The Journal of Animal & Plant Sciences, 25(3): 2015, Page: 708-715
ISSN: 1018-7081

PLANTING PATTERN AND IRRIGATION EFFECT ON FARMLAND MICROCLIMATE AND YIELD OF WINTER WHEAT

X. Y. Wang[1], Z. Zhang[2], X. B. Zhou[1]*, P. Liu[2] and Y. H. Chen[2]

[1]Shandong Agricultural University, Agricultural College of Guangxi University, Nanning 530004, China.
[2]State Key Laboratory of Crop Biology, Shandong Agricultural University Tai'an 271018, China.
*Corresponding author. E-mail: whyzxb@gmail.com

ABSTRACT

The use of water resources should be restricted until a suitable irrigation and planting system is developed in the North China Plain. This study was aimed to study the effects of planting pattern and irrigation on the farmland microclimate, and indentify possible ways to improve the yield of winter wheat. The field experiments in a randomized complete block design with four replicates were conducted during the 2008-09 and 2009-10 growing seasons in Taian, China. The three planting patterns were: 25 cm uniform row planting pattern (U), "20 + 40" wide-narrow row planting pattern (WN), and "20 + 40" furrow planting pattern (F). Three irrigation treatments applied: were 90, 135, and 180 mm during the whole growth period. Results showed that F had 3.5% lower diurnal soil temperature at the 5cm soil depth, 4.7% lower diurnal air temperature at 5cm above the ground, 14.8% lower diurnal relative humidity (RH), 4.8% higher soil water content (SWC) at the 0 cm to 30 cm soil depth, and 9.7% higher yield as compared with U. Irrigation decreased soil temperature and air temperature but increased RH and SWC. The yield of 135 mm irrigation was 6.4% higher than that of 90 mm. The grain yield of winter wheat was not significantly difference between 135 and 180 mm irrigation from 2009-10 ($P > 0.05$). Therefore, F and 135 mm irrigation were regarded the best combination as the optimum conditions for winter wheat considering the water shortage problem in China.

Keywords: soil temperature; air temperature; relative humidity; soil water content.

INTRODUCTION

The Huanghuaihai Plain is an important food production area in China. It comprises approximately 18.3% of the total farmland and produces 25% of the total food supply in the country. Winter wheat (*Triticumaestivum* L.) is the main crop in this area. The water shortage in China is caused by the uneven distribution of precipitation across time and space (Deng *et al*., 2006). Winter wheat is threatened by water shortage, water pollution, and groundwater over exploitation (Zhang *et al*., 2010; Sun *et al*., 2012). Thus, conserving water resources and improving water use efficiency are necessary (Wang *et al*., 2001; Dogan *et al*., 2006; Shao *et al*., 2007).

Numerous methods have been developed to increase crop yields, including early sowing, high planting density, straw mulching, and improving fertilization (Eberbach and Pala, 2005). An appropriate planting pattern can collect water even with a small amount of rainfall, reduce soil surface runoff, and decrease unproductive evaporation (Xie *et al*., 2005; Jia *et al*., 2006). Zhang *et al*. (2007) showed that the yield of winter wheat by raised-bed planting was higher than that by conventional flat planting. Quanqi *et al*. (2012) proved that furrow planting facilitated high winter wheat production in the North China Plain. Similarly, reasonable row spacing (RS) was observed to increase crop yield and optimize plant population (Hill *et al*., 2006; Zhou *et al*., 2007). In India and Pakistan, farmers have adopted raised-bed and furrow planting patterns for growing both rice and wheat crops, and some farmers were also growing mustard, and other oilseed, and pulse crops (Abdelhadi *et al*., 2006; Choudhury *et al*., 2007). The results of many studies have indicated that convert flood irrigation to local irrigation can help reduce the area of soil evaporation and control the invalid evaporation (Li and Gong, 2002). It is impossible to fully meet the demand for irrigation because the water supply is generally limited, so deficit irrigation can play an important role during the period of growth when crop is sensitive to water.

Fahong *et al*. (2004) showed that the microclimate within the field can be changed by the bed planting system, which reduces crop lodging and prevents wheat diseases. Philip and Mustafa (2005) revealed that evapotranspiration increased with increasing RS. The soil temperature of straw mulching was lower than bare, especially during the period of atmospheric temperature was relative high, but the yield production increased evidently (Sarkar *et al*., 2007). The farmland water content increased with increasing irrigation amount, so the ability to absorb solar radiation was enhanced. Because the exchange of the soil and the air heat and the increase of evapotranspiration heat, the diurnal soil temperature varied slightly during the process, especially close to the ground (Erik, 2001). Many studies have focused on farmland microclimate; however, only a few have determined the effects of different planting patterns and irrigation treatments on farmland microclimate. The present study was aimed to investigate the effects of different planting patterns and irrigation treatments on the farmland microclimate [soil temperature, air temperature, air relative humidity (RH), and soil water content (SWC)] and yield of winter wheat.

