

Density effects on the growth of trees at early growing stage in alder (*Alnus hirsuta* var. *sibirica*) stand

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ヤマハンノキ幼令林分の樹木の生長 に及ぼす密度効果について

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要 旨

樹木の生長に及ぼす密度効果について立木密度の異なった4プロットで調べた。
高密度区の樹木の直径生長率と樹高生長率は低密度区のそれより早くにぶった。
 D_0^2H と樹木の各部分の重さとの相対生長関係は、プロット間で差がみられなかった。
C—D効果は樹高生長より直径生長にはっきりあらわれた。
高密度区の樹高の順位変動は低密度区に比べ著しかった。

Résumé

Effects of stand density on the tree growth were investigated in four different planting plots.

The growth rate of both diameter and height of trees in high density plots decreased earlier than those in low density plots seasonally. There were little difference in the allometric relationships to D_0^2H (D_0 ; diameter at base, H ; tree height) and weight of each part among the plots. C—D effect was shown more clearly in diameter than in height of tree. The change of tree height ranking in high density plots was larger than in low density plots.

Introduction

There are many factors which affect the growth of tree and quality of timber, but among the factors density is the only one controllable factor. The density effects on the growth of annual plants have been studied for a long time, but those of perennial plants were recently began. Most of the investigations of density effect have been concerned with the biomass or productivity¹⁾²⁾³⁾⁴⁾. There are many reports about density effects on phenological growth of annual plants, but only a few reports about perennial plants. In broadleaved deciduous forests, there is a need to investigate phenological growth of trees to define the mechanism of density effects. There have been few studies of the effects on vertical direction of stand and on root part.

In this study, phenological density effects are also discussed. This study was carried out with 3-year-old sapling stands of *Alnus hirsuta* var. *sibirica*.

Methods and materials

At the end of March in 1976, 1-year-old saplings of *Alnus hirsuta* var. *sibirica* were planted at the nursery of Kyoto university forests, Japan. They were planted squarely with different four tree densities, and those in plots 1, 2, 3 and 4 spaced at equal distances of 30, 40, 80 and 160 cm respectively. Stand conditions of all plots were same except for the density differences. The size of the plots ranged from 20 m² to 60 m².

In 1977 monthly measurements were taken of the diameter at base, at breast height and at lowest living branch. Tree height and height at the lowest living branch were also measured.

Litterfall traps were set on the floor. Size of the traps were 2m×2m (plot 1 and 2), 2.4m×2.4m (plot 3) and 3.2m×3.2m (plot 4). Litterfall was collected at intervals of ten days, and was classified into leaves, branches, stems and others.

The biomass of parts of sapling trees was estimated by the harvest method in August 1977 and January 1978.

Results

The experimental plots were set in late March 1976. Stand crowns in plot 1 and 2 were closed in summer of the same year and that in plot 3 was almost closed in September, and the emergence of leaves began in late March, a week earlier than an ordinary year. Sapling trees in plot 2 were attacked by *Heptopylla picea* M. in early July and a few trees of the plot was damaged by *Anoplophora malasiaca* T. In 1977 there was no rainy season in Japan, so some trees were killed by drought in plot 1.

Growth of diameter and tree height

The distribution patterns of tree diameters were approximately normal or slightly reverse J-shape in

