Agricultural Water Management 211 (2019) 59–69

Contents lists available at ScienceDirect

Agricultural Water Management

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

Optimized micro-sprinkling irrigation scheduling improves grain yield by increasing the uptake and utilization of water and nitrogen during grain filling in winter wheat

Jinpeng Li, Yunqi Wang, Meng Zhang, Yang Liu, Xuexin Xu, Gang Lin, Zhimin Wang, Youming Yang*, Yinghua Zhang*

College of Agronomy and Biotechnology, China Agricultural University, No. 2 Yuanmingyuan West Road, Beijing, 100193, China

A R T I C L E I N F O

Keywords:
Micro-sprinkling irrigation
Water and nitrogen use
Winter wheat
Yield

A B S T R A C T

The North China Plain (NCP) is the main wheat production area in China; however, irrigation water and nitrogen fertilizer use in this area is relatively inefficient, and must be optimized to attain higher yield and resource use efficiency for winter wheat. In this study, a four-year field experiment was conducted during the 2012–2016 growing seasons. Under quota irrigation conditions, an experiment with various micro-sprinkling frequencies (S2, irrigation at jointing and anthesis; S3, irrigation at jointing, booting and filling; and S4, irrigation at jointing, booting, anthesis and filling) was conducted in 2012–2014. In 2014–2016, different nitrogen application rates (150, 195, and 240 kg N ha^{-1}; denoted as S4N1, S4N2, and S4N3, respectively) under the S4 condition were tested. The local traditional flood irrigation pattern was designated as the control (CK) in 2012–2016. The grain yield, leaf area index of the population (LAI), flag leaf senescence during gain filling, accumulation and distribution of dry matter and nitrogen, and water and nitrogen use characteristics were investigated. The results showed that, no significant difference was observed in grain yield between the CK and S2, whereas S4 and S3 showed increased grain yields of 5.7–22.2% and 4.6–19.1%, respectively, compared with the CK. The increase of yield in micro-sprinkling treatments was mainly due to a significant increase in the 1000-grain weight. With increasing irrigation frequency, the LAI at the filling stage improved significantly; the flag leaf chlorophyll content decreased slowly; and the total dry matter accumulation, dry matter after anthesis, and its contribution to grain yield increased significantly. Meanwhile, the total water consumption of S4 (N2) decreased significantly, and the water use efficiency increased by 10.0–27.8% compared with the CK. In addition, micro-sprinkling irrigation with frequent application of a small amount of water with optimized nitrogen application (S4N2) yielded the highest nitrogen fertilizer use efficiency. Water consumption and nitrogen accumulation during grain filling were significantly increased in S4, which could explain the higher yield and resource use efficiency of S4. Overall, a suitable micro-sprinkling irrigation frequency (S4) and nitrogen application (195 kg N ha^{-1}) can achieve higher grain yields and resource use efficiencies in the NCP.

1. Introduction

The North China Plain (NCP) is the primary food-producing region in China, accounting for 60% of the national wheat production (Zhang et al., 2015). However, in this area, the annual rainfall is uneven and mainly concentrates in the summer maize season, while only 20–30% falls in the winter wheat growing season, which meets only 25–40% of winter wheat requirements (Liu et al., 2001). Thus, supplemental irrigation with groundwater is used to provide the water required for winter wheat production. However, overuse of groundwater for wheat production has resulted in a rapid decline in the groundwater table, threatening sustainable agricultural development in this region (Zhang et al., 2004,). With the development of water-saving agricultural techniques, the main irrigation pattern in this area involves two irrigations: one at jointing and one at anthesis, during the wheat growing season; the total amount of irrigation water applied is about 1500 m^3 ha^{-1} (Li et al., 2010; Wang et al., 2016). Nevertheless, problems related to groundwater overuse remain serious under this irrigation regime (Sun et al., 2015). Therefore, the development of an optimized irrigation regime is urgently required to further improve the grain yield and water use efficiency (WUE) of winter wheat in the NCP.

