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Full Length Article

Precision Planting Patterns Effect on Growth, Photosynthetic Characteristics and Yield of Winter Wheat under Deficit Irrigation

Y.Y. Han†, X.Y. Wang† and X.B. Zhou*
State Key Laboratory of Crop Biology, Agricultural College of Guangxi University, Nanning 530004, China
†Y.Y. Han and X.Y. Wang are co-first authors
*For correspondence: whyzxb@gmail.com

Abstract

Different cultivation patterns affect the grain yields of winter wheat by regulating growth and development. In this study, the growth of wheat was observed for two years (2008–2009 and 2009–2010). We established three cultivation patterns: 25 cm uniform row planting pattern; "20 cm + 40 cm" wide-narrow row planting pattern (wide-narrow row spacing is 40 cm and 20 cm respectively); and "20 cm + 40 cm" furrow planting pattern (double lines in the furrow with 20 cm spacing, 40 cm between furrows, and ridge height of 15 cm). Three irrigation treatments viz. 90, 135 and 180 mm were established. Results showed that furrow planting pattern improved the ratio of variable over maximum fluorescence (Fv/Fm).With increasing irrigation amount, Fv/Fm increased, the amplification declined, and the net photosynthetic rate in flag leaves increased. However, such effect was not obvious beyond the irrigation range stipulated. Therefore, we recommend the furrow planting pattern, which resulted in stable yield and 135 mm deficit irrigation as optimum considering the water shortage in the area.

Keywords: *Triticum aestivum*; Chlorophyll content index; Photosynthetic rate; Fv/Fm; Net assimilation rate

Introduction

As a major crop of North China Plain, the area of winter wheat (*Triticum aestivum* L.) is 14,560,000 ha and accounts for 53% of wheat production in China (Lu and Fan, 2013). However, the amount of water resources is important for wheat production (Sun *et al.*, 2006). Leaf stomatal conductance and inhibition of photosynthetic metabolism are limited by water deficit and reduces plant productivity of winter wheat eventually (Degl'Innocenti *et al.*, 2008). To guarantee the high and stable grain yield, 400 mm to 500 mm of water supply is must during the growth season (Sacks *et al.*, 2010; Sabar and Arif, 2014). The average annual rainfall in Taian from 1971 to 2008 was 696.6 mm, but the precipitation was mainly concentrated in July and August (Han *et al*., 2014). Therefore, we need to protect water resources and improve water use efficiency (Shao *et al*., 2007). Deficit irrigation is the optimal method to reduce the water consumption and maximize yield (Panda *et al*., 2003). Hamid *et al*. (2012) indicated that with deficit irrigation, approximately 22% of irrigation water may be saved without significant loss in wheat grain yield.

The photosynthetic characteristics and associated regulatory mechanisms in different environments have been widely studied in the field of crop science. Water deficit strongly reduces photosynthetic activity at the light saturation level (Shangguan *et al.*, 2000). The response of wheat photosynthesis to irrigation has been well studied and reviewed (Wang *et al*., 2013). The leaf area index (LAI) reduction is delayed at post-anthesis with increased irrigation volume and delayed irrigation. Roy *et al*. (2012) reported that the mean LAI and net assimilation rate (NAR) is important for the extent of aboveground and belowground dry matter production rate.

With the increasing demand of food, the application of non-invasive remote sensing techniques is mainly focused by farmers in China. A reduction in the ratio of variable over maximum fluorescence is linearly correlated with the quantum efficiency of electron transport and is an indicator of photo-inhibition (Maxwell and Johnson, 2000). Collecting water from light rain and reducing un-productive evaporation benefit from an appropriate planting pattern (Jia *et al*., 2006). Zhang *et al*. (2007) focused on decreasing the amount of irrigation and optimizing yield.

The present study determined that different precision planting patterns and deficit irrigation treatments affect the NAR at different growth stages (GSs); chlorophyll content and maximal quantum yield of PS II in flag leaves; grain yield and net photosynthetic rate (Pn) of winter wheat. These could provide good agronomic measures to increase grain yield and water-saving planting pattern in North China Plain for winter wheat.

