The Mechanism and Function of Tree Root in the Process of Forest Production I

Method of investigation and estimation of the root biomass

By

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Summary : Many have been studied in this book concerning the mechanism and function of tree root in the processes of forest production. In this issue have been studied the methods for the investigation and estimation of root biomass. They are "Accuracy for the Investigation of Root Biomass by Soil Block Sampling," "Application of Regression Equations to Estimate Root Biomass in Stands," and "Methods to Analyse the Distribution of Root Biomass."

Contents

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I. Introduction

The root, just like the stem, branch and so on, is one of the most important parts of a tree. It supports the above-ground parts, though existing underground, absorbs water and nutriment dissolving in it, sends them up to the above-ground parts, and continues working usefully as in reserving nutriment. Its function, growth and property of distribution are, therefore, very significant in analysing the tree growth.

In recent years, the study about the forest soil and fertilization has made steady progress. As a result, it has revealed the necessity to make clear the fundamental problems about the forest productivity, such as the function, growth and distribution of root, all of which are directly connected with the soil and support the forest productivity.

But despite this importance, few detailed studies have been made, apparently partly because roots are not self-evident in our actual life, and partly because, being underground, they are not easy to observe and study.

In paying great attention to these points, the author has tried to make clear the distribution and form of roots from the plant sociological viewpoint for the purpose of examining both the ecological properties of trees according to their types, and the responses of them to their environments. As a result, he found the differences in property between the roots of various species*[1]. Whereupon, using these studies as a basis, he investigated and measured the standing biomass, production and storage of each part of a tree, while mainly analysing the root biomass and absorption structure in regard to the problems of the underground parts relating to the forest productivity. Thus, he inquired ecologically into the forest productivity and the mechanism and function of roots.

II. Purpose of study

The mechanism of forest productivity has been, generally speaking, represented only by the structure of assimilation in leaves as the productive structure. In the underground parts as well as in the above-ground parts, however, the productive structure of roots might be counted in, as roots function to sustain the forest productivity. This means, in other words, that the assimilative structure of the above-ground parts and the absorptive structure for water and nutriment of the underground parts play an important role to support the forest productivity.

The purpose of this study is to make clear the relationship between the structures of the under-and-above ground parts and the forest productivity. For this purpose, the analysis was made of distribution of the root biomass under various conditions, such as site conditions, tree densities and stand ages, concentrating on four important species, *C. japonica*, *Ch. obtusa*, *P. densiflora*, and *L. leptolepis*.

From 1957 to 1966, this study was carried out soon after the study about the forms and distributions of roots came to an end. Here is one as of 1967 when finished. Since then, many reports have been published about the forest productivity, and the author has gathered in-

*[1] Karizumi, N.: Studies on the form and distribution habit of the tree root. Bull. Gov. For. Exp. Sta., 94, 205 pp., (1957).

creasing materials about it; but they are not presented here, for there will come another opportunity to do so later.

III. Background of study

This study is a series of the analysis of tree growth. The basic idea to clarify the forest productivity through mainly analysing the standing biomass is backed up by the ecological theories to analyse the productivity of plant community quantitatively.

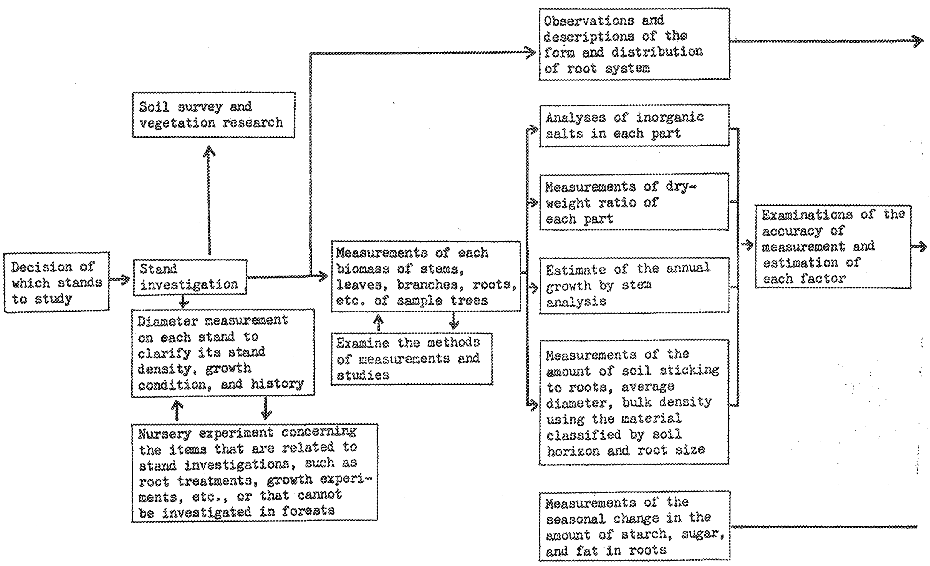
In that respect many works had been performed at home and abroad. But due to difficulty in studyig underground parts as mentioned earlier, few researches had been carried out on these problems in the forest community including the underground parts.

The author and his assistants had already gone through the domestic and foreign reports as to the root system. And in doing so, they found that very few treated root systems quantitatively from the viewpoint of the forest productivity, and that none was noticeable thereafter.

IV. Method of study and measurements of the standing biomass*1

1. Procedure

The standing biomass analyses were made mainly as to the important stands, such as *C. japonica*, *Ch. obtusa*, *P. densiflora*, *L. leptolepis*, etc., which site conditions, stand ages and stand densities, were different from one another. And also experiments were performed in the sampling fields concerning such materials as could not be directly got through investigations of the existing stands, as the study of botanical regularity or root quantity analysis of the isolated trees.



*1 In this study, biomass is presented as dry weight.

The environmental conditions of stands, especially soil factors, were analysed along with the measurements of the standing biomass in forests. The total production of inorganic salts were estimated through these measurements. The principal inorganic salts such as N, P_2O_5, K_2O, CaO, were analysed in relation to the metabolism of roots. The measurements of root respiration and the physiological experiments about the difference of absorption were scrupulously carried out in each part of a root. Each factor necessary for estimation was measured in order to find out the surface area for absorption. As concerns the supporting function, the root form was observed, and the seasonal change of the quantities of starch, sugar and fat of the roots was observed as pertaining to the storing function.

2. **Investigated stands**

The investigated stands were chosen while taking into account different stand ages, site indices and tree densities as accurately and to the extent possible. However, fund limitation restricted a much desired fuller investigation.

The sample stands with equal site and nurturing conditions, and containing over fifty sample trees a site, were chosen. Appendix-Table shows the sample areas, the number of the trees and stand conditions. The location of the sample stands is shown in Fig. 2, and the average values of each measured part biomass in Appendix-Table.

1) Species*[1]

The main objects are the planted species, such as *C. japonica*, *Ch. obtusa*, *P. densiflora*, and *L. leptolepis*. In order to compare the differences in ecological qualities between these species and the other species, investigation was carried out about such trees as *P. thunbergii*, *P. taeda*, *P. strobus*, *Ch. pisifera*, *Eucalyptus globulus*, *Zelkova serrata*, *Abies firma*, *Tsuga canadensis*, *Acacia dencurrens* v. *dealbata*, *Quercus mongolica* v. *grosseserrata*, *Betula platyphylla* v. *japonica*, *Betula davurica*. And here, the abbreviated words are used for convenience such as S for Sugi in Japanese *C. japonica*, H for Hinoki in Japanese *Ch. obtusa*, A for Akamatsu in Japanese *P.*

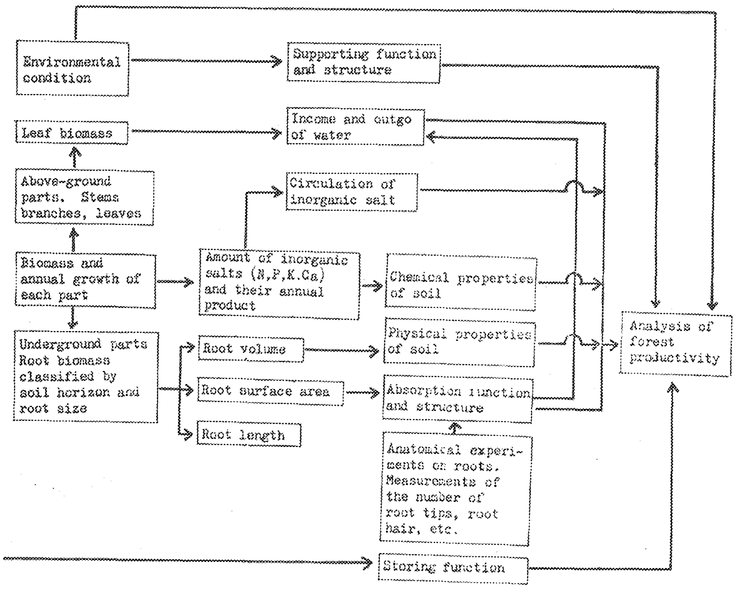


Fig. 1 Procedure of study.

*1 As these species are often used hereinafter, their generic names are abridged as *C.* for *Cryptomeria*, *Ch.* for *Chamaecyparis*, *L.* for *Larix*, and *P.* for *Pinus*.

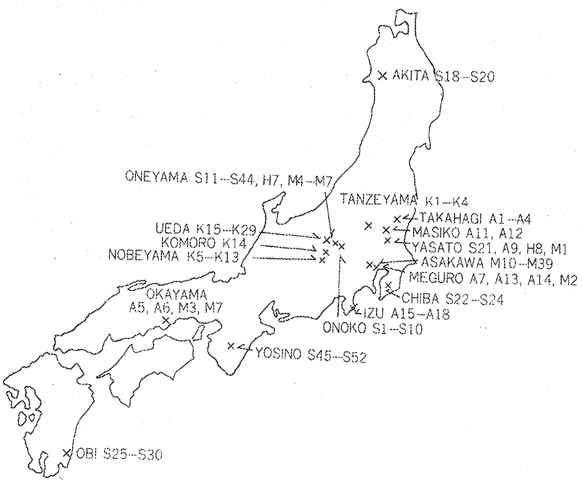


Fig. 2 Map of investigated stands.

densiflora, K for Karamatsu in Japanese *L. leptolepis*, and M for the rest.

The numerals following them are their stand number. S 1 is, for example, the simpler form for stand No. 1 of *C. japonica*.

2) Stand age

The sampling stand age for measuring all standing root biomass is shown in Appendix-Table. As for *C. japonica*, the stand were 10 to 50 years old; 10 stands out of 28 being 20 to 30 years old. Most of *P. densiflora* stands were 10 to 20 years old, and *L. leptolepis* stands were limited to those which were over 30 years old; 17 stands out of 29 being 40 to 50 years.

3) Number of sample stands and trees

Accordingly, we picked out the sample stands, nurseries excluded, while taking account of soil, stand age, site quality, tree density, and locality. Circumstances of investigation, however, made it impossible to decide the uniformity of the sample stands under the fittest condition. And regrettably, the number of the investigated stands are unsettled according to each species. The samples were, for instance, 52 for *C. japonica*, 29 for *L. leptolepis*, 8 for *Ch. obtusa*, and 12 for *P. densiflora*. In each stand, the trees were taken out as in Appendix-Table. As shown in Appendix-Table, the number of the sample trees of each species cut down for investigation are as follows: 180 for *C. japonica*, 41 for *Ch. obtusa*, 135 for *P. densiflora*, 109 for *L. leptolepis*, 8 for *Ch. pisifera*, 3 for *Eucalyptus globulus*, 5 for *Zelkova serrata*, 5 for *Abies firma*, 5 for *Tsuga canadensis*, 5 for *Acacia dencurrens* v. *dealbata*, 2 for *Quercus mongolica* v. *grosse-serrata*, 2 for *Betula platyphylla*, and 2 for *Betula davurica*.

4) Investigated locality

Concerning the *C. japonica* taken here as an example, we attempted to compare and examine differences in growing situations in each locality with its own hereditabilities, environmental conditions and nursing techniques, so the various stands shown in Fig. 2, were taken out from Akita Prefecture in Northern Japan to Miyazaki Prefecture in Southern Japan. The main object for further investigation was still the stands in the North Kanto district, such as Oneyama and Onokoyama, Gumma Prefecture. As to the *Ch. obtusa*, widely distributed stands were selected in the Gero district, Gifu Prefecture, and the *P. densiflora*, stands in the Ibaragi district. The stands in the Okayama district were also picked out as *P. densiflora* stands in the infertile and dry sites. As to *L. leptolepis*, the stands were selected in the Nikko district, Tochigi Prefecture, and the Nobeyama and Wadamura districts, Nagano Prefecture.

5) Soil conditions

The sample stands of *C. japonica* were chosen in the B_A–Bl_E type soils including 12 soil types. Particularly for classification by stand age, 18 stands were taken out in the moderate soil of Bl_D. As emphasis was put on analysis of the moderately grown stands, *Ch. obtusa* were chiefly sampled in the soils of B_D–Bl_D, and moreover, only a dry B_B soil-typed stand was picked out as one having a contrast of the soil conditions. In the same way, the moderately grown and Bl_D–Bl_D(d) soil-typed stands of *P. densiflora* were surveyed, and in order to make comparisons, the Er soil-typed stands were taken out in the Okayama disrict. In the study of *L. leptolepis*, things are different. That is to say, emphasis was put on the connection between soil conditions and growth. Many unproductive plantations, and the normal stands contrasting to them, were chosen in various areas for that reason. In Nobeyama national forest in particular, the unproductive plantation under heavy wet conditions was picked out as a sample stand. As a whole, however, many were in the Bl_D typed stands, and most of them were below the standard in growth.

6) Site quality index*1

Dividing this relation by both the site indices in Appendix-Table and the classes in the yield table, we got twenty-one stands of *C. japonica* in the second-class sites with the site indexes from eighteen to twenty-two, thirteen in the first-class sites or above, and six in the third or below. Thus these stands concentrated on the sites, were they grew moderately; for observation was directed mainly on growth analysis according to stand age, as already mentioned.

Four out of eight *Ch. obtusa* sample stands were on the first-class sites or above in the yield table. *P. densiflora* stands on the second-class sites or above were observed according to stand age, but many of the sample stands in Masiko and Okayama, six out of twelve stands, were on the third-class sites.

The purpose of investigation of *L. leptolepis* was to analyse the unproductive plantations. So eighteen out of twenty-nine stands were on the fourth-class sites or below, which site indices were below twelve.

The yield tables of the main species are as follows:

Forest Agency & Forest Experiment Station: The yield table of *C. japonica* stands in the districts of Northern Kanto and Abukuma, 1955.

Forest Agency & Forest Experiment Station: The yield table of *Ch. obtusa* in the Kiso district, 1954.

Forst Agency: The yield table of *P. densiflora* stands in the Iwaki district.

Forest Agency & Forest Experiment Station: The yield table of *L. leptolepis* stands in the Shinshu district, 1956.

The site index was set up analogizing the heights of 45-year-old trees with the height curve in each yield table.

7) Tree density (Stand density)

The actual tree density is the ratio, i. e., the density index, to the maximum tree density of each stand calculated by the REINEKE's formula*2 in footnotes Appendix-Table. The tree density of each stand is calculated. According to the result, twenty-seven of *C. japonica* stands were within the density indices of 0.3～0.6, twenty-two stands within those of 0.6～0.9, only one in those 0.9 or above, and 2 stands in those 0.3 or below. Most were of moderate density. *Ch. obtusa* sample stands, though not many on the whole, were taken from the comparatively sparse planting stands within those of 0.3～0.6. Eight out of twelve *P. densiflora* sample stands

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*1 A site quality index is used as a site index hereinafter.

*2 REINEKE, L. H.: Perfecting a stand-density index for even-aged forests. Jour. Agric. Res., 46. pp., 627～638, (1933).

were within those of 0.6～0.9. They were rather more dense than those of *Ch. obtusa.*

Fifteen out of twenty-nine *L. leptolepis* stands were within those of 0.3～0.6, twelve out of them within those of 0.6～0.9, and only two within those 0.9 or above. The slightly dense stands were sampled on the whole. The reader may refer to Appendix-Table 1 about the density index of each stand.

8) Forest conditions of sample stands

Appendix-Table 1 shows in each sample stand the square measure, tree number, average tree height, average basal area, volume, and values of each factor per ha which were calculated on these by the square measure ratio.

3. **Investigation of stands in the sampling plots**

1) Diameter measurement and selection of sample trees

After the square measure survey of the sample plots by the circumference measurement and the diameter measurement, the sample trees were divided into three groups in the order of basal area, such as large diameter tree, medium diameter tree, and small diameter tree. The sample trees were picked out at random from each group.

The more sample trees there are, the more reliable the accuracy in estimating the standing biomass becomes.

However, trees were limited to about five to eight because of the efficiency of investigation. In order to examine the accuracy of measurement, fifteen sample trees in S 13 and twenty-three in A 2 were picked out. As concerns *L. leptolepis*, the exact investigating trees per stand were cut down to about three to add to sample stands. See Appendix-Table 2. There will be another opportunity about how to decide the number of the sample trees.

The trees damaged by insects, wind or snow were excluded from the sample trees. And also the trees around which there were big stones or big interstices formed by dead trees, or trees which were too close to each other to make a root biomass survey, were excluded. This is all to facilitate convenience of investigation.

2) Estimation of part biomass*1 and its method

The next step is to fell the sample trees picked out and then to measure the part biomass of their leaves, branches, stem, and each root. As a considerable amount of time and effort must be spent on classifying, leaves, branches and roots, the author devised the following method: The first step is to take a certain amount out of all the branches and leaves or of all the roots. The second is to classify into parts, such as leaves and branches, or fine roots and small diameter roots, etc. And the third or final step is to estimate the total biomass. This process is as follows:

① Method and calculation

When the total biomass to be measured is divided into a certain biomass, the numbers of unit are to be M.

The numbers of m are now to be picked up from them at random. The expression of $(y-rx)$ is to show $N(0, \sigma^2)$. And so, if "r" is to be taken to minimize the equation of $Q_0 = \sum^m (y-rx)^2$, the equation of $Q_0/\sigma^2 = \sum (y-rx)^2/\sigma^2$ is to take the distribution of χ^2 at the freedom degree of $(m-1)$. Sampling unit is equal to one of M. New, f (fine root), s (small root) in the sampling unit are to be contained at a given ratio in each biomass. Here, x is

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*1 "Biomass" is presented by "dry weight" in this study.

to be equal to $s+f$, and y to f.

The average values of $(y-rx)$ of the taken number of m are to be expressed by the equation $\sqrt{(M-1)/(M-m)\,m}\cdot(y-rx/\sigma)=\sqrt{(M-1)/(M-m)}\cdot(\sum y-r\sum x)/\sigma\sqrt{m}$ because those distributions are to be expressed by $(M-m)/(M-1)\cdot\sigma^2/m$. That equation is to show the distribution of N (0, 1). And so, the following equation is to be realized.

$$F=\frac{\dfrac{M-1}{M-m}\;\dfrac{(\sum y-r\sum x)^2}{m\sigma^2}}{\dfrac{\sum(y-ry)^2}{(m-1)\sigma^2}}=\frac{M-1}{M-m}\;\frac{(\sum y-r\sum x)^2}{mS^2}$$

Here, the equation of $S^2=Q_0/(m-1)$ is to show the distributions of F at the freedom degree of 1 or $(m-1)$. According to that equation, the value of F is to be gained.

$$\frac{M-m}{M-1}m\,FS^2\geqq(\sum y-r\sum x)^2$$

$$r\sum^{M}x-M\sqrt{\frac{M-m}{M-1}\;\frac{F}{m}}\,S\leqq\sum^{M}y\leqq r\sum^{M}x+M\sqrt{\frac{M-m}{M-1}\;\frac{F}{m}}\,S \quad \cdots\cdots\cdots(1)$$

Multiplying the whole by M/m, the following is to be gained.

$$r\sum x-\sqrt{\frac{M-m}{M-1}mF}\,S\leqq r\sum x+\sqrt{\frac{M-m}{M-1}\,mF}\,S$$

as $\sum^{M}y\propto M$, the variance coefficient of the errors is to be

$$C=\text{const}\sqrt{\frac{M-m}{M-1}\;\frac{F}{m}}\,S$$

This value is to be 0 when m is equal to M, and S^2 is to approach infinity when m is equal to 1.

Practical application

1. As mentioned before, Q_0 means the sum of the residual squared by the method of least square.

It is the value of Q by the following equations.

$$Q=\sum^{m}(y-rx)^2,\qquad \frac{\delta Q}{\delta r}=-2\sum(y-rx)x=0$$

Here, "r" is to be gained by

$$\text{“}r\text{”}=\frac{\sum xy}{\sum x^2}$$

$$\therefore\quad Q_0=\sum(y-\left(\frac{\sum xy}{\sum x^2}\right)x)^2=\sum y^2-2\frac{\sum xy}{\sum x^2}\sum xy+\left(\frac{\sum xy}{\sum x^2}\right)^2\sum x^2$$

$$Q_0=\sum^{m}y^2-\frac{(\sum^{m}xy)^2}{\sum^{m}x^2}$$

2. $M\sqrt{(M-m)/(M-1)\cdot F/M}$, showing some combination of M and m, is to be calculated beforehand.

3. The value of S^2 is to be estimated.

3) Environment research

Emphasis was put on soil survey. Based on the methods of the Japanese national forest survey, observations and statements about the average soil profile of stands were made. And at the same time the materials for analysis were collected. The physical and chemical analysis were carried out on the same method text. The apparatus and methods devised by Dr.

Mashimo*[1] were used in measuring the value of pF. As for forest floor vegetation, statements were limited to the essential ones and their forest floor type. Besides soil survey, the height above sealevel, geographical features, and careers of stands were surveyed.

4) Measurement of forest biomass

The selected sample trees were felled in order to measure the standing biomass of the above-and-under ground parts.

(1) Above-ground part

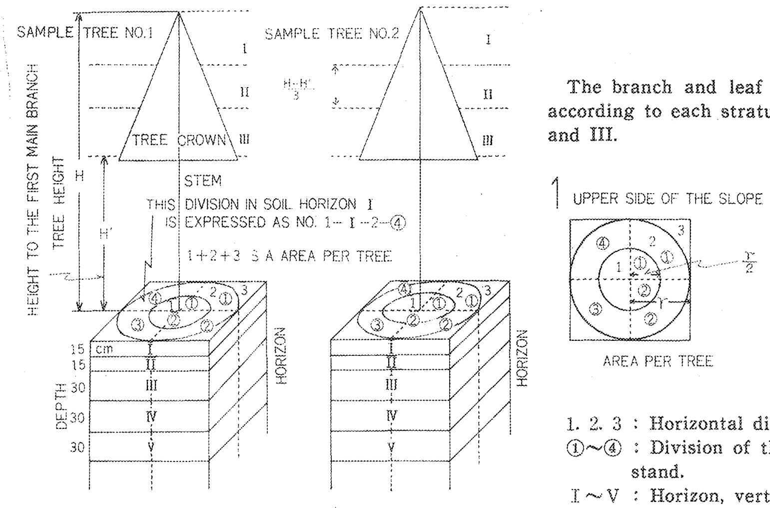
a. Estimate of leaf biomass

After felling the above-ground part of each sample tree, the leaf parts were divided into three equal parts from the lowest branches to the top of the stem as shown Fig. 3. Each part biomass of their leaves and branches were then measured.

All green parts, excluding the tip of trunk, were considered as the leaf biomass, so far as *C. japonica* and *Ch. obtusa* were concerned.

Branches more than 1 cm in diameter were got rid of. They occupied a greater part of all samples of leaves and branches from each class, and showed great variance. After that, a certain amount of the samples were extracted from all the thin branches and leaves. Then, these thin branches and leaves were separated. From this amount, the total biomass of the thin branches and leaves were figured out according to such a method and calculation as already mentioned.

When the leaf biomass and branch biomass are assorted, including the biomass of thick branches among the total biomass, its variance is 1.5 times as large as that of the former. If the material weights are increased to get more accurate measurements in this way, the leaf and the thin branch biomass are to be increased. It requires much time and trouble to do the assorting. As it does not take much exertion to assort large branches, it is better for increasing efficiency to take them out first and then to classify into thin branches and leaves.



The branch and leaf biomass were estimated according to each stratum of a tree crown, I, II, and III.

1. 2. 3 : Horizontal division.
①～④ : Division of the slope or position of a stand.
I～V : Horizon, vertical division.

Any root was where recognized, investigated.

Fig. 3 Diagrammatic sketch of sampling unit.

*1 Mashimo, Y.: Studies on the physical properties of forest soil and their relation to the growth of Sugi (*Cryptomeria japonica*) and Hinoki (*Chamaecyparis obtusa*). Rep. For. Soils Jap., 11, 182 pp, (1960).

