Silva Fennica vol. 51 no. 1B article id 1579
Category: research article
https://doi.org/10.14214/sf.1579

SILVA FENNICA

http://www.silvafennica.fi

ISSN-L 0037-5330 | ISSN 2242-4075 (Online)
The Finnish Society of Forest Science

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Afforestation restoration of saline-sodic soil in the Central Anatolian Region of Turkey using gypsum and sulfur

Yildiz O., Altundağ E., Çetin B., Güner Ş.T., Sarginci M., Toprak B. (2017). Afforestation restoration of saline-sodic soil in the Central Anatolian Region of Turkey using gypsum and sulfur. Silva Fennica vol. 51 no. 1B article id 1579. 17 p. https://doi.org/10.14214/sf.1579

Highlights

- Significantly enhanced height and diameter growth of *Elaeagnus angustifolia* and height growth of *Populus alba* improved with soil chemical amendments in comparison to control.
- Infiltration rate on gypsum application sites was 55% higher than on sulfur application sites.
- *Elaeagnus angustifolia* survival rates with chemical treatments were 43% greater than controls.
- *Tamarix smyrnensis* had the highest mean survival rate of 80%, while *Populus alba* averaged 36%.

Abstract

A significant amount of land area in the Central Anatolian Region of Turkey has saline-sodic soil properties. The aim of the current study was to use both soil amendment and tree to restore these degraded lands. The primary objective was to ameliorate soils by leaching excess sodium with gypsum and sulfur applications. Following soil treatments, salt cedar (*Tamarix smyrnensis* Bunge), Russian olive (*Elaeagnus angustifolia* L.) and silver poplar (*Populus alba* L.) seedlings were planted on experimental and control sites to evaluate the effects of the treatments on survival and growth of these species. In the fall of 2013, three-year-old seedlings were planted using 1.5 × 1.5 m spacing on each plot. Survival rates were determined and height and diameter were measured at the end of September 2015. Second year infiltration measurements indicated that both chemical treatments had significantly increased the infiltration capacity of the soil ($P = 0.0003$). Soil infiltration capacity on gypsum treated sites was about 55% higher than on sulfur sites. Following the second growing season, salt cedar had the highest survival rates of 80%. Silver poplar had 36% survival rates across the treatments. Russian olive had 50 cm height growth on both gypsum and sulfur application sites vs. only 25 cm on controls. Diameters of Russian olive on gypsum and sulfur sites were about 9.3 mm vs. 5 mm on the controls. Silver poplars on gypsum treated sites grew 42% taller than controls. Salt cedar had no significant growth responses among treatments. With appropriate soil amendments, especially gypsum, Russian olive gave the best overall two-year results.

Keywords arid zones; *Elaeagnus angustifolia*; *Tamarix smyrnensis*; *Populus alba*; soil amelioration; exchangeable sodium percent
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Received 10 March 2016 **Revised** 9 January 2017 **Accepted** 1 February 2017

1 Introduction

The Central Anatolia closed basin was covered by lakes in the Pliocene (5.32–1.81 mya). The lakes had deposits that accumulated lacustrine clay and calcareous materials over millions of years (Birkman 1976). Geologic materials resulting from the intense volcanic activities of the Miocene and Pliocene mingled with these lacustrine deposits in the lake bottom. With the drying up of the lake, soil containing volcano-sedimentary materials was exposed along an extensive area, including the Salt Lake and the great plain of Konya (Birkman 1976; Aşk 1977).

The continental tropical air currents coming from the northern African and the Arabian deserts led to the formation of long-term dry and hot climates in this area, especially during the summer months (Özyuvacı 1999). The annual precipitation shows extremely variable spatial and seasonal distributions and there is a considerable soil water deficit due to severe wind and exceeded evaporation (Özyuvacı 1999; Atalay 2002). During dry periods, fine-grained soil is completely dried and transformed into dust. This dry, loose material is transported over long distances by wind (Birkman 1976; Balcı 1978).

Plant cover has been destroyed in significant amounts as a result of long years of grazing and agricultural activities in the arid and semi-arid regions of Central Anatolia. Especially during the last 60 years of ground cover disturbance resulted in soil erosion at an unprecedented level. The area of cultivated land increased from 6.5 million ha to 22 million ha from the 1930s to 1956. The increase in the amount of cultivated areas caused the reduction of pasture land. The 46 million ha of pasture land in 1936 dropped to 29 million in 1960. Tilling the pastures to convert them into agricultural lands destroyed the protective groundcover and decreased the organic matter by increasing its decomposition over time.

The soils in the region possess many unique properties that limit plant growth. Saline and sodic soils cover about 1.5 million ha of land area in the region (Yılmaz 2001). These soils commonly have alkaline reactions, calcium carbonate accumulation, weak to moderate profile development, clay dispersion, a low level of organic matter, and low biological activity (Kapur et al. 2002; Atalay 2002) making them susceptible to erosion and difficult to manage (Dregne 1976; Hillel 1998; Mzezewa et al. 2003; Guarnieri et al. 2005).

Leaching the soil to remove soluble salts below the rooting zone is the most effective method to reclaim saline soils (Khamzina et al. 2008; Hbirkou et al. 2011). Reclamation of sodic soils is a two-step process; The first step involves the replacement of exchangeable sodium with calcium; the second step is to leach the resulting sodium salt from the soil (Richards 1954). There are two main types of amendments; those that add calcium directly to the soil and those that dissolve calcium from calcium carbonate already present in the soil (Richards 1954; Pal et al. 2006; Sahin et al. 2011). Of the amendments used to bring about exchangeable sodium replacement with calcium, gypsum is far and away the most-used material. Gypsum is moderately soluble in water and is very cheap, especially if it has a local source (Anapalı and Tosunoğlu 1997; Yılmaz 2001; Sahin et al. 2011). Acidic amendments can include sulfuric acid, and elemental sulfur. Elemental sulfur must be oxidized by soil bacteria and react with water to form sulfuric acid. Sulfuric acid converts sodium carbonate and bicarbonate to leachable sodium sulfate (Brady and Weil 1999). To avoid resodification, replaced Na^+ has to be leached away from the root zone with adequate amounts of water.