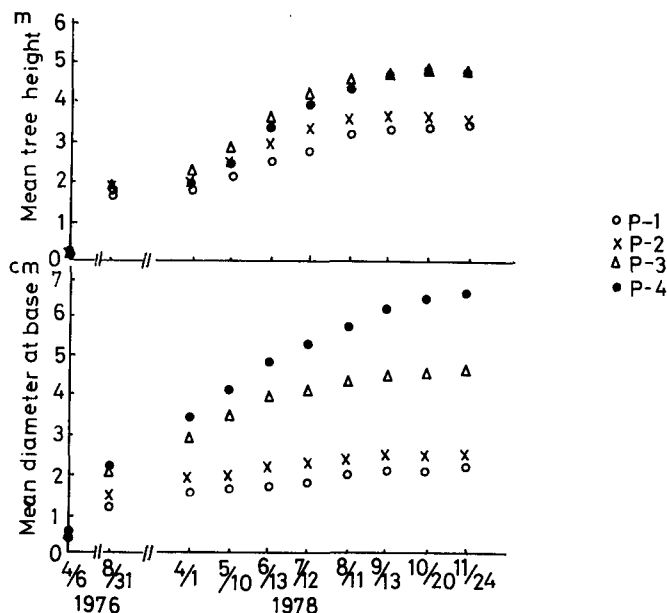


Fig. 1. Seasonal changes of mean diameter at base and tree height.

all plots. Seasonal changes in mean diameter at base and tree height are shown in Fig. 1.

Growth of tree height began in early April for high density plots (plot 1 and 2) and was decreased in mid-July, whereas in low density plots the height increased until late August. Differences in the annual height growth between trees in high and in low density plots occurred from July to September. Differences in diameter growth of trees in each plot were more remarked than differences in tree height. The growth of diameter in plot

4 with lowest density was constant until September while that in plot 3 decreased in mid-June and mid-September. The growth of height in high density plots decreased in late July.

Relationships between mean tree height ($\bar{H}$) and clear bole length ($\bar{H}_B$) are shown in Fig. 2. In each plot, tree height growth was high from 10th May to 12th July while clear bole length increased little. When the dry season began in mid-July, the clear bole length increased more than the tree height in three plots except for plot 4, and then the growth rate of tree height decreased whereas clear bole length increased. At this stage crown depth ($\bar{H} - \bar{H}_B$) decreased in all plots, especially in plot 3. In plot 4, the growth of tree height was almost constant until mid-September and in October, defoliation season, the increment became little while that of $\bar{H}_B$ decreased slightly. In 1977 the crown depth decreased in plot 2, a little in plot 1, almost nothing in plot 3 and twice as much as in 1976 in plot 4.

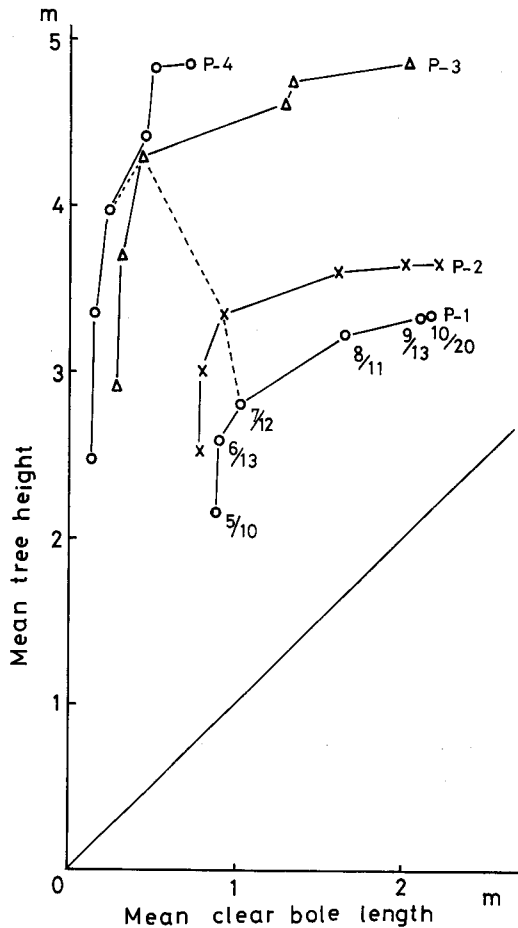


Fig. 2. Relation between mean tree height and mean clear bole length.
Number represents a measuring date.

Table 1. The ratio of tree height to diameter increment at base.

