A vegetation reconstruction method to plant *Sedum spectabile* Boreau using drip-irrigation with saline water on a coastal saline soil in region around Bohai Gulf

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Abstract Soil salinity and saline groundwater are major constraints to the cultivation of crops and landscape plants in coastal regions. With the rapid industrialization and urbanization in these areas, there is an urgent need to improve the landscape to meet the increasing demand of living environments for cities and districts. The aim of this study was to propose a method to plant *Sedum spectabile* Boreau, a common landscape flower plant, on a very heavy coastal saline soil using drip-irrigation with saline water in region around Bohai Gulf. The salinity levels of irrigation water were 0.8, 3.1, 4.7, 6.3a, and 7.8 dS/m, respectively. The results showed that the revegetation method, which mainly included ‘ridge planting + saline water drip-irrigation’, was effective in planting *Sedum spectabile* Boreau for reclaiming coastal saline silt soil. An soil matric potential (SMP) higher above −5 kPa after transplanted and −10 kPa after growing season ended, and 6 mm of irrigation water can be used as indicators for *Sedum spectabile* Boreau drip-irrigation scheduling with 100 % survival rate when irrigated with saline water at <7.8 dS/m in initially saline soils with a gravel–sand layer after tillage. This method is combined with comprehensive utilization of the saline water, agronomic measures, collaborative repair of the soil and plants to offer new

views and theoretical support for the protection and development of saline land in coastal regions.

Keywords Landscape · Irrigation water salinity · Coastal region · Survival · Dry mass production

Introduction

Sedum spectabile Boreau is a perennial flower of sedum genus of sedum family, and is an important landscaping material with good viewing, mostly based on division propagation or cutting propagation (Yu 2013). It does not need extensive management, and can endure cold, barren and other harsh environments. The whole plant of *Sedum spectabile* Boreau has been documented as folk medicines possessing the capability of promoting blood circulation to stop bleeding, clearing heat antitoxicant and so on (Yu 2013). As a kind of cover plant, *Sedum spectabile* Boreau has also been an important landscape plant for its beautiful flowers, longer flowering period, and simple management.

Soil salinization is one of the major environmental and land degradation problems in the world. Serious soil salinization can not only cause the deterioration of land quality and reduce the agricultural production, but also affect the eco-environmental construction of the ecologically fragile areas, such as coastal region. Moreover, saline groundwater is also a major constraint to the cultivation of crops and landscape plants in coastal regions. Soil salinity and saline water have significantly threatened the inhabitation comfort and sustainable land use of the coastal regions environment. In the coastal regions of China, approximately 10⁶ ha of land are salt affected (Wang et al. 2014), where saline water is rich. With the rapid industrialization and urbanization in coastal regions, there is an

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urgent need to improve the landscape to meet the increasing demand of living environments for cities and districts (Li et al. 2015a, b). *Sedum spectabile* Boreau, as a common landscape flower plant, can be used in these regions. However, there is a dearth of information on *Sedum spectabile* Boreau subjected to salinity in field soil irrigated with saline water, and the suitable irrigation water salinity range was still unknown.

Drip-irrigation has been found to be highly useful for utilization and reclamation of saline soils (Dou et al. 2011; Kang et al. 2012; Li et al. 2015a, b). In recent years, the method of water-salt regulation using drip-irrigation has been widely applied in the reconstruction and re-vegetation of the coastal saline regions under flat planting (Chen et al. 2015; Li et al. 2015a, b; Sun et al. 2012, 2013), and saline water as a non-conventional water resource, was also utilized in the reclamation, but lower survival rates were obtained under higher irrigation water salinity (Li et al. 2015a, b). So further studies are needed to improve the reclamation method to enhance the vegetation adaptation to irrigation water with high salinity, and meanwhile more landscape plants should be tested to build the vegetation reconstruction plant library for the reclamation coastal saline soils.

Sedum spectabile Boreau was planted in coastal regions around Bohai Gulf with very heavy saline silt-soil, and received irrigation water at five levels of salinity using drip-irrigation with saline water. The aim of the study was to test the possibility of reclamation of very heavy coastal saline soil using saline water drip-irrigation for *Sedum spectabile* Boreau. Specifically, the objective was to test the impact of irrigation with saline water on plant growth and further to develop a method for *Sedum spectabile* Boreau planting on very heavy coastal saline soils with saline water drip-irrigation.

