Field Crops Research 219 (2018) 169–179

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Coupling effects of water and fertilizer on yield, water and fertilizer use efficiency of drip-fertigated cotton in northern Xinjiang, China

Haidong Wang[a], Lifeng Wu[b], Minghui Cheng[a], Junliang Fan[a,*], Fucang Zhang[a,*], Yufeng Zou[a], Henry Wai Chau[c], Zhijian Gao[d], Xiukang Wang[e]

[a] *Key Laboratory of Agricultural Soil and Water Engineering in Arid and Semiarid Areas of the Ministry of Education, Northwest A&F University, Yangling, Shaanxi 712100, China*
[b] *School of Hydraulic and Ecological Engineering, Nanchang Institute of Technology, Nanchang, Jiangxi 330099, China*
[c] *Department of Soil and Physical Sciences, Faculty of Agriculture and Life Science, Lincoln University, Lincoln, Canterbury 7647, New Zealand*
[d] *Institute of Irrigation and Water Conservancy and Soil and Fertilizer, Xinjiang Academy of Agricultural Reclamation, Shihezi, Xinjiang 832000, China*
[e] *College of Life Science, Yan'an University, Yan'an, Shaanxi 716000, China*

ARTICLE INFO

Keywords:
Drip fertigation
Seed cotton yield
Economic benefits
Water use efficiency
Partial factor productivity

ABSTRACT

Xinjiang is the main cotton-growing region in China, but the shortage of water resources and the low utilization of fertilizers have restricted its agricultural development. Field experiments were conducted during 2012–2014 to investigate the coupling effects of different amounts of water and fertilizers on seed cotton yield, water and fertilizer use efficiency as well as economic benefits in northern Xinjiang of Northwest China. The optimum combinations of water and fertilizer inputs were determined for both single-objective and multi-objective optimizations through the least squares method and multiple regression analysis. The main plots comprised of five N-P_2O_5-K_2O fertilization levels (150-60-30, 200-80-40, 250-100-50, 300-120-60 and 350-140-70 kg ha^{-1}), which were designated as $F_{0.6}$, $F_{0.8}$, $F_{1.0}$, $F_{1.2}$ and $F_{1.4}$, respectively. Three drip irrigation levels, designated as full irrigation (1.0 ETc, ETc is the crop evapotranspiration), medium irrigation (0.8 ETc) and low irrigation (0.6 ETc), were assigned as the sub–plots. For the same fertilization level, the results revealed that leaf area index (LAI), dry matter accumulation, seed cotton yield, partial factor productivity (PFP) and the economic benefits increased with increasing irrigation water. These parameters reached their maximum values at the irrigation amount of 1.0 ETc. At the same irrigation level, the LAI, dry matter accumulation, seed cotton yield and water use efficiency (WUE) first increased and then decreased as the amount of fertilizers increased. These parameters were maximized in 2012 and 2014 when 300-120-60 kg ha^{-1} of fertilizers (N-P_2O_5-K_2O) was applied. A low level of irrigation was not conducive to the functioning of fertilizers. The WUE was low, but the seed cotton yield and economic benefits were obviously higher under the full irrigation level. Therefore, based on the results of this study, full irrigation along with a fertilizer rate of 300-120-60 kg ha^{-1} (N-P_2O_5-K_2O) should be considered as the best fertigation strategy for both high seed cotton yield and economic benefits. By establishing a multi-objective optimization model using binary quadratic regression analysis, it was concluded that the seed cotton yield, economic benefits and water use efficiency reached ≥90% of their maximum values simultaneously when the irrigation interval was 362.3–462.5 mm and the fertilizer (N-P_2O_5-K_2O) interval was 212.5-85-42.5 to 367.5-147-73.5 kg ha^{-1}. The obtained optimum combinations of water and fertilizer can provide a scientific basis for irrigation and fertilization optimization and management in northern Xinjiang of Northwest China and other regions with similar environments.

