Apart from the variation among different species and cultivars in their responses to salt stress, it has been well established that the reaction of plants to salt vary depending the time of exposure to salt, the growth period of the plant, salt concentration, climatic and soil properties [5]. For instance, in some studies [19, 20] it was documented that decrease in vegetative growth parameters was depending on increasing the salinity level.

To date, the effects of salt stress on plant growth and physiology is fairly known. However, the actual mechanisms behind such effects are not perfectly understood. Knowledge of the specific physiological mechanisms in charge of salt stress tolerance would facilitate setting reliable criteria for improving plant tolerance to soil salinity stress. The complexity in analyzing the actual physiological events when plants are subjected to elevated levels of soil salinity might be attributed to several factors interacting with salinity. These factors might include light, temperature, humidity, soil fertility, soil calcium concentrations, flooding, atmospheric CO_2 concentrations, variation in field condition and the type of a potting medium [21, 22, 23, 24, 25, 26].

In the present investigation the main objective was to analyze the growth responses of *Eucalyptus camaldulensis* seedlings exposed to a wide range of NaCl concentration (0 – 100 mM NaCl). *Eucalyptus camaldulensis* has been chosen for this study as it proved an excellent forest tree species for its relative fast growth and thus widely grown in plantation system for the production of wood fuels and constitutes a good source for wood-based industries.

2. Materials and Methods

Preparation of Plant Materials and Growth Conditions

Plant Materials and Experimental Conditions

The current investigation was conducted on copper stress treatments employing young *Eucalyptus camaldulensis* seedlings. Germination and early establishment of the seedlings were performed in a nursery under partial shade. Freshly collected *Eucalyptus camaldulensis* seeds were directly sown in black non-transparent polythene bags (15 cm diameter X 40 cm height), five seeds per bag. The polythene bags were filled with a soil mixture containing silt: sand in a 2: 1 ratio (by volume), leaving the top 5 cm as a margin for irrigation. The bags were also perforated (6 holes/ bag) to ensure good aeration and also to facilitate easy drainage of excess water. Thereafter, the sown bags were placed under partial shade in a nursery. Watering was applied on daily basis by flood irrigation to field capacity for the first two months, then every other day for one month. During this phase of seedlings establishment singling and weeding were timely carried out. A total of 40 seedlings were chosen to run the experiment on the basis of vigour and uniformity in shoot height (mean shoot height 38.6 ± 1.05 cm). These candidate seedlings were grown for two more months for hardening outside the nursery. Watering was similarly maintained close to field capacity every second day.

Experimental Design and Copper Treatments

The seedlings for the experiment were distributed into five groups of seven seedlings each. Each group was assigned for each of the following NaCl treatments: 0 (control), 30, 50, 80 and 100 mM NaCl) identify the range of sub-optimum, optimum and excess NaCl supply. Salt treatments were applied every week by adding a fresh NaCl solution to the seedlings at the same time with irrigation. The salt treatments lasted for four weeks.

Growth Performance

To monitor growth, some growth variables (plant shoot height, number of leaves and stem diameter at the stem-root interface) were regularly determined once a week throughout the entire experimental period. At harvest, the final measurements of these growth parameters were also taken. During copper treatment, the growth rates of these growth variables were calculated for the last two weeks of the Cu treatment.

Dry Mass Production and Partitioning

After four weeks exposure to copper treatments, the experiment was terminated by destructive harvesting of the whole plants. Each seedling was separated into shoot and root. The shoot was further divided into leaves and stem. Similarly, the root system was carefully rinsed with distilled water immediately after harvest then divided into coarse and fine roots. The fresh mass of each plant fraction was determined and for dry mass determination all plant materials were oven-dried to a constant weight at 60°C for seven days.

Statistical Analysis

Results were statistically treated using the statistical programme JMP 5.1 Start Statistics, 3rd edition (SAS Institute, Inc., Cary, North Carolina, USA). The experiment was established in a completely randomized design. Data were expressed as means of eight replicates for each copper treatment. Analysis of variance was performed as One-Way-ANOVA and the separation of the means was performed by Tukey-test. A probability level of $P \leq 0.05$ was chosen to show the statistically significant variations among the means. Means followed by same letters are not significantly different from each other.

