Response of canopy architecture, yield and water use efficiency of winter wheat to irrigation time

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Abstract

Water scarcity makes it imperative to develop water-saving irrigation systems on the North China Plain. A field experiment was carried out for winter wheat to evaluate the effects of single irrigations at different times on the crop canopy development, yield and WUE. Four irrigation times/treatments are adopted: zero irrigating (I0), irrigating at regreening (post winter) (I1), shooting (tillering) (I2) and booting stage (I3). Irrigating at regreening stage produced a shady canopy architecture with many ineffective tillers and large leaf area, which led to more water consumption and low photosynthesis after anthesis. Thus the yield and WUE was comparatively low. Comparing with I1, irrigating at booting stage resulted in water deficit in the early growth stage of winter wheat. This brought about a canopy architecture with appropriate effective tiller number, small leaf area, short basal and long upper internodes, which was helpful to light interception and reduced water consumption in the early stages. These characteristics improved the photosynthesis and dry matter production after anthesis. Finally the yield, WUE, and harvest index were significantly increased. The performance of winter wheat irrigated at shooting stage was between that of other two irrigated treatments. The results showed that canopy architecture of winter wheat could be changed by controlled irrigation time. Late irrigation could save water and obtain high yield through modifying canopy architecture to achieve high photosynthetic rate and low water consumption. Booting stage was the optimal time to irrigate with a single irrigation in this area.

Media summary

Late irrigation in spring could improve yield and water use efficiency of winter wheat by modifying canopy architecture in a single irrigation application system.

Keywords

Wheat; canopy architecture; water use efficiency; yield; irrigation

Introduction

Winter wheat-summer maize is the dominant double cropping system in the North China Plain which produces a high proportion of China's food crops. Precipitation is inadequate for winter wheat growth in this area, since 70% of annual rainfall (around 600 mm) falls in summer. Winter wheat has had to be irrigated many times using underground water in order to obtain a high yield. This leads to the rapid decline of the underground water table (Lan and Zhou, 1995). Water scarcity seriously limits the sustainability of crop production in the area and new water-saving irrigation systems must be found to husband the water resource and improve water use efficiency (WUE). Researchers found that WUE of winter wheat could be substantially improved by reducing irrigation frequency from three times to only one (single irrigation), and different irrigation time also had influence on the crop development and yield (Lan and Zhou, 1995; Zhang et al., 1998). The objective of this work was to find the optimal time to irrigate for a single irrigation system by analyzing the effects of irrigation time on the crop canopy development, WUE and yield.

Material and methods

The field experiment was conducted at Wuqiao experimental station (37?38?N, 116?40?E), Hebei province, China during 1996-1997 in sandy clay soil. Winter wheat (cultivar Ji38) was sown on October 20 and harvested on June 10. Soil water content was maintained at 90% of field capacity before sowing by irrigation. Four irrigation treatments were applied: zero irrigating (I0), irrigating at regreening (yellowing through winter) (I1, on March 10), shooting (I2, on April 10) and booting stage (I3, on April 25) with three replications in a randomized block design. The plot area is 26.5m^2 and 75mm water was provided for each treatment by border irrigation with pipe supply. Growth stage of winter wheat is shown in table 1. The soil water content (w/w) was monitored from 0 to 2 m using gravimetric analysis during the whole growing season. Plants from 0.2m^2 quadrats were counted to investigate the development of tiller density, total green leaf area.. Canopy photosynthetic rate was measured after flowering by using a BAU-photosynthesis measuring system. At maturity, plants from 9m^2 plot were harvested for total dry mass and grain yield and yield components.

Results

Crop canopy architecture and photosynthesis

Irrigation time produced different canopy architecture by affecting the development of tillers and leaf expansion. Irrigating at regreening stage promoted the process of tillering (Fig. 1), but the ineffective tillers were also increased (data not shown).. This led to the shady canopy in the early growth stage of winter wheat. Irrigating at shooting stage was beneficial to the tiller survival and resulted in the highest plant density at maturity. Irrigating at booting stage had no influence on the tiller density compared with that of zero irrigation.