Plot	1	2	3	4
1976	1.42	1.03	0.87	0.74
1977	1.71	2.22	1.56	1.41

Table 1 shows the ratio of tree height to diameter increment at base in 1976 and 1977. The higher the tree density was, the higher the ratio became in 1976. The ratio in plot 2 was the highest followed by plot 1, 2, 3 in descending order though the order of tree density among plots was not changed in 1977.

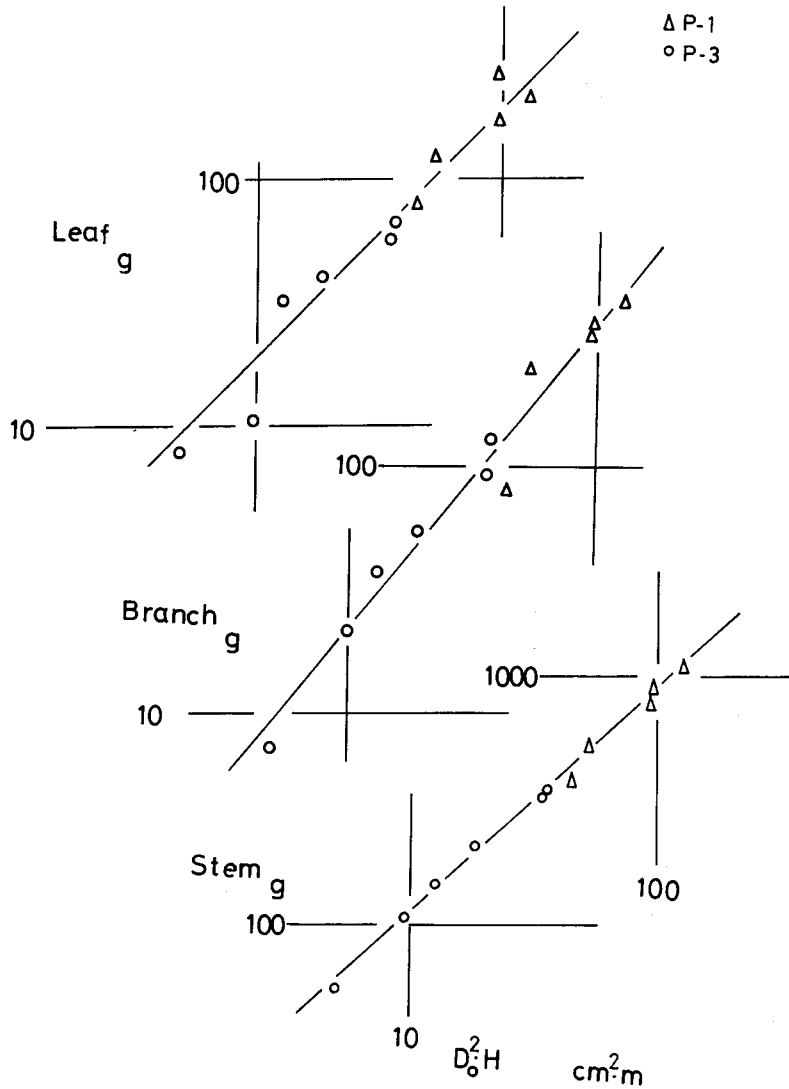


Fig. 3. Allometric relations between D_0^2H and weight of each tree part.

Biomass of each part of sample trees in plot 1 and 3 was estimated by the harvest method in mid-August 1977. Allometric relations between D_0^2H and weight of each tree part are shown in Fig. 3.

The estimations were as follows;

$$\log W_L = \log D_0^2H + 0.2875 \quad (1)$$

$$\log W_B = \log D_0^2H + 0.1144 \quad (2)$$

$$\log W_S = \log D_0^2H + 1.1472 \quad (3)$$

Where W_L , W_B and W_S are dry weight of leaf, branch and stem respectively.

In each part differences among the four plots in 1977 and 1978 were not clearly shown. Biomass of each plot was estimated by the equations ((1)-(3)).

