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A Trial to Accelerate Afforestation of Korean Pine Forests Using a Strip-cutting Method for Deciduous Broad-leaved Secondary Forests in Northeastern China

—An ecophysiological approach—

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Abstract

A strip-cutting method with three different cutting widths (4m, 6m and 8m) was used to try to find an effective means for accelerating the afforestation of Korean pine forests in northeastern China. Generally, growth of planted Korean pines in the 6m treatment plots was significantly larger than that of the 4m and 8m treatment plots. Photosynthetic characteristics were also studied for Korean pines planted in different strip-cutting and control belts and deciduous broad-leaved trees invaded to the belts. The results showed that Korean pines acclimated to the specific microenvironment by way of ecophysiological traits, such as plasticity of needle size, and photosynthetic responses to light. These results may imply that Korean pines in control belts could utilize low PPFD more efficiently than their counterparts in the strip-cutting belts. Net photosynthetic rate and related capacity of daily carbon gain were regulated by stomatal conductance. High PPFD in the 8-m-wide strip-cutting belts induced high leaf temperature and high vapor pressure deficit, which might cause midday depression and consequent lower capacity of daily carbon gain. Comparison of photosynthetic traits between Korean pine and invaded deciduous species showed that the former had a stronger ability to efficiently utilize lower PPFD, whereas deciduous species acclimated to higher PPFD with a higher light compensation point, light saturation point and higher maximum photosynthetic rate, indicating that Korean pines may be able to harvest PPFD efficiently in low light regimes, which seems to be one reason why young Korean pines can survive under slightly shady forest floor. However, width of strip-cutting belts would affect the growth of Korean pines. Wide strip-cutting belts (e.g. 8m) usually resulted in a photosynthetic midday depression caused by stomatal closure, whereas, narrow strip-cutting belts (e.g. 4m) could not greatly improve the light condition. Based on the present results, the optimal candidate width of strip-cutting belts may be 6m treatment in this forest.

Key words: strip-cutting method, Korean pine (*Pinus koraiensis* Sieb. et Zucc), daily carbon gain, vapor pressure deficit, photosynthetic light response curve

Introduction

Mixed broad-leaved and conifer forests dominated by Korean pine are climax vegetation types in northeastern China (Li, J. W. 1993, Zhou 1994). This kind of forest is famous for its production of high-quality timber and its high biomass productivity (Li *et al.* 1981, Zhao 1994, Wang 1994). Korean pine forests have several functions, such as maintaining biodiversity (Li *et al.* 1993, Zhang 1999), its hydrological functions for decreasing surface water flow and mitigating floods (Wang *et al.* 1985) as well as the considerable commercial value of seeds for food and medicine (Zhang *et al.* 1990, Li and Löfgren 2000). However, except for some natural reserves, such as Fenglin Natural Reserve and Liang Shui Natural Reserve (Fig.1), the trees in almost all of the natural Korean pine forests in northeastern China have been cut down for timber production (Wang and Lin 1994). Thus, the re-establishment of Korean pine forests has become a critical issue for forestry scientists and environmental scientists.

Many forestry scientists have been studying ways to reforest this type of forest ecosystem in order to achieve the goal of recovery of originally mixed Korean pine and broad-leaved forests in northeastern China. With initiative study from the research group of Chinese National Seven-Five Key Project (1985-1990), a strip-cutting method, which is a popular way for improving the natural regeneration for fear that even-aged forests are formed (Smith 1986), was applied to plant seedlings of Korean pine in a secondary oak forest. In this study site, it has

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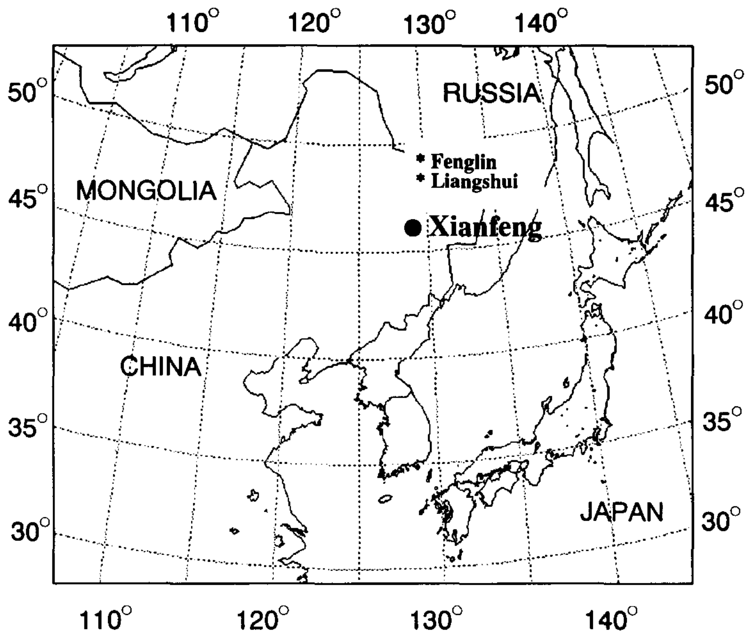

Fig. 1. Location of the study site.
The black dot shows the study site in the Xianfeng Forest Farm of Yilan County. The stars show the natural reserves where original Korean pine forest existed now

been found that the use of the strip-cutting method leads to an increase in the biomass productivity of oak trees (Nie *et al.* 1990), by improving light conditions and tree growth rate (Ding *et al.* 1990, Nie *et al.* 1990), improving soil nutrition (Shi *et al.* 1990a,b) and promoting biodiversity (Zhang 1999). Therefore, systematic study of the current-used strip-cutting method has become increasingly important for its further application to rehabilitate mixed Korean pine and deciduous broad-leaved forest ecosystems in northeastern China.

However, most of previous studies conducted in the present study site paid little attention to the study of Korean pine, especially ecophysiological aspects of growth and improvement in productivity, although there have been studying analysis of age structure (Li, J.W. 1994, Li, R.X. *et al.* 1994), biomass and energy cycle (Zhao 1994, Li, J.Q. *et al.* 1994, Wang 1994), growth model of a Korean pine forest (Li and Löfgren 2000) as well as cold and drought capacity of Korean pine seedlings (Yan *et al.* 1999, Li, J. *et al.* 2000). However, for assessment of the regeneration success of Korean pines in a secondary forest, there are only limited data on photosynthetic characteristics of Korean pines in natural conditions, especially on the characteristics of long-term acclimation to different light regimes (Wang 2000). There is also only limited information on the growth improvement of Korean pines in different strip-cutting treatment plots, especially from the viewpoints of photosynthetic production and growth activity.

Therefore, we selected a young plantation of Korean pine that had been planted in the study site (14-year-old as of 1998) (Wang 2000) to investigate the ability to acclimate to a microenvironment, capacity of carbon gain and growth activity under different light regimes of strip-cutting and control belts. We firstly compared photosynthetic light response curves, chlorophyll contents and stomatal behaviors of Korean pine seedlings planted in different treatment plots. Then, photosynthetic light curves of invaded deciduous trees were compared with those of Korean pine to evaluate the ability of interspecific competition for harvesting light resources in the different light regimes. Moreover, the effects of the width of strip-cutting method as well as the factors affecting growth of Korean pines planted on three belts were examined. Finally, based on the present results, we proposed the optimal candidate width for the belt to be used in the strip-cutting method for recovery of Korean pine forests in northeast China.

Materials and Methods

Climatic conditions

The study site is located in the Xianfeng Forestry Farm of Yilan County, Heilongjiang Province. The geographical coordinates of Yilan County are 45 52’N-46 03’N and 129 28’E-129 45’E (Fig. 1). This region, which is mainly hilly terrain, is a part of Mt. Zhangguangcai. The mean altitude is 300-400 m a. s. l. The mean gradient of the slope is 15 -20 . The soil is characterized by typical dark brown soil originated from granite substrates. This region is characterized by small precipitation and short growing period. Namely, spring and autumn are usually short, summer is hot and humid, and winter is

Table 1. Species composition of the secondary forest in the study site.

	Tree species	Shrub species	Herbaceous species
Species composition	*Acer mono, Betula platyphylla, Fraxinus mandshurica, Quercus mongolica, Phellodendron amurense, Pinus koraiensis,* Populus davidiana, Tilia amurensis, Ulmus macrocarpa*	*Actinidia kolomikta, Coryus mandshurica, Lespedeza bicolor, Rubus sachalinensis, Ribes mandshurica, Schizandra chinensis, Vitis amurensis*	*Anemone amurensis, Aquilegia oxysepala, Carex spp., Cimicifuga dahurica, Filipendula palmate, Glechoma hederacea, Hemerocallis mino,Lamium album, Lathyrus humilis Paris verticillata, Ranunculus spp., Smilacina davurica, Vicia baicalensis Veratrum dahuricum, Vicia unijuga*

* Planted species.

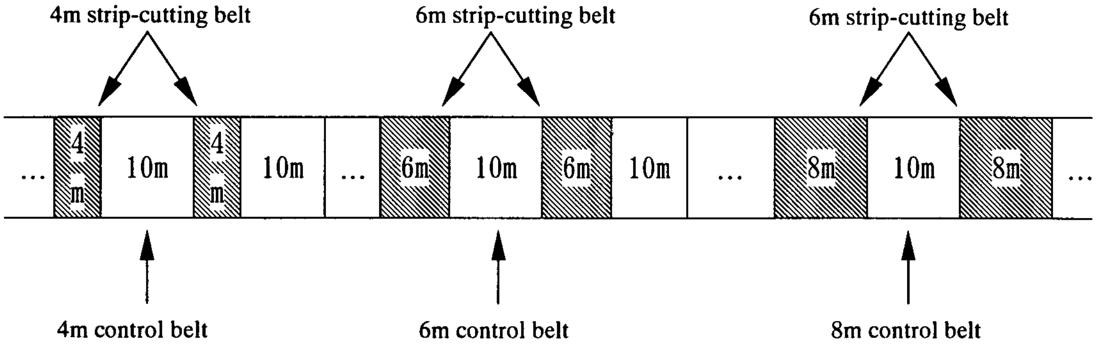

Fig. 2. Schematic representation of the arrangement of strip-cutting belts in the study site. Shaded areas and blank areas show the strip-cutting and control belts, respectively. Three dots in the figure indicate several replicates of different treatments. Vertical length of the research sites ranged between 150m and 200m.

Table 2. Growth characteristics of canopy dominant species i.e.(Oak)

Data in the parenthesis are the standard deviation.

