

# Salt leaching of heavy coastal saline silty soil by controlling the soil matrix potential

XIUPING WANG<sup>1</sup>, ZHIZHONG XUE<sup>1</sup>, XUELIN LU<sup>1</sup>, YAHUI LIU<sup>1</sup>,  
GUANGMING LIU<sup>2</sup>, ZHE WU<sup>1\*</sup>

<sup>1</sup>*Institute of Coastal Agriculture, Hebei Academy of Agriculture and Forestry Sciences, Tangshan Key Laboratory of Plant Salt-Tolerance Research, Tangshan, P.R. China*

<sup>2</sup>*Institute of Soil Science, Chinese Academy of Sciences, Beijing, P.R. China*

\*Corresponding author: wuzhe26@163.com

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**Abstract:** Techniques of drip irrigation are broadly applied for the reclamation of saline-alkali lands, during which effective management of water use to accelerate salt leaching is essential for crop production. In 2017, a field experiment with five treatments of soil matrix potential (SMP) levels of –5, –10, –15, –20, and –25 kPa was conducted in heavy saline silty soil land in Bohai Bay, China to study the effects of drip irrigation on salt leaching. The results showed that salt leaching was enhanced with increasing SMP, particularly under an SMP of –5 kPa within a 30 cm soil profile depth and 15 cm distance from the dripper, and the average electrical conductivity of saturated paste extracts (ECe) decreased from 13.8 to 1.52 dS/m. Water consumption increased with increasing SMP, but the yield of oil sunflower did not differ significantly between SMPs of –5 and –10 kPa. These findings indicated that a relatively high crop yield of oil sunflower and effective salt leaching can be achieved if the SMP can be controlled at –10 kPa in heavy saline silty soil.

**Keywords:** drip irrigation; oil sunflower; reclamation of saline soil; ridge cultivation; water control

China has approximately 100 million ha of saline-alkali land (LI *et al.* 2015). Improving this land type to make it suitable for agricultural production is important for food security (ZHEN 2014; ZHANG *et al.* 2017).

The formation of saline-alkali soil is characterized by a poor water status (KANG & WAN 2005) and remedial measures include methods that improve soil moisture conditions, such as washing and leaching out the salt to decrease its concentration. Other methods include the use of salt-tolerant plants, application of soil conditioner, and adoption of cultivation techniques like crop rotation, intercropping

and deep ploughing; all these methods could directly or indirectly affect the soil structure so that to improve the soil moisture conditions (YUAN *et al.* 2001; WANG *et al.* 2003; YAO *et al.* 2006). Drip irrigation to leach salt is the most widely used method; fresh or brackish water as an irrigation resource can be used to effectively decrease salt content and improve water-use efficiency (LI *et al.* 2015, 2016a, b).

In this research, drip irrigation was tested as a method for reclaiming the coastal saline-alkali land in Caofeidian, Tangshan, China, which consists primarily of heavy silt saline soil with a salt content of 1.2–3.4%. The area is largely barren, with scarcely

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Xiuping Wan and Zhizhong Xue are first co-authors.

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distributed salt-tolerant plants; only a few areas are used for aquatic cultivation or tourism. A comprehensive reclamation scheme was applied to improve the saline-alkali land, using drip irrigation, dam construction, ridge-ditch cultivation, tube laying and plastic film covering with the aim of quickly greening the heavy saline-alkali land.

Soil matric potential (SMP) is a measure of the water holding capacity of soil and it is a critical variable in crop yield, runoff, erosion, evapotranspiration and irrigation scheduling (KANG & WAN 2005). Controlling SMP can improve the efficiency of irrigation and encourage high yield production for different plants. For example, the optimal threshold for starting irrigation for cucumbers was reported to be between  $-15$  and  $-30$  kPa (SUOJALA-AHLFORS & SALO 2005), and  $-15$  kPa for alfalfa growth (SEN *et al.* 2017). SMP is also an important parameter for controlling water use in the reclamation of barren land (LI *et al.* 2015). Therefore, the effects of controlling SMP on water-use efficiency, crop yield production and reclamation of saline land were the foundations for the reclamation scheme in the coastal saline land.