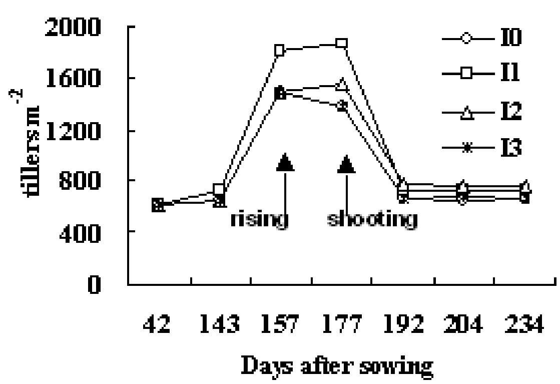

Figure 1. Response of tiller density to irrigation time

Table 1. Growth stage of winter wheat

Growth stage	Correspondent date	DAS†
	day/month	
regreening	10/3	143
rising	24/3	157
Shooting/tillering	10/4	173
Booting	25/4	188

Heading	5/5	199
Anthesis	10/5	204
Maturity	10/6	235

† Days after sowing.

Leaf area index was significantly increased by irrigation (Fig. 2). The influence was more obvious with the early irrigation. Early irrigating (I1) increased not only the plant density in the early growth stages but also the leaf area per plant (Fig. 1 and 3). Leaf area index was improved by irrigating at shooting stage as well, and reached the top at 192 DAS. The maximum LAI of late irrigating (I3) was higher than that of I0, but lower than that of I1 and I3.

Plant size was also changed by irrigation time. Leaf area per plant of I1 was 26.8% more than that of I0 due to the leaf area increased at all positions (Fig. 3). Irrigating at shooting stage promoted the leaf extension from 3rd to flag leaf (especially flag leaf), and the leaf area per plant was 17.47% more than that of I0. Irrigating at booting stage had little influence on the leaf area, but enhanced the elongation of upper internodes (Fig. 3 and 4). Therefore, delayed irrigation in spring appeared to modify canopy architecture with small leaves, short basal and long upper internodes, which is beneficial to light distribution and interception.

Irrigation at all times increased canopy photosynthetic rate (Pn) (Fig. 5). I3 maintained the highest Pn after anthesis. This was mainly due to the favorable light distribution in the canopy and improved drought tolerance because of the water deficit in the early growth stage, maintaining active growth for longer in the season.

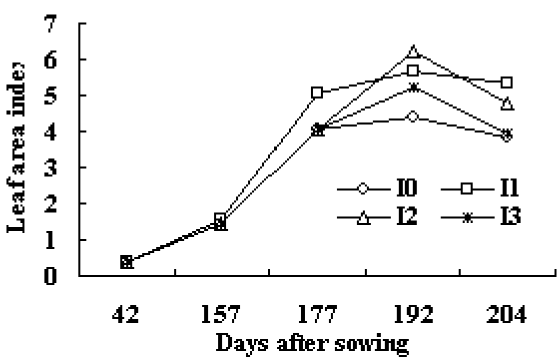

Fig.2. Response of leaf area index to irrigation time.

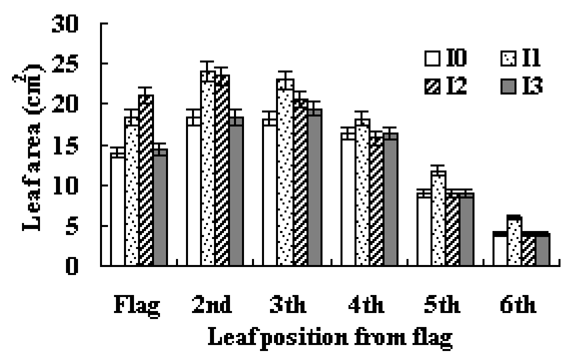

Fig.3. Response of leaf area in different position to irrigation time.

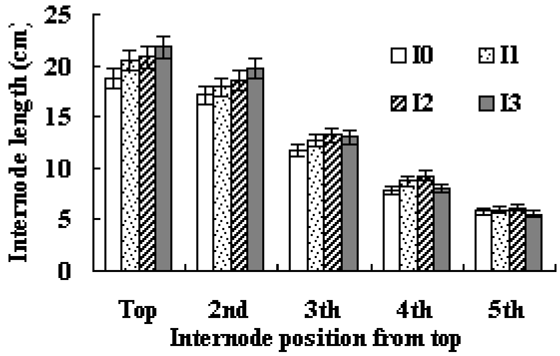

Fig.4. Response of internode length to irrigation time.

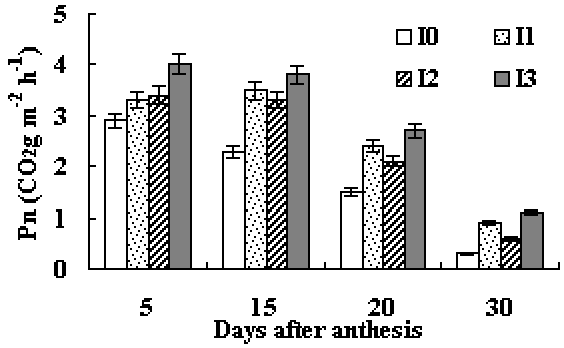

Fig.5. Response of canopy photosynthesis rate (Pn) to irrigation time.

