Effects of Soil Water Stress on Photosynthetic Characteristics and Biomass of Alfalfa (Post-print)

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Abstract

Alfalfa is an important leguminous forage crop in China with strong drought resistance, while water deficit is one of the main stress factors affecting its yield. Through field experiments, the photosynthetic characteristics and yield of alfalfa under different water stresses were studied, and the results showed that: Soil water stress had a significant effect on the light response parameters of alfalfa ($P < 0.05$). With the intensification of water stress, the maximum net photosynthetic rate, apparent quantum efficiency, and light saturation point gradually decreased, while the dark respiration rate and light compensation point gradually increased, thereby directly affecting the absorption and conversion efficiency of alfalfa photosynthesis under low light conditions. With the intensification of water stress, the net photosynthetic rate (Pn) and transpiration rate (Tr) of alfalfa leaves showed a significant decreasing trend, while stomatal conductance (Gs) showed a trend of first decreasing and then increasing, indicating that stomatal factors were the main cause of Pn decline under mild water stress, while non-stomatal factors were the main cause of Pn reduction under moderate and severe water stress. When photosynthetically active radiation (PAR) was 1 200 mol·m-2·s-1, the water use efficiency (WUE) under mild water stress was significantly greater than that under full irrigation ($P<0.05$), indicating that moderate water stress could improve the water use efficiency of alfalfa leaves. There was no significant difference in hay yield between mild water stress and full irrigation, indicating that mild water stress can achieve the goal of high yield and water saving.

Full Text

Abstract

Medicago sativa is an important legume forage in China with strong drought resistance. However, water deficit remains the main stress factor affecting its yield. The photosynthetic characteristics and yield of M. sativa under different water stress conditions were studied through field experiments. The results showed that: Soil water stress significantly affected the photoresponse parameters of M. sativa ($P < 0.05$). With increasing soil water stress, the maximum net photosynthetic rate, apparent quantum yield, and light saturation point gradually decreased, while the dark respiration rate and light compensation point gradually increased, thus directly affecting the light absorption and conversion efficiency of M. sativa in photosynthesis. With increasing soil water stress, the net photosynthetic rate (Pn) and transpiration rate (Tr) of M. sativa leaves were significantly reduced, but the stomatal conductance (Gs) first decreased and then increased, revealing that stomatal factors under light water stress were the main factors resulting in Pn reduction, while non-stomatal factors under moderate and severe water stress were the main factors resulting in Pn reduction. When the photosynthetically active radiation (PAR) value was 1200 $mol \cdot m^{-2} \cdot s^{-1}$, the water use efficiency (WUE) under light water stress was significantly higher than that under full irrigation ($P < 0.05$), indicating that moderate water stress could improve the water use efficiency of M. sativa. There was no significant difference in hay yield between light water stress and full irrigation, indicating that high forage yield and water-saving irrigation could be achieved under light water stress.

Keywords: Medicago sativa; drip irrigation; water use efficiency; soil water stress; photosynthesis; biomass; Yongchang; Gansu

Methods

Field experiments were conducted to investigate the effects of soil water stress on photosynthetic characteristics and biomass of alfalfa. Measurements were taken between 9:00 and 17:00 using a LI-6400XT portable photosynthesis system. The experimental design included four irrigation treatments: CK (control, full irrigation), LK (light water stress), MK (moderate water stress), and SK (severe water stress). Data were processed using Microsoft Excel 2007 and SPSS 19.0 software for statistical analysis.

Results

Photosynthetic Parameters

Soil water stress significantly affected the photosynthetic parameters of alfalfa ($P < 0.05$). Compared with the control, the maximum net photosynthetic rate (Pnmax) under LK, MK, and SK treatments decreased by 12.7%, 36.4%, and 73.6%, respectively. The apparent quantum yield (AQY) under LK and MK treatments

showed significant differences, decreasing by 17.1% and 22.0% compared with CK, while SK treatment decreased by 63.4%. The light saturation point (LSP) under CK and LK treatments was significantly higher than under MK and SK treatments, with values of 1000 and 800 $\mu mol \cdot m^{-2} \cdot s^{-1}$ under MK and SK, respectively, compared to 1200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ under CK. The dark respiration rate (Rd) under CK, LK, MK, and SK treatments showed significant differences ($P < 0.05$). The light compensation point (LCP) under LK and MK treatments was significantly different, increasing by 9.3% and 13% compared with CK.