MATERIALS AND METHODS

The experiments were conducted at Shandong Agricultural University. The experiment site (36°09′N, 117°09′E) is located in Taian, the main winter cultivating region of the Huanghuaihai Plain in China. The total annual solar radiation was 1,414 W/m^2. The average annual sunshine and temperature were 2627 h and 12.9°C, respectively. The accumulated temperature throughout the year was 4213°C (≥ 10°C). The non-frost period was 193 days. The average annual rainfall was 697 mm, in which 70% to 80% occurred in the summer growing season from July to September. The total rainfall was 765.5 mm and 627.5 mm during 2008 and 2009. The rainfall in the winter wheat season was 159.2 mm and 149.3 mm respectively, during 2008-09 and 2009-10 (Table 1).

The soil type in the region was silt loam, with an average SOM of 16.3 g/kg and N, P, and K contents of 92.98, 34.77, and 95.45 mg/kg, respectively. The soil had a bulk density of 1.50 g/cm, pH of 6.9, and field capacity of 38.6% (V%).

Winter wheat (cv Jimai-22) was hand-planted on 14 Oct. 2008 and 8 Oct. 2009, and was harvested on 10 June 2009 and 8 June 2010, respectively. The density of plant population was 1.8 × 10^6 plant/ha. During the sowing period, 120 m^3/ha of manure was needed, and N (225 kg/ha), P_2O_5 (120 kg/ha), and K_2O (105 kg/ha) were supplied.

The experiment included three planting patterns i.e. 25 cm uniform row planting pattern (U), "20 + 40 cm" wide-narrow row planting pattern (WN), and "20 + 40 cm" furrow planting pattern (F) (Fig. 1). For F, the width of the bed bottom was 40 cm, the peak was 20 cm, and the height from bottom to peak was 15 cm. The irrigation times and volumes are listed in Table 2. The plot area was 3 m × 3 m, and the experiment was arranged in a randomized complete block design with four replicates. Nitrogenous fertilizers were supplied as base at stem elongation stage. Phosphate and potassium fertilizers were only used as base fertilizers. F was irrigated into the ditch, and U and WN were flooded. Irrigation was strictly controlled by a water meter.

At growth stage (GS) 65, diurnal soil temperatures were measured on selected sunny days between 8:00 and 17:00 at 5 cm soil depth. Diurnal air temperatures and RH were measured between 8:00 and 17:00 at heights of 5 cm above the ground. Soil temperatures were measured by using a geothermometer, and air temperatures and RH were measured using dry and wet bulb thermometers, respectively.

The aluminum access tubes (diameter 45 mm) of the neutron moisture meter were installed between the rows at each location to a depth of 1.2 m prior to sowing. The soil volumetric water was measured once every 10 cm in the 0 cm to 120 cm profile. The soil water was measured at GS01, GS28, GS30, GS37, GS47, GS50, GS65, GS73, and GS85.

All graphs were prepared from means and drawn using Sigma Plot 10.0 (SPSS Inc., Chicago, IL). All data were analyzed using ANOVA. The treatments (planting pattern, irrigation) were considered as fixed effects, and replications were considered as random effects. Multiple comparisons were conducted for significant effects with the least significant difference test at $P = 0.05$.

RESULTS

Diurnal soil temperature: Under the different planting patterns and irrigation treatments of winter wheat, the diurnal soil temperature at 5 cm peaked at 13:00 to 14:00. The afternoon temperature was higher than the morning temperature. In both growing seasons, the order of the average soil temperature was F < WN < U. The soil temperatures of F and WN were 3.5% and 1.7% lower than that of U, respectively. No significant difference was observed among U, WN, and F ($P > 0.05$). These data showed that F and WN reduced the soil temperature at 5 cm, especially F (Fig. 2).

At the 5 cm soil depth, the order of average soil temperature under the different irrigation treatments was 180 mm < 135 mm < 90 mm. The soil temperatures of 180 and 135 mm were 6.7% and 5.1% lower than that of 90 mm. No significant difference was observed among 90, 135, and 180 mm ($P > 0.05$). The soil temperature of 135 mm was lower by 0.9 °C than that of 90 mm, and that of 180 mm was lower by 0.3 °C than that of 135 mm. These results indicated that the soil temperature gradually decreased with increasing irrigation amount. The maximum differences for the different planting patterns and irrigation treatments were 0.6 °C and 1.2 °C, respectively. These data showed that the effect of irrigation treatment on soil temperature at 5 cm was higher than that of planting pattern.