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Materials and Methods

Experiment Site

The present experiment was conducted at the Experimental Farm of Shandong Agricultural University, Taian (36°10′N, 117°09′E) in Northern China. The soil was silty loam with an average soil organic matter content of 16.3 g kg^{-1}, pH of 6.9, soil bulk density of 1.50 g cm^{-3} and a field capacity of 38.6% (V%).

Taian Agro-meteorological Experimental Station is the site of collecting precipitation and solar radiation data, 500 m away from the experimental site. The precipitation received during the winter wheat growth seasons (October to September) was 159.2 and 149.3 mm in 2008–2009 and 2009–2010, respectively (Fig. 1). The total solar radiations in previous years were 1,414 W m^{-2} with the highest and lowest values obtained in May and December, respectively.

Experimental Design

Winter wheat (cv. 8049) was planted by hand on 14 October 2008 and 8 October 2009 and harvested on 10 June 2009and 13 June 2010 after removal of maize (*Zea mays* L.) stubbles. A total of 36 experimental plots (each 3 m × 3 m in size) were established with the same plant population density of 1.8 × 10^6 plants ha^{-1} (Fig. 2). The timing and amount of irrigation (mm) during the growth season of winter wheat are listed in Table 1. At the time of sowing, 120 m^3 ha^{-1} of manure was applied. Then, 225 kg ha^{-1} of N, 120 kg $ha^{-1}$of P_2O_5, and 105 kg $ha^{-1}$of K_2O were spread over the field as base fertilizers. Plastic pipes were used to supply water with a water meter to measure the irrigation amount. The irrigation methods were furrow irrigation for furrow and flood irrigation for uniform row and wide-narrow row.

Plant Sampling and Computation

An area of 0.5 m^2 was selected with the representative plants at the center of the plots for measurement of the aboveground dry matter weight of winter wheat at GS37, GS47, GS50, GS65, GS73, and GS85. Fifteen representative plants as samples were selected. The leaf, stem, and ears of samples were separated and placed in a drying oven at 105°C (20 min) and dried at 80°C (72 h) until a constant weight reached. The leaf area was calculated using the following equation:

Leaf area = leaf length × leaf width × 0.83

Where, the distance between the leaf pillow and tip measured as leaf length and the widest part measured as leaf width.

NAR (g m^{-2} d^{-1}) was calculated by the following equation (Roy *et al*., 2012):

$$NAR=[(W_2-W_1)/(t_2-t_1)]\times[(\ln LAI_2-\ln LAI_1)/(LAI_2-LAI_1)]$$

Where, W_1, W_2, LAI_1 and LAI_2 stand for dry matter weight and LAI at times t_1 and t_2, respectively.

Table 1: The timing and amount of irrigation (mm) for winter wheat in 2008–2009 and 2009–2010

GS37; (2009 Apr. 2, 2010 Apr. 2)	GS50; (2009 Apr. 24, 2010 Apr. 27)	GS73; (2009 May13, 2010 May15)	Total
30	30	30	90
45	45	45	135
60	60	60	180

