Agricultural Water Management 212 (2019) 252–261

Contents lists available at ScienceDirect

Agricultural Water Management

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

Impacts of lateral spacing on the spatial variations in water use and grain yield of spring wheat plants within different rows in the drip irrigation system

Zhaoyan Lv[a], Ming Diao[b], Weihua Li[b], Jian Cai[a,*], Qin Zhou[a], Xiao Wang[a], Tingbo Dai[a], Weixing Cao[a], Dong Jiang[a,b,*]

[a] *National Technology Innovation Center for Regional Wheat Production/Key Laboratory of Crop Physiology and Ecology in Southern China, Ministry of Agriculture/ National Engineering and Technology Center for Information Agriculture, Nanjing Agricultural University, PR China*
[b] *Agricultural College, Shihezi University, Shihezi, Xinjiang, PR China*

ARTICLE INFO

Keywords:
Drip irrigation
Drip tube to wheat row ratio
Spatial variation
Spring wheat
Yield

ABSTRACT

Xinjiang Uyghur Autonomous Region of China has seen the successful application of drip irrigation to wheat production to cope with the extreme shortage of fresh water resources. However, the cost is high with one drip tube serving only four rows of wheat plants in the current irrigation pattern. Here, performances of irrigation patterns differing in ratios of drip ***t***ube to plant ***r***ows (TR) were compared in a field experiment in the growth seasons of spring wheat in 2014 and 2015. Three ratios were set: one tube served four (TR4, as control), five (TR5) and six (TR6) rows of plants (row spacing: 15 cm), respectively. Variations in grain yield and water use efficiency (WUE) were observed between different wheat rows (R1, R2 and R3 indicated the 1st, 2nd and 3rd rows close to the drip tube, respectively). Grain yield declined in all the rows as the TR ratio increased, with more obvious yield decrease in R3 and R2 than in R1. The ratios of the yield decrease to the decrease in received irrigation water (RIW) in R3 and R2 were not proportionally lower relative to R1; the range of yield decrease was much smaller than the range of RIW decrease in R3 and R2. This was because the decreases in the leaf area index and in the relative water content in the flag leaf of plants were less than that in RIW in R3 and R2 relative to R1, and because of the compensation effect of the enhanced contribution of the redistributed dry matter stored in the vegetative organs before anthesis being translocated into the grains after anthesis in the plants of R3 and R2. This mechanism would be helpful for developing new and economical drip irrigation patterns for wheat production with a higher TR ratio.

1. Introduction

The shortage of fresh water resources has become a serious concern in the world, especially in the agricultural areas (Savary et al., 2005). Xinjiang Uyghur Autonomous Region of China, is a typical arid/semi-arid agricultural area with very limited fresh water resources (Sivamani et al., 2000), with an annual rainfall of only around 150 mm vs. annual evaporation of higher than 1700 mm (Deng et al., 2006). This scarce fresh water resources seriously affects wheat, the most important food crop in Xinjiang (Shen et al., 2013), over the whole season of its growth. The solution to this problem is reasonably to develop water saving irrigation systems.

Drip irrigation is one of the most water-saving irrigation systems, with very high water use efficiency (WUE) (Morison et al., 2008) and fertilizer use efficiency (Mansour, 2013). To date, drip irrigation systems have been well accepted in productions of fruits (Collins et al., 2010; El-Sayed and El-Hagarey, 2014) and other cash crops (Kirda et al., 2007), and the low-density and large-size crops such as cotton (Jaredr et al., 2008; Ning et al., 2015) and corn (Coelho and Or, 1999; Lamm and Trooien, 2003). However, an irrigation system that is both water-saving and fertilizer-saving is seldom applied to high-density and small-size crops such as wheat (Bozkurt et al., 2006), for which one of the major reasons is that the cost is high due to the use of more drip tubes in the much narrower space between the wheat rows. Is it possible to have one drip tube serve more than four rows of wheat, as is currently practiced in Xinjiang? However, this will increase the risk of