Another method of restorating degraded soils and combating desertification is afforestation. Recently, the Turkish government has adopted erosion control in combating desertification. Tree windbreaks have been planted extensively in the area for the purpose of reducing wind erosion and increasing snow accumulation. A major program of planting windbreaks in the region was undertaken in the 1960s. By the end of 2014, an area of 2 378 398 ha had undergone afforestation in Turkey, of this 1 540 008 ha are arid and semi-arid areas.

The results that have been obtained so far are limited to interpretations made about the species of the planted seedlings and their origin (Eşen 2000; Eşen and Yildiz 2000, 2006; Semerci 2002; Genç 2004; Zengin 2009; Gökdemir et al. 2011, 2012). However, data about soil chemical and physical properties and reclamation practices is lacking (Dundar 1973). Therefore, additional new studies about soil reclamation can contribute important information to help solve these problems. The present, experimentally designed field study is the first comprehensive afforestation project of its kind in Turkey.

The first objective of the current study was to investigate the reclamation of sodic soils via chemical amendments in designated experimental soil erosion control sites located in the Aksaray, Ereğli and Kayalı regions of Central Anatolia. A second main objective was to assess the afforestation potential of these treatments on the survival and growth performance of three tree species seedlings: salt cedar (*Tamarix smyrnensis* Bunge), Russian olive (*Elaeagnus angustifolia* L.) and silver poplar (*Populus alba* L.), that were planted on the sites following the treatments.

2 Materials and methods

2.1 Site description

One of our study sites located in the Kayalı region (37°50´N, 33°43´E) is designated as an erosion protection area by the Ministry of Forestry and Water Relations. Another site is called Aksaray (38°18´N, 33°59´E) along the Aksaray-Adana motorway at 980 m elevation. The third site is situated 20 km west of the city of Ereğli (37°37´N, 33°56´E) at 1000 m elevation.

By using aridity indexes, Ceylan et al. (2009) evaluated the Aksaray, Ereğli and Karapınar regions as the driest part of Turkey and considered these areas as very dry, using the method of Walter (1970). The Walter diagrams are based on 60 years of climatic data and indicate that these site locations experience a water deficiency from May to October (Figs. 1a, b and c). The area presents differing geological conditions. All three study sites are situated in the great Konya basin which is a closed basin drainage system with arid zone conditions. The soils have indurated carbonate layers and petrocalcic horizons, thus representing physical features unique to arid regions. In the central Anatolian plain, limestone, marn, marnocalcer, claystone, conglomerate, sandstone and gypsum are commonly distributed. Due to early volcanic activity, basalt, andesitic and tuff formations are common around the Hasandağı and Karacadağ mountains. Near the center of the region, limestone, sandstone and sandy sediments are dominant. Brown soils (cambisol/inceptisol) are common because of the high limestone content of the parent materials in the region.

Due to climatic and soil conditions, the study region is devoid of natural forests. The major part of the region is characterized by herbaceous dry cultivation and unplowed pastures. The Lowlands are generally barren or occupied by patchy growth of mainly rushes (*Juncus* spp.).

2.2 Experimental design and tree species

In the summer of 2012, three abandoned afforestation sites with saline-sodic soil properties were designated for this study. From the results of the earlier trials and experience in the region, three promising plant species, salt cedar (*T. smyrnensis*), Russian olive (*E. angustifolia*) and silver poplar (*P. alba*) were chosen for the experiment. For each species in each block, there is 1 gypsum and 1 sulfur application plot with a control plot adjacent to them. Each of the three study area was considered a regional replicate (block) with a complete block design of the three treatments for each species. The total number of experimental units is: 3 (two treatments + 1 control) × 3 species × 3 blocks = 27.