Diurnal air temperature: A high air temperature was measured at 5 cm above the ground at 12:00 to 13:00 (Fig. 3). The planting pattern affected the air temperature at 5 cm. The order of average air temperature was F < WN < U, and the values were 26.5 °C, 27.1 °C, and 27.8 °C, respectively. The air temperatures of F and WN were 4.7% and 2.5% lower than that of U, respectively. These data showed that F and WN decreased the air temperature at 5 cm above the ground, especially F.

The average air temperatures under the 90, 135 and 180 mm irrigation treatments were 27.4 °C, 27.1°C, and 27.1 °C, respectively. The maximum difference between 90 and 135 mm was 0.3 °C, and no difference was observed between 180 and 135 mm. The air temperature at 5 cm above the ground gradually decreased with increasing irrigation amount; however, the extent of the decrease was small. The maximum differences for the different planting patterns and irrigation treatments were 1.3 °C and 0.3 °C, respectively. Therefore, the effect of planting pattern on air temperature at 5 cm above the ground was higher than that of irrigation treatment.

Diurnal relative humidity: The changes in air temperature and RH at 5 cm above the ground were contradictory (Fig. 4). The morning and evening RH were higher than that the noon RH. The RH from 2009 to 2010 was evidently lower than that from 2008 to 2009. The difference in RH can be attributed to the low amount of rainfall from 2009 to 2010. A low RH was obtained at 5 cm above the ground at approximately 13:00 from 2008 to 2010. The average RH for F, U, and WN were 39.0%, 45.8%, and 47.8%, respectively. The value of F was 14.8% and 18.4% lower than that of U and WN, respectively.

The average RH values under the 90, 135, and 180 mm irrigation treatments were 43.3%, 46.2%, and 47.6%, respectively. The RH gradually increased with increasing irrigation amount. The RH of 135 mm was 3.1% higher than that of 90 mm, and the RH of 180 mm was 1.4% higher than that of 135 mm. The maximum differences for the different planting patterns and irrigation treatments were 8.8% and 4.3%, respectively. Therefore, the effect of planting pattern on RH at 5 cm above the ground was higher than that of irrigation treatment.

Soil water content: Evident differences in SWC were observed among the different planting patterns and irrigation treatments (Fig. 5). At the 0 cm to 30 cm soil depth, the SWC was evidently affected by rainfall and irrigation. The SWCs of U, WN, and F were 23.0%, 23.5%, and 24.1%, respectively. The SWC of F was 4.8% and 2.6% higher than those of U and WN, respectively.

The SWC order of the three irrigation treatments was 180 mm > 135 mm > 90 mm. The SWC increased with increasing irrigation amount, but the extent gradually decreased. The SWC of 135 mm was 14.0% higher than that of 90 mm, whereas that of 180 mm was 2.0% higher than that of 135 mm. The maximum differences for the different planting patterns and irrigation treatments were 1.1% and 3.5%, respectively. The effect of irrigation amount on SWC was higher than that of planting pattern.

Table 1. Monthly rainfall (mm) for the winter wheat growth seasons

Season	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
2008/2009	9.9	4.9	0.3	0.0	12.1	25.7	45.2	42.8	18.3	159.2
2009/2010	12.9	21.3	6.2	3.2	18.9	14.8	20.5	42.0	9.5	149.3

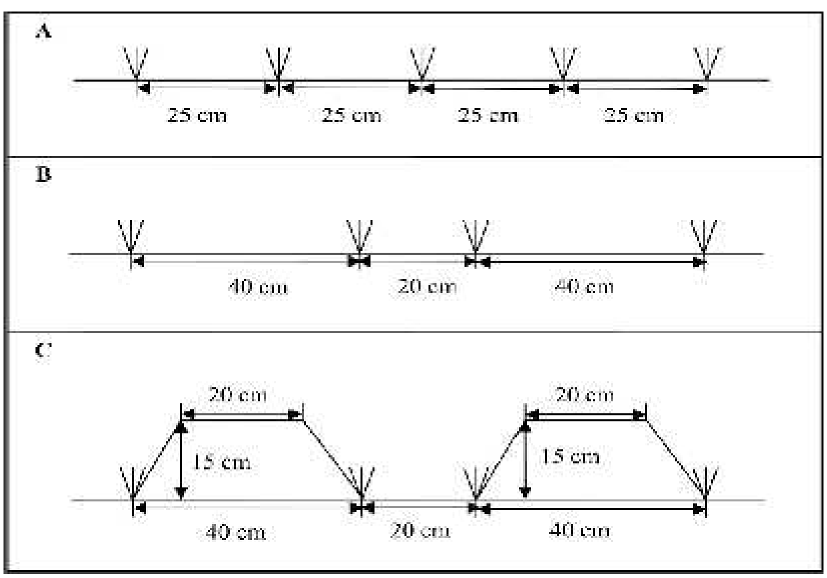

Fig. 1 A schematic diagram showing uniform row planting pattern (A), 20 + 40 wide-narrow row planting pattern (B), 20 + 40 furrow planting pattern (C).

