The Journal of Animal & Plant Sciences, 24(3): 2014, Page: 897-903
ISSN: 1018-7081

EFFECTS OF PLANTING PATTERNS AND IRRIGATION CONDITIONS ON THE PHOTOSYNTHETIC CHARACTERISTICS OF WINTER WHEAT

Z. B. Feng, X. Y. Wang*, X. B. Zhou, Y. H. Chen* and J. J. Bi*

Agricultural College of Guangxi University, Nanning 530004, China
*State Key Laboratory of Crop Biology, College of Agronomy, Shandong Agricultural University, Tai'an 271018, China
Corresponding author email: whyzxb@gmail.com

ABSTRACT

The effects of irrigation and planting pattern on wheat in field conducted at Taian, northern China during 2011-12. The experiments consisted of two planting patterns (single and double rows) and two irrigation levels (0 and 180 mm) resulting in the same plant density (200×10^4 plant/ha). Each experiment plot was 3 m × 3 m in size and replicated thrice in split-plot design. During course of study net photosynthetic rate, H_2O conductance, transpiration rate, and maximum photochemical efficiency of flag leaves and grain yield of winter wheat were recorded. At the maturity stage, the net photosynthetic rate of the plants grown in a double-row planting pattern was higher than that of the plants grown in a single-row planting pattern without irrigation. H_2O conductance and transpiration rate of plants in the double-row planting pattern were higher than those grown in the single-row planting pattern without and with irrigation. The double-row planting pattern exhibited higher capacity utilization to high light and higher resistivity to photo inhibition than the single-row planting pattern. The spike number per square meter of the double-row planting pattern was higher than that of the single-row planting pattern under the same water treatment. The 1000-kernel weight of the non-irrigated plants grown in the double-row planting pattern was higher than that in the single-row planting pattern. Hence, the double-row planting pattern improved the photosynthetic capacity of winter wheat under water stress (non-irrigated plants).

Key words: *Triticum aestivum*; net photosynthetic rate; light response curve; photochemical efficiency; yield.

INTRODUCTION

Row spacing and line spacing are agronomics practices those determine the spatial distribution of a plant population structure, affecting canopy structure, light interception, radiation use efficiency, and biomass production (Eberbach and Pala, 2005). Interplant competition can occur when the supply of a single essential factor of growth decreases below the aggregate demands of plants (Avola, 2008; Abadouz, 2010). If plants are sown sufficiently close to one another, one plant can influence another plant and modify the soil or atmospheric environment of the other plant, thereby decreasing growth rate (De Bruin and Pedersen, 2008). The main competition factors of plants include light, water, nutrients, and weeds (Brant *et al*., 2009). Therefore, plant spacing influences yield (Kazemeini *et al*., 2009; Cox and Cherney, 2011).

Studies have shown the influence of plant spacing on plant growth when water and fertilizer are adequate. For instance, the North China Plain is one of the most important grain-producing areas in China; this area covers approximately 18.3% of the total national farmland and produces approximately 1/4 of the food in the country. However, the lack of water is a very serious problem because of uneven distribution of precipitation across time and space in this area (Deng *et al*., 2006). During the growing season, the water requirement of winter wheat is approximately 400 mm to 500 mm that exceeds the average rainfall in this area.

Most of the damaging effects of drought happen on photosynthesis of plants. Studies have shown that the decrease in photosynthetic activity under drought stress can be attributed to stomatal and non-stomatal limitations (Shangguan *et al*., 2000; Zlatev and Yordanov, 2004). One of the earliest responses to drought is stomatal closure. Stomatal closure allows plants to limit transpiration, but such a response also limits CO_2 absorption, thereby decreasing photosynthetic activity (Nayyar and Gupta, 2006). Limitations to CO_2 absorption imposed by stomatal closure may promote an imbalance between the photochemical activity of photosystem II (PSII) and the electron requirement of the Calvin-Benson cycle; this imbalance leads to an excessive absorption of excitation energy and subsequent photoinhibitory damage to PSII reaction centers (Foyer and Noctor, 2003). Among the characteristics that contribute to increased dry weight and higher grain yield, the delay in leaf senescence is considered as very important. This delay associated with increased dry matter and grain production has been observed in wheat (*Triticum aestivum* L.). In addition, many research results have indicated that planting patterns could significantly affect the photosynthesis of leaves (Hussain *et al*., 2012; Wang *et al*., 2013). Different planting pattern of rice plants, which produced different root characteristics, contribute to different level of Rubisco and nitrogen in leaves and therefore, different rate of leaf photosynthesis at the ripening stage (San-oh *et al*., 2006)

