Advance Journal of Food Science and Technology 6(5): 689-695, 2014
DOI:10.19026/ajfst.6.95
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: February 24, 2014 Accepted: April 14, 2014 Published: May 10, 2014

Research Article

Effects of Irrigation on Photosynthetic Characteristics of Wheat under Drip Irrigation

[1, 2]Zhenhua Wang, [1, 2]Guojun Jiang and [1, 2]Xurong Zheng
[1]College of Water and Architectural Engineering, Shihezi University,
[2]Corps Key Laboratory of Modern Water-Saving Irrigation, Shihezi Xinjiang 832000, China

Abstract: In arid areas, wheat Growth and yield is extremely significant affected by irrigation, under different study of drip irrigation, the irrigation amount has impact on the physiological indicators of wheat, in order to help improve the efficiency of irrigation water use. In order to reveal the effects of irrigation on photosynthetic characteristics of the Wheat Under Drip Irrigation (WUDI), we designed four different irrigation treatments as W1 (315 mm), W2 (360 mm), W3 (405 mm) and W4 (450 mm) by test-pit experiments and investigated the effects of irrigation amount on photosynthetic physiological indexes of the WUDI. The results showed that the increased irrigation amount enhanced the wheat photosynthesis, but excessive irrigation would reduce the net photosynthetic rate and stomatal conductance of the plants (W3>W4>W2>W1). Regression analysis on the photosynthetic physiological indexes and irrigation amount indicated that the transpiration rate was significantly related with irrigation amount (R^2 = 0.99), while the photosynthetic rate and intercellular CO_2 concentration had moderate relations with irrigation amount (R^2 = 0.84). When the irrigation amount was 405 mm, the water utilization rate was highest and more photosynthetic products could be accumulated with more reasonable allocation.

Keywords: Drip irrigation, irrigation amount, photosynthetic index, wheat

INTRODUCTION

Drip irrigation is a water-saving technique that locally moistens soil and effectively uses irrigation water. It is widely applied to economic crops like cotton and shows significant water-saving effect. In recent years, the technique starts its large-scale application to wheat and other high-intensity crops in Xinjiang of China, which has achieved higher yield (Cheng *et al*., 2007; Wang *et al*., 2011a).

Water is a necessary component of crops, which is also one of critical factors limiting crop growth and development. Therefore, understanding water demand and utilization features of crops at different growth stages is important for improving water utilization rate and implementing scientific water-saving irrigation.

Wheat is an important food crop and photosynthesis is one important life characteristic of this crop. Considering the key role of water for photosynthesis, a lot of studies have focused on the effect of water on photosynthetic characteristics of wheat flat leaves under drought conditions (Lawlor and Cornic, 2002; Liu *et al*., 2012; Tezara *et al*., 1999; Wang *et al*., 2011b; Zhang *et al*., 2000). Tan *et al*. (2011) revealed that the increase of irrigation frequency and amount could weaken photosynthetic “nap” of wheat flat leaves. Fang *et al*. (2006) and Srivali and Renu (1998) found that water had a regulation effect on the photosynthetic characteristics of wheat flat leaves and the grain yield. Meanwhile, water could influence the formation mechanisms of light and water utilization of crops and the grain yield (Hui *et al*., 2012; Rekika *et al*., 1998; Zhao *et al*., 2009). However, the above studies were all performed under the traditional irrigation methods and few studies focused on the Wheat Under Drip Irrigation (WUDI). The study about photosynthetic features of the WUDI was very rare.

Therefore, this paper carried out experimental study on different drip irrigation amount influence on photosynthetic characteristics of wheat, trying to further reveal the influence of irrigation amount on photosynthetic physiology of wheat in arid regions of Xinjiang, to determine irrigation quota in favor of the rational allocation of photosynthetic products, improve the efficiency of irrigation water use, so as to provide a theoretical basis for high-yielding wheat irrigation efficiency.