	P-1	P-2	P-3	P-4
Leaves	12.5	12.8	12.8	12.7
Branches	17.3	20.4	26.4	29.7
Stems	70.2	66.8	60.8	57.6
%				
Stand density g/m ³	1745	2039	2038	857

Fig. 4. The ratio of the dry weight of leaves, branches and stems to total dry weight above the ground.

The allocation of growth tissue was expressed as the ratio of the dry weight of leaves, branches and stems to the total dry weight above ground as shown in Fig. 4. Dead plants and litterfall were not included in the ratio of Fig. 4. Though the ratio of leaves slightly decreased with increasing of tree density, it seems approximately equal. The ratio of branches increased with greater tree density whereas that of stems decreased. The almost same results with this investigation were reported in various stands¹⁾²⁾. In a population of the same species and age, the conditions except for tree density being same, relation between mean dry weight of individual trees (w) and tree density (ρ) is as follows;

$$\frac{1}{w} = A\rho + B \quad (4)$$

where A and B are constants and dependent on time.

Relation between w and ρ is shown in Fig. 5. It was fitted with the equation (4). In closed, self-thinning stand when trees are similar figures and same specific gravity of individuals, relation between w and ρ is as follows;

$$w\rho^{\frac{3}{2}}_{\max} = K_1 \quad (5)$$

where $\rho_{\max}$ is the maximum density at a certain stage and K_1 is constant. In relation between $\log w$ and $\log \rho_{\max}$, the slope of formula is -1.5

Phenological changes of leaf-litterfall

The pattern of leaf-litterfall was phenologically investigated among the different density plots (Fig. 6).

In Japan as a rule, the first peak of leaf-litterfall in an alder forest occurs in early July to mid-July when the leaves have already expanded, and the second peak occurs in late October to early November³⁾. In Fig. 6 the first peak of leaf-litterfall appeared in early June to mid-June when the leaves had already expanded, except plot 4 with the lowest density. The second highest in the year was in mid-July to mid-August, and from late

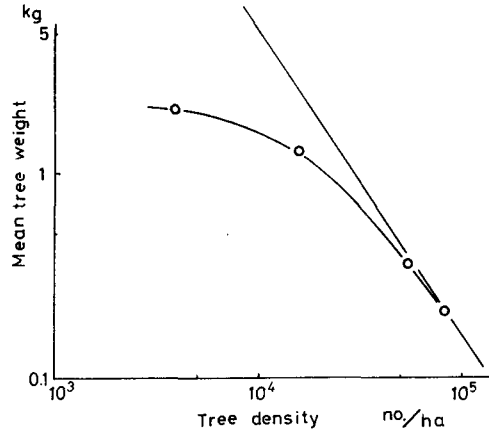


Fig. 5. The relationship between tree density and mean dry weight per tree.

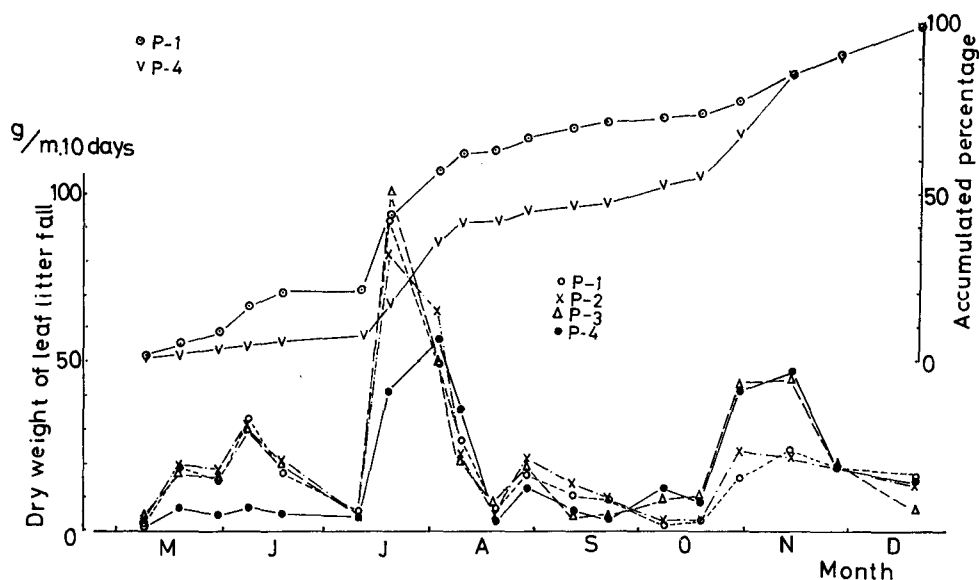


Fig. 6. Phenological changes of leaf litterfall weight.

