# A biological approach to salinized soil amelioration in arid Northwest China – Saline water irrigated trees and shrubs on saline sodic soil

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**Abstract:** A field experiment was carried out to explore the possibilities of planting halophytes on salt-affected land with saline water irrigation. The changes in the salinity of the soil profile, the survival rate and growth conditions as well as the salt tolerance were investigated over a five-year period after the planting of halophyte shrubs and arbours. The results show that halophytes can assimilate salts from soil and improve the soil's physical and chemical properties and at the same time, contribute to the amelioration of the ecological environment and enhance saline soil productivity. This five-year field experiment in arid Northwest China suggests that growing salt-tolerant plants using poor quality water in a saline environment is a practicable and sustainable remediation approach for the restoration of salinized soil.

**Keywords:** Saline; Salt-tolerant plant; Saline water; Soil remediation

## 1 Introduction

Soil salinization is a serious, worldwide ecological problem. Based on the FAO and UNESCO Soil Map of the world, various saline soils occupy 950 million hectares of surface, accounting for about 10 % of the global land area, and are widely distributed in more than 100 countries and regions. Moreover, the area of soil salinization is continuously increasing. According to statistics from FAO (88s1), more than 50 % of the world's irrigated soils are affected by secondary salinization and/or alkalization. Each year, about 10 million hectares of land are abandoned, mainly due to secondary salinization. An UNEP investigation shows that soil degradation by salinization is about 1.11 million km$^2$ in the dry-lands of the world—it has become the third largest cause and manifestation of desertification after wind and water erosion. Due to population expansion and rapid economic development, human activities such as large-area land exploration, irrigation mismanagement, industrial pollution and overuse of fertilizers lead to increased secondary salinization over the years and accelerate the process of soil salinization. Ecological degradation has led to widespread water scarcity in many areas of arid and semi-arid northwest China characterized by the drying up of rivers and groundwater depletion. Originally prosperous meadow vegetations, such as *Phragmites communis Trin, A. cristatum and Achnatherum splendens,* have withered and died out due to this problem. The total area of saline soils in Northwest China has reached 30 million hectares and that of secondarily salinized soils is now 6.7 million hectares, accounting for 14 % of the total arable area (Yang *et al.*, 2006 and Yu *et al.*, 2006). The salinity of the groundwater is generally from 3 to 5 g $L^{-1}$, and in some regions it can reach 10 g $L^{-1}$. In these arid regions, there would be no agriculture without irrigation. Large areas of farmland have to rely on groundwater (saline water) for irrigation, due to lack of fresh water resources, and this result in severe soil salinization. How to ameliorate the saline soil and restore the degraded land is a challenging demand. Numerous studies have been conducted investigating saline soils, halophyte species selection, salt-tolerant plants and the relationship between soil salinity and plant growth. The results of many experiments have shown that halophyte such as *Nitratia, Kalidium foliaturn, Suaeda salsa L. Atriplex centralasi and Lycium barbarum* can absorb salt from the soil (Zhao et al., 2001, 2002, Lu and Su, 2004, Guo, 2004, Luo, 2005, Yang, 2006). Mediterranean zones that had become sterilized by salinity or alkalinity were restored to productive pastures through the planting of salt resistant fodder shrubs. The effect of ecosystem recovery was obvious (Le, 1977). Malcolm (1986) and Squires (1994) proved that halophytes have the ability to survive and grow under saline conditions in which they provide a stable habitat and a source of dry season grazing for livestock. All these regional results have laid a foundation for further investigations on plant salt tolerance. This will in turn play an important role in the advancement of studies on salt resistance, crop yield increases, and the improvement of the ecological environment in salt-affected areas. This is important because the rapid population growth, social development, and corresponding increased demand for food security require more arable land and/or greatly increased grain yield (Zhang *et al.,* 2000).

One of the properties of the salinized soil is the excess of soluble salt and alkali in the soil. As a consequence of soil salinity effects, plant germination rates and yields are affected, and in severe cases, farmlands might be degraded into barren land. The repeatedly appearing sandstorms in the dry areas in China are indications of the negative consequences of regional eco-environmental degradation. Traditionally, the remediation measures have been based on engineering methods such as intense watering of the soil stimulating the salts to be washed out from the top soil downwards to below the root zone and improving the drainage; enclosing salt-affected farmlands for fish breeding grounds; applying soil improvers, such as gypsum, phosphate fertilizer and natural pumice stone, etc. (Xiong, 1990, Wang, 1993, Sha, 1958 and Zhao, 1993). However, these methods are often not cost effective and sustainable in many arid areas (Peck, 1975). They also produce some side effects. For example, the necessary mineral elements for plants, such as N, P, K, Ca, Mg, Fe, are taken away from the soil while leaching; soil hardens and soil permeability is then reduced due to lack of organic matter (Cheng, 1965; Hou, 1961; Soil Fertilizer Institute, 1965). In recent years, more focus worldwide has been put on biological approaches to reclamation and amelioration. Ameliorating saline soil by biological methods means simply planting salt-tolerant plant species in the saline environment. These plants take up salts, which results in the amelioration of the soil's physical and chemical conditions. The growth of other species is facilitated (Akhter *et al.,* 2003 and Mahmood *et al.,* 1989, 1994).

