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Effects of Light Environment on Growth and Chlorophyll Contents of *Pinus strobus* Seedlings

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광 환경이 스트로브잣나무 묘목의 생장과 엽록소 함량에 미치는 영향

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ABSTARCT

This study was conducted to investigate seasonal changes on height, root collar diameter, shoot growth, biomass and chlorophyll contents of *Pinus strobus* seedlings (two-year old) grown under different light environments in Sangju National University Nursery. Four shade treatments provided seedlings with full sunlight (1800 μmol m^{-2} s^{-1}), 75% of full sunlight (1350 μmol m^{-2} s^{-1}), 50% of full sunlight (900 μmol m^{-2} s^{-1}) and 25% of full sunlight (450 μmol m^{-2} s^{-1}). Planting density in four light intensities was 30 cm ×30 cm. In each treatment, 10 trees were planted and height, diameter at root collar, shoot growth, biomass and chlorophyll contents (chlorophyll *a*, *b* and *a*+ *b*) were measured. The highest height, root collar diameter, shoot growth and biomass in *Pinus strobus* seedlings were observed at full sunlight. Specially, root biomass was the most sensitive tree components part and strongly associated with decreases in the total biomass under low light intensity. The lowest chlorophyll contents (Chlorophyll *a*, *b* and *a*+ *b*) were shown at 25% of sunlight, the lowest light intensity in this study.

Key words*: light intensity, biomass, chlorophyll contents, *Pinus strobus

I. INTRODUCTION

Individual trees in the forest have effected various environments such as different light intensities, temperature, nutrients and water relations (Ashton *et al.*, 1999; Kimmins, 1999). Growth of trees has been represented by interaction of these environmental and genetic characteristics. Many studies have shown that different light intensities in the forest change chlorophyll contents and net photosynthesis in many coniferous and broad-leaf tree species, and the changes of these physiological parameters have attributed to changes in growth such as height, diameter and leaf production (Lei and Lechowicz, 1998; Reich *et al.*, 1998; Groninger *et al.*, 1996; Davis *et al.*, 1987; Bjorkman and Holmgren, 1963; 1966).

Chlorophyll content in the leaf is a sensitive indicator of photosynthetic energy conversion. Thus, it is one of the important tree features and functions in any effort to understand shading effects on tree growth because it is positively related to photosynthetic ability in trees. The role of chlorophyll content in mesophyll tissues has been described by many researchers (Jin *et al.*, 2000; Mohammed *et al.*, 1995; Grimm and Fuhrer 1992; Woo and Lee, 1992; Gutschick, 1988).

Pine is the largest and most important timber-producing family of the gymnosperms. It mostly distributed through the northern hemisphere from the forests of the tropics to the northern limits of tree growth beyond the Arctic circle. Although of primary importance in the production of timber, the

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wood of most pines is also suitable for pulp and paper manufacture (Yim, 1997).

Pinus strobus (eastern white pine) introduced species in Korea is probably one of the well-known species in Korea. *Pinus strobus* is intermediate in tolerance, more tolerant than such species as birch, aspen, red pine and jack pine, but less so than sugar maple (Harlow *et al.*, 1996). Even though *Pinus strobus* has been widely introduced, less is known about the ecological characteristics to various environmental factors in Korea. Due to the importance of this species in Korea, the number of nursery has been increased. Especially, the large mountain fire had burned approximately 23,000 ha mountain area and killed most trees in Kang-won province in 2000. So, large numbers of seedling are needed for this area to recover.

Thus, much interest is being expanded in an attempt to produce the *Pinus strobus* seedlings in nursery. If the best environmental conditions especially light intensity were identified, large amount of cost and effort will be saved because of easy control and manipulation of these factors. For instance, a study on the optimum light intensity of *Pinus densiflora* was carried out to identify the best light condition in the nursery for producing pine seedlings (Kim *et al.*, 1998).

Therefore, the objective of this study was to investigate the seasonal changes of chlorophyll contents and growth of *Pinus strobus* seedlings grown under different light intensities.

