

IRRIGATION SCHEDULES AND PLANTING MODES IMPACT ON FARMLAND MICROCLIMATE AND DRY MATTER ACCUMULATION OF WINTER WHEAT

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ABSTRACT

The economic yield of wheat (*Triticum aestivum* L) comes from the grain, and the dry matter accumulation of the grain is affected by the environmental factors, especially the temperature. A field experiment was conducted in Huanghuaihai Plain from 2014 to 2016 using the split-plot design with three replications following three irrigation schedules (main plot): irrigation of 50 mm each at jointing growth stage (GS34) and heading growth stage (GS48, W1); irrigation of 100 mm at GS48 (W2); and irrigation of 100 mm each at both GS34 and GS48 (W3) and three planting modes (split plot): uniform row (U), furrow (F), double-double row (DD) to explore the mechanism for improving yield and dry matter accumulation under reasonable temperature and relative humidity in farmland caused by irrigation and planting modes. The results showed that air temperature and relative humidity (RH) at 5 cm aboveground (AG₅) were greater than those at 50 cm aboveground (AG₅₀) during the two growing seasons. The average air temperature at AG₅ and AG₅₀ of W2 was 3.69% higher than that of W3, and RH was 5.21% lower than that of W3. With the increasing irrigation amount (W3) and frequency (W1), the average air and soil temperature were reduced while RH, dry matter accumulation rate for stem, leaf, spike and yield were increased significantly. Although DD and F as good planting modes have been detected to improve RH, dry matter and yield accumulation rates and decrease temperature as compared with U, the DD contributed more towards them. The AG₅ and AG₅₀ average air temperatures had a significantly negative correlation with total dry matter and yield accumulation rate, whereas RH showed the opposite mode. Meanwhile, spike dry matter accumulation rate plays a dominant role in improving yield because there was an extreme significant positive correlation between spike and yield accumulation rate. Consequently, irrigation 50 mm each at GS34 and GS48 combined with double-double row planting mode is a good agronomy method to be applied in the regions of scarce water resources like the Huanghuaihai Plain based on the water-saving technology.

Keywords: air temperature; dry matter; relative humidity; soil temperature; *Triticum aestivum* L

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INTRODUCTION

Wheat (*Triticum aestivum* L.), which constitutes the main source of the most important basic food stuffs of human beings (Lobell *et al.*, 2013), is one of the most cultivated crops in the world, and irrigated regions contribute a large proportion to global wheat production (Asseng *et al.*, 2017). Current population and economic growth mean a higher demand for food worldwide (Tilman *et al.*, 2011). China is the greatest wheat producer in the world, and the Huanghuaihai Plain is a major wheat region in China. In this region, the precipitation is approximately 700 mm, and approximately 25%–30% of the total precipitation occurs during the winter wheat growing season. The water source usually is a pressure for wheat growth because of the absence of underground and surface water (Shi and Shao, 2000), and a crucial limiting factor for wheat production is insufficient precipitation (Li *et al.*, 2009; Zhou *et al.*, 2020). Therefore, irrigation is needed.

Climate change will positively or negatively affect crop yields. Previous studies have shown that wheat yield in some areas could be reduced by high temperatures

(Shimoda *et al.*, 2015). The wheat yield is inversely related to temperature because high temperature accelerates crop phenological development, resulting in a shorter growing season with less grain yield (He *et al.*, 2015), while it has a positive relationship with precipitation (Doğan and Kan, 2019).

Meteorological records show that mean annual temperatures over global areas where wheat is grown have increased by ~1°C during the last century (Zhao *et al.*, 2017). Crops are sensitive to changes in temperature and precipitation as a result of climate change (Rosenzweig *et al.*, 2014). European farmers are currently adapting to changing the timing of cultivation (Olsen *et al.*, 2011). The adaptation of cropping systems to climate change provides less sensitive information on the climatic drivers of winter wheat production from time-series yield data (Licker *et al.*, 2013). The use of plastic mulch and covered crops increased soil water storage and average soil temperature and decreased soil evaporation, which in turn increased wheat yield (He *et al.*, 2017).

In our previous studies, an optimized planting mode combined with reasonable irrigation was a good

agricultural practice to improve the farmland microclimate, including temperature and humidity (Wang *et al.*, 2015). However, there is no comparison between the furrow and double planting modes under different irrigation schedules. To achieve this objective, we assessed irrigation schedules and planting modes based on air temperature, relative humidity (RH), soil temperature and the dry matter and yield accumulation rate. The dry matter and grain yield of wheat are not only limited but increased as well provided optimum environmental factors during the growing season along with nutrients supported from the soil. A field experiment was conducted to test the hypothesis that farmland microclimates under different irrigation schedules and planting modes are crucial for high yield.

