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Influence of Stand Density on the Increment of Leaf Biomass in the Young *Cryptomeria japonica* Stand before Canopy Closing

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Introduction

Growth of planted trees are influenced not only by the natural environment but also the artificial environment depending on silvicultural methods. Stand density influences the productive structure of standing trees such as the vertical distribution of leaf. At the planting time, leaf biomass should depend on the densities. The difference in leaf biomass depending on densities would diminish as trees grow and the leaf biomass reaches a constant level in mature monocultured stands even with various stand densities (TADAKI, 1977). For example, it was reported that the leaf biomass ratio to the aboveground biomass didn't show the apparent difference among the closed stands of *Pinus densiflora* (SATOO, 1955) and of *Cryptomeria japonica* (NEGISI *et al*., 1988). And after canopy closing, the amounts of dead leaves and leaves developed in a year didn't show apparent difference among the stands with different densities (TANGE *et al*., 1987, 1991).

In this paper, to clarify the density effect on the increment of leaf biomass in young *Cryptomeria japonica* stand before canopy closing, we studied the relationship among the tree density, the tree growth and the leaf biomass in the 8-year-old *Cryptomeria japonica* stands with different densities.

Study Site and Methods

Study site

We made the study plot in the spacing examination *Cryptomeria japonica* stand at Maezawa ($28C_{1-3}$) in the Tokyo University Forest in Chiba. This stand was established in April, 1984. Topographical condition and location of study blocks were shown in Fig. 1. And the general description of each block was shown in Table 1. Planting densities were 2,500 seedlings/ha in block-1, block-6 and block-8, 3,906 seedlings/ha in block-3, block-5 and block-7 and 6,944 seedlings/ha in block-2, block-4 and block-9. Block-3 was omitted from discussion, because block-3 had been pruned before the measurement.

This study plot was situated on the concave slope between two ridges. Tree growth apparently varied among the blocks.

Methods

Biomass

Diameters at breast height and tree heights of all trees in each block were measured. And then, three sample trees with different sizes were selected from each block. After each sample tree was felled, the biomass was analyzed by the stratified clip method, in which stratum was 0.0–0.3 m, 0.3–1.3 m, and at an interval of 1 m upward. The stem, branch and leaf contained in each stratum were weighed, respectively. Small amounts of sample were

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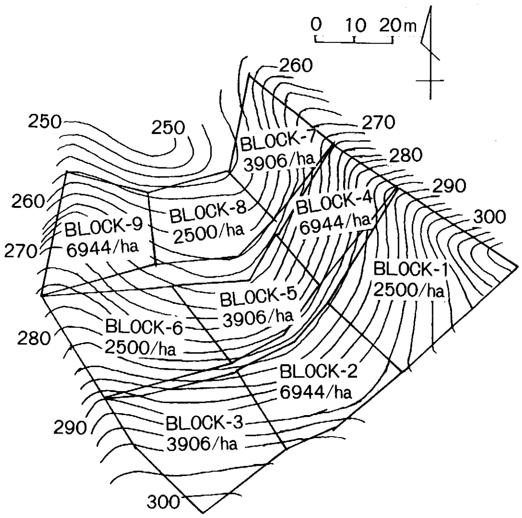

Fig. 1. Topographical condition of each study block.

taken for the estimation of dry weight ratio for each organ in each stratum. Dry weight of each organ was calculated by the ratio of dry weight to fresh weight obtained from the sample.

Stem volume growth was measured by the stem analysis with stem disks sampled at 0.0 m, 0.3 m, and at an interval of 1 m upward. Each organ biomass above ground in each block was estimated from the allometric relationship to the diameter at breast height obtained from three sample trees. These measurements were done as a part of the curriculum of Department of Forestry in the University of Tokyo from 7 May to 9 May in 1992.

Nitrogen content in leaves

Current year leaves collected from sunny crowns of six to nine planted treed in each block were used for nitrogen analysis. Nitrogen content in the green part of leaf except inner woody part was measured by NCS analyzer (NA 1500, CARLO ERBA) and was calculated based on dry weight of the green part.