MATERIAL AND METHODS

Experimental background: The experiments were performed in 2013 at the key laboratory (44°19'28" N; 85°59'47" E; altitude, 412 m; the average ground slope, 6‰) of modern irrigation and water-saving corps in Shihezi University, Shihezi city of Xinjiang, which was

Corresponding Author: Xurong Zheng, College of Water and Architectural Engineering, Shihezi University, Shihezi Xinjiang 832000, China

located in the middle of northern piedmont of Tianshan Mountain in the southwestern margin of Jungar Basin. This region is in the temperate zone with the continental and arid climate. The average annual sunshine time is 2865 h and the accumulated temperatures of more than 10°C and more than 15°C are 3463.5°C and 2960.0°C, respectively. The temperature difference between day and night is large and the temperature changes dramatically between seasons with a frost free period of 170 days. The average annual precipitation and evaporation are 207 mm and 1660 mm respectively, so the crop planting during a year totally depends on irrigation. In this region, the average annual wind speed is 1.5 m/s, including 32% of static wind, 22% of southerly wind, 15% of northerly wind, 14% of easterly wind and 17% of westerly wind.

Experimental design: The experiments were carried out in test pits (2×3×2.3 m) using saline soil as filled soil from April to July of 2013. The initial average salinity of saline soil in each test pit was pretty similar and the initial salinity of tillage layers ranged from 0.4 to 1.0%, belonging to moderate salinized soil. Based on previous investigation, we designed four irrigation treatments as 315 mm (W1), 360 mm (W2), 405 mm (W3) and 450 mm (W4) and each treatment was repeated 3 times. The dripper discharge and irrigation frequency of each treatment remained the same. The drip irrigation was applied once at the tillering stage, 3 times at the jointing-booting stage, 3 times at the heading stage and 2 times at the filling stage, namely, 9 times during the whole growth period. For each treatment, fertilization was applied with drip irrigation according to the standards for local large lands, namely, 90 kg/hm^2 urea and 75 kg/hm^2 potassium dihydrogen phosphate was used at the jointing-booting and grain filling stages and 120 kg/hm^2 urea and 90 kg/hm^2 potassium dihydrogen phosphate was used at the heading stage. The main local salt-tolerant plant named "Spring 6" was selected as the tested wheat. The planting pattern was 5 rows per tube, with the row distance of 15 cm and the dripping tube space of 75 cm. The seeding was determined as 36~40 kg/hm^2, which meant about 4.5 to 6 million seedlings were conserved per hectare.

Measurement indicators and methods: At the jointing-booting stage (May 16th), heading stage (June 31th) and milky stages (June 21th), the CI-340 portable photosynthetic device was used to determine the net photosynthetic rate (*Pn*), transpiration rate (*Tr*), stomatal conductance (*Gs*), intercellular CO_2 concentration diurnal variation (*Ci*) of flat leaves on the third day after irrigation. The measurement was started at 8:00 am and ended at 8:00 pm, with one determination every 3 h. Three flat leaves that were most close to drip irrigation tubes and grew best were selected for determination each time. A leaf chamber was under a flat leaf and about 1~2 cm away far from the sheath. Each treatment should be completed within 1 h and the sunshine should be ensured to directly irradiate towards the leaves during the determination. Moreover, the weather should be cloudless when conducting determination.

RESULTS AND ANALYSIS

Effects of irrigation amount on net photosynthetic rat (*Pn*) of the WUDI: Figure 1 shows diurnal variation of net photosynthetic rate (*Pn*) of wheat under drip irrigation at different growth stages. As shown in Fig. 1, the diurnal variation curves of net photosynthetic rate at different growth stages all present a double-peak pattern with an obvious photosynthetic "nap" phenomenon, although the first peak, the valley and the second peak appear at different time. In the morning, *Pn* gradually goes up along with the increase of light intensity, while it goes down with the decrease of light intensity. After 6:00pm, *Pn* decreases rapidly. Generally, *Pn* is higher in the morning compared with the value in the afternoon. At

