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

Salih Aydemir1* and Halime Sünger (Akıl)2

1Department of Soil Science and Plant Fertility, Faculty of Agriculture, Harran University, 63200, Şanlıurfa, Turkey.
2Trade Stock Market Branch of Undersecretary of Foreign Trade, Ministry of Economy, 63100, Şanlıurfa, Turkey.

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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 Ca2+ and Mg2+ 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 ECe values to 2.1 and 3.41 units, respectively. Plants stimulated calcite dissolution and increased soil soluble Ca2+ 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 580 million ha (Tanjit, 1990). Moreover, there was a dangerous trend of 10% per year increase in salt-affected areas throughout the world (Saboor 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
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; Bahuelos 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, thonic, Vertic Haploxererts) and saline-sodic soils (Aksakale, fine, smectitic, thonic, Aquic Haploxererts) (Aydemir, 2001). The soils were collected from a non-saline soil area of pH (7.67), electrical conductivity of soil paste extract (ECe) (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), ECe (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 ± 2°C day/night temperature regime, with a minimum amperage photon flux density of 400 μmol m⁻² 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 Ca²⁺, Mg²⁺, K⁺, and Na⁺, by atomic absorption spectrometry (Chapman and Pratt, 1982). Concentrations of Cl⁻ for the other herbage subsamples were determined by AgNO₃ 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 Ca²⁺, Mg²⁺, Na⁺, K⁺ and Cl⁻, and soil ECe 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-NO₃ and NH₄-NO₃ method was used (Sumner and Miller, 1996). Exchangeable cations of Ca²⁺, Mg²⁺, Na⁺ and K⁺ were determined using NH₄-NO₃ method (Thomas, 1982). The ESP values were calculated using equation (ESP = ((exch. Na⁺)/CEC) × 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 ≤ 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

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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.
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

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**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.
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 ECe 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 ECe 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 following equation from Qadir et al. (2003):

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

Where $S_{i\text{-removal}}$ is ion removal through harvest (mmol plant$^{-1}$), $S_{i\text{-conc}}$ is ion concentration in harvested plant (mg kg$^{-1}$), $S_{dw}$ is plant dry weight (g pot$^{-1}$), and $MW_{i\text{-ion}}$ is molecular weight of ion.
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\(_s\) values given in Figure 6. As it is seen from the graph, Saline-sodic-II soil shows higher reduction in EC\(_s\) 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,
Plant Growth (fresh weight) (g)

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Biomass Production (g pot⁻¹)

- SS Soil-I
- SS Soil-II
- NS Soil

3. Dissolution 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 ECₑ 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 form 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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