August to late October the weight of leaf-litterfall was approximately constant. Thereafter it rose to the last peak in the year. When leaves expanded, litterfall appeared remarkably in high density plots but not in low density plots. During June to August, the dry season, leaf defoliation was observed in both high and low density tree plots. However the time of the defoliation in high tree density plots was more synchronized with drought than that of low tree density plots. The greater part of weight of litterfall in high density plots in a year was occupied up to late July, whereas in low density plots up to late September.

Rank of tree height

In a forest, the rank of tree heights changes with the growth of trees. The rank of trees in height was investigated in the stand of which structure changed remarkably except plot 4 because of its individuals was not enough (Table 2). The survey was carried out in plots

Table 2. Rank of tree height

Time of ranking compared	1 April-13 June			13 June-11 August			11 August-20 October		
Plot	1	2	3	1	2	3	1	2	3
R_s (1)	0.9287	0.9279	0.8363	0.9471	0.9772	0.6275	0.9511	0.9924	0.9089
Variance of differences (2)	24.04	6.34	17.02	14.81	2.18	38.74	7.80	0.61	9.47
Mean value (3)	3.73	1.83	3.20	2.90	1.00	4.56	2.18	0.50	1.98
Number of trees (4)	45	24	25	41	24	25	32	22	25

$$(1) R_s = 1 - \frac{6 \sum d_i^2}{N(N^2 - 1)}$$

$$(2) \sum d_i^2 / N$$

$$(3) \sum |d_i| / N$$

$$(4) N$$

$$(|x_i - y_i| = |d_i|)$$

1, 2 and 3 at intervals of two months. Changes of the rank were most remarkable between 1st of April to 13th of June when the growth rate of trees was the highest in a year, then changes of the rank in the dry season from 13th June to 11th August followed. In the stable period from 11th August to 20th October, the changes gradually decreased, except for in plot 3 of low tree density. Rank of tree height was divided into three groups; first group was composed of higher trees, second group of middle trees, third group of lower trees. In plot 1, between 1st April to 13th June, variance of rank was in the order of the third > the second > the first group, between 13th June to 11th August; first > second > third and between 1st April to 11th August the variance was in the order of first > second > third group, between 11th August to 20th October it was second > third > first. In plot 3, the variance was in the order of second > first > third in a year.

