The Photosynthetic Physiological Responses of Leaves from Different Shoots of Taxus Cuspidata to Elevated CO_2

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Abstract—Net photosynthetic rate (PN), transpiration rate (E), stomatal conductance (Cond), intercellular CO_2 concentration (Ci), and vapor pressure deficit on the surface (VPD) of *Taxus cuspidata* leaves set at a series of CO_2 concentration were investigated with the LI-COR 6400 portable photosynthesis system. For the annual shoot and the biennial shoots and blades, both PN and E increased with the increase in CO_2 concentration, but the increase in PN was larger than that in E. The maximal PN of the annual shoot (6.95 $\mu mol \cdot m^{-2} \cdot s^{-1}$) was larger than that of the biennial shoot (6.87 $\mu mol \cdot m^{-2} \cdot s^{-1}$) at a CO_2 concentration as high as 1400*10-6. E of the annual shoot was slightly larger than the biennial shoot but with no big disparity. Water use efficiency (WUE=PN/E) of the annual and biennial shoots went up with CO_2 concentration. WUE of the annual shoot was slightly higher than the biennial shoot, yet without significant disparity. The significant ascent of PN played a major role in the WUE of *Taxus cuspidata* going up with the elevated CO_2 concentration.

Keywords-Taxus Cuspidata; Annual Shoot; Biennial Shoot; CO_2 Concentration

I. INTRODUCTION

Taxus cuspidata of the family Taxaceae and genus Taxus is the precious relict species from Quaternary Period[1]. It is mainly distributed in the red pine and broad leaved forests of Changbai Mountains and east Liaoning Province at the altitude of 500 ~1,000 meters. Fifty years ago, there were large areas of adult trees, but due to illegal logging for its excellent quality wood it is now even hard to find. It is superior in texture, structure, elasticity, material strength, glossiness, fragrance, and anti-decay, easy to shape, poor cracking and springing, and free from resin. Its sapwood is yellowish white, while the heartwood is dark reddish brown. It has good performance for coloring and painting, thus suitable for making musical instruments, engraving, high quality furniture and artistic decoration. Apart from the plant alkaloid "taxin" [2,3], it also contains the highly toxic essential oil. However, its aril is slightly sweet and edible, whereas gum material can be extracted from its bark, chip, and seeds. The tree has elegant shape, red fruit, and dense green foliage in four seasons, and can be planted in gardens as ornamental trees. Its root, stem, leaves, and bark can be used as medicine, the leaves being diuretic, effective in treating hypertension, diabetes and heart disease[4].

CO_2, water, and photosynthetic radiation serve as not only the basic matter and energy for plant physiological activities, but also the important ecological factors that affect plant growth, development, reproduction and distribution. Studies have shown that different types of shoots of identical or different species express significant differences in response to changes in environmental conditions. This difference is part of the plant's strategies for survival and competition, and significantly affects the plant in resource acquisition, utilization and distribution, and ultimately affects the vegetation composition and succession[5]. Currently, atmospheric CO_2 concentration on Earth has reached 360 μl/L, about 30% higher than before the Industrial Revolution, and is expected to double in the second half of the 21st century. The rise of global atmospheric CO_2 concentration will have a profound impact on the ecosystem, and the possible effects of the change in CO_2 has become a major concern of plant physiological ecologists[6-11].

The paper expounds the findings on the annual and biennial shoots and blades in their different responses to the ambient changes in CO_2 concentration by observing and comparing physiological indices in relation to the elevating CO_2 concentration. Measuring photosynthetic physiology and water physiology of *Taxus cuspidata* will provide basic data for further studies on *Taxus cuspidata* carbon balance and photosynthesis mechanism.

II. Study Area and Methods

A. Study area

The experiment was conducted on June 10, 2005 in the Forestry College of Beihua University, located in the eastern mountain area of Jilin Province. The region has a temperate continental monsoon climate with four distinct seasons. It is rainy and dry in spring, warm and rainy in summer, cool and sunny in autumn, and cold in the long winter. The annual average temperature is 3-5 ℃, extreme annual maximal high 36.6℃, and maximal low -45℃. The frost-free period is up to 130-140d, annual rainfall 650-750mm, sunshine duration 2400-2600h, and annual total radiation 1150k / mm2.

