

Full Length Research Paper

Growth response and ameliorative effect of a forage plant (*Festuca arundinacea*) in calcareous saline-sodic soils

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Saline-sodic soils are characterized by the occurrence of salt and sodium (Na^+) to levels that can adversely affect several soil properties and growth of most crops. In this study, we reported a pot experiment for studying the biomass production, ion accumulation and potential soil ameliorative effects of tall fescue (*Festuca arundinacea*) grown under calcareous saline-sodic soil conditions. Seed-derived plants of *F. arundinacea*, were grown in pots filled with three different soils collected from two saline-sodic areas and one non-saline area. Results revealed that *F. arundinacea* biomass production was reduced under saline-sodic soils almost twice as much as non-saline soil. Herbage Ca^{2+} and Mg^{2+} concentration were the highest in non-saline soil but Na^+ , K^+ and Cl^- values were the highest in saline-sodic soils. Salty characteristics of the soils led to increased concentrations of Na^+ and Cl^- elements in the plants. *F. arundinacea* plantation in saline-sodic soils reduced the soil initial EC_e values to 2.1 and 3.41 units, respectively. Plants stimulated calcite dissolution and increased soil soluble Ca^{2+} content. This lowered the initial exchangeable sodium percentage (ESP) values of saline-sodic soils from 23 and 26% to 19 and 22%, respectively. At harvest, the plants removed approximately 20 and 33 kg salt ha^{-1} from the saline-sodic soils, respectively.

Key words: Soil salinity, saline-sodic soils, *Festuca arundinacea*, forage plants, soil reclamation, phytoremediation.

INTRODUCTION

The productivity of agricultural crops in many arid and semiarid regions of the world is threatened by the occurrence of salt-affected soils. Saline-sodic and sodic soils have fertility problems due to poor physical properties, such as; slaking, swelling, dispersion of clay, surface crusting and hardsetting, which adversely affect the growth and yield of crops (Shainberg and Letey, 1984; Naidu and Rengasamy, 1993; Sumner, 1993; Qadir and Schubert, 2002). In addition, osmotic and specific ion effects, together with imbalances in plant-available nutrients in such soils affect plant growth (Suarez, 2001; Barrett-Lennard, 2002). The global extent

of sodic and saline-sodic soils has been estimated as 560 million ha (Tanji, 1990). Moreover, there was a dangerous trend of 10% per year increase in salt-affected areas throughout the world (Saboora et al., 2006). Such an extensive area emphasizes the need for efficient, inexpensive and environmentally acceptable management strategies to enhance crop productivity and increase the range of crop species that can be grown in these soils.

Scientific research backed by farmer feedback has demonstrated that sodic and saline-sodic soils can be ameliorated through a plant-assisted approach (phytoremediation) (Kumar and Abrol, 1984; Mishra et al., 2002; Qadir et al., 2002). The phytoremediation of sodic and saline-sodic soils is primarily achieved by removal of Na^+ in plants and by the ability of plant roots to increase

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the dissolution rate of native calcite (Oster et al., 1999). As a potential substitute of cost-intensive chemical amelioration, phytoremediation of saline-sodic soils has been found to be an efficient and low-cost strategy (Qadir and Oster, 2002). Various plant species of agricultural significance have been found to be effective in ameliorating calcareous and moderately sodic and saline-sodic soils.

However, crops vary considerably in their efficacy of use (Batra et al., 1997; Dagar et al., 2004). In general, those species with greater production of biomass, together with the ability to withstand soil salinity and sodicity and periodic inundation, have been found to be suitable for soil amelioration (Qadir et al., 2001). Phytoremediation of saline-sodic soils involves cultivation of certain plant species that can withstand ambient soil salinity and sodicity levels. Several plant species of agricultural significance have been considered to be an effective phytoremediation material (Ghaly, 2002; Qadir et al., 2002). Some forage species are comparatively hardy in nature and can tolerate saline conditions that are detrimental to growth of conventional crops. Tall fescue, *Festuca arundinacea*, a perennial forage grass, is sometimes planted in saline soils with high water tables and drainage problems (Wu et al., 1988; Bañuelos et al., 1992). It has adapted to a variety of climatic (rainfall and temperature), edaphic (soil texture and moisture), and geographic (latitude and elevation) conditions.

Moreover, *F. arundinacea* is a high quality forage that can be useful for producing sufficient biomass in arid and saline regions (Buckner, 1985). Growers worldwide are confronted with the difficulty of selecting alternate crops to grow in salt-affected soils and sustain crop productivity. It was hypothesized that the low maintenance forage plant (*F. arundinacea*) would tolerate the calcareous saline-sodic soils and produce viable products and improve poor soil properties. Hence, the aims of this study were: (1) to determine the biomass production and ion accumulation, and (2) to establish the potential soil ameliorative effects of *F. arundinacea* grown under calcareous saline-sodic soil conditions.

MATERIALS AND METHODS

Plant and soils

Growth response and ion accumulation of a potentially salt-tolerant forage plant grown in non-saline and calcareous saline-sodic soils were investigated under greenhouse conditions in the Agriculture Faculty of Harran University over two months. About 2 g samples of tall fescue (*F. arundinacea* cv. *Au-Triumph*) seeds were planted into 6-L plastic pots filled with 4 kg of surface (0 to 20 cm) non-saline (Ikizce, fine, smectitic, thermic, Vertic Haploxerepts) and saline-sodic soils (Akçakale, fine, smectitic, thermic, Aquic Haploxerepts) (Aydemir, 2001). The soils were collected from a non-saline soil area of pH (7.67), electrical conductivity of soil paste extract (EC_e) (0.21 dS m^{-1}) and exchangeable sodium percentage (ESP) (0.40%) and two saline-sodic soil areas of pH (8.3 and 8.4), EC_e (5.27 and

8.37 dS m^{-1}) and ESP (23 and 26%) located in the Harran Plain.

