Effect of irrigation with brackish water on photosynthesis characteristics and yield of winter wheat

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Abstract. In order to obtain the suitable alternative of saline water irrigation pattern and reveal the physiological and growth response mechanism for winter wheat, a field experiment was conducted in Yellow River Delta, Shandong, North China. Four irrigation treatments(irrigating 80 mm with fresh water each at jointing and heading stages, irrigating 80 mm with fresh water each at jointing, heading and milking stages, irrigating 80 mm with fresh-saline water each at jointing and heading stages, irrigating 80 mm with fresh-saline-saline water each at jointing, heading and milking stages) were designed. The collected datum were used to analyse the effects of saline water irrigation on photosynthesis characteristics, biomass and yield of winter wheat. The results show that, the winter wheat leaf stomatal regulation under saline water irrigation caused decreasing in plant transpiration rate, through improving the non-stomatal limitation factor, while ensuring a high net photosynthetic rate at milky stage, thus high efficiency of leaf water use efficiency significantly. Compared with the treatment of fully irrigated with fresh, plant height and biomass of winter wheat were inhibited, also yield decreased by 3%-13% and fresh water saved 50%-67% under the treatment with fresh-saline water. If saline water irrigation schedule is rational and rainfall reaches to the average level, the utilization of saline water for winter wheat could be prospective, which have important practical significance for the sustainable agriculture in the region.

1. Introduction

Research on the relationship between brackish water irrigation, soil salinity and crop growth has been a very active research field in the world [1]. The current research focuses on the effect of brackish water irrigation methods and water and soil environment, etc., including irrigation technology [2,3], irrigation water quality [4], irrigation system, soil water and salt migration [5], soil physical and chemical properties [6], groundwater environment [7], etc., which accumulated more experience. Most of that focused on the impact on crop yield and quality, etc. [8], but less attention to crop itself. Brackish water irrigation not only provide the crops need water, but also take lots of salt into the farmland. With the increase of the soil salt content, it will inevitably affect the osmotic potential of soil solution, thus the effectiveness of the change of soil water, which may cause physiological drought. At the same time, the water potential gradient’s change of soil, plant root system and plant leaf will lead to adjustment and adaptation of a series of physiological indexes likes stomatal
conductance, transpiration and photosynthesis characteristic by inducing the turgor pressure changes of leaf cell. Finally, it will have a significant impact of the accumulation of photosynthetic product and distribution between its root, stem, leaf and grain [9]. Therefore, in order to further seek the rational way of brackish water use and to reveal the physiological and ecological response mechanism of the crops under the irrigation of brackish water, the winter wheat of the main grain crops in the Yellow River Delta was selected as the research object, and the field experiment of the winter wheat with brackish water irrigation was carried out. In order to provide scientific basis for the development and utilization of underground saline water resources and the sustainable development of irrigated agriculture in this kind of region.

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°34’, east longitude 117°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° 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.

| Soil layer (cm) | pH    | Bulk density (g/cm3) | CO32- (g/kg) | HCO3- (g/kg) | Cl- (g/kg) | SO42- (g/kg) | Ca2+ (g/kg) | Mg2+ (g/kg) | K+ (g/kg) | Na+ (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, 4 irrigation 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 (two factors in consideration of water volume and quality), each treatment was repeated 3 times, a total of 12 plots, area is 18m2. 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. Agronomy Measures are carried out in reference to the general methods of the local field.

The water source used in brackish water irrigation is from shallow groundwater in the test area. As the shallow groundwater in the area is 5-10 g/L, it is not suitable for irrigation. Therefore, a set of salt water desalination device is installed in the experimental area, and the salinity is low to 0.20-0.23 g/L after desalination, which is directly used as a fresh water source. And a reservoir is built to store the treated fresh water and the extracted underground saline water in the cistern to mix sufficiently, converting mineralization to 3 g/L as a water source for brackish water. According to previous studies, it was found that winter wheat seedling stage was sensitive to salt, so it used fresh water during the
design of irrigation experiment. In the middle and late period, a combination of the jointing stage to
the heading stage (brackish water) and heading stage to filling stage of wheat growth (brackish water)
was used. The irrigation scheme is shown in table 2.

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

| Treatment | Irrigation quota /mm | Jointing stages /mm | Heading stages /mm | milkling stages /mm |
|-----------|----------------------|---------------------|--------------------|--------------------|
| T1        | 240                  | 80(0 g/L)           | 80(3 g/L)          | 80(3 g/L)          |
| T2        | 160                  | 80(0 g/L)           | 80(3 g/L)          | 0                  |
| T3        | 240                  | 80(0 g/L)           | 80(0 g/L)          | 80(0 g/L)          |
| T4        | 160                  | 80(0 g/L)           | 80(0 g/L)          | 0                  |

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 (Pn, µmol/m2/s), transpiration rate (Tr,
mmol/m2/s), stomatal conductance (Gs, mol/m2/s), intercellular CO2 concentration (Ci, µmol/mol),
atmospheric CO2 concentration (Ca, µmol/mol) and other physiological indicators. In winter wheat
heading stage, flowering stage, grouting 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.