MATERIALS AND METHODS

Site description: The experiment was conducted at the Agronomy Experimental Station of Shandong Agricultural University, Tai'an, Shandong in China (36°09'N, 117°09'E) from October 2014 to June 2016. The mean monthly temperature and annual precipitation were 10.7°C and 245 mm (2014–2015), 10.8°C and 262 mm (2015–2016), respectively (Fig. 1). The experimental field was a silt loam, and the 0–20 cm soil layer was characterized by a soil bulk density of 1.50 g cm⁻³, pH of 6.9, soil organic matter content of 18.9 g kg⁻¹, and available N, P, and K of 123.2 mg kg⁻¹, 40.6 mg kg⁻¹ and 124.5 mg kg⁻¹, respectively.

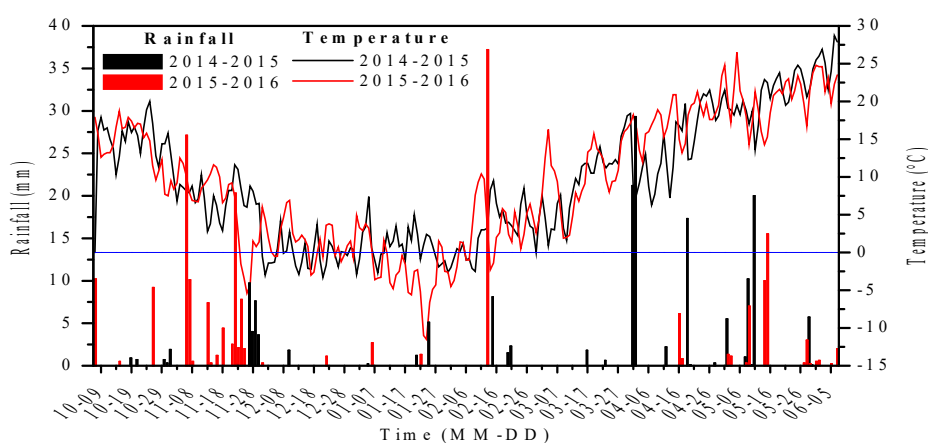


Fig. 1. Daily rainfall and air temperature during the 2014–2015 and 2015–2016 growth seasons.

Experimental design: Winter wheat and summer maize cropping system was adopted in the experiment site. After the harvest of summer maize on 27 Sept., 2014 and 30 Sept., 2015, the land prepared for seed bed was ploughed and levelled on 6 Oct., 2014 and 5 Oct., 2015. The winter wheat (cultivar Jimai 22) plant density was 200×10^4 ha⁻¹, and winter wheat was planted manually on 8 Oct., 2014 and 7 Oct., 2015 and harvested on 7 Jun., 2015 and 7 Jun., 2016, respectively. The experimental plot area was 3×3 m² with three replicates; 112.5 kg ha⁻¹ N, 120 kg ha⁻¹ P₂O₅ and 105 kg ha⁻¹ K₂O as base mineral fertilizers were added to the soil, and half of the total N (250.0 kg ha⁻¹) was applied at the stem elongation stage (GS30, Zadoks *et al.*, 1974) as a top-dressing. The experiment was conducted in a split-plot design. The main plot was the following three irrigation schedules: irrigation of 50 mm each at jointing growth stage (GS34, 27 Mar., 2015 and 27 Mar., 2016) and heading growth stage (GS48, 26 Apr., 2015 and 25 Apr., 2016) (W1); irrigation of 100 mm at GS48 (W2); and irrigation of 100 mm each at GS34 and GS48 (W3, Zadoks *et al.*, 1974). Water was supplied to the plots using plastic pipes, and a flow meter was used to measure the irrigation amount. The plot was buried on all four sides using concrete slabs that were 2 m deep and 15 cm wide. The

split plot consisted of the following three planting modes: uniform row (U), furrow (F), and double-double row (DD, Fig. 2). The row spacing was 30 cm for U, 15 cm and 5 cm (double rows) alternated for DD, and 20 cm and 40 cm alternated for F.

Farmland microclimate: The air temperature and RH were monitored at 5 and 50 cm aboveground (AG₅ and AG₅₀), respectively, in the same inter-row space with a Pocket Weather Tracker Kestrel 4000 (Nielsen–Kellerman Co., Boothwyn, USA) at jointing (GS35), flag leaf (GS44), heading (GS49), filling (GS71) and maturity (GS80) growth stages, respectively. The soil temperature at 0 cm, 5 cm, 10 cm, and 15 cm depth was measured in the center of the row from April 1 to May 30 every 6 d at 8:00 am and 14:00 pm with a geothermometer. The experiment was performed in triplicate.