Surface irrigation is used widely in the NCP (Liu et al., 2013), which

* Corresponding authors.
E-mail addresses: ymyang@cau.edu.cn (Y. Yang), yhzhang@cau.edu.cn (Y. Zhang).

https://doi.org/10.1016/j.agwat.2018.09.047
Received 27 March 2018; Received in revised form 20 September 2018; Accepted 22 September 2018
Available online 01 October 2018

often involves a one-time application that supplies too much irrigation water, making it difficult to increase the WUE. To improve the efficiency of water use in agriculture, various advanced water-saving techniques have been used in agricultural production. For example, Wang et al. (2013a, b) suggested that, under deficit irrigation conditions, employing drip irrigation could significantly increase grain yield, reduce irrigation water consumption, and improve the WUE of winter wheat. In addition, Dar et al. (2017) reported that suitable timing and depth of drip irrigation resulted in higher crop water productivity compared with flooding irrigation. Similarly, many studies have found that sprinkler irrigation can increase the grain yield and WUE of wheat (Bandyopadhyay et al., 2010; Liu et al., 2013). Micro-sprinkling irrigation is a new technology that has been applied to field production in recent years. Irrigation with micro-sprinkling hoses has the advantages of both drip and sprinkler irrigation (Man et al., 2014a). Moreover, compared with drip irrigation, micro-sprinkling irrigation can reduce the required inputs. Research has shown that micro-sprinkling irrigation greatly improves the irrigation uniformity when the optimal sprinkling angle and hose length are chosen, thus improving the winter wheat yield and WUE (Man et al., 2014a,b). Nevertheless, there is little research on grain yield formation and water consumption characteristics under different micro-sprinkling irrigation frequencies.

Nitrogen is one of the main plant nutrients that affect plant growth (Sadras and Lawson, 2013). To increase crop yield, the nitrogen application rate continues to increase each year (Liu et al., 2008; Cui et al., 2010). However, too much nitrogen fertilizer does not increase crop production and nutrient use (Mon et al., 2016), and the efficiency is relatively low due to nitrogen loss (Wang et al., 2014). Sinclair and Rufty (2012) reported that a key parameter for increasing yield may be to increase nitrogen uptake later in the growth cycle, and increasing the total nitrogen storage pool appears to be essential for gaining further yield increases. Micro-sprinkling irrigation can realize the postponed application of nitrogen by integrating water and fertilizer application. However, there is insufficient research on the effects of integrating water and fertilizer application under micro-sprinkling irrigation with different nitrogen fertilizer rates in winter wheat.

In this study, we hypothesized that the optimized micro-sprinkling irrigation scheduling with suitable nitrogen fertilizer rate in winter wheat can ensure water and nitrogen supply during grain filling in the upper soil layer, reduce the risk of soil nitrate leaching into deeper soil layers, and delay the senescence of leaves, increase the dry matter production during grain filling and improve grain weight, and finally improve the grain yield and the use efficiency of water and nitrogen by postponing the application of water and nitrogen fertilizer. To test this hypothesis, a four-year experiment with different micro-sprinkling frequencies and nitrogen rates was conducted, and the leaf area index (LAI), the chlorophyll content of flag leaf after anthesis, the dry matter and nitrogen accumulation, yield and yield components, and the utilization of water and nitrogen were investigated under the integrated water and nitrogen micro-sprinkling irrigation.

2. Materials and methods

2.1. Experimental site

The experiment was conducted in 2012–2016 at the Wuqiao Experimental Station of the China Agricultural University (Hebei Province, China; 116.3 °E, 37.4 °N; altitude: 20 m). The soil in the field was light loam with 11.8% clay, 78.1% silt, and 10.1% sand. In the 2-m soil profile, the average bulk density was 1.51 g cm^{-3}, the average field capacity was 27.6% (g g^{-1}), and the wilting point was 8.6% (g g^{-1}). The upper 40-cm soil profile contained 1.17% total organic matter, 0.95 g kg^{-1} total N, 104.4 mg kg^{-1} available potassium, and 29.2 mg kg^{-1} available phosphorus. The soil physical and chemical properties were measured at the beginning of the field experiment. During wheat growing season, the total precipitation was 161.3 mm in 2012–2013, 137.1 mm in 2013–2014, 179.2 mm in 2014–2015, and 127.7 mm in 2015–2016. Fig. 1 displays the climatic data for the four years.