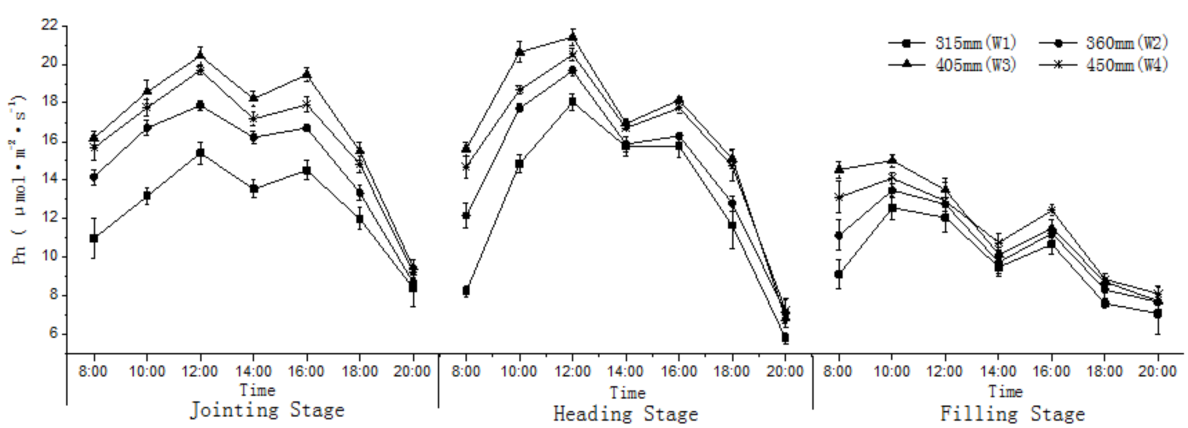


Fig. 1: Diurnal variation of net photosynthetic rate (*Pn*) at different growth stages

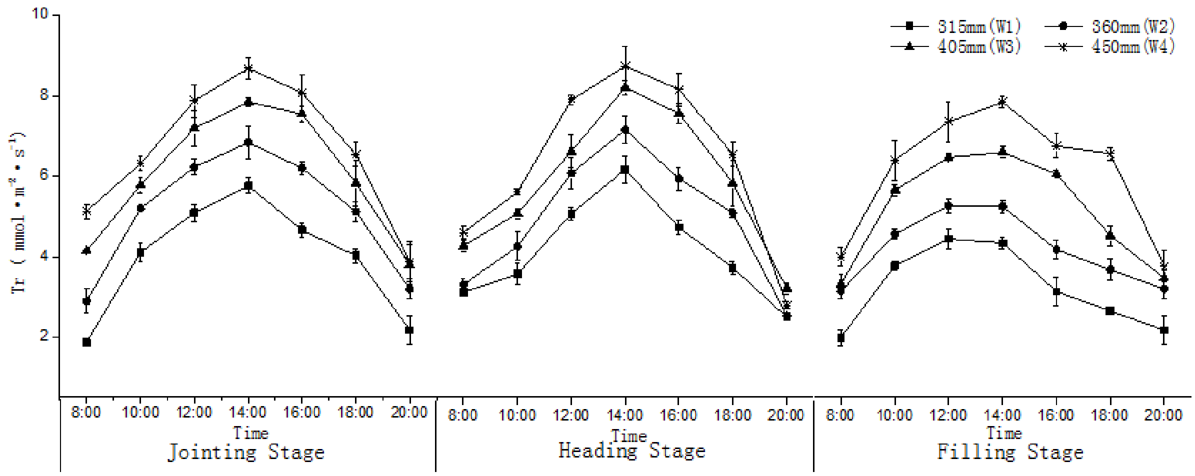


Fig. 2: Diurnal variation of transpiration rate (*Tr*) at different growth stages

noon, photosynthetic "nap" phenomenon occurs at different levels and the strength of "nap" is related with irrigation amount and the growth stage. During each treatment, the "nap" at the jointing stage is weaker than that at the heading or filling stage and the difference between the peak value and valley value is minimal at the jointing stage. The average difference is 2.06 μmol/m^2·s at the jointing stage, 3.39 μmol/m^2·s at the heading stage and 3.75 μmol/m^2·s at the filling stage. At different growth stages, the peak values in the morning are significantly higher than those in the afternoon. Furthermore, the peak-valley difference is obviously different between the morning and afternoon peaks. At the jointing stage, the difference is smallest with the average difference of 1.2 μmol/m^2·s, while at the heading stage, the difference is highest with the average difference of 2.75 μmol/m^2·s. The morning peaks appear at different time for various growth stages, which appear at 12:00 pm during the jointing and heading stages, while at 10:00 am during the filling stage. In contrast, the afternoon peaks and wave valleys at different growth stages show up at the same time. The wave valleys all appear at 2:00 pm and the afternoon peaks appear at 4:00 pm.