Dry matter accumulation and yield: Dry matter was measured at GS80 following Zhou *et al.* (2021). The stochastically collected uniformly-growing fifteen strains and 1 m² of wheat per plot as samples, in which the leaf, stem, and spike of fifteen strains of wheat per plot were separated, and dried in an oven at 105°C for 30 min followed by drying at 80°C until a constant weight was

reached, and then dry matter and yield were determined. The dry matter accumulation rate was computed with the following equation:

Dry matter accumulation rate = Dry matter (kg ha⁻¹)/days

where days refers to the total number of days from sowing growth stage (GS0) to GS80 for stem, leaf and total dry matter, i.e., 234 days (2014–2015) and 238 days (2015–2016), respectively, and from GS49 to GS80 for grain, i.e., 38 days (2014–2015) and 43 days (2015–2016), respectively.

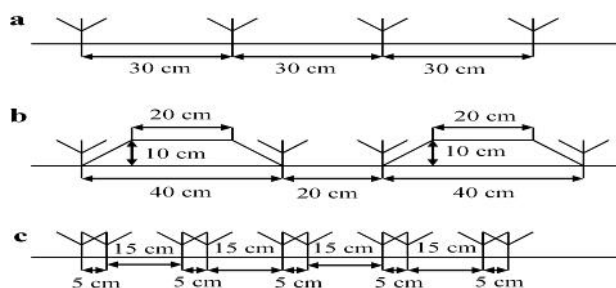


Fig. 2. Planting modes schematic diagram. a, uniform row (U); b, furrow (F); c, double-double row (DD).

Statistical analyses: All graphs were drawn with Origin 8 (OriginLab Corporation, Northampton, USA) and

SigmaPlot 12.5 (SPSS Inc., Chicago, USA), and all data were analyzed with SAS 9.2 software (SAS Institute Inc., Cary, NC, USA) using two-way ANOVA. The means of the different treatments were considered significant with the least significant difference (LSD) test at $P < 0.05$.

RESULTS

Air temperature: The AG₅ and AG₅₀ temperatures were mainly influenced by air temperature and had an increasing trend during the growth stage (Fig. 3). There was a sharp decline at GS44 because of the low air temperature on 6 Apr. (8.7°C), 7 Apr. (6.3°C) and 8 Apr. (7.7°C) during 2014–2015. In 2014–2015, the AG₅ and AG₅₀ temperatures were 25.6°C and 25.3°C; W1, W2 and W3 temperatures were 25.4°C, 25.7°C and 25.2°C; and F, U and DD temperatures were 25.2°C, 25.9°C and 25.2°C, respectively (Fig. 3a1, a2). In 2015–2016, the AG₅ and AG₅₀ temperatures were 24.4°C and 23.7°C; W1, W2 and W3 temperatures were 24.2°C, 24.6°C and 23.3°C; and F, U and DD temperatures were 23.8°C, 24.7°C and 23.6°C, respectively (Fig. 3b1, b2). The air temperature at AG₅ was greater than that at AG₅₀ during the two growing seasons; the order of the average AG₅ and AG₅₀ temperatures was W1 ≈ W2 > W3 and U > F > DD.

