*, 1984). In an adaptation trail near Faisalabad, the *Eucalyptus* spp. performed better than eleven other species studied over seven and half years (Qureshi *et al.*, 1993). We screened thirteen *Eucalyptus* spp in a solution culture experiment for their growth performance under four salinity levels. Species differed significantly for their relative growth and were categorized into four groups viz. tolerant, moderately tolerant, moderately sensitive and sensitive. (Nasim, 2000). Growth of *Eucalyptus camaldulensis* (either Local or Silverton) was extraordinary as both of these species performed better at normal as well as in saline conditions. Van der Moezel *et al.* (1988) also reported that *Eucalyptus camaldulensis* is very tolerant in response to step-wise increases in salinity (42 dS m<sup>-1</sup>) than all the other *Eucalyptus* species.

Taking into consideration the salinity tolerance of *Eucalyptus camaldulensis*, the present project was planned to assess i) the effect of salinity on growth of eucalyptus trees and ii) the amelioration of salt affected land by eucalyptus plantation. The eucalyptus plants were grown on two different sites (highly saline-sodic) at Satiana for three years and physico-chemical properties of soil before and after plantation were compared. The growth of trees at both sites showed wide variation. The present paper reports the ameliorative effect of plantation on soil EC, pH, SAR and water infiltration rate and the reasons for of such wide variation in growth of eucalyptus trees observed at both sites.

## MATERIALS AND METHODS

The experiment was conducted at village Satiana, 28 km in south east of Faisalabad. Two different sites were selected viz site-I at Chak No. 37/GB and site-II at Chak No. 74/GB, each spreading on three hectares. Ten soil samples from each site were collected at random for physico-chemical analysis. At site-I, soil was highly saline-sodic with E<sub>ce</sub> 16.1-37.7, pH 7.4-9.40 and SAR 20.2-47.6. The texture at site-I was sandy clay loam to clay loam, organic matter contents 0.37% and infiltration rate was 0.50 cm hr<sup>-1</sup>. At site II, soil was also saline-sodic with an E<sub>ce</sub> of 8.0-39.9, pH 8.0- 9.60 and SAR of 11.0-30.2. The texture at site-II was clay loam to silty clay loam, organic matter content was 0.30 % and infiltration rate was 0.46 cm hr<sup>-1</sup>.

The study was a part of revegetation program of salt affected area under “Joint Satiana Pilot Project” of Saline Agriculture Research Centre (SARC), University of Agriculture, Faisalabad. Seedlings were grown by the farmers under natural salinity environment. Ground water/drain water [EC 2.0 dSm<sup>-1</sup>, RSC 6.4me L<sup>-1</sup> and SAR 13.3 (mmol L<sup>-1</sup>)<sup>1/2</sup>] was used for irrigation of fields. The cultural practices and growth observations were monitored for three years by SARC.

The growth of eucalyptus trees at both sites was quite heterogeneous. On the basis of their visual growth differences sixteen plants of three years age at each site were selected, with eight good and eight poor in growth. The growth parameters viz plant height, girth, number of branches of selected trees at both sites was recorded. Soil samples under the canopy of each plant were collected (by making holes 25 cm away from tree trunk) from 0-15, 15-30, 30-60, and 60-90 cm depths. The soil samples were analyzed for E<sub>ce</sub>, pH<sub>s</sub>, SAR, organic matter and texture following the methods described by the U.S. Salinity Laboratory Staff (Richards, 1954). Infiltration rate in the root vicinity of selected plants was measured with the help of double ring infiltrometer (Richards, 1954).