Materials and methods

Experimental site

A field experiment was conducted from 2013 to 2014 on coastal saline land 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 study area is characterized by a typical semi-humid monsoon climate with annual precipitation of approximately 554.9 mm, mostly during June–September. 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 electrical conductivity of saturated paste extracts (EC_e) and sodium adsorption rate of

saturated paste extracts (SAR) of the soil at a depth of 95 cm are 27.79 dS/m and 57.63 (mmol/L)^{0.5}, respectively. 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 of sticky structure, poor ventilation, and low permeability. The initial soil texture, soil bulk density, EC_e , pH, and SAR are shown in Table 1.

Plot layout and irrigation water management

In this experiment, soil was prepared for gravel–sand layer treatment as described in Li et al. (2015a, b). Soil was removed to a depth of 100 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. *Sedum spectabile* Boreau was directly planted in 2013. Five treatments with EC of irrigation water (EC_{iw}) of 0.8 (S1), 3.1 (S2), 4.7 (S3), 6.3 (S4), and 7.8 (S5) dS/m were designed in the study, with saline water composed by mixing fresh well-water and highly saline shallow—groundwater in different proportions. Ionic composition of irrigation water was shown in Table 2. Each treatment was replicated three times in 15 plots and laid out permanently following a completely randomized block design. 120 *Sedum spectabile* Boreaus were planted at a spacing of 0.2 m × 0.2 m in each 3.0 m × 3.0 m experimental plot. Each of the 15 plots consisted of four raised (15 cm) beds, with 0.8 m between bed centers (Fig. 1), and two rows of *Sedum spectabile* Boreau in each bed. Each bed was 0.3 m wide and 3.0 m long.

Each treatment had a separate gravity drip-irrigation system consisting of a tank (200 L) and 12 drip tubes (four tubes per plot). The tank was installed at 0.8 m above the ground to contain irrigation water. Drip tubes with 0.3-m emitter intervals were placed in the center of the beds. One vacuum gauge tensiometer was installed 0.2 m directly underneath one emitter located in the center of the plot for each treatment. The tensiometers were observed twice daily (at 8:00 and 18:00 h), and irrigation was applied when the reading value of tensiometers exceeded the target SMP value. Planting pattern, soil treatment, and samplings distributions were shown in Fig. 1.

Irrigation water management was the same as described in Li et al. (2015a, b). Irrigation time was divided into two stages. The first stage was enhanced salt leaching. The second stage was water and salt regulation. Irrigation started based on soil matric potential (SMP). The target SMP value was greater than the corresponding value of SMP for field capacity in the early time, to cause a vertical downward soil water potential gradient which benefited

Table 1 Soil mechanical composition, bulk density, EC_e (electrical conductivity of saturated paste extracts), pHs (pH of saturated paste), and SAR (sodium adsorption rate of saturated paste extracts) in initial soil

Soil depth (cm)	Soil mechanical composition (%)			Soil texture	Bulk density (g/cm^3)	EC_e (dS/m)	pHs	SAR (mmol/L) ^{0.5}
	<0.002 mm	0.002–0.05 mm	0.05–2 mm					
0–5	0.8	79.9	19.3	Silt	1.30	29.53	7.88	57.68
5–15	0.6	79.9	19.6	Silt	1.48	29.25	7.82	56.28
15–25	0.9	77.3	21.8	Silt loam	1.56	29.23	8.01	56.00
25–35	0.7	80.7	18.6	Silt	1.67	27.13	8.03	54.37
35–45	0.3	82.9	16.8	Silt	1.65	28.19	8.12	60.48
45–55	0.6	80.9	18.5	Silt	1.79	26.62	7.89	55.47
55–75	0.6	80.6	18.8	Silt	1.66	27.48	8.14	59.24
75–95	1.1	78.9	20.0	Silt loam	1.64	26.92	7.99	58.78