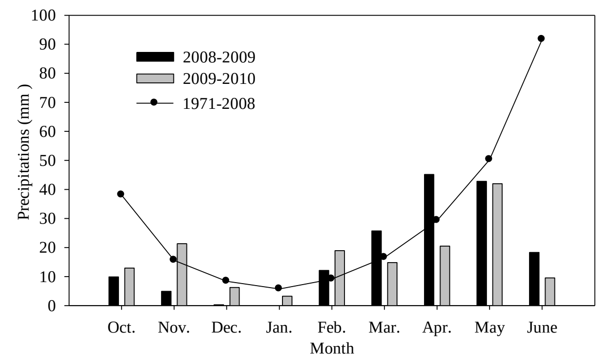

Fig. 1: Precipitations (mm) in the growing season of winter wheat

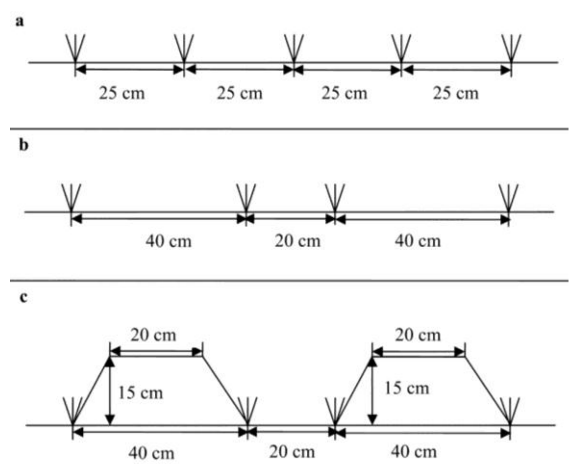

Fig. 2: A schematic diagram showing uniform row planting pattern (a), 20 + 40 wide-narrow row planting pattern (b), 20 + 40 furrow planting pattern (c)

The chlorophyll content index (CCI) of flag leaves was measured by CCM-200 (Opti- Sciences, USA) on a clear day from 9 a.m. to 11 a.m. at GS50, GS65, and GS73. The Pn in flag leaves was measured by a portable infrared gas analyzer (LI-6400; LI-COR Inc., Lincoln, USA). Five pieces of flag leaves with growth consistency and similar light direction were used to measure Pn on a clear day from 9 to 11 a.m. at GS47, GS50, GS65, GS73 and GS85. Chlorophyll *a* fluorescence transients were measured by an integral PEA senior (Hansatech, UK) with dark-adapted leaves under ambient CO_2 conditions. Grain yield was randomly measured in an area of 1 m^2 in each plot on 10 June 2009 and 13 June 2010.

Statistical Analysis

SigmaPlot 10.0 (SPSS Inc., Chicago, IL) was used to draw all graphs and ANOVA to analyze all data. The least significant difference test was used. Effects were considered significant in all statistical calculations at $P \leq 0.05$ (Mishra *et al*., 2001).

Results

Chlorophyll Content Index (CCI)

The effects of different planting patterns and irrigation treatments on CCI in winter wheat are shown in Table 2. The order of the CCI was furrow > wide-narrow row > uniform row (except at GS65 in 2008–2009, in which the order of CCI was furrow > uniform row > wide-narrow row). In both growing seasons, the CCI value of furrow was significantly higher than of uniform row and wide-narrow row ($P < 0.05$) at GS50, GS65 and GS73. At the three GSs, the CCI averages of furrow were higher than of uniform row and wide-narrow row by 2.68 and 2.38 in 2008–2009 and by 3.70 and 1.11 in 2009–2010 respectively, but the difference was not significant ($P > 0.05$).

The values of CCI significantly increased ($P < 0.05$) with increasing irrigation amount at the three GSs, but the amplification decreased. The averages of CCI at the three GSs increased with increasing irrigation amount ($P < 0.05$), and the average of amplification during the two years from 90 mm to 135 mm and from 135 mm to 180 mm were 6.15% and 3.72%, respectively.

By contrast, the values of CCI were significantly affected by planting pattern and irrigation ($P < 0.01$) at the three GSs. The interaction between planting pattern and irrigation was significantly affected ($P < 0.01$) at the GSs.

Quantum Yield of PSII (Fv/Fm)

The Fv/Fm of furrow was significantly higher ($P < 0.05$) than of uniform row at all GSs in the two years and significantly higher ($P < 0.05$) than of wide-narrow row at GS65, GS73 and GS85 in 2008–2009 and at GS47, GS50, GS65 and GS73 in 2009–2010. The Fv/Fm averages of furrow at all GSs were 0.8081 in 2008–2009 and 0.8157 in 2009–2010 and higher than uniform row and wide-narrow row by 0.0191 and 0.0128 in 2008–2009 and 0.0125 and 0.0048 in 2009–2010, respectively. Therefore, the furrow improved Fv/Fm.

Under the different irrigation amounts, the Fv/Fm gradually increased and the maximum values were attained at GS50, after which the Fv/Fm subsequently decreased. The values of Fv/Fm at 135 mm irrigation were significantly higher ($P < 0.05$) than at 90 mm irrigation in both years. The Fv/Fm values at 180 mm irrigation were significantly higher ($P < 0.05$) than at 135 mm irrigation at GS50 and GS65 in 2008–2009 and at GS47, GS50 and GS85 in 2009–2010. The average values of Fv/Fm at 180 mm irrigation were higher than at 90 and 135 mm irrigation at all GSs. The averages of amplification from 90 mm to 135 mm and from 135 mm to 180 mm were 1.41 and 0.95%, respectively. Thus, Fv/Fm increased with increasing irrigation amount, but the amplification decreased.

