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Effects of deficit irrigation and plant density on the growth, yield and fiber quality of irrigated cotton

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ABSTRACT

Deficit irrigation is a new strategy to increase water use efficiency of cotton in arid areas, but it is not clear if it interacts with plant density. The objective of this study was to determine the effects of deficit irrigation and plant density as well as their interaction on the growth, yield and fiber quality of irrigated cotton. Two field experiments were conducted at three sites in 2013 and one site from 2014 to 2015 in an arid area of Xinjiang. A randomized complete block design with three replicates was used to determine the effects of 6 irrigation regimes on seedcotton yield in the first experiment, while a split-plot design was used in the second experiment with the main plots assigned to irrigation regime (saturation, regular and deficit) and the subplots to plant density (high, medium and low) to examine cotton yield, fiber quality and water productivity as affected by plant density under deficit irrigation. Averaged across the three sites, drip irrigation ranging from 3650 to 4700 m^3/ha did not significantly affect cotton yield, but seedcotton yield under 3650 m^3/ha in S1 was 6.3% lower than that under 4000 m^3/ha. Thus, it is quite appropriate to regularly drip-irrigate at 4000 m^3/ha in the experimental area. Deficit irrigation at high plant density also maintained a relatively higher leaf area index (LAI) and net assimilation rate (NAR), particularly at late stages of plant growth and development, than saturation or regular irrigation. Plant density ranging from 18 to 24 plants/m^2 produced more seedcotton than 12 plants/m^2 under regular irrigation. Increasing irrigation to saturation levels had little effects on cotton yield regardless of plant density; saturation irrigation at high plant density even reduced cotton yield compared with regular irrigation at medium plant density. Under deficit irrigation, the high plant density produced 9.1-17% greater yield and 9.3-16.8% higher irrigation water productivity (IWP) than low or medium plant density, and comparable yield to medium or high plant density under regular irrigation. This high yield under deficit irrigation at high plant density was due to increased plant biomass occasioned by high plant population and improved harvest index. Deficit irrigation did not affect fiber quality in 2014, but reduced fiber length and increased fiber micronaire value in 2015. Conclusively, use of high plant density under deficit irrigation can be a promising alternative for water saving without compromising cotton yield under arid conditions.

1. Introduction

Currently the northwest inland is China's largest cotton-growing area. With abundant sunshine and large temperature difference between day and night, improved plant growth and development as well as favorable fiber yield and quality of cotton can be easily achieved with the help of plastic mulching in this area (Dai and Dong, 2014). Therefore, the area has been one of the most dominant cotton growing areas with high yield and fine quality in China. The northwest inland is typically an irrigated agriculture area with scarce rainfall. Although drip irrigation under plastic mulch has been widely adopted for cultivation of cotton and the water use efficiency (WUE) has been increased by 50% (Cao et al., 2012), water shortage has become a key challenge for irrigated agriculture (Zhou et al., 2012). To address this problem, the development and adoption of new water-saving agricultural practices are necessary for high yields with minimum water consumption.

Reduced water consumption in traditional irrigation scheme will lead to significant reduction in crop yields and fiber quality (Feng et al., 2011, 2014), as water stress results in premature senescence (Chen and Dong, 2016; Ibragimov et al., 2007), and reduced leaf area, dry matter accumulation, and the number of bolls and

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boll weight (Gerik et al., 1996; Wanjura et al., 2002; Dagdelen et al., 2009); over irrigation leads to excessive vegetative growth of cotton and results in high water losses and low water use efficiencies (WUE) (Yazar et al., 2002). The ideal irrigation should significantly reduce water consumption without sacrificing crop yield (Yang et al., 2015; Pereira et al., 2002). A recently adopted water-saving practice in arid areas is deficit irrigation (Unlü et al., 2011; Yang et al., 2015), which is defined as the application of water below full crop requirement for evapotranspiration (Oweis et al., 2011), thus it is an promising strategy to save water with little impact on the quantity and quality of the harvested yield (Kirda et al., 1999). Several studies have showed that deficit irrigation with 20 or 25% deviation from full irrigation level did not significantly affect cotton yield (Wanjura et al., 2002; Ertek and Kanber, 2003; Dagdelen et al., 2009; Karam et al., 2006; Kang et al., 2012), while some others showed that a 25% deviation decreased yield and fiber quality (Karam et al., 2006; Dagdelen et al., 2009; Unlü et al., 2011). A number of studies also indicated that drip irrigation of cotton at 70–80% of full irrigation had significant benefits in terms of saved irrigation water and high IWUE or IWP (Dagdelen et al., 2009; Unlü et al., 2011; Yang et al., 2015), although deficit irrigation may cause slight to moderate yield or quality reduction (Dagdelen et al., 2009; Unlü et al., 2011; Li and Lascanob, 2011; Yang et al., 2015).

