EFFECTS OF LIGHT CONDITIONS AT DIFFERENT GROWTH STAGES ON GROWTH AND PHOTOSYNTHETIC CHARACTERISTICS OF *PINUS SYLVESTRIS* VAR. *SYLVESTRIFORMIS* SEEDINGS

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Abstract. *Pinus sylvestris* var. *sylvestriformis* is an endemic plant in Changbai Mountain area of China. Five different light levels were simulated and designed with control experiments: full sunlight (CK), light shading (light transmittance was 10%) (LA), light and moderate shading (light transmittance was 20%) (LB), moderate shading (light transmittance was 40%) (LC), and severe shading (light transmittance was 60%) (LD). The optimal light levels and the main physiological and ecological factors affecting photosynthesis in different growth stages were discussed. The results showed that the phenotypic index and photosynthetic physiological and ecological indicators were the highest when the light transmittance was 40%. In the early growth phase, the physiological factors intercellular CO_2 concentration (C_i) and ecological factors transmittance (*Tran*) and air temperature (*Temp*) jointly affected the changes of net photosynthetic rate (P_n). In the peak growth phase, transpiration rate (T_r), air humidity (*RH*), and *Tran* had greater direct positive effects on P_n, and C_i and stomatal conductance (G_s) had direct negative effects on P_n. In the later growth phase, T_r and C_i had large direct positive effects on P_n. The research results could provide important references for the scientific cultivation and popularization of *P. sylvestris* var. *sylvestriformis*.
Keywords: *P. sylvestris var. sylvestriformis, light transmittance, growth phases, the phenotypic index, photosynthetic physiological and ecological indicators*

Introduction

Light is an important environmental factor that affects the growth and development, morphogenesis, regeneration, and distribution of plants (Rozendaal et al., 2006). Plants regulate their growth and development by sensing the changes of light signals in the external environment (Kim et al., 2017). In the weak light environment, the plant's ability to capture light is limited, which restricts the photosynthetic capacity of plants and causes the decrease of photosynthetic rate, but it will increase the content of photosynthetic pigment to increase the ability to capture light energy (Liu et al., 2011). “Trade- off theory” holds that under shading conditions, plants tend to allocate more biomass to the aboveground part and less to the root, which affects water absorption (Smith et al., 1989). In order to cope with different light conditions, plants can increase the utilization of light energy through morphological and physiological plasticity response, so as to avoid the photoinhibition or photodamage, and finally reduce the photosynthetic rate (Duan et al., 2005).

Pinus sylvestris var. *sylvestriformis* is a rare and endangered tree species in Changbai Mountain, China's national first-class protected plant. The natural population of *P. sylvestris* var. *sylvestriformis* is distributed in the northern slope of Changbai Mountain and Changbai Mountain Nature Reserve in China, with a small area of about 200 hm^2.

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Because of its straight trunk, beautiful tree shape, and handsome posture, the local people called it "beauty pine." However, in recent years, due to the increase of population, economic development, and environmental damage, the number of *P. sylvestris* var. *sylvestriformis* has become less and less, which has reached the edge of extinction and needs further protection (Bu et al., 1995).

There is a strong correlation between plant growth and light environment heterogeneity, especially light intensity (Bazzaz, 1996). The need and sensitivity of seedlings growth to light are high, so it is often necessary to adopt necessary tending measures according to the response of seedlings to light (Welander and Ottosson, 1998; Wang, 2008). In order to obtain the best light environment for the growth of *P. sylvestris* var. *sylvestriformis* seedlings, so as to take corresponding tending measures, it is particularly important to study and practice the response of *P. sylvestris* var. *sylvestriformis* seedlings to the light environment.

At present, researches on *P. sylvestris* var. *sylvestriformis* mainly involve the population, community and ecological investigation, etc. (Hu et al., 1966; Zhao et al., 2002; Zhao et al., 2017; Jin et al., 2015; Chen et al., 2017). It is not reported to study the growth status of *P. sylvestris* var. *sylvestriformis* and analyze the dynamic changes of leaf photosynthesis in the whole growth period by short- term artificial control of light conditions.

In this experiment, through artificial shading treatment, the growth status and photosynthetic parameters of *P. sylvestris* var. *sylvestriformis* seedlings under different light conditions at different growth stages were observed continuously. The adaptability of *P. sylvestris* var. *sylvestriformis* seedlings to different light conditions was discussed, and the effects of environmental factors on Photosynthesis in different growth phases were analyzed. In order to seek the most suitable light conditions to promote the growth of *P. sylvestris* var. *sylvestriformis* seedlings, and to identify the main physiological and ecological factors that affect the photosynthesis of *P. sylvestris* var. *sylvestriformis* in different growth phases. So as to provide theoretical basis and technical reference for scientific management of *P. sylvestris* var. *sylvestriformis* seedlings.

Materials and methods

Overview of experimental sites

The experimental site is located at Northeast Asia Arboretum of Changbai Mountain Nature Reserve, China, with a geographical location of 128°01' E, 42°22' N, and the altitude of 770-780 m, the climate belongs to the temperate continental monsoon alpine climate. The annual average temperature is 3-7 ℃. The minimum temperature has appeared -44 ℃. The annual sunshine hours are less than 2300 hours. The frost-free period is about 100 days. The annual precipitation is between 700-1400 mm, and 6-9 month accounts for 60-70% (Yin et al., 2017).