Leaves were collected from each selected tree to study their ionic composition. The leaf samples were oven dried (70 C) and ground in a mechanical mill. The ground leaf samples (0.5 g) were extracted with HNO<sub>3</sub> for Cl<sup>-</sup> determination (Rashid, 1986). Chloride concentration was analyzed by Chloride Analyzer (Corning Chloride Analyzer 926). For K<sup>+</sup> and Na<sup>+</sup> determination, plant samples were digested in tri-acid mixture of perchloric acid, nitric acid and sulfuric acid. Estimation of Na<sup>+</sup> and K<sup>+</sup> was conducted on a

Flame Photometer (Jenway PFP-7 Flame Photometer). Statistical interpretation of data was carried out according to the standard procedures described by Steel and Torrie (1980).

## **RESULTS**

### **Tree Growth**

Tree height, girth and number of branches in the case of good plants were quite higher than those in poor plants at both sites (Fig. 1a, b & c). The growth data was recorded thrice after every four months of interval. It was observed that growth of plants increased uniformly in case of good plants, But it was decreased in poor plants, with time. Growth data in relation to time is not presented here.

Tree height was significantly more in case of good plants at both sites (Fig 1a.). The variation among good and poor plants was more obvious at site-I as compared to site-II. At site-I tree height of poor plants was 2.05 m, while it was 7.8 m in case of good plants. At site-II height of poor plants was similar to those grown at site-I. However, height of good plants at site-II were significantly lower than those grown at site-I.



*Eucalyptus* plantation on salt affected soils

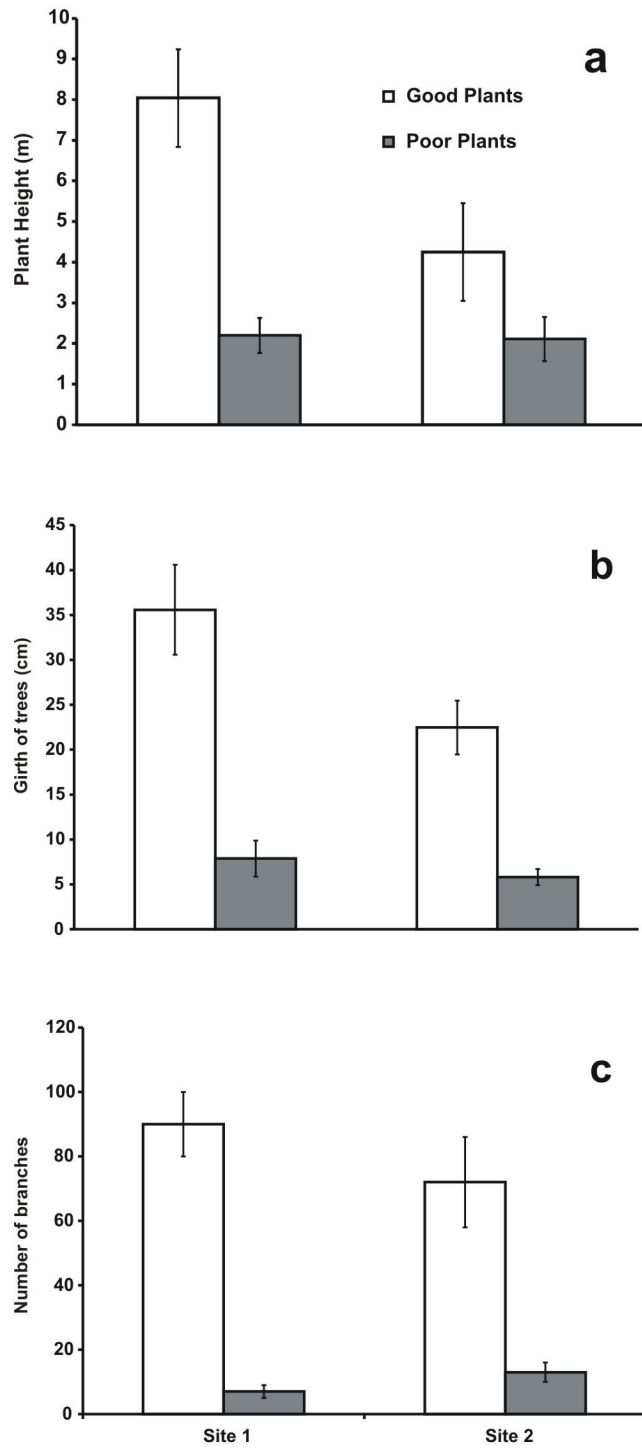


Fig. 1. Tree height (A), girth (B) and number of branches (C) of *Eucalyptus* plants grown on two different sites