If they are, however, to be classified into smaller sections, classification of branches necessitates more effort. And on the contrary, if they are to be classified into larger sections, variance will go larger. The branches over 1 cm in diameter, therefore, were considered as large branches for the sake of accuracy of measurement and efficiency of survey. And then their total biomass were measured. The thin branches and leaves were measured sectionally by the ratio estimate method. The ratios of thin branches to leaves are different at each place of tree-crown, so it follows that accuracy will be heightened if they are classified as minutely as possible. To lessen the immensity of the work, the length of tree-crown was divided here into three equal parts. When the materials extracted from the total biomass in not assorting into each class were classified into leaves and thin branches, the variance was 1.3 times as large as that in doing it. Less total biomass of leaves and thin branches is still needed because fewer measurements are needed. Obviously it is better for increasing efficiency to extract the materials with the thin branch and the leaf biomass together at each class, when it is unnecessary to get them separately.

b. Estimate of branch biomass

As mentioned before, the total thick branch biomass was measured after taking out branches and leaves in every place of tree-crown; then, adding to it the small branch quantity obtained in the abovementioned way, the branch biomass in every place was estimated.

As a result, as the thick branches occupying a large part of branch biomass were measured, accuracy was higher in estimating branch biomass than in the case of leaf biomass.

c. Decision of sample weights necessary for division of leaves and thin branches

To decide the sample weights necessary for classifying leaves and thin branches, the samples for measurement were extracted from each stratum of S 13 stand.

Every material of unit weight 200 g out of the total weight of leaves and thin branches of 4 kg, excluding the thick branches in each stratum, were taken out as samples and divided into leaves and thin branches. Suppose that the total number of M is to be 20, the extracted sample number of m to be 3, 5, 10, 15 and 20, the degress of freedom n_1 and n_2 to be 1 and $n-1$ respectively, and finally the level of significance to be 95%. The errors in the first equation given on page 9 are shown in Table 1, and the ratios of them to sampling ratios and weights, are shown in Fig. 4.

When the sample numbers are to be 3 (each sample weight 600 g*1), 5, and 10, the percentages of error are to be 18, 8.7, and 3.7 respectively. And so, when the sample of about 1 kg is taken out, the leaf biomass is estimated within the significant level of more than 95% and the error of less than 10% of the total biomass. The sampling ratio is one-fourth in this case as the measuring number is 5. The total biomass of leaves and thin branches, however, is not always settled; it varies according to the size of sampling trees. It was, for example, more than 12 kg and heaviest in the 3rd horizon of S 17. Suppose thereupon that M is to be 2 kg, 4 kg, 6 kg, or 8 kg, in order to observe how the sampling errors change when the total weight (M) changes, and that the samples of unit weight 200 g from each of them are to be extracted at the ratios of 3, 5, 10, 20. A result of calculation of errors is shown in Table 2 and Fig. 5. From them we see that the errors are to be 8.5% when the sample of 1 kg is extracted from the total weight of 2 kg, 10% when extracting 1 kg from the total weight of 4 kg, 10.8% in the case of 1 kg from the total weight of 6 kg, and 10.8% even when 1 kg is extracted from the

*1 "Weight" hereinafter always refers to dry weight unless it is given as fresh weight.

Table 1. Sapling ratio and estimated error of leaves and branches for classification on the stand S 13

m	$\sum x$	$\sum y$	Q_0	r	s	$M\sqrt{\frac{M-m}{M-1}\frac{F}{m}}$
3	600	394	211	0.6567	10.3	47.000
5	1,000	633	391	0.6330	9.9	22.060
10	2,000	1,279	759	0.6395	9.2	10.380
15	3,000	1,986	2,634	0.6620	13.7	5.680
20	4,000	2,659	137,614	0.4148	12.3	0.000

m	$M\sqrt{\frac{M-m}{M-1}\frac{F}{m}}S$	$\bar{y}$	C^{*1}	C^{*2}	Sampling ratio
3	484	131	0.0786	0.1847	0.15
5	218	125	0.0792	0.0872	0.25
10	95	128	0.0719	0.0371	0.50
15	78	132	0.1038	0.0295	0.75
20	0	133	0.0924	0.0000	1.00

x: Branch and leaf biomass, 200 g in unit fresh weight. Maximum number of sampling units, M, are 20.
y: Leaf biomass g.
F: Value of significance level 95% when n_1 and n_2 are 1 and $m-1$ respectively.

C^{*1}: $\frac{\sigma y}{\bar{y}}$

C^{*2}: $\frac{\sqrt{\frac{M-m}{M-1}\frac{F}{m}}S}{\bar{y}}$

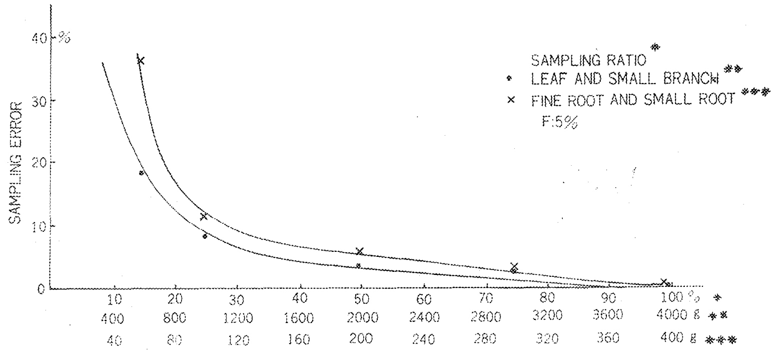


Fig. 4 Sampling ratio and error to measure each part biomass of the *C. japonica* stand S 13.

total weight of the maximum 8 kg. It follows from these that even if the total weight is to be over 4 kg, the sample weights do not need much.

The sampling ratios to the total weight were 50%, 25%, 17%, and 13% when the total weights were 2 kg, 4 kg, 6 kg, and 8 kg respectively. When the sample of 2 kg was taken out of the total weight of over 4 kg, the error was about 5%. Even when the sample weights went across it, the accuracy of measurement did not go much higher.

Ch. obtusa, *P. densiflora*, *L. leptolepis*, and *Zelkova serrata* have the patterns of their own leaving. Let us calculate their sampling ratios and errors in the same way as in Table 1 when their sample weights are all to be 4 kg. The resultant ratios of the errors to the sampling ratios are shown in Fig. 6. When the sampling ratio was 25% (the sample weights of 1 kg) *Zelkova serrata* or *P. densiflora*, *L. leptolepis*, *C. japonica*, and *Ch. obtusa* showed the percentages of error of 14, 12, 8, and 7 respectively. This order was always fixed despite the

Table 2. Sampling errors when the sampled total biomass of leaves and branches change

m	3	5	10	15	20
M : 10					
$(M-m)/(M-1)\ (F/m)$	4.8010	0.8574	—	—	—
$\sqrt{(M-m)/(M-1)\ (F/m)}$	2.19	0.93	—	—	—
$\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	26	11	—	—	—
$M\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	260	110	—	—	—
C^*	0.2000	0.0846	—	—	—
M : 20					
$(M-m)/(M-1)\ (F/m)$	5.5214	1.2174	0.2695	0.0808	—
$\sqrt{(M-m)/(M-1)\ (F/m)}$	2.35	1.10	0.52	0.28	—
$\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	28	13	6	3	—
$M\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	760	260	120	60	—
C^*	0.2154	0.1000	0.0462	0.0231	—
M : 30					
$(M-m)/(M-1)\ (F/m)$	5.7452	1.3292	0.3528	0.1587	0.0756
$\sqrt{(M-m)/(M-1)\ (F/m)}$	2.40	1.15	0.59	0.40	0.28
$\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	29	14	7	5	3
$M\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	870	420	210	150	90
C^*	0.2231	0.1077	0.0538	0.0385	0.0231
M : 40					
$(M-m)/(M-1)\ (F/m)$	5.8563	1.3832	0.1968	0.1123	0.0356
$\sqrt{(M-m)/(M-1)\ (F/m)}$	2.24	1.18	0.1968	0.34	0.19
$\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	29	14	5	4	2
$M\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	1,160	280	200	160	80
C^*	0.2231	0.1077	0.0385	0.0308	0.0154

These values are calculated from the following factors.
s : 12, obtained from Table 1.
$\bar{y}$: 130
m : Number of samples, 200 g in unit fresh weight
C^* : See Table 1.

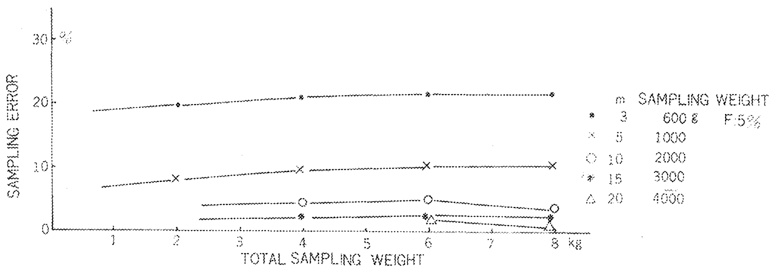


Fig. 5 Total sampling weight of leaf and branch, and sampling error.

change in sampling ratios. And in addition, the denser leaved the species, the greater the errors became.

This explains that the denser the species leave, the smaller the values of S in Table 1 become, and vice versa. At the error of 10%, the needful sampling ratios and the sample weights (the numericals in parentheses) are as follows: They are 36% (1.4 kg), greatest, for *Zelkova serrata*, 30% (1.2 kg) for *P. densiflora*, 29% (1.2 kg) for *L. leptolepis*, 24% (1.0 kg) for *C. japonica*, and 20% (0.8 kg) for *Ch. obtusa*. The maximum rate of *Zelkova serrata* was 1.8 times as high as the minimum of *Ch. obtusa*. When the rate of *C. japonica* was 1, the ratios

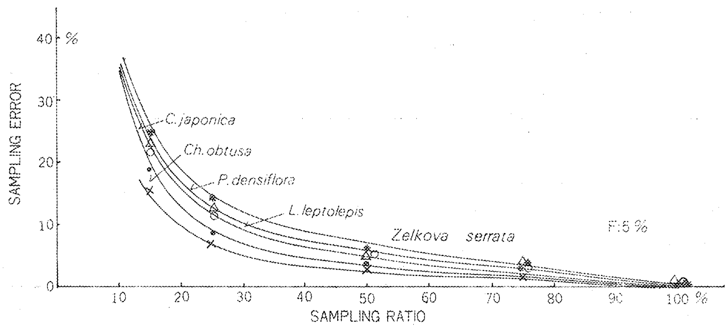


Fig. 6 Sampling ratio and error of leaf and branch of each species.

to it of those of *Zelkova serrata*, *P. densiflora*, *L. leptolepis*, and *Ch. obtusa* were 1.5, 1.3, 1.2 and 0.8 respectively.

From the results, it follows that *C. japonica* taken here as an example, the sample weight of about 1 kg out of the total weight of less than 3 kg or that of about 1.5 kg out of it of more than 4 kg will be sufficient to estimate total weight within the significant level of 95% and the error of 10% of the total biomass. And also it is evident that the other species, weights, multiplied by the above-mentioned ratios, will do.

d. Measurement of stem biomass

Each log cut off at the heights of 0.2 m, 1.2 m, 3.2 m, and every 2 m above from the base to get disks for stem analysis was measured directly on the spot with a large size steelyard (the maximum of measure, 100 kg, the minimum 50 g). When it was too heavy to be measured with a single steelyard, a log was cut into smaller parts or several steelyards were used to measure. There is a method of calculating dry weights by multiplying by each volume by stem analysis the bulk density from the disks collected for stem analysis. Higher accuracy is, however, obtainable with less trouble by measuring fresh weights there and then on the spot.

After that, stem analysis was made to analyse the growth up to then, and the current increment was calculated. The disks collected served as material for measuring the ratios of dry weights.

(2) Underground parts

a. Classification of roots

The border between a stem and roots is clear from the histological viewpoint. For it is where the primary xylem and phloem are differently arranged, and they are also arranged opposite to each other at a stem and alternately in roots. It is difficult, however, to ascertain this of each sample tree. Observations were attempted thereupon of a few stands, and it became clear that the border between them is located near the surface soil unless a stem is excessively buried by soil or the roots go up to the ground because of soil erosion. Investigation was made while considering the upper part of horizon A except for humus in the soil horizon as the border between a stem and roots.

A root is the least differentiated part of all tree organs. For this reason it is difficult to classify them in the same way as to classify the branches or leaves of the above-ground parts. So, we attempted to classify them mechanically into the following six parts; one part less than 2 mm in diameter which contains many primary tissues at root tips; one 2 to 5 mm in diameter with comparatively many young tissues, though lignified; one 5 to 20 mm in diameter working as a pipe which transports the substances absorbed and the products assimilated by

Table 3. Root class

Root class	Small-sized		Large-sized			Root stock
	f	s	m	l	L	St
Diameter	<0.2cm	0.2~0.5cm	0.5~2.0cm	2.0~5.0cm	5.0cm<	The blocky part, not branched.

f : Fine root s : Small root m : Medium root l : Large root L : Very large root St : Root stock

these young tissues; one 20~50 mm or above in diameter for accumulation, and finally a root stock which cannot be classified as a part of the branched roots. These are described here for convenience's sake as fine root (f), small root (s), medium root (m), large root (l), very large root (L), and root stock (St). They are shown in Table 3. This classification is fine and somewhat tedious when it comes to actual measurement. But, the finer it becomes, the higher the accuracy becomes in estimating the root length or surface area. The estimate error of the surface area calculated on the biomass of the roots from fine to large as a group, was 1.7 times as large as that of roots classified minutely. This minute root classification is essential to examine the relationship between the physiological function of roots and the root biomass.

b. Measuring method of root biomass*[1]

There are two methods for measuring the root biomass. One is the total biomass method in which the whole root system of a tree is carefully dug out to be measured. Another is the block method by which the total biomass is estimated by measuring the root biomass in a certain soil volume of a stand. The former method is suitable for examinations, and morphological observations, of the biomass of such small units as a sapling or that of a tree. It requires, however, a considerable long time and much technical effort to dig up the whole root system complicatedly intertwined, and to analyse the distribution of the root biomass, vertical and horizontal. Accordingly, the block method in Fig. 3, by which the area par tree was the object of examination, was taken in this study. Such methods as the Quadrate Bisect Method and Trench Method are suitable for analysing the distribution of the root biomass semi-quantitatively, but not for estimating the root biomass.

c. Establishment of the sample plot by the block method

It is to be noted that in the block method, the root biomass in a block is not the true one of the sample tree because the roots of neighboring trees intrude into the sample plot. The block method was nevertheless employed here. The main reasons for this are the following two. Firstly, those roots, as stated later, being mostly medium roots or below, their biomass are almost equal to the root biomass of a sample tree. Secondly, the total root biomass of a stand can be estimated from the averages by extracting underground parts of a block.

The sample block, shown in Fig. 3, was set up to make it possible to analyse the distribution of root biomass, vertical and horizontal.

Horizontal division: The sample block was horizontally divided into three, 1, 2 and 3 according to the distance from a root stock. Horizontal division 1 is within a circle with a diameter half as long as that of a circle circumscribed by the area a root (a square). Hori-

*[1] Karizumi, N. : Methods of productivity studies in root systems and rhizosphere organisms. Inter. Sym. USSR. Leningrad, 240 pp., (1968).

zontal division 2 is outside that concentric circle and inside the inscribed circle. Horizontal division 3 is the rest of the area between the area a square a root farthest from a root stock and that inscribed circle. This division is definitely useful in determining the horizontal expansion of root biomass.

Division by slope: To ascertain the spread of root biomass distributions both upwards and downwards of a slope, horizontal division 1 was subdivided into the upper side ① and the lower side ②, and horizontal division 2 into the upper sides ①, ④ and the lower sides ②, ③. Moreover, that of 2 was subdivided into ①, ② and ③, ④ to detect the distribution of root biomass in the right and left sides of the slope.

Vertical division: To determine the vertical distribution of root biomass, the sample plot was divided from the surface horizon into soil horizons I and II both by every 15 cm thick, horizon III or below by every 30 cm thick. But, as the alternately accumulated horizons of volcanic gravel and ashes were clearly observed in the stands of S 11-S 17, H 7, and M 4-M 6 in the Oneyama national forest in particular, their vertical divisions were taken according to the thickness of these horizons. As the root biomass becomes much smaller in the deep soil, a considerable amount of effort must be spent to measure a small amount of root. We decided, therefore, to collect a root system in pursuit in horizon V or below, where only a very small amount of roots was obtained. The maximum depth of a root increased thereby, although some of the sample horizons were shallow. The roots of *C. japonica*, *Ch. obtusa*, and *L. leptolepis* got up to soil horizon V in most of the stands, while some of them of *P. densiflora* reached even to soil horizon VI.

The root biomass were measured principally according to these divisions. They could not be measured in every division on account of the extremely small sample plot or the various circumstances of investigation at that time. In those cases, they were measured in two or more divisions together.

d. Sampling errors in estimating the root biomass by the individual whole root system digging method and the sampling soil block method

There is an offset of the root biomass between the block according to the sampling soil block method which deals with an area per tree. Naturally, it makes a difference in root biomass as compared with the individual whole root digging method whereby every one root is carefully dug out.

In order to find the difference between the two methods, investigation was made in the Oneyama S 28 stand to compare the root biomass by the individual root digging method (A) with that by the sampling soil block method (B). Two groups of similar sample trees were picked out. They consisted of 10 trees respectively. The root biomass of one group was measured by the method of (A), while that of another measured by the method of (B). By the former method. the time spent was about 5 times as long as by the latter method. Clearly, it was very difficult to measure the root biomass in each horizontal and vertical division by the former and not by the latter.

As can be seen from the result of investigations, the biomass of the above-and-under ground parts of ten sample trees are obtained. Let us draw x axis for basal area and y axis for part weigh in Fig. 7. The result makes it evident that both part weights had a linear connection with the basal area. Both methods had, besides, the posibility of making a difference between the regression coefficients in the parts where fine, small and medium roots are easily caused to permeate into one another.

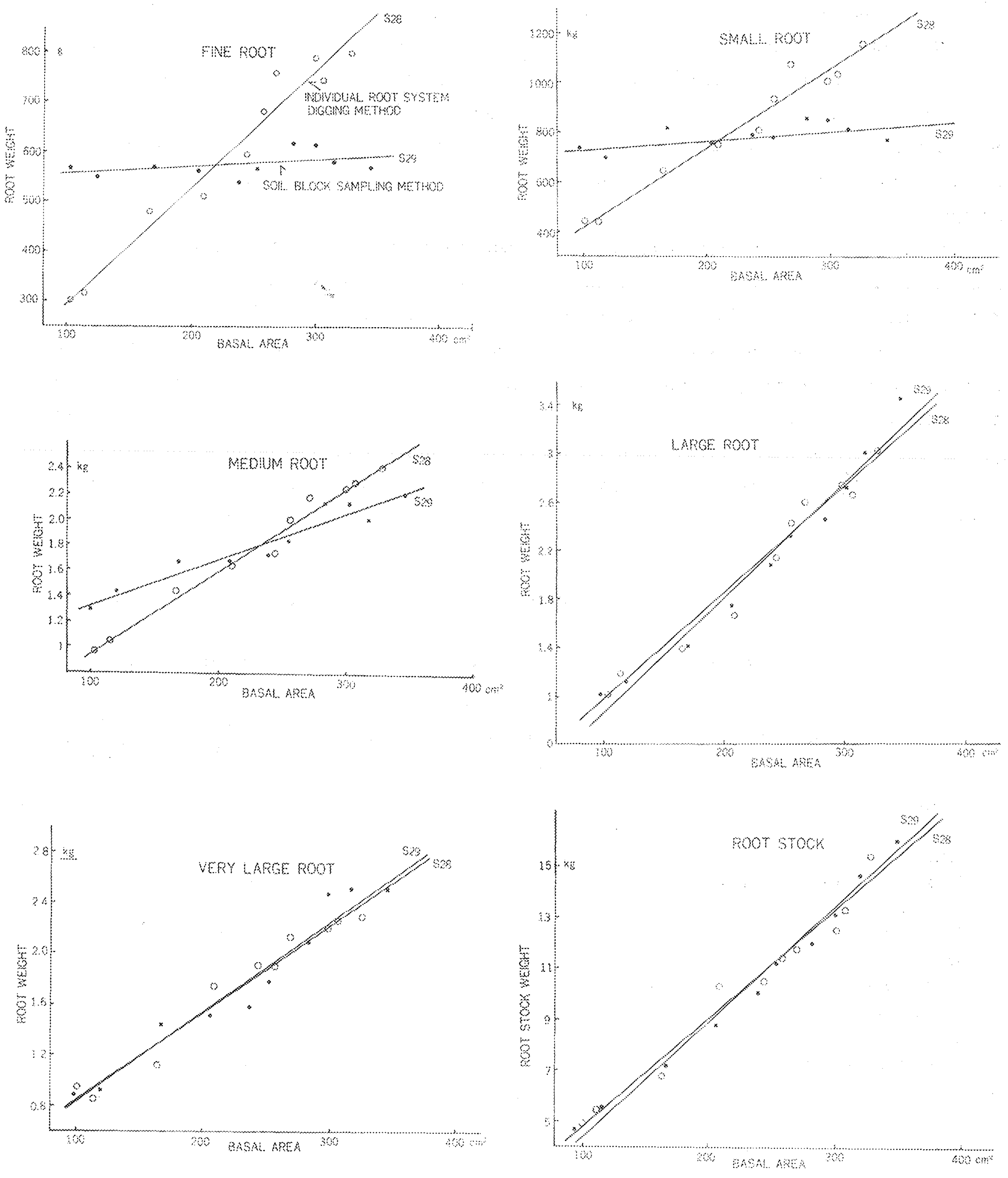


Fig. 7 Difference in part biomass between by individual root system digging method and by soil block sampling method.

The coefficients and the errors, of regression of each above-and-under ground part are shown in Table 4. The table shows that there was almost no difference in regression between both methods in stems, branches, leaves, very large roots, and root stocks, whereas the regression coefficient of fine roots was 2.4 by the individual root system digging method, and 0.14 by the block method. That of small roots was 3.2 by the former method, and 0.35 by the latter method. They explain that the regression coefficients are smaller according to the block method, and that the individual root system digging method causes a greater variation by the increase of diameter of breast height than the sampling soil block method.

Examinations were carried out on the correlation coefficients of regression using both methods. The correlation coefficients of a fine root and a small root were, for example, 0.98 and 0.99 respectively by the individual root system digging method, and 0.48 and 0.61 respectively by the sampling soil block method. It follows from the facts that the biomass of fine and small roots have small correlation coefficients to the basal area according to the sampling soil block method.

Let us calculate each part biomass at the basal areas of 100 cm^2 and 350 cm^2 by the regression equations of both methods. The ratios of the above-mentioned difference to the average root biomass by the individual root system digging method are shown in Table 5.

It was found that the thinner the roots become, the greater the difference in root biomass between by both methods becomes. This is borne out by the fact that at such parts, as a stem, branch, leaf, large root, very large root, and root stock, the differences were less than 5% of the average part weight obtained by the individual root system digging method, but came to 19～20%, 39～48%, and 44～49% at the parts of medium, small and fine roots respectively.

Table 4. Part biomass of *C. japonica* calculated by individual

Stand S28, A, *n* : 10 Individual root system digging method

Tree parts	Regression equation	Average (A)	Standerd deviation
Stem	$y = -426.8+202.7566x$	45,920	1,946
Branch	$y = 638.8+9.0532x$	2,708	268
Leaf	$y = 5,363.9+28.2921x$	11,831	564
Total above-ground part biomass	$y = 5,575.9+240.1019x$	60,459	2,111
Fine root	$y = 60.8+2.3537x$	599	40
Small root	$y = 92.1+3.2131x$	827	54
Medium root	$y = 314.5+6.5152x$	1,804	75
Large root	$y = 21.0+9.0332x$	2,086	144
Very large root	$y = 169.1+6.8770x$	1,741	118
Root stock	$y = 410.2+43.5020x$	10,354	637
Underground part biomass	$y = 1,067.8+71,4941x$	17,410	669
Total	$y = 6,643.6+311.5960x$	77,869	2,636

Stand S28, B, *n* : 10 Soil block sampling method

Tree parts	Regression equation	Average (A)	Standerd deviation
Stem	$y = -2,323.3+210.1218x$	46,727	2,321
Branch	$y = 693.7+8.3683x$	2,647	159
Leaf	$y = 5,013.5+28.5962x$	11,689	718
Total above-ground part biomass	$y = 3,384.0+247.0862x$	61,063	2,976
Fine root	$y = 543.0+0.1397x$	576	23
Small root	$y = 699.1+0.3486x$	781	40
Medium root	$y = 976.8+3.6362x$	1,826	87
Large root	$y = -91.0+9.5160x$	2,130	144
Very large root	$y = 104.1+7.0944x$	1,760	140
Root stock	$y = -308.1+45.8245x$	10,389	493
Underground part biomass	$y = 1,924.0+66.5594x$	17,461	632
Total	$y = 5,307.9+313.6457x$	78,524	3,333

This is shown in Fig. 8. This figure proves that the root system is transiting step by step from a large root to a fine root: the difference is going up, and up rapidly at the roots smaller than a medium root in particular.