---

Abbreviations: TR, drip tube to plant rows; WUE, water use efficiency; RIW, received irrigation water; LS, lateral spacing; DMR, the amount dry matter accumulated before anthesis redistributed into grains after anthesis; DMR-R, the rate of DMR to grains; DMR-C, the contribution of DMR to grains

[*] Corresponding authors at: College of Agriculture, Nanjing Agricultural University, No. 1 Weigang Road, Nanjing 210095, PR China.
E-mail addresses: jiancai@njau.edu.cn (J. Cai), jiangd@njau.edu.cn (D. Jiang).

https://doi.org/10.1016/j.agwat.2018.09.015
Received 2 February 2018; Received in revised form 6 September 2018; Accepted 6 September 2018
0378-3774/

heterogeneity of plant growth and grain yield due to the uneven spatial distribution of both water and nutrition in soil of rows differently distant from the drip tube.

The evenness of water distribution in soil of the drip irrigation systems is highly dependent on the lateral spacing or strip width between the drip tubes, on drip irrigation strategies, such as irrigation frequency or interval between irrigations, water amount and pressure for each irrigation, and outlet design of the drip tube (Wang et al., 2006; Payero et al., 2008; Wang et al., 2013). Drip irrigation is a localized humid irrigation pattern in the form of point source or linear source (Du et al., 2008). Increasing lateral spacing will inevitably lead to a decrease in water supply in soil bulk distant from the drip tube (Chen et al., 2015), and excessive lateral spacing has been reported to reduce corn production in the Mediterranean region of Turkey (Bozkurt et al., 2006).

In addition to the spatial unevenness of soil water supply, the uneven water loss due to differential evapotranspiration of plants and soil bulk differently distant from the drip tube worsens the spatial unevenness of soil water status. Meanwhile, movement of the nutritional elements usually relies on the behavior of soil water status (Li et al., 2004). These will result in large variations in growth and yield performance within plants in different distances from the drip tube (Chen et al., 2015). This is one of the reasons why farmers grow only two rows of wheat plants on each side of the drip tube (one tube serving four rows of plants in total, or a ratio of tube to rows of four, TR4) in the current drip irrigation system for wheat in Xinjiang. Based on this TR4, the effects of different irrigation methods on growth and development, productivity and WUE of wheat plants have been investigated (Wang et al., 2006; Payero et al., 2008; Wang et al., 2013).

Nevertheless, it is necessary to develop economical patterns with a high TR ratio. However, as is mentioned above, the plants distant from the drip tube in the higher TR patterns receive much less water and produce much less grains than the plants adjacent to the drip tube (Chen et al., 2015). On the other hand, it is well-known that moderate water deficit benefits grain yield, because plants will manage with less water consumption (Kang et al., 2003). This raises the possibility that one drip tube serves more than four rows of wheat plants with a smaller range of yield loss of the plants distant from the drip tube. Thereafter, it is necessary to identify the relationships between wheat crop performance and the spatial availability of soil water as affected by the rows differentially distant from the drip tube in the wheat drip irrigation system with higher TR.

Dry matter accumulation is the base of grain yield in cereals (Fan et al., 2015). Moreover, the dry matter redistribution, namely those photo-assimilates being synthesized and stored in the vegetative organs before anthesis that can be redistributed to grains during filling, and play a very important role in maintaining grain yield stability in temporal cereal crops including wheat (Niu et al., 1998). The contribution of the redistributed dry matter to grain yield is greater in deficit irrigation than in conventional irrigation (Gallagher et al., 1976; Scott and Dennis, 1976). For instance, moderate water deficit improves redistribution of photosynthates from vegetative organs to grains, and increases the harvest index of wheat (Yang et al., 2001). Deficit irrigation at grain-filling stage stimulates the redistribution of dry matter accumulated before anthesis from vegetative organs to grains (Hocking, 1994; Plaut et al., 2004). This provides the possibility of reducing the variations in growth and yield performance between plant rows under high TR ratio drip irrigation system.

