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Effects of Different Soil Moisture Contents on Photosynthesis of Lettuce

Xiao Kong[1], Zhen Liu[1] & Weiguo Fu[1]

[1] School of Agricultural Engineering, Jiangsu University, Zhenjiang, Jiangsu, China

Correspondence: Weiguo Fu, School of Agricultural Engineering, Jiangsu University, Zhenjiang, Jiangsu, China. Tel: 86-13775552938. E-mail: fuweiguo@ujs.edu.cn

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Abstract

In order to explore the photosynthetic physiological response characteristics of lettuce under different soil moisture conditions, the photosynthetic indexes and chlorophyll fluorescence parameters of lettuce under different soil moisture gradients were determined by pot water control experiment. The results showed that with the decrease of soil moisture content, Pn, Tr, Gs, Ci, Fv/Fm, ΦPSII and qP of lettuce leaves all showed a downward trend, while NPQ increased with the decrease of soil moisture content. Among them, the water holding capacity in the field was 55~60%, and the net photosynthetic rate of lettuce was the highest, indicating that mild drought promoted photosynthesis of lettuce.

Keywords: lettuce, soil moisture gradients, photosynthesis, chlorophyll fluorescence

1. Introduction

Water is an indispensable environmental factor in plant growth and development, and in recent years, with the increase of ecological problems such as climate warming, drought has become one of the important factors restricting global agricultural production (Wang *et al*. 2018; Yang *et al*. 2021). Drought stress inhibits plant physiological metabolism, which in turn leads to slow plant growth, wilt and even death (Wang *et al*. 2021; Allen *et al*. 2010). It is well documented that one of the primary physiological impacts of drought is on photosynthesis (Flexas *et al*. 2004). Under drought stress, plants generally reduce water loss from transpiration by reducing stomatal opening or closing stomata. Further drought will lead to damage to plant mesophyll cells, decrease the activity of photosynthase, and damage to the structure of chloroplasts, resulting in a decrease in chlorophyll content, which in turn affects the absorption and utilization of light energy by plants (Lawlor *et al*. 2010; Bartels *et al*. 2005).

Lettuce, scientific name leaf lettuce (Lactuca sativa L.), belongs to the leafy vegetables in the genus Asteraceae lettuce, and occupies an important position in the annual production and supply of vegetables (Yavuz *et al*. 2021). Lettuce is not only a water-demanding crop, but also a drought-sensitive species, and an adequate supply of water is critical to lettuce yield and quality (Kizil *et al*. 2012). Therefore, it is of great significance to study the water demand law of lettuce and the photosynthetic physiological changes under drought stress to achieve its efficient production. In this study, lettuce seedlings were treated with different degrees of water, and the effects of different soil moisture content on the photosynthetic characteristics of lettuce were studied, which provided a theoretical basis for drought-resistant and water-saving cultivation of lettuce.

2. Method

2.1 Test Materials and Growth Environment

All trials were conducted in the climate chamber of Jiangsu University, China. The lettuce (Lactvca sativa L.) variety is green collar (Nanjing Green Collar Seed Industry Co., Ltd.). This variety is currently widely cultivated throughout China. On September 11, after soaking and germination, seedlings were sown. On October 3, lettuce seedlings with 4 leaves and 1 heart and basically the same growth were transplanted into plastic pots (upper diameter 23cm, lower diameter 12.5cm and height 14cm), and planted one seedling per pot. The cultivated soil was collected from Jiangsu University, and the soil nutrients were 15.57g/kg in C, 2.66g/kg in N and 0.45g/kg in

P. Each pot is filled with 2.5kg of dry soil. Three days later, the lettuce that grew into slow seedlings was moved into the artificial climate chamber, and the environmental control parameters of the artificial climate chamber were as follows: temperature 25/20°C (day/night), light period of 10/14h (light/dark), light intensity of 400μmol·m^{-2}·s^{-1}, and relative humidity of air of 70%.

2.2 Experimental Design

The experiment used the potted water control method, manually simulated different water environmental conditions, and set up 8 water gradient treatments (Table 1), each treatment was repeated 4 times, for a total of 32 pots. During the water control treatment, the soil volume water content was determined by TRIME-TDR soil moisture meter produced by IMKO every day from 18:00 to 19:00, and then converted into the amount of watering required, so that the soil moisture content of each water treatment group was maintained at the required gradient.