Experimental procedure

Collected soils were air-dried, mixed thoroughly by a mechanical mixer, and passed through a 2-mm sieve before being placed into the pots. Fifteen pots of forage plants were planted in each soil quality (non-saline, saline-sodic-I and saline-sodic-II). Each plant was grown in a temperature controlled greenhouse using a $24 \pm 2^\circ\text{C}$ day/night temperature regime with a minimum amperage photon flux density of $400 \mu\text{mol m}^{-2} \text{ s}^{-1}$ for 12 h. Each plant was irrigated using pure water. Soil water content was maintained between 188 and 192 g kg^{-1} field capacity (on a weight basis). Water was applied by pouring it into perforated containers that were partially submerged in the middle of each pot. The *F. arundinacea* plants were harvested when they reached approximately 30 cm in height, 60 days after planting. Each plant was cut to within 2 cm of the soil surface at harvest. Harvested herbage was oven-dried at 70°C for 2 days to determine dry matter (DM) yield and was then ground in a Wiley mill to pass through a 2-mm screen for the analysis of elements.

One gram of herbage subsamples was wet-acid digested and analyzed for Ca^{2+} , Mg^{2+} , K^+ , and Na^+ , by atomic absorption spectrometry (Chapman and Pratt, 1982). Concentrations of Cl^- for the other herbage subsamples were determined by AgNO_3 titration method (Chapman and Pratt, 1982; Kacar and Inal, 2008). Chlorophyll (Strain and Svec, 1966) and cell membrane leakage (Lutts et al., 1995) values of foliage were determined. Prior to planting, representative composite soil samples were collected from each quality of soil (non-saline, saline-sodic-I and saline-sodic-II). Some initial physical and chemical properties of these soils were determined in order to compare those as control values with after harvest values based on the given methodology as follows. At harvest, composite soil samples were similarly collected after removing root residue from each pot. Each collected 500 g soil sample was dried at 65°C for four days and ground to pass through a 2-mm sieve. Water-soluble fractions of soil Ca^{2+} , Mg^{2+} , Na^+ , K^+ and Cl^- , and soil EC_e and pH were determined from a saturated soil paste extraction (Soil Conservation Service, 1972; Tan, 1996). Calcite percentages of soils were determined by Scheibler Calcimeter (Nelson, 1982). For the cation exchange capacity (CEC) determination of the soils, Na-OAc and NH_4 -OAc method was used (Sumner and Miller, 1996). Exchangeable cations of Ca^{2+} , Mg^{2+} , Na^+ and K^+ were determined using NH_4 -OAc method (Thomas, 1982). The ESP values were calculated using equation ($\text{ESP} = ((\text{exch. Na}^+)/\text{CEC}) \times 100$) (Soil Conservation Service, 1972).

Data was analyzed according to a completely randomized design with five replicates per soil. Comparisons of plant growth among different soils were tested by analysis of variance (ANOVA). When significant main effects existed, differences were tested by Duncan test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Plant growth and elemental concentrations

F. arundinacea produced almost twice as much DM yield in non-saline soil conditions compared with the saline-sodic soils (Figure 1). The saline-sodic soil quality appeared to have high effects on decreasing DM yield, although there were no significant differences in DM yield values of both saline-sodic soils (Figure 1). Figure 2 shows mean concentrations of elements in plants collected from all the various treatments throughout the

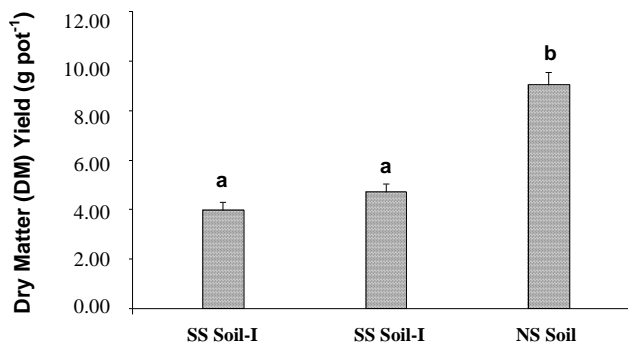


Figure 1. Mean dry Matter yields of forage plant for three different soil qualities (SS: saline-sodic, NS: non-saline). Bars followed by the same letter are not significantly different between soil types.