At different growth stages, irrigation amount has similar effect on the net photosynthetic rate and the only difference is the influencing level on *Pn*. Irrigation has most significant impact on *Pn* at the jointing stage, but shows less effect at the filling stage due to the chlorophyll content decrease caused by flat-leaf senescence. Hence, irrigation treatment does not change *Pn* too much. Meanwhile, increasing irrigation amount can enhance *Pn* at different moment, but excessive irrigation may reduce *Pn*, i.e., W1<W2<W4<W3. At the jointing stage, the average *Pn* under W3 condition is 5% higher than that under W4 condition; at the heading stage, the value is 3.7%; at the filling stage, it is 1.1%. The results suggest that the increased irrigation benefits the increase of *Pn* when the irrigation amount is small, while excessive irrigation has less contribution to *Pn*. From 6:00 pm to 8:00pm, the difference between each irrigation treatment is not significant, which may be related with the rapid reduction of light intensity around the environment.

Effects of irrigation amount on transpiration rate (*Tr*) of the WUDI: Figure 2 shows the diurnal variation of transpiration rate (*Tr*) of the WUDI at different growth stages. As shown in Fig. 2, the diurnal variation curves of transpiration rate at different growth stages under different treatments all present a single-peak pattern and the peak value and shape are different along with various irrigation and growth stages. The peak value is highest at the jointing stage for each irrigation treatment, with a sharp peak pattern; while the value is smallest at the filling stage, with a gentle peak pattern. At the heading stage, the average of maximal *Tr* is 7.58 mmol/m^2·s, which is 3.9 and 25.9% higher than those at the jointing and filling stages, respectively. The change of *Tr* is closely related to environment factors. During one day, *Tr* first increases together with the rising of light intensity and temperature and the reduction of atmospheric humidity, reaching the maximum at 2:00 pm. Then, it sharply decreases due to the reduction of light intensity and temperature and the increase of atmospheric humidity. The irrigation amount at different stages shows significant effect on *Tr*, which is most obvious at the filling stage, followed by the jointing stage. At different growth stages, *Tr* always increases along with the increase of irrigation, i.e., W4>W3> W2 >W1, which indicates that irrigation can significantly improve the transpiration of the WUDI.

Effects of irrigation amount on stomatal conductance (*Gs*) of the WUDI: Stomatal conductance is a key physiological index reflecting

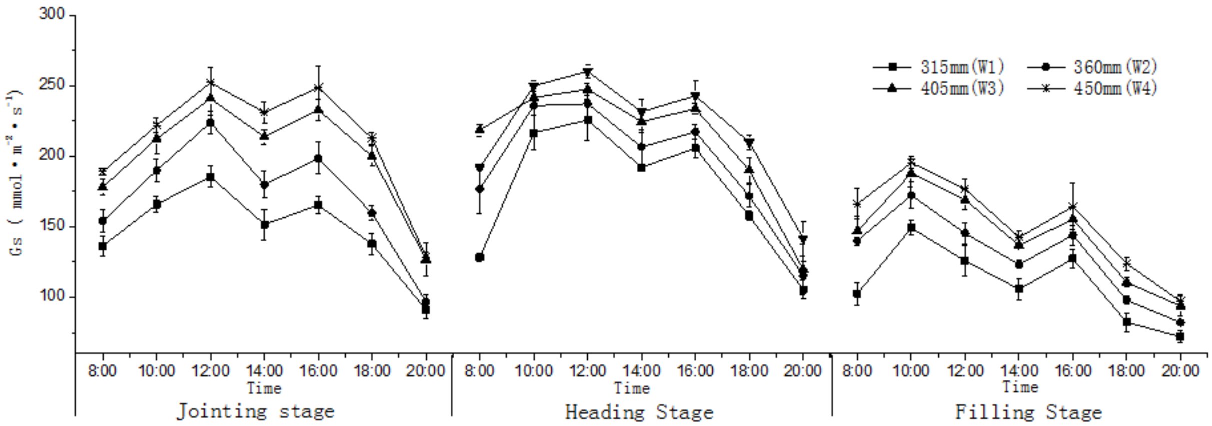


Fig. 3: Diurnal variation of stomata conductance (*Gs*) at different growth stages

