THE EFFECTS AFTER THINNING OF JAPANESE CEDAR AT XITOU

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ABSTRACT

This study sat two experimental plots each for 400m² ha of 40 years old Japanese cedar (Cryptomeria japonica) plantation at National Taiwan University Experimental Forest Xitou Tract: Control (non-thinning) plot and 40% thinning plot. The original planting density was 2000 trees for each ha of all the experimental plots. After complete enumeration of all the experimental plots, measurements of photosynthesis were taken and multiplied by the total leaf area for each sample tree; then accounting for the number of trees in the forest, the percentage of the forest stand that could get the annual carbon sequestration of forest stand was. The results showed significant correlation between tree dominance and increment (R^2>0.7) for non-thinning Japanese cedar, higher and bigger diameter trees showed more growth increment but stagnant for overtopped trees. After thinning, all the low-diameter trees have increase significantly in increment for 30-50%. The photosynthesis ability measured results shown that Japanese cedar photosynthetic efficiency have no significant differences after thinning, but due to the total leaf area growth, so that it could increase carbon sequestration efficiency by 22-38% after thinning.

INTRODUCTION

Global warming has caused worldwide changes in climate. In this regard, the creation of plantation can potentially lead to the absorption of large quantities of carbon. Tending and thinning of such forests promotes their growth and consequently enhances their capacity to sequestrate carbon, which is currently an important topic in forestry management.

Japanese cedar (*Cryptomeria japonica*) is one of the most abundant and important trees in artificial forests in Taiwan, comprising a total forest area of 29,000 ha. In this study, between August 2015 and July 2016, we conducted a moderate (40%) thinning of the lower layers of 40-year-old Japanese cedar trees in the National Taiwan University Experimental Forest Xitou Tract. The effectiveness of thinning on growth and carbon sequestration were studied by comparing with a non-thinned control plot.

MATERIAL AND METHOD

1. Experimental Site and Material

This study was conducted in the National Taiwan University Experimental Forest Xitou Tract (120.775696ºE, 23.669329ºN) at an elevation of 1,290 m. The geological strata in this area are primarily shale and sandstone, and the soil type is a loam to sandy loam. The forest was established in 1978, covering an area of 3.57 ha and with an initial density of 2000 trees·ha^{-1}. In August 2014, we established a 20 × 20 m (400 m^2) sample plot, in which the lower layers were moderately (40%) thinned. Trees within a 20 × 20 m (400 m^2) sample plot, which were not thinned, were designated as a control group. The growth and carbon sequestration of the forest was studied between August 2015 and July 2016. Records collected between 1941 and 2014 showed that the average temperature of the experimental area was 16.5ºC and the annual rainfall was 2590 mm. The climate during the experimental period was slightly warmer and wetter compared with the long-term averages, with an average temperature and annual rainfall of 18.5ºC and 3564 mm, respectively.

2. Complete Enumeration

The study design followed the criteria of complete enumeration of the data for every tree after thinning in October 2014. The first complete enumeration study was conducted in October 2015, during which time data were obtained from 24 trees in the thinned plot and 37 trees in the non-thinned plot. All trees in the sample plots were numbered, and data recorded included height, diameter at breast height (DBH), growth status, crown width, and location within the sample plot. These data analyzed in order to determine population structure and amount of growth.

3. Photosynthetic Measure

On the basis of the complete enumeration data, three sample trees were selected for measurement of photosynthetic parameters. Each month, one tree was selected for measurement between 8 am and 5 pm using a portable photosynthesis system (Li 6400XT; LI-COR, USA). A high platform was constructed to facilitate measurement of the photosynthetic activity of mature leaves in the tree crown. Three samples were collected from each sample tree. Used the 6400-05 leaf chamber to clamp leaves that recorded values, including light intensity, stomatal conductance, relative humidity, and CO_2 concentration. The infrared gas analyzer within the instrument was used to analyze the CO_2 concentration gradient difference between the inside and outside of the chamber, in order to estimate the net photosynthetic rate (Zotz and Winter, 1996).