Table 2. Irrigation times and amount (mm) for different growth stage (GS) of winter wheat

Planting pattern	**GS37 (2 Apr. 2009, 2 Apr. 2010)**	**GS50 (24 Apr. 2009, 27 Apr. 2010)**	**GS73 (13 May. 2009, 15 May. 2010)**	**Total**
25cm uniform row	30	30	30	90
(U)	45	45	45	135
	60	60	60	180
20+40 wide-narrow row	30	30	30	90
(WN)	45	45	45	135
	60	60	60	180
20+40 furrow	30	30	30	90
(F)	45	45	45	135
	60	60	60	180

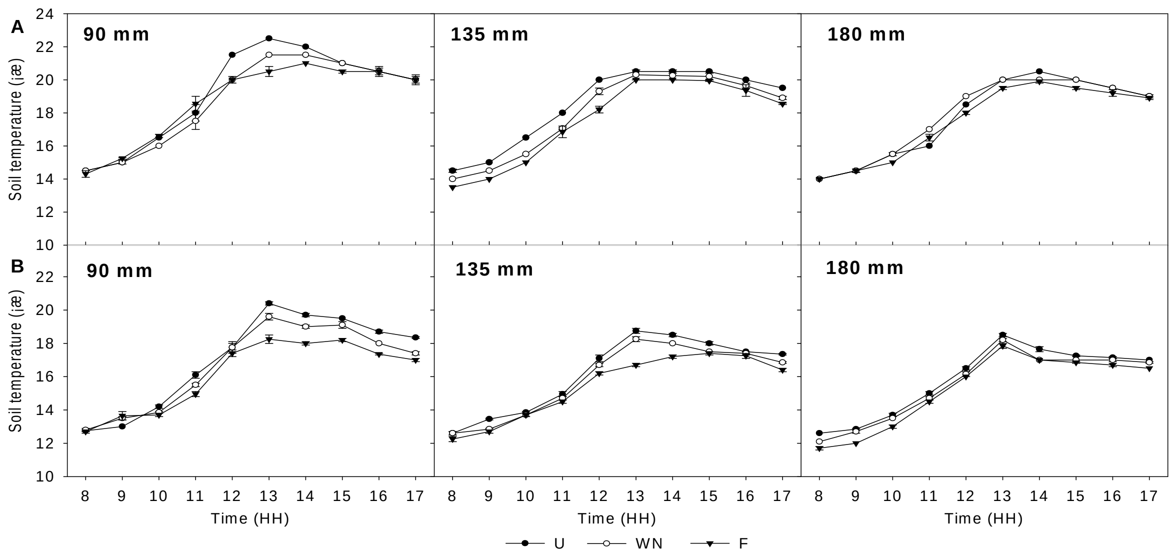

Fig. 2 Diurnal soil temperature at 5 cm depth. A and B are 2008/2009 and 2009/2010, respectively; U, uniform row planting pattern; WN, 20 + 40 wide-narrow row planting pattern; F, 20 + 40 furrow planting pattern. The error bars were the SE.

Farmland microclimate relations with yield: The order of grain yield response for the different planting patterns was F > WN > U (Fig. 6). The yield of F was significantly higher than those of U and WN by 669 and 260 kg/ha from 2008 to 2009 and by 758 and 337 kg/ha from 2009 to 2010, respectively. In 2008 to 2009, the yield of 180 mm was higher than that of 135 mm by 640 kg/ha, and that of 135 mm was higher than that of 90 mm by 478 kg/ha. In 2009 to 2010, the yield of 135 mm was significantly higher than those of 90 mm ($P < 0.05$), and was not significant difference between 135 mm and 180 mm.

The average yields of 90, 135, and 180 mm were 7429, 7903, and 8189 kg/ha, respectively. The yield of 135 mm was higher than that of 90 mm by 6.7%, and that of 180 mm was higher than that of 135 mm by 3.6%. A significant positive correlation was observed among RH, SWC and yield ($P<0.05$). Irrigation was significantly positively correlated with yield ($P<0.05$), whereas soil temperature was significantly negatively correlated with yield ($P < 0.01$), and air temperature was significantly negatively correlated with yield ($P < 0.05$). Soil temperature was significantly negatively correlated with irrigation ($P < 0.01$) and air temperature was significantly negatively correlated with irrigation ($P < 0.05$), whereas RH and SWC was significantly positively correlated with irrigation ($P < 0.05$) (Table 3).