Fig. 8 shows the ratios of the difference to the values obtained by the method of estimation from the individual root system digging method at the basal areas of 100 cm^2 and 350 cm^2. The fine root with the most intricacy had, as shown in the table, the difference equal to 88% of the root biomass estimated by the individual root system digging method in a dominant tree, 100 cm^2 in basal area, and that equal to 33% in a predominant tree. The small root had the difference equal to 78% in the former, and that equal to 33% in the latter. In the case of the tree with the basal area of about 100 cm^2, the root biomass by the block method was measured to be larger by about 80 to 90% than the true one, and in that of 350 cm^2, smaller by about 30%.

The larger classes of the roots showed rapid decreasing values, just as the medium root got the respective values of 39% and 13%. The total root biomass, influenced by the intricacy between the fine and the small roots, were larger by 4% at the basal area of 100 cm^2, and smaller by 3% at that of 350 cm^2 than the true root biomass.

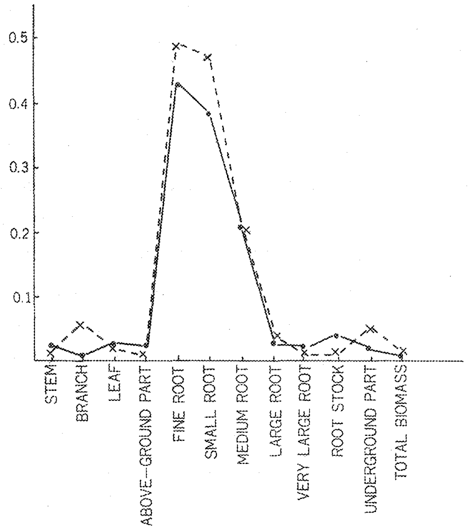
root digging method and soil block sampling method

		Value calculated by regression equation		(B)*1		B/A	
Variation coefficient	Correlation coefficient	Basal area 100cm²	Basal area 350cm²	Basal area 100cm²	Basal area 350cm²	Basal area 100cm²	Basal area 350cm²
0.0424	0.9936	19,849	70,538	1,160	681	0.0253	0.0148
0.0990	0.9434	1,544	3,807	13	184	0.0048	0.0679
0.0477	0.9731	8,193	15,266	320	244	0.0270	0.0206
0.0349	0.9946	29,586	89,612	1,493	252	0.0247	0.0042
0.0668	0.9804	296	885	261	293	0.4357	0.4891
0.0653	0.9805	413	1,217	321	396	0.3881	0.4788
0.0416	0.9909	966	2,595	374	346	0.2073	0.1918
0.0690	0.9826	924	3,183	63	57	0.0302	0.0273
0.0678	0.9800	857	2,576	43	11	0.0247	0.0063
0.0615	0.9852	4,760	15,636	486	94	0.0469	0.0091
0.0384	0.9939	8,217	26,091	363	871	0.0209	0.0500
0.0339	0.9950	37,803	115,702	1,131	618	0.0145	0.0079

0.0497	0.9924	18,689	71,219
0.0601	0.9780	11,531	3,623
0.0614	0.9626	7,873	15,022
0.0487	0.9910	28,093	89,864
0.0399	0.4758	557	592
0.0512	0.6104	734	821
0.0476	0.9655	1,340	2,249
0.0676	0.9860	861	3,240
0.0795	0.9764	814	2,587
0.0475	0.9928	4,274	15,730
0.0362	0.9944	8,580	25,220
0.0424	0.9930	36,672	115,084

*1 B: Difference between the stand S 28 and S 29.

y: Part biomass, g.
x: Basal area, cm^2.



The value of y axis is the ratio of the difference in biomass between individual root system digging method and soil block sampling method average part biomass estimated by individual root system digging method.

• : Difference in ratio between two method when basal area is 100 cm².

× : Difference in ratio between two method when basal area is 350 cm².

Fig. 8 Estimated biomass between individula root system digging method and soil block method.

As to the total root biomass, the former took 3 percent in the former case and the latter 1 percent. It follows from the fact that there is only a slight influence by offsetting between fine and small roots in estimating the total root biomass.

Even the root stock, which is not positively intricated, has the possible biomass error of about 10% by regression calculation. Considering all these together, the maximum difference of 3 to 4% of the total root biomass caused by both methods is not a serious problem. As trees continue to grow, the ratio of fine and small roots to the total biomass decreases. So, the influence of intricacy between roots on the total biomass becomes less.

To make clear their more detailed relation on fine, small, and medium roots which might have a bearing on possible significant differences by some regressions of both method in Table 4, examinations of difference between the coefficients or constants in both regressions were carried out.

The relation between the basal area and each part biomass is to be linear as shown in Fig. 7. Supposing that it is to be expressed as $y=a+bx$ (y : part biomass (g), x : basal area

Table 5. Test of regression coefficients and regression constants of each part of a tree by individual root system digging method and by soil block sampling method

Test / Part	Test of homogeneity of variance by BARTLETT's method. χ^2	Test of regression coefficient F'	Test of regression constant F''
Stem	0.87	0.22	0.25
f	2.14	139.17*	3.97
s	0.67	107.18*	6.43*
m	0.19	37.64*	0.00
l	0.00	0.34	0.00
L	0.24	0.08	0.07
St	0.49	0.50	0.51
Underground part	0.02	1.72	0.95

(cm²)), it was investigated whether or not there was any difference between both regression equation of partial biomass by the individual root system digging method and by the sampling soil block method. First, the distribution uniformity of both regression equations was examined according to BARTLETT's method. And then, the regression coefficients and constants were examined. A comparison of the calculated values of χ^2, coefficients, and constants of F, with each value at the level of significance of 95% is shown in Table 5.

To examine the uniformity of BARTLETT's variance, χ_0^2 is to be equal to the value of χ^2 at the degree of freedom of 1 and the level of significance of 95%. And there is to be no difference in distribution of χ_0^2 greater than χ^2. In this case, the value of χ_0^2 was 3.84. Although χ^2 of the fine roots had a somewhat big value, any other value was below 3.84. It is therefore not necessarily unreasonable to predict that the variance had no significant difference. This is due to the small measured number and instead to the large variance.

We took the second step to examine both regression coefficients and constants. When the degrees of freedom of n_1 and n_2 were to be 1 and 16 respectively and the level of significance of 95%, the value of F_0 was 4.49. This being so, it became clear that the regression coefficients of fine, small and medium roots and the regression constant of small roots had significant differences between the regressions by two methods.

The regression coefficients of each part in each sample stand by the sampling soil block method are shown in Table 35 and 42. According to the table, they all increased regardless of species or stands, as roots were thickening fine, through small, medium, to large. This is partly because of properties of fine or small roots, and partly because of the variation of the root biomass caused by intricacy among roots. Let us take the stands of S 13, H 3, A 2 and K 1 in Table 35 as a good example to go through the variation of the regression coefficients, because they hold comparatively many sample trees.

Table 42 shows the comparison between the regression coefficients of the sample trees in the stands of Table 35 those when the stands with similar site and tending conditions are run altogether.

Table 42 corresponds to the coefficients of a regression equation in S 28 of Table 4. From it, the regression coefficients of the fine and the small roots of every species except for those of *L. leptolepis* turned out to be larger than those in the stands of Table 35.

As variance became larger in the case of each stand included together, the difference between the two was not so clearly mainfested as in comparison of the individual root system digging method with the sampling soil block method in the stand S 28. But then, the regression coefficient of the intricate parts of the root system became larger. Thus, the difference between those methods was perceived hereupon too.

The degree of intricacy among the root biomass according to both methods are different in species. The regression coefficients of the fine roots are smaller in the order of *Ch. obtusa*, *C. japonica*, *L. leptolepis*, and *P. densiflora* as shown in Table 35 and 42. These regression coefficients are, though not always, a direct indicator of intricacy among the root biomass, enough to clear up a tendency that *C. japonica* and *Ch. obtusa* have a great difference in fine root biomass between trees and a small intricacy among root biomass, and that *L. leptolepis* and *P. densiflora* have equalized biomass due to their fine roots intricacy.

Thus, the intricacy among roots by two methods, corresponding to various conditions, are observed only within limits of fine, small, and medium roots, and most clearly in the fine roots. It is, therefore, not necessarily unreasonable to estimate that, of the fine root biomass of the sample trees, the small-diameter trees hold a gain by intrusion from a large-diameter tree, but that the large-diameter trees hold a decrease on the contrary.

This amount, however, is very small when compared with the total root biomass. It does not come out in calculation such as T/R ratio.

And also as calculation by both methods result in almost the same average, it is appropriate to use either method in order to estimate the whole root biomass of the forest.

e. The classification of the root system and the process to measure the root biomass

As mentioned before, the total root biomass dug up at every sample division, horizontal and vertical, i. e., the soil block, was divided and measured at every block in the order as shown in Fig. 9.

In this figure, the first step is the digging up of the soil and the root system. Only the roots of from fine roots to very large root picked out of the first are in the second.

The total biomass of the very large and the large roots are separated out of the total biomass and measured at the third and the fourth.

At the fifth, a certain amount is taken out from the remaining root (fine to medium roots). Then, it is separated into medium roots and " fine roots and small roots ", measured and serves as a sample to determine the ratio of both.

At the sixth, a certain amount is taken out from the rest (fine roots and small roots). These samples are divided into fine roots and small roots to obtain the ratio of them as in the fifth. The root biomass thus classified is measured at the seventh.

Two platform scales for 10 kg and 20 kg measure, and two steelyards for 50 kg and 100 kg measure stems and root stocks were used in this study.

At the eighth, a certain amount is respectively taken out of each measured samples of fine to very large roots in order to get the soil weight sticking to them. The ratio of the root weight to the root weight with the sticking soil is called the root weight ratio. The root weight ratio is, therefore, expressed by (root weight)/(root weight+weight of sticking soil).

At the ninth, a certain amount of samples are taken out of each part of the root system to measure the water content. These operations are done outdoors. The indoor operations are as follows:

At the tenth, the samples to measure the root weight ratio at the eighth are washed, and cleared of sticking soils to get the soil weight.

At the eleventh, the materials at the ninth are dried to obtain the dry weight ratio. The dry weight ratio is expressed by (dry weight)/(fresh weight).

The process of calculation from the measured true weight to the dry weight for each part is as follows:

$$L_D = \text{measured weight} \times \frac{L'}{Si+L'} \times \frac{Ld}{L'}$$

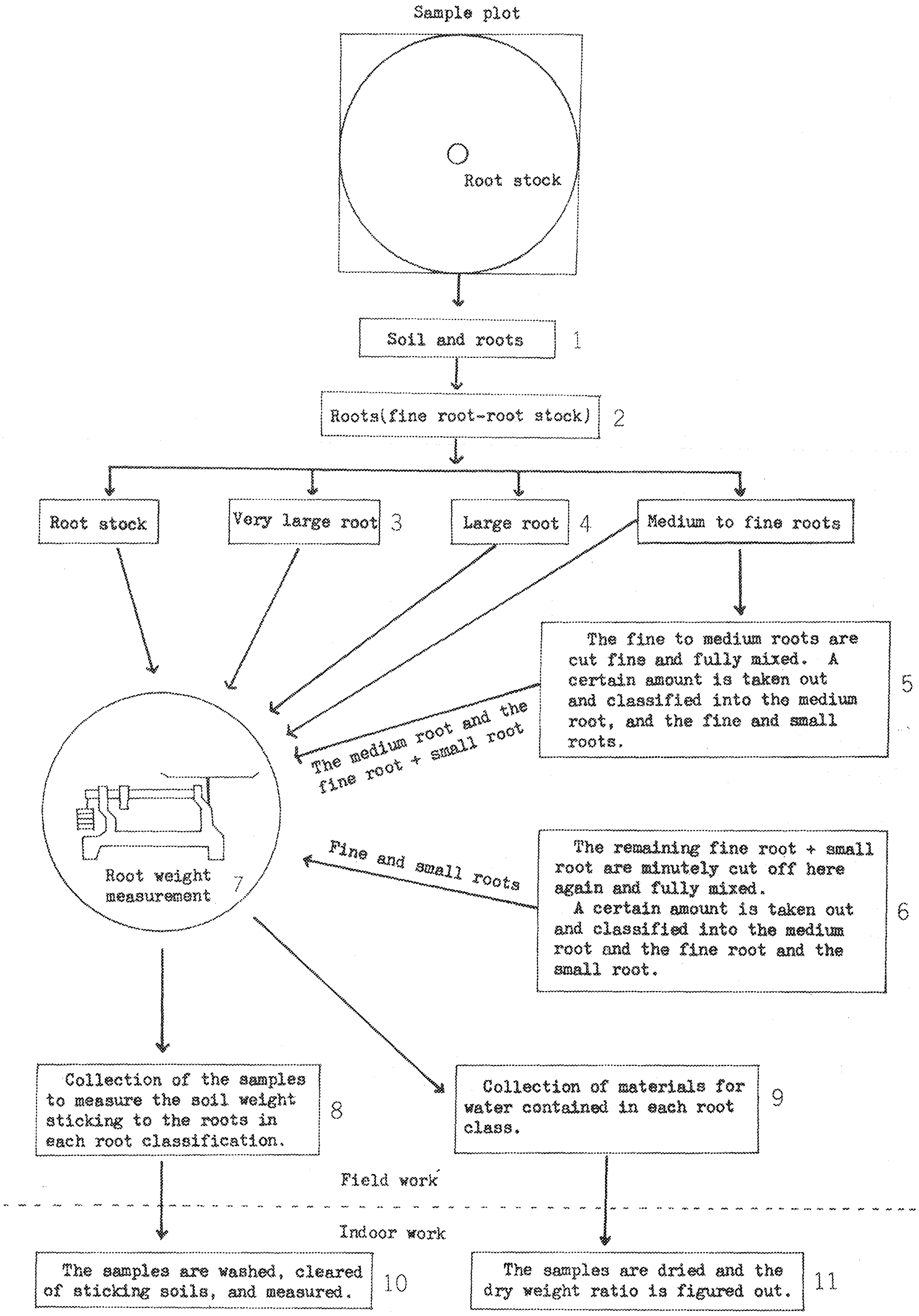
L_D : Dry weight of a very large root.

L' : Washed weight of a very large root (fresh weight).

Si : Weight of sticking soil.

$\frac{L'}{Si+L'}$: Root weight ratio of a very large root.

$\frac{L'd}{L'}$: Dry weight ratio of a very large root.



	Diameter
Very large root	5 cm and above
Large root	2～5 cm
Medium root	0.5～2 cm
Small root	0.2～0.5 cm
Fine root	0.2 cm and below

Fig. 9　The root classification and the procedure to measure the root biomass.

l_D =Measured weight$\times\frac{l'}{Si+l'}\times\frac{l'd}{l'}$

l_D : Dry weight of a large root.

l' : Washed weight of a large root (fresh weight).

Si : Weight of sticking soil.

$\frac{l'}{Si+l'}$: Root weight ratio of a large root.

$\frac{l'd}{l'}$: Dry weight ratio of a large root.

m_D=Measured weight$\times\frac{m_1}{m_1+S_1+f_1}\times\frac{m'}{Si+m'}\times\frac{md}{m'}$

m_D : Dry weight of a medium root

m_1, S_1, and f_1 : Classified root weight.

m' : Washed weight of a medium root (fresh weight).

Si : Weight of sticking soil.

$\frac{m'}{Si+m'}$: Root weight ratio of a medium root.

$\frac{md}{m'}$: Dry weight ratio of a medium root.

$S_D=S+f\times\frac{S_2}{S_2+f_2}\times\frac{S'}{S'i+S'}\times\frac{S_R}{S'}$

$S+f$: $(m+S+f)-(m+S+f)\times\frac{m_1}{m_1+S_1+f_1}$

S_D : Dry weight of a small root

S_2 and f_2 : classified root weight.

S' : Washed weight of a small root (fresh weight).

$S'i$: Weight of sticking soil.

$\frac{S'}{S'i+S'}$: Root weight ratio of a small root.

$\frac{S'd}{S'}$: Dry weight ratio of a small root.

$f_D=f\times\frac{f'}{f'i+f'}\times\frac{f_R}{f'}$

f_D : Dry weight of a fine root.

$f=(m+S+f)-\left[(m+S+f)\times\frac{m_1}{m_1+S_1+f_1}\right]+\left[(S+f)\times\frac{S_2}{S_2+f_2}\right]$

$S'i$: Weight of sticking soil.

f' : Washed weight of a fine root.

$\frac{f'}{f'i+f'}$: Root weight ratio of a fine root.

$\frac{f'd}{f'}$: Dry weight ratio of a fine root.

Of leaves or branches, the dry weights were calculated from the measured fresh weight in the same way as this.

f. Measurement of root biomass

Unlike the above-ground parts, roots were classified into six groups, fine root, small root, medium root, large root, very large root, and root stock. The method of classification is, therefore, more complicated than that of leaves. But the way of thinking and calculation is quite the same.

a) Measurement of root stock: A root stock, equivalent to the stem which is one of the above-ground parts, is an organ of the underground parts for accumulation. It occupies 50～60% of the total root biomass. Its total biomass was measured on the spot with a steelyard, as that of the stem.

b) Measurement of very large root: Generally, a very large root next to a root stock occupies the greater part of the total biomass, although it is not so many in number. Consequently the variance is very large when its weight is estimated from the separated weights of the sample taken from a certain root biomass containing them.

The variation coefficient was over 80% when 15 samples of 1 kg containing very large roots were taken from the S 13 stand of *C. japonica* and the very large root biomass was separated. By taking every 1 kg out of the total root biomass of 20 kg, the error and the sampling ratio were, as shown in Fig. 10, calculated at the significant level of 95%. It was found from it that 90% of the total weight (18 kg) must be measured to keep the error below 10%.

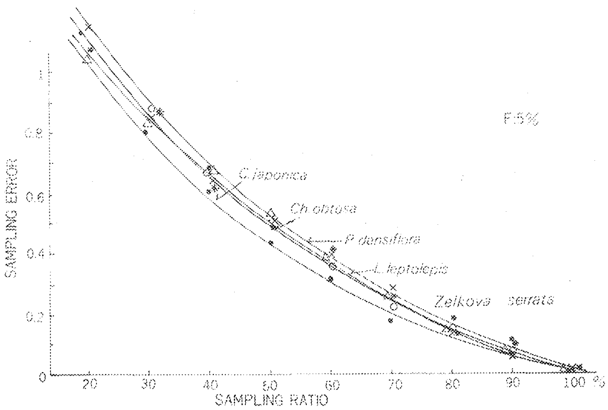


Fig. 10 Sampling ratio and error of very large root.

As very large roots occupy a greater part of the total biomass and the variance is large, it is necessary to measure the total biomass.

The distribution of very large roots varies from one species to another. A calculation of the sampling errors by the above-mentioned way resulted, however, in the fact that each species had its own large error, and that there was no difference among species.

The classification, on the other hand, is very easy in operation. It requires much less time spent per root biomass, as compared with that for fine roots or small roots. It is, therefore, of no effect to shorten the measuring time even if fewer sampling materials are to be taken out for classification. As mentioned before, the very large roots have a greater part of the total root biomass. A reduction of the measuring time makes thereby much larger the error in estimating the total root biomass when the samples for classification are extracted.

This is the main reason why the total biomass of very large roots was measured in this study.

c) Measurement of large root: Fifteen samples of 1 kg unit weight were taken from the total weight of 15 kg for the purpose of measuring the weight of a large root, like that of a very large root. Calculations of their sampling ratios are shown in Fig. 11. According to the figure, the total root weight of 80% (12 kg) has to be measured in order to keep the error below 10%. Measurement of the total biomass was also found to be necessary in this part as in very large roots. The species had all the large error.

The measurement of the separated and extracted samples is of no effect in these roots even when judged from the efficiency of classification. For this reason, the total biomass measurement was taken here again.

d) Measurement of medium root: Fine to medium roots are left unclassified after very large and large roots are separated. Their biomass is equivalent only to about 20 to 30% of the total biomass. Nevertheless, it is necessary to classify and measure them as exactly as possible, since these parts have many young organisms and physiologically they play an important role.

Let us take the following steps to obtain the sampling ratios and the errors, of the species. The first step is to divide the total weight of 1 kg from the fine roots to the medium roots of *C. japonica* into the number of 20 (M) with the unit weight of 50 g. The second is to pick out only the medium roots from them and measure their weight. The third or final is to get the relation between the sampling ratios and the errors. A result of this is shown in Fig. 12. According to the figure, the error was slightly below 10% when the sampling ratio was 30% (300 g). And moreover, this explains that the variance became smaller in the order of *P. densiflora*, *Zelkova serrata*, *L. leptolepis*, *C. japonica*, and *Ch. obtusa*. At the error of 10%, the sampling ratios of *P. densiflora*, *Zelkova serrata*, *L. leptolepis*, *C. japonica*, and *Ch. obtusa* were 32%, 30%, 29%, 28%, and 25% respectively. This arises from two facts, first that *P. densiflora* and *L. leptolepis* make a large variance because the fine and the small roots adhere to the medium roots sparsely, and secondly that *Ch. obtusa* has fine and small roots adhering to them densely, growing all these roots uniformly.

Taking every twenty medium roots with the unit weight of 200 g from various species

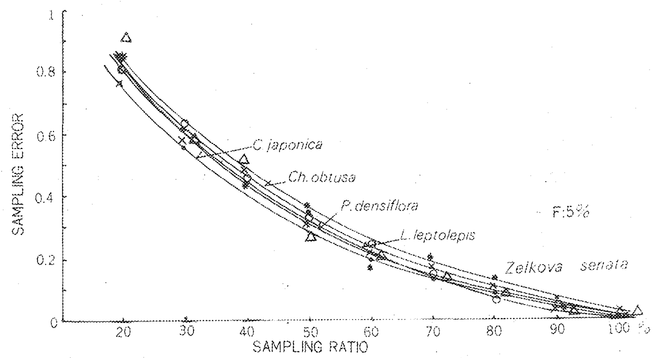


Fig. 11 Samplig ratio and error of large root.

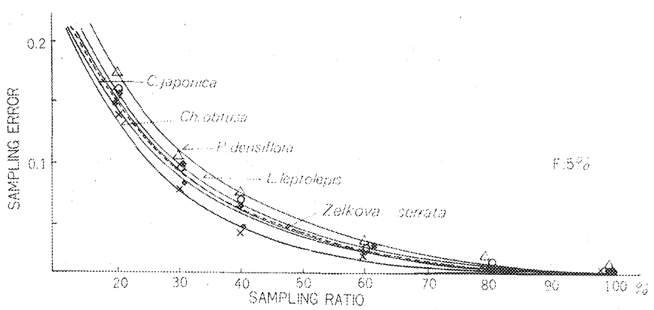


Fig. 12 Sampling ratio and error of medium roots.

and measuring their weight, we got the following coefficients of variation: 0.180 for *Eucalyptus globulus*, 0.178 for *Quercus myrsinaefolia*, 0.170 for *Alnus hirsuta* v. *sibirica*, 0.174 for *Quercus mongolica*, 0.172 for *Fagus crenata*, 0.172 for *Robinia pseudo-acacia*, 0.170 for *Cornus controversa*, 0.168 for *Quercus serrata*, 0.165 for *Zelkova serrata*, 0.165 for *Betula ermanii*, 0.162 for *Betula platyphylla*, 0.161 for *Abies firma*, 0.157 for *Picea jezoensis* v. *hondoensis*, 0.150 for *P. densiflora*, 0.136 for *Acacia decurrens*, 0.135 for *L. leptolepis*, 0.125 for *Tsuga canadensis*, 0.100 for *C. japonica*, 0.083 for *Ch. obtusa*, and finally 0.080 for *Ch. pisifera*. The species with the large coefficient of variation were *Eucalyptus globulus*, *Quercus myrsinaefolia*, *Alnus hirsuta* v. *sibirica*, *Quercus mongolica*, etc., which had fine and small roots sparsely growing out from the medium roots. On the other hand, the species with small coefficient of variation were *C. japonica*, *Ch. obtusa*, etc., which had fine and small roots densely growing out from the medium roots. Generally speaking, of the broad leaved trees, the sparsely rooted trees have a tendency to make large variation and, of the coniferous trees, the densely rooted trees tend to make a small one.

e) Estimation of the fine and small root biomass: After the very large, large and medium roots were measured, the sampling weights necessary for classification of the fine and the small roots were calculated. They had been left unseparated to the last.