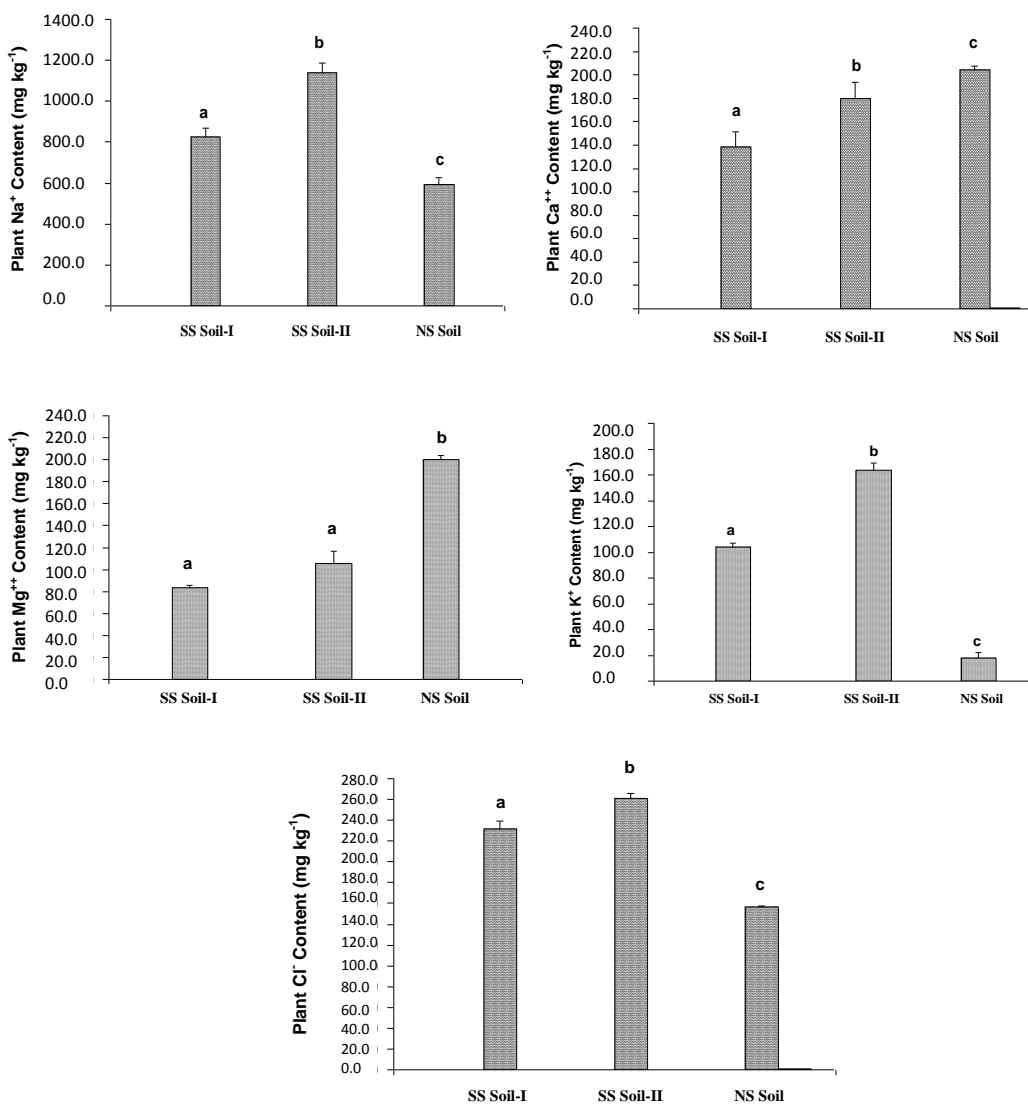


Figure 2. Mean concentrations of Na⁺, Ca²⁺, Mg²⁺, K⁺ and Cl⁻ of forage plants grown on the three different soils (SS: saline-sodic, NS: non-saline). Bars followed by the same letter are not significantly different between soil types.

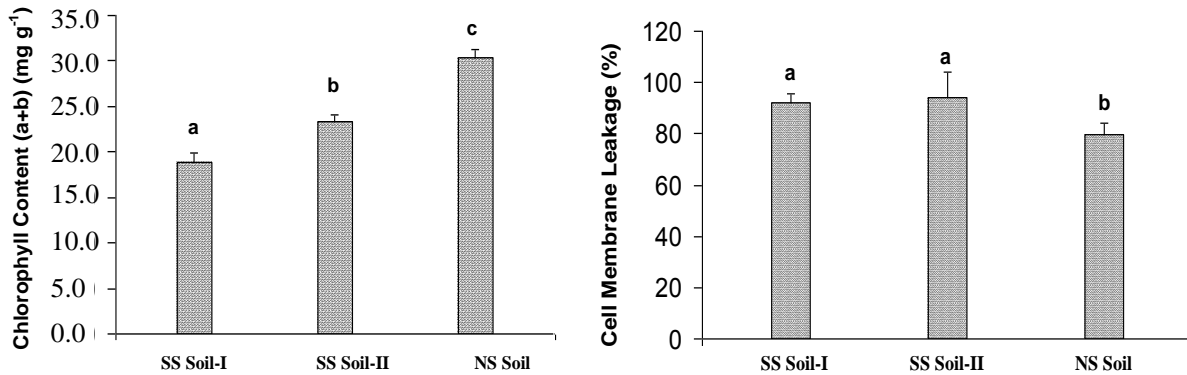


Figure 3. Chlorophyll content and Cell membrane leakage values of forage plant for three different soil qualities (SS: saline-sodic, NS: non-saline). Bars followed by the same letter are not significantly different between soil types.

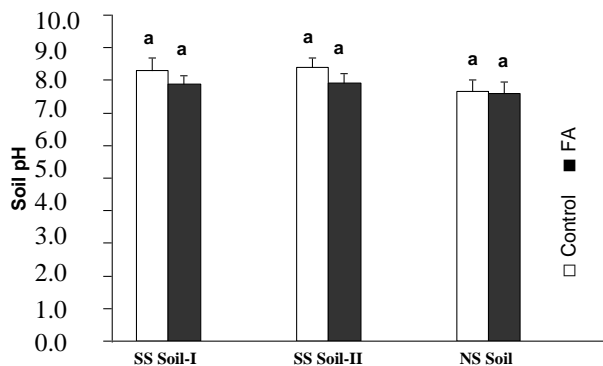


Figure 4. Soil pH values before plantation and after harvest of forage plant (SS: saline-sodic, NS: non-saline). Bars followed by the same letter are not significantly different between soil types.