In the earlier investigations of saline soil remediation based on the cultivation of halophytes, fresh water was used for irrigation. The sustainability of growing plants on saline/alkaline soils with saline or brackish water irrigation has not been thoroughly investigated. In the current study, a field experiment was conducted to explore the possibilities of planting halophyte on salt-affected land and using saline water for irrigation. The changes in salinity within the soil profile, as well as the survival rate, growth conditions, and salt tolerance of the plants are investigated over a five-year period after planting halophyte shrubs and arbours.

## 2 Materials and methods

### 2.1 The general situation of the study area

The field experimental site is located in the Huqu district of Minqin County, in the northeast part of Minqin basin in Gansu province, northwest China, ranging from 103°25'E to 103°55'E and from 38°40'N to 39°10'N. It is surrounded by the Badanjilin desert and the Tenggeli desert in the east, north and west.

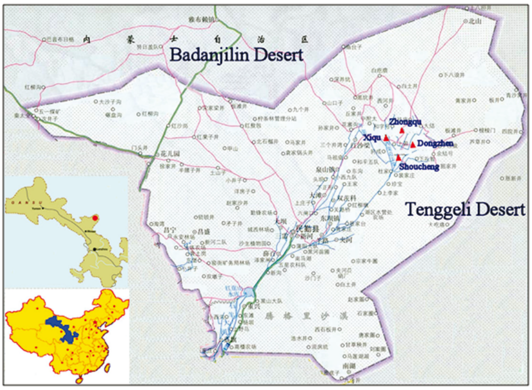


Figure 1. *Location map of the study area.*

The research area covers four villages, Xiqu, Zhongqu, Dongzheng and Shoucheng (see Fig.1), with a total land area of 788 km$^2$ including a farmland area of about 250 km$^2$, accounting for 31 % of the total land area. Minqin Huqu has an arid continental climate with an average annual temperature of 7.8 °C. The mean annual precipitation is 110 mm and its distribution is uneven over the year. Most precipitation appears in June, July and August. The average annual evaporation is about 2650 mm, 24 times higher than the annual mean precipitation. The number of sunshine hours is 3028 hr. Y$^{-1}$, with a total global radiation of 137 kcal cm$^{-2}$ which corresponds to a 12-hour daytime mean of 360 W m$^{-2}$ (Sun *et al.*, 2005). It is very windy and dusty in this area. The mean annual wind speed is 2.8 m s$^{-1}$, and the mean annual highest wind speed is 31 m s$^{-1}$. The non-cultivated land is covered by desert plants. The main crops such as spring wheat, corn, cotton, seeding melon and sunflower are affected by saline groundwater irrigation to different degrees.

### *2.1.1 Soil condition*

The experimental site is located on a piece of non-cultivated wasteland. Sulphate ($SO^{2-}{}_4$) and chloride ($Cl^-$) dominate in the soils. The soil type is dominated by light sandy loam texture with intermediate permeability. The soil contains visible crusts of salts at the surface. After ploughing and levelling the land, the average salt content of the soil was found to be 3 to 5.9 % at 0–60 cm depth (mean value of two layers), and 2.5 to 4.3 % at 0–100 cm depth (mean value of three layers). Numerous studies indicate that high seedbed salinity causes a delay in seed germination and reduces plant vigour during seedling establishment (Qadir *et al.*, 2000; Katerji *et al.*, 2000).

Table 1. *The ion content in the local groundwater samples from Minqin Huqu area.*

| Ions | $HCO_3^-$ | $Cl^-$ | $SO_4^{2-}$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^++K^+$ |
|---|---|---|---|---|---|---|
| Mg $L^{-1}$ | 384.2 | 579 | 1247.5 | 1276 | 154.7 | 679.4 |

The experiment was started on March 1999. Due to high initial soil salinity in the upper soil layer, the soil was flooded with 3900 $m^3$ $ha^{-1}$ in order to leach soluble salts down to the lower depths of the soil. After this leaching process, the average salt content of the soil was 1.0–2.4 % at 0–60 cm, and 1.3 – 2.5 % at 0–100 cm.

