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Effects of Different Water Treatment on Yield and Agronomic Traits of Wheat

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Abstract In order to make clear the effects of water on yield and agronomic traits of wheat in Cangzhou, 18 wheat cultivars from north part of Huanghuai Plain were collected for spring irrigation. The indoor and field surveys were used to analyze the effects of irrigation frequency on stem tiller situation, leaf area coefficient, yield and other traits of different wheat cultivars. The results indicated that the average yield of irrigation 1 increased by 68.07 kg compared with that of irrigation 0, while the average yield of irrigation 2 increased by 60.00 kg compared with that of irrigation 1. The survey of flag leaf area of wheat cultivars at the grain filling stage showed that the leaf area of irrigation 0 was the smallest (18.15 cm^2 on average), the leaf area of irrigation 1 was 20.34 cm^2, and the leaf area of irrigation 2 was 24.05 cm^2. With the increase in the irrigation times, the volume weight of wheat cultivars declined, the number of infertile spikelet dropped, and the plant height gradually increased. In conclusion, every decrease of one time of irrigation times, there will be loss of yield about 60.00 kg.

Key words Wheat, Yield, Irrigation, Agronomic traits

1 Introduction

Wheat is a grain crop requiring much water. Studies have shown that reasonable irrigation period and irrigation times are important guarantees for the high and stable yield of wheat. Reasonable water deficit exercise during the proper growing period of wheat is favorable for increasing the stress resistance and water utilization efficiency of wheat, while water deficit adjustment and irrigation at improper growth stage will lead to a significant decline in wheat yield[1 – 2]. From the period after sowing to the period before jointing, the water consumption accounts for 35% – 40% of the water consumption during the whole growth period, and the daily water consumption is about 6 m^3/ha. The period from jointing to heading is the critical period of wheat growth. In this period, water deficit will lead to yield decline, and the water consumption in 25 – 30 days accounts for 20% – 25% of the total water consumption, and the daily water consumption is about 33.0 – 51.0 m^3/ha. In the period from heading to maturity, the daily water consumption is larger, the water consumption in 35 – 40 days accounts for 26% – 42% of total water consumption. Especially in the heading stage, the daily water consumption is up to 60 m^3/ha. This shows that the main growth stages of wheat are basically consistent with the change process of water demand. Zhang Jinghui[3], Pei Wenshou *et al.*[4 – 5] studied the water demand and winter wheat water-saving and high-yield cultivation techniques, and found that the average water demand per kg of wheat during the whole growth period is 0.723 m^3[6 – 10]. There have been many reports of combined application of nitrogen fertilizer and impact on late wheat under limited water irrigation conditions[11 – 14].

Cangzhou City, located in Heilonggang River valley, Hebei Province, is a main wheat producing area in Hebei Province. Subject to poor natural conditions, the wheat yield is low, the average yield is about 5 4700 kg/ha, it has a high potential of yield increase. It is also a typical funnel area in North China. The exploitation of groundwater is excessive, water resources are seriously deficient. Excessive groundwater exploitation has caused severe ecological problems[15]. According to the latest statistics, the annual average precipitation in Cangzhou City is 551.1 mm, and the average water resource volume is 12 333 million m^3, including 596.14 million m^3 surface water, 692.39 million m^3 underground water, and repeated calculation is 55.23 million m^3. Calculated according to the population (6.847 5 million) of Cangzhou City in 2005 and the area of 0.807 million ha of cultivated land at the end of the 2005, the per capita amount of water resources in the city was 180 m^3 and the average per mu of water resources was 102 m^3, which is 6.8% and 5.9% of the national average value respectively, and 43.0% and 40.8% of that of the average value of Hebei Province[16 – 17]. Therefore, China set forth specific measures of banning the exploitation of groundwater in North China. As Cangzhou wheat production belongs to well-irrigation production, the banning of exploitation will inevitably affect the wheat production, we must actively respond. In this experiment, we studied and analyzed the effects of irrigation times of 19 wheat cultivars on the wheat production.