By contrast, the Fv/Fm values were significantly affected by planting pattern ($P < 0.05$) at all GSs in both years and by irrigation ($P < 0.05$) at GS47, GS73 and GS85 in 2008–2009 and at all GSs in 2009–2010. The interaction between planting pattern and irrigation was not significantly affected ($P < 0.05$) at all GSs in both years, except at GS47 in 2008–2009 and at GS85 in 2009–2010 (Table 3 and 4).

Net Assimilation Rate (NAR)

Under a specific irrigation amount, NAR initially increased, decreased, and then increased again. The lowest NAR value was at GS65 in both years of the study, except at 90 mm irrigation in 2009–2010. The NAR values obtained in both years under the different planting patterns at GS73 were in the following order: uniform row > wide-narrow row > furrow. At all GSs, except at GS73, in both years, the NAR of furrow was significantly higher ($P < 0.05$) than of uniform row and wide-narrow row at all GSs (except at GS50, in which the NAR of wide-narrow row was higher than furrow, but the difference was not significant under 90 mm irrigation in 2009–2010, and GS50 and GS65 under 135 mm irrigation in 2008–2010).

The values of NAR at 90 mm irrigation were significantly higher ($P < 0.05$) than at 135 and 180 mm irrigation at GS37, GS50 and GS73 in 2008–2009 and at GS47, GS65 and GS73 in 2009–2010. The averages of NAR at all GSs decreased with increasing amount of irrigation, and the reduction values from 90 mm to 135 mm and from 135 mm to 180 mm were 11.69 and 12.27% in 2008–2009 and 10.92 and 10.54% in 2009–2010, respectively (Fig. 3).

Regression of Net Photosynthetic rate (Pn) vs. Grain Yield

Grain yield showed a positive trend with increasing Pn under all planting patterns in 2008–2009 and 2009–2010 (Fig. 4). For uniform row, wide-narrow row, and furrow, a linear regression significantly fitted ($P < 0.001$) to these data showed an average increase of grain yield per ha of 5343, 2035 and 2666 kg in 2008–2009 and 579, 733 and 215 kg in 2009–2010, respectively. Under uniform row, wide-narrow row, and furrow, grain yield increased on average by 23.3%, 18.6% and 13.1% in 2008–2009 and by 12.3%, 8.5% and 4.0% in 2009–2010, respectively. The average grain yield values of furrow were significantly higher ($P < 0.05$) than of uniform row and wide-narrow row by 669 and 260 kg ha^{-1} in 2008–2009 and 758 and 336 kg ha^{-1} in 2009–2010, respectively. Regardless of the planting pattern, the equations of grain yield vs. Pn were as follows: y (grain yield, kg ha^{-1}) = 1508x (Pn, μmol CO_2 m^{-2} s^{-1}) − 24032, $R^2 = 0.9409$, $P < 0.0001$ in 2008–2009; and y (grain yield, kg ha^{-1}) = 616x (Pn, μmol CO_2

Table 2: Effects of different planting patterns and irrigation on chlorophyll content index (CCI) in winter wheat

Treatments		GS50		GS65		GS73	
		08-09	09-10	08-09	09-10	08-09	09-10
Planting pattern	Uniform row	42.45c	47.70c	40.80b	46.01c	36.33c	39.51c
	Wide-narrow row	43.39b	50.90b	39.16c	48.33b	37.96b	41.75b
	Furrow	46.26a	51.31a	41.54a	50.26a	39.84a	42.75a
	LSD (0.05)	0.62	0.19	0.62	0.22	0.56	0.42
Irrigation	90 mm	41.35c	48.20c	37.79c	46.68c	35.61c	39.26c
	135 mm	44.69b	49.63b	41.06b	48.40b	38.74b	41.22b
	180 mm	46.06a	52.08a	42.65a	49.52a	39.78a	43.53a
	LSD (0.05)	0.61	0.26	0.57	0.23	0.63	0.36
Source of variation		*P > F*					
Planting pattern		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Irrigation		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Planting pattern × Irrigation		0.0001	0.0001	0.0001	0.0001	0.0003	0.0027