*2.1.2 Groundwater quality and water table fluctuation*

The local groundwater is of high salinity (EC 4.03–7.17 ds $m^{-1}$) with a sodium adsorption ratio (SAR) of 4.6–12 (see Table 1). The water table in the irrigation area has declined from 1987 to 2001. The portion of groundwater area with a depth below 3 metres has increased from 640 $km^2$ in 1987 to 768 $km^2$ in 2001. The corresponding portion of groundwater area with a depth below 10 metres reaches 459 $km^2$, accounting for 68.2 % of the total Huqu area (Song *et al.,* 2004).

## 2.2 Experimental methods

*2.2.1 Materials*

Halophytes are the plants that can live and accomplish the whole life circle in a saline environment (70 mmol $L^{-1}$ univalent salt) as it is defined by Waisel (1972) and Flowers *et al.* (1986). Plants growing in a saline environment generally face certain limitations. Soil salinity may affect crop growth by violating the natural water and nutritional balance of plants. Selection of plant species for the purpose of amelioration of saline soil must therefore be based on their respective salt tolerances and characteristics (Qadir *et al.*, 2000). According to the local special conditions of Minqin Huqu, different halophytes, six arbour species (*Populus euphratica* Olivier, *P. alba L. var. pyramidalis, P. gansuensis, P. simonii Carr, U. pumila and Elaeagnus angustifolia)* and five shrub species (*Nitraria tangutorum, Hippophae rhamnoides, Lycium barbarum, Halimodendron halodendron, T. Ramosissima*) were selected for the field experiment. Drought resistance is an important characteristic besides the high salt tolerance. These selected plants are considered to have a good ability to grow on original wasteland without fertilizer and can be managed under extensive management with minimum labour input.

#### *2.2.2 Experimental design*

After ploughing and levelling the land, it is plotted and arranged to small pieces by ridges. The halophyte plants were planted using dibbling planting by digging a hole for each tree. The number of species was 500 in each plot (spacing between rows 2m*2m). There were three replicate plots for the purpose of minimizing the effect of soil heterogeneity (but the soil analyses were done by mixing the samples from the three replicate plots to reduce the analysis cost). In order to ensure the seeds' germination, border irrigations of about 1200 $m^3$ $ha^{-1}$ (fresh water) were applied directly after planting. During the five-year experimental period, the mean annual precipitation was 67 mm which was of course insufficient to meet the water requirements of the plant growth. 1200 $m^3$ $ha^{-1}$ brackish water (EC=6.25 ds $m^{-1}$) was applied during the growth stages four times per year.

#### *2.2.3 Salt content measurement*

Soil salinity was assessed using soil samples collected from the root zone (divided into 3 layers, 0–40 mm, 40–60 cm and 60–100 cm). A randomized soil sampling approach was applied at five spots in the east, south west, north and middle part of the experimental area. At each of these five spots, ten random soil samples were taken from each of the soil layers. The final soil properties for each layer were obtained by averaging all the values from the respective layers.

## 3 Results and discussion

### 3.1 Survival rate and growing conditions of the 11 species

It has been widely accepted that *P. alba L. var. pyramidalis, U. Pumila, P. gansuensis* and *P. Simonii Carr* are salt-tolerant and drought resistant species. None of them have nitrogen-fixing ability, or a salt-secreting characteristic. In addition, the water requirements of these four species are high compared with *Elaeagnus angustifolia*. For instance, the average transpiration of *Elaeagnus angustifolia* during the growing period from April to October has been found in a study nearby the present experiment site by Sheng *et al.,* (2003) to be 172 mm, but it is 314 mm and 289 mm for *P. alba L. var. pyramidalis* and *P. gansuensis,* respectively. These features have a large impact on the performance of the above four species within a saline environment.

Survival rate is one of the indexes of the salt-resistant capacity and adaptability of plants. The survival rates for the two categories (including six arbour species: *Populus euphratica* Olivier, *P. alba L. var. pyramidalis, P. gansuensis, P. simonii Carr, U. pumila and Elaeagnus angustifolia)* and five shrub species: (*Nitraria tangutorum, Hippophae rhamnoides, Lycium barbarum, Halimodendron halodendron, T. Ramosissima*) of the 11 selected species four months after planting are shown in Fig. 2. The highest survival rate of 99 % can be observed for *P. alba L. var. pyramidalis,* followed by *Elaeagnus angustifolia* at 94 %, *Lycium barbarum* at 85 %, *U. Pumila* at 80 %, *P. Simonii Carr* at 70 % and *T. Ramosissima* at 50 %. The rest of species had a survival rate of less than 50 %. It is usually more interesting to compare the survival rate (one year after planting) with the 5-year preserva-