Plant height: the height of the observation plant at the fixed point is the height of the soil surface to
the highest leaf tip before heading, and the height of the soil to the top of the ear after heading.

Dry matter: take 6 representative strains of plants, separate the aboveground plant and root,
beginning in 105 °C oven for 30 minutes, baking temperature to 70 °C in 48 hours after the
determination of the ground and underground dry matter weight respectively.

Yield: The number of effective spikes, the number of grain per panicle, the number of real grains
and thousand kernel weight were investigated in the experimental plots, and the theoretical yield and
the actual yield were calculated. The theoretical yield (kg/hm2) = the number of effective panicles (ten
thousand spikes /hm2) × the number of real grains (grain / ear) × thousand kernel weight (g) × 10-2.
The actual production according to each district single dozen single collection, weight after sun drying
and winnow cleaning.

2.4. Content and method of observation

Leaf water use efficiency (LWUE, µmolCO2/mmolH2O), It is expressed by the amount of CO2
assimilated by the leaves through the transpiration consumption of a certain amount of H2O,
calculated as LWUE= Pn / Tr, Pn is the net photosynthetic rate, and Tr is the transpiration rate.

Statistical analysis and significance test were completed using IBM SPSS Statistics 22.0. Charting
was done using Microsoft Excel 2013.

3. Results and analysis

3.1. Transpiration rate and net photosynthetic rate

The average transpiration rate of leaf transpiration rate of winter wheat at five moments from 8:00 to
16:00 on the typical day of each growth period after jointing stage was selected to analyze the effect of
brackish water irrigation on leaf transpiration rate of winter wheat (Fig. 1). It can be seen that with the
passage of the growth period, the transpiration rate of winter wheat leaves shows a similar pattern,
from the heading stage to the milk ripe stage, showing a trend of decline, increase, and then decline,
which is related to the growth process, soil moisture and climate environment and other factors. The
difference between brackish water irrigation treatment and freshwater irrigation treatment was obvious.
The transpiration rates of T1 and T2 treatments were significantly lower than those of T3 and T4
treatments. The salt content of soils after brackish water irrigation increased, and the osmotic potential of soil solution increased accordingly. The effectiveness of soil moisture and the decrease of the water potential gradient of the soil-root-leaf decreased, resulting in partial stomata closure and decreased transpiration rate of winter wheat leaves. Especially the T1 treatment was significantly lower than the other three treatments, also shows that the jointing and filling stage two growth stages continuous irrigation with brackish water, further inhibited the transpiration of winter wheat leaves.

Analysis of the change regularity of winter wheat leaf net photosynthetic rate (Fig. 1) can be seen, the net photosynthetic rate of winter wheat leaves showed a gradual increase from the heading and flowering stage, reaching the highest at the filling stage, and then gradually decreasing at the milk stage. This is closely related to the growth and aging of the leaves, and also related to the outside weather conditions. The impact of brackish water irrigation on the net photosynthetic rate of winter wheat showed a difference with the advance of growth period. At the heading stage, the net photosynthetic rate of each treatment showed T4>T1>T3>T2; during the filling stage, the net photosynthetic rate of each treatment showed T3>T2>T1>T4; during the milk ripening stage, the net photosynthetic rate of each treatment showed T1>T2>T4>T3, and the significance of each treatment was not significant (p>5%). Brackish water irrigation did not significantly reduce the net photosynthetic rate of winter wheat, in the milk stage even higher than fresh water irrigation.

**Figure 1.** Effect of brackish water irrigation on Photosynthesis and transpiration rate of winter wheat.

### 3.2. Leaf water use efficiency

Leaf water use efficiency is the ratio of photosynthetic rate and transpiration rate, which is the theoretical value of water use efficiency [10]. Brackish water irrigation on water use efficiency of
winter wheat leaves influence with the growth process showed difference (Fig. 2), at the heading stage, the leaf water use efficiency of each treatment was T1>T2>T4>T3; in the flowering period is T1>T2>T3>T4; in the filling stage is T1>T2>T4>T3; in the milk stage is T1>T2>T4>T3. It can be seen that from the heading stage to the milk stage, the T1 treatment has the highest water use efficiency, followed by T2 treatment, T3, T4 treatment is the lowest, and T1 treatment and T3, T4 treatment have significant differences in flowering and milk ripening stages, indicating that brackish water irrigation significantly improved the water use efficiency of winter wheat leaves. The reason may be that the response of the transpiration rate to the salinity is higher than that of the photosynthetic rate, brackish water irrigation regulates the stomatal opening and closing of winter wheat leaves, and inhibits crop ineffective transpiration. Thus efficient utilization of leaf scale water is achieved.