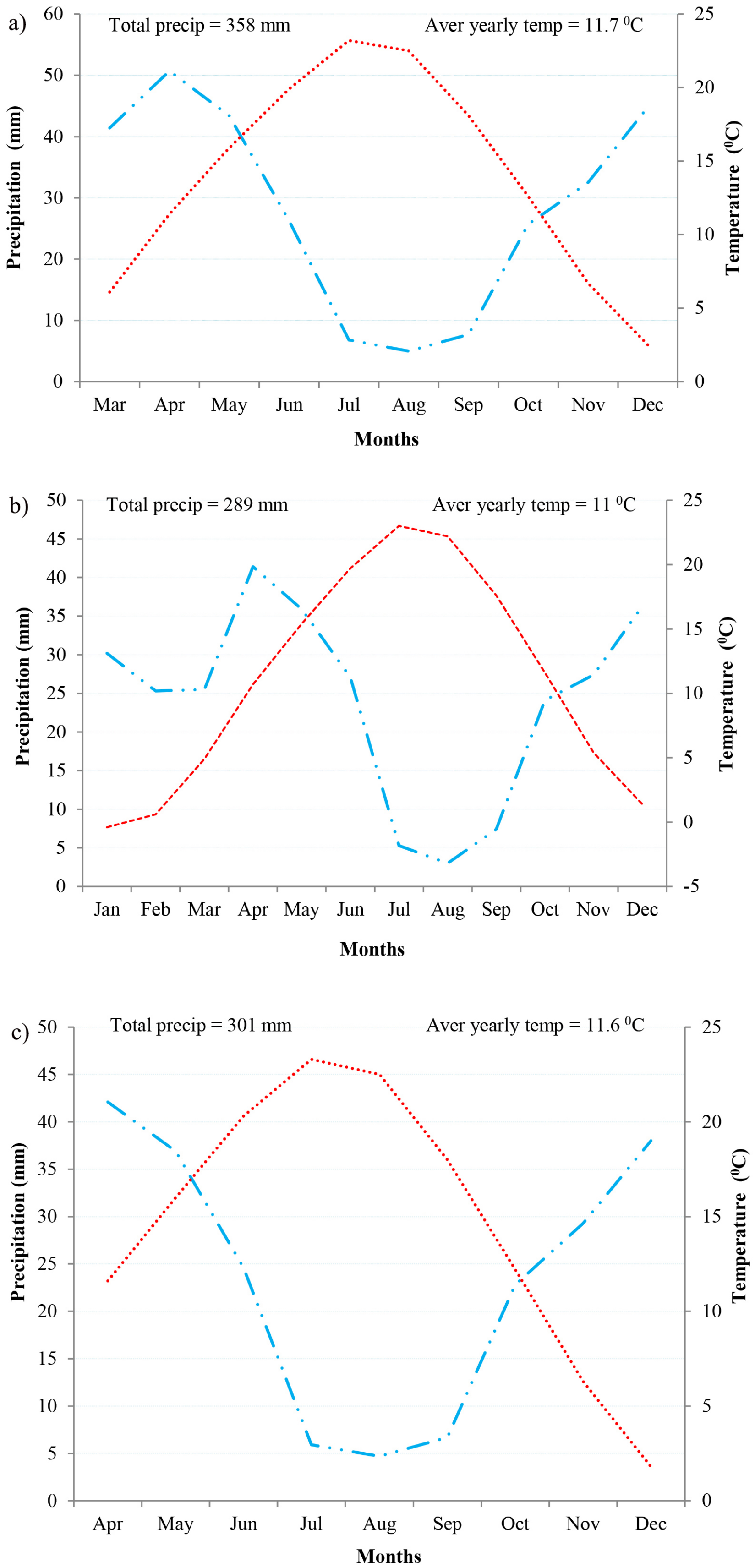

Fig. 1. Walter diagram for Aksaray (a), Kayalı (b) and Ereğli (c) experimental sites used for studying effects of soil amendments on saline-sodic soils in the Central Anatolian region of Turkey.

Table 1. Soil properties (Averages, N = 15) of the experimental sites before treatments applied for studying effects of soil amendments on saline-sodic soils in the Central Anatolian region of Turkey. CEC = cation exchange capacity; ESP = exchangeable sodium percentage; EC = electrical conductivity.

Sites	Soil texture type	pH	CEC ($cmol_c\ kg^{-1}$)	ESP (%)	Total calcite ($CaCO_3$ %)	Soil bulk density ($g\ cm^{-3}$)	EC ($dS\ m^{-1}$)
Aksaray	Clay loam	8.3	38	36	7	1.28	6
Ereğli	Clay	8.7	39	38	49	1.30	7
Kayalı	Loamy clay	8.3	34	43	23	1.36	10

2.3 Soil sampling and analysis

In order to determine appropriate amendment doses to use and to determine the subsequent effects on soil properties two sets of five random soil samples were taken in June, 2012 from the first 30 cm of the soil on 5 spots of each plot using a 200 cm^3 core sampler (Hammer-driven AMS soil core sampler). One set of the soil samples was used for soil bulk density. The soil bulk density was calculated from a known volume of the soil core and from the oven dry mass of the cores. The other set of soil samples (weighing about 2 kg) was air dried and sieved (< 2 mm) for analysis. Soil particle-size distribution was analyzed with a Bouyoucos hydrometer method, thus enabling soil texture determinations (Gee and Bauder 1986). Soil pH and electrical conductivity (EC) were measured using a digital pH meter (Thomas 1996) and an electrical conductivity meter (Rhoades 1996) in a soil and water suspension (Hanna instruments HI 255 pH/EC Meter). Total calcite ($CaCO_3$) content was measured with a Scheibler pressure calcimeter (Loeppert and Suarez 1996). Cation exchange capacities (CEC) were determined with NH_4OAc extractions (Sumner and Miller 1996). Exchangeable sodium (Na^+) was extracted in 1 N CH_3COONH_4 (ammonium acetate) and analyzed with an atomic absorption spectrometer (Wright and Stuczynski 1996). Soil chemical results from the soil samples taken from the sites in 2012 were utilized to calculate the approximate amount of gypsum and sulfur to be applied for the treatments, as well as to determine other soil properties (Tables 1, 2).

2.4 Application of soil amendments

For this study, gypsum (95% purity) and elemental sulfur (98% purity) were chosen as amendments mainly for their cost and ease of application. Upon establishing the experimental units, broadcast application of fine powdered gypsum (95% pure) and elemental sulfur (98% pure) was made to the soil surface, then the surface was raked to incorporate the materials into the soil. To avoid creating a slurry, an application rate of 30 cm of calculated amount of water was applied three times at 8-hour intervals (3 × 30 = 90 cm total).

Table 2. Amounts of soil amendments used for studying effects of soil amendments on saline-sodic soils in the Central Anatolian region of Turkey. ESP = exchangeable sodium percentage.