study period. Herbage Ca^{2+} and Mg^{2+} concentrations were the highest in the non-saline soil. Herbage accumulated a higher Ca^{2+} concentration in saline-sodic-II soil than in saline-sodic-I soil (Figure 2). Differences of the Ca^{2+} levels were statistically significant at the $p < 0.05$ level among the three kinds of soils, although, Mg^{2+} values have not been significantly different between saline and sodic soils (Figure 2). Besides the Ca^{2+} and Mg^{2+} concentrations, Na^+ , K^+ and Cl^- levels were the highest in the saline-sodic-II soil. Herbage Na^+ , K^+ and Cl^- concentrations grown in saline-sodic soils were higher than in the non-saline soil (Figure 2). Among the others, the highest elements accumulated in the plants were Na^+ and Cl^- (Figure 2). The salty characteristic of the soils led to an increase in the concentrations of Na^+ and Cl^- elements in plants (Figure 2). Element uptake and accumulation by plants was reduced under salt-affected soil conditions as a result of competitive interactions between the element and major types of salt minerals (CaCl_2 and NaCl) (Maas and Grattan, 1999). Commonly, the crop absorption of Ca^{2+} and Mg^{2+} is sometimes badly

affected by saline environment (Grattan and Grieve, 1992; Marschner, 1995), which was confirmed for the forage plant with increased exposure to salinity (Figure 2).

On the contrary to decreased Ca^{2+} accumulation, there was an increased accumulation of potentially toxic ions such as Na^+ and Cl^- (Figure 2). Their accumulation by the plants may be reduced depending on the soil concentration of Ca^{2+} in soil solution (Cramer, 1997). A lower accumulation of Na^+ by the plants is beneficial for them (Ca^{2+} and Mg^{2+}) because Na^+ is not considered an essential element for most plants (excluding some glycophytes and many halophytes) (Marschner, 1995). Another element of concern for plants exposed to saline conditions is the excessive accumulation of Cl^- , in spite of the essentiality of Cl^- as a micronutrient for all higher plants (Marschner, 1995). Even though Cl^- concentrations were quite high in the forage plants, no visual toxicities were observed during the study period.

Total chlorophyll concentrations of the forage plants were given in Figure 3. Results showed that the concentrations are the greatest in the non-saline soil, with significant differences between all soil types ($p < 0.05$). Saltier saline-sodic-II soil displayed higher values than less salty saline-sodic-I soil. This might indicate tolerance of forage plants in poor salty conditions. Cell membrane leakage values of the plants given in Figure 3 revealed that values were higher in salty soils than in the non-salty soil. This is due to plant stress and cell damage in salty conditions.

Soil properties

Forage plant growth in the salty soils decreased pH values during the study period. But, there were no significant differences before, between and after this experiment (Figure 4). However, soil calcite values were significantly affected by the plant growth in salt-affected soils. But there was no change in calcite content in the

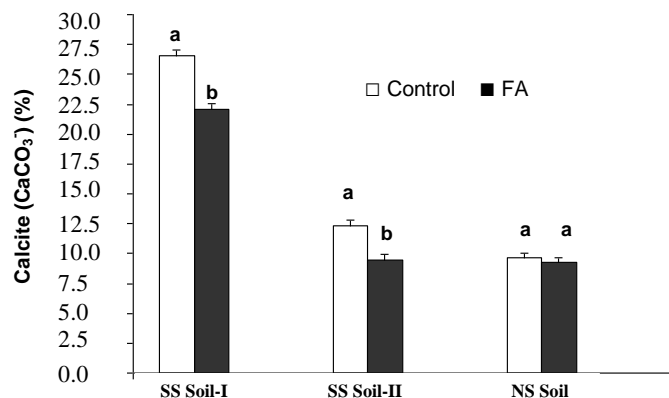


Figure 5. Soil calcite values of the soils before plantation and after harvest of forage plant (SS: saline-sodic, NS: non-saline). Bars followed by the same letter are not significantly different between soil types.

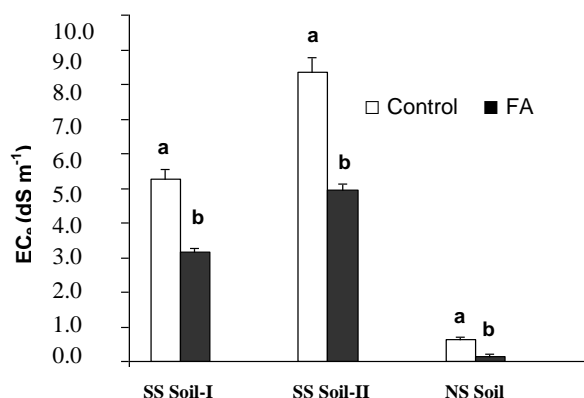


Figure 6. Electrical conductivity (EC_e) values of the soils before plantation and after harvest of forage plant (SS: saline-sodic, NS: non-saline). Bars followed by the same letter are not significantly different between soil types.

non-saline soil (Figure 5). The forage plants showed a dissolution effect on reduction of calcite content for salt-affected soils (Figure 5). This reduction was greater in the saline-sodic-I soil than in the saline-sodic-II soil. Plant effect on the calcite content in soils might be affected by the soil initial concentrations of calcite. Because obtained results indicated that when the initial calcite content of soils was high, the reduction effect of plant on calcite content was high and while the initial calcite content was lower, the reduction effect of plant was also lower (Figure 5).

