Effect of drought stress in jointing stage on the photosynthetic light response of spring maize in Northeast China

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Abstract: The field experiments of drought stress and rewatering for spring maize were carried out in jointing stage in Northeast China. The effects of drought stress on the photosynthetic light response of maize and rewatering compensation recovery were analyzed. The results were showed as followed: Under moderate drought stress condition in jointing stage, drought stress affected the photosynthesis of maize leaves and led to the decrease of the values of photosynthetic light response parameters such as the transpiration rate, photosynthesis rate, stomatal conductance and intercellular CO2 concentration. The longer time of the drought stress, the more severe the damage of the photosynthesis, the more obvious photo inhibition occurred, and the more difficult to recover. The compensation recovery of photosynthetic rate after 10 days of rewatering was better than that of stomatal conductance, transpiration rate, and intercellular CO2 concentration. Therefore, there needed to be moderate water supply in the jointing stage of maize to ensure the photosynthetic structure not to be damaged.

1. Introduction
Drought is the main non-biological limitation of maize production, photosynthesis is the first link that drought affects maize growth and metabolism, and drought stress leads to a decline in biomass and yield through affecting photosynthesis [1-2]. Studies on the photosynthetic physiological response to crops in drought environment have been one of the hot topics in plant physiological ecology science [3]. Many scholars have studied the response and adaption processes of maize growth and main physiological and ecological parameters under drought stress by experimental measurements. Numbers of studies have shown that drought stress has affected the photosynthesis, transpiration and other physiological parameters of maize [4]. Under lighter or moderate drought stress, the leaves stomata close, and the photosynthesis rate and transpiration rate decrease, while under severe drought stress, it will lead to photosynthesis stopped [5-7]. Monitoring the response of different crop physiological processes to drought can provide important information for avoiding or reducing the adverse effects of water deficit on soil and plant tissues [8].

The study found that the effect of drought stress on maize yield depended on the grade of drought and the growth stage when drought occurred [9]. During the jointing stage, when the drought occurred, the transpiration rate and photosynthetic rate of maize leave decreased, and the affection was higher than the other periods [10]. Jointing period is the critical period of water demand during the whole growth period of maize, and this period has poor resistance to adverse environmental conditions. If maize encountered drought in jointing stage, the final yield could be reduced nearly 30% [9]. In this paper, based on water stress and rewatering experiment, the response process and mechanism of light response parameters to continuous drought stress in jointing stage were evaluated to provide a
reference for drought resistance and water saving physiology research.

2. Materials and methods

2.1. Study site

Maize is the main food crop in Northeast China; the sown area is about $6 \times 10^6$ hm$^2$, which is half of the total crop sown area in Northeastern China [11]. The study was conducted at the Ecological and Agrometeorological station of Jinzhou City, Liaoning Province (41°49′ N, 121°12′ E). The station is located in the northeast of the Eurasian continent and belongs to warm temperate zone, and experiences semi-humid monsoon climate. The annual mean temperature is 7.8-9.0 °C, the extreme maximum temperature is 41.8 °C, the annual minimum temperature is -31.3 °C, the frost-free period is 144-180 d, and the annual mean precipitation is 540-640 mm.

2.2. Measurement methods

The experiments were carried out in 2013 in a large mobile water-proof shed with artificial precipitation system to precisely control the amount of irrigation amount. The maize variety was Danyu 39. There were two treatments including control check (CK) and drought stress (DS), with three replications in each treatment. CK was ensured suitable soil moisture during the whole growth period, the soil relative humidity (0-60cm soil moisture) was controlled in 75% ± 5%, field holding capacity (0-60cm) was 21.7%; Water was limited in DS from the jointing stage, and the relative humidity of soil moisture was controlled in 45% ± 5%; and it was rewatering at the end of jointing stage. Three plants representative of the average growth of maize were selected for each treatment and the light response curves were measured on leaves in the same places using a photosynthesis system (LI-COR 6400, Lincoln, NE, USA). The light response curves were observed from 09:00 to 15:00 on sunny days, and each measurement was recorded at 11 levels (2000, 1800, 1600, 1400, 1200, 1000, 800, 600, 400, 200 and 0 μmol·m$^{-2}$·s$^{-1}$) of photosynthetically active radiation (PAR) in sequence of the highest to the lowest.

2.3. Data analyses

The photosynthetic light response parameters measured included photosynthetic rate ($P_n$), stomatal conductance ($G_s$), transpiration rate ($T_r$), and intercellular CO$_2$ concentration ($C_i$). The data used were the averages of three repetitions.