II. MATERIALS AND METHODS

2.1. Experimental design

The seedlings were produced by Forest Research Institute in Kwang-nung Chungbu Experiment Station Nursery and transplanted into Sangju National University nursery on March, 1999. The planting density in four light intensities was 30 cm×30 cm in every light treatment. The average height and diameter at root collar have been shown Table 1. Four different light intensities (1800 μmol m^{-2} s^{-1}, 1350 μmol m^{-2} s^{-1}, 900 μmol m^{-2} s^{-1}, 450 μmol m^{-2} s^{-1}) were treated to the *Pinus strobus* seedlings by using nylon net (Table 1).

2.2. Chlorophyll contents

Intact leaf was collected at every measuring time. Chlorophyll was extracted with 80% aceton for 7 days at 4°C and its absorbance were measured using spectrophotometer (UV/Visible Diode Array, Walden Precision Apparatus Ltd., UK) at wave lengths of 663 and 645 nm. Chlorophyll contents (chlorophyll *a,* chlorophyll *b* and total chlorophyll were determined by using Arnon's equation (Arnon, 1949).

$$\text{Chlorophyll } a\ (\mu g/ml) = 12.7\ A_{663} - 2.59A_{645}$$
$$\text{Chlorophyll } b\ (\mu g/ml) = 22.9\ A_{645} - 4.67A_{663}$$
$$\text{Chlorophyll } a + b\ (\mu g/ml) = 8.05\ A_{663} + 20.29A_{645}$$

2.3. Growth measurement

Height and diameter at root collar were measured on every month and averaged for all measurements of every treatment replicate. At the end of the growing season, trees were harvested and removed from soil, the roots were washed, separated into root, stem and leaves, then oven-dried to constant weight in an oven at 80°C and weighted.

III. RESULTS AND DISCUSSION

3.1. Meteorological conditions of the Sangju city

Climatic data at Sangju city obtained temperature and rainfall (Table 2). Among these climatic data, temperature and rainfall are considered to important factors on tree growth. Mean temperature for growing season ranged from 15 to 23°C. Rainfall ranged from 50 to 350 mm during growing season.

Table 1. Condition of *Pinus strobus* and light treatment in this study

Species	Age	N	Height (cm)	Diameter at root collar (mm)	Light treatments	Light intensity (μmol m^{-2} s^{-1})
Pinus strobes	1-1	10	13.2 ± 2.9*	6.5 ± 1.1*	A (Control; Sun light)	1800
					B (75% of A)	1350
					C (50% of A)	900
					D (25% of A)	450

*standard deviation

Table 2. Meteorological conditions of the Sangju city in 1999

Month	Mean Temperature (°C)	Rainfall (mm)
April	14.3	100.8
May	18.1	128.4
June	19.8	224.4
July	22.9	351.8
August	23.1	316.1
September	19.9	246.2
October	14.8	45.8

(Korean Meteorological Administration, 2000)

Table 3. Soil characteristics of the experimental nursery

Characters	Sangju nursery
pH (H_2O)	6.1
Total N (%)	0.42
P (ppm)	27.0
Al (%)	1.3
CEC (me/100 g)	5.32

(Woo et al., 2000)

3.2. Soil characteristics of the experimental nursery

Table 3 showed the nursery soil characteristics such as pH, organic matter, total Nitrogen, phosphorous, Aluminum concentration and cation exchange capacity. These soil characteristics of the study area were cited from Woo *et al.* (2000).

3.3.Height, diameter at root collar, shoot growth and biomass

Variations of height growth of *Pinus strobus* seedlings for each light intensities are illustrated in Fig. 1. The height growth in full sunlight showed the largest amount while the least growth was observed at the 25% of the sunlight.

However, *Pinus strobus* seedlings have still being proceeded to adaptation in the nursery environment. These seedlings were transplanted in just last year. The seedling height on June 1999 showed little change in every shading treatment except sunlight.

In addition, *Pinus strobus* height may be formed by fixed growth (Kozlowski and Pallardy, 1997). In this study, no changes in height growth of this species have been shown after major flushing (Fig. 1). Mature trees of red pine as well as spruce, fir, beech, green ash and some maple follow this growth pattern (Kozlowski and Pallardy, 1997).

