Grain yield and quality of winter wheat in different planting patterns under deficit irrigation regimes

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ABSTRACT

Limited water resources restrict winter wheat grain yield and quality in the Huang-Huai-Hai Plain of North China, and establishing optimal planting patterns according to crop water requirements is the key factor for achieving rational water use. In this paper, 4 planting patterns were applied, namely, uniform row (30 cm; traditional pattern), wide (40 cm)-narrow (20 cm) row, furrow (double lines in the furrow with 20 cm spacing, and 40 cm between furrows), and seed bed (double lines on the bed with 20 cm spacing, and 40 cm between beds). Each planting pattern was irrigated twice during the jointing and heading stages, and total irrigation water was controlled at 120 mm. Grain yield was significantly (*LSD*, $P < 0.05$) higher in the furrow planting pattern than in the uniform row, wide-narrow row, and seed bed planting patterns, by 73.4, 64.3, and 53.4 g/m^2, respectively, in 2004–2005 and by 54.3, 42.6, and 30.2 g/m^2, respectively, in 2005–2006, mainly because of a significant (*LSD*, $P < 0.05$) increase in the spike and kernel numbers. These results were caused by changes in the contribution of dry matter remobilization to grain yield (CDMRG); the CDMRG was higher in the furrow planting pattern than in the uniform row, wide-narrow row, and seed bed planting patterns by 5.1%, 4.3%, and 2.9%, respectively. Gliadin and glutenin contents in the furrow planting pattern were 4.67% and 5.85%, respectively, and were significantly (*LSD*, $P < 0.05$) higher than those in the uniform row, wide-narrow row, and seed bed planting patterns; however, the furrow planting pattern had no significant (*LSD*, $P < 0.05$) effect on albumin and globulin contents. Dough development time (DDT) and dough stable time (DST) in the furrow planting pattern were 5.6 min and 8.8 min, respectively; they were significantly (*LSD*, $P < 0.05$) improved compared to those in the uniform row, wide-narrow row, and seed bed planting patterns; however, there were no significant (*LSD*, $P < 0.05$) differences in dough breakdown time (DBT) between any of the planting patterns. These results suggest that the furrow planting pattern combined with deficit irrigation during the jointing and heading stages can be applied to winter wheat production in the Huang-Huai-Hai Plain of North China.

Keywords: winter wheat; dry matter accumulation; grain yield; nutrient quality; processing quality

The Huang-Huai-Hai Plain in North China reportedly provides about one-fifth of the total state food supply. The major crops in this region were winter wheat and summer maize, and a winter wheat-summer maize double cropping system was adopted (Fang et al. 2007). During the winter wheat growing season (from October to June of the following year), annual precipitation typically does not exceed 200 mm (Li et al. 2007), and evapotranspiration of winter wheat is 400–500 mm. Thus, irrigation is necessary to obtain a high and stable grain yield. During the summer maize growing season (from early June to the end of

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September), annual precipitation is usually greater than 400 mm and irrigation is not needed (Quanqi et al. 2008). Therefore, for the winter wheat-summer maize double cropping system in the Huang-Huai-Hai Plain of North China, irrigation is usually applied during the winter wheat growing season.

However, the Plain comprises only 7.2% of the total national supply of water resources (Zhang et al. 2007). Currently, the ability of the plain to sustain its contribution to China's food supply is at risk because available water resources are diminishing. Most of the rivers in this region have dried up, and water for agricultural use is pumped from the ground. In recent years, the area of wheat to be irrigated has expanded rapidly. Groundwater resources for irrigation in the Plain were excessively exploited (Zhang et al. 2006), resulting in many environmental problems. Xia et al. (2005) found that the groundwater table is falling steadily at the rate of about 1 m/year. To develop a sustainable winter wheat production in this region, water-conserving agricultural methods should be adopted and conventional flood irrigation should be improved. In recent years, some researchers found that good management and adoption of appropriate practices could improve agricultural water use and crops production would be more efficient (Wang et al. 2004). As a result, many planting patterns were introduced to increase water use efficiency and crops grain yield. Li et al. (2009) found that compared to the uniform row pattern, soil profile depletions were higher in the wide-narrow row and seed bed planting patterns and much higher in the furrow planting pattern. Wang et al. (2004) showed that growing winter wheat in a seed bed planting pattern could save as much as 30% of applied irrigation water; in addition to that grain yield increased by more than 10%. Compared with conventional furrow irrigation, alternate furrow irrigation could significantly increase the water use efficiency of winter wheat (Ali and Seyedeh 2008). Planting patterns could also affect the vertical distribution of leaf area index and radiation use efficiency of winter wheat (Li et al. 2008). These studies, however, did not report on the effect of planting patterns on assimilate transportation and grain quality of winter wheat. North China is considered ideal for the production of high-protein wheat because the region has a relatively short grain-filling period and high heat stress during grain filling (Han and Yang 2009).