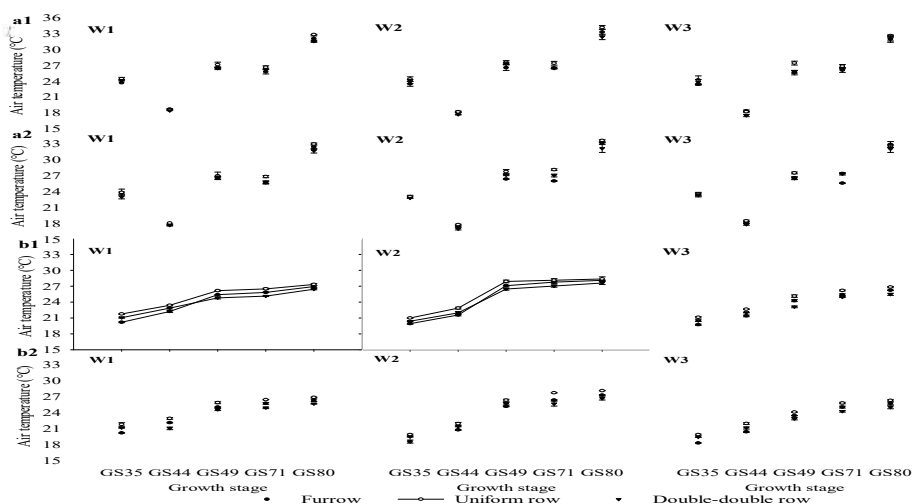


Fig. 3. Effects of planting modes and irrigation on air temperature. a1 and a2 represent air temperature at 5 and 50 cm aboveground in 2014–2015, b1 and b2 represent air temperature at 5 and 50 cm aboveground in 2015–2016; W1, irrigation of 50 mm each at GS34 and GS48; W2, irrigation of 100 mm at GS48; and W3, irrigation of 100 mm each at GS34 and GS48. The bars are the SE.

Relative humidity: The RH changes were similar to the temperatures at AG₅ and AG₅₀; there was an increase at GS44 because of rainfall on 16 Apr. (17.3 mm) during 2014–2015 and at GS35 and GS49 because of irrigation in 2015–2016. In 2014–2015, the RH at AG₅ and AG₅₀ was

53.2% and 49.8%, respectively; that of W1, W2 and W3 was 51.0%, 50.8% and 52.7%, respectively; and that of F, U and DD was 51.9%, 49.7% and 52.9%, respectively (Fig. 4a1, a2).

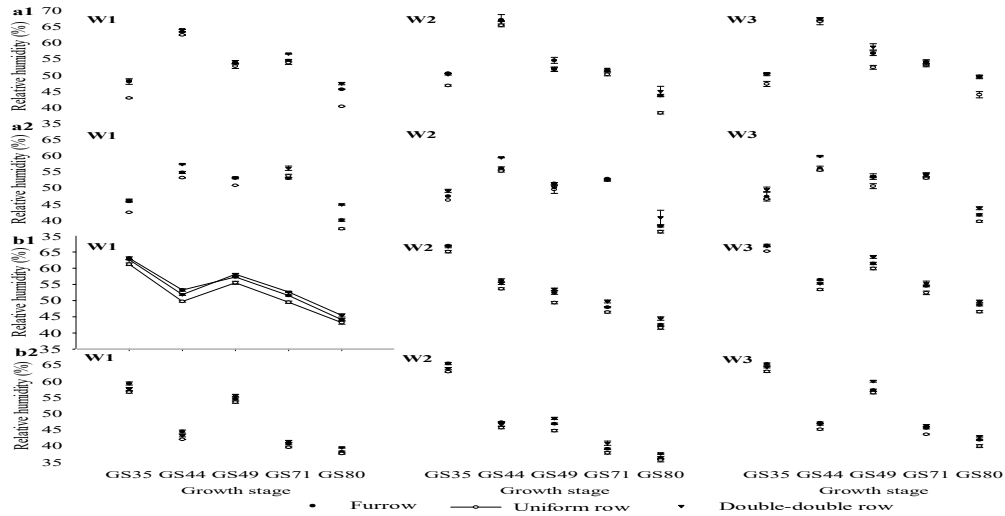


Fig. 4. Effects of planting modes and irrigation on relative humidity. a1 and a2 represent 5 and 50 cm aboveground in 2014–2015, b1 and b2 represent 5 and 50 cm aboveground in 2015–2016; W1, irrigation of 50 mm each at GS34 and GS48; W2, irrigation of 100 mm at GS48; and W3, irrigation of 100 mm each at GS34 and GS48. The bars are the SE.

In 2015–2016, the RH at AG₅ and AG₅₀ was 54.4% and 48.2%, respectively; that of W1, W2 and W3 was 50.1%, 49.7% and 54.0%, respectively; and that of F, U and DD was 51.7%, 49.9% and 52.2%, respectively (Fig. 4b1, b2). During the two growing seasons, RH had a similar change, AG₅ > AG₅₀; the average RH at AG₅ and AG₅₀ was ranked as W3 > W1 ≈ W2 and DD > F > U.

Soil temperature: The soil temperature on 1 Apr., 7 Apr., 13 Apr., and 19 Apr. in 2016 was higher than that in 2015, but on 19 May, 25 May, and 30 May in 2016 was lower than that in 2015 (Fig. 5), which was similar to the air

temperature change (Fig. 1). During the 2014–2016 growing seasons, the soil temperature at all levels presented a wave rising trend. The soil temperatures at 0 cm, 5 cm, 10 cm and 15 cm depths were 19.5°C, 16.2°C, 15.6°C and 15.1°C, respectively, indicating that the soil temperature decreased with the deepening of the soil layer. Soil temperatures at all levels were W2 > W1 > W3 and U > DD > F (Fig. 5). During the two growing seasons, the soil temperature averages at 0 cm, 5 cm, 10 cm and 15 cm depths were ranked as follows: W2 > W1 > W3 and U > DD > F.