Results and Discussion

Leaf biomass

Dry weight of stem, branch and leaf in each sample tree were shown in Table 2. The aboveground biomass in each block estimated from the allometric relationship to diameter

Table 1. General description of each block

Block	Density (trees/ha)	Trees	Area (ha)	DBH* (cm)	H** (m)	Relative tree density***
BLOCK-1	2500	233	0.093	6.9	5.0	0.18
BLOCK-2	6944	443	0.064	7.4	6.2	0.56
BLOCK-4	6944	315	0.045	6.4	4.9	0.44
BLOCK-5	3906	253	0.065	9.9	7.2	0.51
BLOCK-6	2500	247	0.099	9.4	6.3	0.30
BLOCK-7	3906	185	0.047	8.0	5.6	0.36
BLOCK-8	2500	161	0.064	11.2	7.7	0.40
BLOCK-9	6944	354	0.051	7.4	6.0	0.56

* Mean diameter at breast height.

** Mean tree height estimated from relationship between DBH and tree height in about 50 sample trees.

*** Relative tree density (RTD) was calculated from the equations.

$\log D_{max} = -1.6307 \cdot \log \mathrm{DBH} + 5.5100$

$\mathrm{RTD} = D/D_{max}$

where D, D_{max} and DBH were stand density, maximum stand density and mean diameter at breast height, respectively (SAKAGUCHI, 1961).

Table 2. Diameter at breast height, tree height and dry weight of each organ in each sample tree

Block	Sample tree No.	DBH* (cm)	H** (m)	Dry weight Stem (kg)	Branch (kg)	Leaf (kg)	Aboveground (kg)	Annual stem*** volume growth $m^3 \times 10^{-3}$
BLOCK-1	1	4.5	3.2	2.06	1.18	3.88	7.12	1.16
	2	6.9	4.4	4.42	1.52	5.69	11.63	2.33
	3	9.1	6.2	9.62	3.83	10.90	24.35	5.14
BLOCK-2	1	5.1	5.8	3.17	0.34	1.18	4.69	1.02
	2	7.4	7.0	6.18	1.07	4.57	11.82	4.28
	3	8.8	7.3	9.46	1.34	4.50	15.30	4.06
BLOCK-4	1	2.5	3.4	0.87	0.12	0.67	1.66	0.37
	2	6.1	4.7	3.70	0.89	3.45	8.04	2.63
	3	11.5	6.3	6.99	1.76	4.51	13.26	4.92
BLOCK-5	1	7.1	5.5	4.06	0.90	3.25	8.21	2.87
	2	9.5	6.8	9.73	2.14	7.75	19.62	6.57
	3	13.0	7.8	18.19	2.97	7.77	28.93	11.92
BLOCK-6	1	6.7	5.6	4.42	1.30	5.48	11.20	4.18
	2	10.4	6.8	10.50	2.47	8.52	21.49	7.54
	3	11.5	6.7	11.37	3.63	13.41	28.41	8.95
BLOCK-7	1	6.2	4.8	3.90	1.01	4.22	9.13	2.96
	2	8.4	5.9	6.19	2.01	5.45	13.65	5.55
	3	11.3	7.0	10.91	2.57	6.43	19.91	9.11
BLOCK-8	1	6.7	5.3	4.16	1.11	3.87	9.14	2.83
	2	11.9	8.7	16.95	4.00	10.39	31.34	9.10
	3	15.2	9.3	20.98	6.26	19.23	46.47	18.39
BLOCK-9	1	4.6	5.8	2.90	0.38	1.27	4.55	1.45
	2	7.6	6.0	4.86	0.77	2.83	8.46	3.90
	3	11.7	7.7	13.83	2.69	6.14	22.66	6.36

* Diameter at breast height, ** Tree height, *** Annual stem volume growth in 1991.

at breast height and mean nitrogen content in leaves were shown in Table 3.

Leaf biomass in each block ranged from 17 to 26 t/ha. In the same University Forest, Negisi *et al.* (1988) studied on the change in leaf biomass in relation to stand age in the *Cryptomeria japonica* stands in different densities. They showed 31 t/ha in the plot with the density of 3,333 trees/ha and 42 t/ha in the plot with the density of 6,667 trees/ha, indicating that the stand reached the maximum leaf biomass at the canopy closing. The leaf biomass in the study blocks may not have reached the maximum value and were still in a process of leaf biomass increment.

As shown in Fig. 2, the blocks with a high nitrogen content in leaves clearly showed a large aboveground biomass. The increment of aboveground biomass is mainly influenced by the nutrient conditions of leaves and the influence of stand density is small. As shown in Fig. 3, among the blocks with the same aboveground biomass, the block with the low density had a larger leaf biomass than the block with high density. As shown in Fig. 4, leaf biomass had good relationship with mean tree height among the all blocks regardless of density. These results showed that increment of leaf biomass was strongly influenced by tree growth and that the difference in leaf biomass among the blocks with different densities diminished rapidly in case of the planted trees with good growth.