4. Total Leaf Area (TLA) and Annual CO_2 Sequestration Estimate

A leaf area index analyzer (Li 2200; LI-COR, USA) was used to measure photosynthetic activity in the lower canopy of the sample trees. Measurement was taken from the vertical surface of the instrument's fisheye lens, which taken from 10 points in each sample tree for comparison of leaf area index (LAI). The sample tree crown projected area (CPA) was multiplied by the LAI to obtain an estimate the sample tree TLA (Biswasa *et al*., 2014).

Daily CO_2 sequestration measurements were converted from moles to mass (the molecular mass of CO_2 is 44), in units of g CO_2·m^{-2}·d^{-1}. Conversion of the whole-tree leaf area was estimated from the total CO_2 sequestration of one tree over an entire day. Multiplying by the number of days in the month and totaling the value for each month gives an estimate of the total CO_2 sequestration of one tree over a year.

$$A_{TOC} = \sum_{i=1}^{12} AiTiDi$$

A_{TOC}=Aannual net CO_2 sequestration、Ai= Seasonal net daily photosynthetic rate、Ti= Monthly daylight、Di= Number of days in the month.

5. Data Statistics and Analysis

Data were analyzed in SAS 9.4. (SAS Inc., Cary, NC, USA) and Duncan's multiple range tests were run a posteriori. Significance was set at $p < 0.05$ for all analyses. Curve fitting of data was performed using SigmaPlot 12.0 (Systat Software Inc., Chicago, IL, USA). Data are presented as means ± standard error.

RESULTS

1. Complete Enumeration

The density of the non-thinned 40-year-old *C. japonica* trees in the National Taiwan University Experimental Forest Xitou Tract was 950 trees·ha^{-1}, 37 trees were investigated within the control sample plot. The average height and DBH of the trees was 22.23 m and 31.56 cm, respectively. Most of the trees under a height of 20 m were overtopped trees, and their height and DBH were moderately correlated (R^2 = 0.429) (Figure 1). Investigation of growth showed that the average growth in height per sample tree was 0.4 m, the average growth in DBH was 1.13 cm, and the average volume increment was 0.092 m^3. The volume increment in sample trees and dominance were highly correlated (R^2 = 0.7515) (Figure 2).

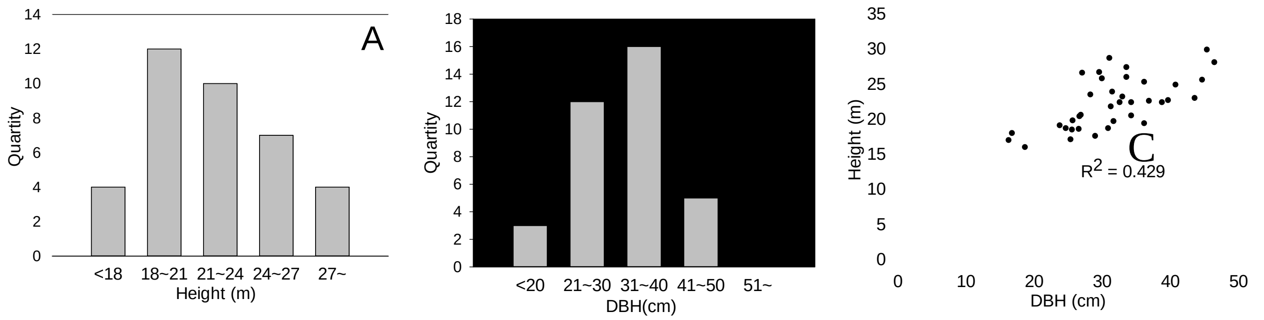

Fig. 1 The height(A), diameter at breast height(DBH)(B) and the relationship between height and DBH(C) of the *Cryptomeria japonica* simple trees without thinning