Table 1. Different soil moisture content

Treatment	Soil relative water content range/(%)	Absolute soil water content range/(%)
A	60~65	21~23
B	55~60	19~21
C	50~55	17~19
D	45~50	16~17
E	40~45	14~16
F	35~40	12~14
G	30~35	10~12
H	25~30	9~10

2.3 Measurement Method and Data Processing

On December 10 (about 60 days after water control treatment), in the period of 9:00-11:00, the light intensity was set to 500 μmol· m^{-2}·s^{-1}, the net photosynthetic rate Pn (μmol CO_2 m^{-2} s^{-1}), stomatal conductance Gs (mol H_2O m^{-2} s^{-1}), intercellular carbon dioxide concentration Ci (μmol CO_2 mol^{-1}) and transpiration rate Tn (mmol H_2O m^{-2} s^{-1}) were determined in lettuce leaves. Measure the middle of the fully expanded leaf and repeat the assay 3 times per pot. Subsequently, different photosynthetically effective radiation intensities (PAR) are set: 800, 700, 600, 500, 400, 300, 200, 100, 0 μmol· m^{-2}·s^{-1}, the system automatically record the corresponding net photosynthetic rate to measure the photosynthetic-light response curve. Using IMAGING-PAM chlorophyll fluorescence imager (Heinz Walz GmbH, Effeltrich, Germany), chlorophyll fluorescence parameters were determined from 9:00 to 11:00, and the leaf selection criteria were the same as above, and the determination was repeated 3 times per pot. After dark treatment of lettuce for 20 min, the maximum photoquantum yield (Fv/Fm), actual photochemical efficiency of PSII (ΦPSII), photochemical quenching coefficient (qP) and non-photochemical quenching coefficient (NPQ) were determined. The leaf temperature is 25 °C ± 0.5 °C at the time of measurement, and if there are water droplets on the leaf, it needs to be blotted with clean absorbent paper and determined.

Excel 2010 was used for data statistics, and SPSS 26.0 was used for ANOVA and multiple comparison of data (Duncans method). Draw with Origin 2022.

3. Results

3.1 Effects of Different Soil Moisture Content on Photosynthetic Parameters of Lettuce

The photosynthetic gas exchange parameters of plants reflect the energy conversion and water metabolism of plants during photosynthesis, and these parameters are closely related to drought stress (Subrahmanyam *et al.* 2006; Yuan *et al.* 2016). Net photosynthetic rate (Pn) is an important indicator to measure the photosynthesis efficiency of plants, and when plants are subjected to drought stress, their photosynthetic rate is significantly affected (Flexas *et al.* 2010; Han *et al.* 2015). The net photosynthetic rate of lettuce under different soil moisture content is shown in Figure 1. With the decrease of soil moisture content, the net photosynthetic rate of lettuce showed a downward trend, which increased slightly under B treatment, and then gradually decreased. B treatment increased by 0.06% compared with A, C treatment began to decrease, and each treatment decreased by 7.06%, 11.42%, 15.57%, 17.88%, 21.16% and 21.86% respectively, among which the significance level was reached at C.

Transpiration is the process of water loss in the plant body in a gas state, and the strength of transpiration is an important indicator reflecting the water metabolism of plants (Morison *et al.* 1984). When subjected to drought stress, plants need to maintain water balance in the body by reducing transpiration (Irvine *et al.* 1998). The transpiration rate (Tr) of lettuce under different soil moisture content is shown in Figure 1. With the decrease of soil moisture content, the transpiration rate of lettuce showed a downward trend, rising slightly under B treatment, and then gradually decreasing. B treatment increased by 0.34% compared with A, and C treatment began to decrease, and each treatment decreased by 2.17%, 6.75%, 15.08%, 18.86%, 22.60% and 23.98% respectively, among which the significance level was reached at D.