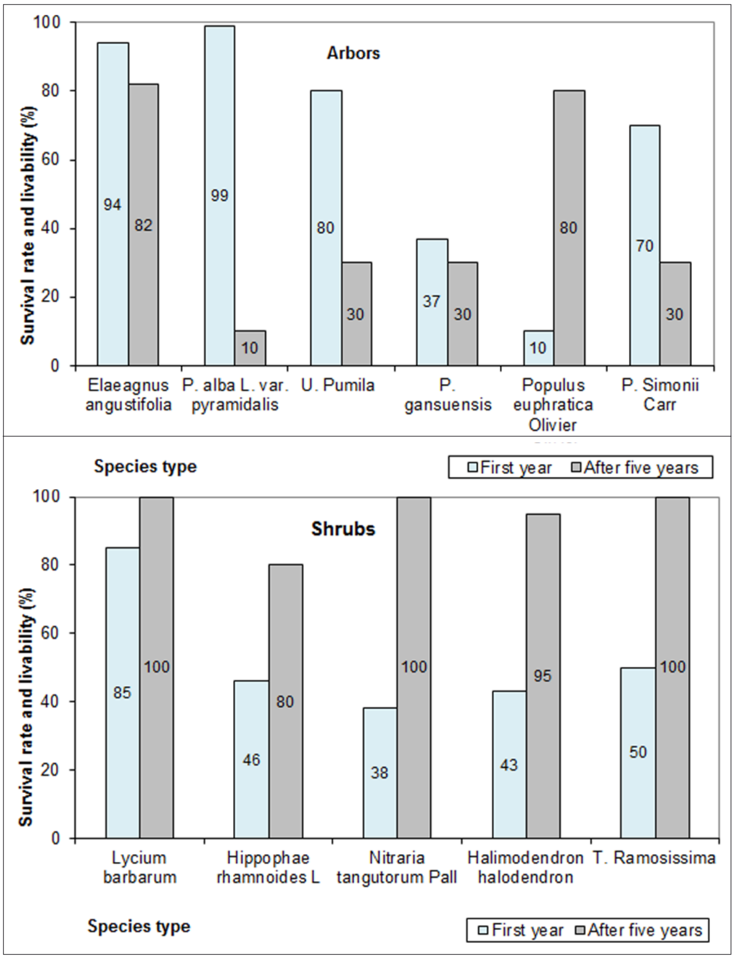


Figure 2. *Survival rate (first year) compared with the preservation rate after 5 years of the selected arbour and shrubs species at the field experiment station Huqu, China (Preservation rate based on resetting the first year survival rate to 100 %).*

tion rate, defined as the total survival rate 5 years after planting. It must be pointed out here that the 5-year preservation rate was calculated by resetting the first year survival rate. This means that only the survived plants after first year were considered. As it is seen in the figure, most of *P. alba L. var. pyramidalis* died, with a 5-year preservation rate as low as 10 %. *Elaeagnus angustifolia, Lycium barbarum and T. Ramosissima* were able to continue growing well, with a 5-year preservation rate of 90 %. It is also especially noteworthy that *Lycium barbarum* could sprout new shoots from the base of an extensive root system, and *T. Ramosissima* had the capacity of regeneration from fallen seeds resulting in increasing reproduction. *Populus euphratica* Olivier had a very low survival rate (10 %), but the survived plants grew well with a high preservation rate (60 %). *U. Pumila and P. Simonii Carr* kept a slow growth rate due to the influence of salt stress with a rather low preservation rate. *Hippophae rhamnoides L and Nitraria tangutorum* grew vigorously with an 80 % preservation rate. *Halimodendron halodendron* grew in a general way and had a 5-year preservation rate of 75 %.

Growth height is another index to visually reflect the ability of a plant to resist the adverse, non-specific effects of excessive root zone salinity. A comparison of the one-year and 5-year growth height for both arbour and shrubs is presented in Fig. 3. As can be derived from the data of Fig 3., the average growth rate for the shrubs group was between 12–24 cm per year, whereas the corresponding rate for the arbours group was 7–10 cm per year except for *Elaeagnus angustifolia* which grew as fast as 35 cm per year. The results show that shrub species generally grew better than arbour species although their absolute heights were generally larger than that of the shrubs. It is apparent that the salt stress affected nearly all of the arbour species and they were weaker than the shrubs.

The reason that *Elaeagnus angustifolia* and the members of the shrub species grew better is that these plants are believed to have higher biological adversity-resistant characteristics. Another reason can be due to the fact that *Elaeagnus angustifolia* and *Hippophae rhamnoides L* and *Halimodendron halodendron* can develop a number of mature nodules through a series of interactions between rhizobia and plant roots and these interactions are known to have strong nitrogen fixing ability which improves the self nutritional condition of the plants. As a result, the plants reduce the risk of nutritional stress caused by high soil salinity and maintain good growth (Wang *et al.*, 2000). This phenomenon is common among the plant family *leguminosae*.