We divided the sum of both root weights of 400 g into the number of 20 samples (M) with every unit weight of 20 g. The number of the samples (m) was to be 3, 5, 10, 15, or 20. On this condition, we calculated each error at the level of significance of 95%, and results of calculation are shown in Table 6. As is clear from this table, the errors were 36%, 12%, 6%, and 4% at m of 3 (60 g), 5 (100 g), 10 (200 g), and 15 (300 g) respectively. The needful sampling ratio was 28% (110 g) here at the error of 10%.

The errors of fine and small roots were larger than those of leaves and thin branches.

Table 6. Sampling ratios and estimated errors of fine roots and small roots for classification. On stand S 13

m	$\sum x$	$\sum y$	Q_0	r	S	$M\sqrt{\frac{M-m}{M-1}\frac{M}{m}}$
3	60	31	5	0.5167	1.6	47.000
5	100	52	5	0.5200	1.1	22.000
10	200	107	16	0.5350	1.3	10.380
15	300	158	26	0.5267	1.4	5.680
20	400	212	29	0.5300	1.2	0.000

m	$M\sqrt{\frac{M-m}{M-1}\frac{F}{m}}S$	$\bar{y}$	C^{*1}	C^{*2}	Sampling ratio
3	75	10.3	0.1553	0.3641	0.15
5	24	10.4	0.1088	0.1154	0.25
10	13	10.7	0.1215	0.0607	0.50
15	8	10.5	0.1333	0.0381	0.75
20	0	10.6	0.1132	0.0000	1.00

x: Fine and small root weight (g)
y: Fine root weight (g)
F: Values of the significant level, 95% when n_1 and n_2 are 1 and $m-1$ respectively.

C^{*1}: $\frac{\sigma y}{\bar{y}}$

C^{*2}: $\frac{\sqrt{\frac{M-m}{M-1}\frac{F}{m}}S}{\bar{y}}$

We calculated the errors when the total weight (M) was 10 (200 g), 20 (400 g), 30 (600 g), or 40 (800 g). As a result, it was found, as shown in Table 7 and Fig. 13, that when (M) went up, they went up slightly, though not greatly, at (m) of three or five. Even when the total weight of 400 g was doubled at (m) of 5, they increased, for example, by only 0.96%. It is thereby clear that even when the total weight goes beyond 400 g, the sampling weights of materials are to be enough within the limits of 100 g to 150 g.

At the sampling ratio of 30% (120 g), *P. densiflora*, *L. leptolepis*, *Zelkova serrata*, *C. japonica*, and *Ch. obtusa* had the errors of 15, 11, 10, 8 and 5% respectively, as shown in Fig. 14. As described on the medium roots, the former two species, showing the large value, are the species which branch fine roots off from small roots sparsely, whereas *Ch. obtusa*, showing the small one, is the species which branches the fine roots off from the small roots densely.

Turning now to the sample weights necessary for estimation at the ratio of error of 10 %, *P. densiflora*, *L. leptolepis*, *Zelkova serrata*, *C. japonica*, and *Ch. obtusa* required 160, 140, 120, 110, and 90 g respectively. When that of *C. japonica* was to be 1, the ratios of those of the remainder to that were as follows; 1.41 for *P. densiflora*, 1.33 for *L. leptolepis*, 1.09 for *Zelkova serrata*, and finally 0.82 for *Ch. obtusa*.

To determine these relations, 20 samples with each unit weight of 100 g were taken out

Table 7. Sampling errors while the sampled total biomass (M) of fine roots and small roots changing

Fine and small roots

m	3	5	10	15	20
M : 10					
$(M-m)/(M-1)\ (F/m)$	—	—	—	—	—
$\sqrt{(M-m)/(M-1)\ (F/m)}$	—	—	—	—	—
$\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	2.8	1.2	—	—	—
$M\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	2.8	1.2	—	—	—
C^{**}	0.2667	0.1143	—	—	—
M : 20					
$(M-m)/(M-1)\ (F/m)$	—	—	—	—	—
$\sqrt{(M-m)/(M-1)\ (F/m)}$	—	—	—	—	—
$\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	3.1	1.4	0.7	0.4	—
$M\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	62	28	14	8	—
C^{**}	0.2952	0.1333	0.0667	0.0381	—
M : 30					
$(M-m)/(M-1)\ (F/m)$	—	—	—	—	—
$\sqrt{(M-m)/(M-1)\ (F/m)}$	—	—	—	—	—
$\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	3.1	1.5	0.8	0.5	0.4
$M\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	93	45	24	15	12
C^{**}	0.2952	0.1429	0.0762	0.0476	0.0381
M : 40					
$(M-m)/(M-1)\ (F/m)$	—	—	—	—	—
$\sqrt{(M-m)/(M-1)\ (F/m)}$	—	—	—	—	—
$\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	3.1	1.5	0.6	0.4	0.2
$M\sqrt{(M-m)/(M-1)\ (F/m)}\ S$	124	60	24	16	8
C^{**}	0.2952	0.1429	0.0571	0.0381	0.0190

These values are calculated from the following factors.
s : It was obtaind from Table 6.
$\bar{y}$: 10.5
m : Number of the samples, 20 g in unit fresh weight.

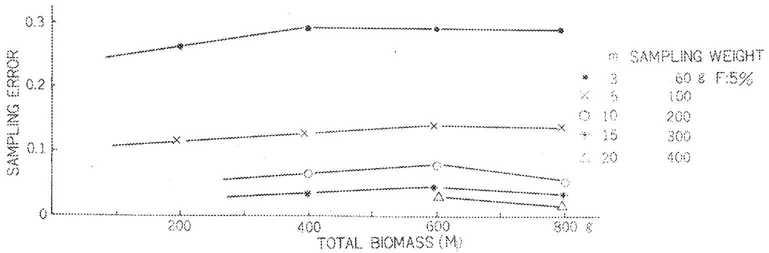


Fig. 13 Total biomass (*M*) of fine and small roots and sampling error.

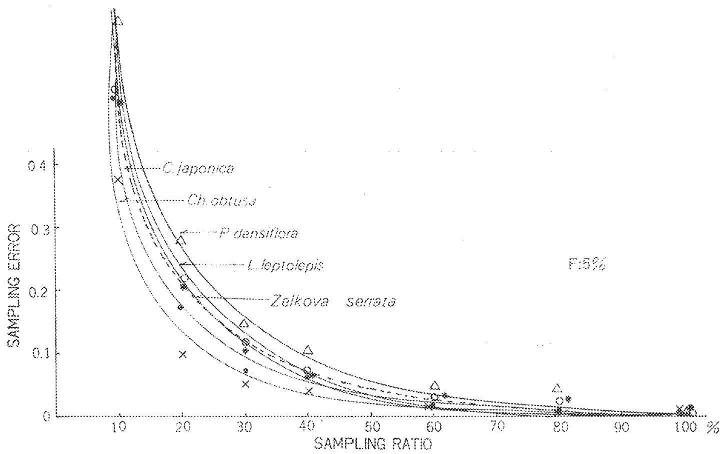


Fig. 14 Sampling ratio, and error of fine and error of fine and small roots.

of each different tree in the same way as done in the case of medium roots, and their coefficients of variation of fine roots were calculated. Result of calculation, show they were 0.060 for *Eucalyptus globulus*, 0.054 for *Cornus controversa*, 0.050 for *Robinia pseudo-acacia*, 0.045 for *Quercus myrsinaefolia*, 0.042 for *Q. serrata*, 0.041 for *Fagus crenata*, 0.041 for *Alnus hirsuta* v. *sibirica*, 0.040 for *Quercus mongolica* v. *grosseserrata*, 0.037 for *Betula ermanii*, 0.037 for *B. platyphylla* v. *japonica*, 0.035 for *Zelkova serrata*, 0.032 for *Acacia decurrens* v. *dealbata*, 0.028 for *Abies firma*, 0.027 for *Picea jezoensis* var. *hondoensis*, 0.027 for *P. densiflora*, 0.024 for *Tsuga canadensis*, 0.023 for *L. leptolepis*, 0.019 for *C. japonica*, 0.012 for *Ch. obtusa*, and finally 0.010 for *Ch. pisifera*. It is evident from the facts that the variances of the broad leaved trees are generally large since their fine roots grow sparsely, while those of the coniferous trees are small; and particularly that of *Ch. obtusa* is small because the fine roots branch and thicken remarkably. These agree well with the results we had observed, described and explained about the root properties of the trees investigated in the Forest Experiment Station before (See page 3).

(3) 1/2 soil block sampling method

A considerable amount of effort must be spent to dig up the whole sample plot (block) considering the area a tree as an object. It would be better to dig up a part of it and thereby to estimate the total amount.

A careful comparison of the distribution of root biomass was carried out thereupon among blocks. It was found that the method was very inacurate for large and very large roots, because they were distributing densely at one block and sparsely at another.

Fine, small, and medium roots made a difference in root biomass up and down a slope, yet making equalized distributing at the right-and-left sides of it. The following process therefore appears to make it possible to estimate the total amount of those roots at the whole sample plot. The first step is to divide a sample plot into two sides, right and left, along a slope; the second, to investigate either of them; and the third, to double the measured amount. This method was taken at some stands to reduce the investigation expenditure. In addition, the 1/4 block method, 1/8 block method, etc. appear to be applicable. True, these methods have the possibility of applying to the roots smaller than a medium root in soil horizons I and II of them distributing evenly; but they lead to inacuracies in the lower soil horizon as a whole because they get highly scattered there. What's worse, it is next to impossible to use the 1/4 block method only in the surface horizon and 1/2 block method in the lower horizons. Hence it is that those methods, even if possible to apply, are not necessarily the better methods.

Taking the 1/2 block method, it will suffice to dig up half of the soil volume for investigation. The operation will thereby be reduced by almost three-fifth times that for investigation of the total root biomass, even if the digging-up in the opposite side, classifications and measurements of large and very large roots are added to it.

Next, the remainings were dug up carefully, and their forms were photographed, drawn, and described. After that, the large and the very large roots were classified into every soil horizon and measured.

This method, if somewhat inacurate in estimating root biomass, proves to be of great use in observing the forms of roots (See Photo. 5).

4. **The root weight ratio (of the soil weight sticking to the root weight)**

The root weight thus measured (those of the fine roots to the root stock) contain the soil weights. It is necessary to estimate the root biomass excluding these soil weights, and this relation is expressed by the following equation:

$$RSi = \frac{R}{Si + R}$$

RSi : Root weight ratio

Si : Soil sticking to the roots.

R : Fresh root weight.

(The root weight ratio means the ratio of the actual root weight, excluding the soil sticking to the roots, to the weight of roots and soils.)

The fresh root weight is to be gained by multipling this ratio by the root weight including soils. From the soil horizons I and II in the *C. japonica* stand, S 4, 50 samples of the fine roots each 40~350 g in weight, were taken out and washed. Assuming the root weight with soils to be an independent variable, and the fresh root weight without soil to be a dependent variable, the relation between both weights is shown in Fig. 15. As is clear from it, the linear regression passing the origin can be recognized between them.

When the regression coefficients, relative coefficient, and errors were calculated, the ratio between both weight (Z) turned out to be 0.85. This means that 85% of the root weight with soils is equivalent to the root weight and 15% of it to the sticking soil weight. Since the relative coefficient (r) was ninety-nine percent, a close correlation was recognized between them. As the coefficient of variation was 1.3%, the error was proved to be very small.

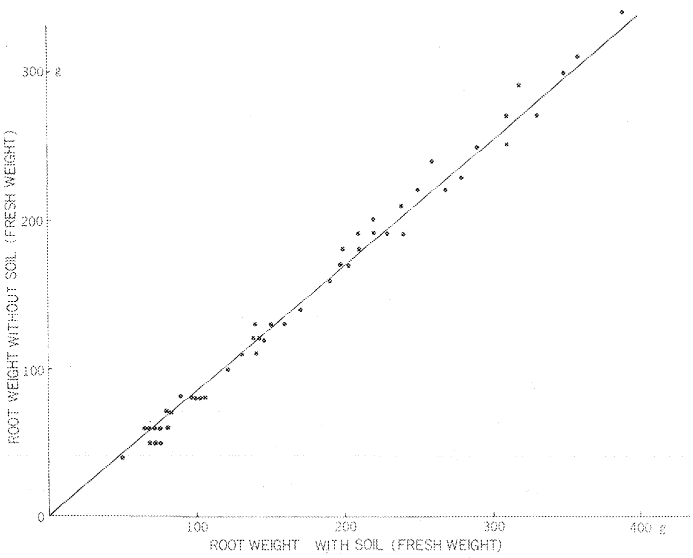


Fig. 15 Root weight ratio and variance of the fine roots in soil horizons I and II of the *C. japonica* stand S 4.

Ratio estimate equation:

$$V_{(z)} \doteqdot Z^2 \frac{N-n}{N-1} \frac{1}{n} \left[\frac{\sigma_x^2}{\bar{x}^2} + \frac{\sigma_y^2}{\bar{y}^2} - 2\frac{Cov\,(x \cdot y)}{\bar{x}\bar{y}} \right]$$

$\sum x$	$\sum y$	Z	S_x^2	S_y^2	$Cov(x \cdot y)$	V_z	σ_z	$\frac{\sigma_z}{Z}$	r	n
9,212	7,849	0.8520	8,037	6,069	6,965	0.0131	0.1140	0.0134	0.9945	50

$* \ Z = \frac{\sum y}{\sum x}$

Table 8. Dry weight ratio in each height of a stem of *C. japonica*

Stand	Tree No.	Tree height (cm)	0.0m	0.2	1.2	3.2	5.2	7.2	9.2	11.2	13.2	15.2	17.2	Average
S 1	3	622	0.30	0.33	0.32*	0.31	0.25	—	—	—	—	—	—	0.32
S 2	17	1,335	0.32	0.39	0.39	0.38*	0.37	0.36	0.28	0.27	—	—	—	0.38
S 3	11	972	0.34	0.38	0.36*	0.34	0.33	0.30	0.25	—	—	—	—	0.36
S 4	21	1,832	0.38	0.42	0.45	0.44*	0.44	0.42	0.37	0.38	0.36	0.35	—	0.44
S 5	25	1,932	0.38	0.41	0.47	0.43*	0.41	0.41	0.39	0.38	0.38	0.37	0.31	0.42
S 6	32	915	0.33	0.32	0.32*	0.30	0.30	0.29	0.29	—	—	—	—	0.31
S 7	22	1,255	0.35	0.35	0.35*	0.35	0.35	0.33	0.30	—	—	—	—	0.35
S 8	42	1,444	0.32	0.33	0.32	0.32*	0.32	0.31	0.30	0.29	—	—	—	0.32
S 9	12	1,400	0.38	0.39	0.38	0.37*	0.36	0.35	0.34	0.32	0.30	—	—	0.37

The weight of soils sticking to roots depends strongly on the weather or the soil condition when study is made. The weight becomes small as the soil dries up, and falls off at the measuring time on a fine and windy day. It becomes large if measured when the soils are wet after raining. Generally speaking, the weight of sticking soils becomes large under wet conditions. It is, for example, larger in the moist soils than in the dry soils, and in the moist subsurface soils than in the dry surface soils. Soil properties, too, have an obvious bearing on this point; for example, weight is larger in the clayey soils with a high power of holding water than in the sandy soils with a low water-holding power.

5. **Dry weight ratio**

To calculate their dry weights, the dry weight ratios were calculated from a certain amount of the collected samples whose fresh weight had been measured beforehand. The dry weight ratios are here the ratio of the dry weight to the fresh weight.

$$R = \frac{W_D}{W_W}$$

R : Dry weight ratio

W_D : Dry weight

W_W : Fresh weight

Measurements of dry weight ratio of each part of a tree were carried out as follows:

1) Leaf

The fresh weight of leaves was measured in each leaving part of the tree-crown which was horizontally divided equally into three parts in this investigation. Dry weight ratios were measured at every unit of measurement (i. e., every horizon). And then the dry leaf weight was estimated multiplying the leaf weights by the dry weight ratios. It is less troublesome to take the materials out of the total weight of leaves run together in each horizon. The dry weight ratios, however, differ in the positions of a tree crown. Measuring them in every horizon makes possible higher accuracy. The materials taken from each layer were 1.0~1.5 kg by fresh weight. The fresh weights were measured at the site.

Each material had been dried for 7 to 10 days at eighty to ninety degrees centigrade. The absolute dry weights were obtained thus.

2) Branch

Of the branches as well as of leaves, some medium-sized branches for dry weight ratio were selected from each level and cut off fine to use as the materials.

The branches of one to two kg (by fresh weight) were taken out as the materials. The fresh weights were measured at the site.

3) Stem

The fresh weights of the disks for stem analysis were measured immediately after the disks were taken out. These disks were absolutely dried. And then, the dry weights of a stem were calculated multiplying by each part weight of a stem, the ratios of the dry weights at every stem classification.

Generally, a dry weight ratio of a stem is lowest near the root stock; it tends to increase towards the tip of a stem. As it differs at each part of a stem, accuracy of estimating it is to be heightened when the stem is divided as fine as possible.

Fig. 16 shows the relation between the dry weight ratio of a stem in each position and the average dry weight ratio in the stem analysis. According to the table, *C. japonica* shows, as in Table 8, the average dry weight ratio of stem at the height of 3 to 4 m when it is 13 m high and of 4 to 5 m when it is 19 m high.

4) Very large root

The very large roots of 2 or 3 kg were taken out of those roots normally grown up in soil horizons I and II, where they were mostly distributed, and their dry weight ratios were calculated. When the weights of the materials are 2 kg, the coefficient of variation of the dry weight ratio is found to be about 7%.

The materials are those from which the sticking soils were taken off clearly and the fresh weights measured at the site.

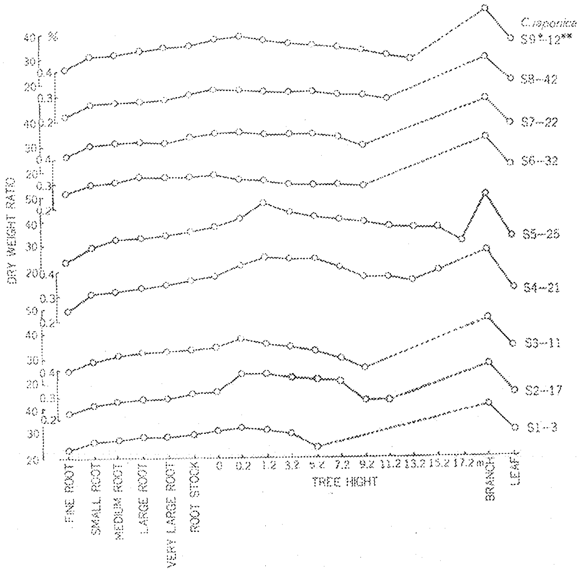
5) Large root

In the way like as done for the very large roots, the large roots of two or three kg were taken as a sample, and their dry weight ratios were calculated. The coefficient of variation of the large roots was about 5% here, and was smaller than that of a very large root.

6) Medium root

The samples, which were taken out on the spot and carried back in vinyl sacks, were carefully washed with water to remove the sticking soil. After that, the fresh weights were measured.

Medium roots are distributed evenly and widely at each horizon. Their growth and dry weight ratios differ in each horizon. They run together to calculate the dry weight ratios; the errors go up. To measure the dry weight ratios, they were divided in the horizons I, II and below.



* Stand No. ** Sample tree No. - - - Not measured.

Fig. 16 Dry weight ratio of each part of trees.

The coefficient of variation is about 5% when each sample of 500 g is taken out in soil horizons I and II.

7) Small root

As samples, the small roots of each weight of 200 to 300 g were taken from soil horizons I, II and below. After they were washed out and dried, their dry weight ratios were calculated. The coefficients of variation are about 3~4%.

8) Fine root

The fine roots of each weight of 50 to 100 g were taken out as samples from soil horizons I, II and below. As in the case of the small roots, their dry weights were calculated after they were washed out and dried. The coefficients of variation are about 3~4%.

The accuracy in measuring the ratios of dry weight of fine and small roots is given in the following.

6. Sample weight for estimating the dry weight ratios and accuracy

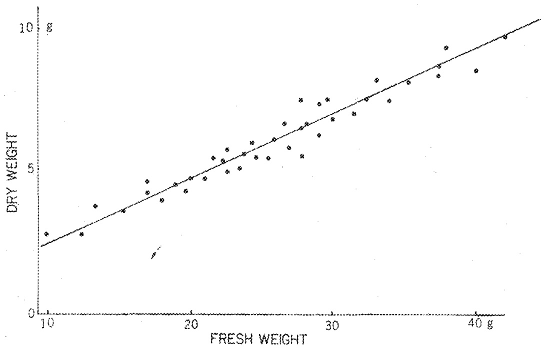
The fresh weights, dry weights, and dry weight ratios of the fine roots were calculated in soil horizons I and II in the stand of S 3 of *C. japonica*.

A linear regression which passes through the origin was, as in Fig. 17, recognized between the fresh weight and the dry weight.

The dry weight ratios and their average values of these materials are measured. According to the result, the dry weight ratio was 24% and the coefficient of variation was 8%.

The ratios of dry weight were then calculated according to the ratio estimate equation in which the same values were used.

A comparison between the two makes clear that the difference in average dry weight



$y = 0.2337x$
$\sigma_{\bar{z}} = 0.00259$
$C = 0.0111$
$r = 0.9441$
x : Fresh weight
y : Dry weight

Fig. 17 Dry weight ratio of the fine roots of *C. japonica*, obtained from the data of stand S 3 and by using ratio estimate equation.

ratio is 0.18% and that the ratio estimate is more accurate, and besides that the error is reduced by one-eight that which is obtained using each dry weight ratio.

Twenty samples each with fresh weight of unit weight, as shown in Table 9, were taken out of the fine and the small roots in soil horizons I and II in the K 1 stand of *L. leptolepis*. Their dry weights were measured, and then the errors were calculated in the same way as mentioned above. Next, a comparison was made between both equations to be used in calculation, while observing how the coefficients of variation change as the samples are putting on weight. The values of the fine roots in soil horizon I, as shown in Table 9, are obtained from this table. According to Table 9, there is almost no difference between the ratios of dry weight according to both equations to be used in calculation. The coefficients of variation, however, are about four times more accurate by the ratio estimate than by the simple equation of error to be used in calculation.

This discrepancy increase as the soil horizons go lower and roots become thicker.

The result counted in the change of the coefficient of variation corresponding to the increasing sample weight is tabulated in Fig. 18. It is clear from this that the coefficients of

Table 9. Weight and variation coefficient of dry weight ratio a sample unit.
Fine root in the horizons I and II of the *L. leptolepis* stand K1

Weight of sample unit	1〜2 g	2〜3 g	3〜4 g	4〜5 g	5〜6 g	6〜7 g	7〜8 g	8〜9 g	9〜10 g
R_1	0.2353	0.2289	0.2350	0.2286	0.2306	0.2325	0.2328	0.2343	0.2333
R_2	0.2352	0.2286	0.2350	0.2285	0.2306	0.2330	0.2337	0.2343	0.2331
C_1	0.0396	0.0419	0.0310	0.0318	0.0262	0.0177	0.0279	0.0460	0.0330
C_2	0.0098	0.0105	0.0077	0.0074	0.0056	0.0039	0.0056	0.0115	0.0069
C_1/C_2	4.04	3.99	4.03	4.30	4.68	4.54	4.98	4.00	4.78

* R_1 : Average of dry weight ratio, n:20.　　R_2 : Dry weight.
C_1 : Variation coefficient of R_1.　　C_2 : Variation coefficient of R_2.