Table 2 Water characteristics in each salinity treatment

Treatments	EC_{iw} (dS/m)	Ionic concentration (mmol/L)						pH	SAR (mmol/L) ^{0.5}
		Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	SO ₄ ²⁻	Cl ⁻		
S1	0.8	6.38	0.16	1.45	0.45	0.29	4.65	8.55	4.63
S2	3.1	24.40	0.51	2.94	2.32	1.58	22.75	8.52	10.64
S3	4.7	36.46	0.74	3.66	3.79	2.46	36.78	8.40	13.35
S4	6.3	47.82	0.95	4.04	5.27	3.37	50.01	8.37	15.68
S5	7.8	62.84	1.24	4.55	7.15	4.34	66.41	8.05	18.37

EC_{iw} is irrigation water electrical conductivity; SAR is sodium adsorption ratio

Fig. 1 Planting pattern, soil treatment, and soil samplings distribution

salt leaching. Based on the experimental results of Sun et al. (2012, 2013), we set the SMP threshold at -5 kPa when the *Sedum spectabile* Boreau were transplanted, and -10 kPa after a growing season ended combining with saving-water and soil salinity environment. The amount of

water for each irrigation event of all treatments was 6 mm when SMP reached the threshold value, which considered the ability to retain moisture in the soil (soil water reserves) and the maximum daily evapotranspiration of plants in the local area.

On 21–24 November, 24 mm of freshwater irrigation was applied to each treatment and then irrigation was terminated until April 2013 due to the onset of winter. On 6–8 April, 24 mm of freshwater irrigation was applied to each treatment to provide a suitable soil moisture environment for plant sprouting in spring.

Observation and measurements

The number of surviving plants was counted in 2013–2014. The height, crown diameter, and leaf water content were measured in 2013 and 2014. The shoot biomass of plants (three plants per replicate) was measured at the end of 2014. Soil cores were obtained from each plot using an auger (2.0 cm diameter, 15 cm high) before transplanting and on August 2014. The samples were obtained at 0, 10, 20, 30, and 40 cm from the emitters. Soil samplings distribution was shown in Fig. 1.

All soil samples were air-dried and passed through a 1-mm sieve. Soluble salt estimates, soluble cations, and soil pH were based on extracts of saturated soil. The EC and pH were determined using a conductivity meter (DDS-11A, REX, Shanghai) and a pH meter (PHS-3C, REX, Shanghai), respectively. The SAR of the saturated paste extract was calculated as follows (Rhoades et al. 1992):

$$\text{SAR} = \frac{[\text{Na}^+]}{([\text{Ca}^{2+}] + [\text{Mg}^{2+}])^{0.5}} \quad (1)$$

where the concentration of each cation is in mmol/L.

In this experiment, average EC_e values within the whole soil profile were integrated to account for both spatial and temporal variations. The average values of EC_e in the soil profile were calculated as follows (Dou et al. 2011):

$$\text{EC}_e(t) = \frac{\sum_{j,k}^{n,m} \text{EC}_e(t,j,k) \times S(j,k)}{\sum_{j,k}^{n,m} S(j,k)} \quad (2)$$

where t represents the time at which soil samples were obtained; j is the distances from the emitter where soil samples were attained; k is the depths of soil samples, and $S(j, k)$ is the depth interval of the soil sample.

Statistical analyses

One empirical function was used to describe the dry matter production while subject to increasing levels of salinity in saline water. The model is as follows (Steppuhn et al. 2005):

$$\text{PIr} = \frac{1}{1 + (C/C_{50})^{\exp(sC_{50})}} \quad (3)$$

where PIr is the relative plant index (actual plant index at the given salinity level divided by plant index with fresh

water or low saline water). C is the EC of the water in dS/m, C_{50} defines C at $\text{PI} = 0.5$ and s represents the response curve steepness.

Many factors influence the survival and dry mass production of plant besides exposure to increasing root-zone salinity. Consequently, the single-value, Salinity Tolerance Index (STI) would seem more appropriate for comparing plants than any of the dual parameters of any of the response functions. The STI identifies a salinity value equal to the 50 % reduction in plant index from that of the nonsaline index plus a measure of the tendency to maintain some product index as the plant is subjected to salinity levels less than but approaching C_{50} . The STI can serve to rate plant tolerance to salinity (Steppuhn et al. 2005). The salinity tolerance index (STI) was used for evaluating salt tolerance of plants as follows:

$$\text{STI} = C_{50} + sC_{50} \quad (4)$$

All data gathered in the research were recorded and classified in Microsoft Office Excel 2007. Analyses of variance (ANOVA) were carried out by SPSS 16.0 statistical software (SPSS Inc., IL, USA). The significance of the effect of all variables was examined by one-way ANOVA. Figures were created using Surfer 8.0 (Golden Software Inc., CO, USA) and Origin 8.0 (Origin Lab Inc., MA, USA).