Test materials and methods

Materials

Biennial seedlings were planted in the spring of 2016 in the test site, and the test was conducted in May 2018. The shading nets with a light transmittance of 10%, 20%, 40%, and 60% were selected.

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Cultivation substrate

The ratio of dark brown loam to river sand was 2: 1. When cultivated, the border was 35 cm high and 120 cm wide.

Experimental methods

There were five treatments in the light environment:
CK control: full sunlight;
LA: light transmittance was 10%;
LB: light transmittance was 20%;
LC: light transmittance was 40%;
LD: light transmittance was 60%.
During the experiment, the maximum light intensity of each treatment was monitored by HOBOU12 environmental factor monitor of American HOBO Onset Company at noon on five sunny days. The light intensity is as follows:
CK control: 112304-128032 lux;
LA: 3313-7594 lux;
LB: 13656-28546 lux;
LC: 45644-69650 lux;
LD: 58762-79364 lux.
Each sunshade was 6 m long, 4 m wide and 2 m high. Each treatment was repeated three times, with 20 plants per repeat. The plant row spacing was 20 cm by 20 cm. The seedling height, ground diameter, and leaf length (maximum leaf length) of *P. sylvestris* var. *sylvestriformis* seedlings were measured in June, July, August, and September, respectively. From May to October, a sunny day was choosing every month, photosynthetic characteristics were measured using an LI- 6400 portable photosynthesis system (American LI- COR Company) between 9 a.m. and 11 a.m. The effective light radiation was set at 1500 lux. The net photosynthetic rate (P_n), stomatal conductance (G_s), transpiration rate (T_r), and intercellular CO_2 concentration (C_i) of *P. sylvestris* var. *sylvestriformis* seedlings of different treatments were measured. Each repeating was measured once, and the data acquisition time was 3 minutes, which would be recorded after it was stable.

During the period from mid-May to October 2019, the HOBOpro automatic temperature and humidity recorder was used to automatically collect the atmospheric temperature and relative humidity during the test period every half an hour.

Data processing and analysis

All data were analyzed by Excel and IBM SPSS statistics software for multiple comparison, significance test, regression analysis, simple correlation analysis and path analysis. The statistical graph was drawn by sigmaplot 14.0. Descriptive statistics were expressed in mean ± SEM and letter notation.

Results and analysis

Changes in temperature and relative humidity

Figure 1 showed course of daily and monthly average temperature and relative humidity in experimental period. The temperature of the experimental area was low in May, with an average monthly temperature of 15.71 ℃, an average monthly relative

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humidity of 63.95%, and the air was dry. From June to August, the temperature rose rapidly. From July to August, the temperature reached its highest value. This period was the main rainfall period. The temperature difference between day and night was large. The monthly average temperature was 20.43 ℃ and 19.36 ℃, respectively. The weather was humid and cool. From September to October, the temperature gradually decreased, with the lowest temperature in October. The monthly average temperature was below 10 ℃. The monthly average relative humidity of the air was maintained at about 66%. The weather was dry and cold.

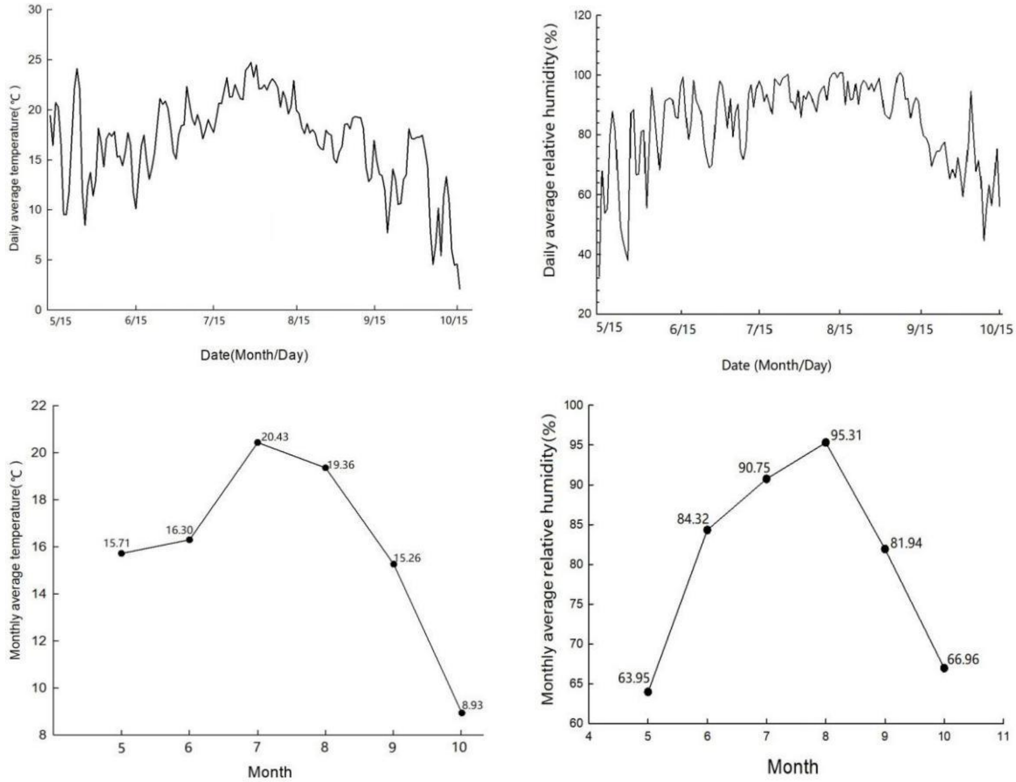

Figure 1. *Course of daily and monthly average temperature and relative humidity in experimental period*

