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Threshold Effect on Photosynthetic Parameters for Soil Volumetric Water Content of *Hippophae rhamnoides*

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In order to make clear the suitable soil volumetric water content (SVWC) for net photosynthetic rate(Pn) and light response parameters of Pn in the Semi arid Loess Hilly Region, common species *Hippophae rhamnoides* used as experimental materials was studied with CIRAS-2 portable photosynthesis system made in PPS corporation of England. Pn and light response parameters of Pn were observed in different SVWC and Photosynthetic active radiation (PAR). The results show that Pn and light response parameters of Pn have notable threshold responses value to SVWC and PAR. In a word, Hippophae rhamnoides can adapt to a wide range of illumination intensity and have the property of strong drought-resistance but can not stand the high soil moisture environment. The experiment results have theoretical value of enriching and developing photosynthetic capacity and water research for plants in Semiarid Loess Hilly Region, and it can provide a solid foundation for plant selection.

1. Introduction

With change of global climate, increase of air temperature and reduce of water resources, soil erosion and desertification become serious (Williams 2001; Lal 2014). Meanwhile, other ecological problems such as loss of forest vegetation and biological diversity have become increasingly prominent. So vegetation restoration and reconstruction have become one of the hot issues in ecology (Huang et al, 2007; Zhao et al, 2015). Vegetation restoration and reconstruction is very important link for ecosystem restoration and reconstruction, and the selection of plant species for vegetation restoration is one of the key links, meanwhile the soil moisture and light are important ecological factors influencing vegetation distribution and plant growth (Wang et al, 1996; Zhang et al, 2004; Cai et al, 2005; Dong et al, 2014; Li et al, 2015). Therefore, how the vegetation adapt to soil drought stress and light stress resulted by global climate change is one of the issues that people are studying.

At present, there were many studies on drought resistance of different trees (Drust-Nacarino et al., 2015; Gullo and Salleo 1988; Wu and Zhang, 2009; Zhang et al, 2015; Pouyafard et al, 2016). The contents were very rich, including the changes of physiological and biochemical factors, responses to water stress or adapting to the characteristics and the mechanism (Hu 1998; Li et al, 2007; Teh and Wu, 2014; Delfine et al, 2015; Jia et al, 2015; Dong and Li; 2016). But the existing researches were mostly confined to the few water deficit levels (such as mild, moderate and severe stress). Especially in the semi-arid hill area of loess plateau, lack of continuous observation on soil drought and multistage soil moisture gradient, resulted the relationships between trees and soil moisture quantitative and other physiology are not very clear.

In order to effectively solve the problem, exploring the drought resistance characteristics and the relationship between their physiological processes and soil volumetric water contents (SVWC) are very important. The purpose of this study is to insight into photosynthetic characteristics in *Hippophae rhamnoides* leaves under different SVWC, which also provides oretical support for use in revegetation of Semi arid Loess Hilly Region. Our objectives are to conform the range of fitting SVWC keeping the leaves higher photosynthetic capacity.

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2. Materials and methods

2.1 Study area

The experiment was conducted in the Semi arid Loess Hilly Region in China, which is located in Tuqiaogou valley, Yukou town, Fangshan county, Lvliang city, Shanxi province (37°36′58″N, 110°02′55″E). It is a hilly and gully region of loess in the middle reaches of the Yellow River, and average altitude of test area is 1200m. The area is a warm temperate with continental monsoon climate. Winter is cold and dry, autumn is cool and little rain, rainfall is concentrated in summer. Years of average annual rainfall is 416mm, and the distribution is very uneven in the year, rainfall accounted for more than 70% of the whole year on the 6th to 9th month. The area mainly blow northeast wind, and the annual average wind speed is 2-4$m \cdot s^{-1}$. July is the warmest month and the annual average temperature is 7.3°C. Cultivated loessial soils are the main soil types.

2.2 Materials

The 2 year old *Hippophae rhamnoides* were selected as the experimental materials. At least 3 plant species were used as observation samples. The index of photosynthetic efficiency under different SVWC was determinated in june. Each plant was repeatedly measured at least 3 leaves, and the data were recorded for 3 times.

