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Assessment of secondary soil salinity prevention and economic benefit under different drip line placement and irrigation regime in northwest China

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ABSTRACT

This study was conducted in order to evaluate the prevention of secondary soil salinity and the economic benefits of different drip line designs and irrigation regimes in northwest China. A three-year experiment (2008–2010) was carried out in the Xinjiang Autonomous Region of China and included five water treatments and two drip line designs. Irrigation was triggered by the soil matric potential (SMP) threshold at 20-cm soil depth, at −10, −20, −30, −40 and −50 kPa for single and double lateral irrigation placements after cotton was established. Soil salinity was significantly affected by the irrigation regime and drip line design. The single line design was more efficient at salt leaching and the areas of low electrical conductivity zones in the soil profile existing throughout the growth season were directly proportional to the SMP threshold. Moreover, the critical SMP value (CSV), which is the lowest SMP threshold that can prevent salinization of soil, was significantly related to soil depth and drip line placement. The lowest CSV of −43 kPa was obtained under single line design within the 0–40 cm soil depth interval. Seed cotton yields were positively correlated with the SMP thresholds and planting years; and the highest yield of 6.41 Mg/ha was achieved under the double lateral design for SMP of −20 kPa in 2010. Economic evaluation showed that total investment cost was around 10% lower for single compared to double lateral design, whereas double laterals produced more net income. From the combined point of economic return and soil salinization prevention, a SMP threshold of −20 kPa with double line design was found to be most appropriate for scheduling of cotton drip irrigation and agronomic practices in Xinjiang.

1. Introduction

Soil secondary salinization is an important worldwide environmental problem and poses a great threat to the development of sustainable agriculture, especially in arid and semi-arid regions (Jordán et al., 2003; Wang et al., 2008). In Xinjiang, an arid region in northwest China, increasing numbers of farmers are engaged in cotton cultivation due to its high profitability. However, due to inappropriate irrigation practice and fertilization, >30% of cultivated fields in Xinjiang suffer from secondary salinization (Li et al., 2009). Although modern drip irrigation systems are commonly found in the region, they may not consistently be managed efficiently, and thus the risk of secondary salinization for crop fields is increasing yearly (Fan et al., 2011). Improved irrigation system design and irrigation scheduling would be expected to alleviate this trend.

Available water, represented by the soil matric potential (SMP) is a critical variable in crop yield and irrigation scheduling (Phene et al., 1989). Irrigation schedules for various crops have been successfully established by means of SMP thresholds to trigger irrigation in different regions (Lynch and Tai, 1989; Rhoads and Stanley, 1973, 1974; Wang et al., 2007a; Wilson et al., 2001). Different crops require different SMPs to meet their growth demand (Kang et al., 2004; Kang and Wan, 2005; Yuan et al., 2001).By using SMP thresholds to trigger irrigation, even strongly saline wasteland could be reclaimed in Xinjiang (Wang et al., 2011, 2012). Although reclamation using SMP trigger strategy has been conducted and shown to be effective in different conditions, the method has not been evaluated for their potential in secondary soil salinization yet.

Drip line layout is an important factor influencing water and salt distribution in salt-affected soils. For this reason, drip line design should also be considered for prevention of soil secondary

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Table 1
Basic properties and EC_e of initial soil profile.

Soil layers (cm)	Soil mechanical composition (%)			Soil texture	Soil bulk density (g/cm^3)	EC_e(dS/m)	pH
	<0.002 mm	0.002–0.05 mm	0.05–2 mm				
0–40	1.44	76.49	22.08	Silt loam	1.42	4.00	7.81
40–60	0.99	85.97	13.04	Silt	1.45	4.14	7.73
60–90	1.20	86.89	11.91	Silt	1.43	6.70	7.63
90–120	0.88	99.12	0.00	Silt	1.52	5.52	8.00
120–180	0.63	96.43	2.95	Silt	1.51	2.40	8.03
180–210	0.38	99.62	0.00	Silt	1.47	2.46	7.91
210–240	0.17	99.83	0.00	Silt	1.77	6.38	7.81
240–270	0.56	92.63	6.81	Silt	1.70	10.10	7.76
270–300	1.58	98.42	0.00	Silt	1.71	9.34	7.74

EC_e, electrical conductivity of saturated soil extracts.

salinization. Some researchers have determined the optimal lateral spacing for drip-irrigated crops in different areas of the world; the evaluations were mainly based on crop yield, water use efficiency (WUE), evapotranspiration (ET) and economic benefit (Aujla et al., 2005; Camp et al., 1997; Cetin and Uygan, 2008; Lamm et al., 1997; Patel and Rajput, 2007; Rawitz et al., 1990). Optimal drip line spacing can differ for different regions and crops. Bozkurt et al. (2006) found for Adana in Turkey that the optimal lateral spacing for maize plants was 1.4 m according to crop yield and WUE; while in the northern Negev of Israel (Plaut et al., 1988), a row spacing of 0.5 m had higher cotton lint yield and higher rates of water withdrawal compared with 1.0 m. Investigation of the effect of drip line spacing on soil salinity is urgently needed particularly in Xinjiang area, China, where large areas of cropland are subject to soil secondary salinization.