2 Materials and methods

2.1 Sample materials We selected 18 wheat cultivars from the National Wheat Industry Technology System and set the local wheat variety Nongda 399 as the control.

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2.2 Experiment design

2.2.1 Overview of the experiment. The experiment was carried out at the Xian County seed farm in Comprehensive Experimental Station of Cangzhou (116°11′59″ E and 38°11′33″ N). This experimental site has uniform soil fertility and flat terrain. The seed was sown on October 16, 2015. The experiment was carried out by the large area comparison method, the area was 7.5 ha, and no repetition was set. The seeding rate was 150 kg/ha, the row spacing was 16 cm, and protection zone was set outside the planting area. In the spring irrigation 2 experiment, the irrigation 1 was implemented at the jointing stage (April 1), the irrigation 2 was implemented at the flowering stage (May 10). In the spring irrigation 1 experiment, the irrigation 1 was implemented at the jointing stage (April 1). In the irrigation 0 experiment, no irrigation was implemented. On April 1, combining the irrigation, 225 kg/ha urea was applied. On June 12, wheat was harvested.

2.2.2 Experimental varieties and field planting diagram. Nonghaha 2BX-9 Wheat Seed Drill was applied, to ensure uniform sowing of every wheat cultivar. After fixing the site, observation road was made, to make the field landscape become excellent. The field planting diagram is illustrated in Fig. 1.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Protection zone	Kenong 2011	Xingmai 13	Han 115276	Heng S29	Cangmai 028	Anmai 1	Luomai 7	Keyuan 088	Bin BY34	Taikemai 33	Yannong 172	Liaomai 18	Yong 1917	Lin 091	Yaomai 16	Shi 10-4393	Jimai 23	Zhongmai 4072	Nongda 399	Protection zone
					2	Irrigation														
Observation road																				
					1	Irrigation														
Observation road																				
					0	Irrigation														

Fig. 1 Field planting diagram for treated wheat cultivars

2.3 Experiment methods

2.3.1 Stem-tiller situation. By means of the fixing site survey, we measured the number of stems, tiller number per plant of representative row No. 1 in the seeding stage, wintering stage, regreening stage, jointing stage, and maturity stage, and converted to the average per unit area.

2.3.2 Determination of leaf area. During the grain filling stage, we measured the flag leaf area using the ruler and selected 10 plants continuously.

2.3.3 Indoor seed evaluation. We evaluated the spike length, number of spikelet, and panicle type of harvested samples, and measured the volume weight of sampled dried wheat.

2.3.4 Yield components. At the maturity stage, we surveyed the number of grains and the number of spikes per ha; in each plot, we selected typical 6.7 m^2 to harvest and threshed separately, dried and calculated the yield and converted into the yield per ha; in the dried wheat, we randomly selected samples and measured the 1 000-grain weight.

2.4 Data analysis We processed data and carried out analysis using Excel and DPS7.05 software.

3 Results and analyses

3.1 Analysis of yield results From Table 1, it can be seen that the yield of irrigation 1 increased by 5.26% – 39.19% (average increase of 16.03%) compared with that of irrigation 0, while the yield of irrigation 2 increased by –8.97% – 34.72% (average increase of 11.33%) compared with that of irrigation 1. The average yield of irrigation 1 increased by 68.07 kg compared with that of irrigation 0, while the average yield of irrigation 2 increased by 60.00 kg compared with that of irrigation 1. Irrigation exerted a very significant effect on the increase of wheat yield. Every decrease of one time of irrigation times, there will be loss of yield about 60.00 kg.