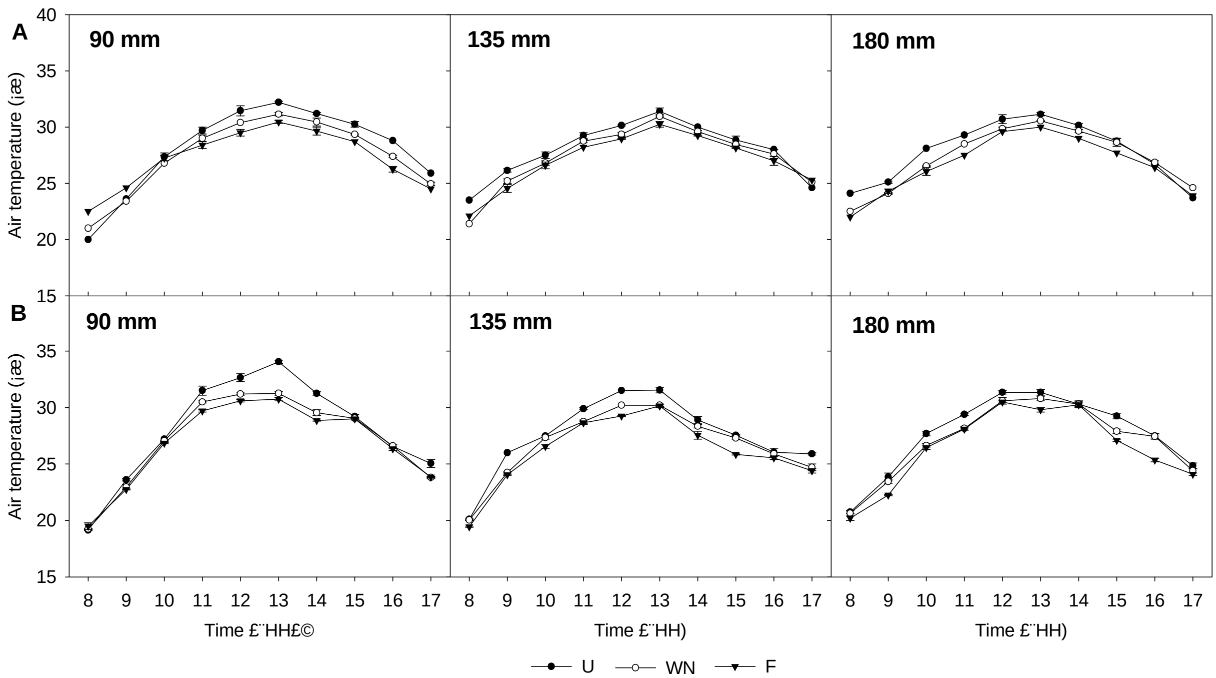

Fig. 3 Diurnal air temperature at 5 cm above the ground. A and B are 2008/2009 and 2009/2010, respectively; U, uniform row planting pattern; WN, 20 + 40 wide-narrow row planting pattern; F, 20 + 40 furrow planting pattern. The error bars were the SE.

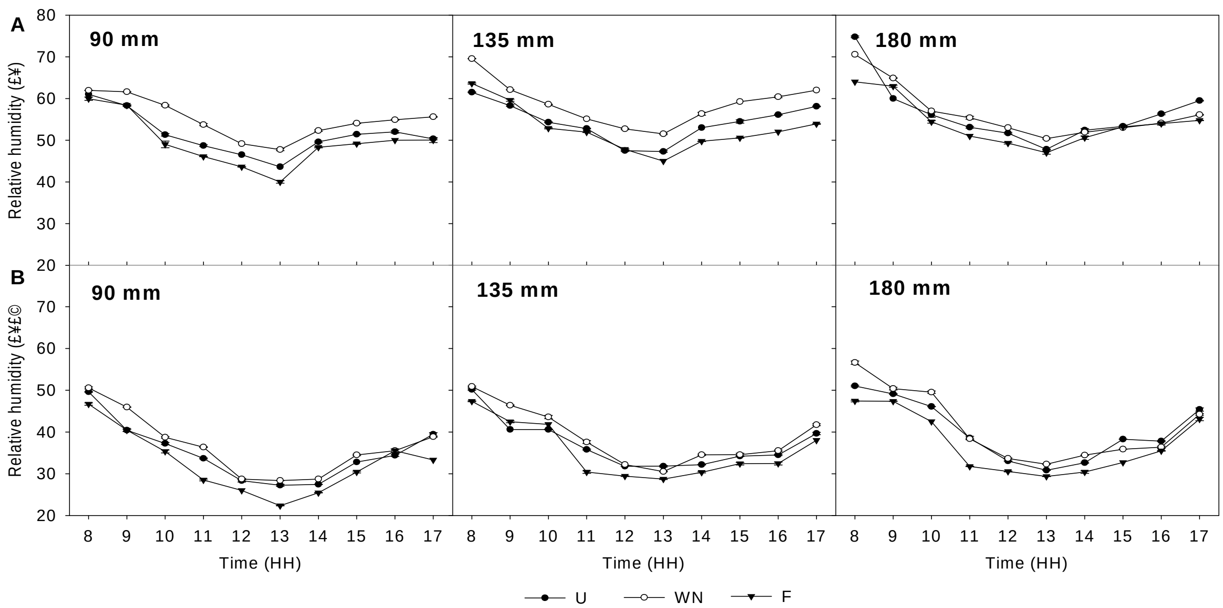

Fig. 4 Diurnal air relative humidity at 5 cm above the ground. A and B are 2008/2009 and 2009/2010, respectively; U, uniform row planting pattern; WN, 20 + 40 wide-narrow row planting pattern; F, 20 + 40 furrow planting pattern. The error bars were the SE.