Stomatal conductance (Gs) is an important indicator reflecting the degree of stomatal opening and closing, and the value of stomatal conductance not only determines the rate of transpiration and water consumption of plants, but also reflects the degree of stress of plants such as drought (Cai *et al.* 2021). The stomatal conductance of lettuce under different soil moisture content is shown in Figure 1. With the decrease of soil moisture content, the stomatal conductance (Gs) of lettuce showed a downward trend, which increased slightly under B treatment and then gradually decreased. B treatment increased by 1.81% compared with A, and C treatment began to decrease, and each treatment decreased by 4.23%, 11.98%, 25.75%, 33.25%, 42.58% and 45.84% respectively, among which the significant level was reached at C.

Intercellular CO_2 concentration (Ci) is one of the factors affecting photosynthetic rate. The intercellular CO_2 concentration of lettuce at different soil moisture content is shown in Figure 1. With the decrease of moisture content in the growth medium, the intercellular CO_2 concentration of lettuce was presented.Out of the overall downward trend. B, C, D, and E treatments decreased by 1.04%, 6.08%, 8.58% and compared with A 11.48%, which has reached a significant level at B. This is followed by a gradual rise, with F, G, and H treatments rising compared to E 1.15%, 2.85% and 6.48%, which have reached significant levels at F.

