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Soil salinity, sodicity and cotton yield parameters under different drip irrigation regimes during saline wasteland reclamation

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ABSTRACT

A field trial consisting of cotton grown employing a combination of ridge planting, mulching with film, and drip irrigation was laid out on a plot with severely saline soil in a typical inland arid area of Xinjiang. The effect of five levels of soil matric potential set up 0.2 m below the drip emitter, namely −5 kPa, −10 kPa, −15 kPa, −20 kPa, and −25 kPa, were studied in terms of changes in soil salinity (EC_e), sodicity (SAR), crop growth and yield components. Drip irrigation increased the leaching of soil salts and decreased the EC_e and SAR of each soil layer. Although the levels of soil salt rose again, in spring and winter, after irrigation was discontinued, the root zone (0–40 cm) remained less saline: the EC_e and SAR value under the soil matric potential of −5 kPa and −10 kPa were 63% and 49% of its values in 2009 respectively, before the land was brought under cultivation ($p \leq 0.05$), showing maximum leaching. The yield of cotton peaked at the soil matric potential of −5 kPa. The germination rate, which was the main factor that influenced the cotton yield, was 67% of that in non-saline soil in the first two years, and increased to 84% in the third year. After three years, the rate of germination in all the treatments exceeded 67%, and the highest rate (78%) was at −5 kPa; in the same treatment, boll yield was 4.40 g per plant. Except for germination rate and the yield of lint and seed, all the yield components increased significantly ($p \leq 0.05$) as EC_e and SAR decreased in 2010 and 2011. The correlation between soil salt (salinity and sodicity) and other components such as the number of cotton bolls per plant, the average weight of a boll, and lint percentage varied, probably because water supply was being regulated and, as a result, the physico-chemical properties of the soil kept changing constantly. Taking into account the extent of leaching, crop growth, and yield, the lower limit for the soil matric potential should be −5 kPa at 20 cm below the dripper for the first three years during reclamation to promote cotton cultivation on the saline-sodic soil of Xinjiang.

1. Introduction

Saline wasteland is found all over the world, and China is probably the country with the largest area of such salt-affected soils. Various types of saline soils occur in north-western, northern, and north-eastern China and in its coastal areas (Zhang et al., 1994; Li et al., 2005). The total area of salt-affected soils in Xinjiang – the largest in the country and accounting for one-third of the total – is 8.5×10^4 km². Because the region is land-locked, the process whereby salt residues are formed and accumulate in soil is intensive, and 32.6% of the total cultivated land in Xinjiang shows secondary soil salinization (Wang et al., 1993; Tian et al., 1999). Xinjiang is the main production area of cotton in China, but soil salinization has reduced cotton production drastically, resulting in losses amounting to about US$0.5 billion annually, or about 8% of the total output from farming (Yang et al., 2013; Hu et al., 2012). Therefore, measures are needed urgently to make the saline wasteland in Xinjiang suitable for cultivation.

The most common salt-affected soils in Xinjiang are saline soils of electric conductivity (EC_e) > 4 dS m^{-1} and pH < 8.5. Current methods of treating the soils mainly include using chemicals, growing plants that are adapted to such soils, and using sand as a soil amendment, but these methods are expensive and take a long time to give desired results (Qadir et al., 2001; Oster and Shainberg, 2001). Combining irrigation and drainage to remove the salt by leaching is widely practiced not only in China but also worldwide (Wang et al., 1993; Oster and Jayawardane, 1998). However, Xinjiang lies in an arid area: precipitation is scanty and evaporation is intense, which is why irrigation, when used inappropriately for leaching salt, often leads to

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Table 1
Salt and ion content of soil before start of the reclamation experiment in 2009 (initial values).

Soil depth (m)	Anion content (g/kg)			Cation content (g/kg)				Total dissolved solids (%)	EC_e (dS/m)	pH	SAR $[(mmol_c\ L^{-1})^{0.5}]$
	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+	Na^+				
0–0.4	0.27	9.18	0.41	0.19	0.11	0.010	4.90	1.51	45.3	7.42	41
0.4–0.8	0.32	4.33	0.27	0.08	0.09	0.007	3.58	0.87	28.6	7.64	23
0.8–1.2	0.34	3.50	0.25	0.06	0.07	0.007	2.92	0.71	15.4	7.68	30

secondary salinization. Moreover, the high concentration of sodium in relation to other cations in saline soils usually causes aggregate dispersion and poor soil infiltration rate, which may lead to waterlogging in cotton fields (Dodd et al., 2010). Therefore, the traditional surface irrigation for the purpose not only requires copious quantities of water and efficient drainage but also makes leaching less effective: in saline-sodic soils with soluble electrical conductivity (EC_e) of more than 4 dS/m and ESP (exchangeable sodium percentage) more than 15%, particles expand on contact with water, thereby decreasing the porosity and water conductivity of soil, resulting in a very low rate of soil infiltration (White, 2006).

