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Influence of mulches on urban vegetation construction in coastal saline land under drip irrigation in North China

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ABSTRACT

In order to generate information for reclaiming coastal saline sandy-loam soil for urban vegetation construction around Bohai Bay in North China, a field experiment combined with drip irrigation and setting a gravel–sand layer beneath the saline soil but above the water table was conducted to study the effect of mulches on irrigated water amount, soil salt control and willow (*Salix babylonica* L.) growth, and construction costs were also estimated during 2012 and 2013. The three mulch treatments were control treatment with no mulch (C1), black shading net mulch (C2) and straw mulch (C3). In order to leach salts in the soil profile, irrigation was triggered by the soil matric potential threshold at 20-cm soil depth of −5 kPa in the early stage, and this was changed to −10 kPa until the end of the first growing year, and to −20 kPa for the second year. The results showed that (1) the straw mulch consumed the least irrigation water, followed by the black shading net mulch and the control treatment. Compared to the control treatment, the amount of irrigation for the straw mulch had decreased by 12% in 2012 and 27% in 2013. (2) The salinity reduction was mainly related to rainfall and the strategy of drip irrigation; and the mulches, especially straw mulch, decreased the risk of salt accumulation in early spring. (3) The best growth characteristic of plants and the optimal investment cost were for straw mulch, and the high investment cost in 2012 was due to soil preparation cost and the willows, gravel and sand cost was high and then it had decreased by 90% in 2013. From the combined points of water saving, plant growth and investment cost, the use of straw mulch with drip irrigation could aid in urban vegetation construction on coastal saline land in North China.

1. Introduction

With the rapid social-economic development in coastal area along Bohai Sea in North China, more and more people move to these areas to seek better opportunities and higher standards of living. The role of urban vegetation to improve environmental quality, increase the economic, physical and social health of communities is important to quality of life (McPherson et al., 2000; Wu et al., 2009). However, in these coastal areas, the soil salinity is high (15–65 dS m^{-1}), with two dominant ions (sodium and chlorine) from sea water (Sun et al., 2013), the groundwater table is shallow (0.8–1.5 m) (Wang et al., 1993; Xing et al., 2013), and windy conditions in spring and winter lead to high evaporation and salt accumulation on the soil surface. In addition, fresh water resource is very limited (Xia, 2002; Zhang et al., 2011). So the construction of urban vegetation in these coastal areas was restricted by the high salt content in soil and fresh water shortage. But, considering a mean annual precipitation of about 560–916 mm in the coastal areas of Bohai Sea (Marine Geology Research Center, Institute of Oceanology, CAS), rainfall is ideal alternative fresh water in coastal regions.

Drip irrigation can apply water precisely and uniformly, leach salts to the fringe of wetted areas, maintain relatively suitable soil water conditions for plant growth and has been confirmed as an effective technology in saline soil reclamation (Goldberg et al., 1976; Bresler et al., 1982; Kang et al., 2008; Hanson et al., 2009). Numerous recent studies have found that different extremely saline soils gradually become moderately saline after 2–3 years of cultivation with scheduled irrigation using a set threshold of soil matric potential (SMP, Jiao et al., 2008; Liu et al., 2011; Wang et al., 2011), and higher SMP treatments have a more evident leaching effect. Wan et al. (2012) found that the irrigation amount decreased significantly as the SMP decreased from −5 to −25 kPa, and the study recommended a SMP threshold of around −10 kPa within the first

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1–2 years, and then decreased to around −20 kPa in the following years, dependent upon salt leaching efficiency, could be used to reclaim the salt-affected soil. The similar result provided by Zhang et al. (2013). Sun et al. (2012a, 2013) found that controlling the SMP above −5 kPa and setting a gravel–sand layer beneath saline soil but above the water table were two useful strategies to reclaim coastal saline soil for vegetation construction.

Mulches can reduce evaporation, delay salt accumulation near the soil surface, increase soil temperature, control weeds and promote plant growth (Kimber, 1973; Ossom et al., 2001; Ramakrishna et al., 2006; Terasaki et al., 2009; Zhao et al., 2014; Aragues et al., 2014). Compared with bare saline land, mulches can store more precipitation and irrigation water in soil and the higher soil water content under mulches can enhance salt leaching by subsequent rains (Adams, 1966; Doring et al., 2005).

Therefore, the objectives of this study were: (1) to evaluate the effects of mulch practices combined with drip irrigation on the irrigation water amount, salt control, plant growth and investment costs and (2) to provide the strategies for urban vegetation construction on coastal saline land in North China.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted during 2012 and 2013 on a coastal saline wasteland in the Caofeidian Industrial Zone (39°01′54″N, 118°28′38″E), southeast of Tangshan city and northeast of the Bohai Bay, China. The study area has a temperate semi-humid monsoon climate with a mean annual precipitation of 607 mm, and most rainfall falls during June–September. Average evaporation is 1900 mm and seasonal winds and droughts are frequent in spring, autumn and winter. The soil was a sandy loam. The average soil texture in the 0–100 cm soil layer was sandy loam, with particle size distribution for <0.002, 0.002–0.05 and >0.05 mm of 0.45, 43.15 and 56.39%, respectively. The electrical conductivity (ECe), pH and sodium adsorption ratio (SAR) of the saturated soil extracts taken from the initial soil profile were in the ranges of 24.8–26.8 dS m^{-1}, 7.6–7.6 and 35.7–38.3 (mmol $L^{-1})^{0.5}$, respectively. The soil bulk density was 1.60–1.74 g cm^{-3} and the groundwater table was 0.8 m below the surface. Detailed information on the initial soil profile is shown in Table 1.