*Eucalyptus* plantation on salt affected soils

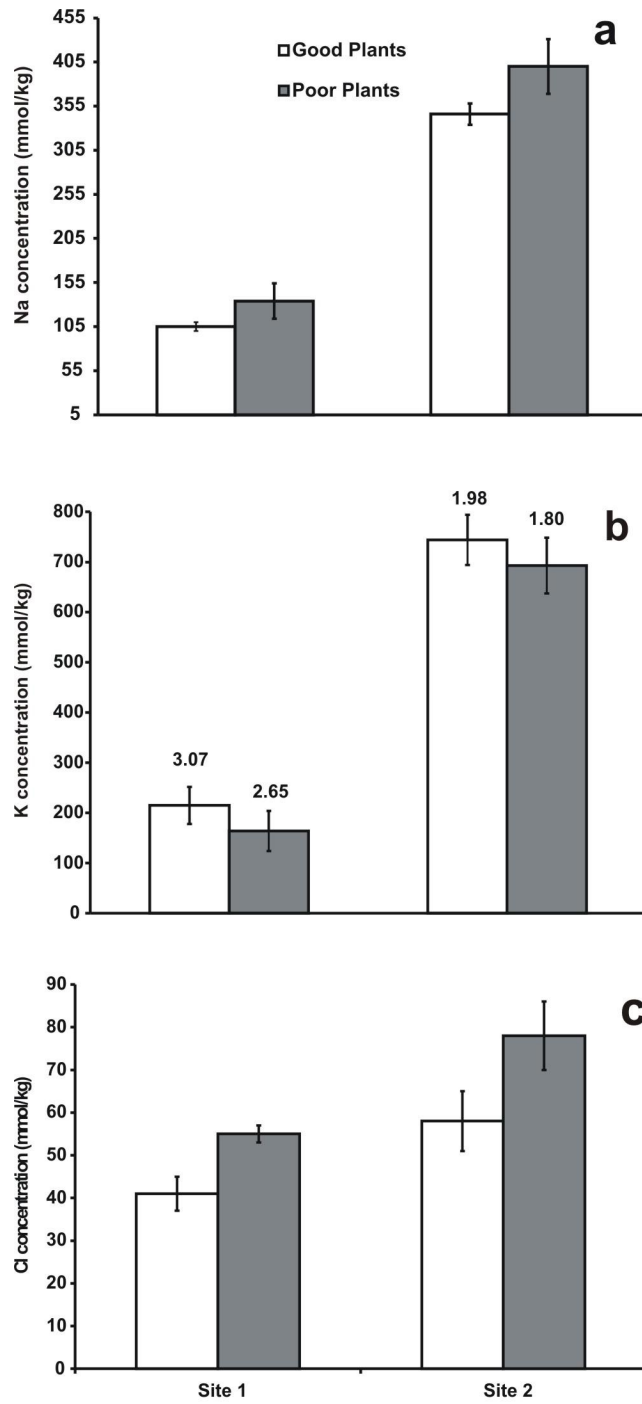


Fig. 2. Sodium (A), potassium (B) and chloride (C) concentration in Eucalyptus plants grown on two different sites. Values on bars in fig b represents K:Na ratio in tissues of eucalyptus trees.