3. Results and Discussion

The present work investigated the response of young *Eucalyptus camaldulensis* seedlings to salt stress treatments (0 – 100 mM NaCl for 4 weeks). To analyse the impact of salt stress on the growth of *Eucalyptus camaldulensis* seedlings, growth indicators (plant shoot heigh, stem diameter and leaf formation) were determined during the course of the experimental period. Additionally, total plant dry mass as well as root-to-shoot ratios were also evaluated.

Growth

The present data showed that exposure of *Eucalyptus camaldulensis* seedlings to low and moderate salt stress (0 – 50 mM NaCl) did not affect leaf formation. However, increasing stress levels was accompanied by significant reductions in the number of leaves of the salt-treated seedlings compared to their respective controls (Table 1). These findings are in conformity with several previous studies [17, 27, 28, 29, 30, 31, 32]. The observed reduction in the number of leaves under exposure to high levels of salt stress might be attributed to the accumulation of NaCl in the cell walls and cytoplasm of the older leaves. Also, the vacuoles sap is likely incapable to accumulate more salt leading to significant drop in salt concentration inside the cell, a situation which eventually leads to quick death and shedding of leaves [33].

Table 1 Influence of salt stress [0 (control), 30, 50, 80 and 100 mM NaCl] on the growth rate (GR) of some plant growth indicators (shoot height, stem diameter and leaf formation) of *Eucalyptus camaldulensis* seedlings. Salt treatments were applied for four weeks. Growth measurements were performed once a week following salt addition. Date presented are the mean growth rate of seven plants per treatment (n =7, ± SE). Means separation was performed by Tukey-test at $P \leq 0.05$ and the means connected by similar letters are not significantly different from each other.

Salt (NaCl) treatment (mM)	Plant shoot height (cm/week)	Stem diameter (mm/week)	Leaf formation (number of leaves/week
0 (control)	11.27 ± 0.98 a	1.24 ± 0.85 a	7 ± 0.83 a
30	10.44 ± 1.02 a	1.13 ± 0.74 a	6 ± 0.77 a
50	9.51 ± 0.81 a	0.84 ± 0.79 a	5 ± 0.24 ab
80	6.72 ± 1.13 b	0.53 ± 0.48 b	3 ± 0.35 bc
100	4.81 ± 0.92 bc	0.37 ± 0.36 bc	1 ± 0.84 c

Similar response pattern was also observed for the plant shoot height which was significantly reduced under the higher concentrations of salt (Table 1). Our results corroborate similar findings of some authors who indicated that increasing the concentration of sodium chloride was accompanied by proportional reductions in plant shoot length [30 34, 35, 36, 37, 38, 39].

The current results showed that the response of stem diameter growth under different levels of salt stress was similar to that of leaf formation and plant shoot height where the stem diameter was significantly reduced under the highest levels of salt stress treatment (Table 1). These results are in conformity with previous studies [40] which reported significant reductions in plant stem diameter under high levels of salt stress.

Dry Mass Production, Accumulation and Partitioning

Exposure of *E. camaldulensis* seedlings to salt stress has resulted in gradual reduction in total plant dry mass. The effect was most pronounced under the highest concentration of salt. Similar response patterns were also observed for the shoot-to-root ratios for the salt-treated seedlings compared to their respective controls (Table 2). Our present results might be in accordance with [18] who reported significant reductions in both fresh and total plant dry mass in walnut cultivars with increasing irrigation water salinity.

Table 2 Influence of salt stress [0 (control), 30, 50, 80 and 100 mM NaCl] on the total plant dry mass and root-to-shoot ratio of *Eucalyptus camaldulensis* seedlings. Salt treatments were applied for four weeks. Date presented are the mean seven plants per treatment (n =7, ± SE). Means separation was performed by Tukey-test at $P \leq 0.05$ and the means connected by similar letters are not significantly different from each other.

