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Effect of field border width for irrigation on dry matter accumulation and distribution, yield, and water use efficiency of wheat

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ABSTRACT

A field experiment was conducted using high-yielding winter wheat cultivar Jimai22 as a test material to examine the effects of different border widths for irrigation on dry matter accumulation and distribution, yield, and water use efficiency of wheat during the wheat growing seasons in 2010 to 2013. Four treatments were installed, i.e., field border widths at 1.0 (W10), 1.5 (W15), 2.0 (W20), and 2.5 m (W25), respectively. In early and middle grain-filling stages, the net photosynthetic rate of W20 was remarkably higher than that of W10 and W15; however, no difference was observed between W20 and W25 at 0 m to 20 m, 20 m to 40 m, and 40 m to 60 m. The net photosynthetic rate of W20 was remarkably higher than that of other treatments. In the late grain-filling stage, the net photosynthetic rate of W20 was remarkably higher than that of other treatments at 0 m to 20 m, 20 m to 40 m, and 40 m to 60 m. In middle and late grain-filling stages, W20 showed the highest transpiration rate and leaf water use efficiency among the treatments, which greatly increased grain filling. Dry matter accumulation in the maturity stage of W20 was considerably higher than that of other treatments. The dry matter distribution to grain and contribution proportion to grain after anthesis, grain filling rate, and 1000-kernel weight of W20 were markedly higher than those of other treatments. The W20 treatment exhibited the highest average grain yield; no difference in grain yield was found in the three regions of the same treatment regardless of the initial border width. Moreover, W20 yielded the highest water use efficiency and irrigation water use efficiency; thus, W20 exhibited the most efficient field border width for irrigation in our study.

The North China Plain (NCP) is known as the most important wheat production area in China. With a summer monsoon climate producing approximately 70% to 80% of the mean annual rainfall (550 mm) concentrated in the summer (July to September), rainfall during wheat growth period can only satisfy 25% to 40% of crop water requirement. Irrigation is necessary to maintain high wheat yield, particularly in the northern part of the NCP [1]. The NCP covers approximately 42% of the total irrigation land, but only 8% of the irrigation supply of China is available; as such, the disparity between irrigation supply and demand is exacerbated [2]. Field border irrigation is the main irrigation form and important research subject in this area because of its low cost, extensive application, and easy implementation [3].

Studies have suggested that the frequency and amount of irrigation should be reduced to increase dry matter accumulation, promote grain-filling rate, and improve the yield and water use efficiency of wheat [4]. The highest net photosynthetic rate and grain yield in the irrigation amount ranging from 0 mm to 300 mm are obtained at 60 mm in wintering, jointing, and filling stages, respectively; as irrigation amount continuously increases, flag leaf senescence is evidently accelerated and net photosynthetic rate decreases significantly [5]. At an irrigation of 60 mm in jointing and anthesis stages, high crop production and water use efficiency (7500 $kg \cdot hm^{-2}$ to 9000 $kg \cdot hm^{-2}$) are obtained [6]. Other studies have revealed that water consumption and grain yield are reduced by 14.61% and 5.18%, respectively, and water use efficiency is increased by 6.84% compared with those obtained at irrigation of 60 mm in jointing and anthesis stages [7].

Studies on field border irrigation showed that the lowest irrigation efficiency can be obtained at the field border width of 1 m; furthermore, similar irrigation efficiencies are obtained at field border widths of 2 and 3 m, but irrigation efficiency decreases when the field border width is increased from 3 m to 4 m [8]. In Henan province, a field border width of <4 m accounts for 14% and a field border width of >6 m accounts for 34%; an average of 6 m is recorded in the eastern plain area of the field border irrigation district [9]. The following field border widths have also been documented: 1.5 m in Huantai, Shandong Province; 1.5 m to 2.0 m in Yanzhou; 2.0 m in Tengzhou and Tai'an; 2.0 m to

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3.0 m in Heze; 3.0 m to 3.4 m in Weifang; and 3.8 m to 4.0 m in Dezhou. Approximately 300 plots in Huimin, Shandong Province have shown that the median field border width ranges from 6 m to 9 m, with an average of 6.8 m, and the excess field border width is one of the main problems in this area [10].

Previous studies mainly focused on the effects of irrigation, time, and amount on photosynthetic characteristics, dry matter accumulation, and distribution and yield of wheat at the same experimental plot sizes. However, the effect of different field border widths for irrigation on dry matter accumulation and distribution, yield, and water use efficiency of wheat has been rarely reported under irrigated land conditions in NCP. In the present paper, the effects of different field border widths for irrigation on dry matter accumulation and distribution, yield, and water use efficiency of wheat under high-yield conditions were examined in Yanzhou, Shandong. This study provided scientific bases to select a suitable field border width to achieve high yields and water conservation of winter wheat in the NCP.