Table 1 Results of effects of irrigation times on yield of wheat cultivars

Cultivar No.	Cultivar name	Yield//kg/ha			Increase of irrigation 1 over irrigation 0//%	Increase of irrigation 2 over irrigation 1//%	Average difference between irrigation 1 and irrigation 0//kg
		Irrigation 0	Irrigation 1	Irrigation 2			
1	Kenong 2011	7 100.40	7 700.40	8 400.45	8.45	9.09	650.025
2	Xingmai 13	6 700.35	7 900.35	8 100.45	17.91	2.53	700.050
3	Han 115276	8 100.45	9 100.50	10 250.55	12.35	12.64	1 075.050
4	Heng S29	7 400.40	8 400.45	9 200.40	13.51	9.52	900.000
5	Cangmai 028	7 100.40	8 200.35	9 300.45	15.49	13.42	1 100.025

(To be continued)

(Continued)

Cultivar No.	Cultivar name	Yield//kg/ha			Increase of irrigation 1 over irrigation 0//%	Increase of irrigation 2 over irrigation 1//%	Average difference between irrigation 1 and irrigation 0//kg
		Irrigation 0	Irrigation 1	Irrigation 2			
6	Anmai 1	6 100.35	7 600.35	7 800.45	24.59	2.63	850.050
7	Luomai 7	7 800.45	9 100.50	10 100.55	16.67	10.99	1 150.050
8	Keyuan 088	7 100.40	8 700.45	8 300.40	22.53	-4.60	600.000
9	Bin BY 34	6 500.40	7 800.45	7 100.40	20.00	-8.97	300.000
10	Taikemai 33	6 600.30	7 400.40	9 100.50	12.12	22.97	1 250.100
11	Yannong 172	7 400.40	10 300.50	10 400.55	39.19	0.97	1 500.075
12	Liaomai 18	6 200.25	6 800.40	8 650.50	9.68	27.21	1 225.125
13	Yong 1917	7 500.45	8 900.40	8 800.50	18.66	-1.12	650.025
14	Lin 091	8 000.40	8 900.40	9 300.45	11.25	4.49	650.025
15	Yaomai 16	8 200.35	9 300.45	10 350.45	13.42	11.29	1 075.050
16	Shi 10 -4393	6 800.40	7 200.30	9 700.50	5.88	34.72	1 450.050
17	Jimai 23	7 700.40	8 700.45	10 250.55	12.99	17.82	1 275.075
18	Zhongmai 4072	6 500.40	8 100.45	10 300.50	24.61	27.16	1 900.050
19	Nongda 399	7 600.35	8 000.40	9 800.55	5.26	22.50	1 100.100

3.2 Effects of irrigation on wheat population situation and the spike rate Through the field survey of population situation of wheat cultivars, the growth conditions were basically consistent from the period after sowing to the period before re-greening between wheat cultivars. The highest number of stems reflected the difference between cultivars and the correlation coefficient with yield was not significant. The spike rate of wheat reflects the changes from the highest number of stems to effective number of spikes. From Table 2, it can be seen that the irrigation 0 and irrigation 1 were negatively correlated with the yield, the irrigation 2 was positively correlated with the yield, showing the significant influence of irrigation on the spike rate.

3.3 Effects of irrigation on the flag leaf area The survey of flag leaf area of wheat cultivars at the grain filling stage showed that the leaf area of irrigation 0 was the smallest (18.15 cm^2 on average), the leaf area of irrigation 1 was 20.34 cm^2, and the leaf area of irrigation 2 was 24.05 cm^2. The leaf area difference S_1 was 2.19 cm^2, and S_2 was 3.71 cm^2. This indicated that the irrigation times affect the size of the flag leaf, and eventually affecting the flag leaf photosynthesis and the yield.