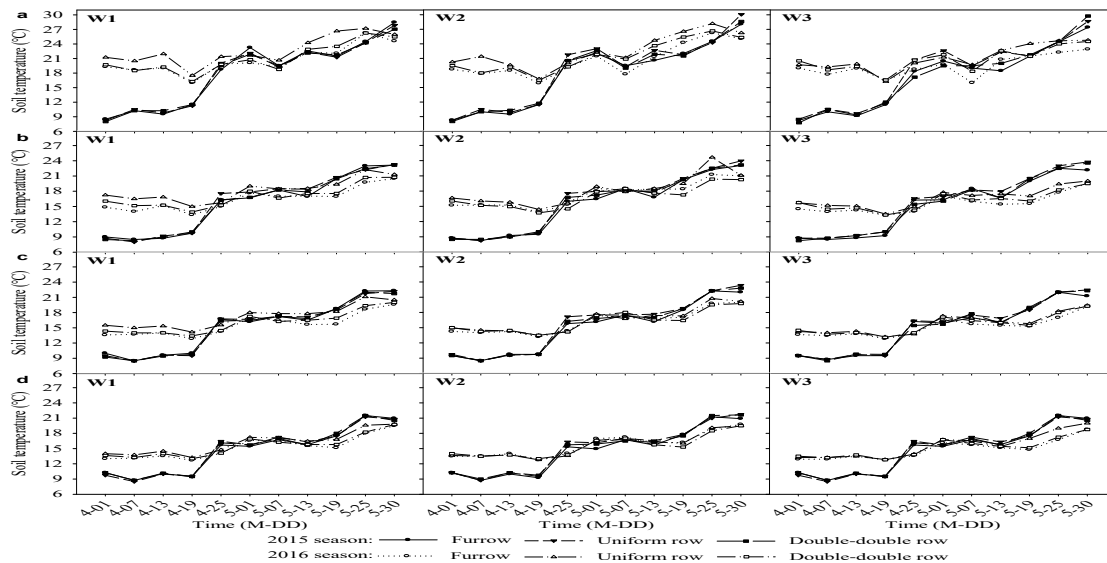


Fig. 5. Effects of planting modes and irrigation on soil temperature. a, b, c and d represent 0 cm, 5 cm, 10 cm and 15 cm depth; W1, irrigation of 50 mm each at GS34 and GS48; W2, irrigation of 100 mm at GS48; and W3, irrigation of 100 mm each at GS34 and GS48.

Dry matter: The results showed that dry matter increased gradually with growth stage development (Fig. 6).

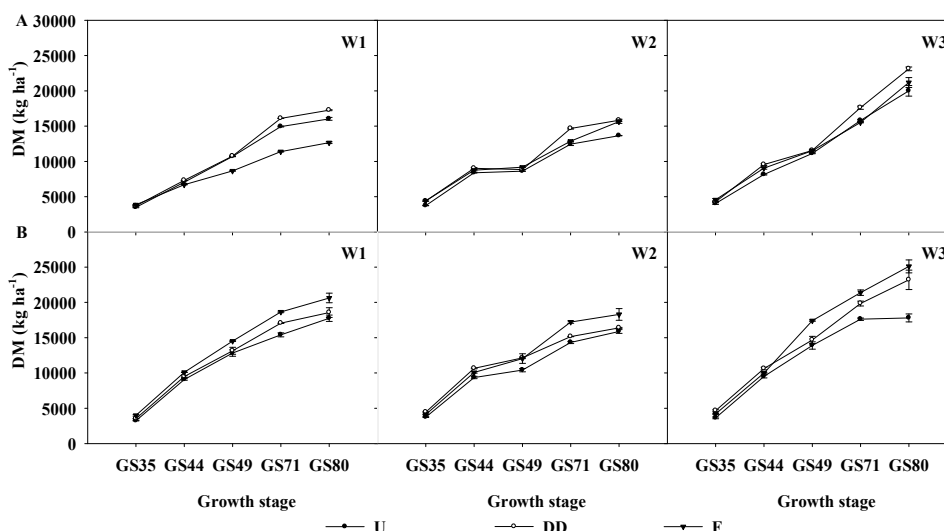


Fig. 6. The dry matter (DM) of winter wheat at different growth stages in 2014–2015 (A) and 2015–2016 (B). W1, irrigation of 50 mm each at GS34 and GS48; W2, irrigation of 100 mm at GS48; and W3, irrigation of 100 mm each at GS34 and GS48. U, uniform row; DD, double-double row; F, furrow; the bars were the SE.