Treatments	H(m)	DBH(cm)	Canopy size	
			N-S(m)	W-E(m)
4m control	15.1(1.7)	21.1(7.9)	4.3(2.4)	4.2(0.9)
6m control	18.2(3.3)	23.1(8.4)	4.3(1.4)	4.1(1.0)
8m control	18.2(3.2)	22.3(5.4)	4.6(1.4)	4.71(1.2)

long and cold. Annual precipitation mainly concentrated in summer season is 540-580mm. The mean annual temperature is about 3 C, and the annual cumulative temperature (≧10 C) is 2400-2500 C. The frost-free period is about 130-140 days.

Study site

The study site was located in a mixed oak and Korean pine forest, about 4 km in east direction from the base of the Xianfeng Forest Farm. Invaded deciduous broad-leaved trees, shrub and herbaceous species were shown in Table 1. Photosynthetic capacity of oak, basswood, poplar and elm was also studied. In 1986, 2-year-old Korean pine seedlings were planted on a south-facing slope in the study site by the strip-cutting method (Fig. 2) for improving the forest productivity (Nie, S. Q. *et al.* 1990) (Photo. 1,2). Percentage of canopy coverage was about 60% until the year of 1999. Gradient of the slope is about 10 degree.

The strip-cutting belts were made for 4m, 6m and 8m in width. Two, three and four rows of Korean pines were planted in each strip-cutting belt, respectively. Between each two strip-cutting belts, there are 10 m belts serving as control belts (Fig. 2). Korean pines were planted with the same density (3300/ha) in both control and strip-cutting belts. The

Photo 1. A view of strip-cutting belts in late autumn of 1986 just after logs had been sawed.

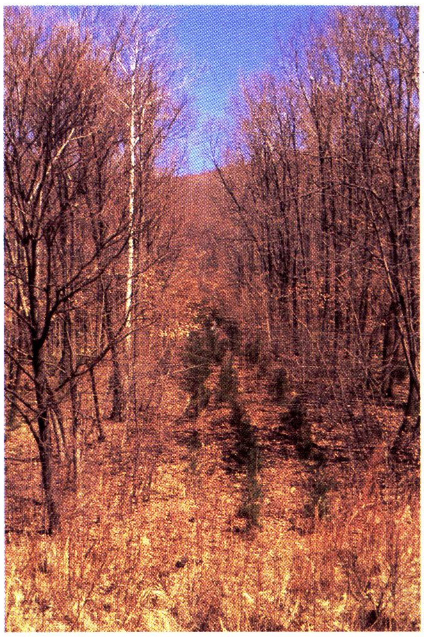

Photo 2. Seedlings of Korean pines planted in strip-cutting belts in the autumn of 1987.

relative light flux for 4, 6 and 8m strip-cutting belts was about 25%, 35% and 75% of light flux in the open sites (ca. 1500 ìmol.m^{-2}s^{-1}), respectively. However, the relative light flux for 4, 6 and 8m control sites were about 10%, 16% and 30%, respectively. The vertical distance of strip-cutting belts was at the range of 150-200 meters from the hill foot to hill ridge. In this paper, we call the strip-cutting belts as 4m, 6m, and 8m strip-cutting belts, respectively. However, just for easy description in this paper, we arbitrarily call the control belts close to each strip-cutting belt as 4m, 6m and 8m control belts, respectively, although the width of all control belts are actually 10m in width (Fig. 2). The replication of each treatment was 5 times.

Plant materials

Fourteen-year-old Korean pine (*Pinus koraiensis* Sieb. et Zucc; as of 1998) trees, planted in different strip-cutting treatments, were studied in 1998 and 1999. Some invaded deciduous species, such as *Quercus mongolica*, *Juglans mandshurica*, *Fraxinus mandshurica* in the cutting belts and *Phellodendron amurense*, and *Alnus sibirica*, *Larix gmelinii* grown in the edge of forest were selected for evaluating the ability of interspecific competition for light harvesting. These deciduous trees were about 12-20 years old. More than 3 individuals were used for each species as replications. Oak (*Quercus mongolica*) tree was the main canopy species. Alder (*Alnus sibirica*) and larch (*Larix gmelinii*) was survived at the edge of forest under slightly shady condition.

Table 2 lists the growth of canopy oak in different treatment plots. Height and DBH of oak tree was 15-18m and 21-23cm, respectively. Canopy size (Diameters from north to south and west to east, measurement was done by projection of the branch.) was around 4m in average. Tree height was measured by a Karl Leiss hypsometer (Changchun, China).

Measurements of growth of Korean pine seedlings

Tree height, canopy size and basal diameter of 43 to 116 saplings were measured to evaluate the growth of Korean pines in different treatment plots (see Appendix Table). Canopy size was approximately calculated from the area formula of a sphere,

$$S=\pi R^2, \tag{1}$$

where S (m^2) is the canopy size and R (m) is the average radius of the canopy, which was calculated from the widths in north-south and east-west directions.

Leaf area was measured using a LI-3000A Portable Area Meter (LiCor, Inc., Lincoln, NE., USA) in combination with a LI-3050A (Transparent Belt Conveyer Accessory). Ten standard trees were selected on the basis of mean values of tree height; basal diameter and canopy size in each treatment plot according all the material trees. Then, 5 branches of average size were selected to measure the leaf area. Total leaf area per tree was scaled up by integration of the number of standard branches per tree and leaf area per standard branch. Original data are shown in Appendix 4.

Net photosynthesis measurements and analysis

All the photosynthetic light curves of Korean pine and broad-leaved species were measured in August because leaf number per shoot was stable and needle maturation. The diurnal courses of net photosynthetic rate (P_n) and photosynthetic photon flux density (PPFD) were measured using a LI-6400 system (LiCor, Inc., Lincoln, NE., USA). Vapor pressure deficit from leaf to air (Vpdl), leaf temperature (T_{leaf}), and stomatal conductance for water (g_s) were concurrently measured using the LI-6400 portable photosynthesis system. Photosynthetic light curves were determined from morning to noon with setting points of 2000, 1500, 1000, 800, 400, 200, 100, 80, 30, 15 and 0 ìmol. $m^{-2}s^{-1}$ PPFD. A LED light source (LiCor, Inc., Lincoln, NE., USA) was used to supplement PPFD. All measurements were conducted under ambient temperature of ca. 28 ℃ and CO_2 concentration of around 360 ppm. Current-year needles (about 80 days old) in south-facing branches were selected in each treatment plot for the photosynthesis measurements. Measurements were conducted on more than 3 individuals in each treatment plot

For measuring the diurnal courses of Korean pine, P_n and PPFD were measured at 8:00, 10:00, 12:00, 14:00 and 17:00 and ambient temperature and natural light flux was used in this measurement. Diurnal courses of P_n of Korean pines planted in different treatment plots were concurrently measured in one day. Moreover, 3 typical sunny days in August of 1998 were selected for the measurements.

Tamiya's equation (Tamiya 1951) was used to evaluate the characteristics of photosynthetic light curve;

$$A=\frac{bI}{(1+aI)}-R, \qquad (2)$$

where A (μ mol. $m^{-2}s^{-1}$) and I (μ mol. $m^{-2}s^{-1}$) are the net photosynthesis rate and PPFD, respectively. R (μ mol. $m^{-2}s^{-1}$) is the dark respiration rate, *b* is the initial slope of photosynthetic light curves, and *a* is the reciprocal value of PPFD at half asymptotic rate of gross photosynthetic rate.

Other parameters derived from Tamiya's equation are,

$$I_c=\frac{R}{b-aR} \qquad (3),$$

$$\text{and } I_s=\frac{0.95A\max+R}{b-a(0.95A\max+R)} \qquad (4)$$

where I_c (μ mol. $m^{-2}s^{-1}$) and I_s (μ mol. $m^{-2}s^{-1}$) are the light compensation point and light saturation point, respectively and A_{max} is the maximum photosynthetic rate under the condition of full sunlight. The light saturation point was assumed to be the PPFD value when P_n reaches 95% of A_{max} of equation (4).

Daily carbon gain (A_{daily}) was calculated by the following equation:

$$A_{daily}=\int_{t1}^{t2}1.2\times10^{-5}Adt, \qquad (5)$$

where t_1 is the time when diurnal course measurements were started and t_2 is the time when the measurements were finished. The constant value of 1.2×10^{-5} is the conversion factor of unit exchange from micromoles of CO_2 to grams of carbon. A (μ mol.$m^{-2}s^{-1}$) is the actual P_n measured at each time point. A_{daily} (g C. $m^{-2}day^{-1}$) is assumed to be the capacity of daily carbon gain per one day per unit leaf area.

Chlorophyll a and b determination

After photosynthesis measurements, foliage samples were obtained for the determination of chlorophyll content. Arnon's method was used to determine chlorophyll contents of foliage samples (Arnon 1949). Chlorophyll contents were calculated using the following equations;

$$C_a=12.7{*}D_{663}-2.69{*}D_{645} \qquad (6)$$

$$C_b=22.9{*}D_{645}-4.68{*}D_{663}, \qquad (7)$$

where C_a and C_b (mg, g FW^{-1}) are the contents of chlorophyll a and b, respectively. D_{663} and D_{645} are the optical density (OD) values measured by a UV-visible spectrophotometer (Pharmacia LKB. Biochrom 4060, Sweden). More than three replicates were used to determine the chlorophyll content. Original data of chlorophyll b and chlorophyll a+b are showed in Appendix 3. Finally, Porra's methods (1991) was used to convert Arnon's chlorophyll value to the more precise values of chlorophyll a+b and Chl. b content (see Appendix 2).

Best-fit regression was conducted by Microcal Origin 5.0 (Microcal software Inc., USA). All figures were drew by Microsoft Excel 2000 and Kyplot (Free software, Koichi Yoshioka, Japan). Analysis of statistical difference was performed by the Kyplot for multiple comparison and Microcal Origin 5.0 for t-Test.

Results

Growth of Korean pines

In the 4m and 6m treatment plots, relative higher values of canopy size, tree height and basal diameter in the strip-cutting belts were generally observed (Fig. 3) although some of the differences cannot up to statistical significant, such as canopy size and tree height in 4m treatment (Fig. 3). However, in the 8m treatment plot, relative lower values of canopy size, tree height and basal diameter were observed in the strip-cutting belt and the differences were generally marked (Turkey-test, $p<0.05$). In case of 4m, 6m and 8m control belts, mean values of canopy size, tree height and basal diameter were larger in the wider strips, i.e. 8m control >6m control> 4m control and some of these differences were statistically marked (Turkey-test, $p<0.05$) (Fig. 3). However, in case of the three types of strip-cutting belts, peak value usually appeared in the 6m strip-cutting belts, which was significantly higher than did in 4m and 8m strip-cutting belts (Turkey- test, $p<0.05$) (Fig. 3).