This study aimed to clarify the difference in the photosynthetic rate of the flag leaves of winter wheat in a single-row planting pattern (SRPP) and a double-row planting pattern (DRPP). This study was also designed to investigate the causes of such differences in photosynthetic rate by comparing the gas exchange characteristics of the leaves and the photochemical activities of PSII.

MATERIALS AND METHODS

Experimental site: The experiment was conducted during the winter wheat growing season 2011–2012 at the Agronomy Experimental Station of the Shandong Agricultural University (36°10’19’’N, 117°9’03’’E) in the North China Plain. The region is located in a warm temperate zone with a continental monsoon climate and an annual precipitation of 697 mm. Each experimental plot was 3 m × 3 m in size with light loamy soil and concrete slabs placed around the plot to prevent the lateral flow of soil water. The levels of rapidly available phosphorus, potassium, and nitrogen in the soil layer from 0 cm to 20 cm were 15.2, 81.8, and 65.2 mg/kg, respectively. At the time of sowing, 26.1 g/m^2 of diammonium hydrogen phosphate, 38.4 g/m^2 of urea, and 21.0 g/m^2 of potassium sulfate were applied on the soil in the plot. Approximately 38.4 g/m^2 of urea was added at the jointing stage.

Winter wheat was hand planted at a density of 400 × 10^4 plants/ha on October 8, 2011. Thinning was done by hand at 5 d after wheat emerged to obtain the final population density (200 × 10^4 plants/ha). The plants were harvested on June 13, 2012. The winter wheat variety used for the experiment was Jimai 22.

Weather data: Weather data were collected from the Taian Agrometeorological Experimental Station located 500 m from the experimental site. The total rainfall value during the 2011–2012 winter wheat growing season was 205.8 mm (Table 1)

Experimental design: A split-plot design was prepared using the two planting patterns (SRPP and DRPP; Figure 1). Moreover, two irrigation schemes were employed: (1) 180 mm irrigation at the jointing, heading, and filling stages; and (2) no irrigation during these growth stages. Water was supplied to the plots from a pump outlet by using plastic pipes. A flow meter was used to measure the amount of water applied.

Measurements: Leaf gas exchange was assessed using a portable infrared gas analyzer (LI-6400; LI-COR Inc., Lincoln, USA). The photosynthetic rate and diffusion conductance in flag leaves were determined on a clear day from 9 a.m. to 11 a.m. before the marked reduction in photosynthesis at midday occurred. The diffusion conductance was calculated with this system according to Von Caemmerer and Farquhar (1981). The quantum flux density on a leaf surface, relative humidity and flow rate in the chamber, and leaf temperature were maintained at 1600 μmol/m^2/s, 60% to 70%, 500 μmol/s, and 30 °C, respectively.

The light response curves were obtained from 9 a.m. to 11 a.m. after the photoperiod began by using fully expanded flag leaves under good illumination. CO_2 concentration, relative humidity and flow rate in the chamber, and leaf temperature were maintained at 400 ppm, 60% to 70%, 500 μmol/s and 30 °C, respectively. Photosynthetic photon flux density (PPFD) was gradually decreased from 2000 μmol/m^2/s to 0 μmol/m^2/s (1800, 1600, 1400, 1200, 1000, 800, 600, 400, 200, 100, 50, and 0 μmol/m^2/s) to avoid limitation of photosynthesis at a high light intensity because of insufficient stomatal opening caused by initial lower light intensities (Singsaas *et al*., 2001). The non-rectangular hyperbolic equation is commonly used to predict photosynthetic parameters (Saito *et al*., 2009). Light response curves were fitted using the non-rectangular hyperbola method.