2.3 Water treatment

Firstly, watered the plants to make the soil water saturated a day before the experiment, and then decreased SVWC by natural water consumption, until reaching the wilting point (In this study, when the net photosynthetic rate is zero). During this period, the SVWC were monitored with the soil moisture meter (Thetaprobe-ML2X). According to previous observation, a soil moisture value can be obtained about every 2 days. In this way, 8-10 observed value can be obtained, which can basically meet the requirements of various photosynthetic efficiency indicators for soil moisture response process and mechanism analysis.

2.4 Observation and calculation of photosynthetic efficiency index

Firstly, 3 mature leaves were selected from each plant, and then the portable photosynthesis system (CIRAS-2, PP System, UK) was used to determine gas exchange parameters under different SVWC. Each leaf was repeated 3 times, and the average value was taken. The daily measurement time is 9:00 ~ 11:00. Each measurement day is a sunny day, the same period of time, the inner and outer boundary light intensity, air temperature, air humidity and atmospheric CO_2 concentration and other environmental conditions are basically similar. when measured, atmospheric CO_2 concentration and artificial light source were used. The light intensity is controlled at 1800, 1600, 1400, 1200, 1000, 800, 600, 400, 150, 100, 50, 20$\mu mol \cdot m^{-2} \cdot s^{-1}$ 12 levels. Each level of control was measured by 120s. The light response curve (PAR - Pn curve) was drawn, and the light saturation point of photosynthesis was calculated (LSP; $\mu mol \cdot m^{-2} \cdot s^{-1}$). Linear regression was performed on the initial part of PAR-Pn curve (Photosynthetic active radiation PAR<200$\mu mol \cdot m^{-2} \cdot s^{-1}$), and the light compensation point (LCP; $\mu mol \cdot m^{-2} \cdot s^{-1}$), dark respiration rate (Rd; $\mu mol \cdot m^{-2} \cdot s^{-1}$) and apparent photosynthetic quantum efficiency (Φ; $mol \cdot mol^{-1}$) were obtained.

3. Results and dicussion

3.1 Net photosynthetic rate(Pn) under different SVWC

Pn to PAR under different SVWC was shown as Fig.1. With the increase of PAR the Pn rised in a straight line in low PAR (PAR<200$\mu mol \cdot m^{-2} \cdot s^{-1}$). When PAR was above 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ the Pn increased in a curve type. With continued increases in PAR the Pn changed slowly, but still maintained at a higher value. Under different SVWC, LSP were different. Under high SVWC (>16.77%), Pn rised with the enhancement of PAR, and LSP was not seen. In other SVWC (>9.01%), with continuous improvement of PAR, Pn reached maximum value, and this was LSP. After more than LSP, Pn decreased, but it still kept a high value. That can be seen the adaptability of photosynthesis to PAR was stronger, and PAR of 800-1300$\mu mol \cdot m^{-2} \cdot s^{-1}$ was higher in the light of the same SVWC.

Compared with other SVWC, when PAR is above 200$\mu mol \cdot m^{-2} \cdot s^{-1}$ the plants at the point of 16.77% SVWC reached the highest value in Pn. The 19.39% SVWC, 13.93% SVWC and 9.01% SVWC increased Pn, whereas 22.43% SVWC, 7.02% SVWC and 6.08% SVWC reduced Pn as compared to the 11.22% VWC.

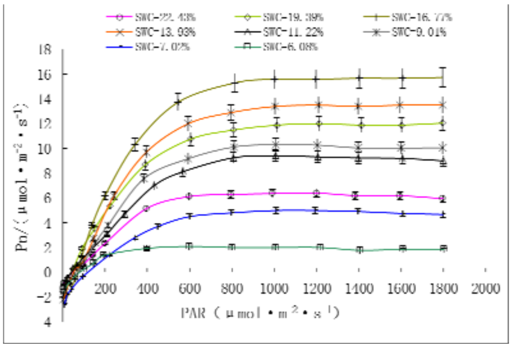

Figure 1: Pn to PAR under different SVWC

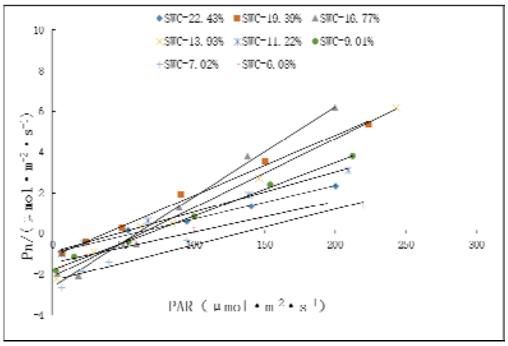

Figure 2: Pn to PAR (PAR＜200μmol·m^{-2}·s^{-1})