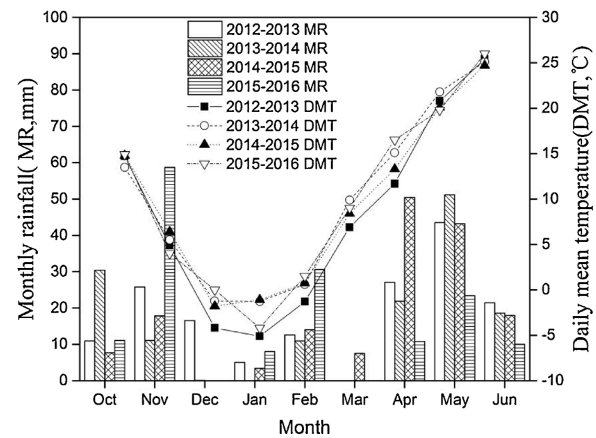

Fig. 1. Rainfall and air temperature in 2012–2016 growing seasons.

2.2. Experimental design

In 2012–2014, micro-sprinkling was applied twice (S2, irrigation applied at the jointing and anthesis stages), three times (S3, irrigation applied at the jointing, anthesis, and filling stages), or four times (S4, irrigation applied at the jointing, booting, anthesis, and filling stages); the total irrigation amount was 150 mm, and the total nitrogen amount was 195 kg ha^{-1} with 105 kg ha^{-1} as the base fertilizer and 90 kg ha^{-1} as the top dressing, and the traditional flood irrigation was used as the control (CK, irrigation 75 mm at jointing and anthesis stage, respectively). In 2014–2016, under the S4 condition, the total irrigation amount was 120 mm, and different nitrogen application levels (N1, N2, and N3, equivalent to total nitrogen amounts of 150, 195, and 225 kg N ha^{-1}, respectively) were applied with 105 kg N ha^{-1} as the base fertilizer and the rest as top dressing. Three replicates for each treatment, and a plot size of 4 m × 30 m.The traditional flood irrigation was used as the control (CK, irrigation 60 mm at jointing and anthesis stage, respectively). Table 1 presents the details of the treatments. The micro-sprinkling system included water and fertilizer integration technology. The high-yield wheat (*Triticum aestivum* L.) cultivar Jimai22 was used in the experiments, which is one of the most important and widely planted crops in Hebei Province. Wheat seeds were sown on 15 October with a row spacing of 15 cm. The micro-sprinkling hose design and details of the orifice arrangement have been described by Man et al. (2014b). The micro-sprinkling hoses were 30-m long with a flow rate of 6.0 m^3 h^{-1}, and the sprinkling angle of the micro-sprinkling hose was 80°. Each experimental plot consisted of 24 rows of wheat spaced 15 cm apart. The inter-row spaces between wheat rows were named L1 to L23. The micro-sprinkling hose was laid between L6 and L18, respectively (i.e., the sprinkled range of each side of every micro-sprinkling hose is one meter) (Fig. 2). Well water was used as the water source. Before sowing, 105 kg N ha^{-1}, 150 P_2O_5 kg ha^{-1}, and 90 kg K_2O ha^{-1} were applied as base fertilizer. For each micro-sprinkling irrigation application, urea as top dressing was completely dissolved in a fertilization device (Fig. 2) and applied together with irrigation water, while in the flood irrigation treatment, urea was spread over the fields before irrigation at the jointing stage.

2.3. Sampling and measurements

2.3.1. Crop phenology

Crop phenology was recorded using the Zadoks scale (Zadoks et al., 1974), following the average phenology of the plot (when 50% of shoots reached at main developmental stage). The corresponding dates were recorded when the 1st node was detectable (jointing, Z31), 50% of