Diameter growth at root collar showed similar trend with height growth changes (Fig. 2). In other words, diameter growth at root collar of *Pinus strobus* seedlings increased with increasing the sunlight on July of this year.

However, diameter growth at root collar showed gradual increase during winter in every light treatment contrast to no changes on height growth after major flushing. *Pinus strobus* is one of the coniferous tree species and has the green leaf during winter. Photosynthesis continuously produces carbohydrates during winter season and allocated the production mainly to diameter at root collar or root growth. It is well known, this species is reactivated to produce xylem inwardly and phloem outwardly during winter season (Kozlowski and Pallardy, 1997; Gretchen and Pearcy, 1994).

Shoot growth from apical meristem in the full sunlight showed greatest growth performance (Fig. 3). Shoot growth also showed similar trend with height and diameter at root collar changes (Fig. 1 and 2).

Biomass production in the full sunlight showed greatest value in total biomass among the four different light intensities (Fig. 4). Probably, height, diameter growth at root collar and shoot growth were correlated with reduction in total biomass

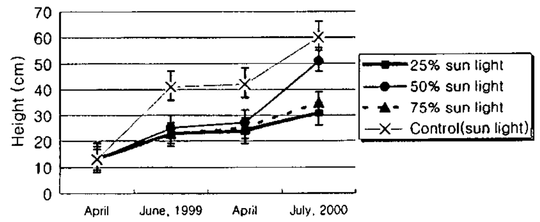

Fig. 1. Height growth changes of *Pinus strobus* seedlings under four different light intensities. Bars indicate standard deviation (n = 10).

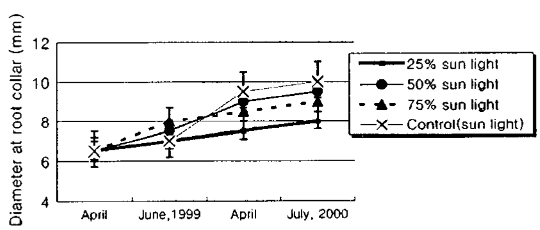

Fig. 2. Root collar diameter growth changes of *Pinus strobus* seedlings under four different light intensities. Bars indicate standard deviation (n = 10).

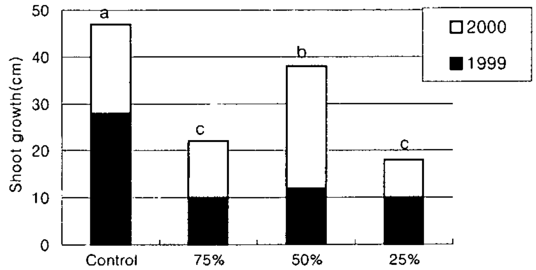

Fig. 3. Shoot growth of *Pinus strobus* seedlings under four different light intensities. Different letters were statistically different at the 5% significant level (n = 10).

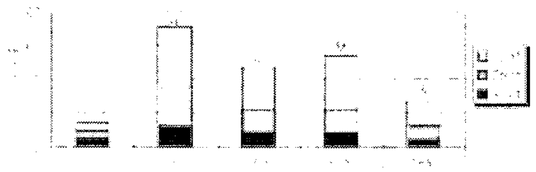

Fig. 4. Biomass changes of *Pinus strobus* seedlings under four different light intensities. Different letters were statistically different at the 5% significant level (n = 10).

under shading treatments.

Among the tree component parts, root biomass was strongly associated with decreases in the total biomass under shading treatments. For trees large reduction in root biomass had responding large reduction in total biomass. The trees of 25% sunlight had largest reduction in root and total biomass (Fig 4).

Reduction of root biomass in trees is typical response to aboveground stress such as too little light, herbivore and air pollution (Mooney and Winner, 1991). Reducing the root biomass is one of the response patterns associated with a physiological adjustment to unfavorable environment such as little light stress.

In the case of shading stress, the impact of shading on foliage function and shoot loss is compensated by an increased carbon investment in the shoot and an associated decrease in the root system (Winner, 1994). As mentioned previously, the trees grown in full sunlight showed higher biomass production than those of other light intensities. As a possible explanation for this result, shading treatment reduces photosynthetic capacity and other physiological functions, thus reducing carbon assimilation (Walters and Reich, 1996).