Electrical conductivity (EC_e) values of the salty and non-salty soils were positively affected with plantation of the forage plant. When the values were compared in both cases (before plantation and after harvest), significant decreases were observed in all soils. Saline-sodic-II soil reflected the highest salt reduction than the other soils (Figure 6). This result was supported with the data of salt removal given in Figure 10.

The forage plant growing in saline-sodic-II soil removed significantly higher amounts of salt than the other salty soil. The lowest decrease in soil EC_e was observed in non-saline soil as was expected. Concentration results (control values) of the soil soluble ions (Ca^{2+} , Mg^{2+} , Na^+ , Cl^- and HCO_3^-) before plantation were higher in salt-affected soils than in non-saline soil (Figure 7). The values of all ions, excluding the Ca^{2+} and HCO_3^- , decreased their concentrations after harvest of the forage plant (Figure 7). The case of Ca^{2+} and HCO_3^- increase might be explained by the dissolution of calcite as a source of Ca^{2+} and CO_3^{2-} . Reductions of other ion concentrations resulted from the plant uptake of those ions as a nutrient. The highest decrease of Na^+ and Cl^- concentrations can be explained by the highest plant uptake in the saline-sodic soils (Figures 7 and 2) because of no drainage occurring during the study. Existence of calcite dissolution during the study resulted in a reduction of exchangeable Na^+ values on the exchange sites of the soil colloids (Figure 8). Increasing Ca^{2+} ions in soils were obtained by all plants and replaced with Na^+ on soil exchange complexes (Figures 7 and 8).

Ameliorative effect

Ameliorative effects of forage plants on calcareous salt-affected (saline, saline-sodic and sodic) soils might be evaluated in two ways. One way is by determining their tolerance capacities to the growing soil conditions as biomass production. Evaluation of the plant tolerance to saline conditions is the growth response on saline conditions compared with plants grown under non-saline conditions (Shannon et al., 1994). Determining growth responses of *F. arundinacea* (FA) of this study indicated that non-saline soil biomass values were about two times more than saline-sodic soils. This indicated that salty and sodic soils reduced the biomass production about 50% compared to the non-saline soil. Within the saline-sodic soils, FA produced more biomass in saline-sodic-II soil than in saline-sodic-I soil, but there was no significant production difference between soils at $p < 0.05$ confidence interval level (Figure 9).

The second way of evaluating the ameliorative effects of plants on salt-affected (calcareous saline-sodic) soils is by determining the salt removal and comparing the EC_e and ESP values of the growing medium of calcareous saline-sodic and non-saline soils before plantation and after harvest.

The amount of ions (salt) removed through the harvested forage plant was calculated by means of the equation from Qadir et al. (2003):

$$S_{\text{ion-removal}} = [(S_{\text{ion-conc}}) (S_{\text{DW}}) / (10^3)] / MW_{\text{ion}}$$

Where $S_{\text{ion-removal}}$ is ion removal through harvest (mmol pot^{-1}), $S_{\text{ion-conc}}$ is ion concentration in harvested plant (mg kg^{-1}), S_{DW} is plant dry weight (g pot^{-1}), and MW_{ion} is molecular weight of ion.