Effects of different light conditions on the growth of P. sylvestris var. sylvestriformis seedlings

Effects of different light conditions on plant height of P. sylvestris var. sylvestriformis seedlings

Table 1 showed the average plant height of each treatment measured in different months. According to the plant height of two adjacent months, the change rate of plant height of different treatments in each month is further calculated. From June to July, plant height change rate of treatment CK was 39.48%, plant height change rate of treatment LA was 14.22%, plant height change rate of treatment LB was 24.46%, plant height change rate of treatment LC was 37.65%, plant height change rate of treatment LD was 42.44%. Based on the change rate of plant height treated with treatment CK, the plant height of *P. sylvestris* var. *sylvestriformis* seedlings decreased by 25.26% after treatment LA,

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15.02% after treatment LB, 1.83% after treatment LC than treatment CK, but after treatment LD, the plant height increased by 2.96% than CK. From July to August, based on the change rate of plant height treated with CK, after each treatment, the height of seedlings increased by 4.46%, 4.76%, 19.39%, and 16.70%, respectively, compared with that of treatment CK (full sunlight). From August to September, based on the change rate of plant height treated with CK, the height of seedlings increased by 0.71%, 2.15%, 3.45%, and 1.43% compared with that of treatment CK.

Table 1. *Growth of plant height in different months (cm)*

Tran	June	July	August	September
CK	12.21±2.74a	17.03±2.38ab	19.04±3.02ab	19.42±3.24bc
LA	13.08±1.17a	14.94±1.69b	17.37±1.91b	17.84±1.75c
LB	14.31±1.34a	17.81±1.31a	20.76±0.74a	21.62±0.29ab
LC	11.9±0.06ab	16.38±0.15ab	21.49±1.08a	22.66±1.13a
LD	9.26±0.98b	13.19±0.38c	16.95±0.59b	17.53±0.63c

Note: Lowercase letters in the same column represented significance differences at the $p<0.05$ level

The growth rates of plant height of *P. sylvestris* var. *sylvestriformis* seedlings treated by CK, LA, LB, LC and LD from June to September were 59.05%, 36.39%, 51.08%, 90.42%, and 89.31%, respectively. The growth rate during the growing season was as follows: treatment LC> LD> CK> LD> LA. The plant height of each treatment showed an upward trend during the whole growing season. The plant height of treatment CK, LB, LC, LD increased rapidly in the period of June-July. The plant height of treatment LA increased rapidly in the period of July- August. Each treatment increased slowly in the period of August- September.

Effects of different light conditions on the ground diameter of P. sylvestris var. sylvestriformis seedlings

Table 2 showed the average ground diameter of each treatment measured in different months. According to the ground diameter of two adjacent months, the change rate of the ground diameter of different treatments in each month is further calculated. From June to July, the ground diameter change rate of treatment CK was 19.25%, the ground diameter change rate of treatment LA was 5.57%, the ground diameter change rate of treatment LB was 15.49%, the ground diameter change rate of treatment LC was 21.49%, the ground diameter change rate of treatment LD was 7.34%. Based on the change rate of the ground diameter treated with treatment CK. the ground diameter of *P. sylvestris* var. *sylvestriformis* seedlings decreased by 13.68% after treatment LA, 3.76% after treatment LB, 11.91% after treatment LD than treatment CK, but after treatment LC, the ground diameter increased by 2.24% than treatment CK. From July to August, based on the change rate of the ground diameter treated with CK, the ground diameter of *P. sylvestris* var. *sylvestriformis* seedlings decreased by 9.14% after treatment LA, 4.53% after treatment LB, 0.04% after treatment LC than treatment CK, but after treatment LD, the ground diameter increased by 0.93% than CK. From August to September, the ground diameter seedlings decreased by 1.34% after treatment LA, 0.83% after treatment LB, 0.72% after treatment LC, 3.68% after treatment LD than treatment CK.

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Table 2. *Growth of ground diameter in different months (mm)*

Tran	June	July	August	September
CK	3.22±0.56a	3.84±0.67ab	4.37±0.59a	4.48±0.08b
LA	3.05±0.34a	3.22±0.34b	3.37±0.35b	3.50±0.37a
LB	3.55±0.06a	4.10±0.08a	4.48±0.11a	4.63±0.17a
LC	3.35±0.12a	4.07±0.12ab	4.63±0.08a	4.78±0.10a
LD	3.54±0.17a	3.80±0.28ab	4.36±0.33b	4.63±0.47a

Note: Lowercase letters in the same column represented significance differences at the $p<0.05$ level

The growth rates of the ground diameter of *P. sylvestris* var. *sylvestriformis* seedlings treated by CK, LA, LB, LC and LD from June to September were 39.13%, 14.75%, 30.42%, 42.69%, and 30.79%, respectively. The ground diameter of each treatment showed an upward trend during the whole growing season. The ground diameter of treatment CK, LB, LC, LD increased rapidly in the period of June- August and increased slowly in the period of August-September. The ground diameter of treatment LA increased slowly during the whole growing season.