3. Results

3.1. Effect of drought stress on photosynthesis rate

Figure 1 showed the changes of $P_n$ between CK and DS after 3 days of water control from the start of jointing stage. As can be seen, with the increase of PAR, the increasing rate of $P_n$ in DS was significantly lower than that of CK, which was 0-33% lower than CK; With PAR increasing from 0 to 2000μmol·m$^{-2}$·s$^{-1}$, the maximum $P_n$ in CK was 22.2μmol·m$^{-2}$·s$^{-1}$, and the maximum $P_n$ in DS was 19.1μmol·m$^{-2}$·s$^{-1}$; when PAR was higher than 1600μmol·m$^{-2}$·s$^{-1}$, $P_n$ in CK showed a decreasing trend, and the leaves of maize occurred photo inhibition phenomenon. When PAR reached 2000μmol·m$^{-2}$·s$^{-1}$, the $P_n$ in DS still had no photo inhibition.

Figure 5 showed the changes of $P_n$ between CK and DS after 24 days of water control. When PAR was higher than 200μmol·m$^{-2}$·s$^{-1}$, the increasing rate of $P_n$ in DS was significantly lower than that of CK, which was 0-43% lower than CK; With PAR increasing from 0 to 2000μmol·m$^{-2}$·s$^{-1}$, the maximum $P_n$ in CK was 32.1μmol·m$^{-2}$·s$^{-1}$, and the maximum $P_n$ in DS was 19.9μmol·m$^{-2}$·s$^{-1}$; when PAR was higher than 1400μmol·m$^{-2}$·s$^{-1}$, $P_n$ in DS showed a decreasing trend, and the leaves of maize occurred photo inhibition phenomenon. The $P_n$ in CK had no obvious photo inhibition.

Figure 3 showed the changes of $P_n$ between CK and DS after 10 days of rewatering at the end of jointing stage. When PAR was in 0-800μmol·m$^{-2}$·s$^{-1}$, the increasing rate of $P_n$ in DS was higher than
that of CK; when PAR was higher than 1000μmol·m⁻²·s⁻¹, the increasing rate of \( P_n \) in DS was lower than that of CK, which was 0-15% higher than CK; With PAR increasing from 0 to 2000μmol·m⁻²·s⁻¹, the maximum \( P_n \) in CK was 29.2μmol·m⁻²·s⁻¹, and the maximum \( P_n \) in DS was 25.3μmol·m⁻²·s⁻¹; when PAR was higher than 1800μmol·m⁻²·s⁻¹, \( P_n \) in DS occurred photo inhibition phenomenon. The \( P_n \) in CK had no obvious photo inhibition.

The longer time of the drought stress, the greater difference in \( P_n \) of maize leaves between DS and CK, and the more obvious photo inhibition occurred. After 10 days of rewatering, \( P_n \) in DS recovered significantly under low PAR, but \( P_n \) in DS was still lower than CK under higher PAR.

3.2. Effect of drought stress on stomatal conductance

Figure 2 showed the changes of \( G_s \) between CK and DS after 3 days of water control from the start of jointing stage. With the increase in PAR, the increasing rate of \( G_s \) in DS was significantly lower than that of CK, which was 5-31% lower than CK; the maximum \( G_s \) in CK was 0.14mol·m⁻²·s⁻¹, and the maximum \( G_s \) in DS was 0.12mol·m⁻²·s⁻¹. Figure 4 showed the changes of \( G_s \) between CK and DS after 24 days of water control. With the increase in PAR, the increasing rate of \( G_s \) in CK was significantly lower than that of CK, which was 16-67% lower than CK; the maximum \( G_s \) in CK was 0.29mol·m⁻²·s⁻¹, and the maximum \( G_s \) in DS was 0.15mol·m⁻²·s⁻¹. Figure 6 showed the changes of \( G_s \) between CK and DS after 10 days of rewatering. With the increase in PAR, the increasing rate of \( G_s \) in DS was significantly lower than that of CK, which was 6-68% lower than CK; the maximum \( G_s \) in CK was 0.25mol·m⁻²·s⁻¹, and the maximum \( G_s \) in DS was 0.17mol·m⁻²·s⁻¹.