The objective of this study was to determine the effect of planting patterns on the CDMRG, grain yield, yield composition, nutrient quality, and processing quality of winter wheat under a deficit irrigation regime.

MATERIALS AND METHODS

Experimental site. The study area was located at Tai'an Experimental Station (36°10'19", 117°9'03"), Agronomy College, Shandong Agricultural University, where the annual mean precipitation is 697 mm, of which approximately 65.2% falls from June to September. The winter wheat-summer maize double cropping system dominates agricultural activities in the region. The experiments were conducted in a light loamy soil. The concentration of organic matter was 1.2%, rapidly available phosphorus was 13.2 mg/kg, potassium was 78.5 mg/kg, and nitrogen was 83.1 mg/kg. Wheat variety 8049 was used for the experiment and was sown at the rate of 180.0 grains/m^2 on October 11, 2004 and October 15, 2005. At the time of sowing, 30.0 g/m^2 of triple superphosphate, 30.0 g/m^2 of urea, and 7.5 g/m^2 of potassium chloride were applied to the soil.

Experimental design. The experiment investigated 4 planting patterns (Figure 1), namely, uniform row (30 cm; traditional pattern), wide (40 cm)-narrow (20 cm) row, furrow (double lines in the furrow with 20-cm spacing and 40 cm between furrows), and seed bed (double lines on the bed with 20-cm spacing, and 40 cm between beds). According to previous studies (Li et al. 2007, 2008, 2009), irrigation with 120 mm of water applied during the jointing and heading stages of winter wheat could result in reasonable grain yield and water use efficiency in this region. Therefore, in this study, each planting pattern was irrigated with 60 mm during both the jointing and heading stages, and total irrigation water was controlled at 120 mm. During the 2004–2005 growing season, the jointing and heading stages occurred on April 6 and April 28, respectively; during the 2005–2006 growing season, the jointing and heading stages occurred on April 2 and April 24, respectively. Treatments were randomized using a complete factorial design and were replicated thrice. The area of the plots was 12.0 m^2. Water was supplied to the plots from a pump outlet using plastic pipes, and a flow meter was used to measure the amount of water applied. In the uniform row and wide-narrow row planting patterns, the plastic pipes were placed randomly; in the seed bed and furrow planting patterns, the plastic pipes were placed specifically at each furrow. A 2-m-wide zone without irrigation was positioned between the 2 irrigation plots to minimize the effects of the 2 adjacent plots.

Measurements. Aboveground biomass was estimated at flowering and maturity by sampling small plots consisting of 20 consecutive plants from the