Table 3. Each organ biomass estimated from diameter at breast height

Block	Density (trees/ha)	Stem (t/ha)	Branch (t/ha)	Leaf (t/ha)	Aboveground (t/ha)	Nitrogen* content (%)
BLOCK-1	2500	14.0	5.4	17.1	36.5	1.4
		(38)	(15)	(47)	(100)	
BLOCK-2	6944	46.6	7.0	26.0	79.6	1.7
		(58)	(9)	(33)	(100)	
BLOCK-4	6944	24.5	5.5	18.5	48.5	1.5
		(51)	(11)	(38)	(100)	
BLOCK-5	3906	42.2	7.7	24.3	74.5	2.0
		(57)	(10)	(33)	(100)	
BLOCK-6	2500	21.0	5.7	21.8	48.5	1.7
		(43)	(12)	(45)	(100)	
BLOCK-7	3906	24.5	6.6	20.1	51.2	1.6
		(48)	(13)	(39)	(100)	
BLOCK-8	2500	32.9	8.8	26.2	67.9	2.0
		(48)	(13)	(39)	(100)	
BLOCK-9	6944	39.8	6.5	19.4	65.7	2.0
		(60)	(10)	(30)	(100)	

Relative value to avoveground biomass showed in parentheses.
* Mean nitrogen content in leaves measured on planted trees at six to nine points.

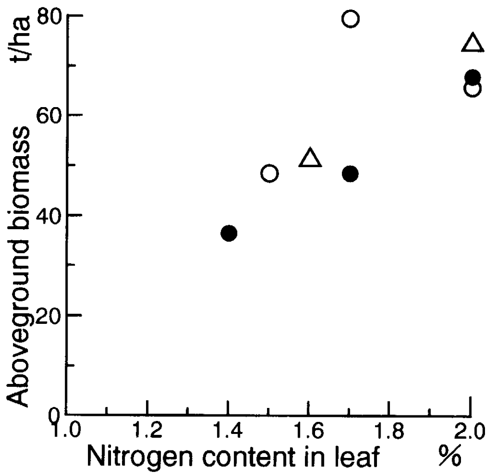

Fig. 2. Relationship between nitrogen content in leaves of planted trees and aboveground biomass.
Legend; ●, 2500 trees/ha; △, 3906 trees/ha; ○, 6944 trees/ha.

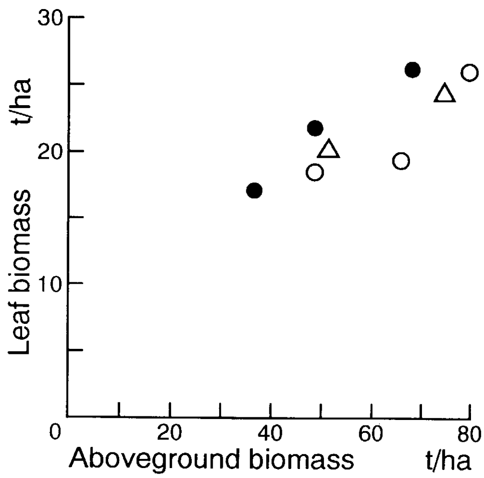

Fig. 3. Relationship between aboveground biomass and leaf biomass.
Legend are same as Fig. 2.

Leaf biomass ratio to aboveground biomass

As shown in Table 3, the leaf biomass ratio to aboveground biomass varied from 39 to 47% in the blocks with the density of 2500 trees/ha, from 33 to 39% in the blocks with the density of 3906 trees/ha and from 30 to 39% in the blocks with the density of 6944 trees/ha. Although the ratio tended to be small in blocks with large aboveground biomass, the block with low density had a large ratio among the blocks with same aboveground biomass

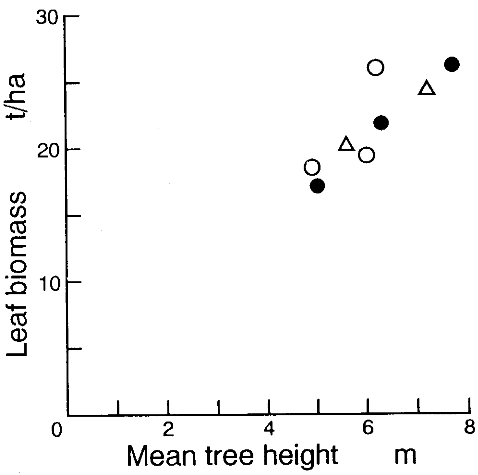

Fig. 4. Relationship between mean tree heights and leaf biomass.
Legend are same as Fig. 1.