Sites	Target ESP (%)	Soil depth (cm)	Gypsum applied ($kg\ m^{-2}$)	Sulfur applied ($kg\ m^{-2}$)
Aksaray	10	100	10.9	2.0
Ereğli	10	100	11.0	2.1
Kayalı	10	100	13.1	2.4

The dose of amendments depends on the initial and final desired level of the exchangeable sodium percentage (ESP). Based on soil analysis, the approximate amounts of gypsum and sulfur were calculated and applied to each site using the following equation by Lebron et al. (2002):

$$GR = 0.00086\,F\,D_s P_b (CEC)\,\left(\left(ESP_i - ESP_f\right)/100\right), \tag{1}$$

where GR = amount of gypsum needed (kg m^{-2}), F = efficiency of Ca to exchange with Na. In this case, it is assumed as 1. P_b = soil bulk density (kg m^{-3}), D = depth of the soil to be reclaimed (1 m in this study), ESP_i initial ESP value, ESP_f = final (target) ESP value, CEC = soil cation exchange capacity (cmol$_c$ kg soil^{-1})

For sulfur, the following equation is used:

$$SR = 0.00016\,D_s P_b (CEC)\,\left(\left(ESP_i - ESP_f\right)/100\right), \tag{2}$$

where SR = amount of sulfur needed (kg m^{-2}), P_b = soil bulk density (kg m^{-3}), D = depth of the soil to be reclaimed (1 m in this study), $ESPi$ = initial ESP value, ESP_f = final (target) ESP value, CEC = soil cation exchange capacity (cmol$_c$ kg soil^{-1}).

2.5 Treatments, data collection and analysis

In the summer of 2012, deep ripping was conducted to break up compacted and poorly structured soil and to help generate structure and porosity. Ripping was done with two vertically mounted ripping shanks on a rubber-tired tractor (135 hp). The shanks are tipped with a replaceable wear shoe and drawn or pushed through the soil at a depth of 80–90 cm. Due to the high clay content of the soil, this ripper had horizontal wings near the tooth tip to increase fracturing. After deep ripping, broadcast surface tillage was conducted with a two-bottom plow.

Following tillage, random allocation of each experimental unit was done in the field. The experimental units were delineated with a 20 m buffer zone. Each selected unit was demarcated in a plot of about 120 m^2. After the designation of experimental units, the periphery of each plot was dug out to a depth of two meters using a backhoe. The excavated materials were piled around the plots to construct a berm, ensuring that the water applied after gypsum and sulfur application pooled, and did not leave the experimental units.

In the fall of 2013, three-year-old seedlings (1+2) were planted by 1.5 × 1.5 m spacing (36 seedlings on each experimental unit). Since they tend to perform better on adverse sites than bare root seedlings, container (plastic bag) seedlings were used. After the establishment the all three sites were fenced to protect the plantations from animals. The competing vegetation in all plots was manually cleared (0.5 m periphery around each seedling) both in June of 2014 and June of 2015. In this way, early competition from grasses and weeds was controlled.

At the end of summer in 2015, infiltration rates were measured on five randomly chosen spots on each experimental unit and control plot using double-ring infiltrometers (Bouwer 1986; Eijkelkamp 09.04 Double Ring İnfiltrometer). To compare the infiltration rates of experimental units to that of non-tilled soil, five infiltration measurements adjacent to each experimental block were also made. Volumetric water content of the soil 30 cm and 100 cm away from the seedling stem base were recorded at a 30 cm soil depth for ten randomly located spots on each experimental unit using a time domain reflectometer (Soil moisture Equipment Corp. Time Domain Reflectometry 6050X3K5B; Rhoades and Oster 1986) several times from May till September.

Diameter and height of seedlings were measured upon planting in fall of 2013 and at the end of the growing season in 2015. Initial seedling height and diameter data were not significantly different among treatments for all three species. Russian olive had an average 30±3 cm height and 3.5±0.8 mm diameter, salt cedar had an average 28±3 cm height and 2.3±0.6 mm diameter and silver poplar had an average 28±2 cm height and 2.1±0.5 mm diameter at the beginning of the 2013 growing season. The survival rates and the growth of the seedlings grown under the different treatments were calculated for the second year of the trials.

2.6 Statistical analysis

The effects of treatments on soil infiltration rates, seedling survival, height and diameter growth were tested with an analysis of variance (ANOVA) procedure for a randomized block design. SAS was used for all statistical analyses (SAS Institute Inc. 1996). Results for ANOVA were considered significant at $P<0.05$. Tukey's HSD test with alpha = 0.05 was performed to compare the means. To compare soil pH among the treatments a non-parametric median test was applied.

3 Results

3.1 Effects of treatments on soils

By the second year after application, ESP values were reduced almost by 50% on gypsum and sulfur treatments compared to that of the control sites (Table 3). The infiltration measurements indicate that both chemical treatments had significant effects on infiltration capacity of the soil ($P=0.0003$; Fig. 2). The infiltration rates of controls (only tillage) were not significantly different from those on the non-tilled sites adjacent to the experimental units. However, tillage + chemical amendments increased the infiltration rates compared to the non-tilled sites (Fig. 2). At the end of the second year, gypsum application gave the best results, since infiltration rates on gypsum application sites were 55% higher than those on the sulfur application sites and 80% higher than those on the no-till sites (Fig. 2). Infiltration rates also were higher on sulfur application sites compared to the non-tilled sites, but the rates were not as high as those for the gypsum treated sites.
TDR measurements showed that the volumetric water content of soils was about 10% in all treatments for both summers. This value is much below the available water content needed for plant growth in these soils.

Table 3. Median and range of soil pH and means and standard errors of exchangeable sodium percentage (ESP) values two years after treatments (N = 4) applied for studying effects of soil amendments on saline-sodic soils in the Central Anatolian region of Turkey. The results of an analysis of variance in randomized block design were considered significant at $P < 0.05$. Means with a common lowercase letter are not significantly different at alpha = 0.05 according to Tukey's HSD test.