Leaf characteristics of Korean pines

The values of leaf area per tree in the three control belts and three strip-cutting belts showed that trees in the strip-cutting belts usually had a larger quantity of leaves for intercepting the PPFD than did in the corresponding control belts with the exception of trees in the 8m strip-cutting and control belts (Fig. 4). Statistical test showed that leaf area of Korean pines in the 6m strip-cutting belts were significantly larger than all others (Turkey-test, $p<0.05$). However, Korean pines in the 8m strip-cutting belts tended to produce low amount of leaf, which had no marked differences between 4m and 8m control sites (Turkey-test, $p>0.05$) (Fig. 4). Mean values of chlorophyll b and chlorophyll a+b contents of Korean pine trees planted in the control belts were slightly higher than those of Korean pine trees planted in the strip-cutting belts, however, statistical analysis showed that no marked differences between the 4m strip-cutting and control belts, 6m strip-cutting and control belts (Turkey-test, $p>0.05$). In case of 8m treatment plot, the difference between strip-cutting and control belts was statistically significant (Turkey-test, $p<0.05$) (Fig. 4).

Photosynthetic light curves of Korean pine

All the data of photosynthetic light curves were obtained from 9:00 am to 12:00 am. There were no obvious differences between the photosynthetic light curves of trees grown in different treatment plots, and also no significant differences between the values of A_{max} (Fig. 5A) (ANOVA, $p>0.05$). The *b* value was generally lower in control belts; however, no statistical difference was observed between each strip-cutting belts and its control belts (ANOVA, $p>0.05$) (Fig. 5B). Higher I_c values in mean were observed in the strip-cutting belts than that in the control belts although statistical analysis showed no

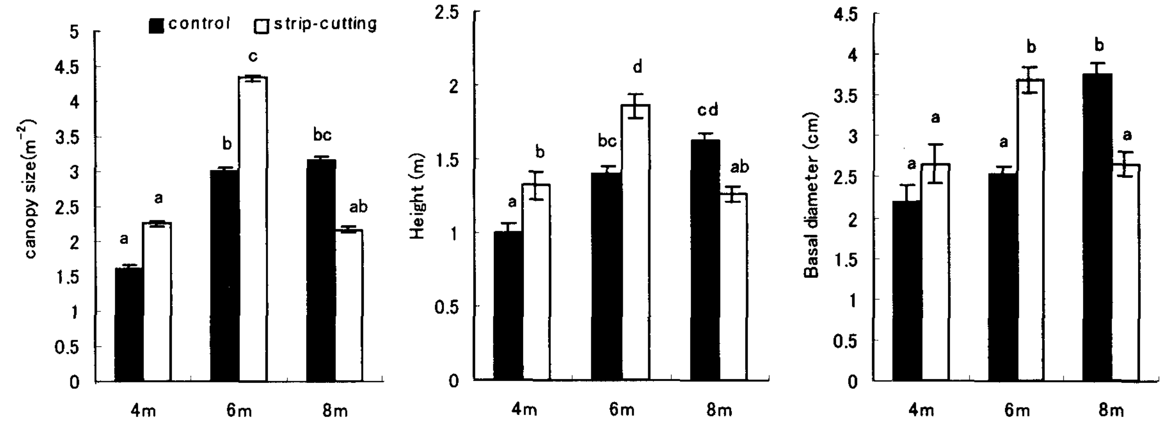

Fig. 3. Growth characteristics of Korean pines in different treatment plots a through canopy size, basal diameter and tree height. Solid and open bars show the control and strip-cutting belts, respectively. Vertical bars show S. E. of the mean values. Different alphabets above the bars indicate statistical difference ($p<0.05$) and same alphabet indicate no statistical difference.

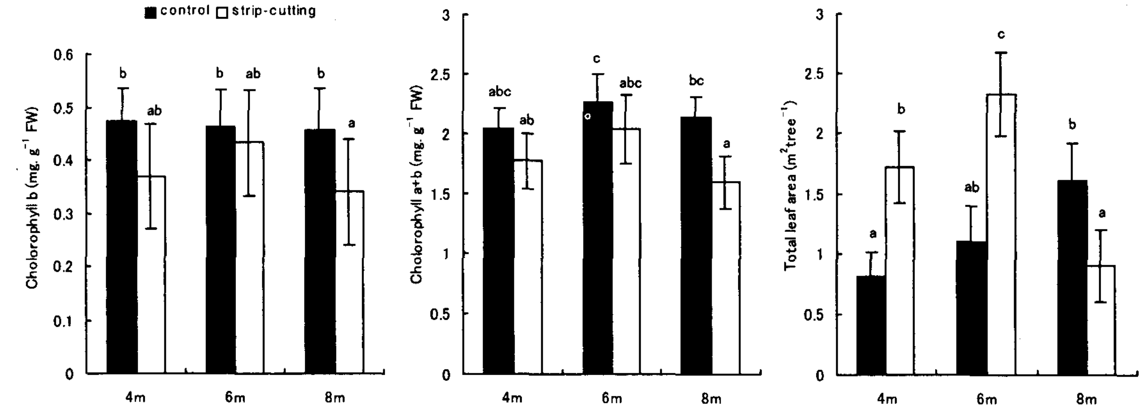

Fig. 4. Leaf characteristics of Korean pines in different treatment plots, Mamely Chlorophyll b, Chlorophyll a+b, and total leaf area per one tree. Vertical bars show S. E. of the mean values. Different alphabets above the bars indicate statistical difference ($p<0.05$) and same alphabet indicate no statistical difference.

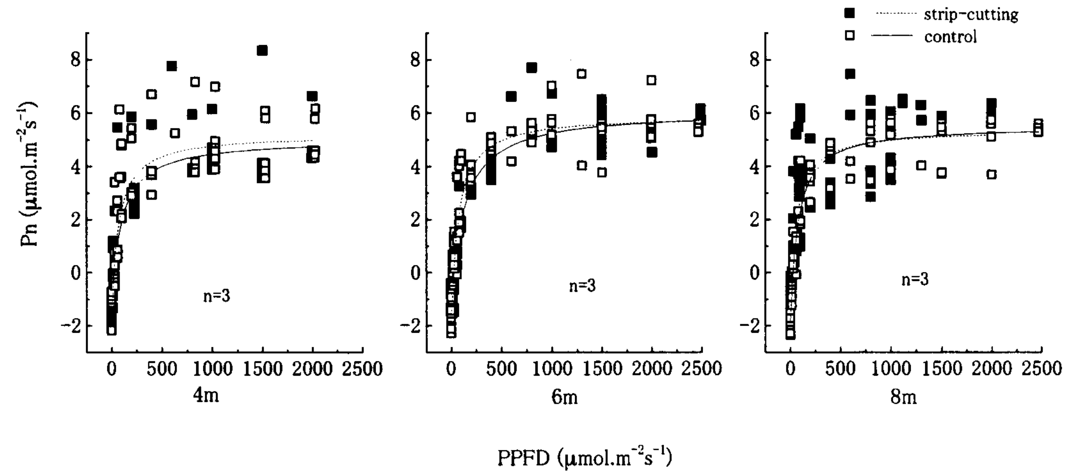

Fig. 5A. Photosynthetic light response curves of the Korean pines in different treatment plots.

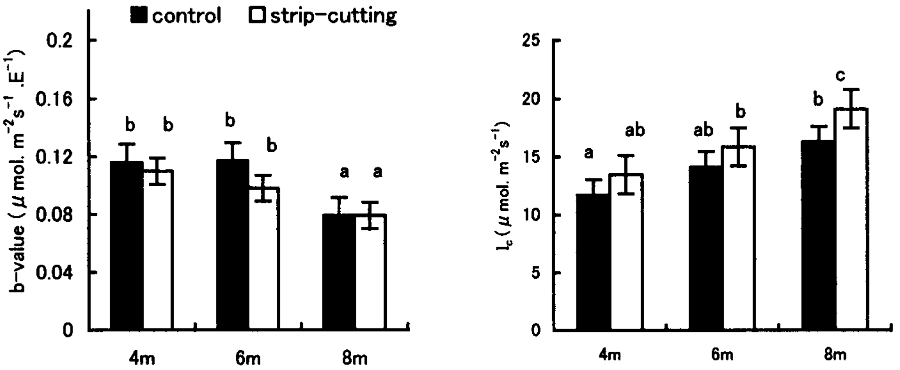

Fig. 5B. Parameters of light photosynthesis curves, initial slope of the curves and light compensation point (Ic).

marked differences (Turkey-test, $p>0.05$) (Fig. 5B). Furthermore, lower *b* value and higher I_c value were found in the 8m treatment plot (Turkey-test, $p<0.05$) (Fig. 5B). Generally, the I_c of Korean pine was lower than 20 ìmol. $m^{-2}s^{-1}$, and its mean value was about 15 ìmol. $m^{-2}s^{-1}$.

Diurnal courses of photosynthesis of Korean pines

Maximum PPFD in the study site, which was observed in the 8m strip-cutting belts, was about 1100 ìmol.$m^{-2}s^{-1}$. However, the highest value in control belts, which was observed in the 8m control belts, was about 500 ìmol.$m^{-2}s^{-1}$ (Fig. 6). The diurnal courses of P_n and simultaneously measured PPFD, which were actually obtained from 8:00 am to 17:00 pm, were closely correlated ($R^2=0.71$, t-Test, $p<0.05$), except for the trees in the 8m strip-cutting belts ($R^2=0.01$, t-Test, $p>0.05$) (Fig. 6). Midday depression in P_n was observed in the 8m strip-cutting belts and the value of P_n reached only about one third of the daily maximum value, whereas midday depression was seldom observed in other treatment plots during the measurement period. The values of A_{daily} showed that trees in the control belts generally had a lower value of daily carbon gain than did trees in the strip-cutting belts with the exception of trees grown in the 8m treatment plot (Fig. 7). The highest value of daily carbon gain was observed in the 6m strip-cutting belts (ca. 1.6 g C. $m^{-2}day^{-1}$). However, in the control belts, the highest value was observed in the 8m control belts (ca. 1.5 g C. $m^{-2}day^{-1}$) (Fig. 7). Statistical test showed that the 6m strip-cutting belts and 8m control belts were significantly higher than all other treatments (Turkey-test, $p<0.05$). However, no statistical differences between 4m treatment, 6m control and 8m strip-cutting belts were found (Fig. 7).

Stomatal regulation in photosynthetic capacities of Korean pines

All the data collected from the different control and strip-cutting belts were used to analyze the relationship between T_{leaf} and Vpdl and their effects on P_n. The results showed that Vpdl increased exponentially with increases in T_{leaf} (Fig. 8). The highest value of g_s was observed at low temperature and low Vpdl, while g_s decreased rapidly with increases in T_{leaf} and Vpdl (Fig. 9).