Not only is carbon production reduced, but also carbon allocation is altered with increasing carbon being allocated to decreasing carbon to the roots. The reduced translocation of assimilates to the root system appears to be disruption of carbon partitioning after shading treatment. The lower photosynthetic capacity in shading treatment may have reduced the ability of nutrient and water uptakes from the root(Gorrisen *et al.*, 1991; Smeulders *et al.*, 1995).

3.4. Chlorophyll contents

Chlorophyll a, b and total contents showed in Table 4, 5 and 6, respectively. In general, chlorophyll contents in April is lower than those of June or July (Table 4, 5 and 6). In other words, chlorophyll contents had been increased with increasing Julian days under most of the light regions.

In this study, chlorophyll contents of the full sunlight were generally higher than those of shading treatments, even though the other chlorophyll contents in 25%, 50% and 75% light intensities is not clearly different (Table 4, 5 and 6). This result is similar to that reported by Woo *et al.* (1999) who observed that the amount of chlorophyll in unshaded condition was greater than in shade condition for *Abies holophylla.* This results suggest that the num-

Table 4. Chlorophyll *a* (mg/g dry weight) changes of *Pinus strobus* seedlings under four different light intensities. Different letters at the each treatment were statistically different at the 5% significant level (n=10)

Light intensity	1999		2000	
	April	June	April	July
25% sun light	0.8a	2b	0.9a	2.8b
50% sun light	0.7a	2b	0.4a	2.9b
75% sun light	0.8a	1.8b	0.5a	2.7b
Control (full sun light)	0.6a	2.3b	0.8a	3b

Table 5. Chlorophyll *b* changes(mg/g dry weight) of *Pinus strobus* seedlings under four different light intensities. Different letters were statistically different at the 5% significant level (n=10)

Light intensity	1999		2000	
	April	June	April	June
25% sun light	0.8a	2.1b	0.5a	2.7b
50% sun light	0.8a	2.1b	0.6a	2.9b
75% sun light	0.8a	2.2b	0.5a	2.7b
Control (full sun light)	0.8a	2.1b	0.7a	3.2b

Table 6. Chlorophyll a + b(mg/g dry weight) changes of *Pinus strobus* seedlings under four different light intensities. Different letters were statistically different at the 5% significant level (n=10)

Light intensity	1999		2000	
	April	June	April	June
25% sun light	1.6a	4.1b	1.4a	5.5b
50% sun light	1.5a	4.1b	1.0a	5.8b
75% sun light	1.6a	4.0b	1.0a	5.4b
Control (full sun light)	1.4a	4.4b	1.5a	6.2b

ber of palisade tissue increases with increasing light intensity and in turn, it increases the thickness of mesophyll contents (Kozlowski and Pallardy, 1997; Woo and Lee, 1992).

Several shading studies have suggested that shading treatments reduced chlorophyll contents of many tree species. *Betula pendula, B. pubescens* (Nygren and Kellomaki, 1984) and *Quercus accutissima* (Woo and Lee, 1992) showed reductions in chlorophyll contents in response to shading treatments. All of these species also showed gradual decline in photosynthesis during shading periods paralleling a gradual decline in both chlorophyll a and b.

Chlorophyll contents is a sensitive indicator of photosynthetic capacity of trees under various environments (Grimm and Fuhrer, 1992). It is well known that higher chlorophyll content may help to maintain high photosynthesis rates for shaded trees (Kudson *et al.*, 1977; Grimm and Fuhrer, 1992).

In summary, all size measurements, namely height, diameter at root collar, shoot length and biomass of *Pinus strobus* seedlings were the highest in the full sunlight treatment, and were generally the lowest in the 25% of full sunlight treatment. Especially, root biomass was the most sensitive tree components part and strongly associated with decreases in the total biomass under shading treatments. The lowest chlorophyll contents (Chlorophyll a, b and total) were observed at 25% of full sunlight, most heavy shading treatment in this study. Even though every growth parameter of *Pinus strobus* seedlings increased with increasing the sunlight, long experiment period is needed to identify the shading effects on the growth and chlorophyll contents. Because some results in 75% and 50% of full sunlight are a wide array of responses.