Effects of different light conditions on the leaf length of P. sylvestris var. sylvestriformis seedlings

Table 3 showed the average leaf length of each treatment measured in different months. According to the leaf length of two adjacent months, the change rate of the leaf length of different treatments in each month is further calculated. From June to July, the leaf length change rate of treatment CK was 10.24%, the leaf length change rate of treatment LA was 10.86%, the leaf length change rate of treatment LB was 10.23%, the leaf length change rate of treatment LC was 16.91%, the leaf length change rate of treatment LD was 14.77%. Based on the change rate of the leaf length treated with treatment CK. the leaf length of *P. sylvestris* var. *sylvestriformis* seedlings increased by 0.62% after treatment LA, 6.67% after treatment LC, 4.53% after treatment LD than treatment CK, but after treatment LB, the leaf length decreased by 0.01% than treatment CK. From July to August, the leaf length of seedlings decreased by 13.22% after treatment LA, 2.25% after treatment LD than treatment CK and the leaf length of seedlings increased by 0.69% after treatment LB, 7.70% after treatment LC than treatment CK. From August to September, the leaf length of seedlings increased by 3.56% after treatment LB, 3.90% after treatment LC, 0.79% after treatment LD than treatment CK, but after treatment LA, the leaf length decreased by 0.45% than treatment CK.

Table 3. *Growth of leaf length in different months (cm)*

Tran	June	July	August	September
CK	5.86±0.82b	6.46±0.70c	8.06±0.92bc	8.36±0.72c
LA	6.17±0.09ab	6.84±0.11bc	7.63±0.48c	7.88±0.33c
LB	6.45±0.15ab	7.11±0.12abc	8.92±0.29ab	9.57±0.07b
LC	6.27±0.11ab	7.33±0.21ab	9.71±0.84a	10.45±0.13a
LD	6.77±0.56a	7.77±0.35a	9.52±0.66a	9.95±0.69ab

Note: Lowercase letters in the same column represented significance differences at the $p<0.05$ level

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The growth rates of leaf length of *P. sylvestris* var. *sylvestriformis* seedlings treated by CK, LA, LB, LC and LD from June to September were 42.66%, 27.71%, 48.37%, 66.67%, and 46.97%, respectively. The leaf length of each treatment showed an upward trend during the whole growing season. The leaf length of treatment CK, LB, LC, LD increased rapidly in the period of July- August and increased slowly in the period of June-July and August- September. The leaf length of treatment LA increased slowly during the whole growing season.

Growth distribution of P. sylvestris var. sylvestriformis seedlings under different light conditions

Table 4 showed that under the condition of treatment LC, the growth of ground diameter was 1.43 mm, which was the highest under each treatment, and the difference from treatment CK was not significant. The growth of ground diameter was only 0.45 mm under treatment LA, which was the lowest under all treatments. The difference was significant compared with other treatments ($p< 0.05$).

Table 4. *Growth distribution of P. sylvestris var. sylvestriformis seedlings under different light conditions*

Tran	Ground diameter /mm	Plant height /cm	Leaf length /cm
CK	1.16±0.12a	7.22±1.01bc	2.50±0.18bc
LA	0.45±0.03b	4.76±0.21c	1.71±0.14c
LB	1.09±0.11a	7.31±1.23bc	3.12±0.22ab
LC	1.43±0.24a	10.76±1.68a	4.18±0.19a
LD	1.08±0.09a	8.28±0.75ab	3.18±0.28ab

Note: Lowercase letters in the same column represented significance differences at the $p<0.05$ level

Under the condition of treatment LC, the growth of plant height was 10.76 cm, which was the highest under each treatment, and the difference was significant ($p< 0.05$). The growth of plant height was only 4.76 cm under treatment LA, which was the lowest under all treatments, and the difference from treatment LD ($p< 0.05$) was significant.

Under the condition of treatment LC, the growth of leaf length was 4.78 cm, which was the highest under each treatment, and the difference from treatment CK ($p< 0.05$) was significant. The growth of leaf length under treatment LA was 1.71 cm, and the difference from treatment CK was not significant.

Division of growth and development stages of P. sylvestris var. sylvestriformis

After years of continuous observation of plant growth law in Changbai Mountain area, the growth period can be divided into three periods: 1. Early growth phase: from mid-May to the end of June, the plant growth is the fastest; 2. The peak growth period: from the beginning of July to the end of August, the plant growth is slower than the initial growth; 3. The late growth period: from the beginning of September to mid- October, the growth is slow or even stopped.

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Changes of leaf photosynthetic parameters in different growth phases

Photosynthetic capacity of P. sylvestris var. sylvestriformis seedlings in different growth phases

It could be seen from *Figure 2* that P_n, G_s, C_i and T_r of *P. sylvestris* var. *sylvestriformis* seedlings under different light conditions could be roughly divided into four stages of "low, rapid rise, stable and decline" in the whole growth phases. Combined with the growth law, growth period division and photosynthesis monitoring of *P. sylvestris* var. *sylvestriformis* seedlings, it was found that the growth and photosynthetic characteristics basically overlapped. Therefore, the seasonal variation of photosynthetic characteristics could accurately reflect the change of its growth cycle.