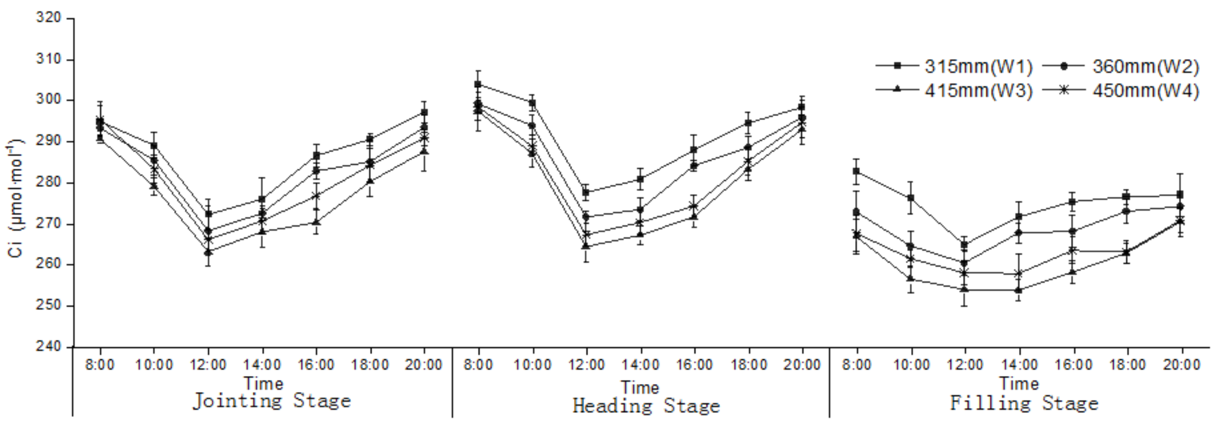


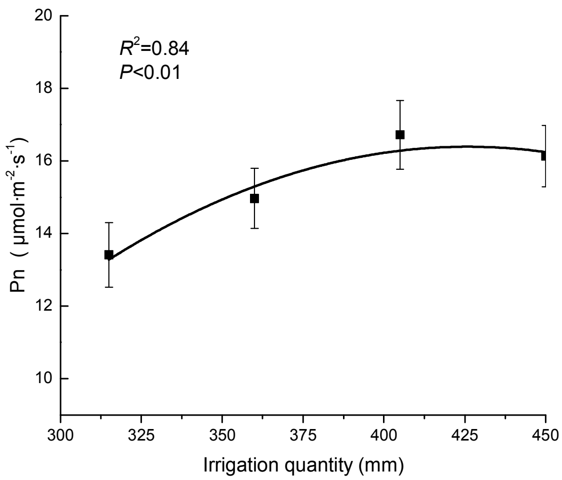
Fig. 4: Diurnal variation of intercellular CO_2 concentration (*Ci*) at different growth stages

stomatal movement. Figure 3 shows the diurnal variation of stomata conductance (*Gs*) of the WUDI at different growth stages. Combined with Fig. 1, it can be concluded that the diurnal variation of *Gs* changes synchronously with *Pn.* The diurnal variation curves at different growth stages all present a double-peak pattern and the first peak, the valley and the second peak appear at different time. At the jointing stage, the average value of morning peaks is 225.66 mmol/m^2·s and it is 242.70 mmol/m^2·s at the heading stage and 176.18 mmol/m^2·s at the filling stage. The morning peaks appear at 12:00 pm at the jointing and heading stages, while appear at 10:00 am at the filling stage. At different growth stages, the peak valleys and afternoon peaks appear at the same time, which occur at 2:00 pm and 4:00 pm, respectively. The difference between them is highest at the filling stage and smallest at the jointing stage. The average difference is 14.29 mmol/m^2·s at the jointing stage, 17.77 mmol/m^2·s at the heading stage and 28.39 mmol/m^2·s at the filling stage. The diurnal variations of *Gs* under different irrigation treatments are basically consistent and the difference of different irrigation treatments is most obvious at the jointing stage. Along with the wheat growth process, the difference between irrigation treatments reduces, which generally presents a sequence as W4> W3>W2>W1.

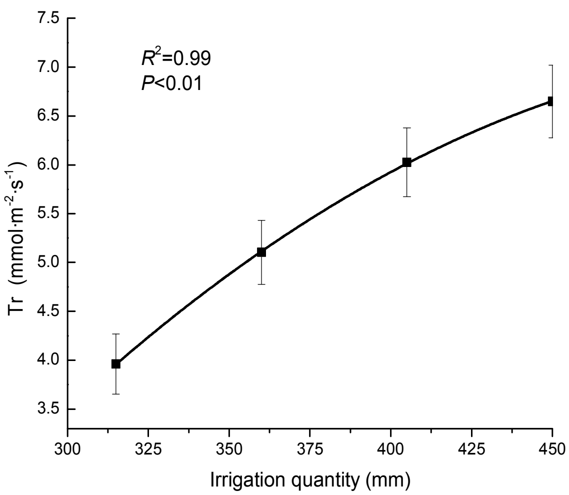
To sum up, *Gs* increases with the increase of irrigation amount, which implicates that irrigation benefits the opening of wheat leaf air holes to enhance the CO_2 utilization of wheat leaves, promoting crop transpiration and improving the microclimate of wheat fields.

Effects of irrigation amount on intercellular CO_2 concentration (*Ci*) of the WUDI: Figure 4 shows the diurnal variation of intercellular CO_2 concentration (*Ci*) of the WUDI at different growth stages. It can be seen that the variation trend of intercellular CO_2 concentration is opposite with those of *Pn*, *Tr* and *Gs*.

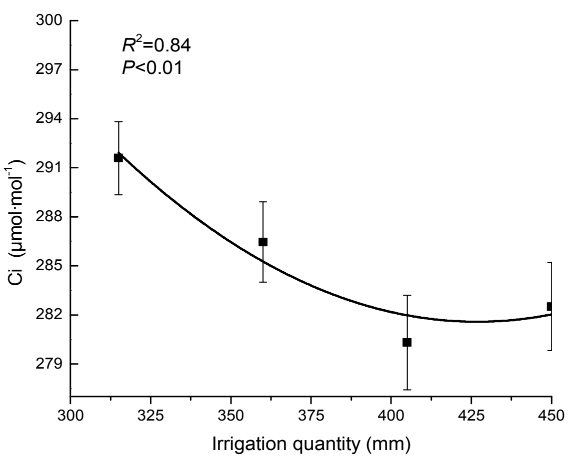
Intercellular CO_2 concentration is greatly impacted by photosynthesis. At different growth stages, intercellular CO_2 concentration first reduces and then increases along with the increase of light intensity during one day, which is highest in the morning and evening and smallest at noon. This is because CO_2 released by nocturnal leaf respiration aggregates in the space of cells, resulting in high intercellular CO_2



(a) Correlation between *Pn* and irrigation



(b) Correlation between *Tr* and irrigation



(c) Correlation between *Ci* and irrigation

Fig. 5: The relationships between growth and photosynthetic physiological indexes and irrigation

concentration. When photosynthesis is enhanced, CO_2 assimilation speeds up, so that CO_2 concentration gradually decreases and reaches the lowest point at about 12:00 pm. After that, it will increase due to the reduced photosynthesis.

Irrigation significantly decreases intercellular CO_2 concentration. At different growth stages, intercellular CO_2 concentration is highest under the W1 condition while lowest under the W3 condition. At the jointing stage, the average intercellular CO_2 concentration under the W3 condition is 3.5% lower than that under the W1 condition; at the heading stage, the value is 4.0%; at the filling stage, it is 5.6%. However, excessive irrigation will increase intercellular CO_2 concentration, i.e., W4>W3, which can be attributed to the reduced wheat leaf photosynthesis and enhanced respiration caused by excessive irrigation.

Correlation between the photosynthetic indexes of the WUDI and irrigation amount: In order to further clarify the effects of irrigation on photosynthesis of the WUDI, the wheat photosynthetic physiological indexes and irrigation amount were selected for regression analysis. The results are shown in Fig. 5.

According to Fig. 5 the photosynthetic physiological indexes of the WUDI are correlated with irrigation amount. Among the indexes, *Tr* is significantly correlated with irrigation (R^2 = 0.99) and *Pn* and *Ci* are also correlated with irrigation (R^2 = 0.84). Meanwhile, *Pn* and *Tr* both present a conic trend along with irrigation amount (Fig. 5a and b) and the increase rates of *Pn* and *Tr* both slow down as irrigation amount increases. Excessive irrigation even leads to the decrease of *Pn* and *Tr*.

Ci is negatively correlated with irrigation amount. The increase of irrigation amount leads to the reduction of flat-leaf *Ci* (Fig. 5c) and the reduction rate slows down together with irrigation amount. Notably, the continuous increase of irrigation may cause the increase of *Ci*.

The above results suggest that the regression curves between the wheat photosynthetic physiological indexes and irrigation amount can be used to predict the effects of irrigation amount on the wheat photosynthetic indexes. Moreover, the curves can determine the reasonable irrigation amount to realize the best allocation of photosynthetic products.

DISCUSSION

Crop photosynthetic products are the material basis of plant growth and yield formation and water has a direct and obvious effect on crop photosynthetic performances. Besides, water also influences the transport of photosynthetic products. In the present study, we found that *Pn*, *Tr*, *Gs* and *Ci* had the same diurnal variation trend at the jointing, heading and filling stages. At different growth stages, the diurnal variation of *Pn* and *Gs* presented a double-peak pattern, *Tr* showed a single-peak pattern and *Ci* was a single-valley pattern. However, *Pn* and *Gn* curves had different peak values and shapes at different growth stage and the time when the morning peaks appeared was obviously different. The morning peaks of *Pn* and *Gs* at the jointing and heading stages lagged behind those at the filling stage. In addition, these morning peaks at the heading and jointing stages were significantly higher than those at the filing stage. Meanwhile, the difference between the morning and afternoon peaks was highest at the heading stage and smallest at the filing stage. At the filing stage, wheat flat-leaf senescence was serious and the photosynthesis was weakened. At the heading stage, the area of wheat flat-leaf was biggest and the photosynthesis was strongest. But the photosynthetic function of wheat was weakened in the afternoon due to the continuous high temperature.

Irrigation significantly regulates crop photosynthetic characteristics and *Pn*, *Tr*, *Gs* and water utilization rate of crops all decrease under water constraint (Jing *et al*., 2013; Zhang *et al*., 2011; Zhang and Li, 2013; Zheng *et al*., 2013). In the present study, we found that *Pn*, *Tr* and *Gs* were all enhanced along with the increase of irrigation. However, excessive irrigation reduced *Pn*. At the jointing stage, the average *Pn* under the W3 condition was 5% higher than that under the W4 condition; at the heading stage, the value was 3.7%; at the filing stage, it was 1.1%. The results were consistent with what Kong *et al*. (2008) proposed, i.e., excessive irrigation inhibited photosynthesis. Excessive irrigation increased the ineffective fertilization, causing the reduction of wheat flat-leaf area. Meanwhile, wheat canopy closure was serious and the light use efficiency of flat leaves was low. In this study, the instantaneous water utilization rate of wheat flat leaves was lowest under the W4 condition and there was no obvious difference between other treatments, which indicated that proper drought stress could significantly improve water utilization rate of crops (Heitholt, 1989).

Wheat photosynthesis is correlated with irrigation amount. The polynomial regression analysis revealed that *Tr* was significantly correlated with irrigation (R^2 = 0.99) and that *Pn* and *Ci* were also highly correlated with irrigation (R^2 = 0.84). The results implicated that water conditions had a stronger effect on wheat transpiration than photosynthesis did.

CONCLUSION

Irrigation had obvious effects on the photosynthetic physiological indexes of the WUDI at different growth stages. 405 mm (W3) irrigation resulted in the highest *Pn* and *Gs* while the lowest *Ci*, which showed the strongest photosynthesis. Increasing irrigation amount could enhance *Pn* and *Gs* but reduce *Ci*, while excessive irrigation might decrease *Pn* and *Gs* but increase *Ci.* At different growth stages, *Tr* under the W4 condition was the highest and increasing irrigation amount could improve flat-leaf transpiration of the WUDI, but with the lowest water utilization rate. Among the photosynthetic physiological indexes, *Tr* was significantly correlated with irrigation and the others had moderate correlation. When the irrigation amount was 405 mm, the water utilization rate of the WUDI was relatively higher and more photosynthetic products were accumulated with more reasonable allocation.

ACKNOWLEDGMENT

The authors are grateful for the support of the National Natural Science Foundation of China (51169022) and the National Science and Technology Support Program of China (2011BAD29B06).

REFERENCES

Cheng, X., F. Zhang and S. Chai, 2007. Effects of different irrigation model on spring wheat yield and water use efficiency. J. Irrig. Drain., 26(2): 80-82.

Fang, Q.X., Y.H. Chen, Q.Q. Li, S.Z. Yu, Y. Luo, Q. Yu and Z. Ouyang, 2006. Effects of soil moisture on radiation utilization during late growth stages and water use efficiency of winter wheat. Acta Agron. Sin., 32(6): 861-866.

Heitholt, J.J., 1989. Water use efficiency and dry matter distribution in nitrogen and water-stressed winter wheat. Agron. J., 81(3): 464-469.

Hui, H.B., Q. Lin, Y.G. Liu *et al*., 2012. Effects of irrigation amount and stage on photosynthetic characteristics and yield of super-high-yield wheat at filling stage. Acta Agr. Boreali-occidentalis Sinica, 21(8): 77-83.

Jing, D.W., S.J. Xing, Z.Y. Du and F.C. Liu, 2013. Effects of drought stress on the growth, photosynthetic characteristics and active oxygen metabolism of poplar seedlings. Chin. J. Appl. Ecol., 24(7): 1809-1816.

Kong, D., Y. Yan, Y. Duan *et al*., 2008. Field experiment on growth and yields of winter wheat under different water and nitrogen treatment. T. Chinese Soc. Agric. Eng., 24(12): 36-40.

Lawlor, D.W. and G. Cornic, 2002. Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants [J]. Plant Cell Environ., 25: 275-294.

Liu, L.P., Z. Ouyang, L.F. Wu, F.D. Li and P.F. Liu, 2012. Effects of phased drought and re-watering on the photosynthetic characteristics and grain yield of winter wheat. Chinese J. Ecol., 31(11): 2797-2803.

Rekika, D., M.M. Nachit, J.L. Araus and P. Monneveux, 1998. Effects of water deficit on photosynthetic rate and osmotic adjustment in tetraploid wheats. Photosynthetica, 35(1): 129-138.

Srivali, B. and K.C. Renu, 1998. Drought-induced enhancement of protease activity during monocarpic senescence in wheat. Curr. Sci., 75(11): 1174-1176.

Tan, N.T., Q. Lin, W. Jiang, Y.G. Liu and L.Y. Li, 2011. Effect of limited irrigation on diurnal variation in flag-leaf photosynthesis and yield of dry land wheat. Chinese J. Eco-Agric., 19(4): 805-811.

Tezara, W., V.J. Mitchell and S.D. Driscoll, 1999. Water stress inhabits plant photosynthesis by decreasing coupling factor and ATP. Nature, 401: 914-917.

Wang, J.C., C.L. Xu, X.F. Han *et al*., 2011a. Effects of different soil moisture on growth, grain yield and water use efficiency of spring wheat under drip irrigation. Res. Agric. Modernization, 32(1): 115-119.

Wang, H.G., Z.W. Yu, Y.L. Zhang, D. Wang, Y. Shi *et al*., 2011b. Effects of supplemental irrigation based on measuring soil water content on wheat photosynthetic characteristics and dry matter accumulation and allocation. [J]. Chinese J. Appl. Ecol., 22: 2495-2503.

Zhang, H.J. and J. Li, 2013. The photosynthetic characteristics and water usage of potato under mulched drip irrigation. T. Chinese Soc. Agric. Mach., 44(10): 143-151.

Zhang, Q.D., H.Q. Liu and J.H. Zhang, 2000. Effects of limited irrigation on some photosynthetic functions of flag leaves in winter wheat. Acta Agron. Sin., 26(6): 869-873.

Zhang, Y.Q., Q. Lin, J.B. Liu, H.S. Zhang and C.X. Zhao, 2011. Effects of drought stress on photosynthetic characteristics and yield of different fertilizer and water types of wheat. J. Tritic. Crops, 31(4): 724-730.

Zhao, F.H., S.H. Zhang, C.J. Guo, R.L. Deng, S.X. Long and K. Xiao, 2009. Effects of nitrogen application methods on photosynthesis and senescence characteristics of flag leaves in wheat under limited irrigation. Plant Nutr. Fert. Sci., 15(2): 247-254.

Zheng, R., S.Z. Kang, X.T. Hu and S. Li, 2013. Effects of water and nitrogen conditions on the diurnal variation of photosynthesis characteristic and yield of grapevine in arid oasis region. T. Chinese Soc. Agric. Eng., 29(4): 133-141.