Table 3. Ranking changes of tree heights

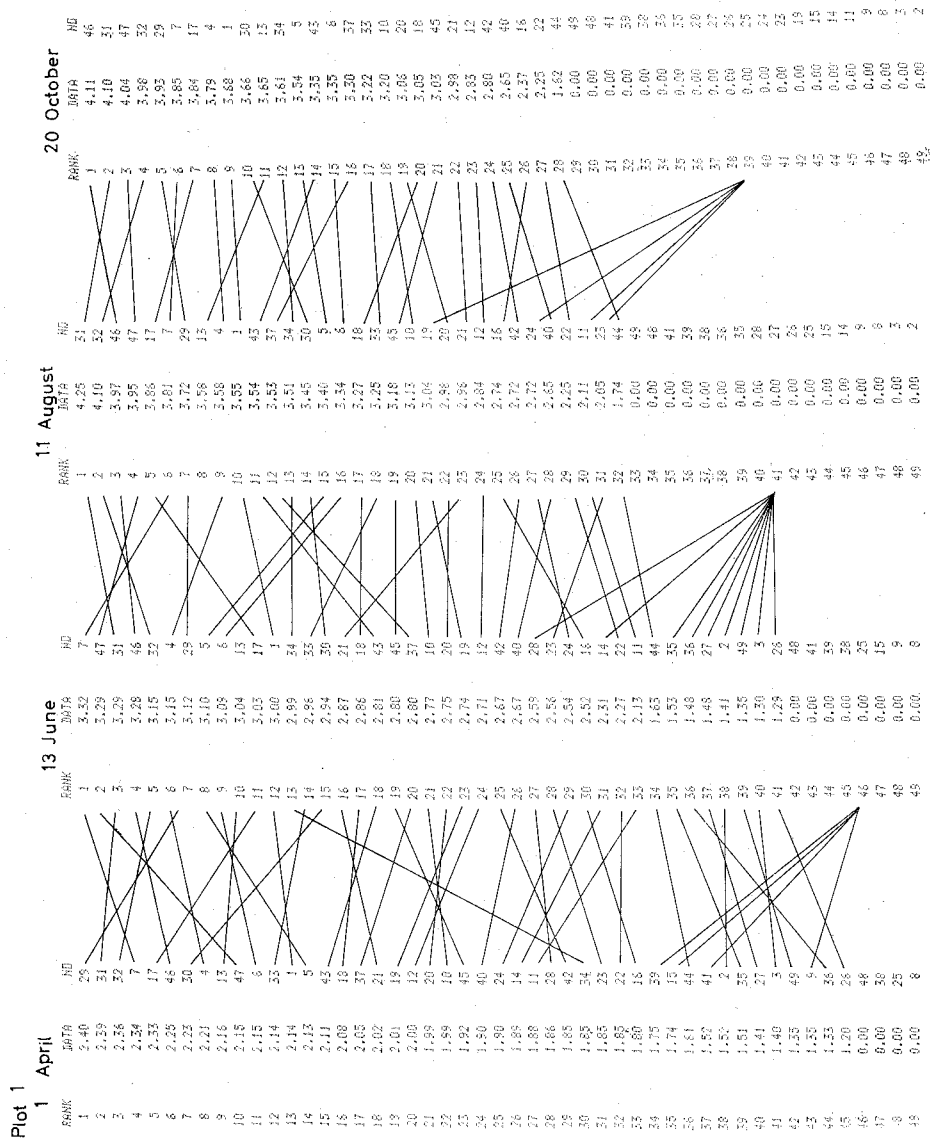
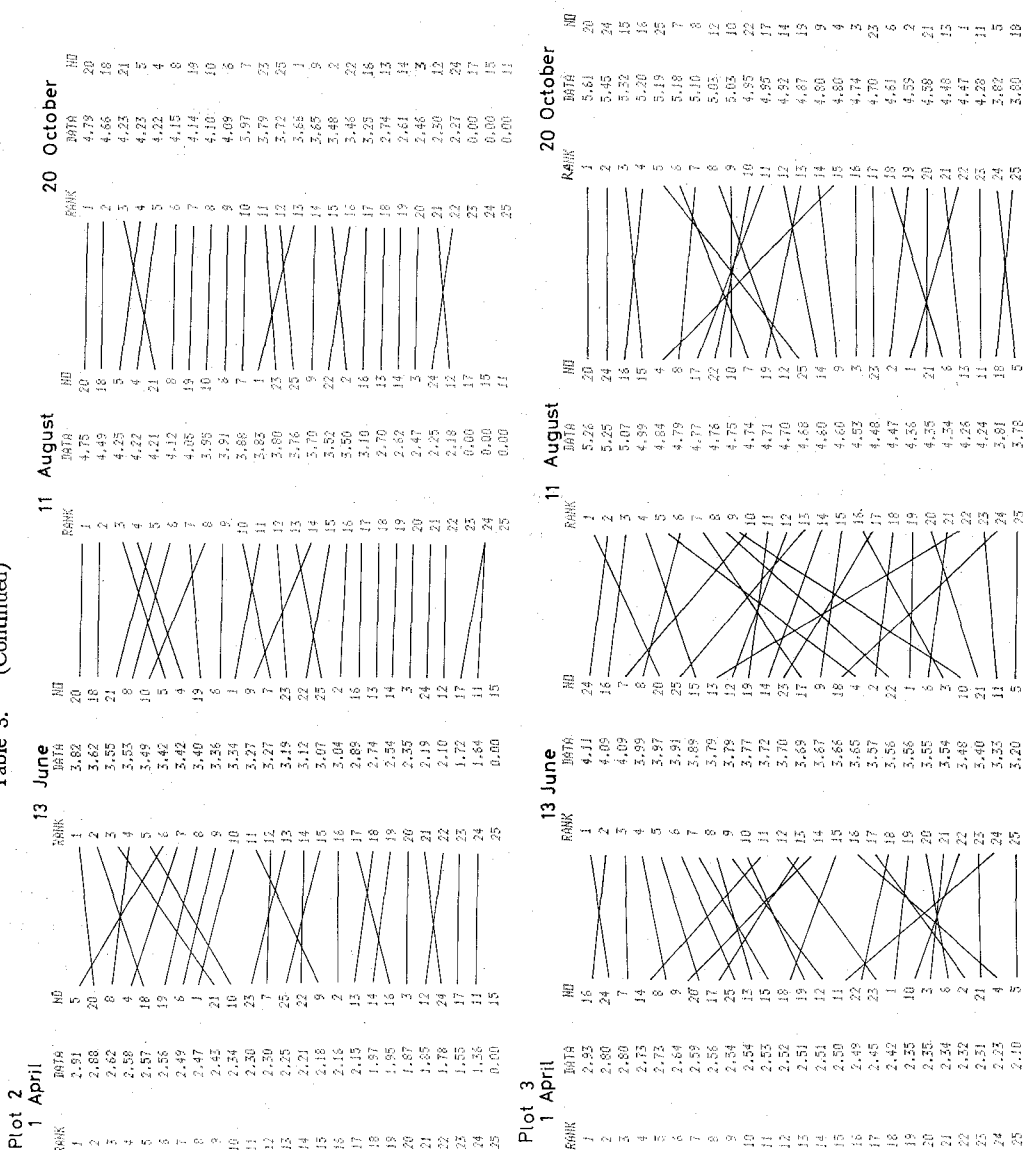