Salt (NaCl) treatment (mM)	Total plant dry mass (g)	Root-to-shoot ratio
0 (control)	13.768 ± 0.44 a	0.19 ± 0.05 a
30	12.024 ± 0.51 a	0.17 ± 0.07 a
50	9.819 ± 0.23 b	0.12 ± 0.05 a
80	7.005 ± 0.65 bc	0.08 ± 0.04 b
100	5.013 ± 0.37 c	0.06 ± 0.02 b

The suppressive effect of high salt stress concentrations on plant growth and biomass production has been reported in numerous early studies which indicated significant reductions in plant biomass under imposed saline conditions [16, 41, 42, 43, 44]. These findings are in well agreement with our present results. However, our findings with regard to the response pattern of plant biomass under salinity stress conditions are in contrast to other investigations which showed a stimulatory effect of salt stress on the growth and production of plant biomass under low levels of salt concentrations [17].

In the light of the present findings it might be speculated that elevated levels of salinity had inhibitory effect on the growth and physiology of *E. camaldulensis* seedlings as attested by the dramatic reductions in growth and total plant dry mass production. Since plant growth is the resultant of photosynthetic performance of the plant under tight hormonal control, it would be logical to link the intensity of salt stress treatment with the photosynthetic capacity and the hormonal status of the plant. Therefore, more experimental work at the molecular level involving hormonal analysis under saline conditions is required to elucidate the mechanisms assumed by the plant under unfavourable soil salinity. Information provided from such investigations would no doubt help improve our understanding for the behavior of plant under salt stress conditions.

4. Conclusions

Salinization of soil is a genuine environmental problem which causes dramatic losses of agricultural crops worldwide. To address such a problem, scientific research has recently been focused to find practical answers to alleviate the impact of salinity on plant growth and productivity especially in agricultural countries. On one hand, some progress has been achieved so far in improving plant tolerance to high salt stress conditions and on the other hand several innovative approaches for reclamation of salt-affected soils have been adopted, which realized some success. The challenge ahead is to maximize the output from the breeding programs and other relevant disciplines towards screening for genes with excellent plant tolerance to salinity stress. Currently, great efforts are exerted by the scientific community towards improving plant tolerance to salt stress via advanced breeding programmes in support with the molecular and biotechnological approaches for screening genes responsible for high salt stress tolerance. Recently, the possibility of identification of special genes that control salt tolerance in plants has led to development of transformation techniques in genetically modified plants which are considered a great breakthrough for salt-stressed plants in acquiring adequate levels of salt stress tolerance.

Acknowledgements

The authors wish to thank Prof. Ahmed Mudawi for critical reading of the manuscript and for the useful remarks and sensible suggestions. The effort Dr. Mohammed Abdalla Kazo exerted in statistical processing of the data is also highly appreciated.