$$Pn = \frac{¤ \cdot PPFD + P_{max} - \sqrt{(¤ \cdot PPFD + P_{max})^2 - 4¤ \cdot PPFD \cdot ¯ \cdot P_{max}}}{2¯} + Rd$$

where P_{max} is the maximum *P*n at light saturation (μmol/m^2/s); ¤ is apparent quantum yield [mol CO_2/(mol photon)]; PPFD is photosynthetic photo flux density (μmol/m^2/s); θ represents the convexity of the curve; and *R*d is the daytime respiration (μmol/m^2/s).

Chlorophyll *a* fluorescence transients were determined using an integral PEA senior (Hansatech, UK) with dark-adapted leaves under ambient CO_2 conditions. The saturating red light of 3000 μmol/m^2/s was produced by an array of four light-emitting diodes (LEDs, peak of 650 nm). Chlorophyll *a* fluorescence transients were obtained with a saturating red light of 2 s and analyzed by conducting JIP test based on the following equation (Strasser *et al*., 2000): maximum quantum yield of PSII (Fv/Fm) = 1 – (Fo/Fm).

Approximately 1 m^2 was selected randomly in each experimental plot to measure the spike number, 1000-kernel weight, and grain yield when the winter wheat plants reached maturity. The plants were harvested manually and air dried. Twenty additional plants were harvested to count the kernel numbers per spike.

Statistical analysis: The experimental data were evaluated by ANOVA. Multiple comparisons were conducted to determine the significant effects by the least significant difference (LSD) test at α = 0.05.

RESULTS AND DISCUSSION

Net photosynthetic rate: At the growth stage, the net photosynthetic rate of the flag leaves of the plants in all of the treatments initially increased and then decreased. However, the highest net photosynthetic rate was observed at different stages (Figure 2). In particular, the highest net photosynthetic rates of the non-irrigated plants grown in SRPP and DRPP were observed at the heading and filling stages, respectively. The highest net photosynthetic rates of the irrigated plants grown in SRPP and DRPP were observed at the milk development stage. At the maturity stage, the net photosynthetic rate of the flag leaves in SRPP was significantly lower by 61.1% than that in DRPP without irrigation ($P < 0.05$).

No differences were observed between the net photosynthetic rates of the flag leaves of the irrigated plants grown in SRPP and DRPP at the flag and heading stages (Figure 2). At the milk development and maturity stages, the net photosynthetic rates of the non-irrigated plants were lower than those of the irrigated plants under the same planting pattern. The photosynthetic rates of the flag leaves of the non-irrigated plants in SRPP were 42.5% and 57.0% lower than those of the irrigated plants, respectively. However, the photosynthetic rates of the flag leaves of the non-irrigated plants in DRPP were 15.2% and 19.4% lower than those of the irrigated plants, respectively.

H_2O conductance and transpiration rate: H_2O conductance showed no significant difference between the non-irrigated plants grown in SRPP and DRPP at the heading and milk development stages; however, H_2O conductance of the flag leaves in SRPP were significantly lower than that in DRPP at the flag and maturity stages ($P < 0.05$; Figure 3).

The transpiration rates of SRPP and DRPP showed similar trends to H_2O conductance (Figure 3). At the flag and maturity stages without irrigation, the transpiration rate of the flag leaves in SRPP was lower than that in DRPP. For SRPP, the transpiration rates of the non-irrigated plants were 20.8% and 33.4% lower than those with irrigation at the filling and maturity stages, respectively. For DRPP, the transpiration rates of the non-irrigated plants were 19.4% and 27.4% lower than those of the irrigated plants at the filling and maturity stages, respectively.