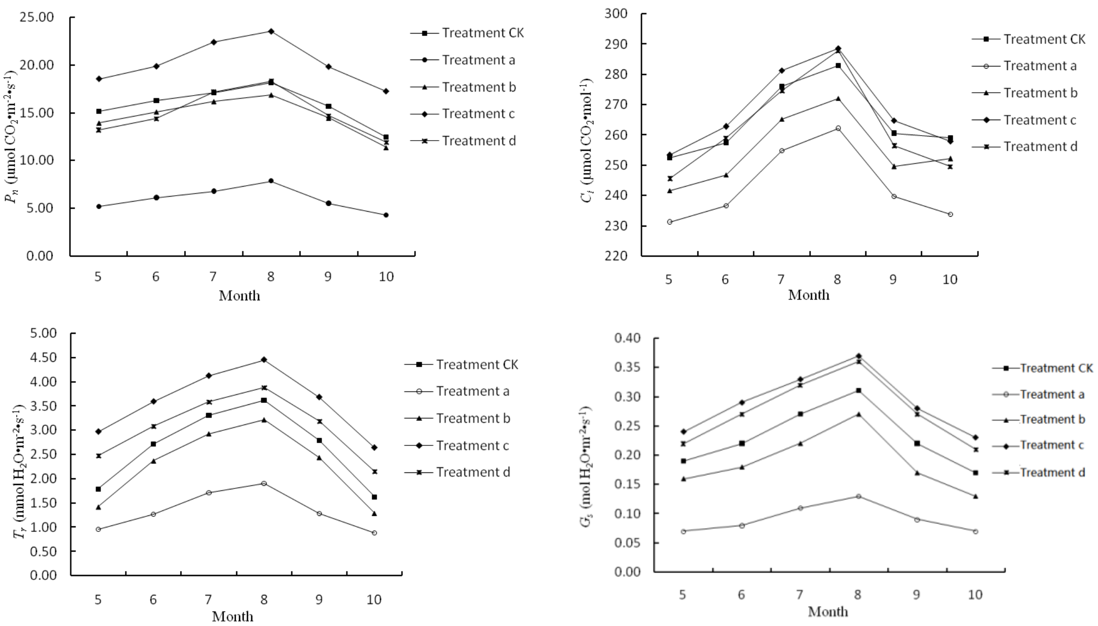

Figure 2. *Variations of P_n, G_s, C_i and T_r in different growth phases*

Photosynthetic capacity of P. sylvestris var. sylvestriformis seedlings under different light conditions

Taking August, where the photosynthetic capacity was the strongest, as an example, the photosynthetic capacity of *P. sylvestris* var. *sylvestriformis* seedlings under different light conditions was listed in *Table 5*. P_n and G_s were treatment LC> LD> CK> LB> LA. Under the condition of treatment LC, P_n and G_s were 23.52 μmol CO_2 m^{-2} s^{-1} and 0.37 mol H_2O m^{-2} s^{-1}, respectively, which were the highest under each treatment. P_n and G_s under treatment LA were only 7.85 μmol CO_2 m^{-2} s^{-1} and 0.13 mol H_2O m^{-2} s^{-1}, which were the lowest under all treatments. The difference was significant compared with other treatments ($p< 0.05$). T_r was treatment LC> LD> CK> LB> LA. Under the condition of treatment LC, T_r was 4.45 mmol H_2O m^{-2} s^{-1}, which was the highest under each treatment, and the difference from treatment CK was significant ($p< 0.05$). T_r was 1.90 mmol H_2O m^{-2} s^{-1} under treatment LA, which was the lowest under all treatments, and the difference was significant compared with other treatments ($p< 0.05$). C_i was treatment LC> LD> CK> LB> LA. C_i was 288.67 μmol CO_2 mol^{-1} under the condition

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of treatment LC, which was the highest, and Gs was 262.05 μmol CO_2 mol^{-1} under the condition of treatment LA, which was the lowest in each shading treatment.

Table 5. *Effects of different light conditions on photosynthetic capacity of P. sylvestris var. sylvestriformis seedlings*

Tran	P_n / μmol CO_2 m^{-2} s^{-1}	G_s / mol H_2O m^{-2} s^{-1}	T_r / mmol H_2O m^{-2} s^{-1}	C_i / μmol CO_2 mol^{-1}
CK	18.16±0.76b	0.31±0.04bc	3.62±0.16b	283.02±1.88b
LA	7.85±0.19d	0.13±0.02d	1.90±0.16d	262.05±3.26d
LB	16.87±0.40c	0.27±0.03c	3.22±0.22c	272.14±1.84c
LC	23.52±0.08a	0.37±0.02a	4.45±0.10a	288.67±1.75a
LD	18.32±0.39b	0.36±0.03ab	3.88±0.09b	287.88±0.84a

Note: Lowercase letters in the same column represented significance differences at the $p<0.05$ level

The relationship between photosynthetic rate and main physiological and ecological factors in different growth phases

According to different growth phases, the order of P_n mean value of *P. sylvestris* var. *sylvestriformis* was peak growth phase > early growth phase > later growth phase (*Figure 2*). *Table 6* showed correlation among photosynthetic and environmental factors. The correlation analysis between main physiological factors (G_s, C_i, T_r) and ecological factors (*Tran, Temp, RH*) and P_n showed that the correlation between P_n and other physiological and ecological factors such as G_s, C_i, T_r, *Tran* reached a significant level of 0.01, The correlation between air temperature and air humidity was not significant, and the correlation between factors was complex.