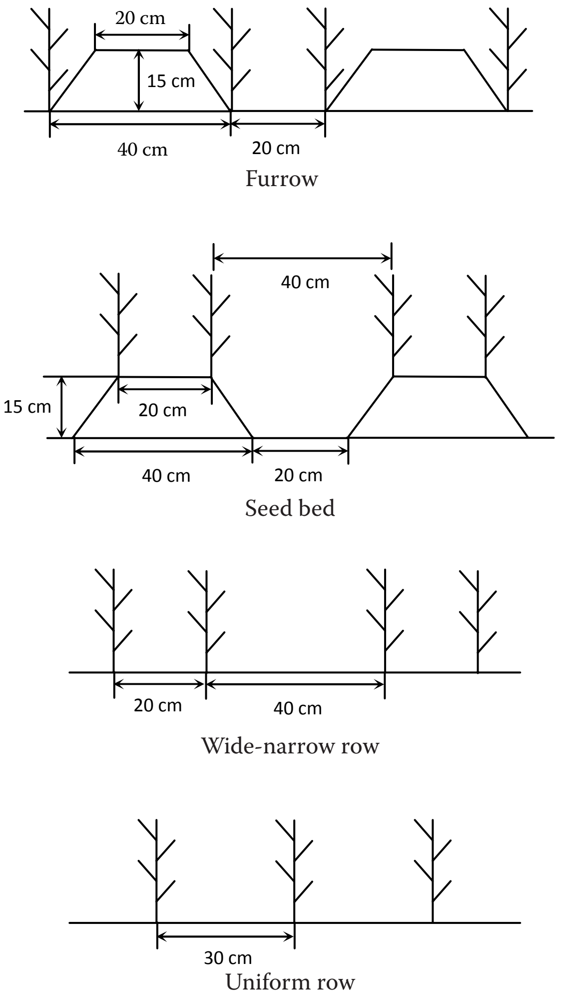

Figure 1. Schematic map of furrow, seed bed, wide-narrow row, and uniform row planting patterns in this study

central rows. The 2 sampling areas were spaced to avoid effects from previous sampling. Dry matter was determined after drying at 80°C for 72 h.

CDMRG was calculated using the following equation (Papakosta and Gagianas 1999):

$$CDMRG = (DMR/GY) \times 100$$

In the above equation, CDMRG is the contribution of dry matter remobilization to grain yield; DMR, dry matter remobilization, is the difference between aboveground dry matter at flowering and at maturity. GY, grain yield, was measured at maturity and corresponded to the central rows of each plot. Spike numbers (per m^2), kernel numbers per spike, and thousand kernel weights were determined.

The grains were milled on a 300-g Brabender Farinograph (Brabender OHG, Duisburg, Germany) following the manufacturer's instructions. Grain protein content was measured with a LECO FP-528 nitrogen/protein determinator and was calculated as 5.7 × N% in grain dry matter. Albumin, globulin, gliadin, and glutenin were sequentially extracted from whole meal flour (Han and Yang 2009).

Mixograph curves (National Manufacturing Division, TMCO, Lincoln, NE, USA) were obtained with a 2-g computerized direct drive mixograph equipped with a water-jacketed bowl maintained at 25°C and 88 rpm; selected responses were wet gluten content (WGC), dough development time (DDT), dough stability time (DST), and dough breakdown time (DBT).

Data statistics. The treatments were run as an analysis of variance (ANOVA). ANOVA was performed at the $\alpha = 0.05$ significance level to determine if significant differences existed among treatments means. Multiple comparison tests were conducted for significant effects using the *LSD* test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

CDMRG. Li et al. (2008) indicated that planting patterns could alter leaf area index in the canopy after heading stages. The leaf area index in the furrow planting pattern at 60–80 cm above the ground surface significantly (*LSD*, $P < 0.05$) increased after the jointing, heading, and milking stages while each was irrigated with 60 mm of water. Approximately 70–80% of the winter wheat yield was the product of the photosynthetic matter of green organs produced after heading in the later growing season; this amount was approximately 60% more than the amount produced by the flag leaves and spikes (Fang et al. 2006). As shown in Figure 2, the CDMRG in the furrow planting pattern was 57.2%, which was by 5.1%, 4.3%, and 2.9% higher than the CDMRG in the uniform row, wide-narrow row, and seed bed planting patterns, respectively. This result indicates that more dry matter was transported from stems and leaves to the grain in the furrow planting pattern than in the uniform row, wide-narrow row, and seed bed planting patterns. The variation in CDMRG could affect grain yield and yield composition of winter wheat.

Grain yield and yield composition. From the figures in Table 1, we can say that grain yield and yield composition were significantly (*LSD*, $P < 0.05$) affected by different planting patterns under deficit irrigation. Yield and yield composition did not differ much among the uniform row, wide-narrow row, and seed bed planting patterns; grain yield in the seed bed planting pattern was higher than those