Table 3: Effects of different planting patterns and irrigation on maximal quantum yield (Fv/Fm) in flag leaves of winter wheat in 2008–2009

Treatments		GS47	GS50	GS65	GS73	GS85
Planting pattern	Uniform row	0.7959b	0.8080a	0.8006b	0.7849b	0.7554b
	Wide-narrow row	0.8104a	0.8142a	0.7997b	0.7883b	0.7639b
	Furrow	0.8192a	0.8217a	0.8161a	0.8006a	0.7828a
	LSD (0.05)	0.0103	0.0096	0.0110	0.0108	0.0087
Irrigation	90 mm	0.7895b	0.8093b	0.8006b	0.7848a	0.7603a
	135 mm	0.8100a	0.8136b	0.8020b	0.7915a	0.7685a
	180 mm	0.8172a	0.8299a	0.8138a	0.7975a	0.7733a
	LSD (0.05)	0.0126	0.0131	0.0105	0.0093	0.0084
Source of variation		*P > F*				
Planting pattern		0.0001	0.0286	0.0164	0.0020	0.0001
Irrigation		0.0001	0.3312	0.0700	0.0207	0.0247
Planting pattern × Irrigation		0.0051	0.9656	0.9631	0.8035	0.7333

Table 4: Effects of different planting patterns and irrigation on maximal quantum yield (Fv/Fm) in flag leaves of winter wheat in 2009–2010

Treatments		GS47	GS50	GS65	GS73	GS85
Planting pattern	Uniform row	0.8050c	0.8210c	0.8155c	0.8120c	0.7625b
	Wide-narrow row	0.8105b	0.8235b	0.8198b	0.8173b	0.7835a
	Furrow	0.8130a	0.8286a	0.8242a	0.8218a	0.7912a
	LSD (0.05)	0.0015	0.0020	0.0039	0.0021	0.0091
Irrigation	90 mm	0.8015c	0.8217c	0.8148b	0.8105b	0.7438c
	135 mm	0.8082b	0.8244b	0.8209a	0.8196a	0.7903b
	180 mm	0.8188a	0.8271a	0.8238a	0.8210a	0.8030a
	LSD (0.05)	0.0010	0.0021	0.0035	0.0032	0.0095
Source of variation		*P > F*				
Planting pattern		0.0001	0.0001	0.0001	0.0001	0.0001
Irrigation		0.0001	0.0005	0.0001	0.0001	0.0001
Planting pattern × Irrigation		0.0559	0.3947	0.0568	0.2874	0.0109

m^{-2} s^{-1}) –4424, R^2 = 0.9549, P < 0.0001 in 2009–2010. The average yields of 90, 135, and 180 mm were 7429, 7903, and 8189 kg ha^{-1}, respectively. The yield of 135 mm was higher than of 90 mm by 6.7%, and of 180 mm than of 135 mm by 3.6%.

Discussion

In previous years, the technique of CCI has become ubiquitous in plant eco-physiology studies (Girma *et al.*, 2013). Low CCI decreases the light absorbance and then reduces the heating effects of high light intensities (Wahid *et al*., 2007). At three GSs, the CCI values of furrow were significantly higher than of uniform row and wide-narrow row (P < 0.05) and capture more light energy for photosynthesis. The furrow improved soil moisture of dry farmland and promoted the development of corn root systems, which favorable increased CCI (Ren *et al*., 2010). The CCI value increased with increasing irrigation amount, but the extent gradually decreased. Too much water can significantly reduce the CCI (Pirzad *et al*., 2011).