## *Eucalyptus* plantation on salt affected soils

Good trees at site 1 were 10 plants. At site 39, girth of trees was quite low (not more than 8.89 cm at site 45 (Fig. 1b). Similarly tree girth increased uniformly with time in case of good plants and reverse was the case in poor plants. Number of branches increased with time in case of good trees at both sites and the difference in number of branches among both sites was more than ten folds (Fig. 1c). The poor plants borne only 6

to 8 branches and good plants > 80 branches per tree. It was interesting to note that number of branches of good plants was quite low at site-I, however reverse was case in number of branches of poor plants.

### **Ionic Composition of Plant Leaves**

Sodium concentration in leaves of good eucalyptus plants was lower than in poor ones at both sites (Fig. 2a), although the difference was non-significant at site-II. It varied significantly among both sites and was more in plants grown at site-II.

Potassium concentration in eucalyptus leaves grown at site-II was quite higher than those grown at site-I (Fig. 2b). Potassium concentration did not differ among good and poor plants at both sites. Potassium sodium ratio in plants grown at site-I was quite higher than those grown at site-II.

Chloride concentration in plants differed among both sites as well as among good and poor plants (Fig. 2c). It was significantly more in poor plants than in good ones at both sites.

### **Soil Chemical Properties**

The trees selected were categorized into two classes on the basis of visual growth viz. good and poor trees. The soil samples were collected from both categories and from both sites. At Site-I, soil pH was > 8.5 at all depths irrespective of the tree condition. The soil reaction (pH) was quite lower in soil under good tree than in soil under poor trees at all depths (Table 1). Soil at site-II was more sodic than site-I as pH was quite high especially at shallower depths. However, at lower depths, soil pH at both sites was almost similar. Soil reaction under good trees was lower than that under poor trees (Table 1).

**Table 1. pH of soil samples taken from root vicinity of different categories of Eucalyptus plants at two sites**

Depths	Site I		Site II	
	Good plants	Poor plants	Good plants	Poor plants
D <sub>1</sub> (0-15 cm)	8.68 ± 0.12	9.03 ± 0.12	9.36 ± 0.60	9.59 ± 0.27
D <sub>2</sub> (15-30cm)	8.90 ± 0.13	9.02 ± 0.32	9.24 ± 0.60	9.20 ± 0.48
d <sub>3</sub> (30-60cm)	8.78 ± 0.32	9.01 ± 0.12	8.73 ± 0.50	9.04 ± 0.35
d <sub>4</sub> (60-90 cm)	8.66 ± 0.07	9.00 ± 0.14	8.81 ± 0.15	8.72 ± 0.42

The electrical conductivity of soil at site-I < 4 dS m<sup>-1</sup> when averaged over all depths and it was low under good plants as compared to poor ones at shallower depths however, the trend was opposite at lower depths (Table 2). At site-II, EC of soil was > 4 dS m<sup>-1</sup> when averaged over all depths and it decreased gradually under good as well as poor plants as depth increased. The soil at surface was quite saline and salinity was significantly more under poor plants.

Sodium adsorption ratio (SAR) of soil at both sites was quite lower when sampled under the canopy of good plants (Table 3). The SAR value of soil at site-I was about two folds higher than that of site-II under poor plants. But difference was not significant in case of good plants. The SAR of soil decreased significantly with increasing depth of soil under the poor plants. However, SAR of soil under good plants did not vary with depth.

Effect of plantation on infiltration was quite obvious as it was more than double of original infiltration rate before plantation at both sites (Fig. 3a). The infiltration rate of the soil at both sites was statistically at par and it was more than 3 folds higher in case of good plants. Organic matter contents of soil at both sites were increased (3.5 folds) significantly after three years of eucalyptus plantation (contents were > 1.4%) when compared to original soil before plantation (<0.4%) at both sites in case of good plants (Fig. 3b). In soil samples collected from poor plants after three years, organic matter contents were statistically similar to that observed before plantation.