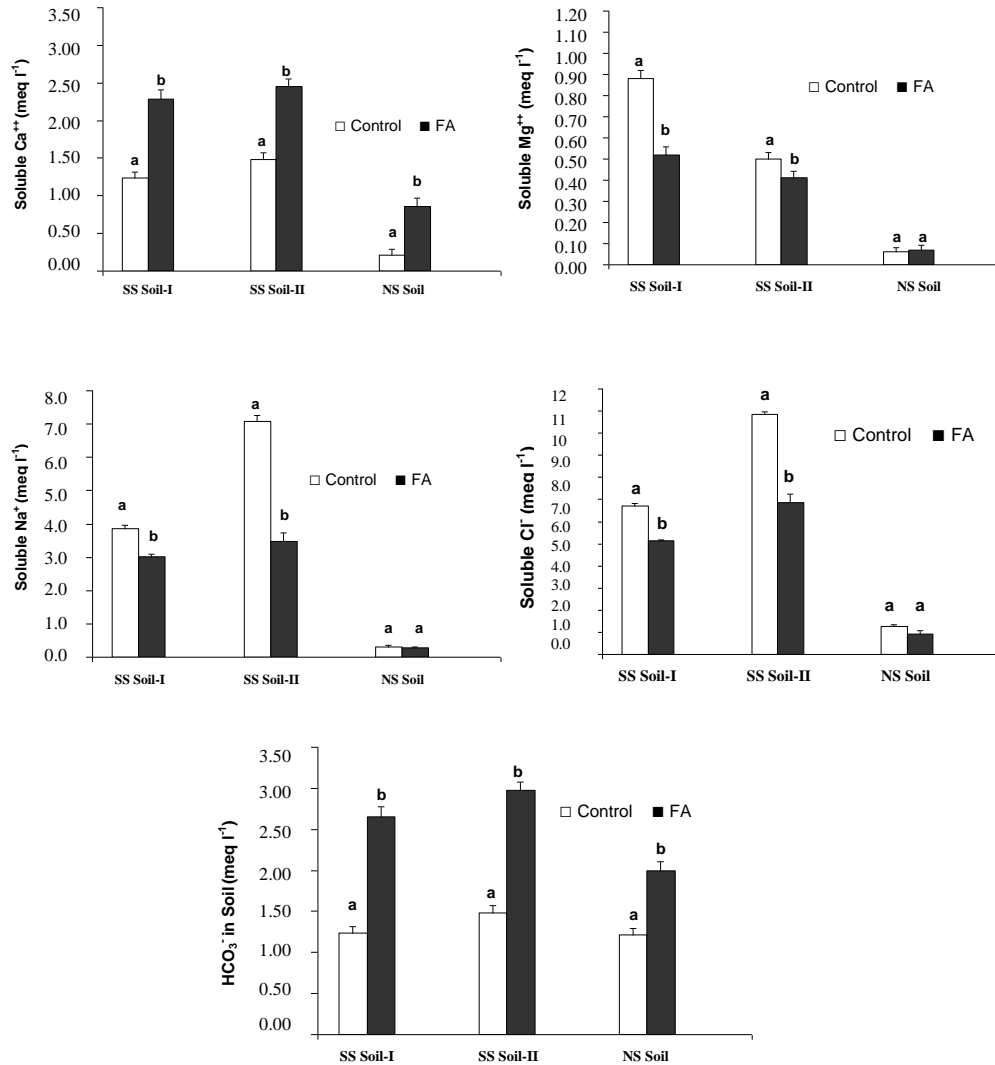


Figure 7. Soil soluble ion (Ca^{2+} , Mg^{2+} , Na^+ , Cl^- and HCO_3^-) values of the soils before plantation and after harvest of forage plant (SS: saline-sodic, NS: non-saline). Bars followed by the same letter are not significantly different between soil types.

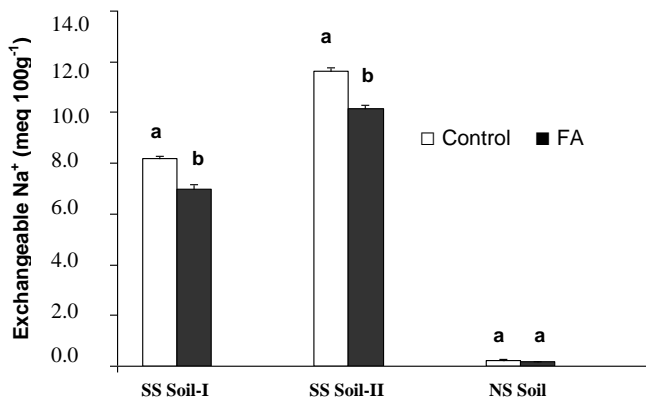


Figure 8. Exchangeable Na^+ values of the soils before plantation and after harvest of forage plant (SS: saline-sodic, NS: non-saline). Bars followed by the same letter are not significantly different between soil types.

The calculated amount of salt removed from salt-affected soils during the study was given in Figure 10 as an amount of kg ha^{-1} . According to the results, FA removed higher amounts of salt from saline-sodic-II soil which is initially highly saline. This result was supported with the EC_e values given in Figure 6. As it is seen from the graph, Saline-sodic-II soil shows higher reduction in EC_e values than the saline-sodic-I soil when compared to the control values. Plant effect on amelioration of calcareous saline-sodic soils has been attributed to the increased partial pressure of carbon dioxide (PCO_2) in the root zone, which helps in dissolution of CaCO_3 (Robbins, 1986; Qadir et al., 1996; Aydemir and Sönmez, 2008). This effect has been outlined through a series of processes;

1. Increase in soil atmosphere CO_2 concentration,

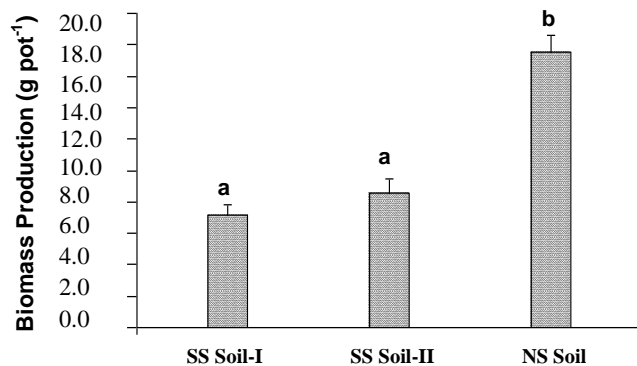


Figure 9. Biomass productions of forage plant for three different soil qualities (SS: saline-sodic, NS: non-saline). Bars followed by the same letter are not significantly different between soil types.

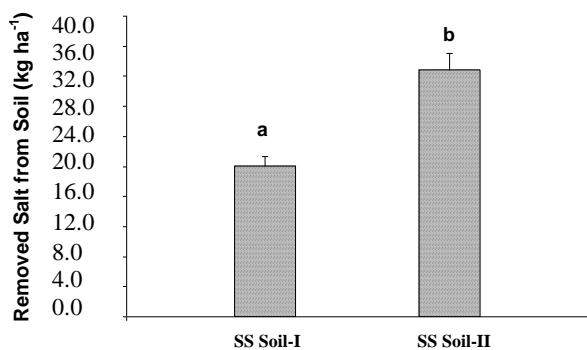


Figure 10. Salt amount removed from the salt-affected soils by harvested forage species (SS: saline-sodic). Bars followed by the same letter are not significantly different between soil types.

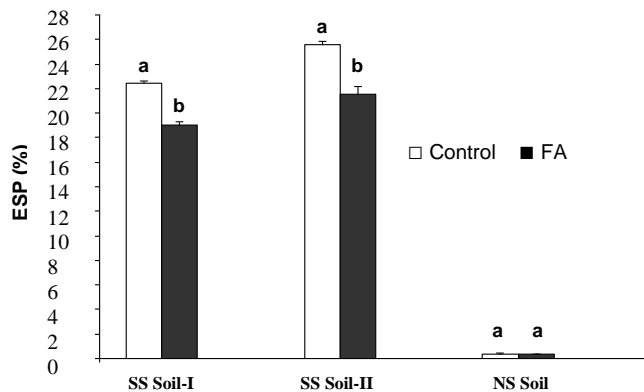


Figure 11. Exchangeable sodium percentage (ESP) values of the soils before plantation and after harvest of forage species (SS: saline-sodic, NS: non-saline). Bars followed by the same letter are not significantly different between soil types.