In this research, different SMPs were used to control water regulation in drip irrigation for the production of oil sunflower, a salt-drought resistant and important oilseed crop in China. The variation of soil electrical conductivity of saturated paste extracts (ECe) and water-use efficiency were examined.

## MATERIAL AND METHODS

The preparation of an experiment began in February 2017 on heavy saline land in the Industrial Zone of Caofeidian District, Tangshan, China (north China,  $39.23^{\circ}\text{N}$ ,  $118.57^{\circ}\text{E}$ ). The average annual precipitation is approximately 600 mm and most rainfall occurs between June and September (LI *et al.* 2015). The soil is mainly a heavy saline silty soil with scattered salt and alkaline tolerant plants (*Suaeda* spp.) occupying less than 5% of the land coverage. The average soil texture in the 0–60 cm soil layer is silt, where 0.7% of the particles are smaller than  $2\text{ }\mu\text{m}$ , 87% of which are  $2\text{--}50\text{ }\mu\text{m}$  and 12% are larger than  $50\text{ }\mu\text{m}$ . The electrical conductivities of the saturated soil extracts taken from the initial soil profile ranged from 12.5 to 24.7 dS/m, and pH ranged from 7.5 to 7.7; the soil bulk density was  $1.46\text{--}1.75\text{ g/cm}^3$ . The groundwater table is 1.5–1.8 m below the ground surface.

**Plot treatment and irrigation.** Restoration engineering of the saline-alkali land was initiated in

autumn 2016, mainly consisting of the construction of levees, ditches, concealed pipes, crushed straw filling and installation of drip-irrigation equipment (Figure 1). A plot with an area of  $4 \times 4\text{ m}$  was prepared for ridge-ditching with a ridge of 40 cm width, 20 cm height, 80 cm intervals and a ditch depth of 15 cm. Each plot was set with four ridges and a drip tube was laid in each (Figure 1). Oil sunflower was sown on May 1 without fertilization and harvested on August 15, 2017. All plots were daily drip-irrigated with a quota of 6 mm for one week from April 30, using an auto-gravitational drip-irrigator controlled at an SMP of  $-5\text{ kPa}$ . Afterwards, all plots were subjected to different SMPs by controlling water levels until harvest. Irrigation water was taken from the Luan River.

**Experimental design.** Five SMPs were set up to determine the optimal soil moisture conditions for oil sunflower production. SMP at a depth of 20 cm below each emitter was maintained at  $-5\text{ kPa}$  (D1),  $-10\text{ kPa}$  (D2),  $-15\text{ kPa}$  (D3),  $-20\text{ kPa}$  (D4) or  $-25\text{ kPa}$  (D5) as five treatments with three replicates for each, set up in a random arrangement. SMP was measured using a vacuum gauge tensiometer that was located immediately under the emitter and buried at a depth of 20 cm.

Soil samples were collected at the beginning stage (May 10), seedling stage (June 1) and harvest stage (July 25), taken at depths of 0–10, 10–15, 15–20, 20–30, 30–40, 40–50 and 50–60 cm, and at a distance from the emitter of 0, 10, 20 and 30 cm. The ECe and

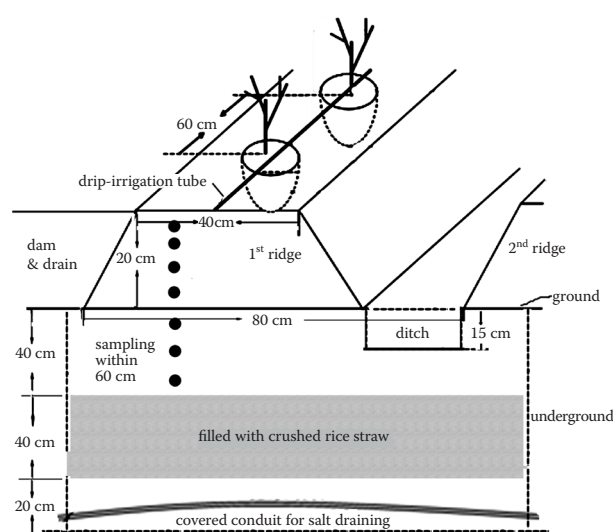


Figure 1. Experimental design and restoration engineering for saline-alkali land

pH of soil, survival ratio and yield of oil sunflower were recorded. All data gathered in the research were recorded in Microsoft Office Excel 2010. Analyses of variance (ANOVA) and Duncan's Multiple Range Test were carried out by SPSS statistical software (Ver. 16.0, 2009). All averages were calculated as a weighted average. Figures were created using the Origin software (Ver. 8.0, 2007).