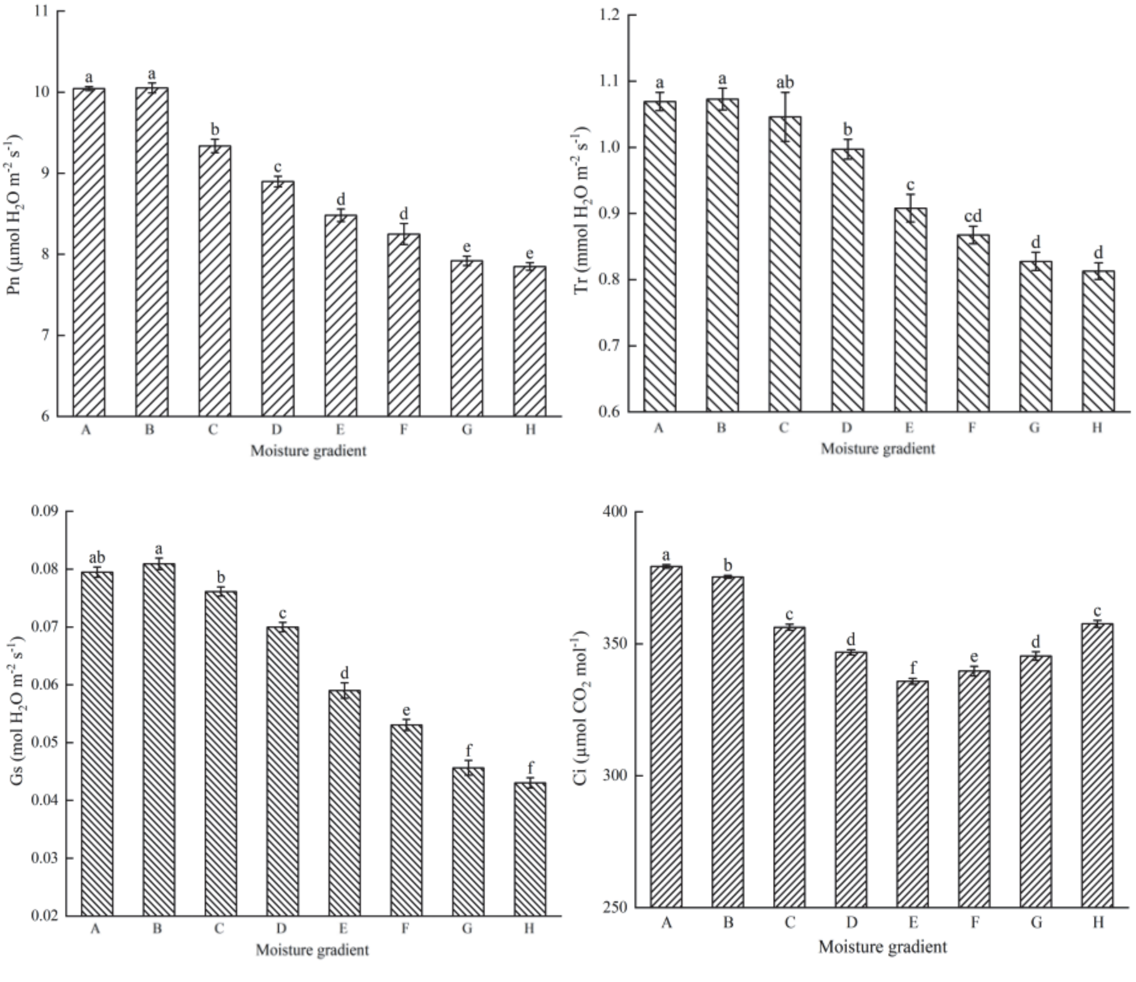

Figure 1. Effects of different soil moisture content on photosynthetic characteristic parameters of lettuce

The photoresponse curve of plants reflects the change of net photosynthetic rate (Pn) of plant leaves with the change of photosynthetically effective radiation (PAR). The light response curves of lettuce under different soil moisture contents are shown in Figure 2. When PAR is at 0~100 μmol·m^{-2}·s^{-1}, the Pn of lettuce increased linearly with the rapid growth of PAR under the soil moisture content, and PAR was the only factor limiting photosynthesis of lettuce. As PAR continued to increase, Pn continued to increase at different rates under the moisture content of each soil, and when PAR increased to 500 μmol·m^{-2}·s^{-1}, the Pn value of lettuce reached the highest under F, G and H treatment, while Pn continued to rise slowly under A~E treatment. When PAR>600 μmol·m^{-2}·s^{-1}, the Pn of lettuce decreased under the soil moisture content, indicating that the light energy utilization rate of lettuce decreased with the decrease of soil moisture content.

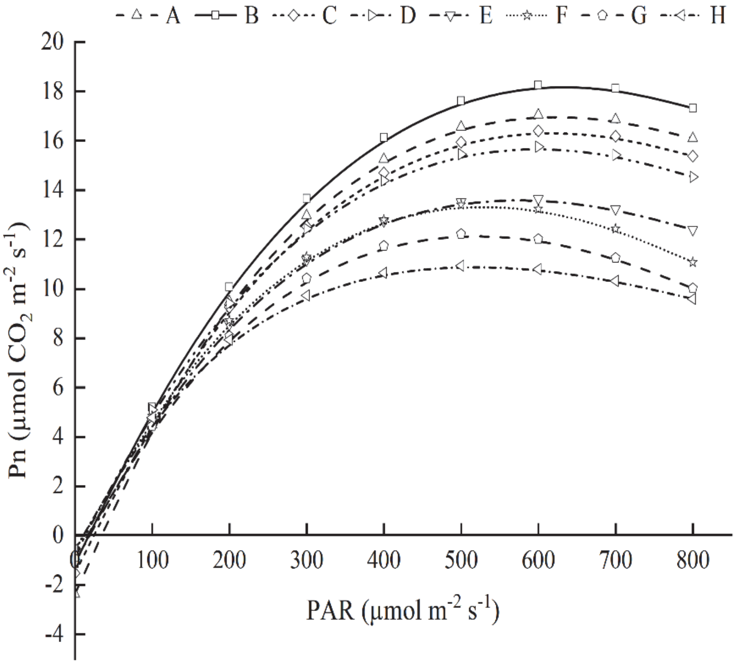

Figure 2. Effects of different soil moisture content on the photoresponse curve of lettuce

3.2 Effects of Different Soil Moisture Content on Chlorophyll Fluorescence Parameters of Lettuce

Chlorophyll fluorescence kinetics is a probe to study the mechanism of photosynthesis and the influence of environmental conditions on photosynthesis, which can quickly, sensitively and non-destructively detect and analyze the effects of drought and other adversities on plant photosynthesis (He *et al.* 2021; Dong *et al.* 2006; Wang *et al.* 2014).

Fv/Fm refers to the maximum photoquantum yield of PSII, reflecting the maximum photochemical efficiency of the active center of PSII in the dark, and the larger the value of Fv/Fm, the higher the potential efficiency of plants using light energy. The Fv/Fm of lettuce under different soil moisture content is shown in Figure 3. With the decrease of soil moisture content, lettuce Fv/Fm showed a decreasing trend, which increased slightly under B treatment, and then gradually decreased. B treatment increased by 0.03% compared with A, C treatment began to decrease, and each treatment decreased by 0.29%, 1.19%, 2.88%, 5.41%, 7.44% and 8.18% compared with A, respectively, and reached a significant level at E.