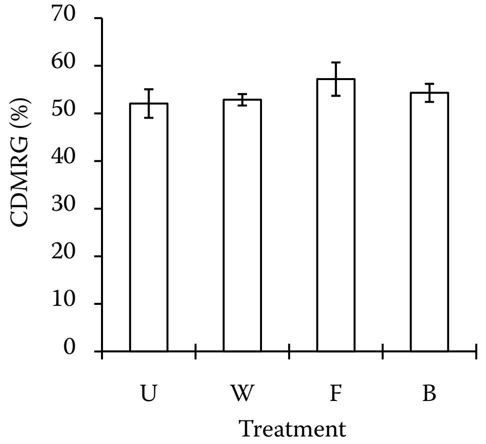

Figure 2. CDMRG in U, W, F, and B under deficit irrigation. Vertical bars are standard errors. U, W, F, and B represent uniform row, wide-narrow row, furrow, and seed bed planting patterns, respectively. The data were the average values in 2005 and 2006

in the uniform row and wide-narrow row planting patterns by only 20.0 and 10.9 g/m^2, respectively, in 2004–2005, and by only 24.1 and 12.4 g/m^2 in 2005–2006. Conversely, grain yield in the furrow planting pattern increased significantly (*LSD*, $P < 0.05$). Compared to the uniform row, wide-narrow row, and seed bed planting patterns, grain yield in the furrow planting pattern increased by 73.4, 64.3, and 53.4 g/m^2 in 2004–2005, respectively, and by 54.3, 42.6, and 30.2 g/m^2 in 2005–2006, respectively. Spike numbers in the furrow planting pattern were significantly (*LSD*, $P < 0.05$) higher than those in the uniform row, wide-narrow row, and seed bed planting patterns by 38.2, 107.6, and 82.9 spikes/m in 2004–2005, respectively, and by 51.4, 62.9, and 62.0 spikes/m^2 in 2005–2006, respectively. The furrow planting pattern produced the highest kernel numbers. Kernel numbers in the furrow planting pattern were significantly (*LSD*, $P < 0.05$) higher than those in the wide-narrow row and seed bed planting patterns by 2.7 and 3.0 kernel/spike in 2004–2005, respectively, and by 0.8 and 1.3 kernel/spike in 2005–2006, respectively. No differences in thousand kernel weight were found between any of the planting patterns. This result suggests that under deficit irrigation, compared with the uniform row and wide-narrow row planting patterns, the seed bed planting pattern has little potential to increase grain yield; however, the furrow planting pattern

Table 1. Yield and yield composition in different planting patterns

Plant patterns	Spike numbers (spikes/m^2)	Percentages in relation to variant U (%)	Kernel numbers (kernel/spike)	Percentages in relation to variant U (%)	Thousand kernel weight (g)	Percentages in relation to variant U (%)	Yield (g/m^2)	Percentages in relation to variant U (%)
2004–2005								
U	806.5^{b}	–	28.5^{ab}	–	46.0^{a}	–	745.2^{bc}	–
W	777.1^{cd}	–3.6	27.7^{bc}	–2.8	46.4^{a}	0.9	754.3^{bc}	1.2
F	844.7^{a}	4.7	30.4^{a}	6.7	46.2^{a}	0.4	818.6^{a}	9.8
B	801.8^{bc}	–0.6	27.4^{bc}	–3.9	46.2^{a}	0.4	765.2^{b}	2.7
LSD (0.05)	26.7		1.4		1.3		23.8	
2005–2006								
U	661.3^{b}	–	25.7^{ab}	–	48.8^{a}	–	730.8^{c}	–
W	649.8^{b}	–1.7	25.2^{bc}	–1.9	48.5^{a}	–0.6	742.5^{bc}	1.6
F	712.7^{a}	7.8	26.0^{a}	1.2	49.0^{a}	0.4	785.1^{a}	7.4
B	650.7^{b}	–1.6	24.7^{c}	–3.9	48.6^{a}	–0.4	754.9^{b}	3.3
LSD (0.05)	34.3		0.7		1.6		21.1	

Each result is the average of three repetitions. In each growing season, values followed by different letters are significantly ($P < 0.05$) different among planting patterns. U, W, F, and B represent uniform row, wide-narrow row, furrow, and seed bed planting patterns, respectively

Table 2. Grain protein content (%) and protein composition in different planting patterns

Plant patterns	Albumin	Globulin	Gliadin	Glutenin	Protein
U	1.16^{a}	0.56^{a}	4.53^{c}	5.45^{b}	11.70^{bc}
W	1.18^{a}	0.55^{a}	4.57^{b}	5.48^{b}	11.78^{b}
F	1.19^{a}	0.57^{a}	4.67^{a}	5.85^{a}	12.28^{a}
B	1.16^{a}	0.54^{a}	4.53^{c}	5.42^{b}	11.65^{c}
LSD (0.05)	0.53	0.61	0.06	0.42	0.11