Soil chemical treatments	pH	ESP (%)
Gypsum	7.9 ± 0.35a	16 ± 6b
Sulfur	7.77 ± 0.32a	15 ± 4b
Control	8.16 ± 0.25a	33 ± 6a
No-tillage	7.97 ± 0.21a	32 ± 5a

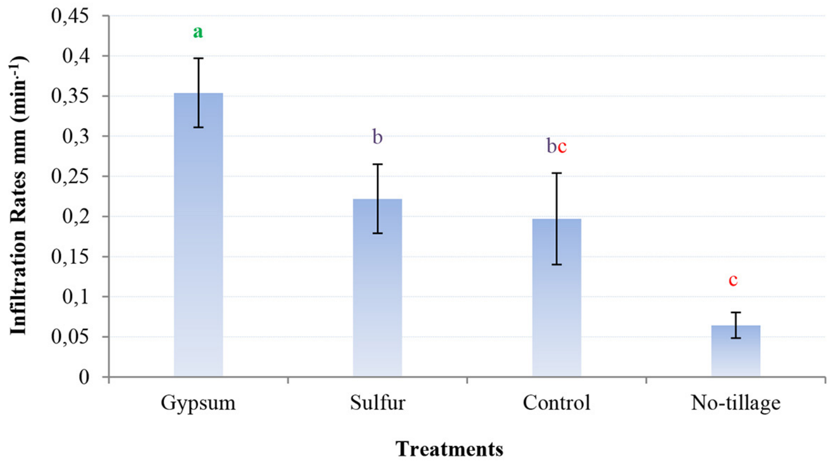

Fig. 2. Mean and standard error (S.E.) of infiltration rates after two years under different treatments (N=4) applied for studying effects of soil amendments on saline-sodic soils in the Central Anatolian region of Turkey. The results of the analysis of variance (ANOVA) procedure for randomized block design were considered significant at $P<0.05$. Means with a common lowercase letter are not significantly different at alpha = 0.05 according to Tukey's HSD test.

3.2 Effects of treatments on tree survival and growth

At the end of the second growing season, salt cedar and silver poplar survival rates did not differ significantly among treatments. But, survival rates of Russian olive on control sites was 30% lower than seedlings on the treated sites ($P=0.00021$; Table 4). The survival rates among the species were also significantly different ($P=0.0001$). At the end of the second growing season, the highest survival rates were observed for salt cedar, with about 80% survival. The lowest survival rates were observed for silver poplar. The survival rates for silver poplar at the end of the second growing season were 50% of those for salt cedar (Table 4).

Right after planting in 2013, there was no difference in seedling height and diameter values for any of the seedlings planted on different experimental units for each of the tree species. At the end of the second growing season, height and diameter values of Russian olive were significantly different among treatments ($P=0.0001$; Fig. 3a, Fig. 4a). Russian olive had 50 cm height growth on both gypsum and sulfur application sites. But these seedlings grew only 25 cm on the control sites during the same period. Diameters of Russian olive seedlings on gypsum and sulfur sites were about

Table 4. Means and standard errors of seedling survival rates (%) under different treatments (N = 3) applied for studying effects of soil amendments on saline-sodic soils in the Central Anatolian region of Turkey. The results of an analysis of variance in randomized block design were considered significant at $P < 0.05$. Means with a common lowercase letter are not significantly different at alpha = 0.05 according to Tukey's HSD test.

Species	Treatments		
	Gypsum	Sulfur	Control
Russian olive	93 ± 5a	91 ± 5a	64 ± 21b
Salt cedar	86 ± 6a	76 ± 14a	80 ± 9a
Silver poplar	43 ± 16a	41 ± 3a	25 ± 12a

