Soil & Tillage Research 146 (2015) 159–173

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Reclamation of very heavy coastal saline soil using drip-irrigation with saline water on salt-sensitive plants

Xiaobin Li [a,b], Yaohu Kang [a,*], Shuqin Wan [a], Xiulong Chen [a,b], Linlin Chu [a]

[a] Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Science and Natural Resources, Chinese Academy of Sciences, 11 A Datun Road, Anwai, Beijing 100101, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 4 August 2014
Received in revised form 23 September 2014
Accepted 12 October 2014

Keywords:
Saline water
Drip-irrigation
Chinese rose
Plant growth
Dry weight
Threshold

ABSTRACT

High salt content in soil, poor soil structure and fresh water shortage are the restricting factors for construction of ecological landscapes in coastal regions with very heavy saline silt-soil. The aim of this work was to develop a method to reclamate the very heavy coastal saline soil using drip-irrigation with saline water for salt-sensitive plants. A field experiment with five treatments of salinity levels of 0.8, 3.1, 4.7, 6.3 and 7.8 dS/m of irrigation water was imposed in the very heavy saline silt-soil in 2012–2014. The initial soil in experimental plots was tilled and broken, and a gravel–sand layer was created at 120 cm depth. Chinese rose (*Rosa chinensis*) is very sensitive to salt and was chosen as the representative plant. Soil indexes (electrical conductivity of soil saturated extract (EC_e), pH and sodium adsorption ratio (SAR)), growth characters and dry matter production of rose were determined. The results showed that the level of salinity in water had no significant effect on salt leaching in the 0–120 cm soil profile, and significant effects only occurred in shallow soil layers. EC_e and SAR of soil profile decreased with irrigation time, but pH of soil initially increased and then decreased. Rose growth and dry weight decreased with increasing of irrigation water salinity. The values of soil salt tolerance threshold were 2.24 dS/m at emergence and 4.48 dS/m in the growth period after emergence. The emergence rate decreased by 53.30% for each unit of EC_e increase in the root zone, and dry weight decreased to zero when EC_e exceeded 5.36 dS/m. A regulatory method was scheduled for drip-irrigation of saline water to control the soil matric potential (SMP) under a gravel–sand layer for initially saline soils and was effective in reclamation of very heavy coastal saline soil (silt soil) for sensitive species such as Chinese rose. An SMP higher above −5 kPa at 20 cm depth under the emitter in the first year and −10 kPa in the second year, and 6 mm of irrigation water of salinity up to 4.01 dS/m can be used for rose drip-irrigation scheduling, while also maintaining a 50% survival rate.

1. Introduction

There is a large region of coastal saline land bordering the Pacific Ocean in China, including 10,000 km^2 along the 6000 km of coastline extending from Jiangsu province to Liaoning province (Yu and Chen, 1999). Most of the coastal saline wasteland is not being used, especially land with silt soil, which is almost never used. These coastal soils are usually quite saline, for example, the mean electrical conductivity of saturated paste extracts (EC_e) is up to 66.7 dS/m in Tianjin coastal soils (Sun et al., 2013) and 32 dS/m in our study area, with the salt composition mainly chlorides in which chloride and sodium account for 60–88% of the anion and cation concentrations, respectively. Most coastal soils are slightly alkaline to alkaline, with pH of 7.5–8.5 (Wang et al., 1993). The average sodium adsorption ratio (SAR) is >30 $(mmol/L)^{0.5}$. When the soil water content reaches saturation, soil porosity is filled and the permeability of soil is reduced. The groundwater table is persistently high, at only 0.5–3 m depth, and has an electrical conductivity (EC) within 2.5–20.5 dS/m. Because of over-mentioned condition, leaching of salts in this soil is difficult and makes them unusable for non-highly tolerant plants. Therefore reed (*Phragmites australis* (Cav.) Trin. ex Steud) and Suaeda (*Suaeda glauca* Bge.) are the only native vegetation of landscape. Afforestation is being tried to improve the landscape. Many methods have been used for reclamation of the coastal saline wasteland, but all have failed. It is necessary to develop a method to reclamate the very heavy coastal saline soils to construct ecological landscapes in coastal regions.

* Corresponding author. Tel.: +86 10 64856516; fax: +86 10 64856516.
E-mail address: kangyh@igsnrr.ac.cn (Y. Kang).

http://dx.doi.org/10.1016/j.still.2014.10.005
0167-1987/

With the rapid industrialization and urbanization in coastal saline regions there is an urgent need to improve the landscape to meet the demand of living environments for cities and districts. The traditional methods of saline soil vegetation rehabilitation were biological, chemical methods and using salt-tolerant species. However, these methods were found to be ineffective and it was difficult to create a good landscape in a short time and to maintain good plant growth. A variety of plant types is also needed to construct a better landscape, but most plants are salt-sensitive and there is poor diversity and monotonous plant types and color of salt-tolerant species. Presently the main method of vegetation rehabilitation is to replace saline soil with non-saline soil for depths of 0–100 cm. However, this method is expensive and unsustainable due to the shallow and saline groundwater (Sun et al., 2012b). Therefore, a cheap, simple and sustainable method is needed.

Irrigation of increasing amounts of landscape will consume large quantities of water, and supplies of fresh water are already low in coastal regions. Thus non-conventional water resources such as saline water, brackish groundwater and treated wastewater are alternatives to fresh water resources (Rhoades et al., 1988). And saline water has been successfully used for irrigating crops and other plants. Particularly in coastal regions, which are rich in saline water resources, saline water is an ideal alternative for irrigation. However, careful management is required to safeguard the environment.