In addition, photosynthesis and several physiological functions such as palisade mesophyll layer and epidermal layer thickness have to be investigated in near future because photosynthesis and chlorophyll contents were strongly related to tree growth with long periods.

IV. CONCLUSION

In conclusion, the greatest height, diameter at root collar, shoot length and biomass in *Pinus strobus* seedlings were shown in full sunlight. Especially, root biomass was the most sensitive tree components part and strongly associated with decreases in the total biomass under shading treatments. The lowest chlorophyll contents (Chlorophyll a, b and total) were observed at 25% of sunlight, heavy shading treatment in this study.

요 약

스트로브잣나무(*Pinus strobus*)가 광환경에 따라서 생장량과 엽록소함량이 어떻게 변화하는가를 관찰하기 위해서 스트로브잣나무 1-1묘목을 대상으로 실험하였다. 광도는 피음막으로 자연광 상태(1800 μmol m^{-2} s^{-1}), 자연광의 75% 광도(1350 μmol m^{-2} s^{-1}), 자연광의 50% 광도(900 μmol m^{-2} s^{-1}), 자연광의 25% 광도(450 μmol m^{-2} s^{-1})의 4가지로 조절하였다. 이들 묘목을 각각 상주대학교 묘포장에 30 cm× 30 cm 간격으로 식재하여 10개체씩 수확하여 수고, 근원경, 신초, 물질생산량 및 엽록소 함량을 비교하였다.

수고, 근원경, 신초, 물질 생산량은 광도가 높은 실험구에서 공통적으로 가장 좋았다. 특히 물질생산량 가운데 뿌리부분이 광도가 낮아질수록 가장 민감하게 줄어들었다. 엽록소함량(a, b 그리고 a + b)은 공통적으로 광도가 가장 낮은 실험구인 25%의 광도에서 제일 낮은 값을 보였다.

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REFERENCES

Arnon, D. I., 1949: Copper enzymes in isolated chloroplasts, polyphenol-oxidase in *Betula vulgaris*. *Plant*

Physiol. **24**, 1-15.

Ashton, P.M.S., H.S. Lee, R. Thadani and G.P. Berlyn, 1999: Seedlings leaf structure of New England Maples (*Acer*) in relation to light environment. *Forest Sci.* **45**, 512-519.

Bjorkman, O. and P. Holmgren, 1963: Adaptibility of the photosynthetic apparatus to light intensity in ecotypes from exposed and shaded habitats, *Physiol. Plant.* **16**, 889-914.

Bjorkman, O. and P. Holmgren, 1966: Photosynthetic adaptation to light in plants native to shaded and exposed habitats. *Physiol. Plant.* **19**, 854-859.

Davis, J. E., T. J. Arkebauer, and J. M. Norman, 1987: Rapid field measurement of the assimilation rate versus internal CO_2 concentration relationship in green ash (*Fraxinus pennsylvanica* Marsh.): the influence of light intensity. *Tree Physiol.* **3**, 387-392.

Gorissen, A., N.N. Joosten and A.E. Janssen, 1991: Effects of ozone and ammonium sulfate on carbon partitioning to mycorrhizal roots of juvenile Douglas fir. *New Phytologist.* **119**, 243-250.

Gretchen, F. S. and R. W. Pearcy, 1994: Regulation of photosynthetic induction state by the magnitude and duration of low light exposure, *Plants Physiol.* **105**, 1115-1123.

Grimm, A. G. and J. Fuhrer, 1992: The response of spring wheat (*Triticum aestivum* L.) to ozone at higher elevations. III. Response of leaf and canopy gas exchange and chlorophyll fluorescence to ozone flux, *New Phytologist.* **122**, 321-328.

Groninger, J. W., J.W. Seiler, J.A. Perterson and P.B. Reich, 1996: Growth and hotosynthetic responses of four Virginia Piedment tree species to shade. *Tree Physiol.* **16**, 773-778.