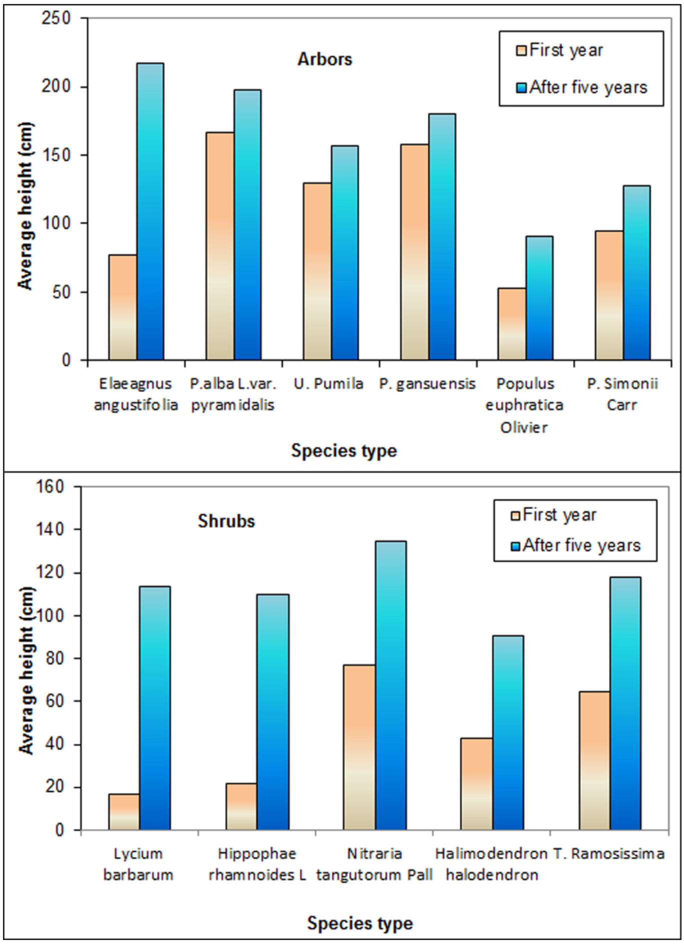


Figure 3. *One-year and 5-year growth height comparison for the selected arbour and shrubs species at the field experiment station Huqu, China.*

*T. Ramosissima* is a typical halophyte with the characteristic of salt-secreting. The species has salt glands and a secreting cell, which can discharge surplus salts in the plant body so as to reduce the salt ions injuring the active tissue of the plants. Besides, *T. Ramosissima* has a deep root system and a large absorbing moisture area, which ensure sufficient supply of moisture. These features keep *T. Ramosissima* growing even under salt stress (Zhao *et al.*, 1999).

*Populus euphratica* Olivier is also a salt-secreting halophyte. However, in this experiment, its survival rate was rather low but with a higher preservation rate. The young plants seem to be very sensitive to salinity. It had difficulties in developing roots, but as long as *Populus euphratica* Olivier survived and became mature, it had a good preservation rate because of its huge horizontal root systems. The extended radius of the roots can reach 20–30 metres.

*Nitraria tangutorum Pall* and *Lycium barbarum* are classified as poly-salt species. This plant species has the ability to absorb moisture in arid and saline environments by means of increasing the osmotic potential of cells through succulent leaves and assimilation branches accumulating salt. In addition, poly-salt species have well-developed water storage tissues or distensible epidermal cells leading to salt concentration reduction. Blades of both *Nitraria tangutorum Palla* and *Lycium barbarum* have a thick cuticle with small surface area of leaves that can reduce moisture loss. They also have deep root systems, lateral roots flourish, and the roots can grow into bunches germinating new plants. These biological mechanisms protect them against the danger of salt stress.