Light Response Curves

Under light stress conditions, when photosynthetically active radiation (PAR) was less than 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$, Pn increased rapidly with increasing PAR. When PAR ranged from 200 to 800 $\mu mol \cdot m^{-2} \cdot s^{-1}$, Pn continued to increase but at a slower rate. When PAR exceeded 800 $\mu mol \cdot m^{-2} \cdot s^{-1}$, Pn reached saturation. At PAR = 1200 $\mu mol \cdot m^{-2} \cdot s^{-1}$, the Pn values under LK, MK, and SK treatments were 20.36, 14.64, and 6.05 $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively, representing decreases of 12.5%, 37.1%, and 74.0% compared with CK (23.28 $\mu mol \cdot m^{-2} \cdot s^{-1}$) [Figure 1: see original paper].

CO Response

With decreasing intercellular CO concentration (Ci), Pn decreased correspondingly. Under LK treatment, Ci was slightly higher than CK, while under MK and SK treatments, Ci was significantly lower than CK [Figure 1c: see original paper].

Water Use Efficiency

Under LK, MK, and SK treatments, WUE was higher than CK, and increased with increasing PAR. At PAR = 1200 $\mu mol \cdot m^{-2} \cdot s^{-1}$, WUE under CK and LK was similar, but significantly higher under MK and SK. When PAR > 1200 $\mu mol \cdot m^{-2} \cdot s^{-1}$, WUE under all water stress treatments showed an increasing trend. At PAR = 1500 $\mu mol \cdot m^{-2} \cdot s^{-1}$, WUE under LK was essentially equal to that under CK, while MK and SK treatments showed higher WUE values [Figure 1e: see original paper].

Correlation Analysis

Correlation analysis revealed that WUE was significantly positively correlated with Pn, Gs, Tr, and Ls ($P < 0.01$), and significantly negatively correlated with Ci. Pn showed significant positive correlations with Gs, Tr, and Ls, and significant negative correlation with Ci. Ls was significantly negatively correlated with Ci .

Table 3. Correlation analysis of photosynthetic physiological parameters of Medicago sativa

Parameter	WUE (mol · mmol ^{1})	Pn (mol · m ^{2} · s ^{1})	Gs (mmol · m ^{2} · s ^{1})	Ci (mol · mol ^{1})	Tr (mmol · m ^{2} · s ^{1})
WUE	1.000	0.917**	0.753**	-0.816**	0.739**
Pn	0.917**	1.000	0.951**	-0.922**	0.946**
Gs	0.753**	0.951**	1.000	-0.924**	0.992**
Ci	-0.816**	-0.922**	-0.924**	1.000	-0.879**
Tr	0.739**	0.946**	0.992**	-0.879**	1.000

Note: ** indicates significant correlation at $P < 0.01$ level.

Discussion

Water use efficiency (WUE) is calculated as the ratio of Pn to Tr and is an important indicator of plant water consumption under drought conditions. Previous studies have shown that moderate water stress can improve WUE in alfalfa. In this study, when PAR was less than 800 mol · m ^{2} · s ^{1}, WUE under LK treatment was equal to CK, but when PAR reached 1200 mol · m ^{2} · s ^{1}, WUE under LK was higher than CK, indicating that under light water stress, WUE of alfalfa could be improved.

The correlation analysis showed that Pn, Gs, Tr, and Ls were significantly positively correlated with WUE, while Ci was significantly negatively correlated. Under light water stress, stomatal limitation was the main factor causing Pn reduction, while under moderate and severe water stress, non-stomatal limitation became the dominant factor. This is consistent with previous research findings.

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Note: Figure translations are in progress. See original paper for figures.