Light response curve: The photosynthetic rates as a response to increasing PPFD were observed in all of the treatments (Figure 4). The photosynthetic rate increased rapidly as PPFD increased to 400 μmol photon/m^2/s (linear phase), gradually increased when PPFD reached a maximum of 1000 μmol photon/m^2/s (light saturation point), and remained constant when PPFD reached a maximum of 1800 μmol photon/m^2/s.

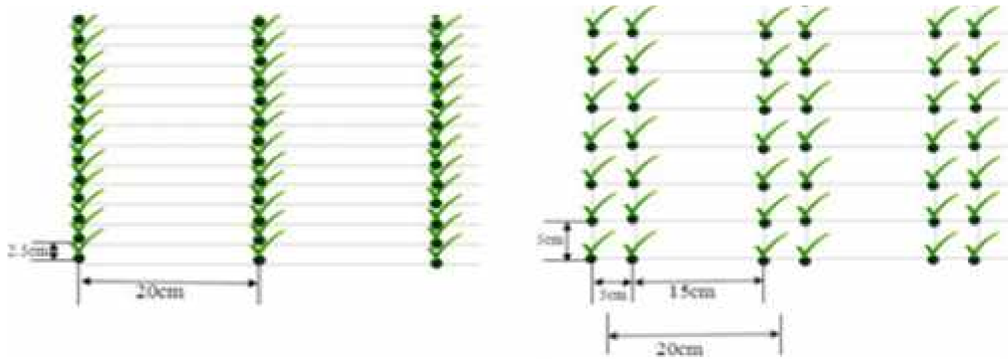
Non significant differences between DRPP and SRPP were observed in terms of ¤, *R*d, and LCP. P_{max} and LSP of the flag leaves of the irrigated plants in SRPP were lower than those in DRPP (Table 2).

Maximum photochemical efficiency: The maximum photochemical efficiency of irrigated plants was higher than that of non-irrigated plants. However, non significant differences were observed between the plants in all of the treatments before the maturity stage (Figure 5). At the maturity stage, the maximum photochemical efficiency of non-irrigated plants decreased by 20.7% and 5.5% for SRPP and DRPP, respectively. Non significant differences were observed in the maximum photochemical efficiency of irrigated plants in both planting patterns. However, the maximum photochemical efficiency of the irrigated plants in DRPP was significantly higher by 17.1% than that in SRPP ($P < 0.05$). At the maturity stage, non significant difference was observed in the maximum photochemical efficiency of irrigated and non-irrigated plants in DRPP. For SRPP, the maximum photochemical efficiency of non-irrigated plants was significantly lower than that of irrigated plants by 16.4% ($P < 0.05$).

Grain yield and yield components: The grain yields and the yield components of different experimental treatments are shown in Table 3. Non significant differences in the grain yields of double-row planting pattern with no irrigation (DNI) and single-row planting pattern with irrigation (SI) were observed ($P > 0.05$). Although the spike number of DI was 8.0% higher than that of SI, the kernel number per spike and 1000-kernel weight of DI were 13.0% and 6.1% lower than those of SI, respectively. Non significant differences were observed in the kernel number per spike between single-row planting pattern with no irrigation (SNI) and double-row planting pattern with no irrigation (DNI) ($P > 0.05$); however, the spike number and 1000-kernel weight of DNI were 33.2% and 7.0% higher than those of SN. The grain yield of DNI was significantly higher than that of SNI by 21.3% ($P < 0.05$). Non significant differences were observed in the grain yield of DRPP under different water conditions. For SRPP, the grain yield of the non-irrigated plants was significantly lower than that of irrigated plants by 18.1% ($P < 0.05$).

Table 1. Monthly rainfall (mm) during the winter wheat growing season.

Month	10	11	12	1	2	3	4	5	6	Total
2011-2012	13.4	99.2	14.7	1.8	0.1	25.9	43.7	7.0	0.0	205.8



Single-row planting pattern (SRPP) Double-row planting pattern (SRPP)

Fig. 1 A schematic diagram showing single-row planting pattern (SRPP) and double-row planting pattern (SRPP).