B. Methods

A portable LI-6400 photosynthesis infrared gas analyzer (LI-6400P, LI-COR Inc.) made by LI-COR and LI6400-01 CO_2 Injector were used to measure net photosynthetic rate (PN), transpiration rate (E), stomatal conductance (Cond), intercellular CO_2 concentration (Ci) and foliar saturated vapor pressure deficit (VPD) in the annual and biennial shoots and leaves of *Taxus cuspidata* set at different CO_2 concentration. CO_2 concentration gradient was set to be (50, 100, 200, 400, 600, 800, 1000, 1200, 1400, 1600) $*10^{-6}$. With each change in CO_2 concentration, the minimal stable time was set to be 120s. The variation rate, when measured to be less than 0.05, was to be automatically recorded by an infrared gas analyzer, and repeated three times. *Taxus cuspidata* has finer blades, resulting in relatively big errors in a single blade measurement. A number of blades were to be placed together in the leaf compartment for measurement, graph paper used to measure the accurate leaf area, with measurements entered before the results got analyzed in Excel.

III. Results and Analyses

A. Stomatal conductance

Stomatal serve as the channel for leaf to exchange matter with the air, and the degree of stomatal closure will significantly affect plants' fixed CO_2 transpiration rate and water loss. As ambient CO_2 concentration increased, annual and biennial stomatal conductance (Cond) showed a downward trend, with no significant decline when CO_2 concentration was (50- 800)$*10^{-6}$, and a significant decrease when CO_2 concentration exceeded 800*10-6. Annual shoots' stomatal conductance was slightly larger than biennial shoots (Figure 1). The relationship between stomatal conductance and CO_2 concentration fitted well in a quadratic equation, correlation coefficients being -0.9608 and -0.9665 (Table 1).

B. Intercellular CO_2 concentration

Intercellular CO_2 concentration (Ci) in the annual and biennial blades went up as ambient CO_2 concentration increased. Ci in the annual blade was slightly larger than that in the biennial blade (Figure 2). Both Ci to CO_2 response equations were linear equations, showing a positive correlation, with coefficient of 0.9961 and 0.9957 respectively (Table 1). Experimental results suggested that

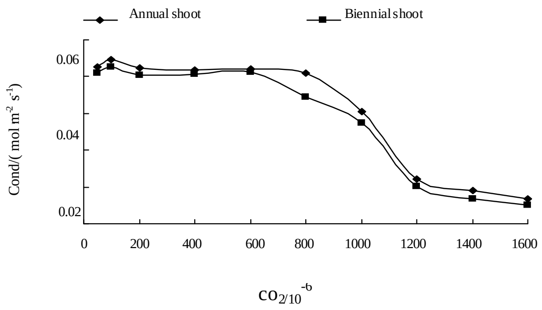

Figure 1. The stomatal conductance responses of leaves from different shoots of *Taxus cuspidata* to elevated CO_2

the impact of ambient CO_2 concentration on Ci was significant, and that partial pressure of atmospheric CO_2 caused CO_2 to enter into the intercellular rate of leaf photosynthetic tissue, thereby affecting the amount and rate of fixed C in plant leaf photosynthesis.

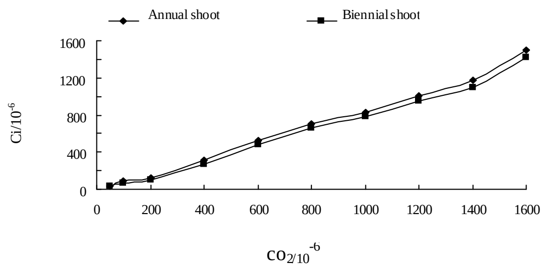

Figure 2. The intercellular CO_2 responses of leaves from different shoots of *Taxus cuspidata* to elevated CO_2