Leaves were able to utilize PPFD more efficiently with an increase in g_s. However, when g_s was large enough, P_n became maximum (Fig. 10). Our results showed that when the value of g_s was larger than 0.07 mol.$m^{-2}s^{-1}$, resistance of stomata only gave a small

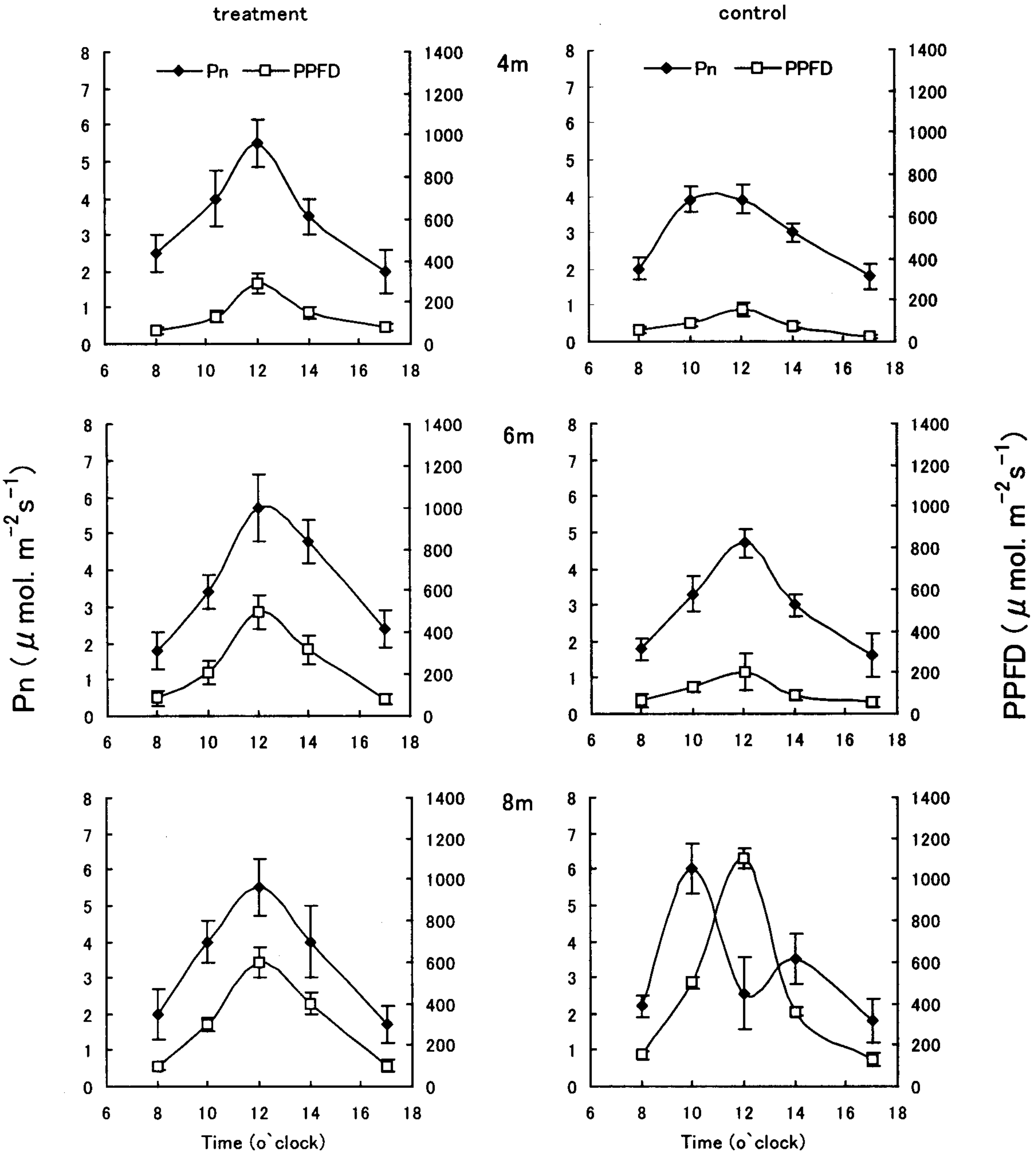

Fig. 6. Diurnal courses of leaf P_n and PPFD in different treatment plots. Closed diamonds show P_n and open squares show PPFD. Vertical bars show S. Es. of the mean values. Time is Beijing time (East 8 time zone).

constraint on the value of P_n of Korean pines. Conversely, resistance of stomata could considerably down-regulate P_n (Fig. 10). For example, when the value of g_s increased from 0.03 mol.m^{-2}s^{-1} to 0.07 mol. m^{-2}s^{-1} at saturated PPFD, P_n increased to a value 3.5-times higher than that at g_s of 0.03 mol.m^{-2}s^{-1}. However, no marked increase in P_n was observed when the value of g_s increased from 0.07 mol.m^{-2}s^{-1} to 0.11 mol.m^{-2}s^{-1}. Generally, g_s was larger in the morning than in the afternoon both in the control belts and strip-cutting belts. In the 4m and 6m control and strip-cutting belts, the value of g_s was usually larger than 0.07 mol.m^{-2}s^{-1} except in the late afternoon. However, in the 8m strip-cutting belts, the value of g_s sharply decreased from 0.11 mol.m^{-2}s^{-1} at 10:00 am to less than 0.07 mol. m^{-2}s^{-1} at around noon (Fig. 11), which remained at a low value throughout the whole afternoon. Stomatal closure was thought to have a strong negative influence on midday depression of P_n in the 8m belts because 0.07 mol. m^{-2}s^{-1} was considered to be the critical value for severe stomatal limitation on photosynthesis (Fig. 6).

Photosynthetic light curves of deciduous broad-leaved trees

Generally, mean value of I_c of invaded deciduous

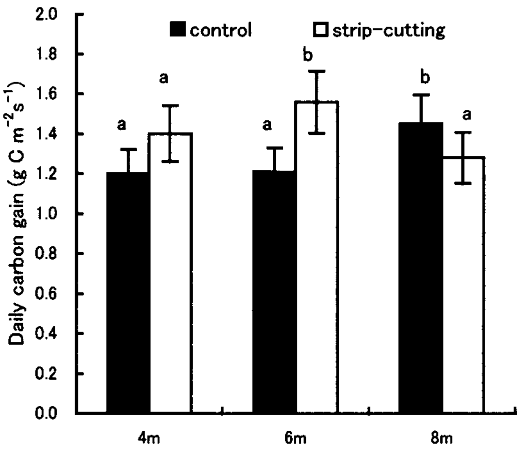

Fig. 7. Capacities of daily carbon gain in different treatment plots. Closed bars are data from control belts, and open bars are data from strip-cutting belts. Vertical bars show S. E. of the mean values. Different alphabets above the bars indicate statistical difference ($p<0.05$) and same alphabet indicate no statistical difference.

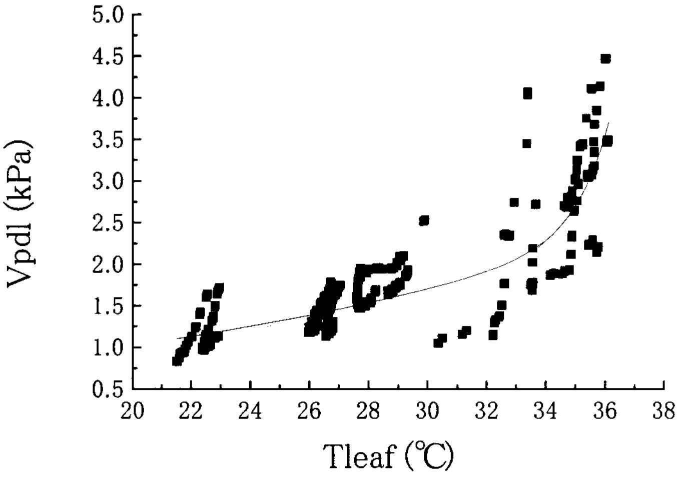

Fig. 8. Relationship between leaf temperature (Tleaf) and vapor pressure deficit (Vpdl). The data were collected from all treatment plots (PPFD>200μmol. $m^{-2}s^{-1}$).

broadleaved trees was higher than that of Korean pines and some of the differences were significant (Turkey-test, $p<0.05$) (Fig. 13). Almost all the A_{max} values of deciduous species were significantly higher than that of Korean pines exclude of *Alnus sibirica* and *Fraxinus mandshurica* (Turkey-test, $p<0.05$) (Fig. 12,13). Moreover, the light saturation point (I_s) of deciduous trees was generally higher than that of Korean pines. For example, the I_s value of *Juglans mandshurica* was 4.3-times higher than that of Korean pines, while the lowest value in *Alnus sibirica* was still 1.2-times higher than that of Korean pines (Fig. 13). Similar to that of A_{max}, in case of I_s, statistical test showed that almost all of the measured species exclude *Alnus sibirica* and *Fraxinus mandshurica* were markedly lower than that of deciduous species (Turkey-test, $p<0.05$) (Fig. 13).

Discussion

Photosynthetic acclimation capacities of Korean pines and possible explanations for the growth differences

Both chlorophyll b and chlorophyll a+b contents were generally higher in trees growing in the control belts than in trees growing in the strip-cutting belts even though marked difference only existed in the 8m treatment plot (Turkey-test, $p<0.05$) (Fig. 3). Similarly, b values were higher in trees growing in the control belts and no statistical differences were observed; however, Korean pine in the 8m treatment was significant lower than others (Turkey-test, $p<0.05$) (Fig. 5B). Moreover, I_c values in mean were higher in trees growing in the strip-cutting belts and I_c values in the 8m strip-cutting belts were significant higher than others (Fig. 5B). These results may suggest that Korean pine growing in the control belts

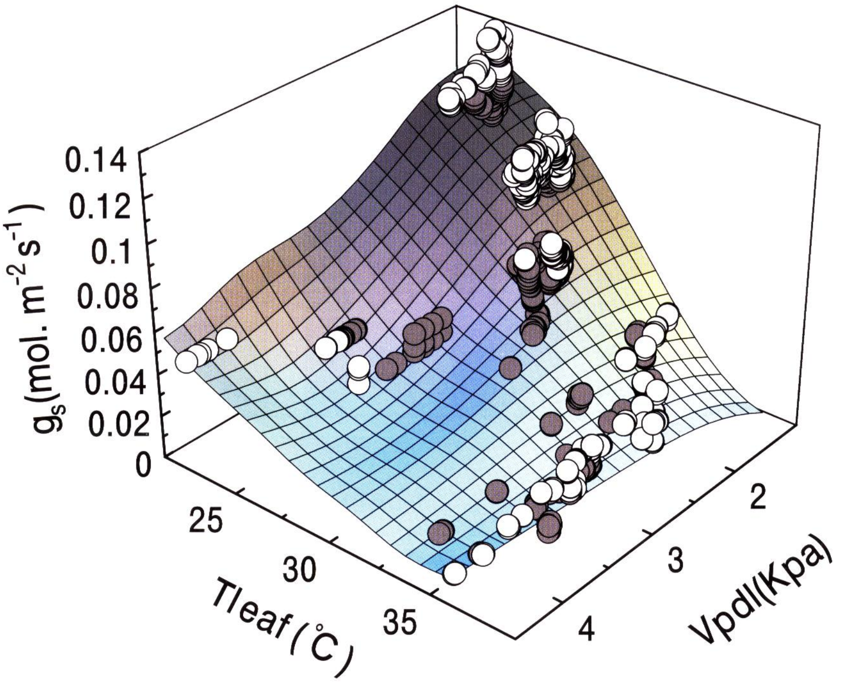

Fig. 9. Relationships between leaf temperature (T_{leaf}), vapor pressure deficit (Vpdl) and stomatal conductance (g_s). The data were collected from all treatment plots. White cycles are the data above the best-fit surface, and black ones are the data under the surface (PPFD>200µmol. m^{-2}s^{-1}).