Table 6. *Correlation among photosynthetic and environmental factors*

Factors	P_n	C_i	G_s	T_r	*Tran*	*Temp*
C_i	0.77**					
G_s	0.91**	0.87**				
T_r	0.90**	0.87**	0.96**			
Tran	0.47**	0.43*	0.49**	0.39*		
Temp	0.33	0.55**	0.43*	0.53**	0.00	
RH	0.32	0.70**	0.48**	0.60**	0.00	0.77**

Note: * represents significant level at 0.05; ** represents significant level at 0.01

In order to further analyze the relationship between P_n and main physiological and ecological factors at different growth phases, path analysis was conducted on each factor (X) and P_n (Y). The weight of each factor influencing P_n was analyzed by path analysis. The results were shown in *Table 7*. The main factors that had great influence on P_n in different growth phases were different. In the early growth phase, physiological factors C_i, ecological factors *Tran* and *Temp* jointly affected the changes of P_n, the most direct effect on P_n was C_i. *Tran* and *Temp* had a greater indirect effect on P_n through C_i. In the peak growth phase, T_r, *RH* and *Tran* had a greater direct positive effect on P_n. C_i and G_s had a direct negative effect on P_n, Tr was the physiological factor that had the greatest

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effect on P_n, *Tran* and *RH* were the ecological factors that had the greatest effect on P_n. In the late growth phase, T_r and C_i had a large direct positive effect on P_n, G_s, *Tran* and *Temp* had a direct negative effect on P_n.

Table 7. *Path analysis between the factors and Pn in different growth phases*

Growth phases	Factors	Direct path	Indirect path	Through C_i	Through G_s	Through T_r	Through *Tran*	Through *Temp*	Through *RH*
Early growth phase	C_i	1.214	-0.335	-	-	-	--0.193	-0.141	-
	Tran	-0.290	0.808	0.808	-	-	-	0.000	-
	Temp	-0.356	0.482	0.482	--	-	0.000	-	-
Peak growth phase	C_i	-0.439	1.322	-	-0.645	1.887	0.047	-	0.034
	G_s	-0.675	1.613	-0.419	-	1.970	0.043	-	0.019
	T_r	2.004	1.613	-0.413	-0.664	-	0.040	-	0.014
	RH	0.086	0.013	-0.171	-0.150	0.334	0.000	-	-
	Tran	0.075	0.414	-0.276	-0.385	1.075	-	-	0.000
Later growth phase	C_i	1.082	-0.158	-	-1.640	1.620	-0.073	-0.065	-
	G_s	-1.781	2.757	0.996	-	1.950	-0.056	-0.134	-
	T_r	2.041	-1.119	0.859	-1.701	-	-0.039	-0.237	-
	Tran	-0.104	0.581	0.760	-0.951	0.772	-	0.000	-
	Temp	-0.452	0.699	0.156	-0.529	1.072	0.000	-	-

Discussion

Plant growth is inseparable from sunlight. Light can directly promote the growth and division of plant cells, promote the differentiation of plant tissues and organs, and affect plant growth and development speed (Huang et al., 2020). The results showed that when the light transmittance was 10%, the growth of plant height, ground diameter, and leaf length in the growing season was the lowest in all treatments. The average plant height increment was only 4.76 cm, the average ground diameter increment was only 0.45 mm, and the average leaf length increment was only 1.71 cm. In a different light environment, the *P. sylvestris* var. *sylvestriformis* seedlings showed different growth characteristics. Within a certain range of light intensity, the growth of plants always increased with the increase of light intensity (Welander and Ottosson, 1998; Wen et al., 1999). Some studies also considered that plants grew best at moderate light intensity (Valladares et al., 2000). The result of this experiment was consistent with that. According to the statistical results of phenotypic data, when the light transmittance was 40%, the growth of plant height, ground diameter, and leaf length in the growing season were the highest in all treatments. The average plant height increment was 10.76 cm, the average ground diameter increment was 1.43 mm, and the average leaf length increment was 4.18 cm. Growth indicators such as seedling height growth and ground stem growth under the light condition of 40% light transmittance were higher than other treatments, indicating that the seedlings of *P. sylvestris* var. *sylvestriformis* can promote plant growth under moderate shading treatment. It is consistent with the research results of *Clerodendrum japonicum* seedlings (Huang et al., 2020).

The growth of plant height, leaf length, and ground diameter were three important phenotypic indexes of *P. sylvestris* var. *sylvestriformis* seedlings, combined with

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photosynthetic characteristics as four indexes, whose differences could comprehensively reflect the effects of different shading treatments. Excessive shading would restrict the photosynthesis of *P. sylvestris* var. *sylvestriformis* seedlings. Choosing suitable light conditions was more conducive to the growth of seedlings. Some scholars have confirmed that heavy shading is not suitable for seedling growth (Jiang et al., 2017). Therefore, understanding the response of seedlings to different light environments is of great practical significance for studying the succession and ecological restoration of *P. sylvestris* var. *Sylvestriformis* community.