Table 3. (Continued)



Changes of the rank among three plots were also investigated (Table 3). The changes of rank were in the order of plot 3>1>2 through the year. Between 1st April to 13th June and 11th August to 20th October, the orders were plot 1>3>2 whereas between 13th June to 11th August, that were plot 3>1>2.

Discussion

There are many reports about the effects of density in view of tree biomass¹⁾²⁾³⁾⁴⁾. In this study, tree density in three dimensions and phenological change was surveyed to estimate weight or volume of parts of a plant, diameter and tree height are useful for the parameters and can be measured easily. As the stands in this study were composed of sapling trees,

diameter at base and tree height were used. Growth of the diameter was more affected by density than that of tree height. It is likely that intolerant plants were more tend to have this characteristics. The higher ratio of mean tree height to mean diameter increment at base in 1976 ranged in the order of tree height density among 4 plots, but in 1977 the highest ratio was observed in plot 2. It seems that this result can be caused by stand density in three dimensions. Stand densities in three dimensions are shown in Fig. 4. In August 1977, stand density in plot 2 was the highest in all plots and followed in the order of plot 1, 3 and 4. This result suggests that growth of trees is more dependent on stand density per unit volume than that per unit area. It seems that differences among stand densities in two dimensions from in three dimensions are caused at an early stage of the life cycle and not at the equilibrium condition of stand structure.