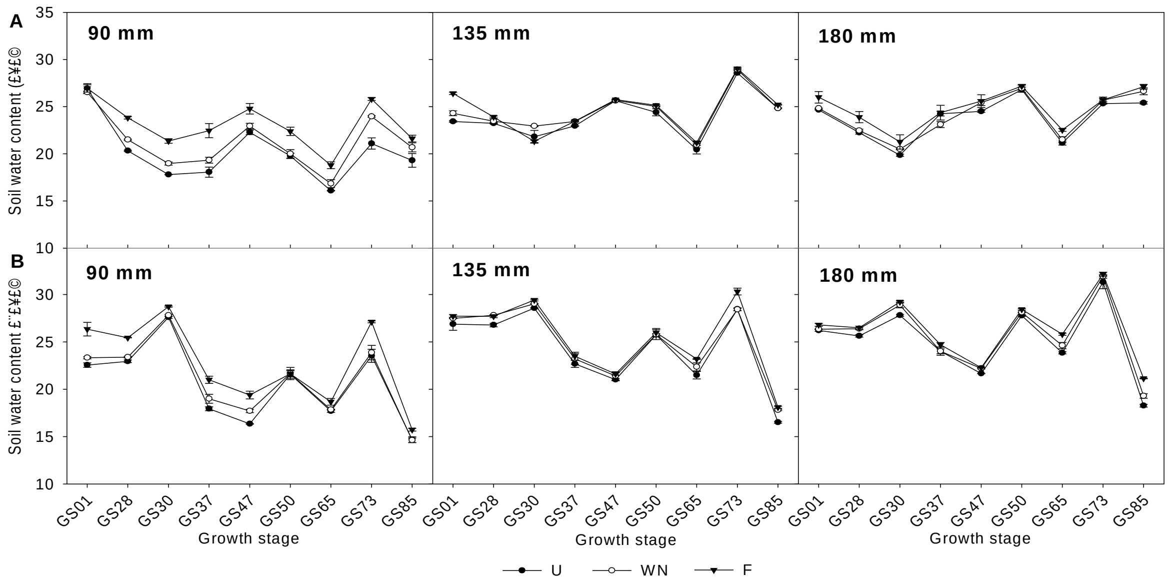

Fig. 5 Changes in soil water content of different growth stage in winter wheat season. A and B are 2008/2009 and 2009/2010, respectively; U, uniform row planting pattern; WN, 20 + 40 wide-narrow row planting pattern; F, 20 + 40 furrow planting pattern. The error bars were the SE.

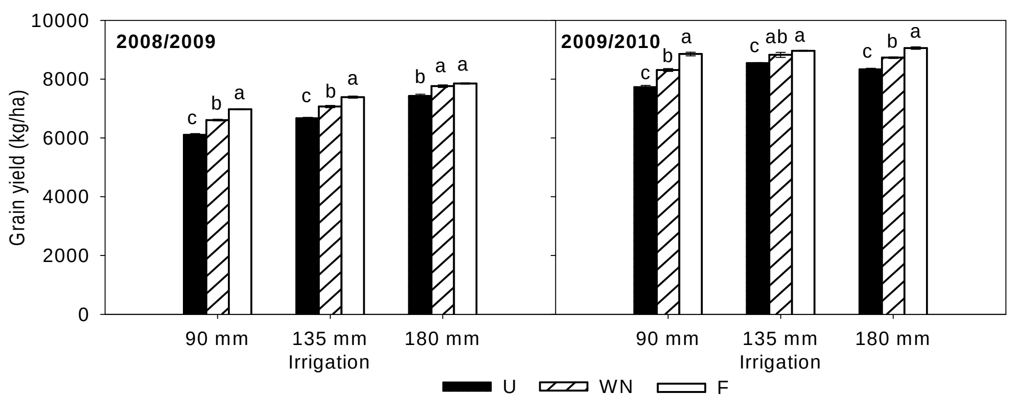

Fig. 6 Yield of different planting patterns and irrigation treatments. U, uniform row planting pattern; WN, 20 + 40 wide-narrow row planting pattern; F, 20 + 40 furrow planting pattern. The error bars were the SE. Within a irrigation treatment, the treatment means with the same lowercase letters are not significantly different according to P<0.05.