When PAR is below 200μmol·m^{-2}·s^{-1} there was no significant difference in Pn under different SVWC. Pn with SVWC below 200μmol·m^{-2}·s^{-1} during the period of study is shown in Fig.2. The correlation coefficient between Pn and SVWC is 0.0443 at the point of 16.77% which is greater than that in other SVWC (Table.1).
PAR also had a clear threshold response to SVWC, that is, in a certain range of SVWC, with the increase of SVWC, Pn had a significant change. When SVWC were below 16.77% with the increase of SVWC the Pn showed a rising trend. But when SVWC were above 16.77% Pn showed a decreasing trend. So 16.77% can be used as the turning point of Pn change, in which maximum value of Pn appeared. Under serious water stress (< 9.01%), with the increase of PAR, Pn maintained at a lower level, and the LSP also significantly decreased. Under the same PAR, the differences of Pn value were bigger in different SVWC, sush as at 800μmol·m^{-2}·s^{-1} Pn (15.3μmol·m^{-2}·s^{-1}) at the point of 16.77% SVWC was 3.1times higher than that (4.8μmol·m^{-2}·s^{-1}) at 7.02% SVWC. Pn in SVWC for 13.93%~19.39% did not change significantly and can be maintained at a higher value.

Table 1: Correlation coefficient between Pn and SVWC

Soil moisture contents	Regression formula	R^2
22.43%	Y=0.0164x-0.9221	0.9924
19.39%	Y=0.0296x-1.0895	0.9942
16.77%	Y=0.0443x-2.6390	0.9882
13.93%	Y=0.0339x-2.1127	0.9930
11.22%	Y=0.0198x-0.9209	0.9917
9.01%	Y=0.0262x-1.7611	0.9966
7.02%	Y=0.0176x-2.3142	0.9604
6.08%	Y=0.0150x-1.4265	0.9671

3.2 Light response parameters of Pn

The dependence of light response parameters on Pn is very important. Pn linear regression diagram under weak light intensity (< 200μmol·m^{-2}·s^{-1}) was shown as Fig.2. Φ, Rd and LCP can be solved by regression equation. The response of Φ, Rd and LCP to SVWC was shown as Fig.3, Fig.4 and Fig.5. It can be seen that Φ, Rd and LCP had obvious threshold response to SVWC.

Variation of Rd of Hippophae rhamnoides also presented certain regular rules (Fig.4), Rd reached the maximum value when SVWC was within 13.93%-19.39%, no matter SVWC increased or decreased, Rd would gradually reduce. The maximum value of Rd of Hippophae rhamnoides was 1.49 μmol·m^{-2}·s^{-1}. LCP of Hippophae rhamnoides reached the minimum value under moderate water stress, when SVWC was too high or too low, LCP had enlarging tendency and utilization efficiency of dim light was reduced(Fig.5). It could be seen from Figure 1 that under moderate water stress, LSP of Hippophae rhamnoides was about 700-900 μmol·m^{-2}·s^{-1}, under other SVWC, its LSP was 1100-1500 μmol·m^{-2}·s^{-1} or so, which indicated that it had strong features of enjoying the light and exposing to the sun.

