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Root distribution and growth of cotton as affected by drip irrigation with saline water

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ABSTRACT

The objective of this field experiment was to study the effects of irrigation water salinity and N rate on cotton (*Gossypium hirsutum* L.) growth and root distribution. A field experiment was established with a 3 × 2 factorial, completely randomized block design: i.e. three levels of irrigation water salinity (fresh water, brackish water, or saline water) and two rates of nitrogen (N) application (0 and 360 kg N/ha). The results showed that cotton root biomass and distribution were significantly affected by water salinity and N fertilization, but not by N-salinity interaction. Between 85 and 90% of the root biomass was in the 0 to 20 cm soil depth. Root biomass was higher in the fresh water (FW, 0.35 dS/m) treatment than in the saline water (SW, 8.04 dS/m) treatment, but was not significantly different from that in the brackish water (BW, 4.61 dS/m) treatment. Nitrogen fertilizer increased total root biomass by 2 to 8% in the FW treatment, by 27 to 28% in the BW treatment and by 15 to 20% in the SW treatment. Most (83–95%) of the root length density was observed in the 0 to 60 cm soil depth. Average root length density, root diameter, and root volume were not affected by water salinity, but decreased sharply as N rate increased. In the unfertilized plot, average root length density, root surface area, and root volume were all higher in the FW treatment than in either the BW or the SW treatments. In the fertilized plot, average root length density, root surface area and root volume were significantly higher in the BW and SW treatments than in the FW treatment. The root/shoot ratio increased significantly as irrigation water salinity increased. Application of N fertilizer increased N uptake, yield, and irrigation water use efficiency. However, saline water irrigation had a negative effect on N uptake, yield, and irrigation water use efficiency; moreover, N application exacerbated the negative effect. These results suggest that saline water irrigation inhibited cotton root growth, resulting in a reduction in shoot growth, N uptake, yield, and water and N use efficiency. Excessive fertilizer application may result in an increase in salt damage when cotton is irrigated with saline water.

1. Introduction

A shortage of good-quality fresh water limits sustainable agricultural development in many arid and semi-arid regions. There is significant interest in using saline and brackish irrigation water to increase crop yields in these areas (Letey and Feng, 2007; Assouline et al., 2006). However, long-term application of either saline or brackish water increases the risk of soil salinization.

Soil salinity is one of the most important abiotic stresses limiting crop production worldwide (Koyro, 2006). Excess soil salt can reduce osmotic potentials to the point that crops cannot take up enough water (Khan et al., 2004). Therefore, it is essential to use good management practices when applying saline or brackish irrigation water. Drip irrigation has gained widespread popularity as an efficient irrigation method. Drip irrigation water is applied precisely and uniformly to meet crop requirements at each growth stage. The benefits include a reduction in subsurface drainage, better control of soil salinity, an improvement in water and nutrient use efficiency, and an increase in yield (Assouline et al., 2006; Hanson and Hopmans, 2008; Hou et al., 2007).

Agricultural crops absorb almost all water and nutrients through the root system. Thus, roots play an important role in crop growth and yield formation (Liang et al., 2000). Crop yield is closely related to root development. A well-developed root system is essential for obtaining high crop yield. Root growth and development are significantly influenced by soil conditions such as fertility and moisture (Qu et al., 2003). Research shows that when salt is non-uniformly distributed in the soil profile, root systems adjust by taking up a

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greater proportion of water and nutrients from parts of the soil profile with low salinity (Dong et al., 2008, 2010; Ortega-Galisteo et al., 2012). Information about the distribution of roots in salt-affected soil has important implications related to crop management.

Previous studies have reported the adverse effects of salt on the physical and chemical properties of soils and on the growth and yield of plants (Liang et al., 2003; Kahlown and Azam, 2003). Most studies indicate that crop biomass and yield both decline as soil salinity increases (Chen et al., 2010; Esmaili et al., 2008; Zhang et al., 2012). Some studies indicate that N application may reduce the adverse effects of salinity on plants (Ahmad and Jabeen, 2009; Albassam, 2001). One reason is that N generally promotes root growth (Proffitt et al., 1985). Nitrogen application significantly increased the growth and N uptake of cotton irrigated with either fresh or brackish water (Hou et al., 2010). However, the same study indicated that N fertilizer had little effect on cotton irrigated with saline water. The main reason for this observation is that saline water inhibited N uptake. Plant responses to salinity and nutrients have been thoroughly researched and frequently reviewed. The effects of either salinity or N fertilizer on cotton growth, yield, and N use efficiency have long been recognized. However, less is known about the interactive effects of irrigation water salinity and N application rate on root distribution and cotton growth under drip irrigation conditions.

The objectives of the work were to evaluate the effects of saline irrigation water, N rate on (1) the spatial distribution of cotton roots and (2) cotton growth, N uptake, and yield. We also determined both irrigation water use efficiency (IWUE) and apparent nitrogen recovery (ANR). The information obtained from this study will be helpful for evaluating the potential of saline irrigation water in arid and semi-arid areas from an environmental standpoint.