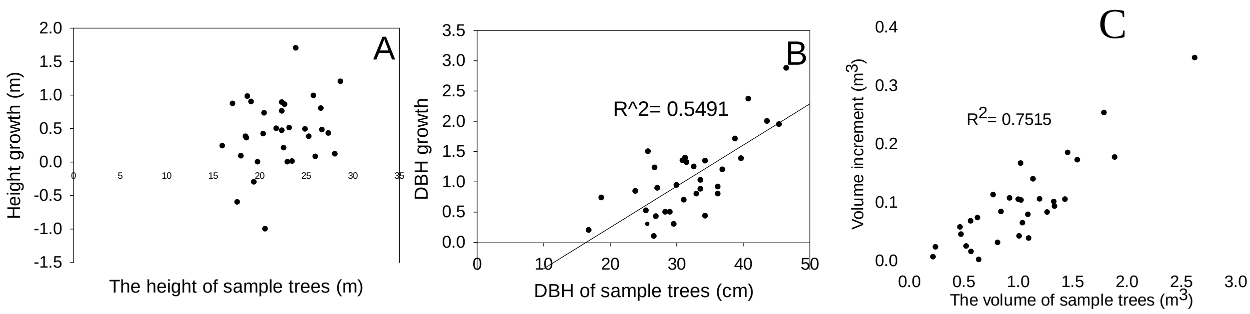

Fig. 2 The height growth(A), DBH growth(B) and volume increment(C) of the *Cryptomeria japonica* simple trees without thinning

After 40% thinning of the lower tree layer, the density of *C. japonica* was 585 trees/ha, 24 trees were investigated within the sample plot. The average DBH was 34.01 cm and the height was 24.06 m. Thinning removed most of the trees with small diameter and damaged large trees, and tree height and DBH were moderately correlated (R^2 = 0.556) (Figure 3). The annual average growth in height of trees in the thinned plot was 0.73 m, whereas the average growth in DBH was 1.41 cm and the average volume increment was 0.136 m^3. The growth rate was significantly increased in trees with diameter smaller than the median value (Figure 4).

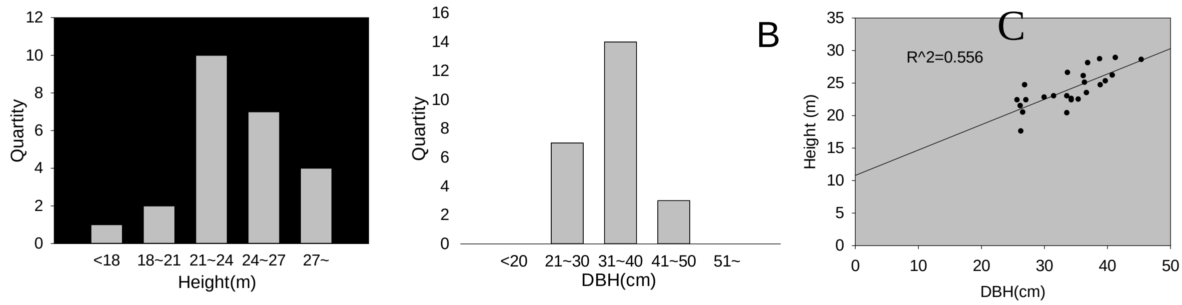

Fig. 3 The height(A), diameter at breast height (DBH)(B) and the relationship between height and DBH (C) of the *Cryptomeria japonica* simple trees with 40% thinning

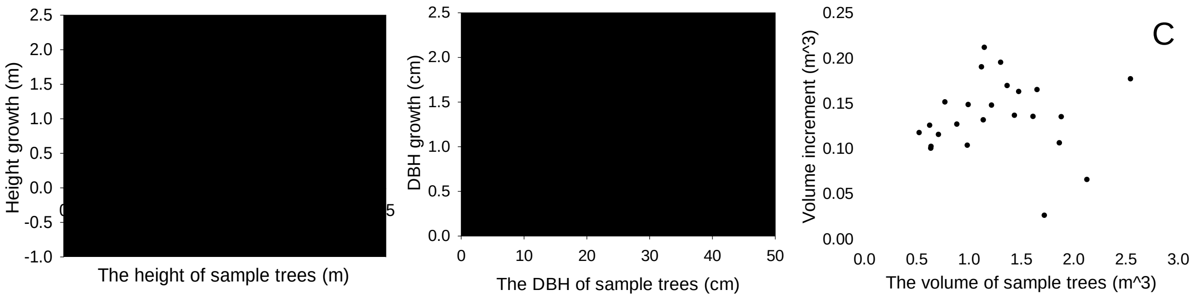

Fig.4 The height growth(A), diameter growth(B) and volume increment(C) of the *Cryptomeria japonica* simple trees with 40% thinning