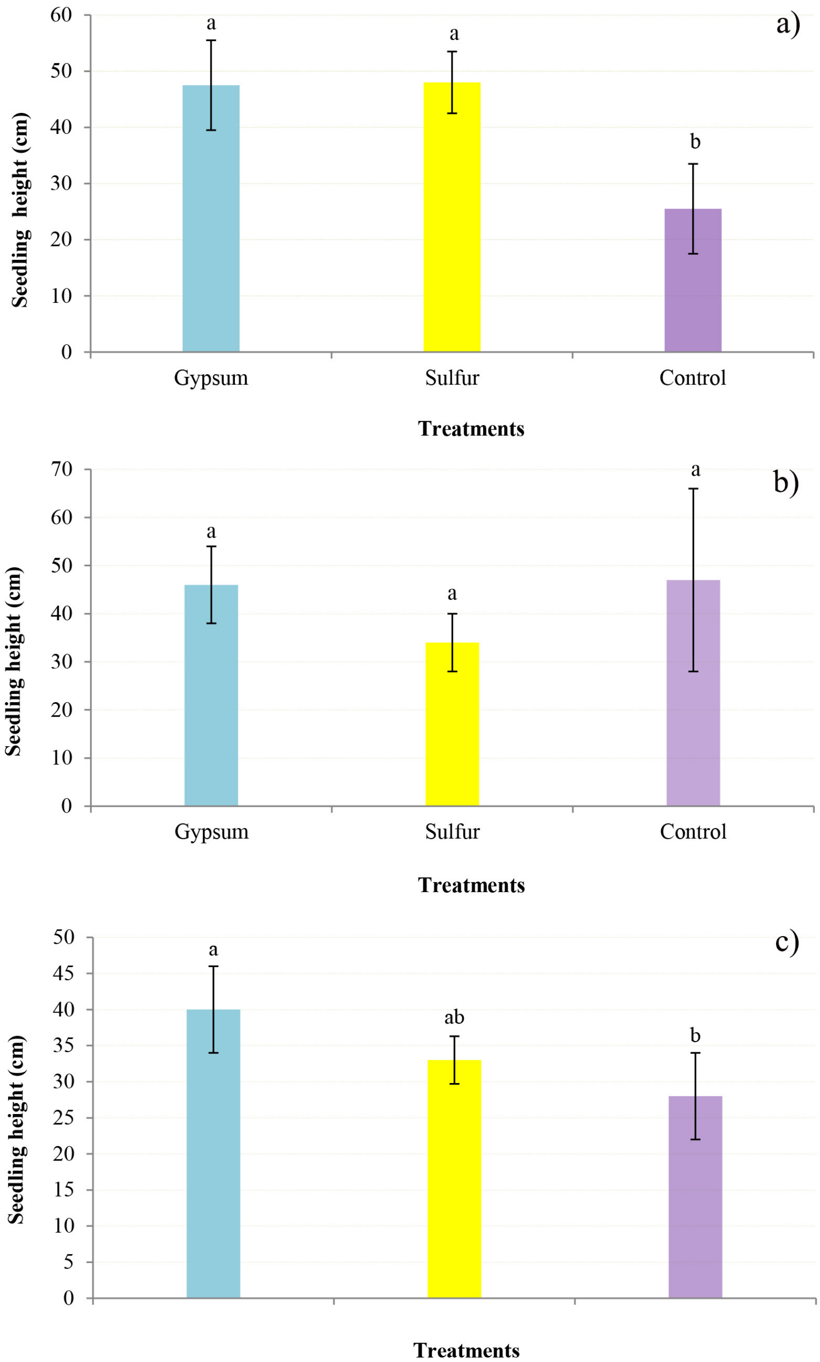

Fig. 3. Mean and standard error (S.E.) of *E. angustifolia* (a), *T. smyrnensis* (b) and *P. alba* (c) height growth after two years under different treatments (N=3) applied for studying effects of soil amendments on saline-sodic soils in the Central Anatolian region of Turkey. The results of the analysis of variance (ANOVA) procedure for randomized block design were considered significant at $P<0.05$. Means with a common lowercase letter are not significantly different at alpha = 0.05 according to Tukey's HSD test.

9.3 mm vs. 5 mm on the control sites (Fig. 3a, Fig.4a). Salt cedar had an average 40 cm height and 6 mm diameter across treatments (Fig. 3b, Fig. 4b). Due to high variability in each experimental unit, these growth response variables for salt cedar were not significantly different among treatments at the end of the second growing season. As for survival data, silver poplar seedlings had the lowest survival among the tree species (Table 4). However, using gypsum as an amendment

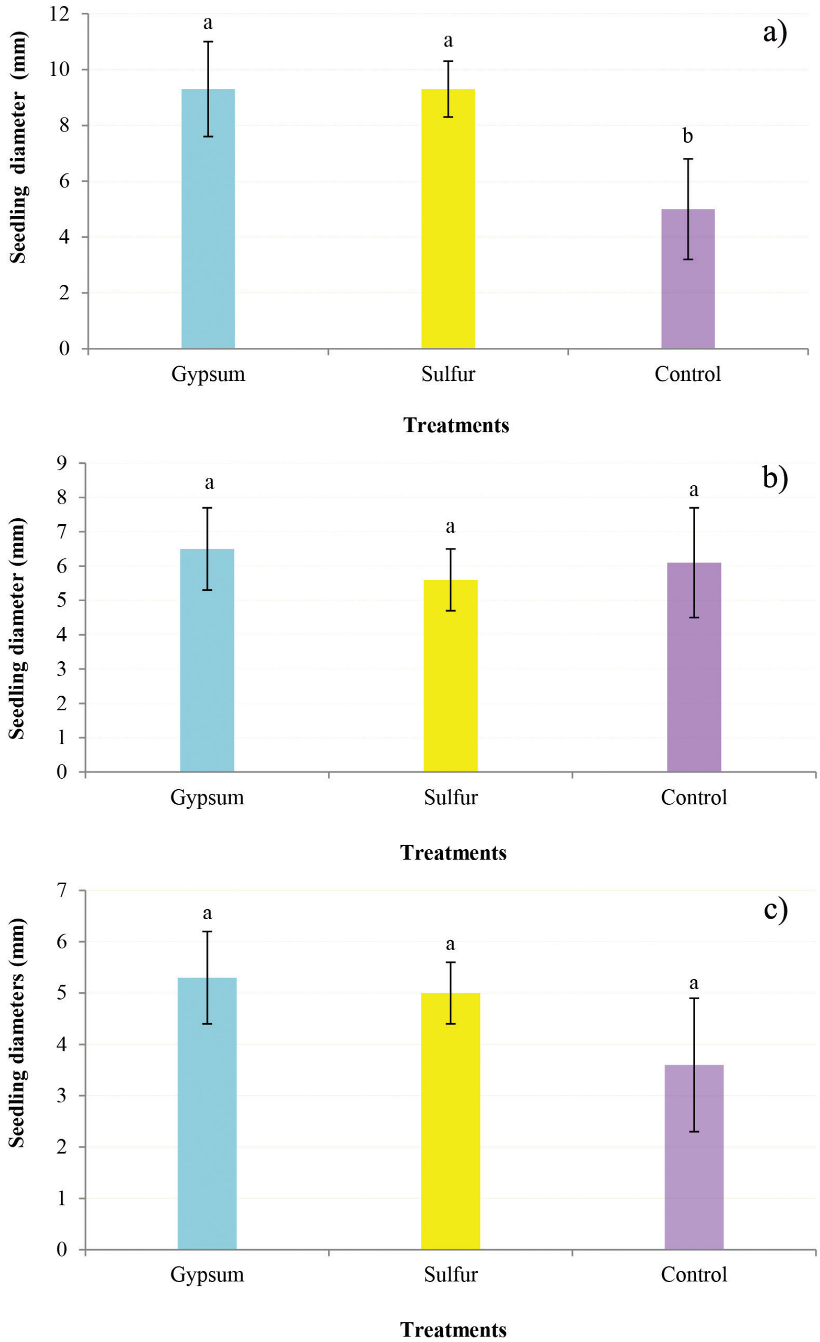

Fig. 4. Mean and standard error (S.E.) of *E. angustifolia* (a), *T. smyrnensis* (b) and *P. alba* (c) diameter growth after two years under different treatments (N=3) applied for studying effects of soil amendments on saline-sodic soils in the Central Anatolian region of Turkey. The results of the analysis of variance (ANOVA) procedure for randomized block design were considered significant at $P<0.05$. Means with a common lowercase letter are not significantly different at alpha = 0.05 according to Tukey's HSD test.

made a significant difference on their height growth ($P=0.0001$). The silver poplar seedlings on gypsum treated sites had 42% greater height growth than on the control site (Fig. 3c). However, the treatments did not affect the diameter growth of silver poplar (Fig. 4c).