1. Introduction

Xinjiang is located in the arid and semi-arid regions of China. The climate is dry and the effective precipitation is generally the lowest during the growing season of crops. With abundant sunshine and large difference in temperature between day and night, it is currently the most dominant cotton-growing region in China (Zhang et al., 2016; Feng et al., 2017), but the shortage of water resources and the low utilization of fertilizers have restricted the sustainable development of agriculture in Xinjiang. However, drip irrigation combined with the use of plastic mulching can localize water and fertilizer through the emitter to the crop root, resulting in improved ground temperature and

* Corresponding authors at: College of Water Resources and Architectural Engineering, Northwest A&F University, Yangling, Shaanxi 712100, China.
E-mail addresses: nwwfjl@nwsuaf.edu.cn (J. Fan), zhangfc@nwsuaf.edu.cn (F. Zhang).

https://doi.org/10.1016/j.fcr.2018.02.002
Received 10 December 2017; Received in revised form 3 February 2018; Accepted 4 February 2018
0378-4290/

reduction in the surface runoff and evaporation among the plants (Wang et al., 2015). In addition to crop yield and quality, water and fertilizer use efficiency can also be significantly improved (Wu et al., 2014; Xing et al., 2015b).

Water is essential for the growth of cotton, and suitable irrigation systems for cotton cultivation have been widely reported by many researchers. DeTar (2008) studied cotton growth and yield under various irrigation regimes and found that deficit irrigation in sandy soils greatly reduced cotton yield. Dağdelena et al. (2009) and Ünlü et al. (2011) revealed that full irrigation was appropriate in areas with no water shortage. Kang et al. (2012) found that a soil matric potential higher than −20 kPa at 20 cm can be used to schedule irrigation for cotton growth in northwestern China, and Papastylianou and Argyrokastritis (2014) concluded that 50% drip irrigation can save water while having no significant negative impact on fiber quality. Other researchers have also investigated the effects of irrigation methods and system uniformity on the growth, physiological characteristics and economic benefits of cotton. Rajak et al. (2006) revealed that, compared to furrow irrigation, the gross income from drip irrigation was greater, but the net profit per unit of applied water was lower. Tang et al. (2005) and Du et al. (2006, 2008) studied the mechanism underlying the physiological and yield of cotton responses to alternating partial root-zone irrigation. Tang indicated that alternate drip irrigation was an effective water-saving irrigation method in arid areas, whilst Du found that stomatal conductance under alternate drip irrigation was lower but water-use efficiency was higher than that under conventional drip irrigation. Additionally, Guan et al. (2013) found that lower system uniformity significantly reduced cotton plant height, leaf area index, nitrogen uptake and lint yield.

Fertilizer is another important factor that affects the growth of cotton (Read et al., 2006; Dong et al., 2012; Geng et al., 2016), which has been shown to produce the highest fiber yield, quality and N agronomic efficiency when the N application rate was 375 kg ha^{-1} (Chen et al., 2016). Leaf senescence can be delayed, and potassium use efficiency, yield and fiber quality can be improved when polymer-coated potassium chloride was mixed with K_2SO_4 at a ratio of 7:3 (Yang et al., 2017). Additionally, Yang et al. (2011, 2012) investigated the effect of fertilization frequency on cotton yield and biomass accumulation in the Yangtze River Valley of China and concluded that one-time fertilization at the first bloom stage reduced labor costs without reducing seed yield. Tsialtas et al. (2016) explored the effects of potassium fertilization on leaf physiology, fiber yield and quality of cotton under irrigated Mediterranean conditions and emphasized the necessity of an adequate supply of potassium fertilizer for optimal cotton physiology, growth, yield and quality.

Different levels of water and fertilizers have significant combined effects on yield, crop growth and water productivity (Oweis et al., 2011). The seed cotton yield has been shown to increase with an increase in N from 0 to 200 kg ha^{-1} under a high water supply. However, the seed cotton yield was found to first increase and then decrease with a lower water supply (Singh et al., 2010). Under fertigation, the water-use efficiency decreased with a reduction in the amount of applied N, and dense paired sowing resulted in higher seed cotton yield and WUE than normal sowing (Thind et al., 2008). Drip irrigation ranging from 365 to 470 mm did not significantly affect cotton yield, but high density under deficit irrigation can be a promising alternative for saving water without compromising cotton yield (Zhang et al., 2016). Dai et al. (2017) also found that the combination of high plant density, reduced N rate and extensive pruning ensured profitable cotton production in the Yellow River Valley. Furthermore, Tsadilas et al. (2012) studied the effects of irrigation and nitrogen fertilization on soil chemical properties and cotton yield and Min et al. (2014) explored the root distribution and growth of cotton in response to drip irrigation with saline water.