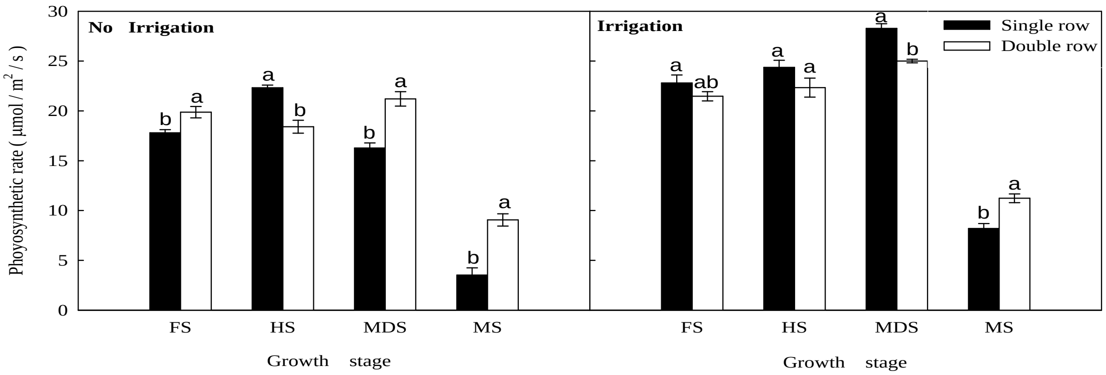


Fig. 2 Net photosynthetic rate of flag leaves of no irrigation and irrigation. FS, flag stage; HS, heading stage; MDS, milk development stage; MS, maturity stage.

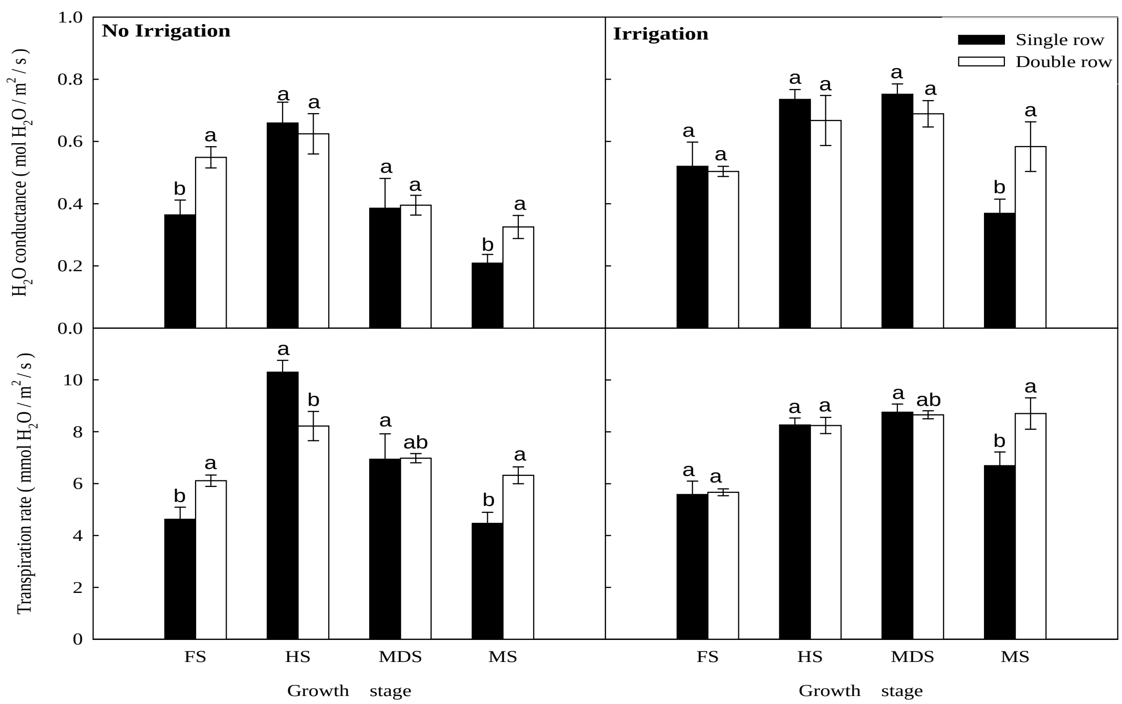


Fig. 3 Conductance to H_2O and transpiration rate of different patterns under no irrigation and irrigation. FS, flag stage; HS, heading stage; MDS, milk development stage; MS, maturity stage.