Relation between W_T and ρ was accorded with $-3/2$ power law. Mean dry weight in plot 1 and 2 was obtained in full density curve. Survivorship rate at the end of the year in plots 1, 2, 3 and 4 were 69%, 90%, 100% and 100% respectively. In plot 1 and 2, self-thinning took place and perfectly closed, but did not in plot 3 and 4. $w\rho^{3/2}$ is equal to K_1 , therefore when tree age and tree specific gravity were same in all plots,

$$w \propto D^3 \text{ or } H^3$$

$$\text{Then } D\rho^{1/2} = K_2 \text{ or } H^{1/2} = K_3$$

$$K_2, K_3; \text{constants}$$

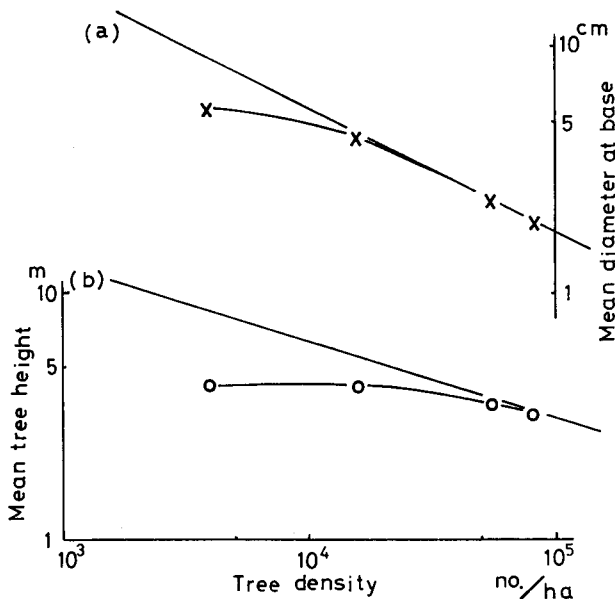


Fig. 7. The relationships between tree density and mean diameter (a), and mean tree height (b).

In Fig. 7, relation between $\bar{D}_0$ and ρ was expressed with the slope of -0.5 , whereas relationships between $\bar{H}$ and ρ was with -0.23 . This result suggests that $\bar{D}_0$ was more dependent on tree density than $\bar{H}$. Though the allometric relationship between D_0^2H and each part of a plant was the same among 4 plots, the allocation was different in each plot. Difference of the allocation was caused by the power value in relation between each part weight of individuals and D_0^2H . Power value estimated from $W_L - D_0^2H$ was equal to 1. D_0^2H of individuals in low density

plots were comparatively distributed at the large values, so that of low density plots which relatively occupied with large trees had relatively large biomass of branch and less stem biomass.

After dry season weight of litterfall was larger in low density plots than in higher

density plots. Judging from leaf biomass estimated on 20th August 1977 and litterfall weight after 20th August, in high density plots leaf biomass was only slightly increased after the dry season and continued the same condition until autumn, the defoliation season. In low density plots leaf biomass recovered a little and the weight of litterfall in November became larger than that of higher density plots. When estimating the allocation of parts in a year, dead part should be included in the total. The allocation ratio in Fig. 3 may be changed and differences in the allocation ratio among plots may become less, as the higher tree density, the larger the part of weight of leaves and branches became.

Changes of rank in tree height were more remarkable in high density plot than in low density plot. The rank in high density plot seems to be affected mostly by light factor, so it may be almost impossible for lower rank trees to become high rank trees. It seems that genetic factors of lower height trees scarcely affected the growth. On the other hand it was possible that genetic factor of higher trees affected the growth. Low height trees can scarcely become relatively high trees as they are shaded by surrounding trees. The same result was shown when trees in a plot were divided into three groups according to tree height. In low density plots, the changes of low trees were quite marked whereas changes of high trees were slight. In high density plots the changes of the middle trees were the most marked whereas those trees in high and low groups did not change much. It is shown in Table 3 that many trees in the middle group moved to either the high or low group. This result shows that low trees in high density plots are not able to become relatively high trees and in man-made forest, those trees should be thinned. It is possible that in low density stand trees of a certain group may join a higher group.

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