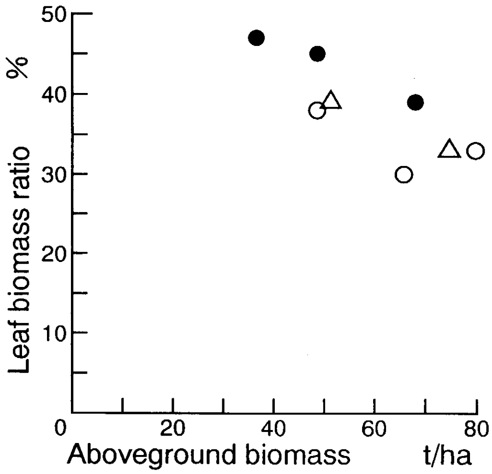

Fig. 5. Relationship between aboveground biomass and leaf biomass ratio to it.
Legend are same as Fig. 1.

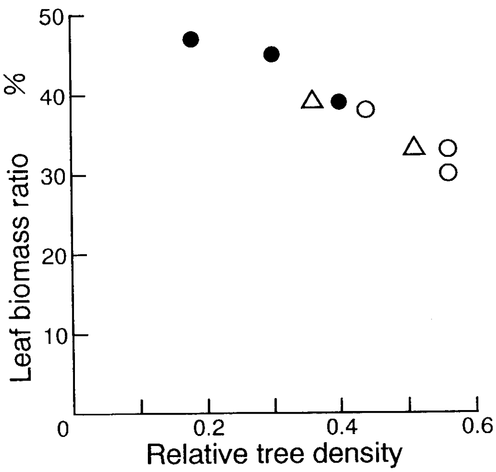

Fig. 6. Influence of relative tree density on leaf biomass ratio.
Legend are same as Fig. 1.

as shown in Fig. 5. Leaf biomass ratio was influenced not only by amount of developed leaves but also by amount of dead leaves in a year. For the blocks, relative density calculated from Sakaguchi (1961) was under 0.6 and the canopies fully didn't close. So that the amount of dead leaves was probably smaller than that of developed leaves in a year. And the difference in leaf biomass ratio was mainly influenced by developing rate of leaves, but not by dying rate.

The leaf biomass ratio tended to be small in the blocks with high relative densities as shown in Fig. 6. This relation existed among the all blocks regardless of density.

In the matured stands after canopy closing, although the branch biomass ratio to aboveground biomass was apparently small in the stand with high density, there was not apparent relationship between the relative density and the leaf biomass ratio (Satoo, 1955; Negisi *et al.*, 1988). Accordingly the apparent density effect on the leaf biomass ratio to be shown in the young stands in the process of leaf biomass increment.

Density effect on increment of leaf biomass

The stem production efficiency of a tree is calculated as annual stem growth per leaf weight. Accordingly the stem production efficiency is expressed by the following equation,

$$SPE = GS/WL$$
$$= (GS/GA)/(GA/WL)$$

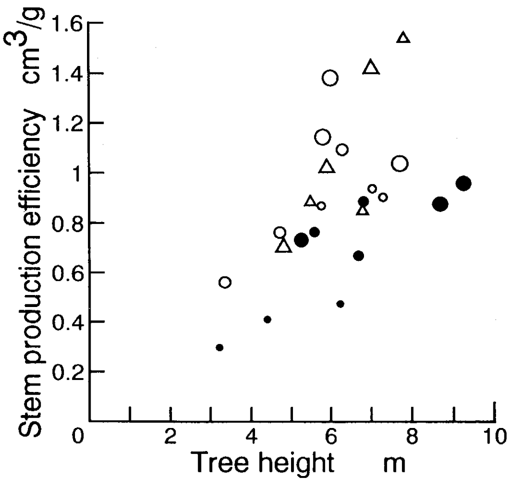

Fig. 7. Density effect on stem production efficiency.
Legend; ●, 2500 trees/ha, Small symbol is for block 1, medium one is for block 6. and large one is for block 8.
△, 3906 trees/ha, Medium one is for block 5 and large one is for block 7.
○, 6944 trees/ha, Small one is for block 2, medium one is for block 4 and large one is for block 9.

where SPE, GS, GA and WL are stem production efficiency, annual stem growth, annual organic matter production and leaf weight, respectively. This equation shows that the tree with high partitioning of assimilation products to stem (i. e. large GS/GA) or with high productive leaves (i. e. large GA/WL) has the high stem production efficiency. And the low partitioning rate to stem means the high partitioning rate to other organs, such as leaf and branch. Accordingly, among the tree with same productive leaves, the difference in the stem production efficiency depends on the difference in the partitioning of assimilation products.