### 3.2 Soil salinity variations with different plant species

Plants can significantly influence the microclimate in several ways, such as lowering the soil temperature by providing a shaded area around the plants and reducing moisture evaporation from the soil, and thus they restrain soil salinity increases. A general significant impact and reduction of soil salinity was observed for most of the 11 salt-tolerant species in the current study after five years (see Fig. 4). In Fig. 4, where soil salinity and its reduction rate are plotted for all the 11 species, it is shown that 9 of them had a reduction rate of over 40 %. It was observed that the height of *T. Ramosissima* was about 1.4 m, but its coronal extent reached to 2 $m^2$, covering bare soil of an equivalent area by the plants. Evaporation from the soil was thus replaced by transpiration from the plants, which lead to a salt redistribution in the root zone. Salt tended to move with percolating water to the deeper layer of the soil for accumulation, or accumulated in the plant parts. As a result, salt accumulation in the tillage layer was reduced. Over the field experiment area the soil salinity ranged from 1.3 % to 2.5 % before planting. After five years, the salinity associated with most of the plants in the tillage layer (0–100 cm) had decreased to less than 1 %, with remarkable variations between different species (Fig. 4). After successive five-year growth as compared with the first year, for the arbour species, a maximum reduction of 63 % was found for the soil where *P. Simonii Carr* was grown followed by 62 %, 61 %, 50 % and 37 % in *U. Pumila*, *Populus euphratica* Olivier, *Elaeagnus angustifolia P.alba L. var. pyramidalis* respectively. For

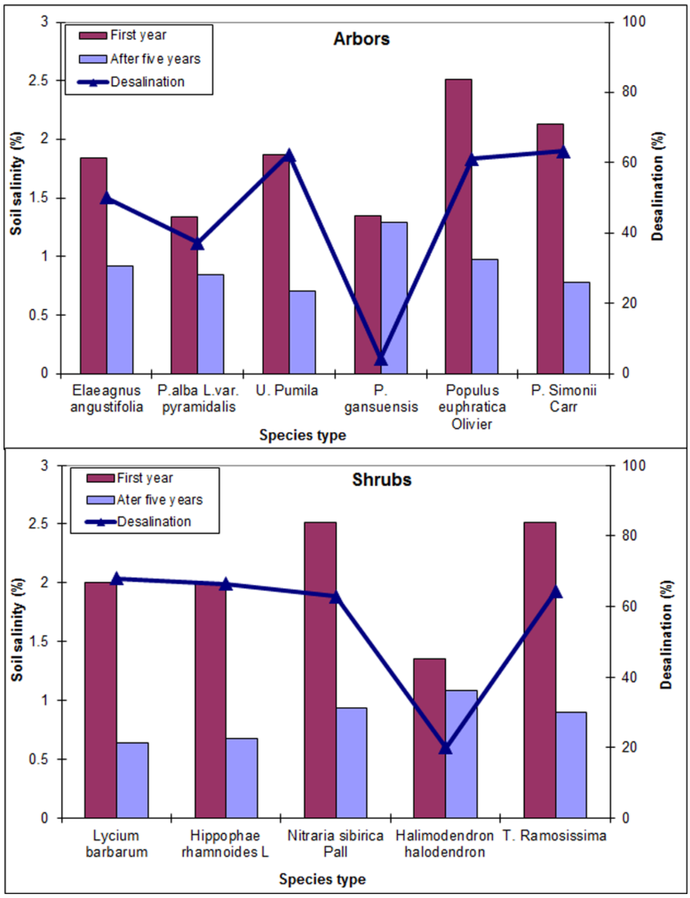


Figure 4. *The variations of average soil salinity at 0–100 cm for the arbour and shrubs species, comparison between the first year and five years growth.*

*P. gansuensis* there was almost no reduction (4 %). For the shrub species, the reduction was 66–76 % for all species except for *Halimodendron halodendron* which only gave a reduction of 20 %. A maximum reduction of 76 % was observed for *T. Ramosissima* followed by 75 %, 68 %, 66 and 20 % reduction for *Nitraria tangutorum Pall, Lycium barbarum, Hippophae rhamnoides L* and *Halimodendron halodendron,* respectively. Comparing the arbour species with the shrub species, the average salt removal rate was higher for the shrub species than for the arbour species. One reason for that is that the shrub species generally were flourishing, while most of the arbour species grew weakly, because the water requirement of the arbours is higher than that of the shrubs (Sheng *et al.*, 2003). In this study, the total applied irrigation during the growing periods was the same for the two categories of species. Under these conditions, the irrigation water could not satisfy the physiological requirement of the plants and thus caused physiological drought.

## 3.3 Critical salt-tolerant content for various plant species at early growth stage

A number of plant species cannot grow well in a saline environment, because an excess of soluble salts in a soil cause the osmotic potential increase of the soil solution, making it difficult for the plants to absorb the soil moisture. In this case the plants are in a physiological drought condition which retards plant growth.

Different plant species have different levels of salt-tolerant ability. Salt-tolerant ability varies with the different growing periods of the plants. Table 2 displays some indicative salt-tolerant contents found for the selected species showing how the different species reacted to the varied salt conditions one year after planting. In Table 2, the plants of high salt-tolerant ability can be identified as *Nitraria tangutorum* followed by *Elaeagnus angustifolia*, *Lycium barbarum, T. Ramosissima* and *Populus euphratica* Olivier, which all showed growth ability at salinity of up to 1.7 %. The rest of the species had weak salt-tolerance.