## RESULTS AND DISCUSSION

The ECe in stage I was significantly lower than that in the other two stages, and variations in values in stages II and III tended to be uniform (Table 1). It is likely that pre-irrigation before germination led to the low ECe values in stage I and the increase in temperature and evaporation led to a slight increase of ECe values in stage III (CAMPBELL *et al.* 1949; BREVIK *et al.* 2004). However, ECe values rose with increasing soil depth, indicating a decrease in the salt-leaching effect. At a depth of 0–30 cm, ECe values in the three stages were all lower than those below 30 cm (Table 1), especially for the SMP of –5 kPa (D1). This finding indicated that the effective depth for drip irrigation to leach salt for oil sunflower growth was within 30 cm; however, this effective depth could be influenced by SMP, soil profile and land restoration methods according to some researches (SUN *et al.* 2012; CHEN *et al.* 2015). LI *et al.* (2016a, b) studied the reclamation of coastal saline soil by replacing the clay soil with sand, and found that drip irrigation could affect the ECe within a 60 cm depth under an SMP of –5 to –10 kPa, but the average ECe after salt

leaching was below 13.25 dS/m, which was higher than that recorded in this study (CHEN *et al.* 2015; LI *et al.* 2016a, b). This difference may be related to the comprehensive strategy of saline land reclamation used in this research, which enhanced water permeability through the filling of straw and salt-draining tubes, which could have been responsible for the lower average ECe. Thus, the optimal control range of SMP for water regulation should be adjusted in response to variation in land structures and cultivation methods (PHENE *et al.* 1989).

The ECe data in the three stages also showed a decrease with increasing SMP, indicating an increased effect of salt leaching; –5 kPa (D1) showed the best salt leaching, followed by –10 kPa (D2), while –25 kPa (D5) showed the least (Table 1). This result was consistent with previous findings (WANG *et al.* 2012; LI *et al.* 2015). Within a depth of 30 cm, the ECe of D1 treatment exhibited significant variation, where ECe was decreased by 89%, 71% and 55%, respectively, in the three stages compared to the control treatment. However, ECe did not significantly change in stages I, III and III in D3–D5.