## **DISCUSSION**



### *Eucalyptus plantation on salt affected soils*

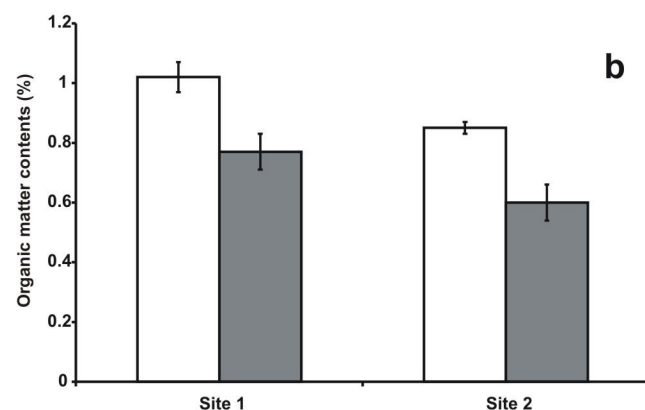
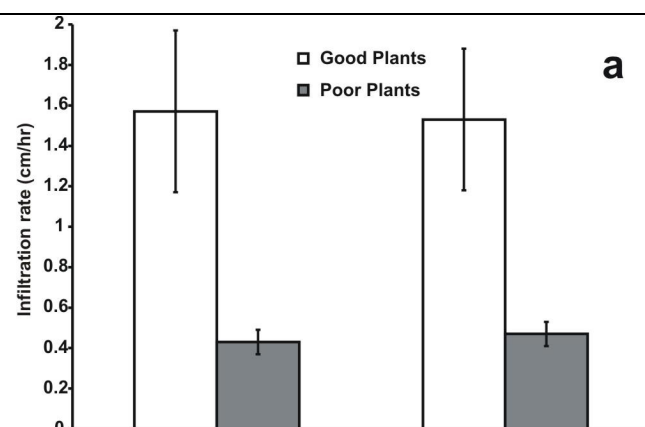
Tree growth at both sites was severely affected by salinity when Eucalyptus growing on nearby good lands was compared with these sites (Visual observation). A huge variation existed among eucalyptus plants grown on same sites. Salt-affected soils are quite heterogeneous (Richards, 1983), under these conditions, differential growth of plants can be expected.

**Table 2. ECe (ds m<sup>-1</sup>) of soil samples taken from root vicinity of different categories of Eucalyptus plants (Av. of 8 plants " SE)**

	Site-I		Site-II	
Depths	Good plants	Poor plants	Good plants	Poor plants
D <sub>1</sub> (0-15 cm)	2.70 ± 0.31	4.38 ± 0.60	6.79 ± 1.82	7.47 ± 1.49
D <sub>2</sub> (15-30cm)	3.61 ± 0.78	3.81 ± 0.54	5.51 ± 2.39	5.19 ± 1.98
D <sub>3</sub> (30-60cm)	4.61 ± 0.73	2.89 ± 0.51	4.93 ± 2.61	3.64 ± 1.61
D <sub>4</sub> (60-90 cm)	4.19 ± 0.54	2.62 ± 0.35	3.16 ± 1.48	2.68 ± 0.49

**Table 3. SAR (mmol L<sup>-1</sup>) of soil samples taken from root vicinity of different categories of Eucalyptus plants ( Average of 8 plants " SE)**

	Site-I		Site-II	
Depths	Good plants	Poor plants	Good plants	Poor plants
D <sub>1</sub> (0-15 cm)	17.93 ± 2.54	45.54 ± 12.12	14.87 ± 9.83	27.87 ± 21.89
D <sub>2</sub> (15-30cm)	22.74 ± 3.98	44.94 ± 20.45	18.31 ± 8.72	29.22 ± 34.98
D <sub>3</sub> (30-60cm)	23.94 ± 3.30	39.76 ± 12.46	18.33 ± 5.76	12.98 ± 4.24
D <sub>4</sub> (60-90 cm)	19.59 ± 2.46	34.51 ± 13.48	15.76 ± 2.59	10.28 ± 3.55



progressively with time, whereas, the poor plants were just surviving and negative trend in the growth of these plants was noticed. Such a great variation may either due to large variation in salinity/sodicity of the soil profile and genetic diversity in the plant species or localized site specific associated problems. The declined growth in poor plants may be because of decrease in the size of the circumference due to excessive shedding of bark and drying up of branches with age, thereby resulting in a less number of branches on these trees. Similar adverse effects of salinity on plant growth are very well documented in the literature (Qureshi *et al.* 1993; Marcar and Crawford, 1996).

