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Effects of different drip irrigation regimes on saline–sodic soil nutrients and cotton yield in an arid region of Northwest China

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ABSTRACT

A field experiment was conducted on a saline wasteland in Xinjiang, Northwest China, during 2008–2010 to evaluate the nutrient behavior and cotton yield during reclamation, applied by different drip irrigation regimes. The experiment included five treatments in which the soil matric potential (SMP) thresholds at 20 cm depth were controlled at −5, −10, −15, −20 and −25 kPa. The results indicated that both soil salinity and sodicity declined significantly at 0–40 cm depth and greater reductions were achieved at higher SMP thresholds (−5 and −10 kPa) than in other treatments. The distributions in soil inorganic nitrogen (N) and available phosphorus (P) and potassium (K) in the soil profile were mainly influenced by the point-source characteristic of drip irrigation, drip irrigation regime and fertilization mode. With the reclamation of both soil chemical and physical properties, there were dramatic increases in soil N, P and K concentration by the end of 2010. The soil nutrient concentrations in N, P and K were all proportional to the SMP thresholds, as higher SMP could result in greater reductions in soil salinity and sodicity. Since crop growth became more vigorous during reclamation, there was also a considerable increase (9.7–31.9%) in soil organic carbon by the end of 2010, and the concentrations were also proportional to SMP thresholds. The highest cotton yield was obtained in S1 (−5 kPa) treatment for both 2009 (2.87 Mg ha^{-1}) and 2010 (3.60 Mg ha^{-1}). Additionally, the soil C:N ratios were inversely proportional to the SMP thresholds in 2009 and 2010. Considering the soil reclamation efficiency, soil nutrient stocks and cotton yield, SMP thresholds of −5 and −10 kPa could be used as effective measures to trigger irrigation in the first 3 years of saline–sodic soil reclamation in Xinjiang, Northwest China.

1. Introduction

Soil salinity and sodicity, and their combination, are worldwide problems posing significant threats to the sustainable development of agriculture, especially in arid and semiarid regions (Oster et al., 1996; Qadir et al., 1997; Ma et al., 2012). In Xinjiang, a typical arid region of Northwest China, there are approximately 1.1×10^7 ha of saline wasteland, of which 7.27×10^6 ha are overly saline–sodic soils (Xi et al., 2005). Salinization and sodification of soils are serious land degradation issues in Xinjiang, where it is estimated that one-third of the arable land is affected by salinity and sodicity, which greatly reduces agricultural output in the area (Chen et al., 2010).

Under saline conditions, the reduced growth of crops is mainly attributed to the osmotic effect, which can reduce soil water potential and nutrient availability and uptake by plants (Al-Karaki, 1997; Elgharably, 2011). Sodicity increases clay dispersion and reduces aggregate stability, which results in declining air permeability, infiltration and hydraulic conductivity (Wong et al., 2010). This can seriously hinder root respiration, hence reducing plant growth and activity of soil organisms. However, the typical inland arid conditions and water resource shortages in Xinjiang increase the difficulty of reclaiming saline–sodic soil.

Drip irrigation with its characteristic of applying water at low discharge rate and high frequency over a long period of time can maintain constant and high soil water potential in the root zone and reduce salinity levels in soil water by leaching, particularly near the drip emitters (Keller and Bliesner, 1990; Wang et al., 2011). Among all the factors, drip irrigation scheduling is the most important in salt leaching efficiency. Previous studies have evaluated the impact of different levels of soil matric potential (SMP) to trigger drip irrigation in arid and semiarid regions (Dou et al., 2011; Sun et al., 2012; Wan et al., 2012; Wang et al., 2012). These studies have

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mainly focussed on soil salinity, sodicity and soil hydraulic properties, particularly with regard to soil salt movement and plant health. However, very few studies have explored soil nutrients during the reclamation process under drip irrigation, and hence understanding of nutrients in saline–sodic soil under drip irrigation is limited.

Soil structure and root activity decline with increasing sodicity in a saline–sodic soil, thus reducing nutrient mobilities and leading to nutrient deficiencies (Wong et al., 2010). Therefore, organic matter and mineral nutrients in saline–sodic soils are generally at low levels. Nutrient behavior in saline–sodic soils during the reclamation process needs to be evaluated because of the changes in soil chemical composition during and after reclamation. Especially under conditions of drip irrigation with mineral fertilizer input, the variations of soil nutrients during reclamation remain largely unknown.

The objectives of this study were (1) to investigate the effects of drip irrigation triggered by different SMP thresholds on distribution of soil mineral nutrients (inorganic N, available P and K); (2) to ascertain variation in soil organic carbon (SOC) and (3) to measure the effects of different SMP thresholds on soil carbon-to-nitrogen (C:N) ratio and seed cotton yield during 3 years of reclamation under drip irrigation.