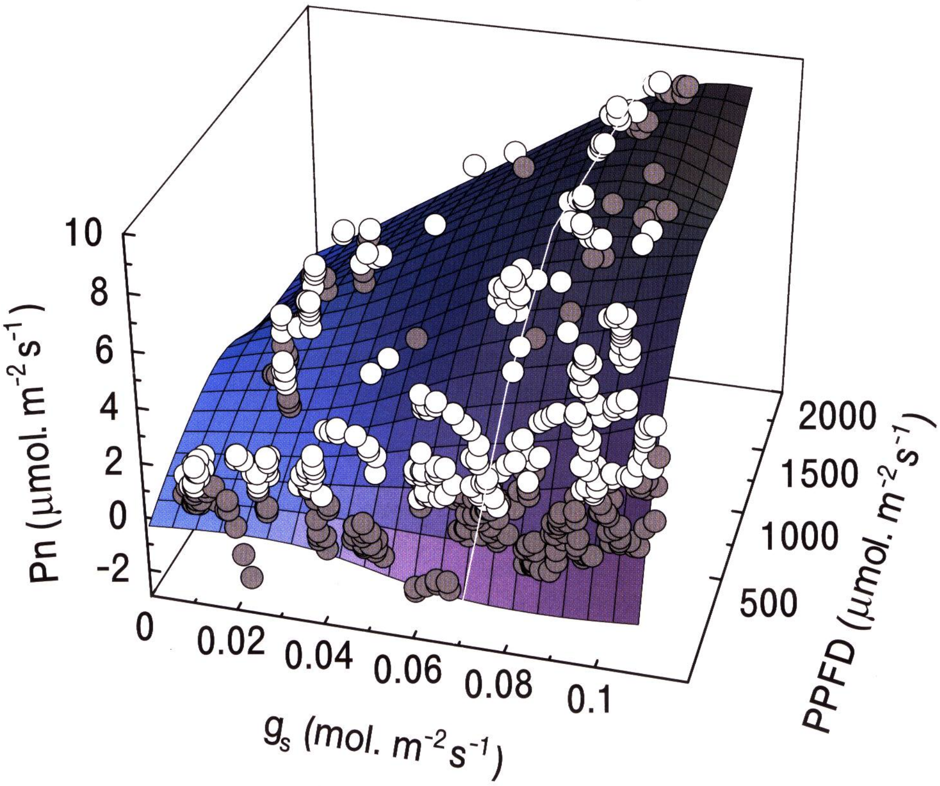

Fig. 10. Relationships between PPFD, g_s and P_n of Korean pine. Data were collected from all treatment plots. White cycles are data above the best-fit surface, and black ones are data under the surface. The dotted white line shows the assumed critical value of stomatal conductance (0.07mmol. m^{-2}s^{-1}) for severely limiting photosynthesis rate of Korean pine.

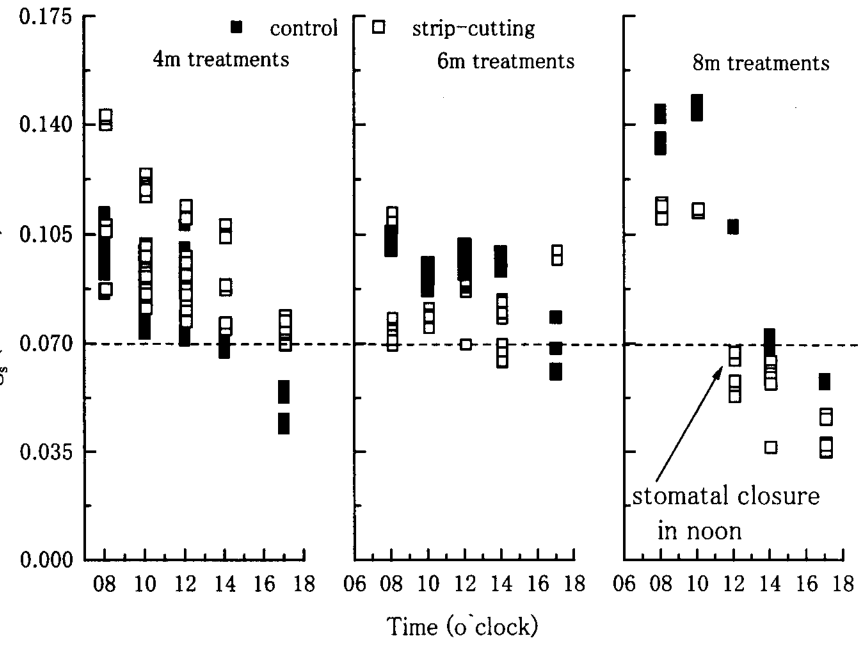

Fig. 11. Diurnal courses of stomatal conductance in different treatment plots. The data were collected from all treatment plots. The dashed line shows the critical value of stomatal conductance (0.07mol. m^{-2}s^{-1}) for severely limiting photosynthesis rate of Korean pine, which was shown in Fig. 10. Time is Beijing time (East 8 time zone).

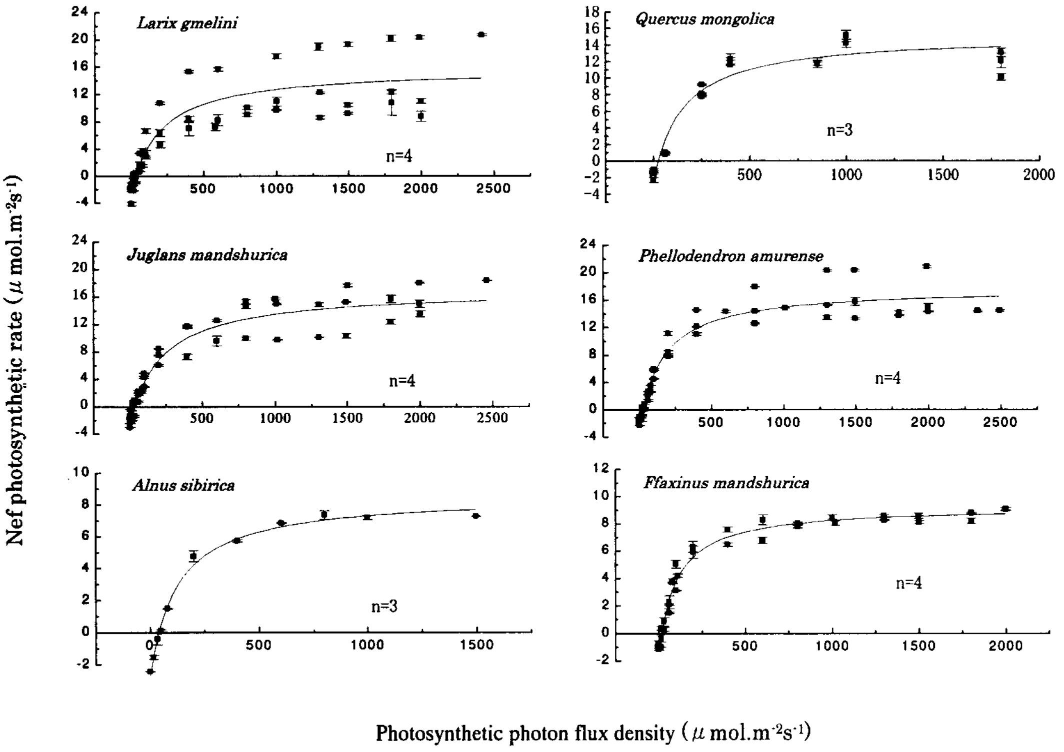

Fig. 12. Examples of light photosynthesis curves of several deciduous tree species: The "n" in each figure indicates the number of sample trees.

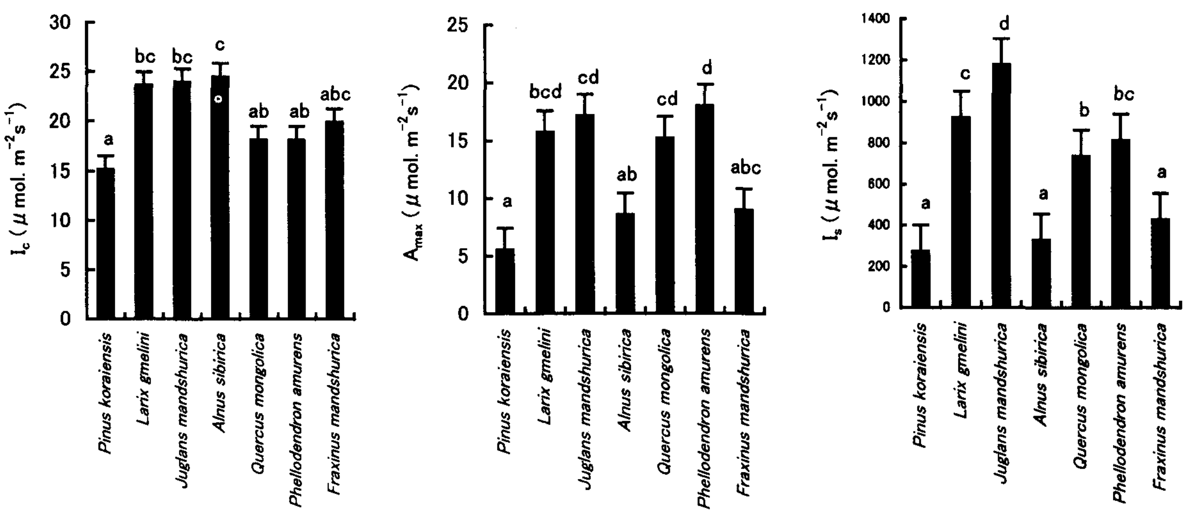

Fig. 13. Differences in I_c, A_{max} and I_s of different deciduous species and Korean pine. Vertical bars show S. E. of the mean values. Different alphabets above the bars indicate statistical difference ($p<0.05$) and same alphabet indicate no statistical difference.

acclimated to the relatively shady environment with a more efficient utilization of lower PPFD. However, no significant difference was observed in the values A_{max}.