4 Discussion

Some of the difficulties of establishing forest species in extremely hostile places have been overcome with greater effort in land preparation, with nursery propagation of young trees, and in other silvicultural practices. In these conditions, afforestation is hardly an economic proposition, since timber yield is insufficient to pay off the heavy investment required. Such tree plantings, nevertheless, may fulfill many of the ecosystem services while providing shelterbelts and windbreaks to protect against soil erosion, provide wildlife habitat, and to provide recreational grounds to meet the increasing demands for outdoor recreation. These efforts afford the opportunity to integrate grazing and forestry, while still increasing the carrying capacity of the land.

Singh and Garg (2007) claimed that species diversity and productivity significantly increased the soil amelioration process in sodic waste land in Lucknow, India. Therefore, natural reconstruction of the vegetation must be taken into account when soil protection represents the major objective. Once any further human disturbance is ceased, vegetation grows again spontaneously. In the current study, the sites were fenced and, while it was not measured, field observations indicated a significant increase in plant cover and diversity compared to the unprotected area. Therefore, manipulation of these conditions is necessary for a feasible reclamation program. Manipulative restoration of plant cover in these areas may have a two-fold purpose: soil protection and planting of green belts. Although these objectives are interrelated, they may have different goals in each case.

In the current study,during the second year after soil amendment applications, ESP values were reduced by almost 50% on gypsum and sulfur treatments compared to those on control sites (Table 3). Gharaibeh et al. (2014) conducted an experiment in southern Jordan on a sandy loam Typic Xerachrept soil for reclamation of saline-sodic soil using phosphogypsum and calcium chloride at application rates between 5–40 Mg ha^{-1}. They stated that ESP values of soil were reduced by 90% for all rates of these amendments. In Turkey, about 100 km west of the current study, Taş and Öztürk (2011) conducted an experiment on agricultural lands. They applied 27–87 Mg ha^{-1} of gypsum on soil which had ESP = 40%, EC = 40.6 dS m^{-1} and $CaCO_3$ = 30% values. These authors used 150 cm water (1500 m^3 ha^{-1}) for washing and reported that the ESP value was lowered below 10% and then the infiltration rates increased significantly. Yılmaz (2001) conducted a smaller scale experiment in the same region of Turkey as the current study. The soil he treated for reclamation is a clay loam and has ESP = 22–27%. He applied 10 Mg ha^{-1} of sulfur, and 10 and 30 tons ha^{-1} gypsum, followed by 210 cm water (2100 m^3 ha^{-1}) to wash these amendments into the soil.

Proper reclamation practice must ensure that salts are concentrated outside the root zone. Yılmaz (2001) estimated that to leach out 80% or more of soluble salts, the water requirement for application should be at least two times the soil depth. In the current study, two years after treatments, ESP values were still above the target level (below 10). In our study, 90 cm of water (900 m^3 ha^{-1}) was used to wash the amendments through the soil profile. This amount of water was 40% lower than the quantity Taş and Öztürk (2011) used and 57% lower than that used by Yılmaz (2001).

Adding chemical amendments or using deep plowing are both useful to increase hydraulic conductivity during the reclamation process. However, our data indicate that infiltration rates of controls (only tillage) did not significantly differ from the non-tilled sites adjacent to the experimental units. In our study, only tillage plus the two chemical amendments used significantly increased the infiltration rates compared to the non-tilled sites. Anapalı et al. (1996) applied gypsum in the Iğdır valley of Turkey, which has 250 mm annual precipitation and silty clay soil with EC = 8–12 dS m^{-1} and ESP = 45–60% values. They used 6 cm of water five times to wash the amendment through the surface soil (totaling 300 m^3 ha^{-1} of water). These authors reported that the infiltration rate was significantly increased in treated surface soil. In our study, the gypsum application obtained the best result. The infiltration rates for gypsum application sites were 55% higher than that for the sulfur treated sites. Infiltration rate was also higher on sulfur application sites compared to the non-tilled sites, but the rate was lower than on the gypsum treated sites (Jeddi and Chaieb 2012). The Yılmaz (2001) study showed infiltration results similar to the current research. In the Yılmaz (2001) study, the infiltration rate for sulfur treated sites increased about 13% compared to controls (2 cm h^{-1}). Gypsum application rates of 1 and 3 Mg ha^{-1} increased the infiltration rates by 7% (2.14 cm h^{-1}) and 12% (2.24 cm h^{-1}), respectively. Based on his results, the sulfur application was more effective than gypsum.

Şahin et al. (2011) evaluated three fungal applications on soil ameliorated with gypsum. Their results showed that hydraulic conductivity significantly increased with microbial application (0.101 cm h^{-1} vs. 0.060 cm h^{-1}). They speculated that secretion of organic acids by these microorganisms may accelerate dissolution of gypsum and native calcite in the soil. Therefore, the differences between gypsum and sulfur treated sites can be partially attributed to the formation rate of Ca ions to replace the Na ions from the colloids. Since dispersion of soil structure will take time to improve, reclamation of sodic soils will be slow, and the differences between treatments may diminish in several years.