Table 2 Correlation coefficient between the highest number of stems, spike rate, and the yield of each treatment

Item	Irrigation times	Correlation coefficient
Highest number of stems	0	r = 0.474 3
	1	r = 0.331 1
	2	r = 0.046 4
Spike rate	0	r = -0.361 1
	1	r = -0.068 1
	2	r = 0.061 0
	$P_{(0.05)}$ = 0.455	

Table 3 Effects of irrigation on the flag leaf area

Cultivar No.	Cultivar name	Flag leaf area//cm^2			Difference of leaf area	
		Irrigation 0	Irrigation 1	Irrigation 2	S1	S2
1	Kenong 2011	17.75	16.51	23.54	-1.24	7.03
2	Xingmai 13	19.46	15.70	24.30	-3.76	8.60
3	Han 115276	15.33	19.54	25.36	4.21	5.82
4	Heng S29	19.34	24.91	27.31	5.57	2.40
5	Cangmai 028	23.06	26.39	25.97	3.33	-0.42
6	Anmai 1	17.76	20.10	22.48	2.34	2.38
7	Luomai 7	18.51	19.92	23.11	1.41	3.19
8	Keyuan 088	17.33	19.46	27.63	2.13	8.17
9	Bin BY 34	18.26	20.03	24.34	1.77	4.31
10	Taikemai 33	20.85	24.32	23.66	3.47	-0.66
11	Yannong 172	12.98	16.78	19.24	3.80	2.46
12	Liaomai 18	21.33	22.35	24.37	1.02	2.02
13	Yong 1917	18.66	20.76	23.45	2.10	2.69
14	Lin 091	17.45	21.15	23.42	3.70	2.27
15	Yaomai 16	18.27	16.52	24.08	-1.75	7.56
16	Shi 10 -4393	16.25	18.32	22.56	2.07	4.24
17	Jimai 23	14.89	19.55	23.41	4.66	3.86
18	Zhongmai 4072	17.09	20.32	22.19	3.23	1.87
19	Nongda 399	20.21	23.74	26.54	3.53	2.80

Note: S_1 is the leaf area of irrigation 1 deducting that of irrigation 0, while S_2 is the leaf area of irrigation 2 deducting that of irrigation 1.

3.4 Effects of irrigation times on indoor seed evaluation indicators Through the field survey and seed evaluation, we found that the irrigation times had significant influence on the plant height of wheat (the plant height of irrigated wheat was about 8 – 20 cm higher that without irrigation). This was most prominent in wheat cultivars Keyuan 088, Yaomai 16, and Jimai 23, showing that these three cultivars were very sensitive to water.

Through the measurement of the spike length, rate of infertile spikelet and volume weight, we found that with the increase in the irrigation times, the volume weight of most cultivars declined, the spike length increased, and the rate of infertile spikelet slightly declined. Results are listed in Table 4.

Table 4 Effects of irrigation times on spike length, volume weight, and infertile spikelet

Cultivar name	Irrigation 0			Irrigation 1			Irrigation 2		
	Spike length//cm	Volume weight//g/L	Rate of infertile spikelets//%	Spike length//cm	Volume weight//g/L	Rate of infertile spikelets//%	Spike length//cm	Volume weight//g/L	Rate of infertile spikelets//%
Kenong 2011	7.2	812	8.33	8.0	804	17.78	7.5	813	25.00
Xingmai 13	6.3	807	26.25	7.0	786	20.00	7.5	806	16.00
Han 115276	7.4	816	21.11	8.7	815	12.22	9.2	811	10.00
Heng S29	7.8	824	15.56	7.6	812	22.22	7.8	831	15.56
Cangmai 028	8.6	801	16.67	8.4	800	19.44	8.3	815	22.22
Anmai 1	7.0	803	13.33	8.3	808	16.00	7.8	808	17.50
Luomai 7	7.8	781	25.00	8.8	782	10.00	8.6	782	16.67
Keyuan 088	5.8	805	10.71	6.5	793	11.11	6.8	811	18.89
Bin BY 34	7.0	785	32.50	7.2	785	15.56	7.2	810	10.00
Taikemai 33	6.2	810	28.57	6.8	805	15.63	7.0	792.0	9.38
Yannong 172	8.0	821	10.00	7.8	826	18.75	7.8	808	21.11
Liaomai 18	9.7	799	16.67	10.0	805	11.00	10.0	806	7.78
Yong 1917	7.5	810	13.89	7.3	800	10.00	7.3	810	8.33
Lin 091	6.5	791	16.67	7.2	800	6.67	7.5	783	13.89
Yaomai 16	7.2	825	22.50	8.4	801	14.00	8.5	810	26.67
Shi 10-4393	7.0	805	13.89	8.6	795	23.64	7.7	803	15.00
Jimai 23	6.5	825	12.50	7.5	800	21.88	7.0	824	13.89
Zhongmai 4072	7.8	808	18.75	8.5	804	21.88	7.6	797	8.89
Nongda 399 ck	7.0	792	12.50	7.5	789	11.00	7.6	805	19.00