Photochemical energy conversion effective quantum yield ΦPSII is the actual photochemical efficiency of PSII, which reflects the actual PSII light energy capture efficiency when the PSII reaction center is partially closed. The ΦPSII of lettuce at different soil moisture content is shown in Figure 2. With the decrease of soil moisture content, ΦPSII showed a decreasing trend, which increased slightly under B treatment, and then gradually decreased. B treatment increased by 0.38% compared with A, C treatment began to decrease, and each treatment decreased by 3.71%, 11.51%, 23.24%, 29.45%, 34.90% and 38.00% respectively, among which the significance level was reached at E. It can be seen that the decrease of soil moisture content inhibits the photosynthetic system of lettuce and reduces the photosynthetic activity.

There are three main ways to obtain energy from plant photosynthesis: one is effective photoelectron transport, the other is non-photochemical consumption, and the third is fluorescence release (Centy *et al*. 1989). The photochemical quenching coefficient qP reflects the share of light energy absorbed by the pigment of the PSII antenna for photochemical electron transport, and to some extent reflects the openness of the PSII reaction center. Non-photochemical quenching coefficient NPQ reflects the part of the excess light energy absorbed by the PSII. antenna pigment that cannot be used for photosynthetic electron transport and dissipates excess light energy in the form of heat dissipation. The qP and NPQ of lettuce under different soil moisture content are shown in Figure 3, and with the decrease of soil moisture content, qP showed a downward trend, increased slightly under B treatment, and then gradually decreased. B treatment increased by 0.27% compared with A, and C treatment began to decrease, and each treatment decreased by 9.34%, 18.18%, 26.43%, 33.15%, 37.06% and 41.36% respectively, among which the significance level was reached at F. In contrast to qP, NPQ showed an upward trend as soil moisture content decreased, decreasing slightly under B treatment and then gradually rising. B treatment decreased by 0.30% compared with A, and C treatment began to rise, and each treatment increased by 3.92%, 7.68%, 13.78%, 17.51%, 22.25% and 24.98% respectively, among which the significance level was reached at E.