However, these previous studies mainly focused on the effects of single factors such as irrigation, fertilization and planting density or the combinations of water and nitrogen application on cotton growth. Furthermore, some of these studies were conducted as pot experiments under greenhouse conditions. Water and fertilizer application should be synchronous and unified organically, and suitable irrigation and nitrogen application as well as an appropriate phosphorus and potassium ratio will not only help ensure crop production but also avoid wasting water and fertilizer. It is often difficult to balance the multiple objectives of high efficiency, yields and economic benefits through a single treatment. Studies on determining the multi-objective optimization of water and fertilizer management based on cotton production, economic and environmental benefits remain scarce. Although China has been one of the largest cotton producers in the world, its per-capita production is low due to its large population and as such cotton still needs to be imported in large quantities. Thus, the objective of this paper was to determine an optimal water and fertilizer management strategy that can comprehensively improve the yield, economic benefits, water and fertilizer use efficiency of cotton by establishing the quantitative relationship between the inputs of water and fertilizers and these parameters. This paper aims to provide a scientific basis for the effective management of local irrigation and fertilization.

2. Materials and methods

2.1. Experimental site description

This field experiments were conducted during the cotton growing seasons in 2012, 2013 and 2014 at the Test Station of the Xinjiang Academy of Agricultural Reclamation Sciences (44°18′52″ N,85°58′50″ E) in Shihezi, Xinjiang Province, China. The region is classified as a temperate arid zone with a continental climate. The annual cumulative temperature greater than 10 °C is 3649 °C. The frost-free period is 168 d and the sunshine duration is 2770 h. During the cotton growing season, the long-term average annual rainfall is 121 mm, and the rainfall in 2012, 2013 and 2014 was 62 mm, 113 mm and 102 mm, respectively. The groundwater depth is below 15 m. The cultivated soil layer (0–40 cm) in the experimental area is sandy loam, with a soil bulk density of 1.51 g cm^{-3}, a field capacity of 32% (volumetric water content), a soil organic matter of 18 g kg^{-1}, a pH of 7.8, a total-N content of 0.95%, an alkali-hydrolyzable nitrogen of 79.76 mg kg^{-1}, an available phosphorus of 31.54 mg kg^{-1}and an available potassium of 154.22 mg kg^{-1}.

2.2. Experimental treatments and design

The experiments consisted of five levels of fertilization and three levels of drip irrigation. The five levels of N-P_2O_5-K_2O fertilizer (150-60-30, 200-80-40, 250-100-50, 300-120-60 and 350-140-70 kg ha^{-1} designated $F_{0.6}$, $F_{0.8}$, $F_{1.0}$, $F_{1.2}$ and $F_{1.4}$, respectively) were applied to the main plots. The proportion of N-P_2O_5-K_2O was 1:0.4:0.2, and the $F_{0.6}$, $F_{0.8}$, $F_{1.0}$, $F_{1.2}$ and $F_{1.4}$ treatments represented 60%, 80%, 100%, 120% and 140% of the locally applied fertilizer rate (250-100-50 kg ha^{-1} N-P_2O_5-K_2O), respectively. Three levels of drip irrigation, designated as full irrigation (1.0 ETc; ETc is the crop evapotranspiration), medium irrigation (0.8 ETc) and low irrigation (0.6 ETc), were assigned to the sub–plots. The fifteen treatments were replicated three times in a randomized complete factorial block design. Each field plot was 4.6 m wide and 15 m long.

A 16-mm-diameter inlaid, thin-walled, labyrinth drip irrigation pipe was used for irrigation. The average discharge of the emitters was 1.8 L h^{-1}. The interval between the emitters was 0.3 m. Water meters and ball valves were installed to control the amount of water applied to each plot.

Urea, ammonium dihydrogen phosphate and potassium chloride were used as fertilizers, which were applied to the fields at eight different times. Except for the early cotton growth, each fertilizer application occurred by drip irrigation during the middle of each irrigation