Introduction of tree plantations may significantly alter landscapes (Lamers et al. 2006; Gharaibeh et al. 2011; Hbirkou et al. 2011). Jeddi and Chaieb (2012) conducted an afforestation study with *Acacia saligna* (Labill.) H.L. Wendl. in a Mediterranean climate in Tunisia where Regosols occur. They evaluated the results at plantation ages of 3, 5, 9 and 13 years. The data showed that tree establishment and development enhanced soil content of total C, N, available P and exchangeable K^{+} and Ca^{++}. These trends increased significantly with increasing plantation age. In India, Singh et al. (2012) evaluated the ecological restoration of degraded sodic lands through afforestation in a Typic Halaquept: pH = 9–10.5, EC = 1–4.19 dS m^{-1}, ESP = 45–75%. They concluded that *Acacia* spp., *Albizia* spp., *Populus* spp. and mixed forest growth played important roles in restoring sodic lands. Soil pH, EC, Na and ESP values decreased significantly in both afforestation and long-term cropping systems. Nevertheless, an afforestation approach has improved the soil more efficiently than using crops for land amelioration.

During plantation trials in the region, the first problem encountered on an ecological basis is that of the species choice. For the first plantation, it is a common practice to resort to species known as pioneer or preparatory, i.e. easily established frugal trees, able to rapidly cover the ground and to prepare it suitably for more demanding species. In this respect, tamarisk and poplar species have been used extensively in afforestation practices, shelterbelts and windbreaks in Tunisia, Algeria, Morocco, the United Arab Republic, Jordan, Iraq, Kuwait, and Israel (Metro 1970; Oedokoven 1970a, b, c; Kaplan et al. 1970).

Silver poplar, grows throughout Asia, Europe and northern Africa, is capable of growing in desert and dry areas and is also tolerant of soil salinity (Dubovyk et al. 2014; Sekawin 1975; Jobling 1990). However, for the current study, the lowest survival rates were observed for silver poplar. At the end of the second year, almost 2/3 of the seedlings were dead across all treatments. Most of the *Tamarix* spp. can tolerate very high salinity and sodicity and they are commonly used in sand dune stabilization (Ahmed and Qanor 2004; Biswas and Biswas 2014; Metwally et al. 2016). Dawalibi et al. (2015) found that two *Tamarix* species had a high tolerance for salt and drought stress. They observed high survival rates (80%) in all treatments for these species. At the end of the second growing season in this study, salt cedar survival rates were high and did not significantly differ among treatments. In the present study, soil treatments increased the survival rates of Russian olive by about 44% compared to the control sites. Khamzina et al. (2006) showed that Russian olive and *Tamarix androssowii* Litv. planted on Gleyic Solonchak soil in the Aral Sea Basin of Uzbekistan, had more than 95% survival rates and superior biomass growth 19 months after planting.

In considering the survival rates and growth performance of both salt cedar and Russian olive, our research suggests that these two species should be good candidates to consider using in afforestation projects to reclaim these degraded arid lands. Since Russian olive is a nitrogen fixing species (Fisher and Binkley 2000; DeCant 2008), it may also increase the available nitrogen and microbial diversity in the rhizosphere.

Repeatedly tried afforestation attempts have been resulted in failure in these problematic sites. Vast land areas are under influence of severe wind erosion. The results of our study show that these soils can be restored for plant growth. Even though more research is needed to determine the cost/benefit ratio, the success of the afforestation practices is in more consideration than the cost of the afforestation practices for the region. Therefore the initial cost will be easily compensated via ecosystem services to the local people if the afforestation succeeds. The establishment of the sites may seem expensive, but gypsum is mined from local deposits and is one of the cheapest materials to use. The amount of water to be used can seem too much for an extensive afforestation program. However, this calculated amount of water is needed to wash about 1 meter deep soil profile for immediate restoration purposes and for planting deep rooted trees. Restoration programs on extensive areas progress slowly and step by step on designated areas with different degree of priorities. This type of water-intensive work can be accomplished on small areas by utilizing the local wells. For extensive areas and with less priority different management options may be required. For example, the first priority on these sites is to stop and prevent wind erosion through establishing wind breaks. To establish wind break, instead of the entire field, 30 meter wide strips are planted every 100 meters. Therefore the priority can be given on these wind break strips with this type of water intensive management. Then management can focus on soil between the wind break strips. For these areas instead of using trees shallow rooted plants can be used at the beginning of the restoration. Therefore a shallower soil depth can be improved with less amount of water as shown by Anapalı et al. (1996) on eastern part of Turkey. Another option for these areas can be that chemicals can be applied on broadcast manner and it can be waited to be washed slowly with precipitation over longer periods.

5 Conclusions

The establishment of forest stands on previously degraded soils offers interesting insights into combating desertification, which may be valuable to afforestation projects being planned for other arid zones considering aggressive afforestation programs. Early results from the current study indicate that gypsum and sulfur applications can wash sodium through the soil profile and increase the infiltration capacity with gypsum improving infiltration significantly more than sulfur. Improving soil conditions by these treatments increased survival rates and growth performance of Russian olive. For silver poplar, only the gypsum treatment increased height growth. Salt cedar had the best mean survival percentage among treatments. Russian olive and perhaps salt cedar would be potential candidates to use in afforestation practices to reclaim these degraded lands. Hopefully, the results from this study will be utilized for future follow-up studies in the region, will contribute to the interpretation of long-term study results, and also contribute to potential beneficial silvicultural applications.

Acknowledgement

This study is funded by TUBITAK (The Scientific and Technological Research Council of Turkey) through a Project no: 113O793 and titled as "İç Anadolu Sodik Sahalarında Jips ve Kükürt Uygulamasının Ağaçlandırma Başarısına Etkisi". We also thank to Ministry of Forestry and Water Affairs, General Directorate of Combating Desertification and Erosion (ÇEM) and General Directorate of Forestry (OGM) for their support.

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