Table 3. Correlation coefficients between irrigation, soil temperature, air temperature, relative humidity (RH), soil water content (SWC), and yield of wheat during 2008-2010

	Irrigation	Soil temperature	Air temperature	RH	SWC	Yield
Irrigation	1.000					
Soil temperature	-0.964**	1.000				
Air temperature	-0.847*	0.939**	1.000			
RH	0.864*	-0.937**	-0.984**	1.000		
SWC	0.911*	-0.980**	-0.952**	0.921**	1.000	
Yield	0.998**	-0.963**	-0.841*	0.860*	0.903*	1.000

**, correlation is significant at the 0.01 level; *, correlation is significant at the 0.05 level.

DISCUSSION

Preparation of suitable seedbed would create a conducive microclimate for the growth and development of winter wheat (Zhou *et al*., 2012). In this study, F and WN decreased the soil temperature at the 5 cm soil depth, especially F. Soil temperature significantly affected the growth and phenology of trees, water absorption, and nutrient intake (Devine and Harrington, 2007). A high temperature leads to the dissipation of energy and the loss of nutrition. F decreased the air temperature and RH at 5 cm above the ground. Decrease in air temperature reduced the energy consumption, hence, more assimilates were transferred toward growth rather used in maintain the growth. High temperature was already one of the major environmental stresses limiting rice productivity, with relatively higher temperatures causing reductions in grain weight and quality (Norwood and Dumler, 2002). The air temperature under the canopy and in the open is related to solar radiation (Morecroft *et al*., 1998). The SWC of F at the 0 cm to 30 cm soil layer was higher than that of the other treatments, and it was helpful for plants. Hence results of present study agreed with the finding of Fahong *et al*. (2004). They reported that there was a savings in some years of as much as 30% of applied irrigation water combined with enhanced water use efficiency by changing from flood to furrow irrigation. Adequate water is a key factor that controls plant growth, productivity, and survival (Namirembe *et al*., 2009; Kamiloğlu, 2011). F significantly increased the yield of winter wheat. This result was supported by the report of Han *et al*. (2014).

Irrigation decreased soil temperature and air temperature but increased RH and SWC. Farmland microclimate evidently improved with increasing irrigation. Irrigation can change the population size and ecological factors (Hou *et al*., 2010). The heading stage appeared during dry period in late spring and early summer, the drying climate, abundant sunshine, and rapidly increasing air temperature promote hot wind damage. Therefore, creating a suitable farmland microclimate was important for winter wheat cultivation. F and irrigation decreased diurnal soil temperature at the 5 cm soil depth and diurnal air temperature at 5 cm above the ground but increased SWC at the 0–30 cm soil depth. Planting patterns and irrigation improved the farmland ecological environment of winter wheat, and reduced the evapotranspiration and increased yield. Soil temperature, air temperature decreased, RH and SWC increased with increasing irrigation amount, but the extent gradually decreased. The yields of U and WN were higher at 135 mm irrigation than those of 180 mm irrigation, so yield of 135 mm was high during 2009-10, but there was not significant difference between 135 mm and 180 mm. In conclusion, F and 135 mm irrigation may be an effective strategy to yield of winter wheat in water-scare regions, and should be adopted to increase the yield of winter wheat.

Acknowledgments: Sincere acknowledgments are due to Lin Qi and Yan Liu for field assistance. This research was supported by the National High Technology Research and Development Program of China (2013AA102903), and the National Key Technology Support Program of China (2011BAD16B14; 2013BAD07B06).

REFERENCES

Abdelhadi, A.W., M.A. Bashir, S.E.A. El-Awad, and H. Takeshi (2006). Evaluation of wheat bed planting system in irrigated Vertisols of Sudan. AMA-Agr. Mech. Asia Af. 37: 62–67.

Choudhury, B.U., B.A.M. Bouman, and A.K. Singh (2007). Yield and water productivity of rice–wheat on raised beds at New Delhi, India. Field Crops Res. 100: 229–239.

Deng, X.P., L. Shan, H. Zhang, and N.C. Turner (2006). Improving agricultural water use efficiency in arid and semiarid areas of China. Agric. Water Manage. 80: 23–40.

Devine, W.D., and C.A. Harrington (2007). Influence of harvest residues and vegetation on microsite soil and air temperatures in a young conifer plantation. Agric. Forest Meteorol. 145: 125–138.

Dogan, E., G.A. Clark, D.H. Rogers, V. Martin, and R.L. Vanderlip (2006). On farm scheduling studies and CERES-Maize simulation of irrigated corn. Appl. Eng. Agric. 22: 509–516.