Total leaf area per one individual tree showed that the 8m strip-cutting belt produced a relative lower leaf area, which may be correlated with the relative dry condition in this treatment plots. This tendency was found for experimentally examined for several tree seedlings raised under different water regimes (Takahashi 1975, Larcher 1985).

Growth parameters of the trees (basal diameter, tree height and canopy size) showed that the strip-cutting method slightly improved the growth of Korean pine trees except those planted in the 8m strip-cutting belts. In present study, Korean pine trees in the 6m strip-cutting belts showed relatively better than that in other belts. Trees planted in the 8m control belts showed the next better growth, but the growth of trees planted in the 8m strip-cutting belts was suppressed (Fig. 3). These findings agreed with the total leaf area per tree and A_{daily} per tree in the different treatment plots (Fig. 8). However, there was no obvious correlation between A_{max} and growth parameter, which was not significantly different among trees growing in different treatment plots. Our results may imply that total leaf area per tree and A_{daily} are more strongly associated with growth differences in the different treatment plots. It is considered that instantaneous value of net photosynthesis rate may be not directly correlated with plant biomass production (Von der Werf 1996). This can be partly explained by the fact that many leaves in a closed canopy do not experience saturating PPFD and that the PPFD *per se* varies between zero and light saturation during a day.

The currently used theoretical framework for plant growth analysis also only takes daily carbon gain and total leaf area into account but not A_{max} (Poorter 1989, von der Werf 1996). Therefore, it is considered that the growth pattern of Korean pines may be associated more closely with the quantity of photoassimilate accumulation per tree, the pattern of photosynthate allocation and the total leaf area per tree or their spatial arrangement, rather than with the instantaneous value of photosynthesis.

What factors do most influence on the difference in daily carbon gains in trees grown under different treatment plots? PPFD may be one of the most important reasons for the capacity of daily carbon gain (Fig. 5). However, PPFD and P_n did not always agree well; for example, trees growing in the 8m strip-cutting belts had the highest PPFD but relative low value of P_n in the midday (Fig. 6). Stomatal closure at full sunlight would have greatly suppressed the P_n when the g_s of the Korean pines were lower than the critical value of about 0.07 mol. $m^{-2}s^{-1}$ (Fig. 9). Conversely, it would have a slight negative effect on photosynthesis rate. The diurnal course of g_s showed that only the trees growing in the 8m strip-cutting belts had a clear stomatal closure (<0.07 mol.$m^{-2}s^{-1}$) from noon to afternoon (Fig. 11), which would have been responsible for the midday depression of P_n (Fig. 6) and the related lower A_{daily} (Fig. 7). Furthermore, possible reason why stomatal closure occurred may be because the high PPFD induced to high T_{leaf} and high Vpdl. (Fig. 9). Stomatal behavior strongly regulates photosynthesis and transpiration, and it is sometimes the main constraint for P_n (Daniel *et al.* 1979, Jones 1992, Ishida *et al.* 1999) because it could greatly constrain the CO_2 diffusion into intercellular space in a leaf when g_s becomes too small for gas diffusion. Multiple environmental factors, such as PPFD, Vpdl, T_{leaf}, and leaf water potentials could regulate the stomatal behaviors (Jones 1992). Our results showed that both Vpdl and T_{leaf} were closely associated with stomatal conductance. Moreover, lower xylem water potential of branches also related with the stomatal closure in the 8m strip-cutting belts (Wang 2000). Based on these results, it is thought that stomatal behavior may be an important internal factor in the regulation of photosynthetic activity of Korean pines in our study site, especially in the case of trees planted in wide strip-cutting belts, such as the 8-m-wide strip-cutting belts. In the future, growth regulation through stomatal behaviors should be taken into account in the afforestation of Korean pine trees by the strip-cutting method.

Light utilization of Korean pine and other deciduous species

Korean pine trees have some degree of shade-tolerance at a young age, however the light demanding trait of this species gradually increases with advance of size. Generally, a mature Korean pine forest becomes a light-demanding forest with high growth rates (Li, J. W. 1993). Afforestation practices in northeastern China have proved that seedlings of Korean pines directly planted under full sunlight usually suffer from diseases and easily become multi-branched in shape in the early growth stage (Li, J. W. 1993). Thus, a shady environment may be important for the afforestation of Korean pines; however, a very low PPFD could decrease the growth of Korean pines. For example, 4m strip-cutting belts cannot considerably improve growth because of low light environment, however, the 8m strip-cutting belt decrease the growth because of too strong sunlight. Korean pine in the 6m strip-cutting belts grew better than the 4m and 8m strip-cutting belt treatment. Therefore, the tending practice should be important for development of Korean pine forests.

Of course, density, position and distribution pattern of invaded species against Korean pine should be most important factors for surveying of Korean pines is a forest. However, we try to consider the interspecific competition for light harvesting capacity between planted Korean pine and invaded species. The competition abilities of some tree species invaded into our study sites were examined through photosynthetic light-resource harvesting ability at mature stage. The light compensation point (I_c) of other deciduous species was found to be potentially higher than that of Korean pines (Fig. 13), and the light saturation point (I_s) of other deciduous species was higher than that of Korean pines (Fig. 13). For example, light saturation point of *Juglans mandshurica* was 1200 ìmol.m^{-2}s^{-1}, which was 4 times than that of Korean pine. The value of A_{max} in Korean pines was also found to be lower than those of other deciduous species (Fig. 12, 13). This implies that Korean pines have a greater ability to utilize low PPFD than do other species, however, Korean pines may be unable to efficiently utilize high PPFD, especially during the early growth stage. These acclimation traits to microenvironment may be very important for the growth of Korean pines. Position and distribution of invaded species against Korean pine is critical important for modification of understory microenvironment, therefore, suitable tending method for keeping good growth of Korean pine should be developed from the view of light harvesting characteristics in Korean pine.

Incident light is important for the growth of understroy tree species and it is a critical important factor to regulate light harvesting capacities of Korean pines. In our study sites, the canopy size of oak was around 4 meter from east to west in all the treatment plots (Table 2), thus, from each edge of the strip-cutting belts, canopy of top layer of dominant oak will invade 2m into the space above the strip-cutting belts and the canopy of oak above the 4m strip-cutting belts will be closed if two oak trees would be parallel on the edge. Diurnal course of PPFD showed that a slight improvement (150 ìmol m^{-2}s^{-1}) in noon was observed in the 4m strip-cutting belt (Fig. 6). However, considerable increases were observed in the 6m strip-cutting belt (450 ìmol m^{-2}s^{-1}) and in the 8m strip-cutting belt (1100 ìmol m^{-2}s^{-1}). Furthermore, light condition in the 6m and 8m control belts was also improved compared with that in the 4m control belt (Fig.6). Of course, tree height and DBH of overstory trees of oak also give some effect on the light condition in understory besides the effect from canopy size. Therefore, light condition in the strip-cutting belts may be directly regulated by the size of dominant canopy tree of oak species.

Practices of strip-cutting method and perspectives

The strip-cutting method was originally used to develop forests in which old trees could be retained and for more reasons, such as understory species liberation, than is the case with seed-trees cutting (Smith 1986). Recently, much interest has been shown by forestry and ecology researchers in strip-cutting methods and their applications to afforestation in some special sites, such as a peatland in Sweden (Hånell 1993, Hånell *et al.* 2000), and a low-quality forest in northeastern China for productivity improvement (Nie *et al.* 1990). Hånell *et al.* (2000) reported that the shelterwood (strip-cutting) method would be a more competitive method when it is desirable to maximize the share of sawn logs. The results of previous studies conducted in the present study site have shown that the strip-cutting method is beneficial both for sawing logs of oaks and for increasing the stand volume growth of the oak forest (Nie *et al.* 1990). Zhang (1999) reported that the use of the strip-cutting method results in an improvement in biodiversity, which is considered to be an important factor for maintenance of ecosystem functions (Schulze *et al.* 1996). The results of photosynthetic characteristics on each sample seedlings perhaps indicate that strip-cutting belts with a wide width (8m) or a narrow width (4m) have a negative effect on growth and photosynthetic capacities. It is thought that the strip-cutting method with a 6-m-wide strip-cutting belt may be adequate for growth of Korean pine seedlings, considering photosynthetic acclimation capacity of Korean pine seedlings. The width of strip-cutting belts should be taken into consideration in future afforestation of Korean pines.

Concluding Remarks

Based on the data of photosynthesis and growth of Korean pine seedlings obtained in the present study, we may conclude that 6 meters is relatively better for the strip-cutting method for development of Korean pine trees in a mixed secondary oak forest in northeastern China. The 4-m-wide strip-cutting belts were too narrow to improve the PPFD and directly limited the accumulation of photoassimilate. On the other hand, 8-m-wide strip-cutting belts provided too much PPFD, which may induce midday depression in photosynthesis through stomatal closure. This treatment sometimes brings growth differences in Korean pines though total leaf area per tree. Korean pines in the control belts acclimated to the microenvironment through physiological and biochemical modifications. Considering the reported improvements in growth of oak trees and financial benefit from sawn logs by using the strip-cutting method (Nie *et al.* 1990), and also the promotion of biodiversity (Zhang 1999), together with our findings of growth and ecophysiological acclimation in Korean pine, we may conclude that strip-cutting belt methods are beneficial for regeneration of Korean pines in northeastern China.

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Appendix 1

Porra (1991) has proved that the errors caused by using Arnon's method for determination of chlorophyll contents can be perfectly corrected by the following equation:

$$(\mathrm{Chl\ a{+}b})^T=0.895(\mathrm{Chl\ a{+}b})^A, \qquad \text{(A-1)}$$

$$(\mathrm{Chl\ a})^T=(\mathrm{Chl\ a{+}b})^T(\mathrm{Chl\ a/b})^T/[(\mathrm{Chl\ a/b})^T+1], \qquad \text{(A-2)}$$

$$(\mathrm{Chl\ b})^T=(\mathrm{Chl\ a{+}b})^T/[(\mathrm{Chl\ a/b})^T+1], \qquad \text{(A-3)}$$

where T and A mean more precise (True) and Arnon's value, respectively. The $(\mathrm{Chl\ a/b})^T$ was derived from Figure A by the measured value of $(\mathrm{Chl\ a/b})^A$.