2. Materials and methods

2.1. Site description

This field experiment began in 2011 and 2012 cotton growing seasons at an agricultural experiment station near Shihezi University, Xinjiang Province, China (44°18′N, 86°02′E, 450 meters above sea level (masl)). Shihezi is a large oasis in northwest Xinjiang Province. About two-thirds of the region's cultivated land is used for cotton production. The region is classified as a temperate arid zone with a continental climate. The soil at the site is an alluvial, gray desert soil. The mean annual temperature in this region is 7.0 °C with 168–171 annual frost-free days. The mean annual precipitation is 210 mm. Mean annual potential evaporation is 1660 mm. The groundwater table is about 6 m below the soil surface.

2.2. Experimental design

The study consisted of a 3 × 2 factorial design with three irrigation water salinities and two N application rates. An irrigation experiment had been conducted at the study site for two years (2009–2010) before the start of this experiment. The irrigation water salinity and nitrogen fertilizer application rate were the same in all plots both years. The electrical conductivity (EC) of the irrigation water was 0.35, 4.61, or 8.04 dS/m. These treatments will be referred to as fresh water (FW), brackish water (BW) and saline water (SW), respectively, throughout the rest of the paper. The fresh water was obtained from a local well. Two water supply pools were built to prepare water for the BW and SW treatments. Each pool was equipped with an independent drip irrigation system, including one pump, one filter, and one pressure gauge. Water in the 4.61 and 8.04 dS/m treatments was produced by adding both NaCl and $CaCl_2$ (a mass ratio of 1:1) to fresh water (van Hoorn et al., 2001). Selected properties of the irrigation water are shown in Table 1. The N application rates were 0 and 360 kg N/ha, (abbreviated as N0 and N360, respectively). The 360 kg N/ha rate is commonly used by local farmers.

The six treatments were replicated three times in a randomized complete factorial block design. Each plot was mulched with one sheet of transparent polyethylene film (1.2 m wide and 16 m long). The plastic film was held in place by burying the edges with soil. Two drip irrigation lines were installed under the plastic film. There was a 0.6 m wide bare strip between each plot.

Each plot had four rows of cotton plants. The cotton plants were sown at 10 cm intervals within each row. The plant population was 222,000 plants/ha. Cotton (*G. hirsutum* L. cv Xinluzao No. 52) was sown 25 April 2011 and on 15 April 2012. Water was applied by drip irrigation at a rate of 2.7 L/h per emitter. The emitters were 0.4 m apart. A flow meter was installed in each plot to control the irrigation amount. All plots were drip-irrigated with 30 mm fresh water at sowing to improve germination and seedling establishment. The plots were irrigated nine times (every 7 to 10 day) between June and August. During the 2011 cotton growing season, 450 mm of irrigation water was applied (rainfall amounts was 136 mm during cotton growing seasons). The 2012 growing season was drier (rainfall amounts was 82 mm during cotton growing seasons), so we applied 510 mm of irrigation water. These irrigation practices were similar to those used by local farmers. The plots were all irrigated on the same dates and with equal watering depths.

Nitrogen fertilizer (urea) was applied through the drip irrigation system. The fertilizer was applied in six equal amounts between 64 and 106 days after planting (DAP). The urea fertilizer solution was stored in a 15 L plastic container and pumped into the irrigation system. All plots were fertilized with 105 kg P_2O_5/ha and 60 kg K_2O/ha before sowing.

2.3. Sampling and measurement methods

Shoot and root biomass was determined when the plants reached the boll stage (20 August 2011 and 15 August 2012). The cotton plants were cut at the soil surface and partitioned into leaves, stems, and bolls. Root samples were collected in 20 cm increments between 0 and 100 cm. The root samples were washed with tap water on a 0.5 mm mesh screen. The roots were scanned with a flatbed image scanner (Epson Expression/STD 1600 scanner). The images were analyzed using WinRhizo commercial software (Regent Instruments, 2001) to determine root length, root length density, root average diameter, root surface area, and root volume. The leaves, stems, bolls, and roots were dried in an oven at 80 °C to a constant weight. The dry samples were weighed and then the root/shoot ratio was calculated. The dry samples were ground to pass through a 1 mm sieve, and then digested with concentrated H_2SO_4–H_2O_2 before elemental analysis. Nitrogen concentrations were measured in each sample using an Auto-Kjeldal Unit (B-339, Buchi Labortechnik AG, Switzerland). Each measurement was made in triplicate. The seed cotton was harvested by hand on September 16 and September 28 was and then weighed. The two amounts were summed to obtain the total yield.

The effect of N application rate on N use efficiency within each water salinity treatment was compared by calculating apparent N recovery (ANR) as follows:

(1)ANR (%) = (NF uptake − NC uptake)/NF × 100where NF uptake is the total N uptake (kg/ha) of cotton plants receiving N fertilizer; NC uptake is the total N uptake (kg/ha) of unfertilized cotton plants; and NF is the total amount of N fertilizer (kg/ha) applied to the crop (Good et al., 2004; Chen et al., 2010).

Irrigation water use efficiency (IWUE, kg/m^3) was calculated on the basis of seed cotton yield as follows: