

# Photosynthetic light response characteristics of winter wheat at heading and flowering stages under saline water irrigation

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**Abstract.** In order to reveal the photosynthetic physiological response mechanism for winter wheat under saline water irrigation, a field experiment was conducted in Yellow River Delta, Shandong, North China. Two irrigation treatments(irrigating 80mm with fresh water each at jointing, heading and milking stages, irrigating 80mm with fresh(0 g/L)-saline(3 g/L)-saline(3 g/L) water each at jointing, heading and milking stages) were designed. Leaf photosynthesis and photosynthetic light response characteristics were observed. The results show that, in comparison with fresh water irrigation (CK), saline water irrigation decreased net photosynthetic rate before noon at heading stage and flowering stage, but it can increase net photosynthetic rate in the afternoon due to the non-stomatal factors improved. The  $C_3$  plant new model of light response were introduced, compared with fresh water treatment, the maximum net photosynthetic rate ( $P_{nmax}$ ) of winter wheat under saline water were increased by 2.27 and 1.58  $\mu\text{mol}/\text{m}^2/\text{s}$  at the heading and flowering stages respectively, light saturation point ( $LSP$ ) were increased by 29.27 and 70.11  $\mu\text{mol}/\text{m}^2/\text{s}$ , light compensation point ( $LCP$ ) decreased by 19.38 and 4.63  $\mu\text{mol}/\text{m}^2/\text{s}$ , dark respiration rate ( $R_d$ ) decreased by 0.96 and 1.53, it showed that the saline water treatment enhanced the adaptability against strong light and high temperature conditions, promoted the ability using weak light of winter wheat. Therefore, saline water irrigation did not negatively affect leaf photosynthesis at heading and flowering stage of winter wheat.

## 1. Introduction

The development and utilization of brackish water resources play extremely important role in alleviating the shortage of freshwater resources, expanding agricultural water sources, and increasing drought resistance and yield. Brackish water is used for irrigation and it also provides a lot of salt [1] to the soil while providing the water needed for crop growth. The current research focused on the methods of brackish water irrigation and its water-soil environmental effect and its impact on crops, including irrigation technology [2,3], irrigation system, irrigation water quality [4], soil water and salt transport [5], soil physical and chemical properties [6], groundwater environment [7], crop growth and yield quality [8]. A lot of experiences have been accumulated through the research, but the inherent mechanism of the brackish water irrigation's impacts on the growth of different crops and the regulation mechanism of crops after salt stress still need further study. Photosynthesis is the basis of crop growth and development and a decisive factor in the level of productivity. It is also an important



indicator for crop breeding, cultivation and the study about crop response to environmental stress. Light is the dominant factor in photosynthesis. Crops have different response characteristics to light in different environmental conditions and development stages [9]. Studying the light response characteristics of crop photosynthesis can help to understand the operation status of photosynthetic apparatus of crop. However, relatively less research has been done on the winter wheat under brackish water irrigation. In this paper, the main irrigated grain in the Yellow River Delta, winter wheat, was selected as the research object. The leaf photosynthesis and photosynthetic light response characteristics of winter wheat flag leaves at heading and flowering stages under brackish water irrigation were studied, revealing the regulation and adaptation of the photosynthetic physio-response of winter wheat under brackish water irrigation and proving scientific basis for formulating more reasonable brackish water irrigation strategies for such areas.

## 2. Materials and Methods

### 2.1. The general situation of the experiment area

The experiment area is located in Xiawa town, Binzhou city, Shandong province, north latitude  $37^{\circ}34'$ , east longitude  $117^{\circ}45'$ , which belongs to the warm temperate monsoon climate zone, the characteristics of continental climate are obvious, and the difference between the four seasons is significant. The annual average sunshine hours for 2690.3 hours, the annual average temperature of  $12^{\circ}\text{C}$ , the average annual rainfall of 575.5 mm, seasonal distribution of precipitation during the year is not uniform, the annually average evaporation-precipitation ratio was 3.22, it is easy to cause the groundwater to rise, the soil to return to salt, and to form the salinization of the soil. The buried depth of the groundwater level in the test area is 2-3 m, the shallow groundwater salinity is 5-10 g/L. According to the soil particle size analysis, 0-20 cm belongs to loam, 20-40 cm is sandy loam, 40-60 cm is sandy loam, 60-80 cm is loam sandy soil and 80-100 cm is loam, soil physical and chemical properties are shown in table 1.

**Table 1.** Soil physical and chemical properties of experimental area

| Soil layer (cm) | pH   | Bulk density (g/cm <sup>3</sup> ) | CO <sub>3</sub> <sup>2-</sup> (g/kg) | HCO <sub>3</sub> <sup>-</sup> (g/kg) | Cl <sup>-</sup> (g/kg) | SO <sub>4</sub> <sup>2-</sup> (g/kg) | Ca <sup>2+</sup> (g/kg) | Mg <sup>2+</sup> (g/kg) | K <sup>+</sup> (g/kg) | Na <sup>+</sup> (g/kg) | Total salt (g/kg) |
|-----------------|------|-----------------------------------|--------------------------------------|--------------------------------------|------------------------|--------------------------------------|-------------------------|-------------------------|-----------------------|------------------------|-------------------|
| 0-20            | 7.30 | 1.39                              | 0.01                                 | 0.01                                 | 0.51                   | 0.46                                 | 0.10                    | 0.03                    | 0.10                  | 0.14                   | 1.36              |
| 20-40           | 7.13 | 1.33                              | 0.01                                 | 0.02                                 | 1.95                   | 0.42                                 | 0.12                    | 0.02                    | 0.08                  | 0.24                   | 2.86              |
| 40-60           | 7.07 | 1.32                              | 0.01                                 | 0.02                                 | 0.76                   | 0.36                                 | 0.07                    | 0.02                    | 0.08                  | 0.23                   | 1.56              |
| 60-80           | 7.03 | 1.36                              | 0.01                                 | 0.01                                 | 0.25                   | 0.18                                 | 0.10                    | 0.03                    | 0.07                  | 0.12                   | 0.78              |
| 80-100          | 7.03 | 1.46                              | 0.00                                 | 0.01                                 | 0.27                   | 0.22                                 | 0.14                    | 0.02                    | 0.06                  | 0.14                   | 0.85              |

### 2.2. Experimental design

In this experiment, 2 irrigation treatments (brackish water and freshwater treatments) were set up in the same condition that winter wheat sowing time, planting mode, planting density, fertilizer amount and field management were the same, each treatment had 3 replicates, a total of 6 plots, area is 18 m<sup>2</sup>. In order to avoid side leakage interference, a 0.5 m separation zone was set up between the test plots, and a plastic film was used to vertically lay 1.5 m deep. The test crop for winter wheat, sowing date for October 8th, harvesting June 13th of the next year, the growth period was 249 days. The source of brackish water comes from shallow groundwater in the area. According to previous studies, it was found that the winter wheat of the seeding stage was more sensitive to salt, so during the design of irrigation experiments, fresh water is used during turning green-jointing stage. In the middle-later period, a combination scheme of jointing-heading (brackish water) and heading-filling (brackish water) was used. The irrigation scheme is shown in Table 2.

**Table 2.** Brackish water irrigation scheme of winter wheat

| Treatment      | Irrigation quota<br>/mm | Jointing stages<br>/mm | Heading stages<br>/mm | filling stages<br>/mm |
|----------------|-------------------------|------------------------|-----------------------|-----------------------|
| Brackish water | 240                     | 80(0 g/L)              | 80(3 g/L)             | 80(3 g/L)             |
| Fresh water    | 240                     | 80(0 g/L)              | 80(0 g/L)             | 80(0 g/L)             |

### 2.3. Content and method of observation

Photosynthetic characteristics: using the ADC company LCpro - SD portable photosynthesis devices, measurement of winter wheat leaf net photosynthetic rate ( $P_n$ ,  $\mu\text{mol}/\text{m}^2/\text{s}$ ), transpiration rate ( $T_r$ ,  $\text{mmol}/\text{m}^2/\text{s}$ ), stomatal conductance ( $G_s$ ,  $\text{mol}/\text{m}^2/\text{s}$ ), intercellular  $\text{CO}_2$  concentration ( $C_i$ ,  $\mu\text{mol}/\text{mol}$ ), atmospheric  $\text{CO}_2$  concentration ( $C_a$ ,  $\mu\text{mol}/\text{mol}$ ) and other physiological indicators. In winter wheat heading stage, flowering stage, filling period and milk ripe period, the typical fine weather was selected, and the flag leaf was measured every two hours at 8:00-16:00.

Light response characteristics curve: At the heading and flowering stages after brackish water irrigation at the jointing stage, typical fine weather was selected and between 10:00 and 12:00 in the observation day, the LCpro-SD portable photosynthesis instrument was used to measure the light response characteristics of the winter wheat flag leaves. The artificial light source was used to automatically control the photosynthetically effective radiation flux density (PPFD) at the time of measurement. It was set at 2000, 1800, 1600, 1400, 1200, 1000, 800, 600, 400, 200, 100, 50 and 0  $\mu\text{mol}/\text{m}^2/\text{s}$  (12 gradients in total), the time of the measurement is 120s for each intensity gradient.

### 2.4. Content and method of observation

The statistical analysis and significance test were completed by using IBM SPSS Statistics 22.0. The solving parametric of nonlinear model simulation were completed by using 1stopt Pro 1.5 and the chart drawing was done with Microsoft Excel 2013.

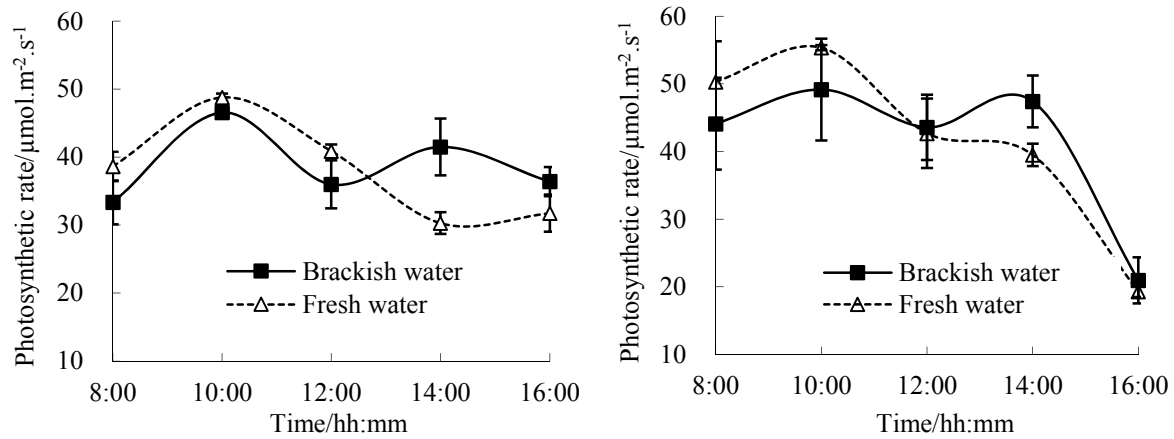
## 3. Results and analysis

### 3.1. Diurnal variation of net photosynthetic rate

It can be seen that the diurnal variations of the two irrigation treatments are more obvious by using analyzing the daily variation of the net photosynthetic rate of winter wheat leaves (Fig.1). In the heading stage (May 1st) and flowering stage (May 10th), the curve of the freshwater irrigation treatment presented a "single-peak" curve change, reached the peak around 10:00, then gradually decreased with time, and the net photosynthetic rate before 12:00 was significantly higher than that in the afternoon; The curve change of brackish water irrigation treatment showed a "double-peak" curve change. The curve reached the first peak around 10:00. It slightly decreased at about 12:00. It reached the second peak at around 14:00. It then gradually decreased with the weakening of the light. This was related to "photosynthetic noon break", a phenomenon resulted from the stress of the strong light at the midday. The result was consistent with previous studies.

Comparing the diurnal variation of the net photosynthetic rate between the two irrigation treatments, it can be seen that the net photosynthetic rate of brackish water irrigation was lower than that of freshwater treatment before 12:00 in the heading stage (May 1st). After 12:00, it showed the opposite trend and the net photosynthetic rate of brackish water irrigation rebounded. In the flowering stage (May 10th), the two irrigation treatments also showed the similar change law, except that the time when the net photosynthetic rate of the brackish water irrigation was higher than that of the freshwater irrigation advanced to 12:00. The sum of the net photosynthetic rate at five times a day can be calculated. It was found that the difference between the two treatments was not significant ( $p=0.05$ ). This also indicated that brackish water irrigation did not significantly reduce the net photosynthetic rate of winter wheat at the heading and flowering stage, but increased the photosynthetic efficiency of

the leaves in the afternoon. Therefore, the crop has a higher photosynthetic rate at high temperatures and strong light.



**Figure 1.** Leaf net photosynthetic rate diurnal change of winter wheat

### 3.2. Photosynthetic light response characteristics

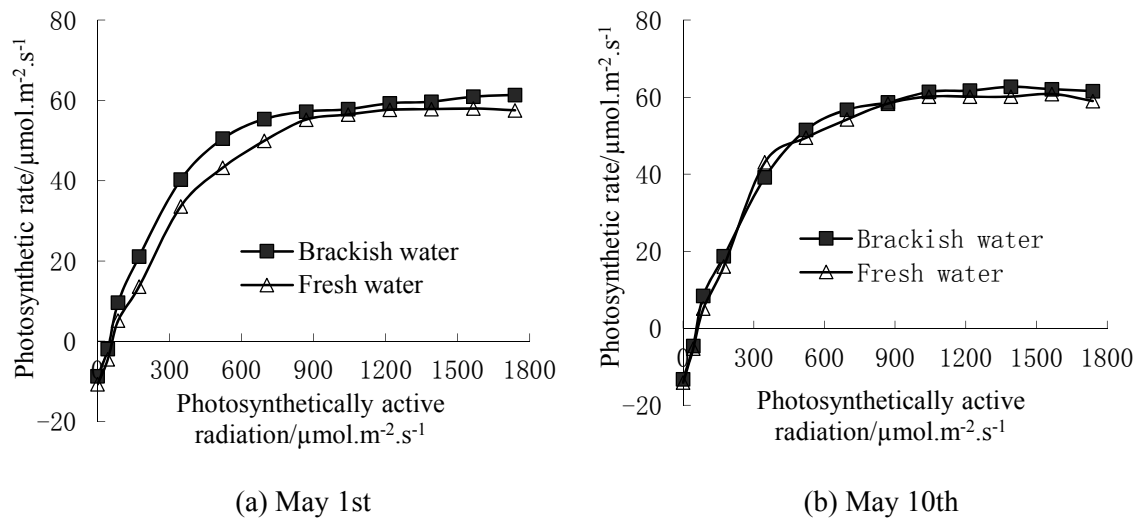
Ye and others conducted a careful analysis of the traditional photosynthesis light-response model and found that the key was not based on photorespiration, and proposed a new light-response model for C3 plants [10]. The model can not only obtain the saturated light intensity, maximum photosynthetic rate and dark respiration rate of the plant leaves, but also can obtain the intrinsic quantum yield of the plant leaves, the quantum efficiency at the light compensation point, and the apparent quantum efficiency. In addition, the problem of light response of plant leaves in the conditions of low light intensity and photo inhibition is effectively solved. A new model was used to fit the experimental measurement data by Ye. Compared with the traditional fitting results of traditional rectangular hyperbola, non-rectangular hyperbola, and binomial regress and so on, the fitting results of the new model were closest to the experimental results [10]. Therefore, the new light response model provided a new research method for studying the photosynthetic characteristics of plants under the condition of photo inhibition and low light intensity. The expression of the model is as follows:

$$P_n(I) = \alpha \frac{1 - \beta I}{1 - \gamma I} I - R_d \quad (1)$$

Where:  $P_n(I)$  is the net photosynthetic rate;  $\alpha$ ,  $\beta$ ,  $\gamma$  are three coefficients;  $I$  is the (photosynthesis effective) photo flux density (PPFD) incident on the blade;  $R_d$  is dark respiration rate of the plants. The calculation method of model parameters was detailed described in the paper.

**3.2.1. Photosynthetic light response curve.** The light response curve reflected the variation between light intensity and photosynthetic rate of plants and was an important means for evaluating the photosynthetic capacity of plants. As shown in Figure 6, under the low light intensity (0~200  $\mu\text{mol}/\text{m}^2/\text{s}$ ), the net photosynthetic rate of winter wheat leaves increased almost linearly with the increase of light intensity, whether under freshwater treatment or brackish water treatment. The increase rate of brackish water treatment was slightly faster than that of freshwater treatment. Under the medium light intensity (200~800  $\mu\text{mol}/\text{m}^2/\text{s}$ ), the net photosynthetic rate's increase of different treatments slowed down. Under the high light intensity (>800  $\mu\text{mol}/\text{m}^2/\text{s}$ ), the net photosynthetic rate of winter wheat reached the maximum value, and the net photosynthetic rate tended to be stable or

even decreased slightly with the increase of the light intensity. However, under different light gradients, at the heading and flowering stages, the net photosynthetic rate of brackish water treatment showed slightly higher than that of fresh water treatment, which has been further verified the results in section 3.1.



**Figure 2.** Winter wheat leaf photosynthetic light response curves at heading and flowering stages

**3.2.2. Characteristic parameters of Light Response Curve.** It can be seen from Table 3 that the correlation coefficient of the light response curve is 0.997 to 0.999, which indicated that the new model can better simulate the response relation between net photosynthetic rate ( $P_n$ ) of winter wheat and photosynthetically active radiation (PAR). Compared with the freshwater treatment, the maximum net photosynthetic rate ( $P_{nmax}$ ) of the winter wheat under brackish water treatment increased by  $2.27 \mu\text{mol}/\text{m}^2/\text{s}$ , the light saturation point (LSP) of that increased by  $29.27 \mu\text{mol}/\text{m}^2/\text{s}$  and the light compensation point (LCP) decreased by  $19.38 \mu\text{mol}/\text{m}^2/\text{s}$ , during the heading stage; The maximum net photosynthetic rate ( $P_{nmax}$ ) of winter wheat increased by  $1.58 \mu\text{mol}/\text{m}^2/\text{s}$ , the light saturation point (LSP) increased by  $70.11 \mu\text{mol}/\text{m}^2/\text{s}$  and the light compensation point (LCP) decreased by  $4.63 \mu\text{mol}/\text{m}^2/\text{s}$  during the flowering stage. It showed that brackish water irrigation improved the photosynthetic capacity of winter wheat, enhanced the adaptability of winter wheat to strong light and high temperature, and improved the ability to use low light. Comparing the intrinsic quantum yield ( $\phi_0$ ) and the quantum yield at light compensation point ( $\phi_c$ ) under different irrigation treatments, it can be found that the parameters of the brackish water treatment at the heading stage was higher than that of the freshwater treatment. The parameters of the two treatments are almost the same at the flowering stage. It can be seen that brackish water irrigation didn't inhibit the ability of winter wheat to convert light energy into net energy and the potential of utilizing light energy. Some growing stages are even better than the control. At the same time, compared with the freshwater treatment, the dark respiration rate ( $R_d$ ) of winter wheat under brackish water treatment decreased by 0.96 and 1.53 respectively, at the heading stage and flowering stage. A lower dark respiration rate can ensure faster dry matter accumulation. To a certain extent, it promoted the potential of winter wheat to use light energy.

**Table 3.** Characteristics of light response curves of heading and flowering stages of winter wheat under different irrigation treatments

| Growing stage   | Treatment      | Pnmax | $\phi_c$ | $\phi_0$ | LCP   | LSP     | Rd    | R     |
|-----------------|----------------|-------|----------|----------|-------|---------|-------|-------|
| Heading stage   | Brackish water | 60.74 | 0.2548   | 0.3076   | 37.48 | 1391.80 | 10.49 | 0.998 |
|                 | Fresh water    | 58.47 | 0.1844   | 0.2196   | 56.86 | 1362.53 | 11.45 | 0.999 |
| Flowering stage | Brackish water | 62.70 | 0.2547   | 0.3169   | 49.10 | 1311.07 | 13.96 | 0.999 |
|                 | Fresh water    | 61.12 | 0.2560   | 0.3243   | 53.73 | 1240.96 | 15.49 | 0.997 |

#### 4. Conclusion

This paper mainly focused on the effect of brackish water irrigation from the viewpoint of crop photosynthetic physiology, and revealed the impact of brackish water irrigation on the photosynthetic light response characteristics of winter wheat at heading and flowering stages and its regulation mechanism. The following conclusions were initially obtained.

(1) The diurnal variation of photosynthetic rate of winter wheat showed that, compared with fresh water (0g/L) treatment, the photosynthetic rate of winter wheat before 12:00 decreased under brackish water (3g/L) irrigation. At the heading stage, the decline of photosynthetic rate of winter wheat was mainly affected by non-stomatal factors, but the decrease of photosynthetic rate was mainly influenced by stomatal factors at the flowering stage. The increase of photosynthetic rate of winter wheat under brackish water treatment after 12:00 was mainly due to the improvement of non-stomatal factors.

(2) A new model of C3 plants light response was used to fit the photosynthetic characteristics. The results were as follows. The maximum net photosynthetic rate (Pnmax) of winter wheat under brackish irrigation increased by 2.27 and 1.58  $\mu\text{mol}/\text{m}^2/\text{s}$  respectively at heading and flowering stages, the light saturation point (LSP) increased by 29.27 and 70.11  $\mu\text{mol}/\text{m}^2/\text{s}$  respectively, the light compensation point (LCP) decreased by 19.38 and 4.63  $\mu\text{mol}/\text{m}^2/\text{s}$  respectively and the dark respiration rate (Rd) decreased by 0.96 and 1.53 respectively. The results indicated that the photosynthetic efficiency of the brackish water treatment was higher than that of the freshwater treatment. The higher photosynthetic efficiency not only enhanced the adaptability of winter wheat to strong light and high temperature at the heading and flowering stages, but also enhanced the ability of winter wheat to use low light, which promoted the potential of winter wheat to use light energy.

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