2. Dissolution of CO₂ in soil water to form carbonic acid (H₂CO₃),

3. Dissociation of H₂CO₃ resulting in proton (H⁺) and bicarbonate (HCO₃⁻),
4. Dissolution of soil CaCO₃ with reaction of H⁺ to produce Ca²⁺ and HCO₃⁻,
5. Na⁺-Ca²⁺ exchange at the soil's exchange sites as a consequence of increased Ca²⁺ concentration in soil solution,
6. Removing of the exchanged Na⁺ by plant uptake and
7. Subsequent reduction in soil sodicity (ESP) (Qadir et al., 2003).

One lysimeter experiment reported that the crops producing the highest PCO₂ were the ones with the greatest Na⁺ removal efficiency from a calcareous sodic soil (Robbins, 1986).

The present study revealed that plantation of the *F. arundinacea* in saline-sodic soils significantly decreased the ESP values of the soils compared to the control values (Figure 11). Higher reduction occurred in calcareous saline-sodic-II soil. This result also supported the reduction of exchangeable Na⁺ values given in Figure 6.

Conclusion

Amelioration and production potentials (biomass production and ion accumulation) of a forage plant (*F. arundinacea*) were evaluated at three different soil qualities during the 60 day pot experiment in a controlled greenhouse condition. The results indicated that the contents of Na⁺ and Cl⁻ in plants increased as salinity levels of growth medium were high. The noticeable contents of Na⁺ and Cl⁻ were accumulated in plant aerial parts at the highest level of salinity and sodicity, whereas minimum values occurred at non-saline condition. Although the biomass production of the plant decreased with increasing salinity, its survival or noticeable growth during the short period of time indicated that plantation of this forage plant could be acceptable in saline-sodic soil conditions.

As an ameliorative effect, *F. arundinacea* plantation on salt-affected soils reduced the soil initial EC_e values as 2.1 and 3.41 unit for the saline-sodic soils, respectively. Plant stimulated calcite dissolution and increased soil soluble Ca²⁺ and this decreased exchangeable Na⁺ and lowered the initial ESP values of saline-sodic soils from 23 and 26% to 19 and 22%, respectively. At harvest *F. arundinacea* removed approximately 20 and 33 kg salt ha⁻¹ from saline-sodic soils, respectively. Overall, it might be concluded that, in spite of the proportional reduction in biomass production under saline-sodic soil conditions, *F. arundinacea* appeared to be efficient and capable of growing and reclaiming the calcareous saline-sodic soils as a promising phytoremediation plant.