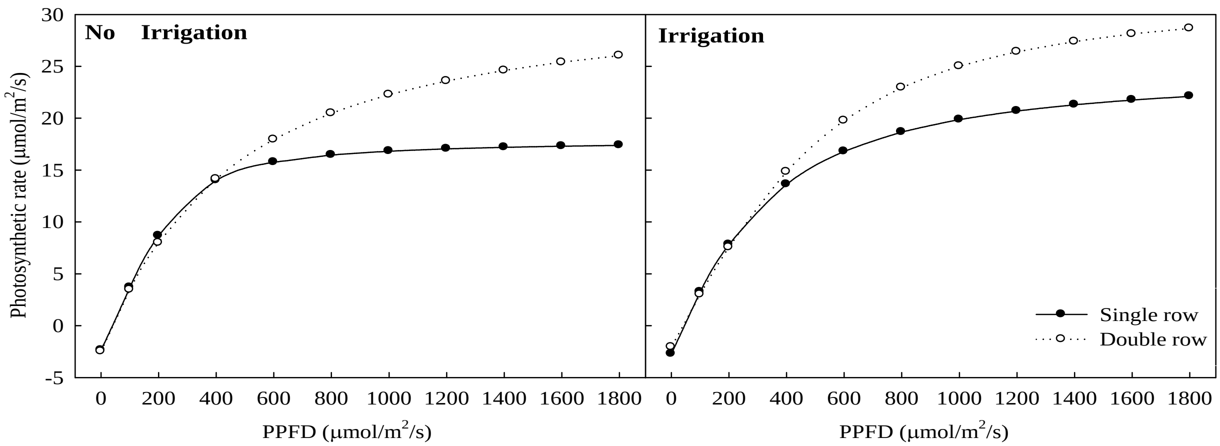


Fig. 4 Light response curves of different planting patterns at filling stage under no irrigation and irrigation. PPFD, Photosynthetic photon flux density.

Table 2. Physiological parameters of light response curves at filling stage for winter wheat

Treatments	¤	P_{max} (μmol/m²/s)	Rd (μmol/m²/s)	LCP (μmo/m²/s)	LSP (μmo/m²/s)
SNI	0.064	20.302	2.371	37.047	896.076
SI	0.067	27.686	2.723	40.642	1019.818
DNI	0.068	34.426	2.494	36.676	1045.625
DI	0.053	34.631	2.069	39.038	1389.976

¤, Apparent quantum yield; P_{max}, Maximum photosynthetic rate; Rd, Daytime respiration; LCP, Light compensation point; LSP, Light saturation point; SNI, single-row planting pattern with no irrigation; SI, single-row planting pattern with irrigation; DNI, double-row planting pattern with no irrigation; DI, double-row planting pattern with irrigation.