3.3. Plant height, dry matter and yield
Table 3 shows the plant height, dry matter, yield, and yield components of each treated winter wheat. It can be seen that the plant height and dry matter of T1 and T2 treatments are lower than T3 and T4 treatments, especially T1 treatment is significantly lower than other treatments, indicating that the salinity brought by brackish water irrigation has an inhibitory effect on plant height and dry matter accumulation of winter wheat, and continuous salt water irrigation will increase salt stress on crops and affect crop growth and development.

Comparison of the output of different treatments found, the T3 treatment was the highest, reaching 9825.6 kg/hm², followed by T1 treatment, T4 treatment and T2 treatment. Under the same irrigation quota, the yield of brackish water irrigation decreased compared with that of fresh water treatment. T1 treatment reduced 2.9% compared with T3 treatment, and T2 treatment reduced 2.7% compared with T4 treatment, but the difference was not significant. The analysis of yield components showed that the difference of thousand kernel weight in each treatment was not significant. The decrease of grain number caused by the brackish water irrigation was the main reason for the reduction of yield. In addition, T2 treatment and T4 treatment, T1 treatment and T3 treatment were significantly higher than non-irrigated water yield water pouring grouting, T1 treatment increased 11.2% compared with T2, T3 treatment increased 11.4% compared with T4. Grain filling stage is the critical period for yield formation of winter wheat. Suitable soil moisture is conducive to grain filling, according to the analysis of the yield components, the main reason for increasing production is to increase thousand kernel weight, using thousand kernel weight Make up for the reduction of the number of spikes.

| Treatment | Height /cm | Biomass /g | Grain number per spike / unit | 1000 grain weight /g | Yield /kg·hm-² |
|-----------|------------|------------|-------------------------------|----------------------|---------------|
| T1        | 68.33 a    | 3.46 b     | 50.15 b                       | 45.11 a              | 9547.47 a     |
| T2        | 72.67 a    | 3.68 ab    | 51.5 b                        | 43.54 a              | 8579.45 b     |
| T3        | 74.00 a    | 3.73 a     | 52.05 ab                      | 45.19 a              | 9825.60 a     |
| T4        | 73.67 a    | 3.80 a     | 55.4 a                        | 44.68 a              | 8821.90 b     |

Note: different letters indicate significant difference at 5% level.

4. Conclusion
This study mainly focused on the effect of brackish water irrigation from the perspective of crop physiological growth, revealed the photosynthetic physiological response mechanism of winter wheat after brackish water irrigation, and obtained the following conclusions. (1) Brackish water irrigation increased the salt content in the root zone of the soil and inhibited the absorption of effective moisture from the soil by the winter wheat roots. To prevent excessive water loss, the leaves closed some of the stomata, which directly led to a decrease in transpiration rate. The early moderate salt exercise
promoted the root ligation, postponed the senescence of the leaves, improved the photosynthetic capacity of the leaves, and improved the utilization of intercellular CO2, making the net photosynthetic rate of winter wheat in milk-mature stage higher than that of freshwater irrigation. Because the response of transpiration rate to salinity is higher than that of photosynthetic rate, the photosynthetic rate of winter wheat under brackish water irrigation conditions is still high, and the efficient utilization of leaf-scale water is achieved. (2) Compared with freshwater irrigation, brackish water irrigation inhibits the plant height and dry matter accumulation of winter wheat, and freshwater brackish water combined irrigation slightly reduces winter wheat yield, generally reaching 87% to 97% of the full freshwater treatment, at the same time saving 50% to 67% of freshwater resources, it is clear that brackish water is suitable for irrigation in winter wheat fields in the region. Comparing 2 kinds of saline irrigation methods, grouting water ensured the suitable soil moisture conditions, which was conducive to grain filling, increased thousand kernel weight, made up for the reduction of grain number per spike, and realized the yield increase of winter wheat. Therefore, from the two angles of output and water resources, combined irrigation of fresh water, brackish water and brackish water can not only guarantee crop yield and save fresh water resources, but also has important practical significance for the sustainable development of agriculture in the Yellow River Delta.

Acknowledgments
This work was financially supported by The National Natural Science Fund (NO. 51509105) and Shandong Natural Science Foundation (NO. ZR2014EEQ020)

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