To test the irrigation patterns proposed above, we extended the current drip irrigation system for wheat from TR4 to TR5 and TR6, to observe the variations in growth and grain yield of plants between the rows differently distant from the drip tube as affected by varied soil water supply in a field experiment. The results would be significant in establishing lower-cost drip irrigation systems for crop production in areas with scarce fresh water resources.

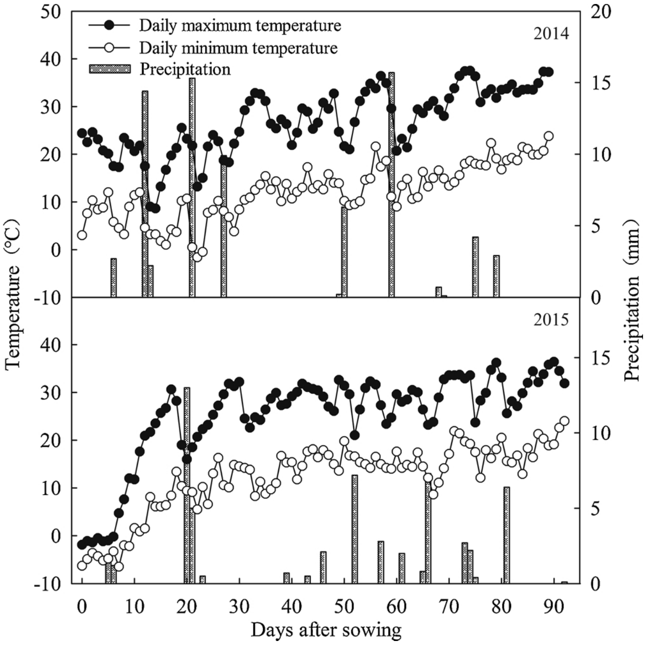

Fig. 1. The daily maximum and minimum air temperature, and daily precipitation over the spring wheat growth seasons in 2014 and 2015.

2. Materials and methods

2.1. Experimental design

The field experiment was conducted in the two growth seasons of spring wheat in 2014 and 2015 at the Agronomy Experiment Station of Shihezi University (44°27′N, 86°01′E) of Xinjiang Uyghur Autonomous Region, P. R. China. Locally released and widely planted spring wheat (*Triticum aestivum* L. cv Xinchun 6) was used. The daily maximum and minimum air temperature, and daily precipitation over the experimental period were shown in Fig. 1.

The physical and chemical properties of the soil profile (average of the two years) at the experimental site before sowing were shown in Table 1. The soil at the $0-20$ cm depth contained 65.8 mg kg^{-1} available nitrogen, 25.4 mg kg^{-1} Olsen-Pof and 145 mg kg^{-1} available potassium. The sowing dates were 2 April, 2014 and 27 March, 2015. The plot size was 3.6 m in width and 6.0 m in length. The seedling rate was ca. 5.5×10^6 ha^{-1} with a row spacing of 15 cm in both years. The experiment was a completely randomized block design with three replicates for each treatment. Three drip irrigation patterns with different ratios of drip ***T***ube to ***R***ows (TR) of wheat plants and corresponding differential drip ***L***ateral ***S***pacing (LS) or differential width strips were applied; i.e., one drip tube served four rows (TR4, LS = 60 cm), five rows (TR5, LS = 75 cm) and six rows (TR6, LS = 90 cm), respectively. The 1st, 2nd and 3rd rows close to the drip tube were named R1, R2 and R3, respectively, for investigation of the spatial variations in grain yield between different rows under different TR patterns. The schematic diagram of the TR patterns was shown in Fig. 2. The total irrigation water amount and total nitrogen rate were 4500 m^3 ha^{-1} and 300 kg ha^{-1} for all treatments, respectively. The timing and amount of each irrigation and of nitrogen fertilization followed previous studies and locally recommended protocols, as shown in Table 2 (Liu et al., 2013; Jin et al., 2014). In addition, a dose of 105 kg ha^{-1} P_2O_5 and K_2O was applied to the soil before sowing. The emitter discharge rate was 2.6 L h^{-1}. The Zadoks scale (Zadoks et al., 1974) was used to indicate the growth stages for each irrigation.