In 2014–2015, the dry matter of W1, W2 and W3 were 10036, 10025 and 12462 kg ha⁻¹ respectively, W3 was significantly higher than those of W1 and W2 ($P < 0.05$); U, DD and F were 10537, 11595 and 10391 kg ha⁻¹ respectively, DD was significantly higher than those of U and F ($P < 0.01$). At GS49–GS80, the dry matter of U and DD under W1 was higher than those of W2. In 2015–2016, the dry matter of W1, W2 and W3 were 12533, 11617 and 14240 kg ha⁻¹ respectively, W3 was significantly higher than that of W2 ($P < 0.05$); U, DD and F were 11634, 12907 and 13850 kg ha⁻¹ respectively. At GS71–GS80, the

dry matter of W1 was higher than that of W2. The average dry matter of W3 was significantly higher than those of W1 and W2 by 18.31% and 23.38% ($P < 0.05$); DD and F were significantly higher than those of U by 10.51% and 9.34% ($P < 0.05$).

Dry matter and yield accumulation rates: The spike dry matter accumulation rate was the highest, followed by that of the yield, stem and then the leaf during the growing season (Table 1).

Table 2. The correlation analysis between total dry matter and yield accumulation rate, air and soil temperatures, and relative humidity.

Variable	Air temperature	Soil temperature	Relative humidity	Spike accumulation rate	Total dry matter	Yield accumulation rate
Air temperature	1.0000	-0.3599	-0.5494*	-0.5219*	-0.6152**	-0.5709*
Soil temperature		1.0000	-0.4652*	-0.1741	-0.1282	-0.4511
Relative humidity			1.0000	0.6162**	0.6655**	0.8962**
Spike accumulation rate				1.0000	0.9877**	0.7507**
Total dry matter					1.0000	0.7789**
Yield accumulation rate						1.0000

Average air temperature and relative humidity at 5 and 50 cm aboveground; average soil temperature at 0 cm, 5 cm, 10 cm and 15 cm depth in 2014–2015 and 2015–2016.

*, **Correlation is significant at the 0.05 and 0.01 levels, respectively.

The spike, total dry matter and yield accumulation rates in 2015–2016 were higher than those in 2014–2015 (except U and DD under W1, and U under

W3). No matter what planting mode was applied in winter wheat in both years, the dry matter and yield accumulation rate of W3 were significantly higher than those of W1 and

W2 ($P < 0.05$). Additionally, W1 resulted in more pronounced increment in dry matter and yield accumulation rate related to W2. Dry matter accumulation rate was significantly affected not only by the irrigation, but also by the planting modes ($P < 0.05$). The dry matter accumulation rates at different organs of wheat in DD and F remained higher than those in U in both years. However, the dry matter accumulation rates in DD and F showed the opposite trend in two years as DD contributed more towards dry matter and yield than F in 2014–2015. Either irrigation or planting modes interacted with years significantly affected spike dry matter and yield accumulation rates ($P < 0.05$). Although not statistically significant ($P > 0.05$), the average dry matter of two years in DD was improved by 4.2% for spike and 3.3% for total dry matter compared in relation to F. The average

accumulation rate in two years was 209.7 kg ha⁻¹ d⁻¹ for F and 207.5 kg ha⁻¹ d⁻¹ for DD, showing no significant difference between the yield accumulation rates of DD and F ($P > 0.05$).

Correlation between air and soil temperatures, relative humidity, spike and total dry matter and yield accumulation rates: The RH had a significantly negative correlation with air temperature and soil temperature ($P < 0.05$), with r values of -0.5494 and -0.4652, respectively (Table 2). A significant linear regression relationship. With an equation of $y = 82.7347 - 1.2668x$ ($R^2 = 0.5347$, $P < 0.0001$) between RH with air temperature is shown in Fig. 7, showing that RH is decreased with the increasing of air temperature ($P < 0.0001$).

Table 1. Effects of planting modes and irrigation on the dry matter accumulation rate (kg ha⁻¹ d⁻¹).