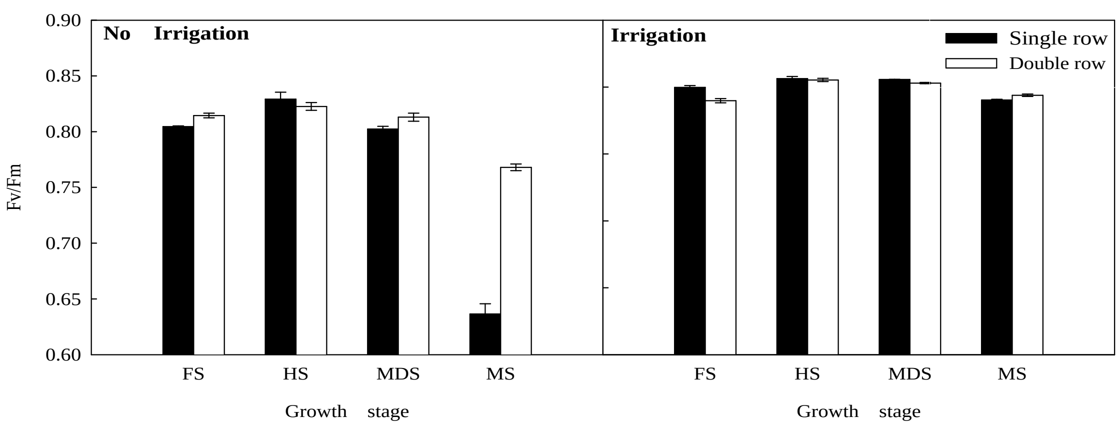


Fig. 5 The maximum photochemical efficiency of different growth stages under no irrigation and irrigation. FS, flag stage; HS, heading stage; MDS, milk development stage; MS, maturity stage.

Table 3. Grain yield and yield components.

Treatments	Spike number (spike/m²)	Kernel numbers per spike	1000-kernel weight (g)	Grain yield (g/m²)
SNI	634a	24.2b	34.1a	632c
SI	522b	27.2a	34.8a	732b
DNI	678a	28.7b	35.4a	703b
DI	641a	27.8b	34.3a	781a

SNI, single-row planting pattern with no irrigation; SI, single-row planting pattern with irrigation; DNI, double-row planting pattern with no irrigation; DI, double-row planting pattern with irrigation.

DISCUSSION

Plants cultivated in different patterns under the same planting density produced different amounts of dry matter at the ripening stage (San-oh *et al*., 2004). The photosynthetic characteristics of individual leaves of the canopy are also important determinants of dry matter production in canopies. Hence, the following factors should be considered: the photosynthetic rate of a leaf immediately after full expansion under optimum conditions; the photosynthetic of a leaf during senescence (Makino *et al*., 1985); and the photosynthetic of a leaf under stressful conditions. In this study, the flag leaves of the treatments were young before the filling stage. The photosynthetic rate and the maximum photochemical efficiency of irrigated plants exhibited no differences between DRPP and SRPP. These results indicated that the leaf photosynthetic rate is possibly similar in plants. The photosynthetic rate of the flag leaves of the irrigated plants decreased because of senescence. Furthermore, the photosynthetic rates of DRPP were consistently higher than that of SRPP at the milk development and maturity stages. The maximum photochemical efficiency of the flag leaf showed similar trends to the photosynthetic rates. These results indicated that the slower decrease in the photosynthetic rate of the leaves during ripening may contribute to the production of higher 1000-kernel weight in DRPP than in SRPP.

The H_2O conductance and the transpiration rate of the irrigated plants were higher than those of the non-irrigated plants at the milk development and maturity stages. By contrast, no differences were observed in these factors between the two planting patterns. Thus, the planting pattern does not significantly affect H_2O conductance and transpiration rate of crops. Light response curves showed that the maximum photosynthetic rate of DRPP was significantly higher than that of SRPP under the same water condition. The apparent quantum yield did not exhibit a significant difference between the two planting patterns. Therefore, plants under the two planting patterns exhibited average capacity utilization at low light intensity. However, plants grown in DRPP exhibited higher capacity utilization at high light intensity.

This study discovered that there were little differences between DRPP and SRPP under irrigation, however, the grain yield of DRPP was significantly higher than that of SRPP under rainfed. The DRPP can maximize the advantages of Jimai 22, a drought-resistant variety. This study demonstrated that the drought-resistant variety combined with DRPP could be taken advantages.

Acknowledgments: 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 (2011BAD32B02; 2013BAD07B06).

REFERENCES

Abadouz, G., A. H. Gorttapeh, A. A. Rahnema, and A. Behradfar (2010). Effect of row spacing and seeding rate on yield component and seed yield of alfalfa (*Medicago sativa* L.). Not. Sci. Biol. 2: 74–80.

Avola, G., R. Tuttobene, F. Gresta, and V. Abbate (2008). Weed control strategies for grain legumes. Agron. Sustain. Dev. 28: 389–395.