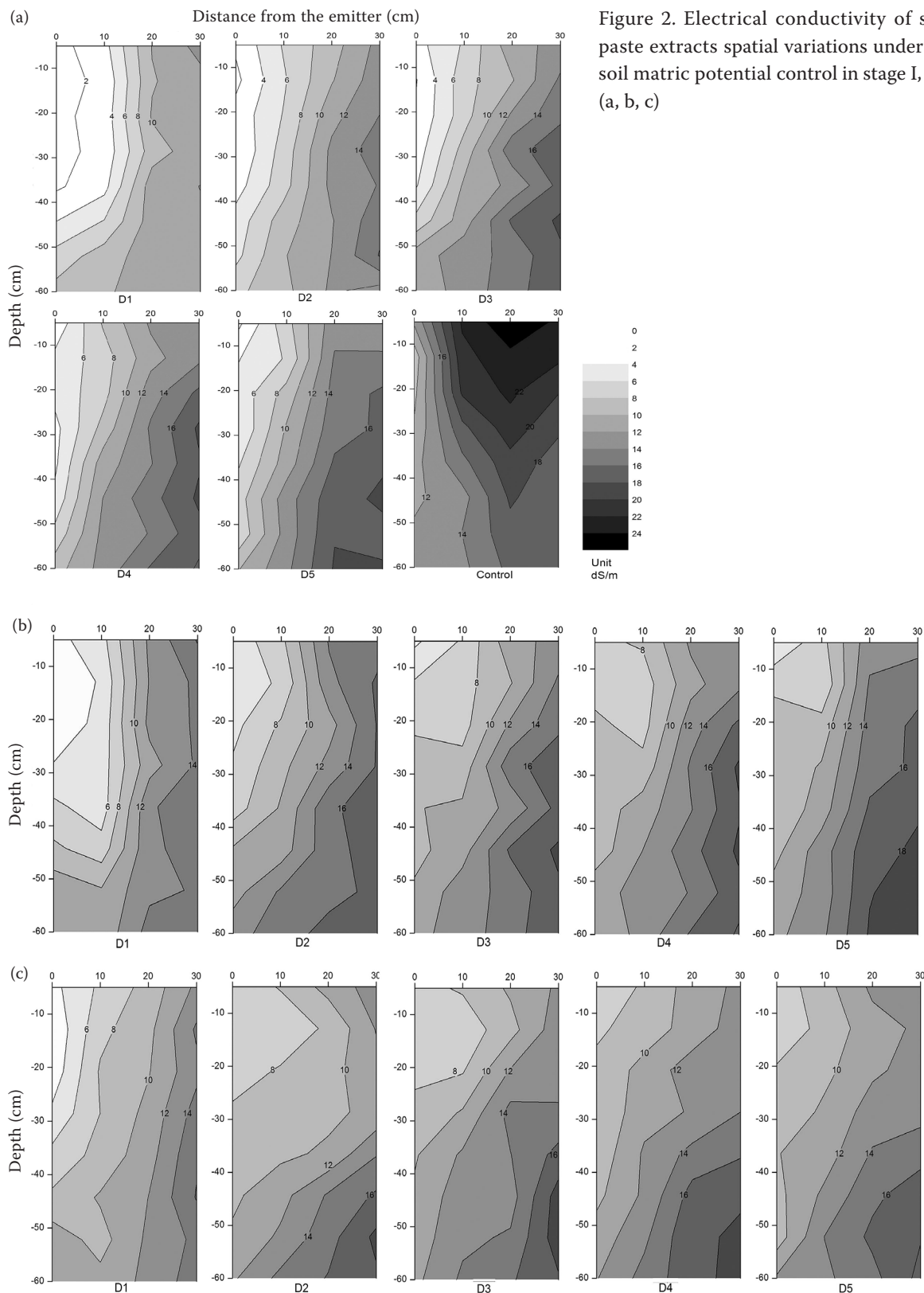
The average ECe within the overall tillage layer (60 cm) was higher than that within 30 cm, but the variation of ECe in stages II and III tended to be similar in the decrease of SMP, notably at a depth of 40–60 cm in D3–D5; ECe values varied from 10–12 dS/m (Table 1). This indicated that the salt-leaching effect with drip irrigation was confined to the increase of depth; this may have been due to the water control causing the water to penetrate beyond its depth limit (WANG *et al.* 2012).

Table 1. Electrical conductivity of the saturated paste extract (ECe, dS/m) distributions at different depth under different soil matrix potentials (SMPs)

Depth (cm)	Control	D1			D2			D3			D4			D5		
		I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
0–10	18.2	1.4	2.2	5.5	1.5	6.4	6.7	1.9	6.2	6.4	4.5	7.2	7.6	3.9	7.7	6.8
10–15	14.3	1.5	2.5	6.8	2.7	8.5	7.4	2.2	7.5	7.7	4.6	8.5	8.6	4.7	8.7	8.2
15–20	10.2	1.4	4.1	6.9	2.0	8.9	8.2	2.9	9.4	8.4	3.4	8.8	8.2	4.0	8.4	8.3
20–30	10.8	1.7	6.5	6.4	3.1	8.3	9.3	3.8	9.9	9.8	3.6	8.8	8.6	5.8	8.2	9.9
Mean 1	13.8	1.52	4.00	6.25	2.32	7.8	7.93	2.75	8.18	8.08	4.03	8.21	8.2	4.68	8.15	8.32
30–40	10.3	4.0	8.4	8.4	3.8	8.6	9.6	6.6	9.4	10.3	4.5	8.8	9.5	7.1	9.3	10.3
40–50	11.2	6.8	11.5	9.2	5.4	8.4	10.3	11.0	10.3	10.9	6.6	11.4	10.8	6.5	10.8	11.2
50–60	12.5	8.7	10.9	11.6	7.5	8.6	11.7	10.8	11.5	11.5	9.1	10.1	11.9	9.9	11.4	11.4
Mean 2	12.5	4.01	7.13	7.99	3.94	8.17	9.23	6.11	9.29	9.49	5.38	9.16	9.47	6.26	9.33	9.64