2. Materials and methods

2.1. Experimental site

The field experiments were conducted during 2008–2010 on a saline wasteland at Karamay farm (latitude: 45°22′N and longitude: 84°50′E, 350 m a.s.l.), which is located in the middle of the Jungger Basin in the Xinjiang Province, Northwest China. The area has a typical inland arid climate with annual precipitation of about 105 mm, mainly concentrated in June–August, and average annual evaporation capacity and temperature of about 3545 mm and 8.0 °C, respectively (Wang et al., 2007). The average depth to groundwater is about 2.5–3.0 m, and the electrical conductivity of the groundwater (EC_{gw}) ranged between 30 and 52 dS m^{-1}. Irrigation water is pumped from the reservoir in the west suburbs of Karamay, with EC_{iw} of 0.3 dS m^{-1}. The soils in the area are chloride-sulfate-type saline–sodic soils, which are typically in Xinjiang (Wang et al., 1993; Xi et al., 2005). The climate and special geographical conditions make this region liable to accumulate salt on the soil surface. The EC_e (electrical conductivity of saturated paste) and the nutrient concentration of soil samples at different soil depths are reported in Tables 1 and 2.

2.2. Plot layout and irrigation water management

The experiment included five water treatments (S1–S5) based on the SMP, measured with tensiometers located at a depth of 20 cm beneath a dripper near the center of the plot for each treatment (Fig. 1), that determined when to irrigate or to trigger irrigation. The SMP thresholds that triggered irrigation were −5 (S1), −10 (S2), −15 (S3), −20 (S4) and −25 kPa (S5). These treatments were replicated three times in a completely randomized block design. Plots consisted of 20 rows of cotton planted on 10 raised (15 cm) beds during 2008–2010, spaced at 0.8 m. The beds were mulched with white polyethylene sheets after sowing. Each bed was 0.4 m wide and 3.8 m long (Fig. 1). The size of plots was 8.0 m × 3.8 m. The location of water treatments was the same during the 3 years of the experiments.

Each treatment was irrigated with an independent irrigation system. The system consisted of a water tank (1000 L) and 30 drip tubes (10 tubes per plot). A tank filled with irrigation water was placed at 1 m above the ground to maintain water pressure in the irrigation system within the range of 10–20 kPa. The drip tubes with 20 cm emitter intervals were placed at the center of each raised bed. To enable seedlings to emerge, 40 mm of water was applied to all treatments immediately after seeding. Cotton seedlings were thinned to the spacing described below, and irrigation treatments were initiated on 15 June (16 days after seeding), 2 June (23 days after seeding) and 5 June (26 days after seeding) in 2008, 2009 and 2010, respectively. Thereafter, 9.8 mm of water was applied when SMP reached the target values. The tensiometers were observed three times daily: 8:00, 12:00 and 18:00 h.

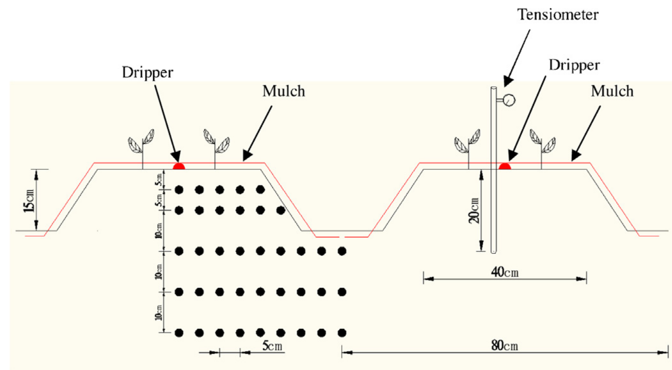

Fig. 1. Dimensions of beds and position of the tensiometer and soil sampling.

2.3. Plant and fertilizer management

Seeds of cotton were sown on 30 May 2008, 10 May 2009 and 8 May 2010 in double rows. The rows were 30 cm apart; within a row, the seeds were sown 10 cm apart. Soon after emergence, the plants were thinned to a spacing of 30 cm. Since the seeding date was relatively late in 2008, the emergence rate was low and the bolls did not grow well enough for harvest due to the low temperature in the late growing stages. Accordingly, there were no yield data for 2008. In 2009 and 2010, harvest was started on 2 October and 30 September and finished on 20 and 25 November, and the total harvest period lasted 49 and 57 days, respectively. The seed cotton was picked by hand at 4–7-day intervals, and the total weight per plot was checked at each harvest time.

Basal dose of 450 kg ha^{-1} of a compound fertilizer (16% N, 35% P_2O_5 and 8% K_2O) was uniformly applied to the plots at the time of plowing before seeding in 2008–2010. This fertilizer dose was supplemented with urea (46% N), applied with the irrigation water; 0.15 L of an 11 mg kg^{-1} urea solution was added to the irrigation tank every time irrigation was applied.

2.4. Soil sampling and chemistry analyses

In a saline soil, the soil salinity distributions clearly showed leaching near the drip lines, an area where the root density has been found to be maximum (Hanson et al., 2006; Hu et al., 2009). Since the low EC_e zones we found were usually within 40 cm (Wang et al., 2011), a soil depth interval of 0–40 cm was analyzed. Soil samples were obtained on soil cores from each plot with an auger (2.0 cm in diameter and 15 cm long) on 12 May 2008 (before seeding), 13 September 2008, 14 September 2009 and 13 September 2010 (after irrigation ended). The distances of sampling points to drip emitters were 0, 5, 10, 15, 20, 25, 30, 35 and 40 cm, and all sample depths were the same: 0–5, 5–10, 10–20, 20–30 and 30–40 cm (Fig. 1). All soil samples were air-dried and sieved through a 1 mm sieve.

The soluble salt estimates were based on extracts of saturated soil. The EC values were determined with a conductivity meter (DDS-11A, REX, Shanghai). Sodium adsorption ratio (SAR) was