Each result is the average of three repetitions. Values followed by the same letter in the same column are not significantly different. Different small letters indicate significance at the 0.05 level. U, W, F, and B represent uniform row, wide-narrow row, furrow, and seed bed planting patterns, respectively

has the potential to significantly increase winter wheat yield because of increased spike and kernel numbers. In addition, the uniform row planting pattern produced the lowest grain yield, possibly because of the use of flood irrigation. Wang et al. (2004) reported that the use of flood irrigation in flat planting can result in low potential irrigation water use efficiency and inefficient use of nitrogen. It can also cause crusting of the soil surface and can contribute to the degradation of some soil properties.

Grain protein content and protein composition. As shown in Table 2, planting patterns had a relatively significant effect on grain protein content. Grains grown using the furrow planting pattern had the highest protein content, followed by those grown using wide-narrow row and uniform row planting patterns; the lowest protein content (only 11.65%) was found in the grains grown using seed bed planting pattern. Compared with grain yield, the seed bed planting pattern had a reverse influence on grain protein content. Based on these findings, the best planting pattern for protein content was furrow planting.

The effect of planting patterns on protein composition was inconsistent. For albumin and globulin contents, no significant (*LSD*, $P < 0.05$) differences were found between planting patterns. However, for gliadin and glutenin contents, the furrow planting pattern produced the highest values, followed by the wide-narrow row and uniform row planting patterns; the seed bed planting pattern resulted in the lowest values, but no significant (*LSD*, $P < 0.05$) differences were found between the uniform row and seed bed planting pattern. Albumin and globulin accumulated in the early stages of grain filling and gliadin and glutenin accumulated in the later stages (Liu et al. 2007). This result suggests that the furrow planting pattern had a significant effect on the growth and development of winter wheat in the later growing season. Gliadin and glutenin are the main protein components of gluten; hence, the planting patterns could affect the processing quality of winter wheat.

WGC and flour dough farinographic properties. As shown in Table 3, when the uniform row planting pattern was changed to the furrow planting pattern, WGC increased significantly (*LSD*, $P < 0.05$), mainly because the furrow planting pattern produced the highest gliadin and glutenin contents. Han and Yang (2009) found that WGC was significantly influenced by uniconazole concentration. Increasing uniconazole concentration contributed to a significant increase in WGC content at 3 densities. These results strongly suggest that winter wheat quality responded well to the environment and reinforce the importance of crop management strategies to reach desired flour quality.

Table 3 also presents the values of DDT, DST, and DBT. Values were higher in the wide-narrow row, furrow, and seed bed planting patterns than in the uniform row planting pattern, which suggests that planting patterns could improve the processing quality of winter wheat. However, the effects of planting patterns on DDT, DST, and DBT were inconsistent. Compared to the uniform row planting pattern, DDT and DST in the furrow and seed bed planting patterns were significantly (*LSD*, $P < 0.05$) increased; however, there were no significant (*LSD*, $P < 0.05$) differences in DBT between any of the planting patterns.

Considering the deficit conditions of water resources in China and the need for economic efficiency, farming profitability may benefit through (1) less input when the cost of irrigation water is included in deficit irrigation, or (2) increased grain yield and quality. Alternate planting patterns, such as combining furrow planting with deficit

Table 3. Effect of planting pattern on parameters of the processing quality of winter wheat

Plant patterns	WGC (%)	DDT	DST	DBT
		(min)		
U	31.0^{b}	5.0^{c}	6.9^{d}	8.1^{a}
W	31.4^{ab}	5.1^{c}	7.6^{c}	8.2^{a}
F	32.1^{a}	5.6^{a}	8.8^{a}	8.3^{a}
B	31.7^{ab}	5.3^{b}	8.2^{b}	8.2^{a}
LSD (0.05)	0.9	0.1	0.4	0.4

Each result is the average of three repetitions. Values followed by the same letter in the same column are not significantly different. Different small letters indicate significance at the 0.05 level. U, W, F, and B represent uniform row, wide-narrow row, furrow, and seed bed planting patterns, respectively

irrigation, may be a useful method for developing agriculture in the Huang-Huai-Hai Plain of North China.

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