Table 10. Sample weight when 20 samples were measured at the variation coefficient of 1%

Root class / Soil horizon	f	s	m
I	2.5	3.5	5.5
II	2.5	5.5	10.0<
III	5.5	5.5	10.0<
IV	—	5.5	10.0<

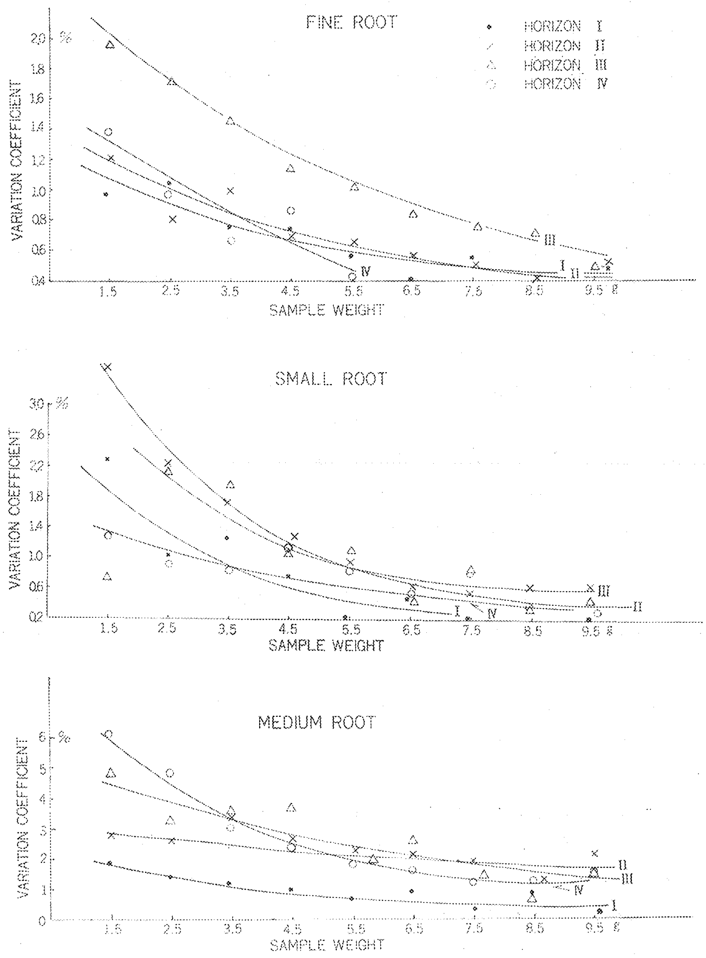


Fig. 18 Variation coefficient of dry weight ratio.

variation of the fine, small and medium roots decrease steeply as their sample weights increase. This tendency differs according to root class or to soil horizon. The sample measured weights increased, as shown in Table 10, as the root became thicker and the soil went deeper under the condition of 1% of the coefficient of variation obtained from Fig. 18. This is because the variance of measurement becomes large as a root becomes thicker and soils go deeper.

7. **Moisture content of every part of a tree**

The measurements of dry weight ratio made it possible to estimate the moisture content of each part of a tree. This content has a close correlation to the growth of a tree.

Here dry weight ratios and how the ratios of containing water went up and down both in each part of a tree and under environmental conditions were gone into.

1) Dry weight ratio in every part of a tree

The dry weight ratios in every part of sample trees which make medium growth in every stand are shown in Fig. 16.

The dry weight ratio of fine roots are lowest and within the range of twenty to thirty per cent. This is common to the species like *C. japonica*, *Ch. obtusa*, *P. densiflora*, and *L. leptolepis*. It increased gradually as the root became thicker, and to the highest at the root stock or at the part about 20 cm above the ground. To give an example, it was 40 to 45% for *C. japonica*.

It increased remarkably to four to five per cent between fine and small roots, while from a small root to a root stock it increased to only about 1%. This is partly because the fine roots have many young tissues, inclusive of white roots, which contain much water, and partly because the roots larger than small roots consist of uniformly lignified tissues. For this reason it becomes necessary to measure the dry weight ratios of every part of a root.

As already explained in the section about the measurements of those of a stem, the dry weight ratios decrease, but the water contents increase gradually according to the transit from downward to upward. Particularly near the tip, they decrease with rapid speed because many young tissues are there. *Ch. obtusa* taken here as an example, the change of the dry weight ratio in each part of the stem is shown in Fig. 19.

This is due to good or bad growth of a tree, or to its size. The change in dry weight ratio tends to go similarly, but their values are not uniform. They also differ from species to species.

The dry weight ratio of branches is the highest of all as they grow more slowly than the rest of the parts and are highly lignified. That of *C. japonica*, for example, showed 45～50%.

Generally, the dry weight ratio of leaves is lower than those of a stem or branches. It is almost the same as those of small and medium roots.

2) Species

Species promote their own growth or change in dry weight ratio. A further examination of this is shown in Fig. 20 giving the average dry weight ratios both of the young trees, four to five years of age, planted at Asakawa nursery and of the sample trees growing moderately. Many species showed the dry weight ratio of leaf of 30% at Asakawa nursery, but the evergreen coniferous species with hard tissues, as *Biota orientalis*, *P. densiflora*, and *C. japonica* showed the higher percentages of 35 to 40. Of broad-leaved trees, the species with rather hard leaf tissue, such as *Celtis sinensis*, *Aphananthe aspera*, *Quercus serrata*, *Ulmus parvifolia*, and *Zelkova serrata*, showed a higher ratio than the species with soft and thin leaf tissue, such as *Catalpa ovata*, *Mallotus japonicus*, *Melia azedarach*, *Robinia pseudo-acacia* v. *inermis*, and *Cornus controversa*, *Firmiana platanifolia*.

The tendency was alike in the sample stand. The dry weight ratios of *Ch. obtusa*, *Ch. pisifera*, *Abies firma*, *Tsuga canadensis*, etc. were high in particular. That of *Ch. obtusa* was as much as 52%. The main species taken here as an example became lower in the order of *Ch.*

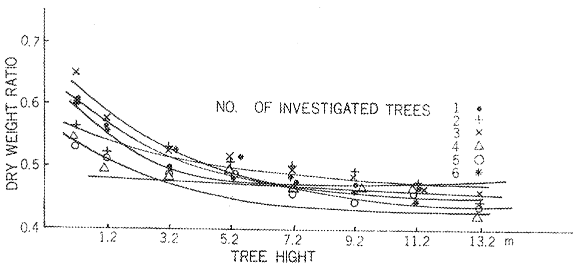


Fig. 19 Dry weight ratio of each height of a stem, in *Ch. obtusa* stand H 3.

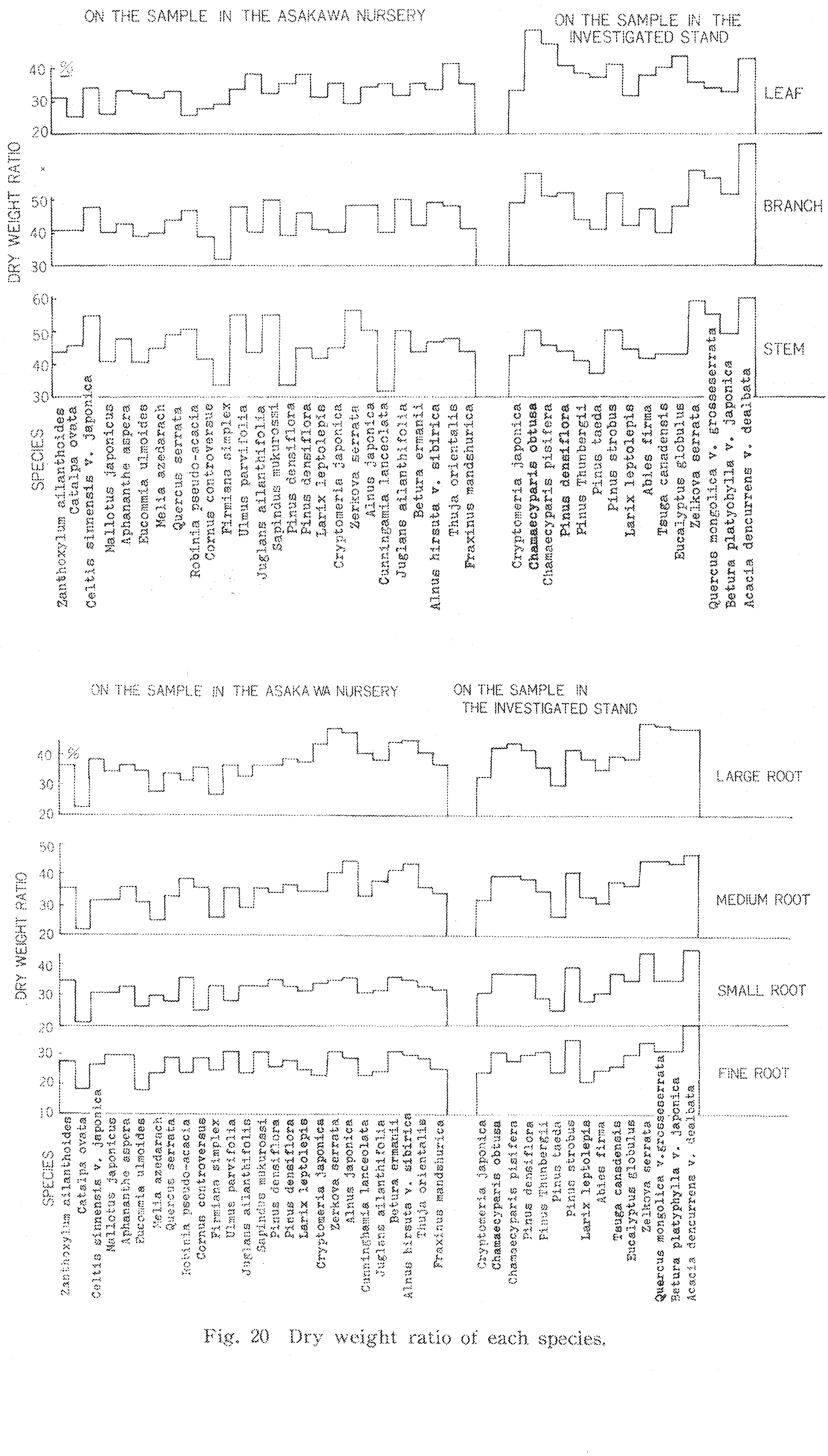


Fig. 20 Dry weight ratio of each species.

obtusa, P. densiflora, C. japonica, and *L. leptolepis.*

Sometimes the dry weight ratio of leaf changes according to the turning of the seasons. Even so, there appears to be no great difference among species.

The dry weight ratios of branches and of a stem have a particular relationship to the growth rate. Low are, for example, those of the species which grow quickly and which are abundant in many young tissues. High are instead those of the species which grow slowly.

As a result of investigations at Asakawa nursery, it was found that the high were those of both branches and stems of the species as *Celtis sinensis* v. *japonica, Ulmus parvifolia, Sapindus mukurossi, Zelkova serrata, Alnus japonica, Alnus hirsuta* v. *sibirica,* and *Biota orientalis,* etc. And also high were those of the sample species as *Ch. obtusa, Acacia dencurrens, Zelkova serrata, Ch. pisifera,* and *P. strobus* (growing poor).

The dry weight ratios of a large root, very large root, and root stock like those of the above-ground parts, are affected by character of species and growth condition. Particularly those of fine and small roots are affected mainly by the former. At Asakawa nursery, the species of which medium and large roots show a high percentage are *Catalpa ovata, Eucommia ulmoides, Cunninghamia lanceolata, C. japonica, Juglans ailanthifolia, L. leptolepis, P. densiflora.* Of the sample trees, they are the broad-leaved trees as *Mallotus japonicus, Aphananthe aspera, Quercus serrata, Ulmus parvifolia, Sapindus mukorossi, Zelkova serrata, Betula ermanii, Alnus hirsuta* v. *sibirica, Biota orientalis,* etc.

The species which have a large amount of thick white roots show a low dry-weight ratio of fine and small roots. This was observed at Asakawa nursery. The examples are the species such as *Catalpa ovata, Eucommia ulmoides, Cunninghamia lanceolata, C. japonica, Juglans ailanthifolia,* and *L. leptolepis,* etc. Vis-a-vis with them, there are the species such as *Mallotus japonicus, Aphananthe aspera, Ulmus parvifolia, Quercus serrata, Sapindus mukurossi, Zelkova serrata, Betula ermanii, Alnus hirsuta* v. *sibirica, Biota orientalis,* etc.

Of the sample trees, *C. japonica* and *L. leptolepis* show a low percentage. The species which are vis-a-vis with these *Acacia decurrens, Betula platyphylla, Quercus mongolica, Zelkova serrata, P. densiflora, P. thunbergii, P. strobus, Ch. obtusa,* etc. This shows a close similarity to the result of investigations at Asakawa nursery.

The species which show the high dry-weight ratio of fine roots, grow fine roots sparsely. Their white roots are fine and highly lignified, and root types are mostly of dry *Quercus myrsinaefolia* type. There are many species which stand against drought strongly.

On the contrary, the species, showing a low percentage belong to the root types of *C. japonica, Firmiana platanifolia,* and *Cinnamomum camphora.* Those species also are of moderately moist type.

3) Site index and dry weight ratio

The dry-weight ratios of each part depend upon the growth conditions. It is likely that they are closely related to site index. The relation between site index and dry-weight ratio is shown in Fig. 21.

All the species and their above-and-under ground parts, although their variance is wide, tend to decrease their dry-weight ratios because the site index and then the water contents increase. The main reasons for this are the following two. Firstly, there are many young tissues with high moisture content distributing in the stand showing large site indices and sufficient growth. Secondly, there are instead many older tissues with low moisture content distributing in the stand showing small site indices and insufficient growth.

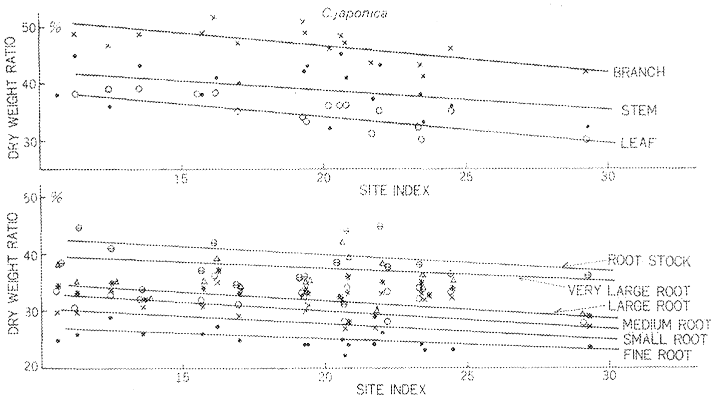


Fig. 21 Site index and dry weight ratio of each part of trees.

The change in dry weight ratio answering to the site index does not take place only in the stems, large roots, very large roots and root stocks, which are the parts for storage. It also occurs in the leaves, fine roots, etc. with younger tissues. Hence it is not unreasonable to presume that the tissues of these working parts and even their efficiency depend strongly upon the growth conditions.

Generally, the stand soil with a small site index is either dry or heavy wet. In this site, the fine roots have comparatively few new shooting white roots and many lignified parts. So, the dry weight ratio of the fine root becomes higher there.

The low dry weight ratio in a heavy wet site explains that each part of a tree grows poor. It also makes clear that the white roots with high moisture content, shot from a fine root, come to decrease thence to decay to death.

8. **Accuracy of measurement of part biomass**

Accuracy in measuring each part biomass of a tree is to be obtained after the above-mentioned are all finished. But each part biomass calculated in the final procedure comes out with errors made at each stage of investigations, such as sample divisions, measurement of root weight, root classification, measurement of the ratios of the root weights and their dry weights.

The sample weights were decided and measured to make those errors as small as possible. The error of 10% of the average value was aimed at under the significance level of 95%.

The errors were fairly different at each stage of measurements. It was therefore impossible to measure on a constant error. The errors were different even at each part of a tree too, so the part biomass could not be estimated with the same precision. It is within reason to predict that estimation error of the total biomass is 10～20% when calculated in terms of the coefficient of variation.

9. **Latest annual growth of branches and leaves**

The annual growth of branches and leaves is not here figured out accurately. For there has been left much to resolve the difficult problems either as how to deal with the difference of leaving periods or as how to estimate the amount of dead branches and fallen leaves; also, there are few measured samples. Studies done so far run together, and estimated by stand

Table 11. Coefficients for estimating annual leaf and branch growth

Part	Stand age (yrs) \ Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*
Leaf (p)	0～10	0.40	0.40	0.60
	10～20	0.35	0.30	0.55
	20～30	0.30	0.30	0.55
	30～	0.25	0.22	0.50
Branch (q)	0～10	0.40	0.40	0.60
	10～20	0.35	0.35	0.50
	20～30	0.35	0.35	0.40
	30～	0.30	0.30	0.30

*1 Annual leaf growth (p) multiplied by leaf biomass.
*2 Annual branch growth (q) multiplied by branch biomass.

age: The annual growth of branches is got by multiplying the latest annual growth of a stem by the coefficients in Table 11: and that of leaves is gained by multiplying the leaving amount by them shown in the table. To determine the accurate values of those coefficients, it is necessary to continue this type of study. The annual growth of branches and leaves was thus calculated.

10. **Representation of the absorption structure**

Nutriment and water in soils are taken into a tree through the surface of roots.

Efficiency of absorption is dependent upon each part of roots. It is highest in the white roots existing in the tips and lowest in the lignified parts. But as nutriment and water are to be absorbed through their surface in any case, the absorptive structure of the underground part is to be expressed with the surface area of roots.

Greater parts of the root biomass are those of a large root to a root stock which have little to do with absorption. But the fine and the small roots, whose tissues are young, have much greater surface area.

1) Estimation of the surface area of roots

It is necessary to estimate the root system surface area. As the root biomass in each stand had already been measured, the author thought of a method whereby calculating the surface area of roots from these biomass could be done. There is to exist the following relations between the surface area and the root biomass.

$$A \fallingdotseq \pi D l, \qquad G \fallingdotseq k\frac{\pi D^2}{4}l$$

$$A \fallingdotseq G\frac{4G}{kD}$$

A : Root surface area (cm^2), G : Root weight (g), D : Root diameter (cm),
k : Bulk density (g/cc), l : Root length (cm)

That is to say, with the root weight, bulk density, and diameter obtained beforehand, the surface area is to be calculated from the root biomass. The next step is to consider root diameter and bulk density necessary for calculating the surface area, and the root length calculated from them.

2) Root diameter

(1) Root classification and the accuracy of diameter measurement

When the root biomass is measured without classifying roots according to size, it is very difficult to get the corresponding diameter of the root to them. And at the same time, the average diameters calculated from them come to have very large variance. The finer the classification of roots is done, the more accurate the measurement of average diameter will become. As finer classification involves greater trouble, the roots were classified into five classes as shown in Table 4; fine root (0～0.2 cm), small root (0.2～0.5 cm), medium root (0.5～2.0 cm), large root (2.0～5.0 cm) and very large root (5.0 cm and above).

The diameter of a fine root was measured with a micrometer and those of the other larger roots with a pair of slide calipers.

Measurement of diameter cannot escape some errors due to the variances of samples or methods of measurement. The distribution of thickness is different from species to species, too; consequently the average diameters are more or less different.

The average diameters and the coefficients of variation of each classified root in soil horizons I and II of S 4 stand are measured. There it can be seen that the coefficients of variation became larger as the roots became thicker from a fine root to a very large root.

The coefficients of variation in each horizon are measured. According to the result, they are 8% in soil horizon I and 26% in soil horizon V. It is also clear that they become larger as soil horizons go down lower. This indicates that in the upper horizons roots tend to grow evenly due to a uniform growth condition, but that in the lower horizons the growth condition tends to go unbalanced.

(2) Various conditions concerning the change in diameter of roots

The average diameters of a root depend largely upon species or environmental conditions.

a) Species

The branching of roots is dependent upon the characters of tree. The trees of which the roots are branched fine give small average diameters, while those having roots branched roughly give large average diameters.

Table 12 shows in the order of their magnitude the average diameter of every classified root in soil horizons I and II, which were got from investigations both at stands and at Asakawa nursery (The stands of moderate habitat type were chosen from many stands for *C. japonica*, *Ch. obtusa*, *P. densiflora*, and *L. leptolepis*).

The average diameters of the fine roots of all the species were within the range of 0.06～0.132 cm, and the average values were within 0.7～0.8 cm. The species which were comparatively large and 0.13～0.90 cm in diameter are *Acacia decurrens*, *Ch. obtusa*, *Ch. pisifera*, *Cunninghamia lanceolata*, *C. japonica*, *Abies firma*, *Tsuga canadensis*, *Cornus controversa*, *Biota orientalis*, *Firmiana platanifolia*, *Eucommia ulmoides*, etc. The species which are larger in diameter than those species are *P. densiflora*, *L. leptolepis*, *Eucalyptus globulus*, *Zerkova serrata*, *Quercus mongolica*, *Betula platyphylla*, *Betula davurica*, *Aphananthe aspera*, *Ulmus parvifolia*, *Celtis sinensis*, *Alnus japonica*, *Alnus hirsuta* v. *sibirica*, *Quercus serrata*, *Juglans ailanthifolia*, *Mallotus japonicus*, *Melia azedarach*, *Fraxinus mandshurica*, etc. This is due to the difference in distribution of their fine roots; in other words, the former trees have many thicker fine roots while the latter have many thinner roots.

This also has much to do with the size of the absorptive roots. As in Table 13, the trees with thinner absorptive roots inclined to have fine roots with smaller average diameters. Of all those trees, the trees with thin absorptive roots, for detail, had fine roots with large average diameter when their roots were fewer in number, and they had many thick parts. And yet, the trees with many thin roots inclined to have small average diameters.

Table 12. Average root diameter of each species

Species	Diameter (cm)	
Fine rood		
Acacia decurrens v. *dealbata*	0.132	
Catalpa ovata	0.112	
Chamaecyparis obtusa	0.090~0.130 0.110	
Abies firma	0.110	
Eucommia ulmoides	0.110	
Tsuga canadensis	0.109	
Zanthoxylum ailanthoides	0.107	
Biota orientalis	0.104	
Chamaecyparis pisifera	0.102	
Cunninghamia lanceolata	0.095	
Cornus controversa	0.092	
Fraxinus mandshurica	0.087	
Cryptomeria japonica	0.074~0.098 0.086	(0.092)
Sapindus mukurossi	0.082	
Larix leptolepis	0.074~0.090 0.082	(0.081)
Eucalyptus globulus	0.080	
Pinus densiflora	0.072~0.085 0.079	
Alnus japonica	0.072	
Betula ermanii	0.072	
Ulmus parvifolia	0.071	
Mallotus japonicus	0.070	
Firmiana simplex	0.068	
Zelkova serrata	0.070	(0.070)
Celtis sinensis v. *japonica*	0.069	
Aphananthe aspera	0.068	
Juglans ailanthifolia	0.068	
Alnus hirsuta v. *sibirica*	0.067	
Quercus serrata	0.067	
Quercus mongolica v. *grosseserrata*	0.065	
Betula davurica	0.064	
Betula platyphylla v. *japonica*	0.063	
Robinia pseudo-acacia	0.062	
Melia azedarach	0.060	
Small root		
Firmiana simplex	0.42	
Melia azedarach	0.41	
Zanthoxylum ailanthoides	0.41	
Robinia pseudo-acacia	0.41	
Sapindus mukurossi	0.41	
Cornus controversa	0.41	
Cryptomeria japonica	0.35~0.44 0.40	(0.36)
Larix leptolepis	0.35~0.44 0.40	(0.40)
Fraxinus mandshurica	0.40	
Juglans ailanthifolia	0.40	
Pinus densiflora	0.35~0.43 0.39	
Eucommia ulmoides	0.39	
Catalpa ovata	0.39	
Chamaecyparis obtusa	0.32~0.44 0.38	
Biota orientalis	0.38	
Cunninghamia lanceolata	0.38	
Acacia decurrens v. *dealbata*	0.37	
Abies firma	0.36	
Mallotus japonicus	0.35	
Eucalyptus globulus	0.35	
Ulmus parvifolia	0.35	
Alnus hirsuta v. *sibirica*	0.34	
Zelkova serrata	0.33	
Celtis sinensis v. *japonica*	0.32	(0.33)
Quercus serrata	0.33	
Tsuga canadensis	0.33	
Quercus mongolica v. *grosseserrata*	0.33	
Chamaecyparis pisifera	0.32	
Aphananthe aspera	0.32	
Alnus japonica	0.32	
Betula ermanii	0.31	
Betula platyphylla v. *japonica*	0.31	
Betula davurica	0.30	
Medium root		
Chamaecyparis obtusa	1.43~1.72 1.58	
Larix leptolepis	1.30~1.69 1.50	(1.50)
Biota orientalis	1.47	
Cryptomeria japonica	1.45	
Melia azedarach	1.35~1.53 1.44	(1.38)
Zanthoxylum ailanthoides	1.43	
Cornus controversa	1.42	
Pinus densiflora	1.42	
Juglans ailanthifolia	1.28~1.53 1.41	
Catalpa ovata	1.41	
Eucommia ulmoides	1.41	
Firmiana simplex	1.41	
Robinia pseudo-acacia	1.40	
Fraxinus mandshurica	1.39	
Cunninghamia lanceolata	1.39	
Sapindus mukurossi	1.38	
Quercus serrata	1.37	
Zelkova serrata	1.35	
Alnus japonica	1.15	(1.35)
Mallotus japonicus	1.34	
Celtis sinensis v. *japonica*	1.33	
Betula ermanii	1.32	

( ) : Values measured in Asakawa nursery.