The most prominent difference in soil properties under the good and poor plants at both the sites was of water intake rates, which were much lower in the root zone of poor plants than the good plants. The water intake is generally related to the texture and SAR values of the soil. It was observed that the soil under the poor plants was more compact and hard as compared to soil under the good plants. Sodic soils which have high relative  $\text{Na}^+$  content, can impede root growth due to poor aeration and may also create nutritional disorders/imbances because of elevated soil pH (Marcar and Crawford, 1996). This could be one of the reasons for poor growth of plants, since compact soil has negative effect on nutrient availability and root penetration (Borges *et al.*, 1986). Thus soil, under the poor plants with high pHs and sodicity (SAR), ultimately resulted in severe reduction of growth.

Salt stress affects uptake, transport and utilization of different nutrients (Marschner, 1995; Grattan and Grieve, 1999; Zhu, 2003), which may results in excessive accumulation of  $\text{Na}^+$  and  $\text{Cl}^-$  in tissue (Saqib *et al.*, 2000) and ultimately reduction in crop yield. The other possible reason of poor growth could be the ion excess (upto toxic level) in case of poor plants at both sites. This hypothesis is further strengthened when overall growth of plants at site II was found inferior to plants grown at site I: Plants of sites II had in general higher concentration of ions in their leaves as compared to plants of site I. Sodium and  $\text{Cl}^-$  concentrations in the leaves of poor plants were significantly higher as compared to good plants. High  $\text{Na}^+$  and  $\text{Cl}^-$  concentrations are considered responsible for reduced growth in *Eucalyptus* (Marcar, 1989), and wheat (Akhtar *et al.*, 1998).

Many earlier researchers have used Na:K ratio as an indicator of salinity tolerance (Saqib *et al.*, 2004; Saqib *et al.*, 2005; Munns, 2005) as a low Na:K ratio in the cytosol is essential for normal cellular functions of plants (Chinnusamy, *et al.*, 2005). In leaves of poor plants, K:Na ratio was quite lower than found in good plants. Low K:Na ratio in the plant tissue may be the result of loss in capacity to maintain  $\text{K}^+$  selectivity over  $\text{Na}^+$  at higher external salinity/sodicity (Huang and Van Stevinck, 1989). Lower K:Na ratio in leaves of salt affected plants of *Eucalyptus camaldulensis* was also indicated by Marcar (1993).

Ameliorative effects of Eucalyptus plantation on soil characteristics were noticed by comparing the soil physico-chemical properties observed before plantation and after three years. A large decline in initial soil salinity/sodicity ( $\text{EC}_e$ , SAR & pHs) was observed on both sites. The reduction in soil salinity might be attributed to decreased surface evaporation because of vegetative cover, consequently revising the process of upward movement of salts through capillary fringe (Qureshi *et al.*, 1993). Good plants caused high reduction in soil pH through root action. Similar changes in soil pH were recorded by other researchers (Qureshi *et al.*, 1993; Singh, 1989, Hussain and Gull, 1991). In the present study soil SAR under poor plants was highest at surface and decreased continuously with depth. Decreasing trend in SAR because of tree plantation in light textured salt-affected soil was also reported by Qureshi *et al.*, (1993). Not only soil SAR was lowered, but the infiltration capacity under healthy plants was more which was attributed to more development of roots and enhanced root exudates (Dormaar, 1988). Root exudates might have resulted in an increased solubility of soil precipitated  $\text{Ca}^{2+}$  as calcium sulfate, calcium bicarbonate or calcium carbonate that replaced  $\text{Na}^+$  ions and simultaneously resulted improvement in physical conditions of the soil (Shah, 1992; Hussain and Gull. 1991).