Photosynthesis is the basis of plant material production. It is not only affected by environmental factors, but also closely related to its own growth and development and physiological and ecological characteristics. The continuous changes in environmental temperature and humidity brought about by the growth of plants and the changing of seasons will inevitably cause the photosynthetic characteristics of plants to change with the changing of seasons and growth phases. Under treatment CK, the light transmittance of 20%, the light transmittance of 40%, and light transmittance of 60%, plant height of *P. sylvestris* var. *sylvestriformis* grew rapidly in the period of June-July, and the seedlings could make good use of light energy. When the light transmittance was 10%, the plant height grew slower than that of other treatments in the period of June-July, and the seedlings could not get enough light energy. However, in the period of July-August, when other treatments showed strong light suppression, the seedlings had enough light energy for photosynthesis under 10% light transmittance.

The net photosynthetic rate (P_n) is the result of the comprehensive effect of plant growth and the external environment, and its size restricts the speed of plant growth (Shang et al., 2020). The higher the P_n, the stronger the adaptability of the plant and the more favorable it is for growth. The intercellular CO_2 concentration (C_i) is an important factor affecting plant photosynthesis, and stomata is an important channel that directly affects the exchange of water vapor and CO_2. Excessive closure of stomata will have certain effect on the transpiration of plants and cause certain effects (Yue et al., 2020). P_n, C_i and the transpiration rate (T_r) were LC> LD> Ck> LB> LA, LC treatment was higher than other treatments, and LA treatment was the lowest. It showed that moderate shading could increase the P_n, C_i, and T_r of plants. When excessive shading, the net photosynthetic rate of *P. sylvestris* var. *sylvestriformis* decreased sharply. In addition, the intercellular CO_2 concentration was low, and the degree of stomata opening restricted the transportation of CO_2, the transpiration rate also decreased (Yue et al., 2020).

In the early growth phase, the internal structure and function development of the leaves were not perfect, the stomata of the leaves were partially closed, G_s was still relatively low. P_n of the leaves changed with the change of C_i. This was a regular reflection of the relationship between the two. At this time, P_n was low. In the peak growth phase, the color of leaves gradually changed from light green to thick green, and the internal structure and function of leaves gradually developed and perfected G_s, T_r and C_i were higher. The resistance of water and CO_2 entering and exiting the stomata and photosynthesis was small, which was conducive to the analysis of photosynthesis (Chen et al., 2015). It was worth noting that path analysis showed that *Tran* and *RH* were important ecological factors affecting photosynthesis at this stage. In later growth phase, the growth of *P. sylvestris* var. *sylvestriformis* was slow or even stagnant, and G_s was still an important physiological factor affecting photosynthesis.

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Conclusion

There were some differences in the growth of *P. sylvestris* var. *sylvestriformis* seedlings under different shading treatments. Plant height, ground diameter, and leaf length were the most direct reflection of seedling growth and seedling quality. *P. sylvestris* var. *sylvestriformis* showed a good growth trend under the shading condition of 40% light transmittance. Under low light intensity, the light was the limiting factor for seedling growth. Under the condition of insufficient light resources, the growth of plant height, ground diameter, and leaf length in the growing season were all inhibited by a light factor, showing the smallest with significant change, whose growth was inhibited.

Excessive shading or full light was not conducive to the growth of *P. sylvestris* var. *sylvestriformis* seedlings. Excessive shading inhibited the normal progress of photosynthesis and reduced the content of photosynthetic products. under full light conditions, although photosynthesis was the strongest, photoinhibition would appear, Inhibiting the normal progress of photosynthesis. The research results showed that P_n, C_i, and T_r were the highest when light transmittance was 40%.

In conclusion, through the study on the growth status of *P. sylvestris* var. *sylvestriformis* under different light conditions, it was found that moderate light environment could promote the growth of *P. sylvestris* var. *sylvestriformis* seedlings. The phenotypic index and photosynthetic physiological and ecological indicators were the highest when the light transmittance was 40%. It was the best light condition for the growth and ecological adaptation of *P. sylvestris* var. *sylvestriformis* seedlings. Through the observation of photosynthetic characteristics in different growth phases, it was found that the growth of *P. sylvestris* var. *sylvestriformis* and their photosynthetic changes overlapped. In different growth phases, the physiological and ecological factors affecting the photosynthesis of *P. sylvestris* var. *sylvestriformis* were different. In the early growth phase from May to June, the photosynthetic rate of *P. sylvestris* var. *sylvestriformis* increased rapidly, C_i was the decisive factor affecting the photosynthetic rate of *P. sylvestris* var. *sylvestriformis* in this phase, and the light transmittance and air relative temperature were the important environmental factors affecting the photosynthetic rate. In the peak growth phase from July to August, *Tran* and *RH* were the important ecological factors affecting photosynthesis in this phase. In the later growth phase from September to October, the photosynthetic rate gradually decreased. Therefore, in the peak and later growth phases, shade conditions could be used to properly adjust the air temperature and humidity to achieve the optimum temperature and humidity range for photosynthesis, increase the photosynthetic rate of the leaves, promote and extend the growth season of *P. sylvestris* var. *sylvestriformis*.

P. sylvestris var. *sylvestriformis* is unique and rare woody plants in Changbai Mountain of China. The limitation of the number of experimental materials has caused many restrictions on the experiment. In the future, under the premise of limited experimental materials, it is necessary to explore the light response of *P. sylvestris* var. *sylvestriformis* from the perspectives of morphology, anatomy and gene expression. In addition, it is more convincing to analyze the specific mechanism of the influence of light environment on *P. sylvestris* var. *sylvestriformis* from the molecular level.