C. Foliar saturated vapor pressure deficit

Foliar saturated vapor pressure deficit (VPD) was affected by the foliar minor environmental changes in water vapor pressure, and was closely related to the transpiration loss of plant foliage. VPD in the annual and biennial foliage showed an upward trend in the initial stage of elevating CO_2 concentration. Both VPD values declined (Figure 3) when CO_2 concentration was more than 1000 μ mol/mol. A feedback mechanism existed among VPD, Cond, and E to regulate foliar transpiration and moisture loss. VPD serves as the driving force resulting in transpiration, and when the water loss exceeds the allowable range, blades limit it by regulating stomatal conductance, so as to achieve the effective use of limited moisture. The relationship between the VPD and CO_2 concentration fitted well in a quadratic equation, correlation coefficients being 0.9706 and 0.9617 respectively (Table 1).

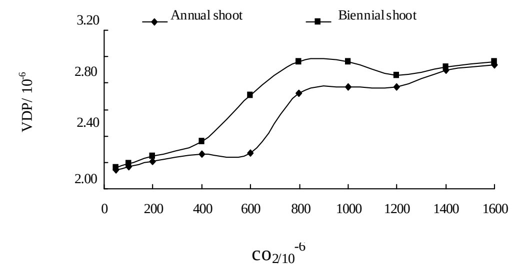

Figure 3. The VPD responses of leaves from different shoots of *Taxus cuspidata* to elevated CO_2

D. Responses of transpiration rate and net hotosynthetic rate to the changes in CO_2 concentration

(1) Transpiration rate

Transpiration rate (E) in the annual and biennial shoots and blades of *Taxus cuspidata* gradually increased with the increase of CO_2 concentration in the leaf compartment, and within the range of measurement of CO_2 concentration, E of the annual shoots was slightly larger than the biennial ones (Figure 4). When CO_2 concentration increased from 50μmol/mol to 1600μmol/mol, E of the annual shoots rose from 1.31 mol m^{-2} s^{-1} to 1.94 mol m^{-2} s^{-1}, 0.63 mol m^{-2} s^{-1} up. E of the biennial shoots rose from 1.24 mol m^{-2} s^{-1} to 1.92 mol m^{-2} s^{-1}, 0.68 mol m^{-2} s^{-1} up. Both response equations to the elevating CO_2 concentration were logarithmic equations, correlation coefficients being 0.9715 and 0.9758 respectively (Table 1).

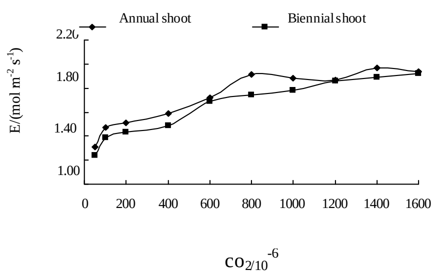

Figure 4. The transpiration rate responses of leaves from different shoots of *Taxus cuspidata* to elevated CO2

(2)Net photosynthetic rate

CO_2 is one of the important raw materials for photosynthesis, and the atmospheric CO_2 concentration will significantly affect net photosynthetic rate of plant leaves (PN). As the CO_2 concentration increased, PN in the annual and biennial shoots showed an upward trend (Figure 5). Both response curves to the elevating CO_2 concentration were logarithmic curves, correlation coefficients being 0.9709 and 0.9758 respectively (Table 1). PN average of the annual shoots at the given CO_2 concentration was 5.553 μmol·m^{-2} s^{-1}; PN average of the biennial shoots was 5.072 μ mol • m^{-2} • s^{-1}. As can be seen, PN of the annual shoots was larger than that of the biennial ones, showing the two kinds of shoots differ in physiological function.

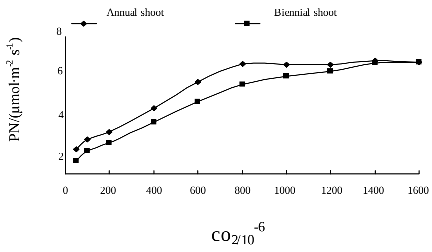

Figure 5. The net photosynthetic rate responses of leaves from different shoots of *Taxus cuspidata* to elevated CO_2

E. Instantaneous water use efficiency

Water use efficiency (WUE) in both annual and biennial shoots and blades of *Taxus cuspidata* increased with the increase of CO_2 concentration (Figure 6). Both response equations to the elevating CO_2 concentration were logarithmic curve equations, correlation coefficients being 0.9543 and 0.9787 respectively (Table 1). WUE was determined by the ratio of PN and E. Thus, the changes of PN and E were to affect WUE. Experimental results showed that although PN of the annual shoots and blades was more than that of the biennial ones, transpiration consumption was equally enormous, resulting in WUE average in the annual shoots and blades being slightly higher than the biennial ones, with no significant difference.