Brant, V., K. Neckář, J. Pivec, M. Duchoslav, J. Holec, P. Fuksa, and V. Venclová (2009). Competition of some summer catch crops and volunteer cereals in the areas with limited precipitation. Plant Soil Environ. 55: 17–24.

Cox, W. J., and J. H. Cherney (2011). Growth and yield responses of soybean to row spacing and seeding rate. Agron. J. 103: 123–128.

De Bruin J. L., and P. Pedersen (2008): Effect of row spacing and seeding rate on soybean yield. Agron. J. 100: 704–710.

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

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.

Foyer, C. H., and G. Noctor (2003). Redox sensing and signalling associated with reactive oxygen in chloroplasts, peroxisomes and mitochondria. Physiol. Plant. 119: 355–364.

Hussain, S., A. Ali, M. Ibrahim, M. F. Saleem, and M. A. A. H. A. Bukhsh (2012) Exogenous application of abscisic acid for drought tolerance in sunflower (*Helianthus annuus* L.): a review. The J. Anim. Plant Sci. 22: 806–826.

Kazemeini, S. A., M. Edalat, and A. Shekoofa (2009). Interaction effects of deficit irrigation and row spacing on sunflower (*Helianthus annuus* L.) growth, seed yield and oil yield. Afr. J. Agric. Res. 4: 1165–1170.

Makino, A., T. Mae, and K. Ohira (1985). Photosynthesis and ribulose-1, 5-bisphosphate carboxylase/ oxygenase in rice leaves from emergence through senescence. Quantitative analysis by carboxylation/oxygenation and regeneration of ribulose 1, 5-bisphosphate. Planta 166: 414–420.

Nayyar, H., and D. Gupta (2006). Differential sensitivity of C 3 and C 4 plants to water deficit stress: Association with oxidative stress and antioxidants. Environ. Exp. Bot. 58: 106–113.

Saito, M., S. Maksyutov, R. Hirata, and A. D. Richardson (2009). An empirical model simulating diurnal and seasonal CO_2 flux for diverse vegetation types and climate conditions. Biogeosciences 6: 585–599

San-oh, Y., Y. Mano, T. Ookawa, and T. Hirasawa (2004). Comparison of dry matter production and associated characteristics between direct-sown and transplanted rice plants in a submerged paddy field and relationships to planting patterns. Field Crop Res. 87: 43–58.

San-oh, Y., T. Sugiyama, D. Yoshita, T. Ookawa, and T. Hirasawa (2006). The effect of planting patternon the rate ofphotosynthesis and related processes during ripening in rice plants. Field Crop Res. 96: 113–124.

Shangguan, Z. P., M. A. Shao, and J. Dyckmans (2000). Nitrogen nutrition and water stress effects on leaf photosynthetic gas exchange and water use efficiency in winter wheat. Environ. Exp. Bot. 44: 141–149.

Singsaas, E. L., D. R. Ort., and E. H. DeLucia (2001). Vriation in measured values of photosynthetic quantum yield in ecophysiological studies. Oecologia 128: 15–23

Strasser, R. J., A. Srivastava, and M. Tsimilli-Michael (2000). The fluorescence transient as a tool to characterize and screen photosynthetic samples. Probing photosynthesis: mechanisms, regulation and adaptation. London: taylor and Francis, CRC Press, pp445–483.

Von Caemmerer, S., and G. D. Farquhar (1981). Some relationships between the biochemistry of photosynthesis and the gas exchange of leaves. Planta 153: 376–387.

Wang, X. H., Y. P. Song, J. Ren, T. K. Liu, X. L. Hou, and Y. Li (2013). Response of bio mass and photosynthesis in non-heading Chinese cabbage to excess copper. J. Anim. Plant Sci. 23: 1659–1665.

Zlatev, Z. S., and I. T. Yordanov (2004). Effects of soil drought on photosynthesis and chlorophyll fluorescence in bean plants. Bulg. J. Plant Physiol. 30: 3–18.