Results and discussion

Rainfall and irrigation

During the experiment period, the total rainfall was 379.7 and 444.7 mm in 2013 and 2014, respectively (Table 3), but the precipitation in the period of July to November was similar in the two years. The amounts of irrigation with saline water were 276–384 and 390–570 mm in 2013 and 2014, respectively. For the same period (Jul–Nov), less irrigation water was applied for all treatments with the values of 204–300 mm in 2014, this was mainly because that SMP threshold was controlled lower in 2014 than that in 2013.

Salt leaching

On the experimental land before transplanting of *Sedum spectabile* Boreau, the average EC_e value in the 0–95 cm soil profile was up to 27.79 dS/m (Table 1; Fig. 2). After nearly 1 year of drip-irrigation with saline water, the salts in all of the sampled layers were well leached. There were two high salt zones (Fig. 2), and one was the center of ridge, the other was the deeper of soil layer. The average EC_e value in soil profile for five treatments was 5.81 and

Table 3 Rainfall and saline water irrigation amount for each treatment in 2013 and 2014

Treatments	EC _{iw} (dS/m)	Rainfall (mm)			Saline water irrigation depth (mm)		
		2013 (Jul–Nov)	2014 (Jul–Nov)	2014 (Apr–Nov)	2013 (Jul–Nov)	2014 (Jul–Nov)	2014 (Apr–Nov)
S1	0.8	379.7	361.1	444.7	366	252	504
S2	3.1				384	300	570
S3	4.7				276	204	390
S4	6.3				312	294	558
S5	7.8				294	234	426

Fig. 2 The spatial distribution of EC_e (electrical conductivity of saturated paste extracts) in the vertical transects perpendicular to the drip lines before transplanting (S0) and for each treatment in 2014. 8 (S1–S5)

9.03 dS/m in 0–35 and 0–95 cm, respectively, which were reduced by 79.8 and 67.5 % compared to the corresponding initial EC_e values prior to planting. Salt leaching occurred for all soil profiles, but the effect decreased with soil depth and the distance from emitter.

The average EC_e values in 0–35 cm soil profile were 4.98, 5.99, 5.79, 5.04, and 7.23 dS/m for S1–S5, respectively, and the corresponding values in 0–95 cm soil profile were 7.98, 8.73, 9.29, 8.92, and 10.23 dS/m, respectively. Salt leaching effects slightly decreased with irrigation water salinity increasing. Many studies have reported the better salt leaching effect under drip-irrigation, with saline soil becoming moderately or even mildly saline as planting age increases (Chen et al. 2009; Dou et al. 2011; Kang et al. 2012; Li et al. 2015a, b)—similar results were also found in the present study. Although differing in irrigation water quality, there were no significant differences in salt leaching effect for S1–S5 treatments in all soil profiles. This was similar with Li et al. (2015a, b), who reported that the soil indexes such as salinity and SAR decreased with time, when a suitable value of SMP was maintained at 0.2 m directly underneath drip-irrigation emitters in different growth years, using saline water of <7.8 dS/m, resulting in a suitable soil environment for plants.

Growth and dry mass

The data of plant growth characteristics of *Sedum spectabile* Boreau for different treatments during the experiment and the ANOVA results are shown in Table 4. Survival rates were all 100 % for all treatments in 2013 and 2014, respectively. This indicated that *Sedum spectabile* Boreau is a salt-tolerant plant. Salt stress has a negative effect on osmotic potential in soil, and results in restricting the uptake of water (Cai et al. 2014). Under our experimental conditions, relative leaf water content (RWC) increased with irrigation water salinity, especially in 2014 (Table 4), which may have important implications for osmotic adjustment under saline irrigation. This information is inconsistent with the results of Li et al. (2015b), who reported that irrigation with saline water had a negative effect on leaf water status for Chinese rose: RWC decreased with increasingly salinity of irrigation water. This may be because that different species responded differently to salinity, and that Chinese rose is sensitive to salt but *Sedum spectabile* Boreau is salt-tolerant.