Irrigation	Planting mode (PM)	Stem		Leaf		Spike		Total		Yield	
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
W1	Furrow	17.8 ^c	20.8 ^c	5.6 ^c	7.2 ^{bc}	209.9 ^f	324.5 ^b	57.5 ^g	86.7 ^c	201.6 ^d	213.3 ^c
	Uniform row	24.3 ^b	18.9 ^{cde}	5.7 ^c	5.9 ^{de}	301.0 ^d	275.4 ^c _d	79.0 ^d	74.6 ^{de}	181.2 ^f	166.8 ^g
	Double-double row	24.7 ^b	19.7 ^{cd}	8.3 ^a	6.5 ^{cd}	310.0 ^c	286.2 ^c	83.4 ^c	78.0 ^d	213.4 ^a _b	193.8 ^d
W2	Furrow	21.0 ^{cd}	19.1 ^{cde}	6.5 ^d	6.0 ^{de}	238.3 ^e	286.7 ^c	66.3 ^f	76.9 ^d	190.2 ^e	189.6 ^d _e
	Uniform row	19.1 ^{de}	17.4 ^c	4.9 ^f	5.2 ^c	236.0 ^e	244.2 ^d	62.4 ^h	66.7 ^f	183.1 ^{ef}	169.5 ^{fg}
	Double-double row	21.6 ^c	18.6 ^{de}	7.1 ^c	5.7 ^{de}	242.6 ^e	246.8 ^d	68.1 ^e	68.9 ^{ef}	199.6 ^d	178.9 ^{ef}
W3	Furrow	27.9 ^a	26.6 ^a	7.8 ^b	9.7 ^a	300.9 ^d	382.4 ^a	84.5 ^c	105.5 ^a	210.7 ^b _c	252.9 ^a
	Uniform row	25.4 ^b	20.1 ^{cd}	7.1 ^c	6.3 ^{cd}	334.8 ^b	267.9 ^c _d	87.0 ^b	74.8 ^{de}	203.9 ^c _d	198.9 ^d
	Double-double row	29.4 ^a	23.5 ^b	8.6 ^a	7.8 ^b	363.6 ^a	366.2 ^a	97.1 ^a	97.5 ^b	219.9 ^a	239.5 ^b
Source of variance						$P > F$					
Irrigation		0.0038	0.0005	0.0001	0.0016	0.0001	0.0001	0.0001	0.0001	0.0001	0.0006
PM		0.0001	0.0003	0.0001	0.0002	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001
Irrigation × PM		0.0001	0.0351	0.0001	0.0272	0.0001	0.0252	0.0001	0.0001	0.0467	0.0006
Years × Irrigation		0.1788		0.0637		0.0018		0.0001		0.0003	
Years × PM		0.0012		0.0008		0.0001		0.0001		0.0001	
Years × Irrigation × PM		0.0015		0.0004		0.0076		0.0001		0.0252	

W1, irrigation of 50 mm each at GS34 and GS48; W2, irrigation of 100 mm at GS48; and W3, irrigation of 100 mm each at GS34 and GS48. Values followed by different letters in the same column are significantly different according to LSD_{0.05}.

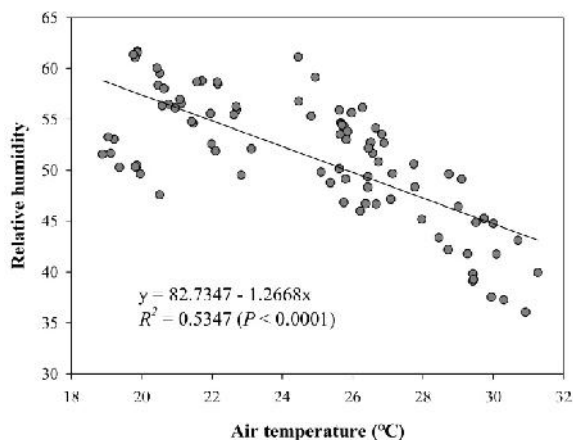


Fig. 7. Regression analysis of air temperature and relative humidity in the field of winter wheat.

The spike and total dry matter accumulation rates were significantly negatively correlated with air temperature while they had a significant positive correlation with RH and spike accumulation rate ($P < 0.01$), with a r value of 0.6162 and 0.6655, respectively. A significant positive correlation with spike and total dry matter accumulation rate was found, and r value was 0.9877 ($P < 0.01$). Moreover, yield accumulation rate had a negative correlation with air or soil temperature but it was significantly positively correlated with RH, spike and total dry matter accumulation rates ($P < 0.01$). The results showed that relatively high RH could increase dry matter accumulation, which improved yield accumulation rate; however, high temperature was an unfavorable factor for wheat production.