2. Net Photosynthetic rate

Figure 5 shows the net daily photosynthetic rate change per unit area in the thinned and non-thinned trees. In the initial stage after thinning of *C. japonica*, the photosynthetic rate (0.834 μmol $m^{-2}\cdot s^{-1}$) of trees in the thinned plot was slightly higher than that of non-thinned trees (0.787 μmol $m^{-2}\cdot s^{-1}$). After November, however, the difference gradually declined. With the exception of the period from February to March 2016, during which photosynthetic rate was at its lowest over the entire year, the differences between thinned and non-thinned trees were not significant. The annual average photosynthetic rate was 0.77 μmol $m^{-2}\cdot s^{-1}$ in the non-thinned trees and 0.81 μmol $m^{-2}\cdot s^{-1}$ in the thinned trees. The net photosynthetic rate after thinning was slightly increased by approximately 4%, but the difference was not significant.

2.1 Annual CO_2 Sequestration Estimate

Table 1 shows the LAI and CPA of the sample trees. Figure 6 shows the estimated monthly carbon sequestration of thinned and non-thinned *C. japonica* trees. Non-thinned *C. japonica* were shown to fix an annual average of 4261.65 g of CO_2 per tree and sequester a monthly average of 355.14 g of CO_2, *C. japonica* thinned by 40% fixed an annual average of 6206.79 g of CO_2 and sequestered a monthly average of 517.23 g of CO_2. Thus, thinning can increase the carbon storage capacity of a single *C. japonica* tree by between 22% and 38%.

Table 1 Average values (± standard error) of leaf area index (LAI) and crown projection area (CPA) of non-thinning and 40% thinning *Cryptomeria japonica* across different seasons

		Autumn	Winter	Spring	Summer
non-thinning	LAI(m^2m^{-2})	2.601±0.099[a*]	2.592±0.113[a]	2.623±0.031[a]	2.685±0.049[a]
	CPA(m^2)	9.621±1.203[ab]	9.562±0.858[b]	10.117±0.512[a]	10.343±0.683[a]
40% thinning	LAI(m^2m^{-2})	2.733±0.103[a]	2.601±0.065[b]	2.786±0.121[a]	2.792±0.082[a]
	CPA(m^2)	10.639±0.59[b]	10.636±0.41[b]	11.171±0.227[a]	11.256±0.190[a]

* Different letters indicate significant differences between difference seasons.

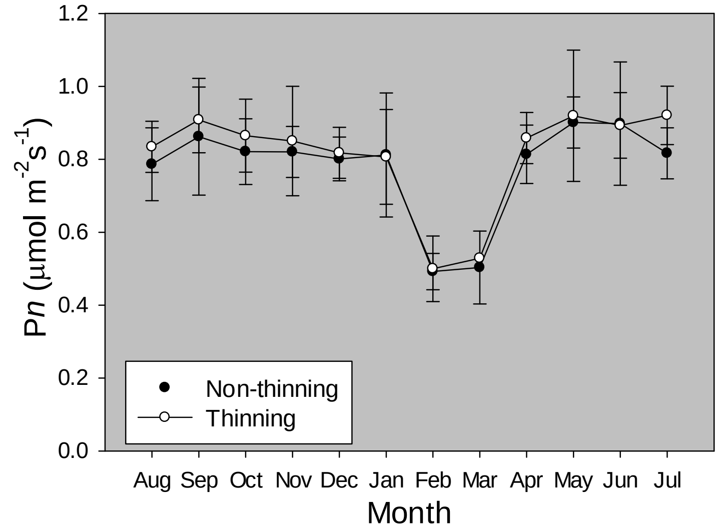

Fig. 5 The monthly variation of daily average net photosynthesis of non-thinning and 40% thinning *Cryptomeria japonica*