Gutschick, V. P, 1988: Optimization of specific leaf mass, internal CO_2 concentration and chlorophyll content in crop canopies. *Plants Physiol.* **26**, 525-537.

Harlow, W.M., E.S. Harrar, J.W. Hardin and F.M. White, 1996: Textbook of Dendrology. McGraw-Hill Inc. New-York p99-101.

Jin, H. O., E.Y. Kim and C. H. Lee, 2000: Effects of Simulated Acid Rain on the Growth, Nutrient Status of Korean pine (*Pinus koraiensis*) Seedlings and Soil Acidification. *J. of Kor. For. Soc.* **89**, 422-430.

Kim, J.J., S.K. Hong and H.P. Hong, 1998: Studies on the optimum photoperiod and light intensity during extended photoperiod of containerized seedlings of *Pinus densiflora, Larix leptolepis* and *Betula platyphylla. J. of Forest Sci.* **58**, 135-145.

Kimmins, J. P., 1999: Forest Ecology, Macmillan Publishing Company New York 596pp.

Korean Meteorological Administration, 2000: http://www.kma.go.kr/

Kozlowski, T. T. and S. G. Pallardy, 1997: Physiology of Woody Plants (2nd Eds.), Academic Press, London, 411pp.

Kudson, L. L., T. W. Tibbitts and G. E. Edwards, 1977: Measurement of ozone injury by determination of leaf chlorophyll concentration. *Plant Physiol.* **60**, 606-608.

Lei, T.T. and M. J. Lechowicz,1998: Diverse responses of maple saplings to forest light regimes. *Ann. Bot.* **82**, 9-19.

Mohammed, G. H., W. D. Binder and S. L. Gillies, 1995: Chlorophyll fluorescence: A review of its practical forestry applications and instrumentation. *Scan. J. For. Res.* **10**, 383-410.

Mooney, H. A., W. E. Winner, 1991: Partitioning responses of plants to ozone stress. In: Mooney, H. A., W. E. Winner, E. J. Pell (Eds.) Response of plants to multiple stresses. New-York Academic press. p129-141.

Nygren, M. and S. Kellomaki, 1984: Effects of shading on leaf structure and photosynthesis in young Birches, *Betula pendula* Roth. and *B. pubescens* Ehrn., *Forest Ecol. and Manag.* **7**, 119-132.

Reich, P.B., M.G. Tjoelker, M.B. Walters, D.W. Vanderklein and C. Buschena, 1998: Close association of RGR, leaf and root morphology, seed mass and shade tolerance in seedlings of nine boreal tree species grown in high and low light. *Func. Ecol.* **12**, 327-338.

Smeulders, S.M., A Gorissen, N.N. Joosten, 1995: Effects of short term ozone exposure on the carbon economy of mature and juvenile Douglas-fir (*Pseudotsuga menziessi* (Mirb.) Franco). *New Phytologist.* **129**, 45-53.

Walters, M.B. and P.B. Reich, 1996: Are shade tolerance, survival and growth linked to low light and nitrogen effects on hardwood seedlings. *Eclo.* **77**, 841-853.

Winner, W. E., 1994: Mechanistic analysis of plant responses to air pollution. *Ecol. Applic.* **4**, 651-661.

Woo, S. Y., D. S. Lee and O. K. Kwon, 1999: Shading effects on growth and chlorophyll contents of *Abies holophylla. Korean J. of Agricultural and Forest Meteorology* **1**, 97-102.

Woo, S. Y., D. K. Kim and D. S. Lee, 2000: Effects of Air Pollution on Physiological Characteristics of *Styrax japonica* in Yeochon Industrial Complex. *J. of society of Korean atmospheric environment* **16**, 121-128.

Woo, S. Y. and D. K. Lee, 1992: Effects of different light intensities and nutrition conditions on photosynthesis and ribulose diphosphate carboxylase activity of *Quercus accutissima* Carr, seedlings. *J. of Korean For. Soc.* **81**, 11-20.

Yim K. B, 1997: Principle of Silviculture. Seoul. Hwangmunsa. 330pp.