Relationship between the tree height and the stem production efficiency was shown in Fig. 7. Stem production efficiency of each sample tree was calculated with annual volume growth in the last year and leaf weight. NEGISI *et al.* (1988) reported that the *Cryptomeria* stands with large leaf biomass and high leaf density decreased the stem production efficiency by increase of low productive leaves by shading. For the blocks, although the trees in the blocks with high density had more amount of low productive leaves by shading than ones in the blocks with low density, the trees in the blocks with high density had the high stem production efficiency.

In the University Forest, the young *Cryptomeria japonica* trees under 10 years of age have good relationship between the height growth and the nitrogen content in leaves (TANGE *et al.*, 1989). The same relationship was recognized among the blocks regardless of density (TANGE and MITA, unpublished). And it was reported that the leaf with same nitrogen content had same productivity (WATANABE, 1981). Accordingly, on the assumption that the trees with same tree height have leaves with same productivity, the difference in the efficiency of the sample trees with same tree height shows the difference in the partitioning rate of assimilation products to stem. From the study on the stem production efficiency of young *Pinus densiflora* stands with various densities, SATOO (1955) reported that the stem production efficiency was low in a low density stand because of the high partitioning rate to branch. In our study plot, although branch biomass in the blocks with low density was larger than ones in the blocks with high density, difference in leaf biomass ratio was larger than difference in branch biomass ratio among blocks with different densities. These results suggest that the trees in the block with low density have high partitioning rate to the increment of leaf biomass.

Summary

To clarify the density effect on increment of leaf biomass in young *Cryptomeria japonica* stand before canopy closing, we studied on the relationship between leaf biomass, stand density and stand growth. The study plot was a 8-year-old spacing experiment stand in Tokyo University Forest in Chiba. We used three blocks with density of 2500 trees/ha, two blocks with density of 3906 trees/ha and three blocks with density of 6944 trees/ha. The biomass of each block was estimated from the allometric relationship between diameter at breast height and each organ weight obtained from three sample trees.

Leaf biomass was from 17 to 26 t/ha. Leaf biomass had good relationship to mean tree height and didn't differ apparently among the blocks with different densities. Leaf biomass ratio to aboveground biomass decreased with relative density, for example 45% on the block with relative density of 0.2 and 30% on the blocks with relative density of 0.5. Stem production efficiency tended to be large on the sample trees with high nitrogen content in leaves or stand in the blocks with high density. Accordingly trees in blocks with low density had high partitioning rate to other organs but stem, such as leaf and branch. These results suggested the density effect on the leaf development.

Key words: Young *Cryptomeria japonica* stand, Leaf biomass, Density effect, Stem production efficiency

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林冠閉鎖前のスギ幼齢林の葉現存量変化に対する密度の影響

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要　旨

林冠閉鎖前の若いスギ人工林の葉現存量の増加過程に対する林分密度の影響を明らかにするために，林分密度，成長と葉現存量との関係を調べた。東京大学千葉演習林前沢（28 林班 $C_{1\text{-}3}$ 小

班，1984 年 4 月植栽，調査時（1992 年 5 月）現在 8 年生）にある密度試験地内に 3 段階の密度で設定された 8 試験区画（2500本/ha が 3 区画，3906本/ha が 2 区画，6944本/ha が 3 区画）を対象とした。各試験区画の現存量は，3 本の供試木で得られた胸高直径との相対成長関係から推定した。

葉現存量は 17〜26 t/ha の範囲にあり，密度によらず平均樹高の大きい試験区画ほど多い傾向にあり，密度による葉現存量差は小さかった。地上部現存量に占める葉現存量の割合は，相対密度が 0.2 の試験区画では 45%, 0.5 の試験区画では 30% であり，相対立木密度が低いほど大きい傾向にあった。供試木の葉の幹生産能率は，葉中窒素濃度が高いほど，また密度が高いほど，高い傾向にあった。密度の低い試験区画の供試木で幹生産能率が低いことは，幹以外の器官，つまり葉や枝への同化物の配分率が高いことを示しており，葉現存量比率が高い結果と一致した。これらの結果から，葉現存量増加への密度効果が示唆された。

キーワード: スギ幼齢林，葉現存量，密度効果，幹生産能率