Mean 1 – average ECe within 0–30 cm depth; mean 2 – average ECe within 0–60 cm depth; control – untreated land; D1–D5 – different SMP treatments; I, II and III – data collected in different stages

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ECe increased with increasing distance to the emitter (Figure 2); this was visible by a reduced area of soil with a light colour indicating that the salt-leaching effects

declined when SMP increased. Compared to the control, the area within a depth of 30 cm and a distance of 15 cm from the emitter was very shallow, especially for

Table 2. Water consumption and the production of oil sunflower

	Water consumption (t/ha)	Emergence (%)	Survival ratio (%)	Yield (kg/ha)	AWE (t/kg)
D1	20 160 ± 78 <sup>a</sup>	100	99.6 ± 0.4 <sup>a</sup>	2 430 ± 112 <sup>a</sup>	8.30
D2	7 560 ± 63 <sup>b</sup>	100	98.7 ± 1.1 <sup>a</sup>	2 370 ± 102 <sup>a</sup>	3.11
D3	1 680 ± 21 <sup>c</sup>	100	90.3 ± 1 <sup>b</sup>	1 530 ± 48 <sup>b</sup>	0.69
D4	1 620 ± 19 <sup>c</sup>	100	88.5 ± 0.7 <sup>c</sup>	1 470 ± 42 <sup>bc</sup>	0.67
D5	1 260 ± 16 <sup>d</sup>	100	86.2 ± 1 <sup>c</sup>	1 425 ± 42 <sup>c</sup>	0.52

Data are presented by mean values ± standard deviations; different small letters in the same column show significant differences ( $P < 0.05$ ) between five soil matric potential treatments; AWE – average water production efficiency, calculated by the total water consumption divided by yield

D1 in stage I (Figure 2a), indicating that the effects of drip irrigation on salt leaching effectively worked within this area. The distribution of ECe values in stages II and III was similar to that of stage I (Figure 2b, c), although the shallow area was smaller than that in stage I.

These results were similar to previous reports that drip irrigation can utilize the gravitational action to transport salt in the soil to the lower layers through continuous droplets, which creates a relatively safe and low-salt space for the growth of crops in the upper soil layers (ZHANG *et al.* 2015; SUN *et al.* 2017). Other studies have found that the scope for effective salt leaching using drip irrigation in the coastal saline-alkali soil was 60 cm depth and 20 cm distance from the dripper (LI *et al.* 2016a, b). The effective space identified in this research was smaller than that published elsewhere and may be due to the crushed straw remedial technique which caused water in the upper layers to rapidly penetrate the silty soil layer to the packing layer and then drain out from the concealed tubes (ZHANG *et al.* 2009).

Water consumption rose sharply with an increase of SMP; D1 showed the highest water consumption and D5 the lowest (Table 2). The rate of seedling emergence was 100% because of pre-irrigation before germination, which ensured the consistency of experimental conditions. However, with the control of drip irrigation, the final survival rate and yield of oil sunflower differed significantly (Table 2). Considering the water consumption or water efficiency, D2 showed the highest production efficiency due to the similar yield in D1 and D2. Thus, the most economical drip-irrigation control for oil sunflower appears to be at an SMP of –10 kPa.

## CONCLUSION

Drip irrigation used to control SMPs can significantly reduce the salt content in coastal saline land.

The effects of drip irrigation on salt leaching increased with decreasing SMP and with the distance from the dripper. The most effective salt leaching occurred in the space within 30 cm depth and 15 cm from the dripper. The highest yield of oil sunflower was reached under an SMP of –5 kPa; however, the optimal SMP was –10 kPa if total water consumption and yield are considered together, although the average ECe within the whole tillage layer (60 cm) under an SMP of –5 and –10 kPa was almost the same in stage I.

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