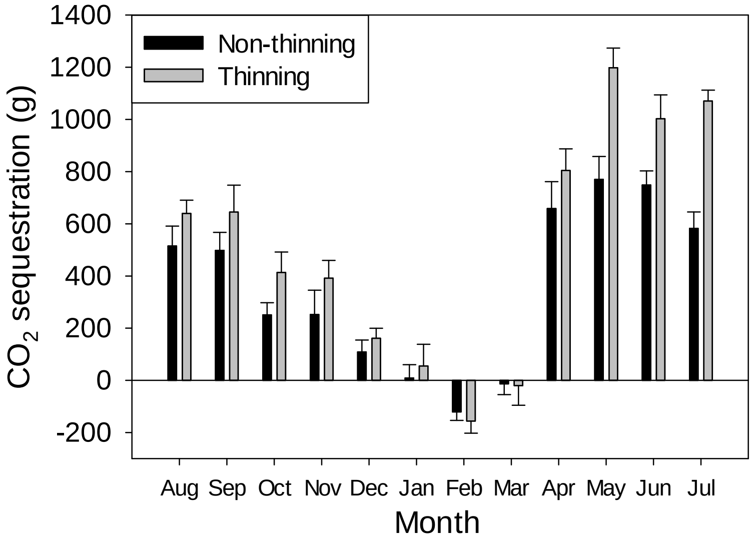

Fig. 6 The monthly CO_2 sequestration of non-thinning and 40% thinning *Cryptomeria japonica*

DISCUSSION

In this study, the diameter and height of 40-year-old *C. japonica* trees in a plantation had different distributions but were positively correlated. This shows that dominant trees can obtain more resources for continued growth, whereas the growth of overtopped trees stagnates. This phenomenon is often observed in single-trunk conifer species, and particularly in non-shade-tolerant trees, such as *C. japonica*, in which the phenomenon of large-diameter trees dominating and small-diameter trees in being overtopped is even more apparent (Kohama *et al*., 2006, Takashima *et al*., 2009). This study of a *C. japonica* plantation, in which the lower layers were thinned by 40%, revealed that the average volume increment per extant tree increased from 0.092 m^3 to 0.136 m^3, an increase of approximately 30%-50%. Past research on *C. japonica* has shown that these trees are sensitive to change in the light environment and exhibit clear self-pruning (Kohama *et al*., 2006, Yamashita *et al*., 2006). In the present study, the increase in LAI and crown width after thinning indicated increases in the number of branches and leaves, thus promoting growth in height and an increased volume increment of the whole tree (Hiroaki *et al*., 2008).

There was no significant difference between the photosynthetic activity rate per leaf in thinned and non-thinned trees, which may be because photosynthetic activity in the *C. japonica* trees we examined had reached the upper limit of light energy processing, known as the maximum assimilation rate (A_{max}) (Taiz and Zeiger, 2006). However, in response to changes in the light environment, thinned *C. japonica* trees grew more branches and leaves, which benefit the photosynthetic activity of the entire tree (Hiroaki *et al*., 2008). The light environment and climate during February and March 2016 were poor, and the net daily photosynthetic rate during this period was negative. Consequently, there was carbon emission (Chen *et al*., 2016). On average, non-thinned *C. japonica* absorbed 4261.55 g CO_2 per tree annually, whereas thinned *C. japonica* absorbed 6206.79 g CO_2 per tree, which represents an increase of 22%–38% per tree, with more energy being used to promote growth (Wang *et al*., 2005). There are accordingly long-term benefits associated with carbon fixation and volume increment (Dwyer *et al*., 2010).

CONCLUSION

In Taiwan, *C. japonica* is one of the most important trees grown in artificial forests. One year after 40% thinning, growth of this species increased by 30%–50% and carbon sequestration increased by 22%–38% per remaining tree. In the future, continued follow-up studies should be conducted over an even longer period.

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