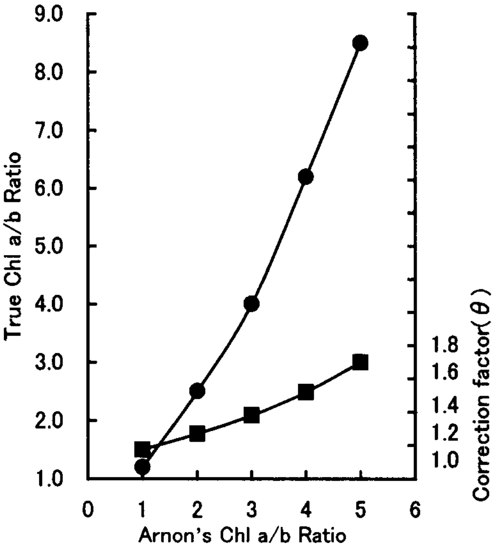

Figure A. True Chl a/b ratios (closed circles) and correction factors (closed squares) plotted against Arnon's Chl a/b ratios (reprinted from Porra, 1991).

Appendix 2

Table A-2-1, growth of Korean pine in the 4m control belts

No.	Height(m)	Basal diameter(cm)	Canopy radius (m) N-E	Canopy radius (m) W-E	No.	Height(m)	Basal diameter(cm)	Canopy radius (m) N-E	Canopy radius (m) W-E
1	0.87	2.3	0.60	0.79	17	1.09	2.1	0.77	0.73
2	0.85	2.0	0.80	0.73	18	0.80	2.0	0.90	0.40
3	1.23	2.6	0.51	0.60	19	0.93	2.1	0.60	0.49
4	0.96	2.8	0.73	0.70	20	0.94	2.1	0.64	0.70
5	1.25	2.3	1.00	0.89	21	0.52	1.2	0.60	0.46
6	1.09	2.1	0.80	0.78	22	0.44		0.39	0.41
7	1.45	3.0	0.80	0.49	23	0.40	0.5	0.34	0.26
8	0.98	2.0	0.79	0.63	24	0.35	0.5	0.52	0.35
9	1.35	2.5	0.16	0.85	25	0.33	0.2	0.32	0.34
10	1.25	2.4	0.48	0.58	26	0.32	0.6	0.33	0.32
11	0.90	2.3	0.73	0.70	27	1.98	3.5	1.18	1.23
12	1.15	3.2	0.90	0.88	28	1.79	4.2	1.26	1.32
13	1.09	3.0	0.71	0.90	29	1.94	3.5	1.26	1.16
14	0.80	2.0	0.70	0.50	30	1.72	3.2	1.06	1.25
15	0.85	2.2	0.70	0.60	31	0.96	1.7	0.64	0.52
16	1.03	3.0	0.69	0.77	32	1.63	1.0	1.20	1.00

No.	Height(m)	Basal diameter(cm)	Canopy radius (m)	
			N-E	W-E
33	1.28	2.7	0.88	0.88
34	1.26	2.4	0.71	0.79
35	1.22	8.2	0.90	1.00
36	1.07	1.5	0.70	0.60
37	0.98	1.5	0.69	0.77
38	0.90	1.8	0.77	0.73
39	0.76	1.8	0.51	0.66
40	0.74	1.8	0.73	0.70
41	0.56	1.2	0.44	0.46
42	0.50	0.8	1.04	1.15
43	0.55	0.4	0.51	0.50

Table A-2-2 growth of Korean pine in 4m strip-cutting belt

No.	Height(m)	Basal diameter(cm)	Canopy radius (m)	
			N-E	W-E
1	2.10	5.2		
2	2.40	5.3		
3	3.15	6.1		
4	2.15	5.0	1.18	1.23
5	1.70	4.5	1.26	1.32
6	2.30	5.0	1.26	1.16
7	1.95	5.0	1.06	1.25
8	1.63	4.1	0.64	0.52
9	2.20	4.8	1.20	1.00
10	2.20	5.0	1.30	0.88
11	1.45	3.6	0.71	0.79
12	1.60	3.8	0.90	1.00
13	2.05	4.3	0.70	0.60
14	1.15	2.4	0.69	0.77
15	1.30	3.2	0.77	0.73
16	1.40	3.2	0.51	0.66
17	0.95	2.3	0.60	0.70
18	1.40	3.1	0.55	0.59
19	1.65	3.2	0.85	0.65
20	1.00	2.4	0.58	1.00
21	1.62	2.7	1.17	1.12
22	1.25	2.8	1.01	1.02
23	1.25	2.2	0.87	0.90
24	1.23	1.7	1.00	0.95
25	1.15	2.2	0.16	1.01
26	1.15	2.1	0.99	0.97
27	1.00	1.4	0.89	0.79
28	1.00	1.1	0.64	0.63
29	0.92	1.4	0.71	1.00
30	0.92	1.8	0.68	0.79
31	0.88	1.4	0.86	0.60
32	0.84	1.2	0.76	0.78
33	0.83	1.2	0.54	0.49
34	0.82	0.9	0.79	0.63
35	0.82	1.5	0.16	0.85
36	0.78	1.3	0.48	0.58
37	0.74	1.0	0.73	0.70
38	0.70	1.0	0.93	0.82
39	0.70	1.2	0.62	0.60
40	0.64	0.3	0.93	0.67
41	0.64	1.0	0.67	0.65
42	0.56	0.5	0.49	0.39
43	0.54	0.8	0.38	0.45

Table A-2-3 growth of Korean pine in 6m control belt

No.	Height(m)	Basal diameter(cm)	Canopy radius (m)	
			N-E	W-E
1	2.90	3.5	1.70	2.10
2	2.64	4.9	1.70	1.65
3	2.20	4.5	1.46	1.50
4	2.15	2.5	1.50	1.35
5	2.10	2.5	1.00	0.97
6	2.04	3.5	1.69	1.67
7	1.95	4.5	1.75	1.63
8	1.95	2.5	1.45	1.60
9	1.91	3.5	1.20	1.08
10	1.90	4.5	1.65	1.45
11	1.90	2.4	1.00	0.80
12	1.89	2.5	1.55	1.20
13	1.89	3.5	1.75	1.45
14	1.89	3.5	1.69	1.43
15	1.85	3.5	1.15	1.16
16	1.84	2.5	1.36	1.04
17	1.82	3.5	1.51	1.65
18	1.80	4.0	0.98	0.64
19	1.79	3.2	1.09	1.23
20	1.76	3.5	1.30	1.45
21	1.73	3.5	1.12	0.94
22	1.72	3.1	1.00	1.08
23	1.71	2.5	0.75	1.12
24	1.70	2.5	1.13	1.27
25	1.69	2.5	1.00	1.35
26	1.65	2.7	1.20	1.03
27	1.65	2.5	1.08	1.20
28	1.62	2.4	0.95	1.10
29	1.61	2.7	0.92	1.00
30	1.60	2.7	0.75	0.63
31	1.50	2.2	1.20	1.00
32	1.48	3.0	1.30	1.10
33	1.44	2.5	0.85	0.13
34	1.43	2.4	0.81	1.15
35	1.42	2.7	1.22	1.45
36	1.41	2.2	0.80	0.75
37	1.36	1.9	1.01	0.57
38	1.35	3.5	1.17	1.20
39	1.35	2.2	0.70	0.69
40	1.30	1.5	0.95	0.75
41	1.25	2.7	1.10	0.80
42	1.23	2.0	0.57	0.63
43	1.23	2.5	1.15	1.05
44	1.23	2.5	0.90	1.00
45	1.15	1.8	0.98	0.76
46	1.10	2.7	0.90	0.75
47	1.10	2.2	0.90	1.10
48	1.09	2.7	0.84	0.64
49	1.08	1.9	0.72	0.86
50	1.07	2.5	0.60	0.50
51	1.05	2.0	0.75	0.68
52	1.05	1.5	0.65	0.45
53	0.99	2.2	0.88	0.79
54	0.97	1.2	0.43	0.58
55	0.97	1.5	0.65	0.45
56	0.97	2.1	0.61	0.72
57	0.94	1.2	0.78	0.90
58	0.93	0.2	0.72	0.65
59	0.90	2.2	0.70	0.95
60	0.88	1.5	0.68	0.85
61	0.85	3.2	1.40	0.65
62	0.71	1.0	0.60	0.53
63	0.71	0.8	0.50	0.60
64	0.65	1.5	0.69	0.37
65	0.52	1.5	0.43	0.38
66	0.50	1.1	0.50	0.43
67	1.04	1.7	0.84	0.52
68	0.72	1.0	0.60	0.55
69	0.61	1.0	0.65	0.50
70	1.41	2.2	0.96	0.85
71	1.51	2.7	1.21	1.47
72	1.45	2.7	0.86	0.89
73	0.84	1.8	0.77	0.60
74	1.50	3.2	1.06	1.10
75	1.56	2.8	1.10	0.90
76	0.93	3.0	0.65	0.60
77	1.88	2.8	1.20	1.06
78	0.50	0.2	0.30	0.20
79	0.46	0.2	0.30	0.20
80	2.07	3.5	1.31	1.37
81	1.89	3.2	1.37	1.29
82	1.22	2.8	1.10	0.90
83	1.25	2.8	0.80	0.75
84	1.27	2.1	1.01	0.81
85	1.62	3.9	1.15	0.92
86	2.40	4.5	1.50	2.20
87	1.57	2.4	0.92	0.81
88	1.99	5.0	1.47	2.20
89	1.85	4.5	1.40	1.00
90	0.90	2.8	1.10	0.75
91	0.74	2.0	0.54	0.55
92	0.98	2.0	0.60	0.57
93	1.40	2.8	1.10	1.00
94	1.35	2.7	0.77	1.24

No.	Height(m)	Basal diameter(cm)	Canopy radius (m)	
			N-E	W-E
95	0.38	0.2	0.35	0.28
96	1.52	1.3	1.03	1.04
97	0.80	3.2	0.70	1.10
98	0.54	1.0	0.55	0.60
99	2.15	3.2	1.71	1.32
100	1.32	2.8	0.85	0.74
101	1.05	2.4	1.03	0.81
102	1.38	2.5	0.97	1.05
103	2.00	4.0	1.50	1.60
104	2.05	3.0	1.46	1.70
105	1.47	2.7	1.10	1.00
106	1.03	2.1	0.72	0.61
107	0.53	0.8	0.48	0.37
108	1.10	1.4	0.60	0.67
109	1.05	2.1	1.10	0.95
110	1.70	3.1	1.20	0.90
111	1.53	3.0	0.94	1.15
112	1.90	4.0	1.20	1.50
113	1.16	2.8	0.70	0.58
114	1.88	2.8	1.00	1.05
115	2.20	3.5	1.33	1.52
116	0.72	2.2	0.54	0.52