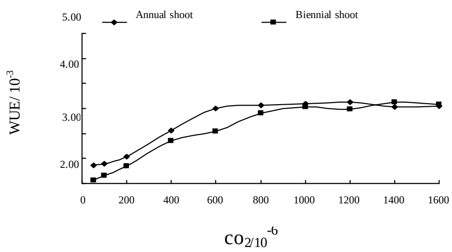

Figure 6. The water use efficiency responses of leaves from different shoots of *Taxus cuspidata* to elevated CO2

IV. CONCLUSION AND DISCUSSION

The results of this experiment showed that the photosynthetic indexes in the annual *Taxus cuspidata* shoots were slightly larger than the biennial ones, and the growth of annual shoots were significantly greater than biennial ones. Net photosynthetic rate (PN), transpiration rate (E), intercellular CO_2 concentration (Ci) and foliar saturated vapor pressure deficit (VPD) of the two types of shoots and blades showed a positive correlation with CO_2 concentration, while stomatal conductance (Cond) showed a negative correlation with CO_2 concentration. However, as there was no much difference, so the impact of elevating CO_2 concentration on the two types of shoots was not big.

Many studies have concluded that as the ambient CO_2 concentration increases CO_2 can enter the mesophyll cells more easily. To reduce the loss of the limited water, plant leaves usually close pores to some extent, lowering Cond to reduce E[12]. This study showed that the average E in the two types of shoots rose, and that under the condition of high CO_2concentration the reduction of Cond did not lead to lower E. This may be the result of the impact of larger VPD as VPD is the driving force[13] for water to evaporate from the leaf into the air.

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TABLE I RESPONSE EQUATIONS OF PHYSIOLOGICAL PARAMETERS OF ANNUAL AND BIENNIAL SHOOTS OF *TAXUS CUSPIDATA* TO THE ELEVATING CO_2 CONCENTRATION

Shoot type	**Y**	**X**	**Equations**	**R**
Annual shoots	Cond /(mol m-2 s-1）	CO_2	y = -2E-08x2 + 5E-06x + 0.0637	R = -0.9608
Biennial shoot	Cond /(mol m-2 s-1）	CO_2	y = -2E-08x2 + 7E-07x + 0.0625	R = -0.9665
Annual shoots	Ci(10-6)	CO_2	y = 0.8982x - 31.783	R = 0.9961
Biennial shoot	Ci(10-6)	CO_2	y = 0.8558x - 44.141	R = 0.9957
Annual shoots	VPD(10-6)	CO_2	y = -5E-07x2+ 0.0014x + 2.0328	R = 0.9706
Biennial shoot	VPD(10-6)	CO_2	y = -8E-08x2+ 0.0007x + 2.0685	R = 0.9617
Annual shoots	E(H2O)/ (mol m-2 s-1)	CO_2	y = 0.1905Ln(x) + 0.5453	R = 0.9715
Biennial shoot	E(H2O)/ (mol m-2 s-1)	CO_2	y = 0.196Ln(x) + 0.4376	R = 0.9758
Annual shoots	PN(CO2)/ (μmol·m-2 s-1)	CO_2	y = 1.2852Ln(x) - 2.3522	R = 0.9709
Biennial shoot	PN(CO2)/ (μmol·m-2 s-1)	CO_2	y = 1.363Ln(x) - 3.3119	R = 0.9758
Annual shoots	WUE/ (10-3)	CO_2	y = 0.433Ln(x) + 0.5092	R = 0.9543
Biennial shoot	WUE/ (10-3)	CO_2	y = 0.508Ln(x) - 0.1157	R = 0.9787