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REFERENCES

[1] Bazzaz, F. A. (1996): Plants in changing environments: linking physiological, population, and community ecology. – Cambridge University Press, Britain.

[2] Bu, J., Zou, C. J., Xu, W. D. (1995): Study on the relationship between growth and development and ecological conditions of *Pinus sylvestriformis*. – Journal of Shenyang Teachers College (Natural Science) 3: 47-51.

[3] Chen, Y., Yu, J., Huang, B. (2015): Effects of elevated CO_2 concentration on water relations and photosynthetic responses to drought stress and recovery during rewatering in Tall Fescue. – J Am Soc Hortic Sic 140: 19-26.

[4] Chen, X. L., Li, L., Huang, Y. S. (2017): The growth laws of *Pinus sylvestris* var. *Sylvestriformis* (Takenouchi) Cheng et C. D. Chu. – Shaanxi Forestry Science and Technology 6: 35-37.

[5] Duan, B. L., Lü, Y. W., Yin, C. Y., Li, C. (2005): Morphological and physiological plasticity of woody plant in response to high light and low light. – Chinese Journal of Applied and Environmental Biology 11(2): 238-245.

[6] Hu, Y. M., Xu, W. D., Zheng, Y. R. (1996): Spatial distribution pattern of natural *Pinus sylvestriformis* population with same age. – Journal of Applied Ecology 7(02): 113-116.

[7] Huang, W. Y., Feng, Z. J. (2020): Effect of light intensity on the growth and photosynthetic characteristics of *Clerodendrum japonicum*. – Forestry and Environmental Science 36(04): 96-101.

[8] Jiang, R. F., Liu, Y. H. (2017): Effects of light intensity on photosynthesis and growth characteristics of *Davidia involucrata* seedlings. – Ecological Science 36(05): 114-120.

[9] Jin, H., Zhao, Y., Zhao, W. et al. (2015): Natural population status and endangered mechanism of *Pinus sylvestriformis* in Changbai Mountain. – Journal of Beihua University (Natural Science) 16(5): 661-665.

[10] Kim, J. H., Lee, H. J., Park, C. M. (2017): HOS1 acts as a key modulator of hypocotyl photomorphogenesis. – Plant Signaling & Behavior 12(5): e1315497.

[11] Liu, J. F., Yang, W. J., Jiang, Z. P., Guo, Q. (2011): Effects of shading on photosynthetic characteristics and chlorophyll fluorescence parameters in leaves of the endangered plant *Thuja sutchuenensis*. – Acta Ecologica Sinica 31(20): 5999-6004.

[12] Rozendaal, D. M. A., Hurtado, V. H., Poorter, L. (2006): Plasticity in leaf traits of 38 tropical tree species in response to light: relationships with light demand and adult stature. – Functional Ecology 20(2): 207-216.

[13] Shang, S. J., Wang, Y. J., Wang, N., Yang, J. L., Xu, S., He, X. Y., Chen, W. (2020): Effects of light intensity on physiological and growth characteristics of *Paeonia suffruticosa* var. *papaveracea*. – Chinese Journal of Ecology 39(9): 2963-2973.

[14] Smith, T., Huston, M. (1989): Atheory of the spatial and temporal dynamics of plant communities. – Vegetatio 83(1/2): 49-69.

[15] Valladares, F., Wright, S. J., Lasso, E., Kitajima, K., Pearcy, R. W. (2000): Plastic phenotypic response to light of 16 congeneric shrubs from a panamanian rainforest. – Ecology 81(7): 1925-1936.

[16] Wang, J. M. (2008): Brief analysis of Korean pine plantation translucent tending. – Journal of Heilongjiang Ecological Engineering Vocational College 21(2): 21-22.

[17] Welander, N. T., Ottosson, B. (1998): The influence of shading on growth and morphology in seedlings of *Quercus robur* L. and *Fagus sylvatica* L. – Forest Ecology and Management 107: 117-126.

[18] Wen, D. Z., Kong, G. H., Lin, Z. F., Ye, W. H. (1999): A comparative study on the growth responses to light intensity in seedlings of four subtropical tree species. – Journal of Tropical and Subtropical Botany 7(2): 125-132.

[19] Yin, H., Zhao, Y., Jin, H., Liu, L. J., Zhang, D. W., Bing, G. P., Wang, C., Meng, Q. J. (2017): The experiment of preventing *Thuja koraiensis* cutting seedling frost heaving

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DOI: http://dx.doi.org/10.15666/aeer/1902_11491162

damage in Changbai mountain. – Journal of Jilin Forestry Science and Technology 46(3): 1-2.
[20] Yue, G. F., Han, Z. Q., Xue, Z. W. et al. (2020): The effect of different shades on the flowering period and photosynthetic characteristics of *peony*. – Jiangsu Agricultural Sciences 48(17): 166-170.
[21] Zhao, S. J., Yan, K. S., Zhang, H. J. et al. (2002): Investigation report on introduction of Pinus sylvestris. – Hebei Forestry Science and Technology 5: 13-14.
[22] Zhao, Y., Jin, H., Yin, H., et al. (2017): Effects of different exogenous hormones on Seed Germination Ability of *Pinus sylvestriformis*. – Journal of Beihua University (Natural Science) 6: 722-726.

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