4 Conclusions and discussions

According to the requirements of state for limiting the exploitation of underground water in North China, Hebei Province set forth the goal of gradually realizing zero-exploitation of agricultural water in excessively exploited areas. Cangzhou is the main implementation area. Its production mode, farming system and application technologies will have fundamental changes. The wheat industry of Cangzhou City should be based on guaranteeing the total yield, formulate the target of limiting irrigation, select drought resistant and high yield wheat varieties, and rely on high technology to explore the potential of biological water saving, to realize the high yield and high efficiency of wheat production under the condition of limiting irrigation[18]. Zhang Yongping *et al.*[19] studied the stomatal characteristics of different green organs of wheat under different water supply conditions. The results showed that the photosynthetic rate of leaves declined under drought conditions, while the photosynthetic rate of non-leaf organs remained relatively stable, which could relatively increase the water utilization efficiency. Guo Xiaowei[20] studied the effects of different water treatments on the flowering and seed setting of winter wheat, and found that in severe drought conditions, drought-resistant varieties have strong ability of flowering and seed setting.

This experimental study provides a support for limiting irrigation water in the limited exploitation area. In October 29 – 30, there was a process of little precipitation. Wheat realized planting with adequate moisture. After sowing, the average temperature was relatively high, it was suitable for wheat germination. In November, the sunshine time was seriously insufficient. At the end of November, rainfall occurred in the whole country, the snow fell ahead of previous years. Just because of sharp temperature drop, some areas suffered the extreme low temperature, which exerted a great impact on the growth of winter wheat (varying degrees of frost damaged occurred to the winter wheat). In the early March of this year, winter wheat started re-greening. On the whole, the re-greening was normal and wheat seedlings grew well. Although the temperature in late January was 4.6℃ lower than that in normal years, and there was the extreme minimum temperature of –20.1℃ (January 23), there was very good moisture content in the early stage of precipitation and there were very few dead seedling due to frost damage, which made winter wheat live through the winter safely. However, since the experiment was just one year field experiment, and the rainfall of this year was 147.1 mm, 5.5% less than normal years, it would have a certain influence on the experimental results.

Cangzhou is typical funnel area in North China. The exploitation of groundwater is excessive, water resources are seriously deficient. Excessive groundwater exploitation has caused ecological problems, thus, it is required to limit the groundwater exploitation. In this experiment, the average yield of irrigation 1 increased by 68.07 kg compared with that of irrigation 0, while the average yield of irrigation 2 increased by 60.00 kg compared with that of irrigation 1. Irrigation exerted a very significant effect on the increase of wheat yield. Every decrease of one time of irrigation times, there will be loss of yield about 60.00 kg. Through the field survey and seed evaluation, we found that the irrigation times had significant influence on the plant height of wheat (the plant height of irrigated wheat was about 8 – 20 cm higher that without irrigation). This was most prominent in wheat cultivars Keyuan 088, Yaomai 16, and Jimai 23, showing that these three cultivars were very sensitive to water. Through the measurement of the spike length, rate of infertile spikelet and volume weight, we found that with the increase in the irrigation times, the volume weight of most cultivars declined, the spike length increased, and the rate of infertile spikelet slightly declined.

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