Eberbach, P., and M. Pala (2005). Crop row spacing and its influence on the partitioning of evapotranspiration by winter-grown wheat in Northern Syria. Plant Soil 268: 195–208.

Erik, K. (2001). Surface energy fluxes and control of evapotranspiration from a Swedish Sphagnum mire. Agric. Forest Meteorol. 110: 101-123.

Fahong, W., W. Xuqing, and K. Sayre (2004). Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China. Field Crops Res. 87: 35–42.

Han, Y.Y., G.Y. Wang, X.B. Zhou, Y.H. Chen, and P. Liu (2014). Radiation use efficiency and yield response of winter wheat to planting patterns and irrigation in northern China. Agron. J. 106: 168–174.

Hill, J., E. Nelson, D. Tilman, S. Polasky, and D. Tiffany (2006). Environmental, economic, and energetic costs and benefits of biodieseland ethanol biofuels. PNAS 103: 11206–11210.

Hou, Y.H., S.T. Dong, G.F. Hou, C.Y. Chen, Z.Q. Dong, and M. Zhao (2010). The effect of ecological factors on the indexes of yield property equation and quantitative analysis. Agric. Sci. China 9: 536–548.

Jia, Y., F.M. Li, X.L. Wang, and S.M. Yang (2006). Soil water and alfalfa yields as affected by alternating ridges and furrows in rainfall harvest in a semiarid environment. Field Crops Res. 97: 167–175.

Kamiloğlu, Ö. (2011). Influence of some cultural practices on yield, fruit quality and individual anthocyanins of table grape cv. 'Horoz Karasi'. J. Anim. Plant Sci. 21: 240–245.

Li, X.Y., and J.D. Gong (2002). Effect of different ridge: furrow ratios and supplemental irrigation on crop production in ridge and furrow rain harvesting system with mulches. Agric. Water Manage. 54: 243–254.

Morecroft, M.D., M.E. Taylor, and H.R. Oliver (1998). Air and soil microclimates of deciduous woodland compared to an open site. Agric. Forest Meteorol. 90: 141–156.

Namirembe, S., R.M. Brook, and C.K. Ong (2009). Manipulating phenology and water relations in *Senna spectabilis* in a water limited environment in Kenya. Agrofor. Syst. 75: 197–210.

Norwood, C.A., and T.J. Dumler (2002). Transition to dryland agriculture: limited irrigation vs. dryland corn. Agron. J. 94: 310–320.

Philip, E., and P. Mustafa (2005). Crop row spacing and its influence on the partitioning of evapotranspiration by winter-grown wheat in northern Syria. Plant Soil 268: 195–208.

Quanqi, L., Z. Xunbo, C. Yuhai, and Y. Songlie (2012). Water consumption characteristics of winter wheat grown using different planting patterns and deficit irrigation regime. Agric. Water Manage. 105: 8–12.

Sarkar S., M. Paramanick, and S.B. Goswami (2007). Soil temperature, water use and yield of yellow sarson (*Brassica napus* L. var. *glauca*) in relation to tillage intensity and mulch management under rainfed lowland ecosystem in eastern India. Soil Till. Res. 93: 94-101.

Shao, H.B., L.Y. Chu, G. Wu, J.H. Zhang, and Z.H. Lu (2007). Where is the road to bio-water saving for the globe? Colloid Surf. B 55: 251–255.

Sun, B., L. Zhang, L. Yang, F. Zhang, D. Norse, and Z. Zhu (2012). Agricultural non-point source pollution in China: causes and mitigation measures. Ambio 41: 370–379.

Wang, H., L. Zhang, W.R. Dawes, and C. Liu (2001). Improving water use efficiency of irrigated crops in the North China Plain-measurements and modelling. Agric. Water Manage. 48: 151–167.

Xie, Z., Y. Wang, and F. Li (2005). Effect of plastic mulching on soil water use and spring wheat yield in arid region of northwest China. Agric. Water Manage. 75: 71–83.

Zhang, J., D.L. Mauzerall, T. Zhu, S. Liang, M. Ezzati, and J.V. Remais (2010). Environmental health in China: progress towards clean air and safe water. Lancet 375: 1110–1119.

Zhang, J., J. Sun, A. Duan, J. Wang, X. Shen, and X. Liu (2007). Effects of different planting patterns on water use and yield performance of winter wheat in the Huang-Huai-Hai Plain of China. Agric. Water Manage. 92: 41–47.

Zhou, X.B., Q.Q. Li, S.Z. Yu, W. Wu, and Y.H. Chen (2007). Row spacing and irrigation effects on water consumption of winter wheat in Taian, China. Can. J. Plant Sci. 87: 471–477.

Zhou, X.B., S.J. Sun, G.M. Yang, Y.H. Chen, and P. Liu (2012). Farmland microclimate and yield of winter wheat under different row spacing. Tarim Bilim. Derg.18: 1–8.