As the ratio of variable to maximal fluorescence, Fv/Fm defines the efficiency of excitation energy capture in dark-adapted leaves (Escobar-Gutiérrez and Combe, 2012). By analyzing the change of chlorophyll fluorescence can

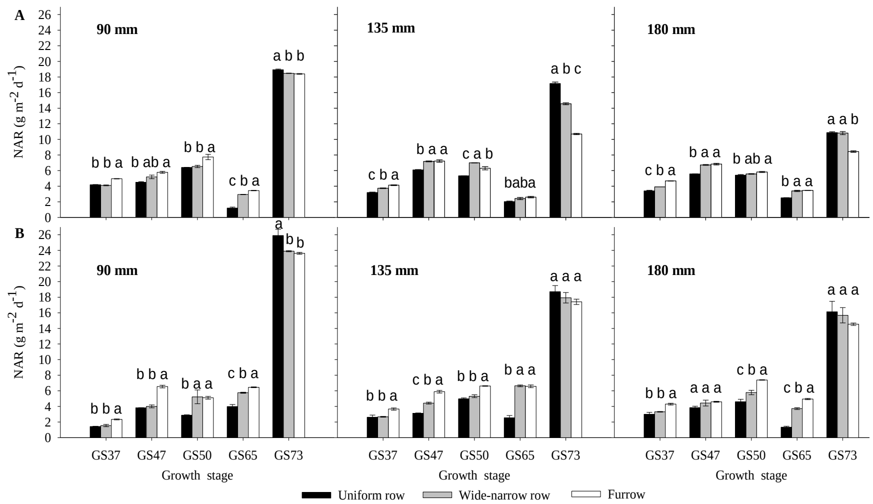

Fig. 3: Effects of different planting patterns and irrigation on net assimilation rate (NAR) of winter wheat in 2008–2009 (A) and 2009–2010 (B)

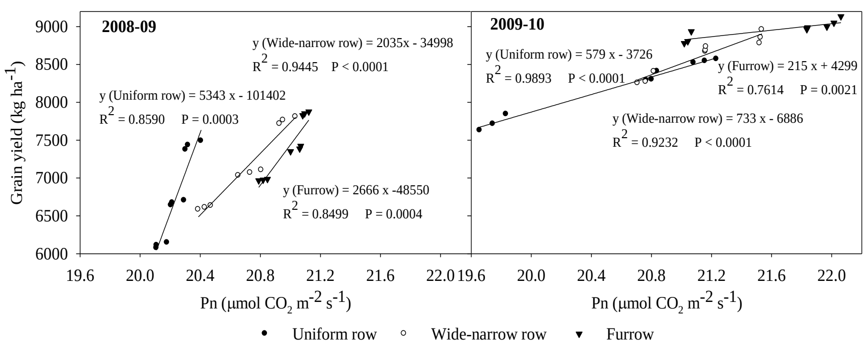

Fig. 4: Regression of Pn vs. grain yield for winter wheat in 2008–2009 and 2009–2010

understand the influence of environmental factors on the crops (Jiang *et al*., 2003). In this study, the value of Fv/Fm at 90 mm irrigation was lower than of 135 mm and 180 mm. The Fv/Fm of furrow was significantly higher ($P < 0.05$) than of uniform row. The drought stress had great inhibitory effect on Fv/Fm (Wu and Bao, 2011).

NAR affected the extent of aboveground and belowground dry matter production rate (Roy *et al*., 2012). We found that under a specific irrigation amount, NAR increased-decreased-increased trend and the lowest NAR was at GS65. This variation may be due to leaf assimilation ability restrained with vegetative growth at jointing stage, but the nutrient in the vegetative organs start to transport for reproductive growth, thus leaf assimilation ability raise.

Tambussi *et al*. (2005) indicated that the photosynthesis after anthesis and during grain filling play important role for the final grain yield. The wide-narrow planting pattern improved leaf photosynthesis by changing the local farmland microclimate (Fernado *et al*., 2002). In our study, the grain yield gradually increased with the increasing photosynthesis. The photosynthesis and yield of furrow was higher than of uniform row and wide-narrow row. Water supply conditions affect the wheat leaf extension and leaf stomatal opening and then affect the photosynthesis (Winkel *et al*., 2001). The yield of winter wheat increased with the increasing irrigation, but the amplification decreased.

Conclusion

This study reinforces the potential of planting pattern and irrigation to dynamically vary the NAR at different GSs; CCI, Pn and Fv/Fm in flag leaves; and grain yield. The furrow planting pattern produced stable yield of winter wheat. Considering the water shortage in the Huanghuaihai plain, 135 mm irrigation should be widely adopted to achieve sustainable grain production in this region.

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