Drip-irrigation has been found to be highly useful for utilization and reclamation of saline soils (Kang et al., 2010; Liu et al., 2012; Sun et al., 2013; Wan et al., 2012), and is widely regarded as the most promising irrigation system to use with saline water (Malash et al., 2008; Meiri et al., 1992). It applies water precisely and uniformly at high frequencies, maintaining high soil matric potential (SMP) in the root zone and thus compensating for the decreased osmotic potential caused by irrigation with saline water, and constant high total water potential can be maintained for crop and plant growth (Goldberg et al., 1976; Kang, 1998). In recent years, our research has shown that SMP measured by tensiometer is an ideal indicator of soil water content, and can be easily used to help users schedule their field irrigation (Wan et al., 2010). Several studies have been conducted that focused on the use of different SMP to trigger irrigation with saline water for a wide variety of crops (Chen et al., 2009; Kang et al., 2010; Wan et al., 2010). It was found that saline water up to 4.9 and 10.9 dS/m can be applied respectively to irrigate tomato (or cucumber) and oleic sunflower without obvious negative effects on yield and soil salinity, when keeping the SMP at 0.2 m depth immediately under the emitter higher than −20 kPa under drip-irrigation with saline water throughout the growing season. However, studies aimed at developing drip-irrigation schedules with saline water for reclamation of coastal saline soil by SMP are rare, especially for landscape plants. Many studies have been performed on crops or plants planted in non-saline soil irrigated with saline water, or in saline soil irrigated with fresh water; however, few have considered the influence of both saline water and soil on plants, especially for landscape plants. Thus further studies are needed concerning irrigation using saline water on coastal saline soils.

A gravel–sand layer combined with drip-irrigation soils was effective during reclamation for initially saline coastal soils (Sun et al., 2012a, 2013) and will likely ensure the acceptable levels of soil salinity in such soils. Sun et al. (2012a, 2013),) also confirmed that SMP higher than −5 kPa at a depth of 20 cm could be used as an indicator for vegetation rehabilitation under drip-irrigation scheduling in the first three years of the reclamation. Plants of low salt-tolerance were growing at the end of the third year of SMP treatment, but a low average survival rate of 48.9% was obtained, and low EC of local groundwater with 1.7–2.1 dS/m was used for irrigation (Sun et al., 2012a, 2013). Currently, few studies were reported about the effect of irrigation water with high EC on landscape plants, especially on low salt-tolerant plants. Thus, further studies are needed concerning suitable salinity of irrigation water for plants and optimal irrigation scheduling and their affect on the survival rate of low salt-tolerance and landscape plants.

Chinese rose (*Rosa chinensis*), as a conventional landscape flower plant and confirmed as sensitive to soil salinity, was examined in the present study. The aim was to test the possibility of reclamation of very heavy coastal saline soil using drip-irrigation with saline water for Chinese rose. Specifically, the objective was to test the impact of irrigation with saline water on plant growth and dry matter production in the process of reducing soil salinity; furthermore, to develop a method of reclamation of the very heavy coastal saline soil using drip-irrigation with saline water for salt-sensitive plants.

2. Materials and methods

2.1. Experimental site

The experiment was conducted during 2012–2014 at the International Eco-City of Caofeidian District (39°20′N, 118°54′E) in the south of Tangshan city, east China, and north of Bohai Gulf which borders the Pacific Ocean. The station has a typical semi-humid monsoon climate with annual precipitation of approximately 554.9 mm, mostly during June–September (Fig. 1).

According to Wang et al. (1993) the saline soil of the experiment is a typical coastal saline soil developed from beach mud, with the main ions being chlorine and sodium. The EC_e and SAR of the soil at a depth of 120 cm are 28.08 dS/m and 57.50 $(mmol/L)^{0.5}$, respectively. The soil bulk density of initial saline soil was in the range of 1.6–1.75 g/cm^3. According to the USDA soil classification, the soil in our experiment field was silt soil, with clay (<0.002 mm) content of 0.7%, silt (0.002–0.05 mm) of 80.13% and sand (0.05–2 mm) of 19.17%, and has a characteristic sticky texture structure and poor ventilation and permeability. The soil texture, soil bulk density, EC_e, pH and SAR are shown in Table 1.

2.2. Experimental design

2.2.1. Plot layout and irrigation water management

The successful reclamation of the coastal saline wasteland for plant growth in the Dagang district and drip-irrigation with saline water on crops in Jinghai county of Tianjin, located on the east coast of China in recent years were a great experience which can help the authors in this study (Chen et al., 2009; Sun et al., 2012a, 2013).

In this experiment, Soil was prepared for gravel–sand layer treatment as described in Sun et al. (2012a, 2013),) (Fig. 2). Soil was removed to a depth of 120 cm and a 15-cm thick gravel layer was laid in the bottom and then covered with a 5-cm thick layer of sand – with native soil placed back above the sand. In order to increase soil infiltration, a rotary tiller was used to break clay blocks. The primary irrigation strategies are controlling the SMP at a depth of 20 cm immediately under the emitter throughout the growing season. The optimal SMP threshold was −5 kPa for the first year, and SMP threshold could be controlled at slightly higher than −5 kPa according to the soil salinity environment from the second year. Based on the experimental results of Sun et al. (2012a, 2013),), we set the SMP threshold at −5 kPa when the roses were transplanted, and −10 kPa after a growing season ended.

In order to determine the effective use of irrigation with saline water on Chinese rose, during 2012–2014, five treatments with EC of irrigation water (EC_{iw}) of 0.8, 3.1, 4.7, 6.3 and 7.8 dS/m were designed, with saline water composed by mixing fresh well-water