Table 2. Grain yield and yield components of winter wheat differing in irrigation time.

	Density ears hm^{-2}(?10^{6})	Kernels/ear^{-1}	Kernel weight mg	Grain yield kg/ha	Harvest index	Biomass Kg/ha
I0	6.64 b‡	27.84 d	41.12 a	7589 b	0.51	15511
I1	7.23 a	28.11 c	41.65 a	8469 a	0.49	17426
I2	7.57 a	29.86 b	38.01 b	8589 a	0.49	17637
I3	6.73 b	31.42 a	42.25 a	8939 a	0.50	17771

Table 3. Water consumption and water use efficiency (WUE) of winter wheat differing in irrigation time.

	Water consumption (mm)					WUE
	0-45DAS	45-157DAS	157-204DAS	204-235DAS	total	kg ha^{-1} mm^{-1}
I0	55.03	72.64	126.83	153.67	408.15	18.59 c‡
I1	55.03	89.42	177.55	155.68	477.68	17.73 b
I2	55.03	72.64	176.30	142.17	446.12	19.25 a
I3	55.03	72.64	145.40	181.74	454.79	19.65 a

‡ Means followed by the same letter within a column are not significantly different at *P*≤0.05

Grain yield and yield components

Statistical analysis (Table 2) showed that irrigation increased the ears per hectare, kernels per ear and hence grain yield. Comparing with that of I0, the grain yield of irrigated treatments was increased by 11.59~17.79%. Irrigating at booting stage achieved the highest grain yield while irrigation at regreening stage had the lowest yield. The differences between the irrigation treatments was not significant. Although the ears per hectare of I3 was reduced in contrast with that of I1 and I2, the kernels per ear, kernel weight and harvest index were improved. This was attributed to a relatively high photosynthetic rate and dry matter production in the post-anthesis phase. The grain yield of I2 was similar to that of I1, as in spite of the higher number of ears per hectare I2 produced lower kernel weight. This showed that different irrigation time has an effect on different yield components. Irrigating at the regreening and shooting stage increased both ears per hectare and kernels per ear while irrigating at booting stage increased kernels per ear and kernel weight.

Water use efficiency

Water consumption was assessed by changes in volumetric water content and increased by irrigation (Table 3). The total water consumption of I1, I2 and I3 was 17.03%, 9.30% and 11.43% higher respectively than that of I0. I1 had the highest water consumption. Early irrigation (I1) mainly increased water consumption from regreening to shooting stage. Late irrigation (I3) decreased water consumption before anthesis, because of the reduced tillers, LAI and modified canopy architecture. The difference of WUE among treatments was significant (Table 3). I1 had the lowest WUE while I3 had the highest. WUE of I2 was similar to that of I3. It showed that delayed irrigation time was helpful in improving WUE and yield.

Discussion and conclusion

Grain yield and water consumption were influenced by irrigating at different growth stages of winter wheat, due to the varying effects on plant growth. The effects of irrigating at booting stage on growth were: 1) inhibiting the growth of ineffective tillers, so as to reduce unnecessary nutrient and water consumption; 2) producing a modified canopy architecture with elongated upper internodes and reduced leaf area which is good for light distribution and canopy photosynthesis. This improved the dry matter production post-anthesis and improved harvest index, since grain yield mainly comes from the photosynthesis after blooming; 3) possibly promoting deep root distribution (Lan and Zhou, 1995), so as to take up more soil water from deeper in the profile in late growth stage because of the long period water deficit before booting. Irrigating at the regreening stage produced a shady canopy architecture with many ineffective tillers, large leaf area and short upper internodes. This led to more water consumption pre-anthesis, less water allocation for post-anthesis and relatively low post-anthesis photosynthesis. Appropriate water deficit in the early growth stage of winter wheat was beneficial to yield production and water saving through the establishment of a modified canopy architecture in a water limited area. Our results showed that booting was the optimal irrigation time to obtain high yield and WUE in single irrigation systems in this area.

Water deficit in the early stage had obvious effects on the growth of winter wheat: on the one hand, changing the canopy architecture; on the other hand, reducing the ears per hectare. The former effect could be used to produce “ideal” canopy architecture, and the later could be mitigated by increasing the amount of seeds sown to ensure adequate ear survival. Hence, properly using water deficit can be helpful to achieve water-savings and high yield production.

Reference

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