Yield and benefits of deficit irrigation are dependent on good crop management (Rao et al., 2016); only appropriate use of deficit irrigation can achieve favorable yield and benefits (Karam et al., 2006). Effects of deficit irrigation on yield, quality and benefits of cotton may be influenced by a number of agronomic factors (Rao et al., 2016). Interaction effects of deficit irrigation with nitrogen (Stamatiadis et al., 2016; Singh et al., 2010; Li and Lascanob, 2011), plant growth regulators (Singh et al., 2010) or cotton cultivars (Papastylianou and Argyrokastritis, 2014) on seed cotton yield and water productivity have been well documented. Interaction effects of deficit irrigation and plant density on yield and quality of cotton, however, have not been reported particularly under plastic mulching conditions. Little is yet known of the impact of plant density on yield and quality of cotton under deficit irrigation. The growth and development of individual cotton plants will be reduced to some degree under deficit irrigation, and total biomass per ground area and lint yield decreased accordingly (DeTar, 2008; Ko and Piccinni, 2009). Thus we assumed that increased plant density may increase total biomass and compensate for the yield loss due to water stress under deficit irrigation. Our objective was to determine the effects of irrigation regime and plant density on the growth, yield, yield components and fiber traits of cotton under field conditions, with a focus on cotton yield, fiber quality and water use efficiency as affected by plant density under deficit irrigation.

2. Materials and methods

2.1. Experimental sites and cultivars

Two field experiments were conducted at southern Tumushuke city (39°51′N, 79°3′E), Xinjiang, China, during the growing seasons of 2013 and 2014–2015, respectively. The experimental area is in the warm-temperate arid zone with a continental climate. Based on 53-year (1963–2015) meteorological data for the area, the average annual sunshine duration is 4400 h with 225 d of frost-free crop growth season. Daily average temperature steadily above 10 °C starts in late March and ends in late October with a period of 210 d. Relative humidity during summer months is 40–50%, with an annual precipitation of 100.3 mm. Meteorological data from a nearby meteorological station showed that from April to October in 2013, 2014 and 2015, the mean temperature (°C) was 20.6, 19.8 and 21.1; the relative humidity (%) was 44, 40 and 49 and precipitation (mm) was 138.4, 165.3 and 55.2, respectively.

The first experiment was conducted in three sites approximately 0.5–1 km from each other, to ensure the similar environmental conditions among fields in 2013, while the second experiment was carried out in site 1 in 2014 and 2015. Soil fertility parameters for the three sites are presented in Table 1.

CRI 49, a dominant cotton cultivar in the local area, was used in both experiments.

2.2. Experimental design

The first experiment was conducted at three sites in 2013 to compare yield performance under different drip irrigation regimes (5050, 4700, 4350, 4000, 3650, 3300 and 2950 m^3/ha). For each site, treatments were arranged into a randomized complete block design with three replications. Each plot was 60 m^2 and contained 6 rows with each row being 13.3 m long.

A split-plot design with three replications was used for the second experiment in site 1 (S1) in 2014 and 2015. The main plots were plant densities of high (24 plants/m^2), medium (18 plants/m^2) and low (12 plants/m^2), while irrigation levels (4800, 4000 and 3200 m^3/ha, hereafter referred to as saturation, regular, and deficit irrigation based on results of the first experiment) were assigned to the subplots. Each subplot was 60 m^2 and contained 6 rows with each row being 13.3 m long.

Field plot was flood-irrigated with 2250 m^3/ha water each 15–20 d before sowing; within-season irrigation was applied through a surface drip irrigation system under plastic mulching according to Yang et al. (2015) and Wang et al. (2014). Each treatment was supplied with an independent irrigation system consisting of a water tank and drip tubes. A tank filled with irrigation water was placed 1 m above the ground to maintain enough water pressure. Three drip tapes were placed in each sub plot with each drip tape responsible for two rows of cotton. Drip irrigation started in mid June and ended in late August or early September for a total of 10 times in both experiments. Because precipitation in 2015 was 110 mm less than that in 2014, the actual irrigation regime in 2015 was adjusted with 10% increase for each treatment relative to that in 2015.

2.3. Field management

Cotton (CRI 49) was sown on 14–17th April and harvested in late-September of 2013–2015. About 80% ground surface of each plot was mulched with plastic films during the entire growing season.

The experimental plot was cultivated and fertilized in accordance with local guidance to ensure full seedling establishment and normal plant growth & development. Each plot was fertilized with 750 kg/ha of compound fertilizer containing 15% N, 12% P_2O_5 and 15% K_2O as base fertilizer before sowing. Additional 825 kg/ha of urea (46% N) and 300 kg/ha of K_2PO_4 were applied through drip irrigation during the growing seasons according to local recommendations.

2.4. Data collection

Data were collected for seedcotton yield in the first experiment and for plant height, stem diameter, leaf area, net photosynthetic (Pn) rate, net assimilation rate (NAR), biological yield, harvest index, lint yield, yield components, fiber parameters and irrigation water productivity (IWP) in the second experiment. The Pn rate was measured on the fourth main-stem leaf at peak flowering, which was conducted between 10:00 and 12:00 on cloudless days when ambient photosynthetic photon flux density exceeded

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