## **CONCLUSION**

Eucalyptus plantation showed a wide variation in growth at the two sites. Site specific problems and heterogeneity in soil salinity and sodicity may be attributed for these variations. A three years old plantation significantly decreased soil EC, pH and SAR at both sites under good plants. The soil under poor plants did not showed significant reclamation of salinity and sodicity. Soil infiltration rate was also improved at both sites after three years of plantation.

## REFERENCES

- Akhtar, J., J. Gorham, R.H. Qureshi and M. Aslam. 1998. Does tolerance of wheat to salinity and hypoxia correlation with root dehydrogenase activities or aerenchyma formation? *Plant Soil* 201: 275-284.
- Ashraf, M. 1994. Breeding for salinity tolerance in plants. *Crit. Rev. Plant Sci.*, 13: 17-42.
- Aslam, M., R.H. Qureshi, S. Nawaz and J. Akthar. 1997. A sustainable farming system to make salt-affected soils productive. PP.33-50. In: Mushtaq *et al* (eds.) proceeding of the international Seminar on farming System Research in the Context of Food Security, D.I. khan, Pakistan August 4-6, 1996.
- Aslam, M., R.H. Qureshi and N. Ahmad. 1993. A rapid screening technique for salt tolerance in rice (*Oryza stive*). *Plant and Soil*. 150:99-107.
- Borges, E.N., R.F. DeNeves, N.F. Debarros, N.F. L.M.da Costa and J.C.L. Neves. 1986. Responses of Eucalyptus seedlings to compacted soil layers. *Revista Arvore* 10(2):181-195.
- Chinnusamy, V., A. Jagendorf and J.K. Zhu. 2005. Understanding and improving salt tolerance in plants. *Crop Sci.*, 45: 437-448.
- Dormaer, J. F. 1988. Effect of plant roots on chemical and biochemical properties of surrounding discrete soil zones. *Canadian J. Soil Sci.* 68: 233-242.
- Flowers, T.J. 2004. Improving crop salt tolerance. *J. Exper. Bot.*, 55(396): 307-319.
- Grattan, S.R. and C.M. Grieve. 1999. Salinity-mineral nutrient relations in horticultural crops. *Scientia Hort.*, 78: 127-157.
- Huang, C.X and R.F.M. Van Steveninck. 1989. Longitudinal and transverse profiles of K and Cl concentration in low and high salt barley roots. *New Phytol.* 112: 475-480.
- Hussain, A. and P. Gul. 1991. Selection of suitable tree species for saline and waterlogged areas. *Pak. J. Forestry*. 41(1):34-43.