Species	Diameter (cm)	
Ulmus parvifolia	1.32	
Alnus hirsuta v. *sibirica*	1.31	
Aphananthe aspera	1.30	
Betula davurica	1.30	
Eucalyptus globulus	1.30	
Chamaecyparis pisifera	1.30	
Abies firma	1.25	
Betula platyphylla v. *japonica*	1.25	
Acacia decurrens v. *dealbata*	1.24	
Tsuga canadensis	1.20	
Quercus mongolica v. *grosseserrata*	1.20	
Large root		
Eucalyptus globulus	3.71	
Betula davurica	3.62	
Acacia decurrens v. *dealbata*	3.62	
Zelkova serrata	3.52	(2.50)
Betula platyphylla v. *japonica*	3.51	
Chamaecyparis pisifera	3.46	
Tsuga canadensis	3.46	
Cryptomeria japonica	3.02~3.81 / 3.42	(2.15)
Quercus mongolica v. *grosseserrata*	3.40	

Species	Diameter (cm)	
Chamaecyparis obtusa	3.09~3.62 / 3.36	
Larix leptolepis	3.05~3.62 / 3.36	(2.21)
Abies firma	3.20	
Pinus densiflora	2.70~3.67 / 3.19	
Firmiana simplex	3.00	
Melia azedarach	2.85	
Cornus controversa	2.84	
Aphananthe aspera	2.75	
Robinia pseudo-acacia	2.75	
Zanthoxylum ailanthoides	2.75	
Mallotus japonicus	2.65	
Betula ermanii	2.65	
Cunninghamia lanceolata	2.57	
Alnus hirsuta v. *sibirica*	2.45	
Sapindus mukurossi	2.42	
Ulmus parvifolia	2.41	
Biota orientalis	2.41	
Celtis sinensis v. *japonica*	2.35	
Alnus japonica	2.30	
Eucommia ulmoides	2.30	
Fraxinus mandshurica	2.25	
Quercus serrata	2.22	
Juglans ailanthifolia	2.17	
Catalpa ovata	2.15	

The average diameters of the fine roots depend also on the states of growth. The trees which took fine roots in cluster, such as *Zelkova serrata*, *Quercus mongolica*, *Betula platyphylla*, *Betula ermanii*, etc., had smaller average diameters; on the other hand those which took fine roots sparsely had larger average diameters.

Let us examine the relation of the dimensions of the average diameters of roots to the types of the roots already investigated. Results obtained show that the moderatly moist-typed trees as *Cornus controversa*, *Firmiana platanifolia*, and *C. japonica* are inclined to have a large average diameter, whereas such dry-typed trees as *Quercus myrsinaefolia* etc. are inclined to have a small diameter. This was, however, not very clear. The relation among the root types, ramifications, growing of fine roots, and thickness of absorptive roots is shown in Table 13.

The above-mentioned relation is also observed on the small and the medium roots. For example, the trees with many thin roots branching, such as *Zelkova serrata*, *Quercus mongolica*, *Betula platyphylla*, *Betula davurica*, *C. japonica*, and *Ch. obtusa* had smaller average diameters. The small, medium and large roots did not show such a great discrepancy as the fine and very large root did, because they were given a definite range of diameter. *P. densiflora* and *L. leptolepis* with less fine roots and rough distribution had a rather large average diameter.

The large and the very large roots are different in thickness by the size or characters of sample trees; those of the larger tree have larger average diameters.

This was dependent upon the pattern of branching. In the trees with greater branching and less thick roots such as *Tsuga canadensis* and *Acacic decurrens*, the average diameter of

Table 13. Root properties of each species

Species	Root type	Branching habit of small and medium roots*1	Amount of fine root*2	Diameter of root tip mm
Acacia dencurrens	*Cornus controversa*	5	5	1.0~1.2
Eucommia ulmoides	*Firmiana simplex*	2	4	1.0~1.2
Cornus controversa	*Cornus controversa*	3	5	0.8~1.0
Chamaecyparis pisifera	*Cornus controversa*	5	5	0.7~0.8
Chamaecyparis obtusa	*Quercus myrsinaefolia*	5	5	0.7~0.8
Biota orientalis	*Quercus myrsinaefolia*	4	5	0.7~0.8
Cunninghamia lanceolata	*Cryptomeria japonica*	3	4	0.6~0.7
Cryptomeria japonica	*Cryptomeria japonica*	3	4	0.6~0.7
Abies firma	*Pinus densiflora*	2	2	0.6~0.7
Tsuga canadensis	*Quercus myrsinaefolia*	5	4	0.6~0.7
Zanthoxylum ailanthoides	*Cinnamomum camphora*	1	2	0.6~0.7
Pinus densiflora	*Pinus densiflora*	2	2	0.5~0.6
Fraxinus mandshurica	*Firmiana simplex*	3	5	0.5~0.6
Larix leptolepis	*Quercus myrsinaefolia*	3	4	0.5~0.6
Catalpa ovata	*Firmiana simplex*	2	2	0.3~0.4
Firmiana simplex	*Firmiana simplex*	2	2	0.3~0.4
Juglans ailanthifolia	*Quercus myrsinaefolia*	2	1	0.3~0.4
Melia azedarach	*Firmiana simplex*	2	1	0.3~0.4
Alnus japonica	*Quercus myrsinaefolia*	4	3	0.3~0.4
Alnus hirsuta v. *sibirica*	*Quercus myrsinaefolia*	4	3	0.2~0.3
Betula platyphylla v. *japonica*	*Quercus myrsinaefolia*	4	3	0.2~0.3
Betula ermanii	*Quercus myrsinaefolia*	4	2	0.2~0.3
Betula davurica	*Quercus myrsinaefolia*	4	2	0.2~0.3
Quercus mongolica	*Cercidiphyllum japonicum*	4	2	0.2~0.3
Quercus serrata	*Quercus myrsinaefolia*	4	2	0.2~0.3
Robinia pseudo-acacia	*Firmiana simplex*	2	2	0.2~0.3
Sapindus mukurossi	*Firmiana simplex*	2	2	0.2~0.3
Ulmus parvifolia	*Quercus myrsinaefolia*	3	2	0.1~0.2
Zelkova serrata	*Quercus myrsinaefolia*	4	3	0.1~0.2
Celtis sinensis v. *japonica*	*Quercus myrsinaefolia*	4	3	0.1~0.2
Eucalyptus globulus	*Cornus controversa*	2	1	0.1~0.2

*1 Branching habits of small and medium roots
1 : Very few branching, 2 : Few, 3 : Moderate, 4 : Frequent, 5 : Very frequent.
*2 Amount of fine root
1 : Very few, 2 : Few, 3 : Moderate, 4 : Frequent, 5 : Very frequent.
*3 Root type : See footnote on the page 3.

the very large root was small; however, it was large in such trees as *L. leptolepis*, *Zelkova serrata* with less branching.

b. The growth of a tree and the average diameter of roots

As fine and small roots are susceptible to the properties of trees, correlation with basal area is hardly recognized. The diameter of large and very large roots becomes larger as trees grow. Particularly in very large roots, this trend is remarkable. A concave regression rather upward was recognized between them. A very large root was 6 cm in average diameter when the basal area was 100 cm^2, and it was 8 cm at the basal area of 500 cm^2.

Thus, the diameter of roots increases slowly in the case of a small tree and rapidly in the case of a large tree. This is presumably because a very large root grows in stand increase at an earlier time and so the average diameter does not increase. And besides, it may be due to the diameter increment of an almost given number of roots in the case of a large-diameter tree. Both the small-and large-diameter trees, for example, impede their large and very large roots from increasing in number. Or rather, they facilitate the thickening growth of their very large roots in definite number to support their above-ground parts. That these roots show the high rate of increse in particular is why they don't keep off growing by root classification.

c. Average diameter in each soil horizon

The pattern of branching or growth of the root system differs in each soil horizon. This accompanies the change in average diameter. The average diameter of a fine root of each species increases as the soil horizon goes lower. For, due to the bad aeration and high percentage of water in the core soil, the white roots are deterred from branching off and besides, the skin tissues are caused to grow extraordinarily thick. This change is observed horizontally. A white root, for example, is larger in diameter in the wet site than in the dry one.

Change of a fine root in thickness according to the depth of the soil horizon differs from species to species. It is, for example, big for *C. japonica* and *Ch. obtusa* and little for *Zelkova serrata*, *Quercus mongolica*, and *Betula platyphylla*.

The diameter of small and medium roots tends to become a little larger in the low soil horizon, but not so clearly as that of a fine root, the reason being that the root system is checked from branching and the thin roots become fewer in number in the core soil.

Large and very large roots, on the contrary, are small in diameter in the deep soil. This arises from a twofold reason. Firstly, they get smaller in diameter as they go farther from the root stock. Secondly, they have their secondary growth checked physically, say, by soil pressure. This change is more remarkable in the shallow-rooted trees such as *L. leptolepis*, *Ch. obtusa*, etc. than in such deep-rooted trees as *P. densiflora*, and *C. japonica*. This is because the growth of the root system in *Ch. obtusa* and *L. leptolepis* tend to be easily checked in the low and hard soil horizon.

d. Soil type and soil moisture

The diameter of a fine root has a close relationship to the soil conditions, particularly to water condition. It was generally observed that it is larger in the moderately wet soil than in the dry soil. This relation on the stand of *C. japonica* is shown in Table 14.

As can be seen in Table 14, the fine roots are 0.075 to 0.088 cm in average diameter in the dry soils of $B l_A$ to B_A of the stands of S 6 to S 24, and are 0.090 to 0.098 in the moderately wet or wet soils of $B l_E$ to B_E of the stands of S 1 to S 22, evidencing that they are larger in diameter in the wet soil than in the dry soil.

This was compatible with the inclination of the pF value and the amount of water in the field condition.

As already mentioned regarding the relation between the diameter of a root and the soil,

Table 14. Soil types and average diameter of fine root of *C. japonica* in the soil horizons I and II

	Dry soil				Moist soil			
Stand	S 6	S 7	S 20	S 24	S 1	S 5	S 8	S 22
Soil type	Bl_A	Bl_C	B_A	B_A	Bl_E	Bl_D(w)	Bl_D(w)	B_E
Value of pF in field condition	2.00	2.50	3.00	2.80	1.70	2.00	1.90	1.90
Soil water in field condition (%)	47	45	35	36	60	53	54	67
Average diameter (mm)	0.75	0.78	0.88	0.74	0.90	0.96	0.97	0.98

this originates in the fact that a fine root is large in diameter for little branching in the moist soil, whereas it is small for big branching in the dry soil. The hypertrophy of cortical cells of a white root is observed in the moist soil.

The phenomena similar to it can be recognized on *Ch. obtusa*, *P. densiflora*, *L. leptolepis*. It was observed there that the change in diameter by water condition tends to make them larger in *C. japonica* and *Ch. obtusa*, and instead smaller in *P. densiflora* and *L. leptolepis*.

e. Soil property

Generally a fine root grows worse and the average diameter becomes smaller in the clay loam than in the loose and porous soil such as the volcanic ash soil.

Let us make a comparison of the diameter of a fine root between the S 23 stand with a clay-loamy property from sandstone, and soil horizons I and II in the stands S 2 and S 4 with a volcanic ash property. It is evident from the result that of the former is 0.082 cm across, and that of the latter is 0.091 to 0.093 cm across.

The difference of soil property is also related to the amount of water in soil. The percolation velocity of the S 23 stand, for example, was 60 cc/min., that of the S 2 stand 125 cc/min., and that of the S 4 stand 100 cc/min. The clay loamy stand of S 23 was insufficiently aired. It can be presumed from this fact that fine roots grow unfavourably in the clay loam soil rather than in the porous volcanic ash soil.

3) Bulk density of root

Another needful factor in calculating the surface area of the root system is bulk density. The bulk density is expressed as follows:

$$R=\frac{G_0}{V_g}$$

R : Bulk density, expressed here by g/cm^3

G_0 : Dry weight (g)

V_g : Volume in the fresh condition (cm^3)

The volume of fine and small roots was measured by the Metra chemical balance and the Beckmann air-comparison type specific gravity tester. That of the larger roots was measured by the small type xlometer. After sufficient supply of water, the extra content of water was put away from the fine and the small roots. From 10 to 15 samples each with fresh weight of 5 g were then picked out from them to measure their volume and to use their averages. The coefficients of variation were 3～4% in this case. The samples each with weight of 200 to 300 g were taken out on the other larger roots. The coefficients of variation were 5～8% in this case. As can be seen, the coefficient of variation does not change greatly when 10 samples or more are taken out. About 10 samples were measured, because the number of samples must be greatly increased to get higher accuracy.

The bulk density of the roots in each stand was measured in this way.

a. Species

The bulk densities of different species were compared with one another to find out how they varied from one species to another on the yuong trees and the sample trees planted at Asakawa nursery.

The bulk density according to every root classification of each species becomes thinner in such order of magnitude as shown in Table 15.

The species the fine roots of which have a high bulk density are *Betula ermanii*, *Alnus japonica*, *Betula davurica*, and *B. platyphylla*, etc., and the species with fine roots having a low

Table 15. Root bulk density of each species

Species	Bulk density
Fine root	
Betula ermanii	0.3432
Alnus japonica	0.3421
Betula davurica	0.3400
Betula platyphylla v. *japonica*	0.3352
Ulmus parvifolia	0.3349
Biota orientalis	0.3304
Sapindus mukurossi	0.3287
Fraxinus mandshurica	0.3270
Quercus mongolica v. *grosseserrata*	0.3250
Quercus serrata	0.3248
Mallotus japonicus	0.3240
Alnus hirsuta v. *sibirica*	0.3234
Cornus controversa	0.3212
Cunninghamia lanceolata	0.3135
Tsuga canadensis	0.3012
Larix leptolepis	0.2831~3152 / 0.2992 (0.2937)
Chamaecyparis obtusa	0.2870~3044 / 0.2957
Celtis sinensis v. *japonica*	0.2938
Abies firma	0.2901
Pinus densiflora	0.2785~2955 / 0.2870 (0.2712)
Chamaecyparis pisifera	0.2850
Cryptomeria japonica	0.2750~0.2905 / 0.2828 (0.2747)
Zanthoxylum ailanthoides	0.2912
Acacia decurrens v. *dealbata*	0.2802
Aphananthe aspera	0.2800
Eucalyptus globulus	0.2756
Firmiana simplex	0.2750
Zelkova serrata	0.2741 (0.3070)
Juglans ailanthifolia	0.2581
Melia azedarach	0.2520
Robinia pseudo-acacia	0.2462
Catalpa ovata	0.1997
Eucommia ulmoides	0.1951
Small root	
Alnus japonica	0.4320
Zelkova serrata	0.4256 (0.4246)
Alnus hirsuta v. *sibirica*	0.4246
Cornus controversa	0.4224
Celtis sinensis v. *japonica*	0.4201
Quercus mongolica v. *grosseserrata*	0.4182
Quercus serrata	0.4160
Betula ermanii	0.4177
Tsuga canadensis	0.4122
Mallotus japonicus	0.4102
Betula davurica	0.4051
Aphananthe aspera	0.4035
Chamaecyparis obtusa	0.3912~0.4150 / 0.4031
Abies firma	0.4012
Biota orientalis	0.3960
Larix leptolepis	0.3622~4220 / 0.3921 (0.3772)
Chamaecyparis pisifera	0.3905
Betula platyphylla v. *japonica*	0.3900
Ulmus parvifolia	0.3900
Cryptomeria japonica	0.3404~0.4351 / 0.3878 (0.3550)
Acasia decurrens v. *dealbata*	0.3852
Sapindus mukurossi	0.3835
Zanthoxylum ailanthoides	0.3815
Pinus densiflora	0.3505~0.4050 / 0.3778 (0.3529)
Eucalyptus globulus	0.3704
Fraxinus mandshurica	0.3692
Cunninghamia lanceolata	0.3508
Juglans ailanthifolia	0.3416
Eucommia ulmoides	0.3136
Robinia pseudo-acacia	0.3136
Firmiana simplex	0.2875
Melia azedarach	0.2786
Catalpa ovata	0.2472
Medium root	
Alnus japonica	0.5663
Betula ermanii	0.5100
Alnus hirsuta v. *sibirica*	0.5060
Betula platyphylla v. *japonica*	0.4821
Cornus controversa	0.4680
Biota orientalis	0.4677
Sapindus mukurossi	0.4538
Ulmus parvifolia	0.4538
Zelkova serrata	0.4521
Celtis sinensis v. *japonica*	0.4520 (0.4256)
Quercus mongolica v. *grosseserrata*	0.4513
Aphananthe aspera	0.4500
Chamaecyparis obtusa	0.4218~0.4572 / 0.4395
Tsuga canadensis	0.4322
Betula davurica	0.4321
Quercus serrata	0.4290
Fraxinus mandshurica	0.4172
Abies firma	0.4152
Larix leptolepis	0.3825~0.4475 / 0.4150 (0.3870)
Chamaecyparis pisifera	0.4104
Pinus densiflora	0.3772~0.4417 / 0.4095 (0.3859)

Table 15. (Continued)

Species	Bulk density
Cryptomeria japonica	0.3445~0.4678 / 0.4062 (0.3888)
Zanthoxylum ailanthoides	0.4056
Acasia decurrens v. *dealbata*	0.3962
Cunninghamia lanceolata	0.3900
Eucalyptus globulus	0.3845
Mallotus japonicus	0.3840
Eucommia ulmoides	0.3720
Robinia pseudo-acacia	0.3614
Juglans ailanthifolia	0.3463
Firmiana simplex	0.3042
Melia azedarach	0.2864
Catalpa ovata	0.2684
Large root	
Alnus japonica	0.5670
Alnus hirsuta v. *sibirica*	0.5589
Thuja orientalis	0.5562
Acacia decurrens v. *dealbata*	0.5425
Zelkova serrata	0.5208 (0.4700)
Quercus mongolica v. *grosseserrata*	0.5124
Quercus serrata	0.5067
Betula davurica	0.5053
Chamaecyparis obtusa	0.4920~0.5150 / 0.5026
Juglans ailanthifolia	0.4913
Aphananthe aspera	0.4884
Betula ermanii	0.4876
Cornus controversa	0.4864
Tsuga canadensis	0.4827
Betula platyphylla v. *japonica*	0.4815
Sapindus mukurossi	0.4810
Ulmus parvifolia	0.4810
Mallotus japonicus	0.4809
Zanthoxylum ailanthoides	0.4563
Chamaecyparis pisifera	0.4502
Pinus densiflora	0.3952~0.4970 / 0.4461 (0.4221)
Larix leptolepis	0.3972~0.4755 / 0.4364 (0.4088)
Abies firma	0.4321
Cryptomeria japonica	0.3700~0.4755 / 0.4228 (0.4150)
Cunninghamia lanceolata	0.4215
Eucommia ulmoides	0.4209
Celtis sinensis v. *japonica*	0.4191
Fraxinus mandshurica	0.5150
Eucalyptus globulus	0.4132
Robinia pseudo-acacia	0.4080
Melia azedarach	0.3304
Firmiana simplex	0.3294
Catalpa ovata	0.2825
Very large root	
Zelkova serrata	0.5617
Quercus mongolica v. *grosseserrata*	0.5542
Betula davurica	0.5528
Tsuga canadensis	0.5234
Betula platyphylla v. *japonica*	0.4925
Chamaecyparis obtusa	0.5305~0.5109 / 0.4913
Acacia decurrens v. *dealbata*	0.4827
Chamaecyparis pisifera	0.4761
Pinus densiflora	0.4250~0.4601 / 0.4601
Abies firma	0.4542
Larix leptolepis	0.4012~0.5004 / 0.4508
Cryptomeria japonica	0.3857~0.5100 / 0.4479
Eucalyptus globulus	0.4424

* ( ) : Valus measured in Asakawa nursery.

bulk density are *Melia azedarach*, *Robinia pseudo-acacia*, *Catalpa ovata*, and *Eucommia ulmoides*, etc. Of the main species, *L. leptolepis*, *Ch. obtusa* and *P. densiflora* show a higher percentage than *C. japonica*.

Let us turn now to the size or striking of fine roots. Investigation reveals that bulk density tends to be high in the species with fibrous roots growing sparse, and yet to be low in the species with thick absorptive roots and bunchy fine roots. This is because the bulk density is related to the content of water present in roots; it becomes thinner as the water content increases. It is safe to say, therefore, that the bulk density is low in the species which spread fine roots inclusive of many young absorptive roots, while it is high in the species which have greater parts of lignified fine roots inclusive of absorptive roots growing sparse. Hence it is that the bulk density of the fine root is greatly affected by the sticking pattern and amount of absorptive roots.

Concerning such root types as shown in Table 13, the bulk density is generally high in the dry-typed species as *Quercus myrsinaefolia*; yet it is low in the moderately moist-typed species as *Cornus controversa*, *Firmiana platanifolia* and *C. japonica*.

That the fine roots of dry-typed species have high bulk density is not that the young and soft tissues, such as absorptive roots containing a lot of water, are many, but that the fine roots are highly lignified. This property keeps the root system from drying, giving it stronger resistance against drought.

The bulk density of a small root ranges from 0.247 to 0.432. This range of change is wider than that of a fine root. The larger a root grows, the wider it becomes. That is to say, almost every species is characterized by bulk density, indicating that although the tissues of root tips seem to be very similar to species, they develop differently as they grow.

As concerns the roots larger than a small root, the species as *Alnus*, *Quercus* and *Zelkova* spp., which grow slowly, have little water content, are fine-grained, and show high bulk density, while the species as *Zanthoxylum ailanthoides*, *Fraxinus mandshurica*, *Eucommia ulmoides*, *Firmiana platanifolia*, *Melia azedarach*, and *Catalpa ovata* with much water content, soft quality of wood and sparse roots, show low bulk density.

Of all the coniferous trees *Ch. obtusa* had the highest bulk density. The bulk density became lower in the order of *Ch. obtusa*, *L. leptolepis*, *C. japonica*, and *P. densiflora*. As far as *Ch. obtusa* is concerned, it can be pointed out that the roots grow so slowly and branch off so remarkably that the growth of a root becomes small and the fine roots contain many lignified parts.

The species, such as *Quercus myrsinaefolia* the white roots of which are short in general and branch off remarkably, have high bulk density owing to that property.

As concerns the large and the very large roots, the growth condition as well as the characters of species has a connection with the bulk density. The species of which the roots grow unfavourable tend to make the bulk density go lower. For example, *Zelkova serrata*, *Quercus mongolica*, *Betula davurica*, etc., the very large roots of which grow unfavourably, have high bulk density. On the other hand, *P. densiflora*, *Abies firma*, *L. leptolepis*, *C. japonica* or *Eucalyptus globulus*, etc. have low bulk density (For detail, see Table 15).

b. Bulk density of every root class

The typical stands of each species taken here as an example, have bulk density, as shown in Table 16, that increases as roots become thicker. Between the fine and small roots, a particularly high rate of increase occurs. That of each species, for example, increased to nearly 10%.

As for *C. japonica*, the rate of increase is low between the roots larger than a small root.

Table 16. Bulk density of each root class in soil horizons I and II

Species	Stand	Root class				
		f	s	m	l	L
C. japonica	S5	0.28	0.38	0.40	0.41	0.43
Ch. obtusa	H5	0.29	0.40	0.44	0.51	0.53
P. densiflora	A4	0.28	0.37	0.39	0.42	0.44
L. leptolepis	K1	0.28	0.37	0.40	0.41	0.43

For instance it was 2% between a small root and a medium root, 1% between a medium root and a large root, and 2% between a large root and a very large root.

This difference is directly connected with the water content contained in each part of a root. A fine root with much water content is, low in bulk density, while large and very large roots with little water content is thick in it. Hence it is that the change of bulk density tends to be similar to that of the change of dry weight ratio.

The bulk density obtained from the fresh weights and the volume range from 1.1 to 1.3. They had not so great a difference in each part as those of the bulk density.

c. Growth of a tree and bulk density

The relation between the basal area and the bulk density of a small root and a very large root is shown in Fig. 22.

The bulk density of both roots tends to increase somewhat as a tree becomes large. The young small-diameter trees have many young tissues and much water content as compared with the large-diameter trees, even if both roots of them belong to the same classification.

According to Fig. 26, the bulk density becomes lower in the order of *Ch. obtusa*, *P. densiflora*, *L. leptolepis*, and *C. japonica*. The very large roots are a particularly good example. The difference by over 10% was recognized between *Ch. obtusa* and *C. japonica*. This is due to the differences in the properties of species, such as growth, tissue, etc.

d. Bulk density in each soil horizon

The bulk density of roots, becomes higher as the soil horizon becomes lower. This means that a root grows worse and it is lignified more highly as the soil horizon goes down.

e. Soil condition and bulk density

Tree growth depends upon the soil conditions. Particularly, root growth is easily affected by them. Table 17 shows the bulk densities of the typical *C. japonica* stands with the different soil conditions extracted from the detailed data. As is clear from it, as the soil gets less moist from the wet moderately moist-soil-typed S 5 and S 18 stands, the bulk density becomes higher in every part of a root. This tendency is especially remarkable in the large and very large roots. A large root and a very large root had a difference of 0.07 and 0.08 respectively between in the stands S 5 and S 24, while a fine root had a difference of only 0.01 there.