In order to optimize drip irrigation of cotton in the Xinjiang region of China, we investigated different drip line spacings and scheduled irrigation by different SMP thresholds. Specific evaluation was made regarding: (1) soil salt spatial distribution over three years; (2) soil salt accumulation and temporal variation; and (3) cotton growth and economic benefits.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted during 2008–2010 at Karamay Farm (latitude: 45°22′N, longitude: 84°50′E, 350 m a.s.l.) located in the middle of the Jungger Basin in Xinjiang Province, northwest China. The region has a typical inland arid climate with annual precipitation of about 105 mm, mainly concentrated in June–August, and average annual evaporation and temperature of about 3545 mm and 8.0 °C, respectively (Wang et al., 2007b). The average depth to the groundwater table is about 2.5–3.0 m and the electrical conductivity of which is about 20 dS/m. Irrigation water with electrical conductivity of 0.3 dS/m is pumped from a reservoir in the west suburbs of Karamay. The field capacity and wilting point in the 0–30-cm soil layer for the experimental soil were 0.33 cm^3/cm^3 (−17 kPa) and 0.17 cm^3/cm^3 (−1.7 MPa), respectively. The EC_e (electrical conductivity of saturated-soil extract) in the 0–40 cm soil layer was 4.0 dS/m, making it moderately salt-affected (Table 1),but lower than 7.7 dS/m, the threshold of cotton salt tolerance (Maas and Hoffman, 1977). The soil texture, soil bulk density, EC_e and pH for each soil layer are shown in Table 1.

2.2. Experimental design

2.2.1. Drip line placement and irrigation water management

The experimental layout of drip-lateral and crop row spacing was the same as used by local farmers to grow cotton. The row spacing was 20 + 40 + 20 cm (Fig. 1).The rows were covered with 140-cm wide plastic film. For the single lateral method, one drip line was placed between in the middle of the four cotton rows (Fig. 1a); for double laterals, two drip lines were placed between the two outer cotton rows (Fig. 1b). For each placement there were five treatments according to the SMP, with the tensiometer used for all treatments to measure SMP placed at a depth of 20 cm directly under a drip emitter (Fig. 1a and b). The SMP treatments were: higher than −10, −20, −30, −40 and −50 kPa (S1–S5, respectively).

The five treatments for each lateral placement were replicated three times in 15 plots consisting of 24 rows of cotton planted straight on a flat field during 2008–2010. Each film sheet was 140 cm wide and 380 cm long. Each plot was therefore 840 × 380 cm and laid out in a split-plot design. The position and location of beds was the same throughout the three years.

Each treatment was an independent unit with its own gravity drip irrigation system. The system consisted of a tank (1000 L) and several drip tubes (six tubes per plot for the two lateral placements). We used a lateral with drippers every 0.2 m designed to emit 2.7 L/h under 10 m operating pressure. Under the actual operating pressure of 1.0 to 2.0 m, depending on the water level in the tank, actual discharge rates ranged from 0.85 to 1.21 L/h. Irrigation was applied as soon as SMP came close to the target value for each treatment and the amount of applied water was 10.4 mm each time (one tank of water per treatment), except during the seedling stage when more water was required. The tensiometers were observed three times daily (at 8:00, 12:00 and 18:00 h).

2.2.2. Plant management and measurement

Seeds of cotton (*Gossypium hirsutum* L.) hybrid ‘Xinluzhong No. 26′ were sown on 2 June 2008, 10 May 2009 and 8 May 2010 for the two lateral placements. Within a row, the seeds were sown 10 cm apart. Plastic film was put in place after sowing. Approximately 42 mm water (four tanks of water per treatment) was applied after sowing each year to all plots. Irrigation treatments were initiated on 17 June (15 d after seeding), 2 June (22 d after seeding) and 5 June (27 d after seeding) at which time the seedlings were thinned in 2008, 2009 and 2010, respectively. Consequently, irrigation was triggered only when target SMPs were reached.

A basal dose of 450 kg/ha of a compound fertilizer (monoammonium phosphate: 16% N, 35% P_2O_5 and 8% K_2O) was uniformly applied to the plots at the time of plowing for 2008–2010. The dressing was supplemented with urea (46% N), applied by mixing it with irrigation water at a concentration of 30% (w/w). Every time the irrigation was applied, 0.15 L urea solution was added per tank.