## 3.4 Effect of halophyte planting on the physical and chemical properties of soil

Along with the intrusion and extension of plant roots after the planted salt-tolerant plants have established a root system, the surrounding soil tends to become looser and form more granular particles. In addition, rotted roots and deadwood increase not only the portion of organic matters in the soil, but also the soil porosity. Physical properties of the soil are improved in terms of organic contents and porosity after five years (Fig. 5). In Fig. 5a, where soil bulk densities at three layers as well as the average of the whole profile down to 100 cm are shown, the average soil bulk density was reduced from 1.53 g $cm^{-3}$ to 1.47 g $cm^{-3}$ after five years' growth. Similarly, the corresponding general soil porosity was increased from 39.6 % to 43.9 % for the same period (Fig. 5b).

During the five year periods after planting halophyte in salt-affected soils, both the cat ions and anions at the farming layers tended to decrease due to the assimilative function of the plants and the percolation of irriga-

Table 2. *Indicative salt-tolerant contents found for different plant species one year after planting.*

| Plant species | Salt content (%) | | Growth Condition |
|---|---|---|---|
| | 0–40 cm | 0–60 cm | |
| *Elaeagnus angustifolia* | 1.009 | 0.945 | plant was growing normally |
| | 1.917 | 1.749 | plant was slow-growing and growth was retarded |
| | 1.944 | 2.543 | plant was wilting and the top of tree was withered |
| *P. alba L. var. pyramidalis* | 1.362 | 1.38 | plant was growing normally but leaves lacked moisture |
| | 1.93 | 2.02 | plant died back |
| | 1.646 | 1.323 | plant was wilting and leaves rolled up |
| *U. pumila* | 0.824 | 0.351 | plant was slow-growing |
| | 2.005 | 1.912 | plant was wilting |
| *P. Simonii Carr* | 0.73 | 0.33 | plant was growing normally but leaves lacked moisture |
| | 0.865 | 1.136 | plant was slow-growing and leaves rolled up |
| | 1.336 | 1.259 | plant died back |
| *P. gansuensis* | 1.246 | 1.956 | plant was slow-growing and growth was retarded |
| | 2.033 | 2.227 | plant was wilting |
| | 1.678 | 2.962 | plant died back |
| *Populus euphratica* Olivier | 0.936 | 1.082 | plant was growing normally |
| | 1.685 | 1.626 | plant was slow-growing and growth was retarded |
| | 2.255 | 2.524 | plant was wilting and died back |
| *Lycium barbarum* | 0.986 | 0.957 | plant was flourishing |
| | 1.823 | 1.49 | plant's growth was slightly retarded |
| | 1.656 | 1.427 | plant was growing normally |
| *T. Ramosissima* | 0.994 | 1.11 | plant was flourishing |
| | 1.805 | 1.956 | plant was slow-growing |
| *Hippophae rhamnoides L* | 0.337 | 0.817 | plant was growing well |
| | 0.665 | 0.93 | plant's growth was slightly retarded |
| | 1.201 | 1.439 | plant was wilting |
| *Nitraria tangutorum Pall* | 1.272 | 1.895 | plant was growing well |
| | 2.033 | 2.084 | plant's growth was retarded |
| *Halimodendron halodendron* | 1.044 | 1.797 | plant was growing well |
| | 1.42 | 1.652 | plant's growth was slightly retarded |
| | 1.659 | 1.949 | plant was wilting |

tion water. As shown in Fig. 6 (Fig. 6a for the soil profile down to 60 cm and Fig. 6b for soil profile down to 100cm), chloride ($Cl^{-1}$) was reduced from 0.09 % to 0.05 % and 0.07 % to 0.05 % at 0–60 cm depth and at 0–100 cm depth respectively, corresponding to a range of reduction of 39 % at 60

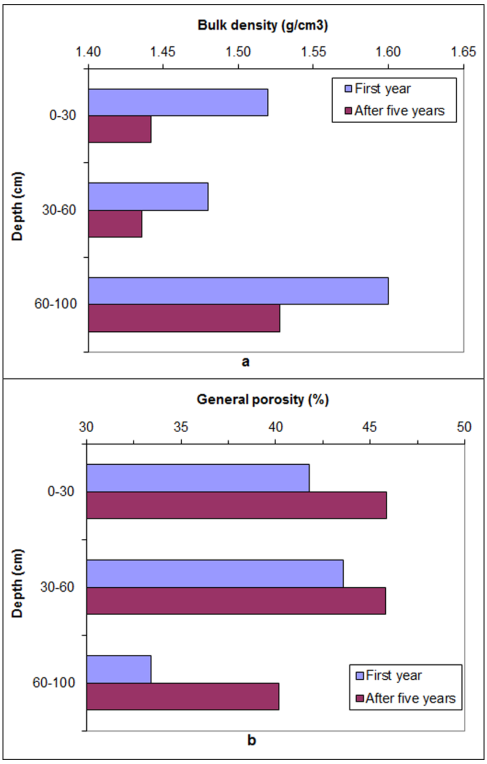


Figure 5. *The changes of soil bulk density and general porosity at different depths after five years plant growth.*