It is evident from these that the soil conditions have a greater influence upon the thick

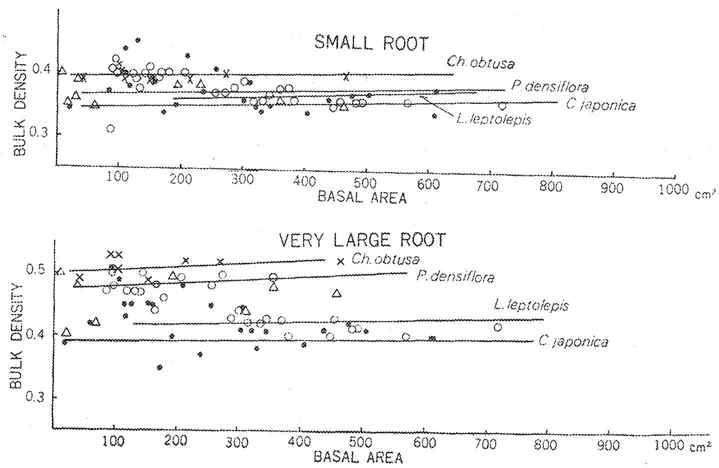


Fig. 22 Basal area and bulk density of root system.

Table 17. Soil condition and root bulk density in soil horizone I and II of *C. japonica*

Stand	S 5	S 18	S 4	S 13	S 6	S 24
Soil type	Bl_D(w)	B_E	Bl_D	Bl_D	Bl_A	B_A
Value of pF in field condition	2.00	2.20	2.20	1.92	2.50	2.80
Site index	19.3	23.4	19.4	24.5	11.3	11.0
f	0.28	0.28	0.28	0.28	0.29	0.29
s	0.38	0.35	0.36	0.34	0.44	0.45
m	0.40	0.38	0.39	0.36	0.45	0.47
l	0.41	0.40	0.40	0.38	0.47	0.48
L	0.43	0.41	0.41	0.40	0.49	0.51

roots than on the tips of the fine and the small roots. The relation of the bulk density to the pF values is shown in Table 17. This table makes clear that the bulk density increases rapidly when the pF value exceeds 2.0.

The relation between the site index and the bulk density is shown in Table 17. From this table it is evident that when the site index becomes smaller, the bulk density becomes higher. The bulk density of a very large root was 0.40 in the S 13 stand with the largest site index of 25, and 0.41 in the S 4 and S 18 stands with the site index of 19~23. And yet it was 0.49 to 0.51 in the S 6 and S 24 stands with the site index of 11.

As already mentioned, bulk density changes according to the species, root classification, soil horizon, growth, and soil condition. In this study, therefore, it was measured under each condition and according to each soil horizon in each stand.

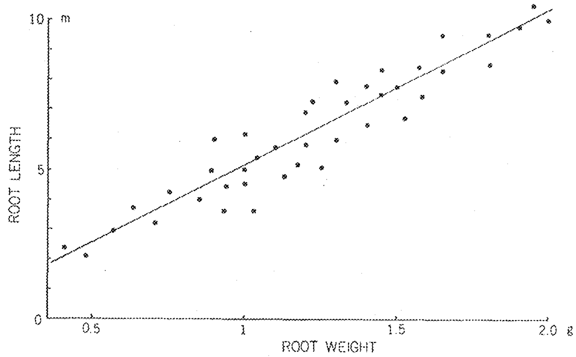
4) Root length per unit root weight

When the average diameter and the bulk density of the root system are given, it is possible to calculate root length per unit root weight and surface area of the root system. The root length according to each root classification of each sample tree was calculated in this study.

a. Calculated values and measured values

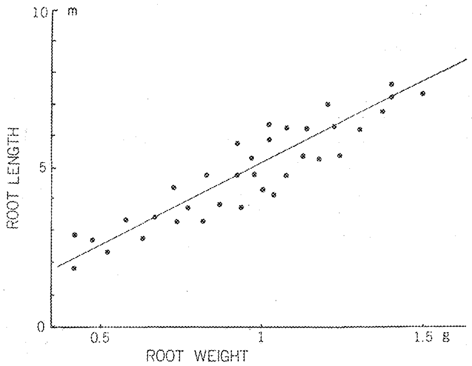
The fine roots of *C. japonica* in soil horizons I and II were used as a sample in order to examine the difference between the root lengths calculated from the average diameter and bulk density and the measured values actually. To do this, the root length was projected on paper and measured with a curvimeter and a ruler. The results are shown in Fig. 23.

Calculating by the ratio estimate, the length of the fine root per gram, for example, was



$y = 512.5179x$
$\sigma_z = 9.8$
$c = 0.02$
$r = 0.88$
$n : 40$

Fig. 23 Measured root weight and length of the fine roots of *C. japonica* measured actually.



$y = 502.8657x$　$\sigma_z = 11.11$
$c = 0.022$　$r = 0.8352$　$n : 35$

Fig. 24 Fine root weight and length of *C. japonica* obtained from the average root diameter and the bulk density.

found to be 513 cm long and the coefficient of variation 2%. When the root length is calculated from the diameter and the bulk density of the samples taken up in the same way, results are those given in Fig. 24. In this case, the average root length per gram was 503 cm long, and the coefficient of variation was 2%. The difference in root length per unit root weight between these two was 10 cm. This was equivalent to 2% of the actual measurement.

The diameters of the fine roots were also calculated from the average actual measurement of the root lengths. As shown there, little difference was recognized between them.

b. Species

Table 18 shows the root length per unit root weight calculated from the root diameters and bulk densities of the fine to very large roots at Asakawa nursery and in each sample stand. According to the table, they change remarkably with changing diameter and pattern of branching. From the calculation it is evident that the length of roots does not become so long as that of the roots of the species with smaller average diameter and lower bulk density.

The species in which the fine root is longest and all beyond 10 meters per gram in length are *Melia azedarach*, *Robinia pseudo-acacia*, *Betula platyphylla*, *Betula davurica*, *Juglans ailanthifolia*, *Quercus mongolica*, *Zelkova serrata*, *Firmiana platanifolia*, and *Celtis sinensis*. The species in which the fine root is only 3 to 5 meters per gram, on the contrary, are *Cornus controversa*, *Fraxinus mandshurica*, *Catalpa ovata*, *Cunninghamia lanceolata*, *Ch. picifera*, *Ch. obtusa*, *Zanthoxylum aelanthoides*, *Abies firma*, *Biota orientalis*, *Tsuga canadensis*, and *Acacia decurrens*. The root length of the principal species became shorter in the order of *L. leptolepis* (671 cm), *C. japonica* (622 cm), *P. densiflora* (547 cm), and *Ch. obtusa* (386 cm). Of all these, that per unit of *Ch. obtusa* was shortest because its average diameter was big and its bulk density was high.

As for the relation to the type of the root system, the broad-leaved trees such as *Quercus myrsinaefolia* have long roots in general. The species such as *Cornus controversa*, *Cinnamomum camphora*, *Firmiana platanifolia*, *C. japonica*, etc. have the short roots per unit root weight because their fine root is small in diameter and do not branch off so greatly.

Many species with long roots are the dry-type trees, and many species with short roots are the trees suitable for moderately moist or moist ground condition. Coniferous trees have, generally speaking, shorter roots than broad-leaved trees.

Although they have a low proportion of the biomass of fine roots to the total biomass, even the broad-leaved trees, the fine roots of which have small biomass in general have, as could be expected, the considerable total length of those roots; for those roots, are long for unit root weight.

Table 18. Root length par unit weight of each species (cm/g)

Species	Root length (cm)	
Fine root		
Melia azedarach	1404	
Robinia pseudo-acacia	1327	
Betula platyphylla v. *japonica*	1140	
Betula davurica	1110	
Juglans ailanthiforia	1067	
Quercus mongolica v. *grosseserrata*	1035	
Zelkova serrata	1004	(771)
Firmiana simplex	945	
Celtis sinensis v. *japonica*	910	
Alnus hirsuta v. *sibirica*	877	
Quercus serrata	873	
Aphananthe aspera	834	
Mallotus japonicus	802	
Ulmus parvifolia	754	
Eucalyptus globulus	722	
Alnus japonica	718	
Betula ermanii	716	
Larix leptolepis	550～792 / 671	(639)
Cryptomeria japonica	441～802 / 622	(525)
Sapindus mukurossi	576	
Eucommia ulmoides	569	
Pinus densiflora	255～838 / 547	(605)
Cornus controversa	515	
Fraxinus mandshurica	514	
Catalpa ovata	508	
Cunninghamia lanceolata	450	
Chamaecyparis pisifera	429	
Chamaecyparis obtusa	255～516 / 386	
Zanthoxylum ailanthoides	382	
Abies firma	363	
Biota orientalis	356	
Tsuga canadensis	356	
Acacia decurens v. *dealbata*	261	
Small root		
Betula davurica	34.9155	
Betula platyphylla v. *japonica*	33.9616	
Catalpa ovata	33.8519	
Betula ermanii	31.7094	
Aphananthe aspera	30.8248	
Quercus mongolica v. *grosseserrata*	29.7413	
Zelkova serrata	29.2242	(28.9073)
Alnus japonica	28.7912	
Tsuga canadensis	28.3743	
Ulmus parvifolia	28.2390	
Eucalyptus globulus	28.0643	
Celtis sinensis v. *japonica*	27.8408	
Alnus hirsuta v. *sibirica*	27.5457	
Eucommia ulmoides	26.6843	
Cunninghamia lanceolata	26.3703	
Abies firma	25.9098	
Acacia decurens v. *dealbata*	25.5015	
Chamaecyparis obtusa	16.3470～34.3530 / 25.3500	
Pinus densiflora	16.3470～34.3530 / 25.3500	(17.9206)
Mallotus japonicus	25.3413	
Firmiana simplex	25.1138	
Robinia pseudo-acacia	24.3977	
Quercus serrata	23.4966	
Juglans ailanthiforia	23.0686	
Cryptomeria japonica	18.0954～27.8901 / 22.9928	(24.0764)
Melia azedarach	22.9794	
Chamaecyparis pisifera	22.5822	
Biota orientalis	22.2685	
Larix leptolepis	17.3297～26.6729 / 22.0013	(20.8914)
Sapindus mukurossi	19.9507	
Zanthoxylum ailanthoides	19.6642	
Cornus controversa	18.1134	
Fraxinus mandshurica	17.5995	
Medium root		
Catalpa ovata	2.3860	
Melia azedarach	2.1740	
Firmiana simplex	2.1354	
Zelkova serrata	2.1295	(1.6415)
Acacia decurens v. *dealbata*	2.0901	
Betula platyphylla v. *japonica*	2.0782	
Tsuga canadensis	2.0458	
Abies firma	1.9626	
Eucalyptus globulus	1.9595	
Quercus mongolica v. *grosseserrata*	1.9592	
Mallotus japonicus	1.8744	
Juglans ailanthiforia	1.8493	
Betula davurica	1.7436	
Cryptomeria japonica	1.2391～2.2121 / 1.7256	(1.5688)
Cunninghamia lanceolata	1.7143	
Eucommia ulmoides	1.6974	
Aphananthe aspera	1.6742	
Ulmus parvifolia	1.6350	

Table 18. (Continued)

Species	Root length (cm)
Quercus serrata	1.6285
Celtis sinensis v. *japonica*	1.6167
Zanthoxylum ailanthoides	1.5121
Larix leptolepis	1.1741～1.8181 / 1.4961 (1.3253)
Sapindus mukurossi	1.4949
Alnus hirsuta v. *sibirica*	1.4890
Chamaecyparis pisifera	1.4756
Betula ermanii	1.4328
Robinia pseudo-acacia	1.4282
Pinus densiflora	0.9740～1.7625 / 1.3683 (1.4568)
Cornus controversa	1.3492
Biota orientalis	1.2598
Alnus japonica	1.2521
Fraxinus mandshurica	1.2454
Chamaecyparis obtusa	0.9740～1.3780 / 1.1760
Large root	
Catalpa ovata	0.9750
Juglans ailanthiforia	0.6574
Quercus serrata	0.5783
Eucommia ulmoides	0.5718
Celtis sinensis v. *japonica*	0.5501
Fraxinus mandshurica	0.4884
Melia azedarach	0.4744
Ulmus parvifolia	0.4558
Sapindus mukurossi	0.4520
Firmiana simplex	0.4295
Robinia pseudo-acacia	0.4127
Biota orientalis	0.3941
Alnus japonica	0.3857
Mallotus japonicus	0.3770
Betula ermanii	0.3718
Zanthoxylum ailanthoides	0.3690
Cunninghamia lanceolata	0.3661
Alnus hirsuta v. *sibirica*	0.3602
Aphananthe aspera	0.3447
Cornus controversa	0.3245
Cryptomeria japonica	0.2157～0.3580 / 0.2869 (0.4732)
Acacia decurens v. *dealbata*	0.2724
Pinus densiflora	0.1890～0.3514 / 0.2702 (0.5495)
Larix leptolepis	0.2106～0.3199 / 0.2653 (0.5561)
Betula platyphylla v. *japonica*	0.2519
Chamaecyparis pisifera	0.2362
Abies firma	0.2338
Betula davurica	0.2314
Chamaecyparis obtusa	0.1890～0.2650 / 0.2270
Eucalyptus globulus	0.2238
Tsuga canadensis	0.2203
Zelkova serrata	0.2181 (0.3082)
Quercus mongolica v. *grosseserrata*	0.2150
Very large root	
Abies firma	0.0779
Acacia decurens v. *dealbata*	0.0779
Eucalyptus globulus	0.0732
Cryptomeria japonica	0.0204～0.1049 / 0.0627
Pinus densiflora	0.0250～0.0942 / 0.0596
Chamaecyparis pisifera	0.0594
Tsuga canadensis	0.0572
Betula platyphylla v. *japonica*	0.0572
Chamaecyparis obtusa	0.0250～0.0870 / 0.0560
Larix leptolepis	0.0193～0.0898 / 0.0546
Quercus mongolica v. *grosseserrata*	0.0437
Betula davurica	0.0415
Zelkova serrata	0.0350

* ( ) : Values measured in Asakawa nursery.

A small root gets to 18～35 cm in length par gram. The range of distribution is narrower than that of a fine root. The species in which the small roots are long are *Betula davurica*, *Catalpa ovata*, *Betula platyphylla*, and *Betula ermanii*; the short small root species are *L. leptolepis*, *Sapindus mukurossi*, *Cornus controversa*, and *Fraxinus mandshurica*.

In the medium roots, the distribution becomes much narrower, and it ranges from 1.8 to 2.4 cm. That of the large roots ranges from 0.2 to 1.0 cm, and of the very large roots from 0.4 to 0.8 cm.

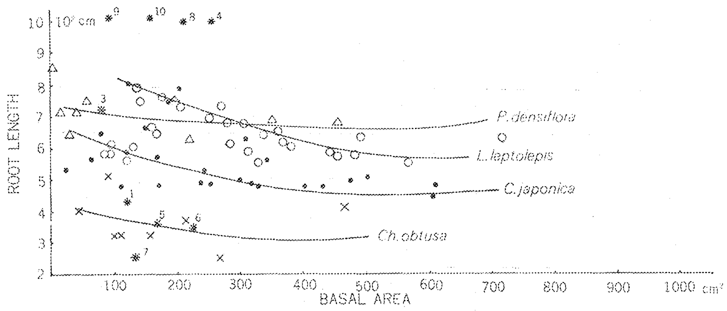


Fig. 25 Root length per unit fine root weight.

c. Basal area

The fine root length per unit weight in soil horizons I and II goes on decreasing gradually before the basal area increases to 300 to 400 cm², as shown in Fig. 25. And besides, the small-diameter trees all have the long roots.

In *C. japonica* taken here as an example, the fine root length was about 600 cm at the basal area of 100 cm², 500 cm at 300 cm², 480 cm at 500 cm², and 480 cm at 800 cm². When the basal area went beyond 500 cm², the root length remained nearly unchangeable.

The root length at the basal area of 500 cm², was 700 cm for *P. densiflora*, 600 cm for *L. leptolepis*, 480 cm for *C. japonica*, and 320 cm for *Ch. obtusa*. Hence it is that the fine roots of the species as *P. densiflora* and *L. leptolepis* are longer than those of *C. japonica* and *Ch. obtusa*.

d. The root length in each soil horizon

The average diameter and the bulk density of the root system change according to soil horizon. Along with it, the root length per unit root weight changes. Table 19 dealing with the stands S 5～K 1 was derived from the already calculated data for every stand. The fine, small, and medium roots of every species became shorter as the soil horizon went lower. This tendency is particularly remarkable in the fine and the small roots. The rate of decrease is, for example, higher for *Ch. obtusa* or *L. leptolepis* than *C. japonica* or *P. densiflora*.

The root length of the large and the very large root, on the other hand, increased slightly in the lower soil horizons, because the diameter became smaller.

e. Soil conditions

The relation between the soil conditions and the root length is shown in Table 20 on a few stand from the detailed data, which had already been measured.

In the roots larger than a small root, no particular relation was observed but in the fine root. The fine root length per gram ranged from 570 to 800 cm in the dry soils of Bl_C–Bl_A type, from 530 to 560 cm in the moderately moist soil of Bl_D type, and from 480 to 500 cm in the more moist soils of Bl_D (w)–B_E type. In the dry soils, fine roots became longer for unit root weight in spite of increasing bulk density because they were small in average diameter.

The pF value and the site index in the field condition ran nearly parallel to the soil type. As shown in Table 27, their changes corresponded to the root length. That is to say, the roots were shorter in the site with a small pF value or a large site index than in the site with a large pF value or a small site index.

5) The surface area per unit root weight

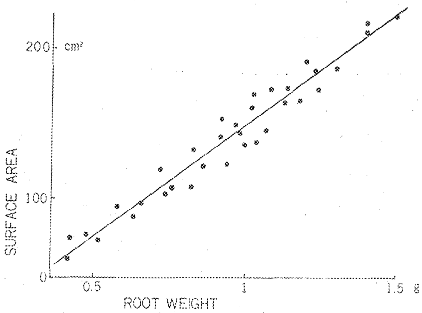
The surface area of the root system is to be determined by average diameter and root length obtained from the equation, already used in calculation. It can be presumed hereby

Table 19. Root length per unit weight in each soil horizon (cm/g)

Root class	Stand	S 5	H 5	A 4	K 1
	Site index	19.3	16.0	14.4	16.6
	Soil type	Bl_D(w)	B_D	Bl_D(d)	Bl_{D-E}
f	I・II	496	422	690	639
	III・IV	397	315	638	517
	V	303	234	443	404
s	I・II	22	26	19	20
	III・IV	17	19	14	16
	V	13	14	13	13
m	I・II	1.4	1.2	1.6	1.3
	III・IV	1.2	1.0	1.1	1.2
	V	0.9	0.8	0.9	1.1
l	I・II	0.2	0.2	0.2	0.2
	III・IV	0.3	0.2	0.3	0.3
	V	0.3	—	—	—
L	I・II	0.04	0.03	0.05	0.03
	III・IV	0.06	0.05	0.09	0.04
	V	—	—	—	—

Table 20. Root length per unit weight of *C. japonica* and soil conditions, in soil horizons I and II

	Moist soil			Moderately moist soil		Dry soil		
Stand	S 5	S 8	S 22	S 4	S 2	S 7	S 24	S 20
Soil type	Bl_D(w)	Bl_D(w)	B_E	Bl_D	Bl_D	Bl_C	B_A	B_A
Value of pF in field condition	2.00	1.90	1.90	2.20	2.00	3.00	2.80	3.00
Site index	19.3	20.7	21.8	19.4	21.7	13.6	11.0	15.4
f	496	487	479	556	534	742	802	572
s	22	19	24	26	26	25	21	21
m	1.4	1.6	1.7	1.6	1.6	1.5	1.2	1.4
l	0.2	0.3	0.3	0.2	0.3	0.3	0.3	0.2



$y=149.0149x$　$\sigma_z=10.70$
$c=0.072$　$r=0.9509$

Fig. 26 Weight and calculated surface area of the fine roots of *C. japonica*.

that the smaller the root is in length and the lower the bulk density is, the longer the root is and the wider the surface area is, if the root weight is given.

The surface areas of every measured sample in the S 4 stand which root length is known have already been calculated. The average value and variance of the materials calculated by the ratio estimate are shown in Fig. 26. According to the figure, the surface area per gram was 149 cm², the coefficient of variation was 7%, and the correlation coefficient was 95%. It is evident from the fact that the coefficient of variation has a large value for root length. This is due to the wide

Table 21. Root surface area per unit weight of each species (cm²/g)

Species	Root surface area (cm²)
Fine root	
Melia azedarach	264
Robinia pseudo-acacia	258
Juglans ailanthifolia	228
Betula platyphylla v. *japonica*	225
Betula davurica	223
Quercus mongolica v. *grosseserrata*	211
Firmiana simplex	208
Celtis sinensis v. *japonica*	197
Eucommia ulmoides	196
Alnus hirsuta v. *sibirica*	184
Quercus serrata	184
Eucalyptus globulus	181
Catalpa ovata	179
Pinus densiflora	167～189 / 178 (162)
Aphananthe aspera	178
Mallotus japonicus	176
Zelkova serrata	169 (214)
Larix leptolepis	153～177 / 166 (163)
Alnus japonica	162
Betula ermanii	162
Cryptomeria japonica	113～186 / 149 (152)
Cornus controversa	149
Sapindus mukurossi	148
Fraxinus mandshurica	141
Chamaecyparis pisifera	138
Cunninghamia lanceolata	134
Zanthoxylum ailanthoides	128
Abies firma	125
Chamaecyparis obtusa	104～146 / 125
Tsuga canadensis	122
Biota orientalis	116
Acacia decurrens v. *dealbata*	108
Small root	
Betula platyphylla v. *japonica*	33.0582
Betula davurica	32.8904
Eucommia ulmoides	32.8452
Firmiana simplex	32.7258
Robinia pseudo-acacia	31.4096
Aphananthe aspera	30.9728
Betula ermanii	30.8659
Eucalyptus globulus	30.8427
Cunninghamia lanceolata	30.7198
Ulmus parvifolia	30.1480
Quercus mongolica v. *grosseserrata*	29.8841
Melia azedarach	29.5837
Tsuga canadensis	29.4014
Zelkova serrata	29.3645 (29.9537)
Juglans ailanthifolia	28.9742
Alnus japonica	28.9294
Celtis sinensis v. *japonica*	28.8486
Acacia decurrens v. *dealbata*	28.8269
Alnus hirsuta v. *sibirica*	28.5429
Abies firma	28.4749
Mallotus japonicus	27.8501
Cryptomeria japonica	23.8999～31.5270 / 27.7135 (27.2160)
Chamaecyparis obtusa	22.5850～32.3608 / 27.4729
Pinus densiflora	25.2496～29.6392 / 27.4444 (23.6337)
Larix leptolepis	23.7408～30.1510 / 26.9459 (26.3708)
Chamaecyparis pisifera	26.9451
Biota orientalis	26.5708
Sapindus mukurossi	25.4966
Zanthoxylum ailanthoides	25.4392
Quercus serrata	24.3472
Cornus controversa	23.4329
Fraxinus mandshurica	22.1050
Medium root	
Catalpa ovata	10.5788
Melia azedarach	9.7276
Firmiana simplex	9.4006
Juglans ailanthifolia	8.1876
Betula platyphylla v. *dealbata*	8.1569
Acacia decurrens v. *dealbata*	8.1380
Eucalyptus globulus	7.9987
Cryptomeria japonica	5.7583～10.0022 / 7.8926 (6.7733)
Mallotus japonicus	7.8279
Tsuga canadensis	7.7086
Abies firma	7.7032
Eucommia ulmoides	7.5417
Cunninghamia lanceolata	7.4284
Quercus mongolica v. *grosseserrata*	7.3823
Betula davurica	7.1174
Quercus serrata	6.9032
Aphananthe aspera	6.8341
Pinus densiflora	6.4526～7.1793 / 6.8160 (6.4224)
Zanthoxylum ailanthoides	6.7516

Table 21. (Continued)

Species	Root surface area (cm²)
Ulmus parvifolia	6.7254
Chamaecyparis pisifera	6.7184
Celtis sinensis v. *japonica*	6.7009
Larix leptolepis	5.7009～7.4215 / 6.5612 (6.2546)
Sapindus mukurossi	6.4308
Robinia pseudo-acacia	6.2335
Alnus hirsuta v. *sibirica*	6.0781
Zelkova serrata	6.0455 (6.9583)
Cornus controversa	6.0158
Betula ermanii	5.9387
Chamaecyparis obtusa	5.2604～6.4038 / 5.8321
Biota orientalis	5.8150
Fraxinus mandshurica	5.4239
Alnus japonica	5.2683
Large root	
Catalpa ovata	6.5822
Juglans ailanthifolia	4.4794
Melia azedarach	4.2454
Eucommia ulmoides	4.1338
Celtis sinensis v. *japonica*	4.0506
Firmiana simplex	4.0459
Quercus serrata	4.0221
Robinia pseudo-acacia	3.5637
Ulmus parvifolia	3.4535
Fraxinus mandshurica	3.4505
Sapindus mukurossi	3.4276
Zanthoxylum ailanthoides	3.1863
Mallotus japonicus	3.1370
Betula ermanii	3.0937
Biota orientalis	2.9823
Aphananthe aspera	2.9776
Cunninghamia lanceolata	2.9544
Cryptomeria japonica	2.3976～3.3948 / 2.8962 (3.1946)
Cornus controversa	2.8938
Pinus densiflora	2.6110～3.1045 / 2.8578 (3.7494)
Alnus japonica	2.7855
Acacia decurens v. *dealbata*	2.7798
Alnus hirsuta v. *sibirica*	2.7744
Larix leptolepis	2.4078～3.0637 / 2.7358 (3.8660)
Eucalyptus globulus	2.6071
Abies firma	2.6062
Chamaecyparis pisifera	2.5662
Betula platyphylla v. *japonica*	2.5627
Betula davurica	2.3978
Tsuga canadensis	2.3934
Chamaecyparis obtusa	2.1483～2.5878 / 2.3681
Quercus mongolica v. *grosseserrata*	2.2953
Zelkova serrata	2.2942 (2.4194)
Very large root	
Abies firma	1.4676
Eucalyptus globulus	1.4411
Acacia decurens v. *dealbata*	1.4236
Pinus densiflora	1.1659～1.6682 / 1.4171
Chamaecyparis pisifera	1.2515
Cryptomeria japonica	0.7717～1.7246 / 1.2482
Betula platyphylla v. *japonica*	1.2070
Larix leptolepis	0.7606～1.5880 / 1.1743
Tsuga canadensis	1.1710
Chamaecyparis obtusa	0.7717～1.4916 / 1.1317
Quercus mongolica v. *grosseserrata*	0.9948
Betula davurica	0.9708
Zelkova serrata	0.8847

* ( ) : Values measured in Asakawa nursery.

variance of bulk density.

a. Species

As the average diameters and bulk densities are different from species to species, the surface areas of the root system as well as root lengths depend upon the characters of roots of each species.