2.2. Plant management and experimental design

2.2.1. Soil preparation and plant management

The soil in the experimental area (54 m × 24 m) was first deep-plowed to a depth of 60 cm using an excavator on 10 May 2012. During 20–21 May 2012, the soil was removed to a depth of 60 cm and a 15-cm thick gravel layer was placed at the bottom. This was then covered with a 5-cm thick layer of sand and then 100-cm of native saline soil was placed above the sand (Fig. 1A), similar to a previous study (Sun et al., 2013). Two 110-cm diameter polyvinylchloride pipes were used to connect the gravel–sand layer with a drainage ditch. When the soil preparation had finished, the surface of the experimental soil was about 60 cm higher than the surrounding area. Several small drainage ditches were then dug around the experimental area to provide drainage for runoff. The experimental area was divided into 12 experimental treatment plots. The soil bulk density was 1.69–1.72 g cm^{-3} before the soil was deep-plowed and decreased to 1.48–1.52 g cm^{-3} after deep-plowing.

The experimental material was willow (*Salix babylonica* L.), a salt-tolerant plant with salt threshold values of 6–8 dS m^{-1} (Maas, 1986). The willows were transplanted on 24 May 2012. There were 144 plants in the whole experiment area, and the area was transplanted into five rows with 3 m between rows and 3-m intervals within rows. Each plant was transplanted into a hole bigger than the root ball, and then non-saline sandy soil was placed in the space between the root ball and the saline soil (Fig. 1A). A similar method was used in a previous study (Zhang et al., 2013). After all willows transplanted, all plants were fixed by wooden poles (length of about 1.4 m and stem diameter of 4–6 cm, four poles per willow) in order to against the wind. The experiment lasted from 24 May 2012 to the end of 2013. The survival rate, plant height, stem diameters and average crown diameters were measured simultaneously on 25 October 2013. An automatic weather station was installed on 23 May 2012 to monitor the rainfall, temperature, humidity, and wind speed and direction.

2.2.2. Experiment design

Three mulch treatments were set up to determine the optimal cover material for willow growth on this coastal saline soil: control treatment without mulch (C1), black shading net (C2) and straw (C3) mulches. Each treatment was replicated four times in a completely randomized block design and each plot was 9 m × 12 m in size. With salt leaching, weeds grew naturally in the C1 treatment plots and were not controlled by human activity in both growing seasons. Black shading net was chosen as mulch material because it is easy to purchase in the market and simple to lay on the soil surface; and allows rainfall pass through the material into soil. Two layers of black shading net (light intensity was reduced by 90%) covered the C2 treatment plots. Rice straw at 12,000 kg ha^{-1} was used in the C3 treatment plots, and was easy to get from the surrounding area at a low price. During two growing years, the weeds were regular weeded out from both C2 and C3 treatment plots. Irrigation water was taken from a 300-m deep motor-pumped well with a mean electrical conductivity (EC) of 0.63 dS m^{-1}, mean pH of 8.2 and SAR of 3.8 (mmol $L^{-1})^{0.5}$.

2.2.3. Irrigation

After willows were transplanted (24 May 2012), all experiment zones were uniformly irrigated with a high intensity of drip irrigation without mulching in the first 5 d to rapidly wet the whole soil

Table 1
The physical properties of soil, electrical conductivity of the saturated paste extracts (ECe), SAR and pH values of the initial soil profile.

Soil layers (cm)	Soil mechanical composition (%)			Soil texture	Soil bulk density (g cm^{-3})	ECe (dS m^{-1})	SAR (mmol $L^{-1})^{0.5}$	pH
	<0.002 mm	0.002–0.05 mm	0.05–2.0 mm					
0–10	0.25	40.90	58.85	Sandy loam	1.74	26.0	37.2	7.6
10–20	0.51	42.67	56.82	Sandy loam	1.74	26.1	37.4	7.6
20–30	0.42	44.70	54.89	Sandy loam	1.69	26.8	38.3	7.6
30–40	0.45	47.44	52.11	Sandy loam	1.70	26.3	37.7	7.6
40–60	0.36	42.46	57.18	Sandy loam	1.69	24.8	35.7	7.6
60–80	0.49	41.39	58.12	Sandy loam	1.68	26.7	38.3	7.6
80–100	0.60	45.10	54.31	Sandy loam	1.60	26.3	37.7	7.6
Average	0.45	43.15	56.39	Sandy loam	1.69	26.1	37.4	7.6