The longer time of the drought stress, the lower value of \( G_s \) of maize leaves in DS. After 10 days of rewatering, \( G_s \) in DS was still significantly lower than that of CK.
3.3. Effect of drought stress on transpiration rate

Figure 5 showed the changes of \( P_n \) between CK and DS after 10 days of rewatering. When PAR was 0 and 2000\( \mu \text{mol}\,\text{m}^{-2}\,\text{s}^{-1} \), \( P_n \) in DS was higher than that of CK; with the increasing of PAR from 200 to 1800\( \mu \text{mol}\,\text{m}^{-2}\,\text{s}^{-1} \), the increasing rate of \( P_n \) in DS was significantly lower than CK, which was 7-20%; the maximum \( P_n \) in CK was 6.2\( \mu \text{mol}\,\text{m}^{-2}\,\text{s}^{-1} \), and the maximum \( P_n \) in DS was 6.3\( \mu \text{mol}\,\text{m}^{-2}\,\text{s}^{-1} \). Figure 6 showed the changes of \( G_s \) between CK and DS after 10 days of rewatering.

3.4. Effect of drought stress on intercellular CO\(_2\) concentration

Figure 7 and Figure 10 showed the changes of \( C_i \) between CK and DS after 3 days and 24 days of water control. With the PAR increasing, \( C_i \) in DS and CK showed an “L”-shaped curves. Higher values were observed in low PAR and lower values were recorded in high PAR. After 3 days of drought stress, \( C_i \) in DS was close to that of CK; after 24 days, \( C_i \) in DS was significantly lower than CK, which was 14-36%. Figure 11 showed the changes of \( T_r \) between CK and DS after 24 days of water control. When PAR was higher than 800\( \mu \text{mol}\,\text{m}^{-2}\,\text{s}^{-1} \), \( T_r \) in DS was lower than CK, which was 5-18%; the maximum \( T_r \) in CK was 5.9\( \mu \text{mol}\,\text{m}^{-2}\,\text{s}^{-1} \), and the maximum \( T_r \) in DS was 5.2\( \mu \text{mol}\,\text{m}^{-2}\,\text{s}^{-1} \). The longer time of the drought stress, the lower value of \( T_r \) of maize leaves in DS. After 10 days of rewatering, \( G_s \) in DS slightly recovered, but was mostly lower than CK.

4. Discussion

Many researchers have concluded that the affection of drought stress on photosynthesis of maize was related to the growth stage, drought duration time and grade. Wu et al. [12] found that moderate drought had a higher effect on photosynthetic capacity at jointing stage than during milking stage. Yu et al. [10] found that moderate drought stress affected the photosynthetic capacity of spring maize at jointing stage more than milk and seedling stage. Yao et al. [13] found that the net photosynthetic rate of maize was reduced under drought stress at the jointing stage and the booting stage, and after 5 days of rewatering, it could recover quickly. Guo et al. [14] found that the compensation effect of rewatering was obvious after light drought, but that would weaken after serious drought.

This study found that moderate drought stress inhibited the photosynthesis of maize leaves during jointing stage, and the light response parameters were significantly lower than adequate water supply conditions; and the longer time under drought stress, the more severe the damage was, and the more difficult to recover. The compensation recovery of photosynthetic rate after rewatering was better than
stomatal conductance, transpiration rate, and intercellular CO₂ concentration.

5. Conclusion

With the PAR increasing, $P_n$, $G_s$, and $T_r$ showed a gradually increasing trend both in drought stress and adequate water supply condition, and when it reached a certain high value, there might occur a photo inhibition phenomenon and the light response parameters might decrease; $C_i$ showed an “L”-shaped curves with higher values in low PAR and lower values in high PAR, which was opposite to the pattern observed for $P_n$, $G_s$, and $T_r$. The longer time of the drought stress, the greater lower in $P_n$, $G_s$, $T_r$ and $C_i$ of maize leaves, and the more obvious photo inhibition occurred. After 10 days of rewetting, $P_n$ recovered significantly under low PAR, but was still lower than CK under higher PAR; $G_s$, $T_r$ and $C_i$ was still mostly lower than that of CK.

Figure 7. The changes of $T_r$ between CK and DS after 3 days of water control.

Figure 8. The changes of $C_i$ between CK and DS after 3 days of water control.

Figure 9. The changes of $T_r$ between CK and DS after 24 days of water control.

Figure 10. The changes of $C_i$ between CK and DS after 24 days of water control.
The filed experiments in this paper showed that the drought stress affected the photosynthesis of maize leaves, led to the light response parameters such as photosynthesis rate, stomatal conductance, transpiration rate and intercellular CO₂ concentration decreased, the limitation of photosynthesis was not only during the drought stress but also continued after rewatering. Therefore, there needed to be moderate water supply in the jointing stage of maize to ensure the photosynthetic structure not to be damaged.

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