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REFERENCES

- Aydemir S (2001). Properties of Palygorskite-Influenced Vertisols and Vertic-like Soils in the Harran Plain of Southeastern Turkey (Ph.D., Dissertation). Texas A&M University, College Station TX 77843, USA.
- Aydemir S, Sönmez O (2008). Ameliorative effect of indigenous calcite on sodium-saturated clay systems. *Soil Sci.*, 178(2): 96-107.
- Bañuelos GS, Mead R, Wu P, Beuselinck P, Akohoue S (1992). Differential selenium accumulation among forage plant species grown in soils amended with selenium-enriched plant tissue. *J. Soil Water Conserv.*, 47: 338-342.
- Barrett-Lennard EG (2002). Restoration of saline land through revegetation. *Agric. Water Manage.*, 53: 213-226.
- Batra L, Kumar A, Manna MC, Chhabra R (1997). Microbiological and chemical amelioration of alkaline soil by growing Karnal grass and gypsum application. *Exp. Agric.*, 33: 389-397.
- Buckner RC (1985). The fescues. In: Heath M E, Barnes RF, Metcalfe DS (eds) *Forages*, 4th edition. Iowa State University Press, Ames, Iowa, pp. 233-240.
- Chapman HD, Pratt, PF (1982). Methods of analysis for soils, plants and water. *Methods of Soil Analysis Part 1: Physical and Mineralogical Methods* 2nd Edition. Agronomy Series No: 9. Am. Soc. of Agronomy and Soil Sci. Soc. of Am. Inc. Publisher, Madison, Wisconsin USA, pp. 363-381.
- Cramer GR (1997). Uptake and role of ions in salt tolerance. In: Jaiwal RK, Singh RP, Gulati A (eds) *Strategies for improving salt tolerance in higher plants*. Science Publishers, Inc. New Hampshire, pp. 55-86.
- Dagar JC, Tomar OS, Kumar Y, Yadav RK (2004). Growing three aromatic grasses in different alkali soils in semi-arid regions of northern India. *Land Degrad. Dev.*, 15: 143-151.
- Ghaly FM (2002). Role of natural vegetation in improving salt affected soil in northern Egypt. *Soil Tillage Res.*, 64: 173-178.
- Grattan SR, Grieve CM (1992). Mineral element acquisition and growth response of plants grown in saline environments. *Agric. Ecosyst. Environ.*, 38: 275-300.
- Kacar B, Inal A (2008). *Plant Analysis*. Nobel Publication and Distribution Ltd. Ostim-Ankara.
- Kumar A, Abrol IP (1984). Studies on the reclaiming effect of Karnalgrass and para-grass grown in a highly sodic soil. *Indian J. Agric. Sci.*, 54: 189-193.
- Lutts S, Kinet JM, Bouharmont J (1995). Changes in plant response to NaCl during development of rice (*Oryza sativa* L.) varieties differing in salinity resistance. *J. Experi. Bot.*, 46: 1843-1852.
- Maas EV, Grattan SR (1999). Crop yields as affected by salinity. In: Skaggs RW, Van Schilfhaarde J (eds) *Agricultural drainage*. Agronomy Monograph No. 38, Agronomy Society of America, Madison, Wisconsin, pp. 55-110.
- Marschner H (1995). *Mineral nutrition of higher plants*, 2nd edition. Academic Press, San Diego, California, USA, pp. 87-96.
- Mishra A, Sharma SD, Khan GH (2002). Rehabilitation of degraded sodic lands during a decade of *Dalbergia sissoo* plantation in Sultanpur district of Uttar Pradesh, India. *Land Degrad. Dev.*, 13: 375-386.
- Naidu R, Rengasamy P (1993). Ion interactions and constraints to plant nutrition in Australian sodic soils. *Aust. J. Soil Res.*, 31: 801-819.
- Nelson RE (1982). Carbonate and Gypsum. In: Page AL, Miller RH, Keeney DR (eds) *Methods of Soil Analysis Part 2: Chemical and Microbiological Properties* 2nd Edition. Agronomy Series No: 9. Am. Soc. of Agronomy and Soil Sci. Soc. of Am. Inc. Publisher, Madison, Wisconsin USA, pp.181-196.
- Oster JD, Shainberg J, Abrol JP (1999). Reclamation of salt-affected soils. In: Skaggs R W, Van Schilfhaarde G (eds) *Agricultural drainage*. Agronomy Monograph No. 38, Agron. Soc. Amer, Madison, Wisconsin, pp. 659-694.
- Qadir M, Schubert S (2002). Degradation processes and nutrient constraints in sodic soils. *Land Degrad. Dev.*, 13: 275-294.
- Qadir M, Schubert S, Ghafoor A, Murtaza G (2001). Amelioration strategies for sodic soils: A review. *Land Degradation and Development*, 12: 357-386.
- Qadir M, Oster JD (2002). Vegetative bioremediation of calcareous sodic soils: history, mechanisms, and evaluation. *Irrig. Sci.*, 21: 91-101.
- Qadir M, Qureshi RH, Ahmad N (2002). Amelioration of calcareous saline-sodic soils through phytoremediation and chemical strategies. *Soil Use Manage.*, 18: 381-385.
- Qadir M, Qureshi RH, Ahmad N (1996). Reclamation of a saline-sodic soil by gypsum and *Leptochloa fusca*. *Geoderma*, 74: 207-217.
- Qadir M, Steffens D, Yan F, Schubert S (2003). Sodium removal from a calcareous saline-sodic soil through leaching and plant uptake during phytoremediation. *Land Degrad. Dev.*, 14: 301-307.
- Robbins CW (1986). Sodic calcareous soil reclamation as affected by different amendments and crops. *Agron. J.*, 78: 916-920.
- Saboora A, Kiarostami K, Behroozbayati F, Hashemi SH (2006). Salinity (NaCl) tolerance of wheat genotypes at germination and early seedling growth, Pakistan. *J. Biol. Sci.*, 9(11): 2009-2021.
- Shainberg I, Letey J (1984). Response of soils to sodic and saline conditions. *Hilgardia*, 52: 1-57.
- Shannon MC, Grieve CM, Francois LE (1994). Whole-plant response to salinity. In: Wilkinson, RE (eds) *Plant-environment interactions*. Books in Soils, Plants, and the Environment. Marcel Dekker, New York, pp. 199-244.
- Soil Conservation Service (1972). *Soil survey laboratory methods and procedures for collecting soil samples*. Soil Survey Invest. Rep. No. 1. U.S. Gov. Print. Office, Washington, DC.
- Strain HH, Svec WA (1966). Extraction, separation, estimation and isolation of chlorophylls. In: Vernon LP, Seely Gr (eds) *The Chlorophylls*, Academic Press: New York, pp. 21-66.
- Suarez DL (2001). Sodic soil reclamation: Modelling and field study. *Aust. J. Soil Res.*, 39: 1225-1246.
- Sumner ME (1993). Sodic soils: New perspectives. *Aust. J. Soil Res.*, 31: 683-750.
- Sumner ME, Miller WP (1996). Cation Exchange Capacity and Exchange Coefficients. In Sparks DL (eds) *Methods of Soil Analysis Part 3: Chemical Methods*. SSSA Book Series No: 5. Am. Soc. Of Agronomy and Soil Sci. Soc. of Am. Inc. Publisher, Madison, Wisconsin USA, pp. 1201-1230.
- Tan KH (1996). *Soil Sampling and Analysis*. Marcel Dekker, Inc. 270 Madison Avenue, New York, NY, 10016. p. 191.
- Tanji KK (1990). Nature and extent of agricultural salinity. In: *Agricultural salinity assessment and management*. Tanji KK (eds) American Society of Civil Engineers New York, pp. 1-17.
- Thomas GW (1982). Exchangeable Cations. In: Page AL, Miller RH, Keeney DR (eds) *Methods of Soil Analysis Part 2: Chemical and Microbiological Properties* 2nd Edition. Agronomy Series No: 9. Am. Soc. of Agronomy and Soil Sci. Soc. of Am. Inc. Publisher, Madison, Wisconsin USA, pp.159-164.
- Wu L, Huang ZZ, Burau RG (1988). Selenium accumulation and selenium-salt tolerance in five grass species. *Crop Sci.*, 28: 517-522.