- Marcar, N.E. 1989. Salt tolerance of forest-resistant Eucalyptus. *New Forests*. 3(2):141-149.
- Marcar, N.E. 1993. Water logging modifies growth, water use and ion concentration in seedlings of salt-treated *E. camaldulensis*, *E. tereticornis*, *E. robusta* and *E. globules*. *Aust. J. Plant Physiology*. 20:1-13.
- Marcar, N.E. and D.F. Crawford. 1996. Other productive uses of saline land; Tree growing strategies. In: Key note address, 4<sup>th</sup> National Conference and Workshop on the productive use and rehabilitation of saline; ands. Albany, West. Australia. 25-30 Marsh, 1996.
- Marschner, H. 1995. Adaptation to adverse chemical soil conditions. In: *Mineral Nutrition of Higher Plants*. 2<sup>nd</sup> ed. Academic Press Ltd. pp. 596-680.
- Mashali, A.M. 1991. Management practices under saline conditions. In: *Plant Salinity Research*. [R. Choukr-Allah (ed.)] pp. 213-229. *Proc. Intl. Conf. Agric. Management of Salt-Affected Areas*, 26 April to 3 May 1991, Agadir, Institute Agronomique et Veterinaire Hassan II-C.H.A., Agadir, Morocco.
- Munns, R. 2005. Genes and salt tolerance: bringing them together. *New Phytol.*, 167: 645-663.
- Nasim, M. 2000. Growth and ionic composition of eucalyptus species as affected by saline and hypoxic conditions. Ph.D. Dissertation. Dept. Soil Science, University of Agriculture, Faisalabad, Pakistan.
- Qadir, M., R.H. Qureshi, N. Ahmad and M. Ilyas. 1996. Salt tolerant forage cultivation on a saline-sodic field for biomass production and soil reclamation. *Land Degrad. Develop.*, 7:11-18.
- Qureshi, R.H., S. Nawaz and T. Mahmood. 1993. Performance of selected tree species under saline-sodic field conditions in Pakistan. In: H. Lieth and Al-Masoom (eds.) *Towards the Rational Use of High Salinity Tolerant Plants*. Vol. 2:259-269. Kluwer Academic Publishers, Netherland.
- Rashid, A. 1986. Mechanisms of salt tolerance in wheat (*Triticum aestivum* L.) Ph.D. Thesis, Dept. Soil Science, Univ. Agri., Faisalabad, Pakistan.
- Richard's R.A. (Eds.) 1954. *Diagnosis and improvement of saline and alkali soils*. USDA, Hand Book 60. U.S. Govt. Printing Office, Washington, D.C. 160 p.
- Richards, R.A. 1983. Should selection for yield in saline regions be made on saline or non-saline soils? *Euphytica* 32:431-438.
- Saqib, M., J. Akhtar and R.H. Qureshi. 2005. Na exclusion and salt resistance of wheat (*Tricticum aestivum*) in saline-waterlogged conditions are improved by the development of adventitious nodal roots and cortical root aerenchyma. *Plant Sci.*, 169: 125-130.
- Saqib, M., J. Akhtar and R.H. Qureshi. 2004. Pot study on wheat growth in saline and waterlogged compacted soil II. Root growth and leaf ionic relations. *Soil & Till. Res.*, 77: 179-187.
- Saqib, M., J. Akhtar, R.H. Qureshi, M. Aslam and S. Nawaz. 2000. Effect of salinity and hypoxia on growth and ionic composition of different genotypes of wheat. *Pak. J. Soil Sci.*, 17: 1-8.
- Shah, B.H. 1992. Effect of forest vegetation on Salinity, sodicity and infiltration capacity of soil. *Pak. J. Forest*. 42(4):31-36.
- Siddiqui, K.M., J.A. Khan and S.M. Yasin. 1984 *Eucalyptus camaldulensis* DEHN, its growth properties and utilization. Bulletin Number 4, Pak. Forest Institute Peshawar, Pakistan.
- Singh, B. 1989. Rehabilitation of alkaline waste land on the gangetic alluvial plains of Uttar Pradesh, India, through afforestation. *Land Degradation and Rehabilitation*. 1(4):305-310.
- Steel, R.G.H. and J.H. Torrie. 1980. *Principles and procedures of statistics*, 2<sup>nd</sup> Ed. McGraw Hill Book Co. Inc., New York.
- Szabolcs, I. 1992. Salinization of soil and water and its relation to Desertification. *Desertification Control Bulletin*. 21:32-37.
- Vander Moezel, P.G., L.E. Watson, G.V.N. Pearce-Pinto and D.T. Bell. 1988. The response of Six Eucalyptus species and Casuarina obesa to combined effect of salinity and water logging. *Aust. J. Plant Physiol.* 15:465-474.
- Zhu, J.K. 2003. Regulation of ion homeostasis under salt stress. *Curr. Opin. Plant Biol.*, 6: 441-445.