References

[1] Kozlowski TT. Response of woody plants to flooding and salinity. Tree Physiol. Monograph No. 1. Heron Publishing. Victoria, Canada. 1997; pp: 1 – 28.
[2] Abrol IP, Yadav JSP, Massoud FI. Salt-affected soils and their management. U.N. Food and Agriculture Organization, Rome. Soils Bulletin 1988; 39: 131p.
[3] Rhodes JD, Loveday J. Salinity in irrigated agriculture. In. Salinity in Irrigated Agriculture. Eds. JD Rhodaes and J Loveday. J. America. Soc. Agron. Madison, WI 1990; pp.: 1089 – 1142.
[4] Jouban Z. The effects of salt stress on plant growth. Tech. J. Eng. Appl. Sci. 2012; 2 (1): 7 – 11.
[5] Greenway H, Munns RA. Mechanisms of salt tolerance in non-halophytes. Ann. Rev. Plant Physiol. 1980; 31: 149 – 190.
[6] Munns R, Termatt A. Whole plant responses to salinity. Aust. J. Plant Physiol. 1986; 13: 143 – 160.
[7] Marschner H. Mineral nutrition of higher plants. Academic Press. 1995; pp: 657 – 680.
[8] Taffouo VD, Tester M, Devenport R. Na^+ tolerant and Na^+ transport in higher plants. Annals of Bot. 2003; 91: 503 – 527.
[9] Grattan SR, Grieves CM. Salinity-mineral nutrient relations in horticultural crops. Scientia Hort. 1999, 78: 127 – 157.
[10] Abd El-Wahab MA. The efficiency of using saline and fresh water irrigation as alternating methods of irrigation on the productivity of *Foeniculum vulgare* Mill subsp. Vulgare var. vulgare under North Signal conditions. Res. J. Agric. Bio. Sci. 2006; 2 (6): 571 – 577.
[11] Ashraf M, Orooj A. Salt stress effects on growth, ion accumulation and seed oil concentration in an arid zone traditional medicinal plant ajwain (*Trachyspermum ammi* L. Sprague). J. Arid Environ. 2006; 64 (2): 209 – 220.
[12] Baghalian K, Haghiry A, Naghavi MR, Mohammadi A. Effect of saline irrigation water on agronomical and phytochemical characters of chamomile (*Matricaria recutita* L.). Scientia Hort 2008; 116: 437 – 441.
[13] Braun G, von A Schanbom, Weber E. Investigations on the relative resistance of woody plants to de-icing salt (sodium chloride). Allg. Forst Jagdzig1978; 149: 21 – 35.
[14] Mohammed RM, Campbell WF, Rumbauch MD. Variation in salt tolerance of alfalfa. Arid Soil Res. 1989; 3: 11 – 20.
[15] Hussain G, Sadiq M, Nabulsi YA, Helweg OJ. Effect of saline water on establishment of windbreak trees. Agric. Water Manage. 1994; 25: 35 – 43.
[16] Minhas PS, Singh YP, Tomar OS, Gupta RK. Effect of saline irrigation and its schedule on growth biomass production and water use of *Acacia nilotica* and *Dalbergia sisso* in a highly calcareous soil. J. Arid Environ. 1997; 36: 181 – 192.
[17] Rawat JS, Banerjee SP. The influence of salinity on growth, biomass production and photosynthesis of *Eucalyptus camaldulensis* Dehn. and *Dalbergia sisso* Roxb. seedlings. Plant and Soil 1998; 205: 163 – 169.
[18] Akca Y, Samsunlu E. The effect of salt stress on growth, chlorophyll content, proline, nutrient accumulation, and K/Na ratio in walnut. Pakistan J. Bot. 2012; 44 (5): 1513 – 1520.
[19] Sixto H, Grau JM, Alba N, Alia R. Response to sodium chloride in different species and clones of genus Populus L. Forestry 2005; 78: 93 – 104.
[20] Pessarakli M, Hayat T. Growth responses of Bermuda grass and Seashore Paspalum under various levels of sodium chloride stress. J. Food, Agric. Environ. 2006; 4: 240 – 243.
[21] Shannon MC. In quest of rapid screening techniques for plant salt tolerance. HortiScience1979; 14: 587 – 589.
[22] Townsend AM. Effect of sodium chloride on tree seedlings in two potting media. Environ. Poll. 1984; 34: 333 – 344.
[23] Thomson LAJ. Salt tolerance in *Eucalyptus camalsulensis* and related species. PhD Dissertation, University of Melbourne, Melbourne, Australia1988; 307 p.
[24] Pezeshki SR, DeLaune RD, Jr. Patrik WH. Flooding and saltwater intrusion: potential effects on survival and productivity of wetland forests along the US Gulf Coast. Forest Ecol. and Manage. 1990; 27: 41 – 51.
[25] Rengel Z. The role of calcium in salt toxicity. Plant, Cell and Environ. 1992; 15: 625 – 632.
[26] Maas EV. Salinity and citriculture. Tree Physiol. 1993; 12: 195 – 216.
[27] Karen W, Anthony RY, Timothy JF. Effects of salinity and ozone, individually and in combination on growth and ion contents of two chickpea (*Cicer aritinum* L.) varieties. Environ. Poll. 2002; 120 (2): 397 – 403.
[28] Raul L, Andres O, Armado L, Bernardo M, Enrique T. Response to salinity of three grain legumes for potential cultivation in arid areas (plant nutrition). Soil Sci., Plant Nutr. 2003; 49 (3): 329 – 336.
[29] Jamil M, Lee CC, Rehman SU, Lee DB, Ashraf M, Rha ES. Salinity (NaCl) tolerances of *Brassica species* at germination and early seedling growth. E. J. Environ. Agric. Food Chem. ISSN 2005: 1579 – 4377.
[30] Gama PBS, Inanaga S, Tanaka K, Nakazawa R. Physiological response of common bean (*Phaseolus vulgaris* L.) seedlings to salinity stress. African J. Biotech. 2007; 6 (2): 79 – 88.
[31] Rui I, Wei S, Mu-xiang C, Cheng-jun J, Min W, Bo-ping Y. Leaf anatomical changes of *Burguiera gymnorrhiza*