The key to exploit saline soils is to maintain a relatively high soil osmotic potential around the root zone, to make the soil reasonably porous, and to make the soil moisture moving downward. Drip irrigation allows water to be applied more frequently, in small quantities, and over a long time, which maintains the soil matric potential (SMP) around the root zone at higher levels to compensate for the reduced soil permeability resulting from high soil salinity and sodicity, thereby facilitating the absorption of water by plant roots—which is why drip irrigation is widely used in improving saline and saline-sodic soils (Goldberg et al., 1976; Wang et al., 2007; Wan et al., 2007; Kang et al., 2012). Recently, by controlling soil moisture 20 cm below the drip emitter and combining drip irrigation with planting on ridges and mulching (Wang et al., 2012; Zhang et al., 2013), some progress has been made in improving saline and saline-sodic soils: Sun et al. (2012) demonstrated that keeping the SMP at −5 kPa reduced the salt level in coastal saline soils by 64% in two years; Zhang et al. (2014) reported that maintaining the SMP beneath the dripper at −15 kPa improved the physicochemical properties and nutrient status of a saline-sodic soil in Ningxia Xidatanbaijiang markedly; and Li et al. (2015) used brackish water for drip irrigation in a severely saline coastal land and found that more than 50% of the plants survived when the SMP was −5 kPa for the first year and −10 kPa in the second year. These studies mainly focused on the response of soil salinity, moisture and plant growth (Wang et al., 2014; Li et al., 2016). However, for the commercial cotton grown in Xinjiang, soil salinity and sodicity are two significant causes of the poor performance of commercial cotton. A number of studies have shown the sole effect of soil salinity or sodicity on cotton growth (Dodd, 2007; Zhang et al., 2017), whereas the combined effects especially on yield components under drip irrigation have received little attention. Hence, more investigations are needed on the variation of soil, growth and yield parameters of crops – especially cotton – grown on soils with high salinity and sodicity in Xinjiang under drip irrigation during the period of saline wasteland reclamation.

In view of the above, the present study examined the salt level (salinity and sodicity) at different soil layers in a severely saline soil by controlling the SMP thresholds 0.2 m below the drip emitter and also analyzed its effects on the yield parameters of cotton to provide a theoretical basis for the technology of regulating water through drip irrigation and to promote cotton cultivation in the saline soils of Xinjiang.

2. Materials and methods

2.1. Experimental site

The experimental site was in the Agricultural Comprehensive Development Zone, Karamay City, Xinjiang (45°22′–45°40′ N, 84°50′–85°20′ E), part of the lacustrine plain on the north-western rim of the Junggar basin and 20 km from Karamay city. The elevation is 370 m. The region enjoys a typical temperate continental arid desert climate. The average annual precipitation is 105.3 mm whereas the annual potential evaporation is as high as 1269 mm. The area is low lying, the depth of the water table is 2.0–3.0 m, and the soil is mostly the swamp soil from the lacustrine material and saline soil from sedimentary materials. The soil at the experimental site belongs to the chloride-sulfate saline soils category with 1.51% salt, which places the soil in the severely saline grade according to the classification standard for saline soils in China (Wang et al., 1993).

The ion composition and the EC_e of a saturated soil extract (taking the soil from three layers, namely 0–0.4, 0.4–0.8, and 0.8–1.2 m) were determined in 2009, before beginning the experiment. The results are shown in Table 1. For soil samples obtained at the 0.4 m depth at the experimental site, the EC_e and sodium adsorption ratio (SAR) were 45.3 dS/m and 41 $(mmol_c\ L^{-1})^{0.5}$ respectively, which far exceeded the threshold salinity and sodicity for cotton (Maas and Hoffman, 1977; Abrol and Bhumbla, 1979). The major cation in all the three layers was Na^+, which accounted for 32%–65% of the total salts; the main anion was Cl^-, which accounted for 20%–60% of the total. The pH of the entire profile (0–120 cm) at the experimental site varied from 7.4 to 7.7. The local source of irrigation was the reservoir from the western suburbs (the primary source being the Ertix River), and the total dissolved solids (TDS) of the water was 0.2 g/L. Groundwater in the test area was saline, with TDS as high as 31.2 g/L. The field capacity in 0–0.4 m and 0.4–0.8 m soil depths for the experimental soil were 0.31 and 0.29 $cm^3\ cm^{-3}$, respectively.

2.2. Experimental design and arrangement

2.2.1. Experimental design

The experiments spanned three cotton-growing seasons (2009, 2010, and 2011). The variety was Xinluzhong 26, a common variety in the area. The crop was drip irrigated and the SMP of soil 0.2 m directly underneath the drip emitter was set to different levels. The SMP levels that triggered irrigation follow: −5 kPa (S1), −10 kPa (S2), −15 kPa (S3), −20 kPa (S4), and −25 kPa (S5). The experiment was laid out in a completely randomized block design with three replications. A tensiometer was installed in the second replicate to observe the matric potential of soil at a point 20 cm below the drip emitter (Fig. 1).

2.2.2. Experimental arrangement

The management practices for the crop consisted of ridge planting, mulching with film, and drip irrigation. The ridges were 0.4 m wide, 0.15 m high, and 3.8 m long, spaced 0.8 m apart. Each ridge had its separate drip line and accommodated two rows of cotton, spaced 0.2 m apart, with plants within each row spaced 0.1 m apart. Each plot, occupying 30.4 m^2, consisted of 10 ridges with 10 drip lines (Fig. 1). The crops were sown on 31 May 2009, 10 May 2010, and 7 May 2011. Each