At the end of 2014, some plant shoots were collected to determine the dry mass (Table 4). Irrigation with saline water had a negative effect on shoot dry mass, and shoot

Table 4 *Sedum spectabile* Boreau growth characteristics for different irrigation water quality (EC_{iw}) in 2 years

Treatments	Survival rate (%)		Relative leaf water content (%)		Shoot dry mass (g)
	2013.11	2014.11	2013.10	2014.10	
S1 (0.8 dS/m)	100.00a	100.00a	92.02a	91.42c	116.00a
S2 (3.1 dS/m)	100.00a	100.00a	92.27a	92.71b	65.43b
S3 (4.7 dS/m)	100.00a	100.00a	92.70a	93.09b	56.90b
S4 (6.3 dS/m)	100.00a	100.00a	93.15a	93.15b	54.75b
S5 (7.8 dS/m)	100.00a	100.00a	93.43a	93.89a	37.00c

Values followed by different letters within the same year in column differ significantly at $p < 0.05$

Fig. 3 The response of average plant height and crown diameter of the two years to EC_{iw} . *** $p < 0.001$

dry weights significantly decreased with irrigation water salinity increasing. In the present study, plant height and crown diameter significantly declined in 2013, especially in 2014 (Fig. 3). In all, plant growth were significantly affected by salinity, which has also been confirmed in crops and other plants (Chauhan et al. 2008; Karlberg et al. 2007; Malash et al. 2008; Mantell et al. 1985; Oster and Schroer 1979; Rhoades 1977; Rhoades et al. 1988; Sonneveld et al. 1999; Valdez-Aguilar et al. 2011).

Salt tolerance threshold

The effect of salinity of irrigation water on dry weight was analyzed by the model introduced above (Fig. 4). The C_{50} and STI of *Sedum spectabile* Boreau with data of dry weight was 4.71 and 5.02 dS/m, respectively. Based on the model, there were 58 and 59 % reductions in dry weight. The differences between the both values and 50 % implied that other factors, such as rainfall or soil reclamation process, also affected the dry mass of plant in addition to the salinity of irrigation water. The STI of Chinese rose with

Fig. 4 The response of relative dry weight of 2014 to EC_{iw} . ** $p < 0.05$

data of dry weight by Li et al. (2015a) was 6.03 dS/m, but lower survival rates occurred at the same irrigation water salinity. It indicated that although higher survival rates

observed in *Sedum spectabile* Boreau, dry mass of this plant is sensitive to salt.

We concluded that the maximum acceptable salinity for irrigation water suitable for *Sedum spectabile* Boreau under field conditions should not exceed 4.71 dS/m in order to obtain a dry mass of >50 %. If regardless of the landscape quality, <7.8 dS/m of irrigation water could be applied in irrigating *Sedum spectabile* Boreau during reclamation of very heavy coastal saline soils, and get 100 % of survival rate.

Conclusions

The present study showed that drip-irrigation worked well in combination with saline water for the survival of *Sedum spectabile* Boreau in a coastal saline soil. Soil salts were well leached and there were a slight increase in soil EC_e value with irrigation water salinity increasing. Plant height, crown diameter, and dry matter decreased with increasing salinity of irrigation water, but leaf water statue increased, which may have important implications for osmotic adjustment under saline irrigation.

A method to plant *Sedum spectabile* Boreau on very heavy coastal saline soils with saline water drip-irrigation was developed, that is ‘ridging planting + saline water drip-irrigation’ system, and an SMP above −5 kPa at 20 cm depth under the emitter after transplanted and −10 kPa after growing season ended, and 6 mm of irrigation water can be used as indicators for *Sedum spectabile* Boreau drip-irrigation scheduling with 100 % survival rate when irrigating with saline water at <7.8 dS/m in initially saline soils with a gravel–sand layer after tillage. If taking landscape quality into consideration, the maximum acceptable salinity for irrigation water suitable for *Sedum spectabile* Boreau under field conditions should not exceed 4.71 dS/m in order to obtain a dry mass of >50 %. This method is combined with comprehensive utilization of the saline water, agronomic measures, collaborative repair of the soil and plants to offer new views and theoretical support for the protection and development of saline land in coastal regions.

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