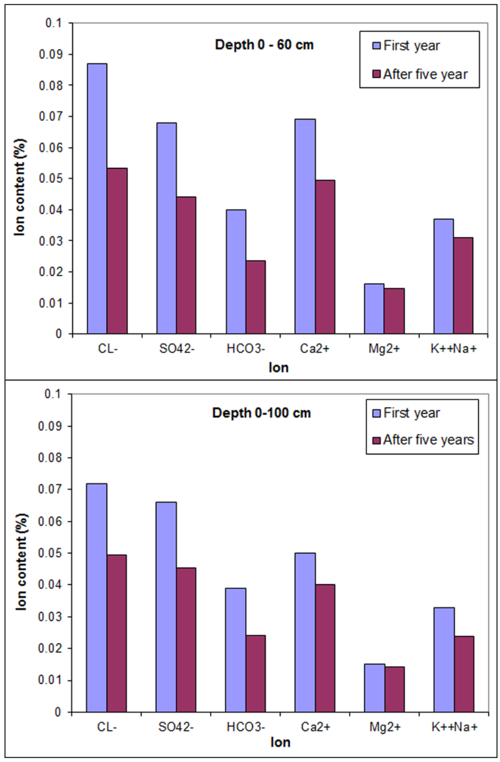


Figure 6. *The changes of ions concentration after five year at two different depths for the 6 selected ions.*

cm soil depth to 31 % at 100 cm. The concentrations of sulphate ($SO^{2-}{}_4$) and bicarbonate ($HCO^{1-}{}_3$) were reduced by 35 % to 40 % at the corresponding soil depths. The cations such as calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$) and the total sodium ($Na^+$) and potassium ($K^+$) were reduced by 28 % , 9 % and 16 % at 0–60 cm depth, and 20 %, 6 % and 28 % at 0–100 cm depth. These results demonstrate the apparent ability to grow salt-tolerant plants at the same time improve the soil environment and mitigate soil salinization.

## 4 Conclusions

The results from the present study indicate that shrubs and some arbour species are suitable for planting in saline environments. However, the survival probabilities of many arbour species are low for the first year. Even for the plants surviving the first year, the continued growth conditions are weaker than for shrubs mainly because the water requirements of arbour species are higher than those of shrubs. Most arbour species have lower salt-tolerance than shrub species and in the experiments their growth was retarded by salt stress. However, the nitrogen-fixing arbour species, *Elaeagnus angustifolia,* shows high salt-tolerance and high survival rate and grows vigorously.

High soil evaporation in excess of the rainfall is one reason for saline soil formation. When growing salt-tolerant plants in a saline environment, the bare soil is covered by plants. Soil evaporation is replaced by plant transpiration, thereby reducing or hindering the salt accumulation, thus reducing salt accumulation in the tillage layer. The plants also assimilate salt from the soil and accumulate salts in aerial plant parts. The salt is then removed through harvest. This study has shown that growing salt-tolerant plant species for five years reduces the soil salinity significantly. A reduction of 60–75 % was obtained for most of the shrubs and some of the arbours, while about 40 % reduction was obtained for the other arbours. However, hardly any salt at all was removed by *P. gansuensis.*

After growing salt-tolerant plant species in a saline environment, the amount of organic matter micro-organisms in the soil is increased because of the humic action of rotted roots and fallen leaves. The soil's nutrient conditions are improved, resulting in enhanced soil fertility. After the five years' successive growing period the porosity increased by up to 20 % at the tillage layer (0–100 cm) and a reduction in the soil bulk density was also observed.

The soil salinity decreased although brackish water was used as irrigation water. The salinity of the irrigation water was less than that of the soil solution so salts could be removed by the leaching process. However, young plants are more sensitive to salt than mature plants. To ensure plant germination, fresh water is recommended to be applied during the beginning of growing periods.

The above results indicate that growing salt-tolerant plants in saline soil can improve the ecological environment and enhance land productivity. In addition, some halophytes have great economic value, such as *Nitraria tangutorum Pall, Lycium barbarum* and *Hippophae rhamnoides L.*

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