DISCUSSION

The cultivation mode changed the ecological environment of wheat growth, which affected the physiological process of wheat and led to the change of yield (Izzi *et al.*, 2008). Other agricultural practices, including tillage, fertilizer, sowing date, straw return, irrigation, and planting pattern, will influence the farmland microclimate. Different irrigation treatments have different microclimate characteristics, and irrigation significantly reduce formation of temperature and increase RH (Lu *et al.*, 2015). The results of present study also showed that, with increasing of irrigation amount, the air temperature decreased and the RH increased at AG₅ and AG₅₀. The air temperature at AG₅ and AG₅₀ had a significant negative correlation with yield and spike dry matter accumulation rate, whereas RH was reverse. Previous research has shown that temperature increase has the most likely negative impact on crop yields (Ottman *et al.*, 2012) which was confirmed in our study. The DD (wide-precision) and F were good planting modes, which

weaken competition among individual crop plants (Yan *et al.*, 2018).

Irrigation could reduce soil temperature while increase RH, and temperature change range decreased with increasing of soil depth. The W3 maintained the lowest air temperature and the highest RH. At the same time, the increase in the irrigation frequency by reducing the irrigation amount per application will relatively decrease temperature and improve RH. Feng *et al.* (2017) reported that increasing irrigation frequency would maintain higher soil water content in top soil layer, which might result in low temperature and high RH in W1 and then promote dry matter as well as yield accumulation rate. The regions with scarce water resources like north China, W1 was considered to be the optimal water-saving irrigation mode. Reasonable plant spacing could decrease heat consumption for evapotranspiration and improve the microclimate of farmland. This study showed that DD significantly reduced air temperature at AG₅ and AG₅₀, and improved air humidity. These were consistent with previous studies (Philip *et al.*, 2005).

The dry matter mass was biological yield, and high biological yield was also an excellent character of wheat. The increment of dry matter partitioning to the spikes could increase grain partitioning leading to high yield as a significant positive correlation between spike with yield accumulation rates was found, which was identified with the report of Rivera-Amado *et al.* (2019). The experimental results showed that the total dry matter and yield accumulation rates of winter wheat increased with the increase of irrigation times under irrigation quota as well as irrigation amount, so the total dry matter and yield accumulation rate of W3 were higher than those of other irrigation treatments. The total dry matter of DD planting mode was relatively better than that of other planting modes. In conclusion, the total larger dry matter was beneficial to increase grain yield.

Irrigation schedules and planting modes improved farmland microclimate and contributed to increase dry matter accumulation (Plaut *et al.*, 2004). Dry matter is the final form of photosynthetic products of crops, and its accumulation, transport and distribution are closely related to formation of economic yield (Guo *et al.*, 2020). Studies have shown that most of wheat grain yield comes from the redistribution of post-flowering photosynthetic production and pre-flowering storage, and suitable irrigation can significantly increase dry matter accumulation after flowering and its contribution to grain yield, thus increasing the yield (Ma *et al.*, 2019). Irrigation can promote the transfer of preanthesis homologous compounds to seeds, and narrow row planting can improve the yield of maize by improving its dry matter production capacity (Lin *et al.*, 2016). In this study, dry matter accumulation for stem, leaf and spike increased with increasing of irrigation amount and frequency in DD were superior to other planting modes, which it may be due to

the large population number in the DD, and created suitable field microclimate for the growth of winter wheat and the grain dry accumulation. Additionally, years interacted with planting mode and irrigation also significantly affected dry matter accumulation for stem, leaf, spike and grain ($P < 0.05$). Higher dry matter and yield accumulation were found in 2015–2016 rather than in 2014–2015, which might be attributed to the precipitation in 2015–2016 (262 mm) being higher than that in 2014–2015 (245 mm).

As have discussed above, the results showed that irrigation amount and frequency could decrease air temperature and increase RH, dry matter and yield accumulation. Soil temperature decreases with increasing soil depth. Irrigation schedules and planting modes have important impacts on farmland microclimate, including air and soil temperatures and RH, and changes in the microclimate accelerate or retard crop growth, especially dry matter accumulation. DD is a new precision planting mode, compared with F and U. The temperature and precipitation records help to analyze the microclimate. By improving irrigation schedules under field conditions, we confirmed the best planting mode to prevent agricultural water stress. This experiment showed that F and DD decreased air and soil temperatures and increased the RH and dry matter and yield accumulation rates compared with U, but the dry matter and yield accumulation rates of DD were relatively high. It may be recommended that farmers with scarce water resources (like this area) could adopt W1 with DD due to scarce water resources in the Huanghuaihai Plain.

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