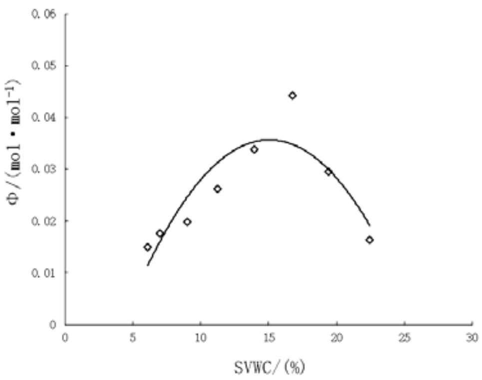

Figure 3: Response of Φ for SVWC

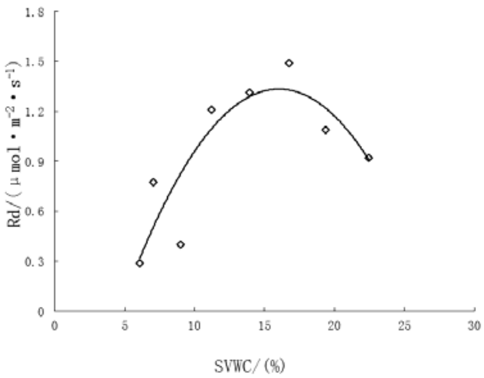

Figure 4: Response of Rd for SVWC

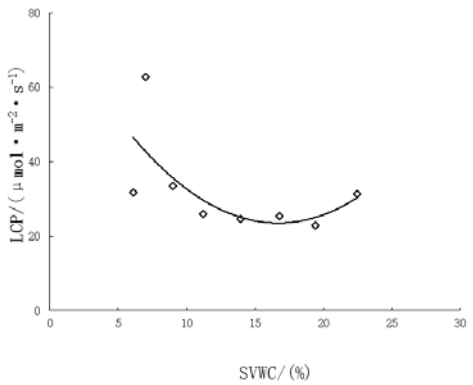

Figure 5: Response of LCP for SVWC

4. Conclusions

Through threshold value response of plant blade gas exchange parameters to SVWC and PAR, suitable SVWC and scope of PAR which were good for plant growth could be determined, and it was an important basis for judging water regime of forest land and improving photosynthetic productivity of woods. It is generally accepted that photosynthetic capacity can be effected by high or low SVWC. According to analysis results of relation between physiological factors like photosynthetic rate and photosynthetic parameters and SVWC, it preliminarily determined the appropriate SVWC and maximum plant water deficit which took improving photosynthetic productivity as the core for Hippophae rhamnoides in semi-arid region. The above analysis showed that if the photosynthetic productivity of Hippophae rhamnoides could be improved under strong PAR, suitable SVWC must be coupled. The suitable SVWC range for maintaining high photosynthetic productivity was 13.93% to 19.39%, the water within the range of suitable PAR is 800~ 1300μmol·m^{-2}·s^{-1}. Among them, the maximum value of Pn appeared at about SVWC 16.77%, and the corresponding PAR is about 1100μmol·m^{-2}·s^{-1}. When SVWC was slightly enough or mild water stress, the medium Pn could be obtained, but when the SVWC was below 7.02%, Pn was significantly decreased, and the normal growth of Hippophae rhamnoides was inhibited.

Φ reflected the utilization of light energy in leaves, especially the ability to use low light (Llusià 2005). With the increase of SVWC Φ also increased. The maximum Φ of Hippophae rhamnoides is about 0.04 mmol·mol^{-1}, and the value was in general plant experimental value range. (0.03~0.05 mmol·mol^{-1}) (Xu 2001). It was shown that under suitable SVWC Hippophae rhamnoides had a higher ability to use weak light. Φ under different SVWC changed greatly, the magnitude of change is 0.01 to 0.04 mmol·mol^{-1}, and it indicated that at low PAR, light utilization rate was greatly affected by SVWC.

LSP and LCP of plant photosynthesis displayed ability of plant blades in utilizing hard light and dim light. Plant LCP directly reflected its ability in utilizing dim light and it was an important index evaluating plant shade tolerance (Wallin et al, 1992; Craine and Reich 2005, Llusià et al, 2005, Lusk and Jorgensen 2013). Thus it could be seen that because of difference in SVWC, Hippophae rhamnoides presented certain adaptability and plasticity to PAR, and it had high abilities in utilizing hard light and dim light under appropriate SVWC, hence, it had wide illumination ecological amplitude, and its shade tolerance and property of enjoying light were enhanced.

The above indicated that under high SVWC and severe drought stress, consumption of photosynthetic products was quite small, which indicated that physiological activity of Hippophae rhamnoides blade was influenced by water stress, while growing under appropriate SVWC, its Rd was high, and physiological activity of its blades was high (Volpe et al, 1988), which was beneficial for its growth and laid a good material foundation for accelerating biological yield.

In this paper, the threshold effect of photosynthetic parameters on water conditions is studied, and the fluorescence parameters can be added to the follow-up study.

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