Table A-2-4. Growth of Korean pine in 6m strip-cutting belt

No.	Height(m)	Basal diameter(cm)	Canopy radius (m)	
			N-E	W-E
1	0.95	2.8		
2	2.40	6.0	0.80	1.10
3	1.55	4.2	1.71	1.42
4	1.70	4.6	0.90	0.74
5	2.20	5.6	1.00	0.81
6	1.90	5.1	1.01	1.05
7	1.48	3.6	1.50	1.40
8	1.60	3.2	1.03	1.04
9	1.75	4.2	0.60	0.70
10	2.38	6.1	1.20	1.00
11	1.70	5.0	0.55	0.60
12	3.12	6.6	0.90	1.40
13	2.40	5.8	1.08	1.40
14	1.80	3.8	1.62	1.58
15	2.10	4.2	0.74	0.90
16	2.41	4.0	0.60	0.65
17	1.92	3.7		
18	1.83	3.8	1.83	1.86
19	2.00	4.8	1.82	1.48
20	2.00	4.7	1.03	1.17
21	2.15	5.0	1.02	1.36
22	2.90	6.0	1.50	1.75
23	2.30	4.7	1.70	1.40
24	2.40	5.8	1.40	1.25
25	1.80	4.5	1.35	1.20
26	1.85	4.0	1.30	1.25
27	2.10	4.2	1.10	1.52
28	3.08	4.0	1.70	1.90
29	2.90	5.0	1.37	1.45
30	2.80	5.2	1.45	1.55
31	2.65	4.5	1.55	2.15
32	2.63	4.7	2.10	1.75
33	2.54	4.2	1.20	1.40
34	2.46	4.5	2.10	1.87
35	2.40	4.5	1.83	1.86
36	2.34	3.7	1.82	1.48
37	2.25	3.0	1.03	1.17
38	2.17	3.5	1.02	1.36
39	2.15	3.0	1.50	1.75
40	2.00	3.2	1.70	1.40
41	1.92	3.0	1.40	1.25
42	1.85	3.5	1.35	1.20
43	1.80	2.3	1.30	1.25
44	1.65	3.1	1.10	1.52
45	1.49	2.7	0.85	1.07
46	1.33	3.5	0.97	1.05
47	1.23	2.0	1.00	0.94
48	1.23	1.2	1.10	0.95
49	1.17	2.4	1.05	0.98
50	0.65	0.3	0.54	0.39
51	0.59	1.1	0.39	0.44
52	1.38	2.8	1.31	0.97
53	1.55	2.5	0.90	0.75
54	2.05	3.9	1.13	1.09
55	0.59	0.8	0.40	0.42
56	0.78	1.8	0.70	0.71
57	1.01	3.0	0.67	0.70
58	0.96	1.9	0.72	0.70
59	2.20	4.2	1.80	1.75
60	0.55	0.3	0.40	0.40
61	2.00	4.5	1.60	0.70
62	2.15	3.5	1.20	1.07
63	1.68	3.5	1.08	1.40
64	2.85	4.0	1.62	1.58

No.	Height(m)	Basal diameter(cm)	Canopy radius (m)	
			N-E	W-E
65	1.03	2.8	0.74	0.90
66	1.05	2.4	0.60	0.65
67	0.84	1.8	0.55	0.91
68	1.65	2.8	1.21	0.77

Table A-2-5 growth of Korean pine in 8m control belt

No.	Height(m)	Basal diameter(cm)	Canopy radius (m)	
			N-E	W-E
1	1.60	3.4	1.70	1.48
2	1.50	3.4	1.27	1.43
3	1.72	4.1	1.51	1.45
4	1.78	4.2	1.50	1.10
5	1.71	3.9	0.91	1.00
6	1.84	4.2	0.59	1.14
7	1.56	3.0	1.25	1.10
8	2.07	4.2	1.34	1.65
9	1.67	4.2	1.07	1.13
10	1.90	5.1	0.98	0.80
11	1.60	3.2	0.77	0.71
12	1.50	3.0	1.10	1.30
13	1.80	5.4	1.21	1.35
14	1.60	3.3	0.85	0.98
15	1.60	4.0	1.25	0.76
16	1.50	3.5	0.76	0.67
17	1.50	4.1	0.70	0.64
18	1.50	3.0	0.70	0.73
19	1.40	4.0	1.20	1.15
20	1.25	4.1	0.80	0.67
21	1.50	5.4	0.52	0.90
22	1.50	4.8	0.88	0.61
23	0.65	3.0	0.78	0.53
24	1.30	3.6	0.63	0.96
25	1.20	3.5	0.80	0.61
26	0.80	3.2	0.61	0.52
27	2.07	6.0	0.88	0.61
28	2.35	6.3	1.48	1.19
29	2.30	5.1	1.77	1.53
30	2.75	5.0	1.26	1.43
31	2.07	4.2	1.51	1.44
32	2.40	5.5	1.17	1.10
33	2.01	5.2	0.91	1.00
34	1.50	4.6	0.59	1.14
35	1.94	5.0	1.25	1.09
36	2.25	3.4	1.34	1.67
37	2.15	4.8	1.20	1.00
38	1.90	4.2	0.78	1.10
39	1.84	3.0	1.20	1.12
40	1.84	3.2	0.99	1.27
41	1.64	3.0	0.93	0.42
42	1.68	2.8	1.20	0.90
43	1.70	3.6	0.70	0.70
44	1.82	3.0	1.12	1.14
45	1.81	3.6	0.97	1.02
46	1.95	3.8	1.20	1.40
47	1.66	4.5	1.21	1.05
48	1.63	2.4	0.98	0.15
49	1.84	4.5	1.13	1.22
50	1.82	4.6	1.14	0.95
51	1.64	4.5	1.19	1.00
52	1.49	2.2	0.75	0.70
53	1.35	3.2	0.90	1.15
54	1.75	2.6	1.05	1.13
55	1.70	3.2	1.08	1.16
56	0.64	1.8	0.65	0.36
57	0.57	2.1	0.56	0.46
58	0.87	2.5	0.85	0.82
59	1.23	2.5	1.02	0.89
60	0.57	1.8	0.56	0.65
61	0.68	1.7	0.70	0.66
62	1.75	2.4	1.15	1.39

Table A-2-6, growth of Korean pine in 8 m strip-cutting belt

No.	Height(m)	Basal diameter(cm)	Canopy radius (m)	
			N-E	W-E
1	1.58	3.8		
2	1.42	2.5		
3	0.70	1.6		
4	1.30	1.3		
5	1.45	2.3		
6	1.60	3.1	0.96	0.89
7	1.52	2.0	0.84	0.67
8	1.60	2.4	0.94	0.88
9	1.26	2.4	1.09	0.70
10	1.65	3.0	1.40	1.15
11	1.55	2.4	0.71	0.88
12	1.74	2.6	1.43	1.52
13	1.45	2.8	0.64	0.86
14	1.40	2.1	0.81	0.85
15	1.23	2.2	0.67	0.66
16	1.41	2.2	0.69	0.73
17	1.81	2.8	1.51	1.19
18	1.30	1.8	1.51	1.24
19	1.15	2.8	0.87	0.68
20	1.05	2.4	0.62	0.49
21	1.02	1.6	0.51	0.67
22	1.01	1.2	0.52	0.44
23	0.96	2.8	0.48	0.61
24	0.87	5.8	0.55	0.53
25	0.86	1.8	0.63	0.62
26	0.85	1.5	0.51	0.61
27	0.82	1.8	0.61	0.52
28	0.78	2.5	0.88	0.61
29	0.78	1.2	0.65	0.58
30	1.52	3.9	0.90	1.10
31	0.68	1.9	0.63	0.72
32	0.64	1.9	0.78	0.60
33	1.09	2.5	0.71	0.77
34	0.97	2.4	0.68	0.49
35	0.77	2.1	0.52	0.76
36	0.78	1.7	0.57	0.55
37	1.76	3.5	1.20	1.19
38	2.20	4.5	1.90	1.40
39	0.82	5.3	0.60	0.50
40	1.82	3.9	0.91	0.64
41	1.13	1.9	0.69	0.48
42	2.30	6.0	1.41	1.44
43	1.06	2.3	0.90	0.56
44	1.49	3.2	0.83	1.43
45	0.74	1.4	0.61	0.54
46	1.20	2.7	0.82	0.56
47	1.35	3.1	1.07	1.13
48	1.69	4.5	0.67	0.80
49	0.89	2.4	0.77	0.71
50	1.98	4.2	1.10	1.30
51	1.98	3.2	1.21	1.35
52	1.58	2.7	0.85	0.98
53	1.49	4.0	1.25	0.76
54	1.24	1.3	0.76	0.67
55	1.02	2.1	0.70	0.64
56	1.20	2.0	0.70	0.73
57	1.45	3.8	1.20	1.15
58	0.92	1.5	0.64	0.51
59	0.58	1.7	0.52	0.39
60	0.96	1.8	0.67	0.92
61	1.42	3.9	0.90	1.00

Appendix 3

Original chlorophyll data measured by Arnon method in different treatment plots.

Table 3-1 chlorophyll b content of Korean pine leaf in different treatment plots (mg g^{-1} DW)

Treatments	4m	6m	8m
	0.635	0.694	0.645
Control	0.629	0.638	0.699
	0.68	0.621	0.61
	0.514	0.574	0.512
Strip-cutting	0.451	0.578	0.401
	0.6	0.705	0.539

Table 3-2 Chlorophyll a+b content of Korean pine leaf in different treatment plots (mg g^{-1} DW)

Treatments	4m	6m	8m
	2.348	2.527	2.384
Control	2.323	2.319	2.495
	2.153	2.726	2.271
	1.782	2.053	1.875
Strip-cutting	2.04	2.19	1.6
	2.117	2.584	1.875

Appendix 4

Table 4 leaf area differences in different treatment plots (unit: m^{-2})

4m		6m		8b	
Control	Strip-cutting	Control	Strip-cutting	Control	Strip-cutting
0.65	2.46	0.86	3.16	1.81	1.07
0.77	1.86	1.29	2.06	1.91	0.94
1.67	0.98	1.00	1.65	1.17	0.87
0.89	2.12	0.93	3.06	1.59	0.67
0.56	1.53	0.93	2.24	1.91	0.87
1.53	1.27	1.22	2.36	2.02	0.80
0.35	1.48	1.22	2.24	1.59	1.15
0.83	2.14	1.43	2.47	1.82	1.21
0.59	1.89	1.79	2.47	1.07	0.40
1.18	0.68	0.90	2.12	0.94	1.08