1. Materials and methods

1.1. Experimental site

Field experiments were conducted using Jimai22 wheat cultivar in Shiwang Village (35.41° N, 116.41° E), Yanzhou, Shandong Province, China during the wheat growing seasons in 2010 to 2013. The area belongs to a sub-humid warm temperate climate, the mean annual temperature is 13.6 °C, and the average precipitation is 706.0 mm. The ground slope of the experimental field was measured as 2.09‰. Before sowing, we returned the previous maize straw to the field. The land was plowed using a moldboard and then harrowed. The border check was formed, and the seed was seeded with a common seeder. The soil nutrient condition of the experimental field at soil layers of 0 cm to 20 cm before the soil was sown are shown in Table 1. The field capacity and mass water content of the experiment field soil at soil layers of 0 cm to 200 cm are shown in Table 2. The precipitation amounts in different wheat growth stages during the experiment are shown in Table 3.

1.2. Experimental design

During the wheat growing season in 2010 to 2011, four field border widths were established: 1.0 (W10); 1.5 (W15); 2.0 (W20); and 2.5 m (W25). During the wheat growing seasons in 2011 to 2012 and 2012 to 2013, three field border widths were established: 1.5 (W15); 2.0 (W20); and 2.5 m (W25). The field border length of the experimental plots was 60 m, and border check was 40 cm in width and 15 cm in height. The field was prepared using a randomized block design with three replicates. The plots were separated from one another at an interval of 1.5 m with the same wheat cultivar and seed density.

All of the treatments were irrigated in the jointing stage, and the inflow cutoff was designated as 90% [11]. Irrigation was stopped when the flow front reached 90% of the field border length. A flow meter was used to measure the amount of water applied. Table 4 shows the relative soil water contents in the soil layers at 0 cm to 200 cm in different regions in the anthesis stage.

Before plowing, we applied chemical fertilizers $CO(NH_2)_2$, $(NH_4)_2HPO_4$, and KCl on the plots to provide nitrogen, phosphorus, and potassium at the following densities: 105 $kg \cdot m^{-2}$ N; 150 $kg \cdot m^{-2}$ P_2O_5; and 150 $kg \cdot m^{-2}$ K_2O. Approximately 135 $kg \cdot m^{-2}$ N was added to the soil in the jointing stage. Wheat was sown on October 8 and harvested on June 13 of the following year. Seedling density was controlled at 180 plants m^{-2} in the four-leaf stage. Other field management practices were performed in compliance with local practices in high-yield production.

1.3. Sampling method and measurement

1.3.1. Determination of the sampling region

The field border was divided into three sampling regions, particularly 0 m to 20 m, 20 m to 40 m, and 40 m to 60 m along the direction of water flow, designated as the front, middle, and end, respectively. Sampling was conducted again in each sampling region, and data were the means of the three sampling regions except those indicated in Tables 5 and 8.

1.3.2. Evapotranspiration (ET)

Soil samples were collected from the soil layer 0 cm to 200 cm by using a drill and divided into 10 samples at an interval of 20 cm. The soil water content of the soil samples was measured by oven-drying method. Soil moisture content was calculated as follows:

Soil moisture content (%) = (fresh weight of soil sample − dry weight of soil sample) / dry weight × 100.

Table 1
Soil nutrient condition of experimental field at soil layers of 0 cm to 20 cm.

Growing seasons	Organic matter /(g/kg)	Total nitrogen /(g/kg)	Available nitrogen /(mg/kg)	Available phosphorus /(mg/kg)	Available potassium /(mg/kg)
2010–2011	15.98	1.05	100.41	25.46	126.23
2011–2012	15.91	1.14	100.24	26.07	128.50
2012–2013	15.97	1.19	101.14	25.95	126.21

Table 2
Field capacity and mass water content of the experiment field soil at soil layers of 0 cm to 200 cm/%.

Growing seasons		Soil layers/cm									
		0–20	20–40	40–60	60–80	80–100	100–120	120–140	140–160	160–180	180–200
2010–2011	I	27.68	26.49	24.08	24.84	24.34	25.29	25.15	25.47	25.85	26.01
	II	17.93	18.39	20.23	22.31	21.80	21.83	22.02	22.04	21.74	21.78
2011–2012	I	27.79	26.88	24.81	24.78	24.43	25.25	25.51	25.49	25.89	25.99
	II	21.32	21.81	22.29	22.70	22.02	22.96	22.51	22.60	22.78	22.57
2012–2013	I	27.05	26.54	25.12	24.41	23.89	25.02	25.74	25.64	25.18	25.72
	II	16.36	17.37	18.41	19.44	19.78	20.08	20.71	21.81	22.16	22.30

I: Field capacity; II: mass water content of soil.