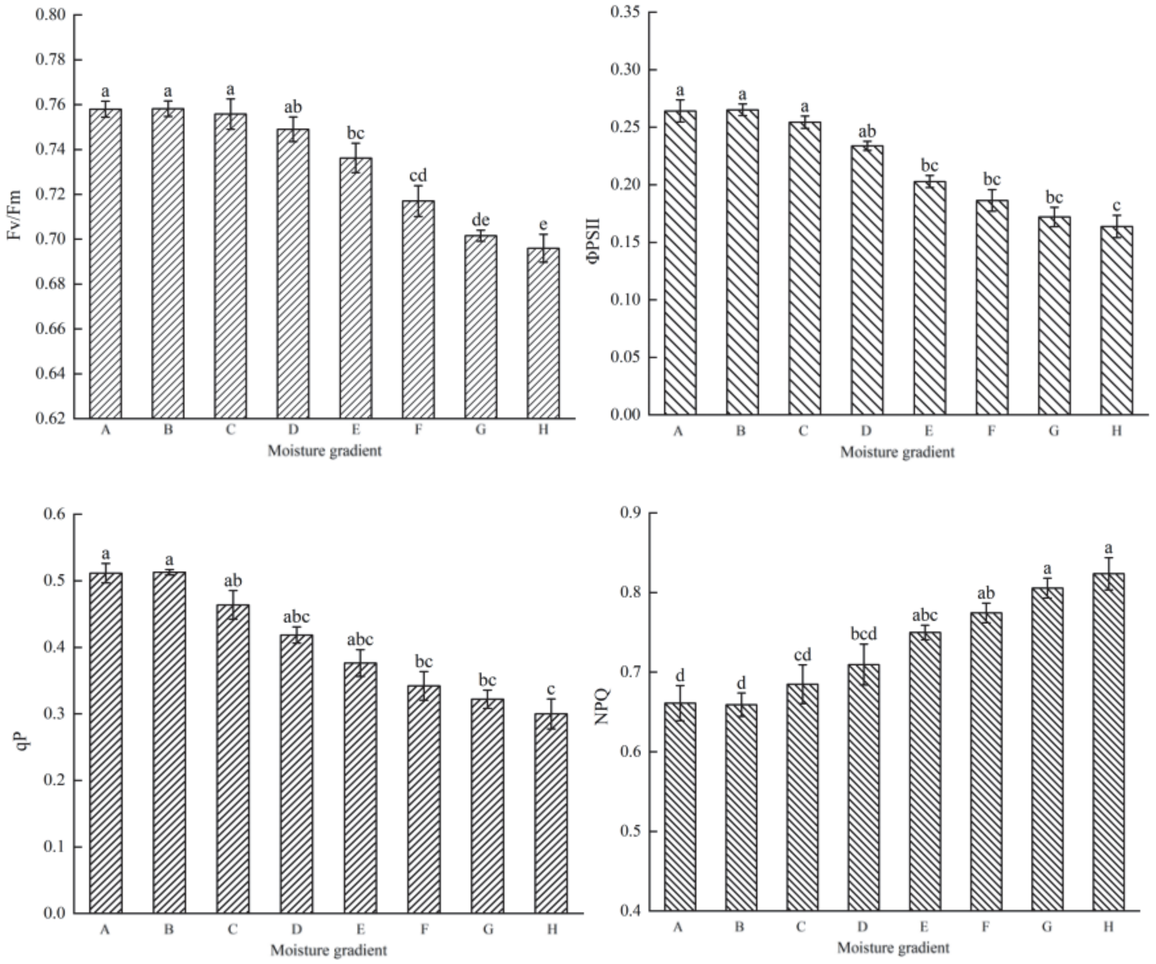

Figure 3. Effects of different soil moisture content on chlorophyll fluorescence parameters of lettuce

4. Discussion

It is well known that water stress can inhibit gas exchange characteristics, and as a result affect the photosynthetic capacity of plants (Subrahmanyam *et al*. 2006). The results of this experiment showed that the photosynthesis of lettuce was promoted under mild drought stress, indicating that mild drought may stimulate the growth and adaptive response of lettuce and increase its photosynthesis rate, which is consistent with the results of Bruna et al. that found that mild drought stress improves the yield and quality of lettuce (Paim *et al*. 2020). With the decrease of soil moisture content, the photosynthetic physiology of lettuce was significantly affected. The inhibition of plant photosynthesis by drought stress includes stomatal and non-stomatal restriction, drought stress leads to cell water loss, plants reduce water loss by adjusting stomatal opening, inhibit transpiration, and save water, but this also affects the entry and exit of CO_2 and inhibits photosynthesis. When the net photosynthetic rate decreases, if the stomatal conductance and intercellular CO_2 concentration decrease at the same time, it indicates that the net photosynthetic rate decreases mainly due to stomatal limitation. The results of this study showed that with the decrease of soil moisture content, the transpiration rate, stomatal conductance, net photosynthetic rate and intercellular CO_2 concentration of lettuce all showed a downward trend, indicating that the gradual decrease of the net photosynthetic rate of lettuce under drought stress conditions was mainly caused by stomatal restriction, which was consistent with the effect of different soil moisture content on the photosynthetic physiology of lettuce in Pei Yun et al (Pei *et al*. 2015). Fluorescence quenching refers to a decrease in chlorophyll fluorescence production, which can be caused by increased photosynthesis or by increased heat dissipation.Fluorescence quenching caused by enhanced photosynthesis is called photochemical quenching, which is the proportion of light energy absorbed by PSII for photochemical reactions, which reflects the openness of the PSII reaction center to a certain extent. The results of this experiment showed that with the decrease of soil moisture content, the Fv/Fm, ΦPSII and qP of lettuce showed a downward trend, while NPQ showed an upward trend. The decrease of Fv/Fm and ΦPSII indicated that the active center of PSII. of the leaf was damaged, the primary reaction process of photosynthesis was inhibited, and the actual photochemical efficiency of PSII was reduced. The decrease in qP and NPQ in lettuce indicate that lettuce prevents the damage of excess light energy to the photosystem, thereby protecting the photosynthetic mechanism.

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