seedlings under salt stress. J. Trop. Subtrop. Bot. 2009; 17 (2): 169 – 175.

[32] Abdul Qados AMS. Effect of salt stress on plant growth and metabolism of bean plant *Vicia faba* (L.). J. Saudi Soc. Agric. Sci. 2011; 10: 7 – 15.

[33] Munns R. Comparative physiology of salt and water stress. Plant, Cell and Environ. 2002; 25: 239 – 250

[34] Hamada AM. Alleviation of the adverse effects of NaCl on germination, seedling growth and metabolic activities of maize plants by calcium salts. Bull. Fac. Sci, Assiut University1995; 24: 211 – 22

[35] Misra A, Sahu AN, Misra M, Singh P, Meera I, Das N, Kar M, Sahu P. Sodium chloride induced changes in leaf growth, and pigment and protein contents in two rice cultivars. Biol. Plant. 1997; 39 (2): 257 – 262.

[36] Dantus BF, Rebeiro L, Aragao CA. Physiological response of cowpea seeds to salinity stress. Rev. Bras. Sementes 2005; 27 (1): 144 – 148.

[37] Beltagi MS, Ismail MA, Mohamed FM. Induced salt tolerance in common bean (*Phaseolus vulgaris* L.) by gamma irradiation. Pakistan J. Bio. Sci. 2006; 6: 1143 – 1148

[38] Houimli SIM, Denden M, Elhadj SB. Induction of salt tolerance in pepper (B or Hbt 1mmtt1) by 24-epibrassinolide. Eurassia J. Bio. Sci. 2008; 2: 83 – 90

[39] Memon SA, Hou X, Wang IJ. Morphological analysis of salt stress response of pak Choi. EJEAFChe 2010; 9 (1): 248 – 254.

[40] El-Juhany LI, Aref IM, Ahmed AIM. Response of *Eucalyptus camaldulensis*, *Eucalyptus microtheca* and *Eucalyptus intertexta* seedlings to irrigation with saline water. World J. Agric. Sci. 2008; 4 (S): 825 – 834

[41] Suwalka RL, Quresh FM. Amelioration of some sodic soils in arid regions of Rajasthan. J. Ind. Soc. Soil Sci. 1995; 43: 660 – 662

[42] Sun D, Dickenson G. Response to salt stress of 16 *Eucalyptus* species, *Grevillea robusta*, *Lophostemon confertus* and *Pinus caribaea* var. *hondurensis*. For. Ecol. Manage. 1993; 60: 1 – 14

[43] Gebauer J, El-Siddig K, Salih AA, Ebert G. *Tamarindus indica* L. seedlings are moderately salt tolerant when exposed to NaCl-induced salinity. Scientia Hort. 2004; 108: 1 – 8

[44] Mazher AMA, El-Quesni EMF, Farahat MM. Responses of ornamental and woody trees to salinity. World J. Agric. Sci. 2007; 3 (3): 386 – 395