Table 21 shows the surface areas of the roots of every species calculated from the avarege diameters and the root length. The species of which the fine root is 220 to 260 cm² per gram in length are *Melia azedarach*, *Robinia pseudo-acacia*, *Juglans ailanthifolia*, *Betula platyphylla*, *Betula davurica*, and *Quercus mongolica* v. *grosseserrata*. And the species of which the fine root is 110~130 cm² in length, about half of the former species, are *Abies firma*, *Ch. obtusa*, *Tsuga canadensis*, *Biota orientalis*, and *Acacia decurrens*. This tendency is mainly dependent on the root diameter. In more detail, many of the former are small in diameter, while many of the latter are large in diameter and their bulk density is high.

Generally speaking, the root surface areas of coniferous trees are small in width. For example, those areas of *P. densiflora*, *L. leptolepis*, *C. japonica*, and *Ch. obtusa* are 178, 166, 149, and 125 cm² in width respectively.

The surface areas of the small roots are large in width. They are, for example, within the range of 22~33 cm² for *Betula platyphylla*, *Betula davurica*, *Eucommia ulmoides*, *Firmiana platanifolia*, and *Betula Ermanii*, and within the range of 26 to 27 cm² for *C. japonica*, *Ch. obtusa*, *P. densiflora*, and *L. leptolepis*.

Those of the medium roots ranged from 5 to 10 cm². The species of which the medium root is large in width are *Catalpa ovata*, *Melia azedarach* and *Firmiana platanifolia*, while the vis-a-vis examples are *Ch. obtusa*, *Biota orientalis*, *Fraxinus mandshurica*, and *Alnus japonica*.

Those of the large roots ranged from 2 to 7 cm². Those of the very large roots ranged from 1.5 to 0.9 cm². These roots do not show a given inclination so distinctively as the former three do.

b. Root class

As already mentioned, the surface area of roots varies with each root class. This relation is shown in Table 22 on the typical stands of *C. japonica*, *Ch. obtusa*, *P. densiflora*, and *L. leptolepis*. According to the table, the surface areas of their fine roots range from 135 to 175 cm² in horizon I・II. There is a great difference among species. They became narrower in the order of *P. densiflora*, *L. leptolepis*, *C. japonica*, and *Ch. obtusa*. The small root had the

Table 22. Surface area of root per unit weight in each soil horizon (cm²/g)

Root class	Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
	Stand	S5	H5	A4	K1
	Site index	19.3	16.0	17.4	16.6
	Soil type	Bl_D(w)	B_D	Bl_D(d)	Bl_{D-E}
f	I・II	149	135	175	169
	III・IV	132	115	168	151
	V	114	99	140	133
s	I・II	27	29	25	26
	III・IV	23	24	20	23
	V	19	18	19	19
m	I・II	7	6	7	7
	III・IV	6	5	6	6
	V	5	4	5	5
l	I・II	2.6	2.3	2.6	2.7
	III・IV	2.7	2.2	3.0	3.0
	V	3.0	—	—	—
L	I・II	1.1	0.8	1.2	1.0
	III・IV	1.3	1.1	1.5	1.1
	V	—	—	—	—

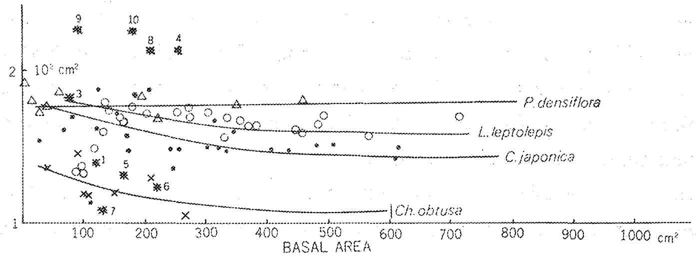


Fig. 27 Fine root surface area per unit weight in soil horizons I and II.

surface areas of 25～29 cm². Of the four, *Ch. obtusa* had the slightly wider area. No great difference, however, was observed. Difference was almost unrecognizable among the roots larger than a medium root.

c. Basal area

The relation between the basal area and the surface area of the fine roots in soil horizons I and II is shown in Fig. 27. According to the figure, there is no great difference between the large-diameter trees and the small-diameter trees belonging to all species. The root surface areas, however, tend to become wider concerning the young and small trees of *L. leptolepis*, *C. japonica* and *Ch. obtusa*. This is because their fine roots have narrower average diameter and more water content, connecting closely with bulk densities, than those of large trees.

According to this table, the surface areas at the basal area of 500 cm² are 175 cm² for *P. densiflora*, 160 cm² for *L. leptolepis*, 150 cm² for *C. japonica*, and 110 cm² for *Ch. obtusa*.

d. The root surface area in each soil horizon

The relation between the soil horizon and the surface area of the root system is shown in Table 22. The surface areas of a fine root to a medium root decrease, corresponding to the lower soil horizons, as the roots become smaller in diameter there. This held good in the case of root length. That tendency is more marked in *Ch. obtusa* and *L. leptolepis* than in *C. japonica* and *P. densiflora*. The surface areas of the large and the very large roots, on the other hand, increase as the soil horizon goes down lower. This makes clear that their average diameters become narrower, corresponding to the deeper soil horizons.

e. Soil condition

Table 23 shows the relation between the soil type and the surface area of the root system. According to this table, the surface areas of the root system increases from the slightly moist B*l*D(w)-typed soil to the dry-typed soil. Those of fine roots ranged from 148 to 149 cm² in the

Table 23. Soil conditions and root surface areas per unit weight in the 1st and 2nd soil horizons of the *C. japonica* stand (cm²/g)

	Moist soil			Moderately moist soil		Dry soil		
Stand	S 5	S 8	S 12	S 4	S 2	S 7	S 24	S 3
Soil type	B*l*D(w)	B*l*D(w)	B*l*D(w)	B*l*D	B*l*D	B*l*C	BA	B*l*D(d)
Value of pF in field condition	2.00	1.90	1.73	2.20	2.00	3.00	2.80	3.10
Site index	19.3	20.7	23.4	19.4	21.7	13.6	11.0	17.0
f	149	148	148	159	156	182	186	169
s	27	25	26	30	30	28	24	30
m	7	7	7	7	7	7	6	7
l	3	3	3	3	3	3	3	3

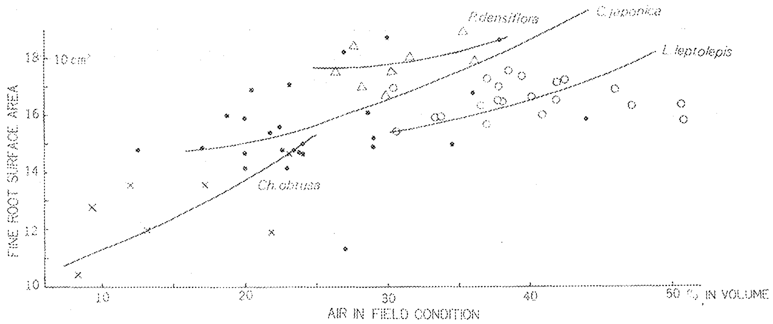


Fig. 28 Fine root surface area per unit weight in horizons I and II.

soils of B$_{lD}$(w)-type, while they ranged from 170 to 186 cm² in the dry soils of B$_{lD}$(d)-B$_A$ types. The difference of 20 to 30 cm² was recognized between them. This is because the root system is smaller in average diameter, as with the length, in the dry soil than in the moist soil.

This tendency is particularly remarkable in the fine root. The difference of the root surface areas caused by the different soil conditions disappears gradually as roots become larger from a small root to a large root.

The pF value and site index in the field condition are both closely connected with the soil type. The surface area was recognized to increase when the pF value increased and the site index decreased.

f. Air in field condition

The amount of air in field condition of the soil is closely connected with the productivity of soil. As shown in Fig. 28 of the relation between the amount of air and the surface area of the fine root in soil horizons I and II, variances are large irrespective of species. The surface area of a fine root increased, on the whole, in a slightly upward curve with the increase of the air in field condition. This arises from a twofold reason, first that the average diameter becomes narrower owing to the large amount of air in field condition in the dry soil, and secondly that the surface areas of roots become wider owing to intricate branching.

It is not unreasonable to estimate from figure that when the amount of air in field condition ranges from 20 to 30%, the surface areas of the fine root range from 150 to 160 cm² for *C. japonica*, from 140 to 160 cm² for *Ch. obtusa*, from 170 to 180 cm² for *P. densiflora*, and from 140 to 150 cm² for *L. leptolepis*.

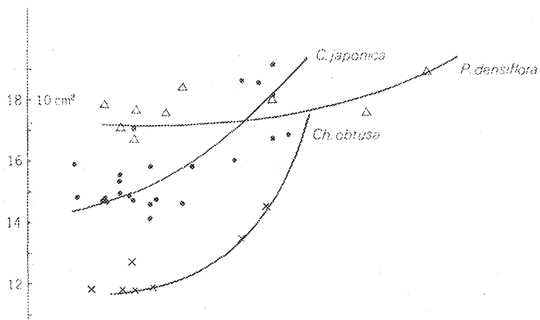


Fig. 29 Fine root surface area per unit weight in horizons I and II.

g. pF value

Fig. 29 shows the relation between the pF values and the surface area of the fine roots of each species in soil horizons I and II of the sample stands. When the pF value went over 2.5, the root surface areas of *C. japonica* and *Ch. obtusa* increased rapidly; but that of *P. densiflora* increased, describing a gentle curve upward. The fine roots of *C. japonica* and

Table 24. Root hairs and

Species	Distance between root hairs μ	Diameter of a root hair μ	Length of a root hair μ	Diameter of a root tip μ	Length from a root tip to a root hair μ
P. densiflora	50	18	158	410	1,527
σ		7	81	42	366
n	45	30	30	30	30
P. thunbergii	72	23	168	432	2,067
σ		9	99	40	400
n	40	30	30	30	30
Picea jezoensis v. *hondoensis*	63	27	190	554	1,441
σ		6	47	135	550
n	50	25	30	30	28

Ch. obtusa become thinner and their branching becomes more intricate rapidly as soils get drier.

When the pF value was 3, the surface areas of the fine roots were 180 cm^2 for *C. japonica*, 175 cm^2 for *P. densiflora*, and 150 cm^2 for *Ch. obtusa*. That the root surface area of the last is narrower is because the fine roots are larger in diameter.

Their variances are smaller than those of the amount of air in field condition because the change of the amount of water contained is more directly connected with the change in surface area than in the amount of air in field condition of soil.

h. The root hair and its surface area

The root hairs develop at the rear of the elongation zone of the root tip. They affect the surface areas of the root tip. In several species of the one-year or two-year-old saplings in the nursery of the Forestry Experiment Station, the existence of root hairs was examined and the root surface area calculated.

i. Measurement of the root hair

Samples: *P. densiflora*, *P. thunbergii*, and *Picea jezoensis* v. *hondoensis*.

Period for observation: July to August, 1963.

The one-year or two-year-old saplings of *C. japonica*, *Ch. obtusa*, *P. densiflora*, *L. leptolepis* and others in Meguro nursery were observed to find out whether or not the root hairs existed in the roots in the surface soil horizon. Those of *P. densiflora*, *P. thunbergii* and *Picea jezoensis* v. *hondoensis*, which were then observed to have root hairs, were measured according to the following process.

The fine roots were carefully collected, put into water for some time, and cleared of soils sticking to them with a soft brush lest they should be impaired. After that, they were taken out into a watered vessel. From them, 20 to 30 samples with the evenly grown white roots were selected and their root hairs were measured on their density, diameter and length through a microscope of 150 magnification. It was not possible to observe the root hairs of *C. japonica*, *Ch. obtusa*, and *L. leptolepis*.

Measurements obtained are shown in Table 24. Taking *P. densiflora* as an example from the table, the distance between the root hairs ranged from 50 to 63μ; the root hair was 18 to 27μ in diameter, and 158 to 190μ in length; the surface area a root hair was 9,000 to 10,000μ^2 in width; the root hairs a white root tip were 380 to 680 in number; the surface area of the root hairs a white root tip was 4.6 to 10.9 mm^2 in width, and 2 to 4 times as wide as the surface area of the root tip alone. The total surface area of the white root tips including the surface areas

Distance between living root hairs μ	Surface area per root hair μ^2	Number of root hairs per root tip	Surface area of root hairs per root tip μ^2	Surface area per root tip μ^2	Surface area of root hairs/ Surface area where root hairs spread	Whole surface area including that of root hair/ Surface area excluding that of root hair
1,328	8,944	684	6,117,696	1,709,667	3.58	1.420
417	—	—	—	—	—	
30	—	—	—	—	—	
1,450	12,151	379	4,605,229	1,966,896	2.34	1.356
470	—	—	—	—	—	
30	—	—	—	—	—	
1,538	16,129	674	10,870,946	2,675,443	4.06	1.524
553	—	—	—	—	—	
30	—	—	—	—	—	

root hairs was 1.4 to 1.5 times as wide as that of the white root tip alone.

Root hairs have much higher efficiency of absorption than the ordinary epidermal cells. There is positive difference in absorptive power far greater than that of the surface area when that efficiency is counted in.

Although *Pinus* species have a much smaller fine root weight than *C. japonica* and *Ch. obtusa*, it can be estimated that the existence of root hairs causes them to greatly heighten absorbing power of their fine roots. That *Pinus* species can grow in the dry soil may have something to do with the existence of the root hairs. Many points on the working of the root hairs of a tree still remain unknown, hence future study is necessary.

11. Distribution of the root biomass in a stand

The distribution of root biomass was investigated in each block of a stand, horizontally and vertically. According to the block method, offset among the root biomass takes place mainly in the fine, small and medium roots. The biomass of the large and the very large roots, which occupy greater parts of root biomass, vary in proportion to the biomass of their above-ground parts.

The root biomass is to be expressed as a function of the basal area. The changes in this function was then examined according to each root class and the sample horizontal and vertical blocks.

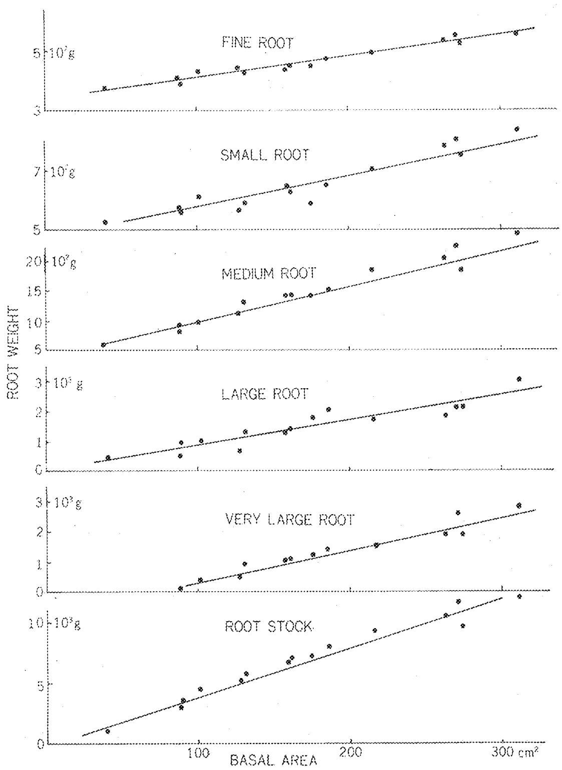


Fig. 30 Basal area and each root of the *C. japonica* stand, S 13.

Particular attention was here paid to the S 13 stand with many sample trees which were investigated in detail. This is also dominant over the other stands.

1) Root class

Fig. 30 shows the relation between each biomass of the root system and the basal area. It is evident from the figure that each biomass from a fine root to a root stock is almost primarily in linear relation with the basal area, and in addition, that there is a high correlation between them. The regression coefficient (b) is also recognized to increase as the root system becomes larger in diameter. The coefficients, constants, and errors, as shown in Table 35 and 42, are calculated from the following equation applied to the relation;

$$Y=a+b\left(\frac{\pi D^2}{4}\right)$$

Y : Partial biomass of the root system (g)

D : D.B.H (cm)

(The above-used equation is to be applied to the following calculations of regression)

Table 35 and 42 shows the numerical values of each part of the root system. According to that table, the regression coefficient increased as the root system became larger.

As already mentioned on the comparison between the block method and the total weight method, it takes place partly because of the offset between the root systems, and partly because the roots of a small tree grow slower than those of a large tree, and they are thin roots rather than thick roots. In other words, the samll tree and the large tree have a small difference in biomass between the fine and the small roots, and a large one between the large roots.

The coefficient of variation of regression $(S_{yx}/\bar{y})$*1 is smallest in the fine root. It increases as the root system becomes larger. That of a large root was 18%, for example; that of the total root biomass, on the other hand, was 8%, smaller than those of from a large root to a root stock. This is due to the offset of errors by the change in root biomass according to every root class.

That the variance of the fine to medium roots is small means that these roots have a tendency to be evenly distributed along the surface ground. It is not unreasonable to estimate therefrom that they and the other larger parts of the root system have extremely different patterns of distribution and function.

The correlation coefficient between the biomass of each part and the basal area ranges from 93 to 99%; 93% for the large root, and 99% for the root stock or the total biomass. It is possible to conclude from this that there exists a close connection between the last two.

2) Change according to soil horizon

The above-mentioned relation is also recognized according to every soil horizon even if roots go into the same root class. This is shown in Fig. 31 on the fine roots. The difference in tree size between the root biomass was smaller and the gradient of the regression line was gentler, in the upper soil horizons than in the lower ones. This is very similiar to the relation between the root biomass according to every root class and the basal areas in Fig. 31.

The relation is more remarkable in the larger roots. Fig. 31 shows the relation between the large root biomass and the basal areas according to every soil horizon. As is clear from it, the gradient of the regression line was sharper in soil horizon I than that of a fine root.

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*1 S_{yx} : Standard deviation in a regression equation.
$\bar{y}$: Average of regression.

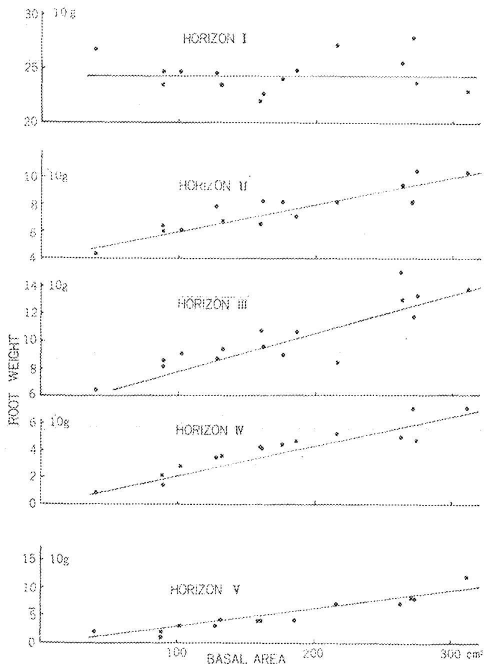

Fig. 31-1 Basal area and the fine root biomass of *C. japonica* stand S 13 in each soil horizon.

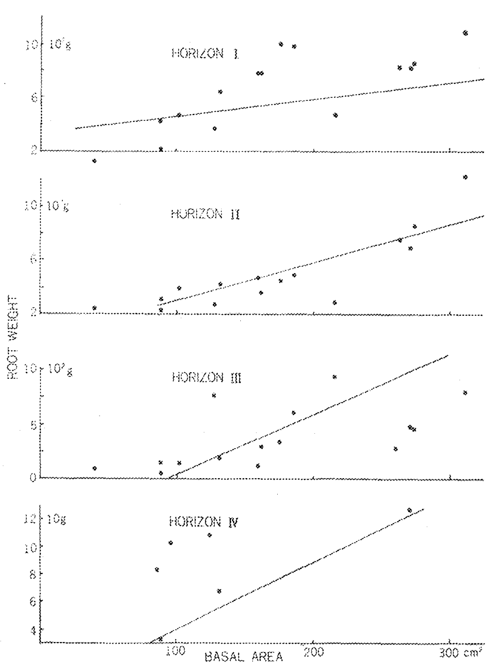

Fig. 31-2 Basal area and the large root biomass of *C. japonica* stand S 13 in each soil horizon.

Table 25. Regression coefficients in each soil horizon of the *C. japonica* stand, S 13 (Fine root density, Horizontal division I)

Soil horizon \ Root class	Regression coefficient	Variation coefficient	Root density
I	−0.04	0.15	216
II	0.04	0.08	36
III	0.09	1.18	34
IV	0.17	0.34	32

In addition, it becomes sharper as soil horizons go lower.

Table 25 shows the result from the root density of a fine root calculated in the horizontal block division 1. The regression coefficient became larger as soils went deeper. The variance went up with it.

(In Table 25 the coefficient of variation is small in soil horizon II because the second soil horizon S 13 stand the volcanic gravel soil and its texture is extremely uniform.)

To sum up: First, the root biomass shows the changing distribution according to tree size as soil horizons go down lower. Second, a large-diameter tree gets the larger root biomass and spreads more roots in the lower soil horizon than a small-diameter tree; and a small-diameter tree maldistributes the roots to the surface soil horizon. Third, it is clear from the change in variance that the root biomass is evenly distributed to the upper soil horizons, and that the variances are large and the root biomass is unevenly distributed to the lower horizons.

Table 26. Root distribution on the upper and the lower part of the slope (stand; S 13. Soil horizon I) (g)

Root class \ Division	Upper part U ①+④	Lower part L ②+③	Ratio of L to U
f	32	36	1.1
s	45	53	1.2
m	109	124	1.1
l	57	141	2.5
L	22	60	3.0

3) The root biomass distribution up and down a slope

The distribution of the root biomass to the upward sides (the investigated plots ① and ④) and to the downward sides (the investigated plots ② and ③) of a slope is shown in Table 26 on the root biomass in soil horizon I. There it can be seen that the root biomass become larger in the downward sides than in the upward ones as roots grow thicker.

When the ratio of distribution of the root biomass upward is to be 1, the ratios downward are 1.1 for the fine root, 1.2 for the small root, 1.1 for the medium root, 2.5 for the large root, 3.0 for the very large root. Hence it is that the thicker root gain the higher ratio, the thick roots, which support the above-ground parts, are distributed down a slope rather than up a slope, and the fine and the small roots are almost evenly distributed near the surface soil horizon.

Let us go through this relation on the root density of the fine and the large roots. The result is shown in Table 27. It is clear from the table that there was a difference between the root biomass distributed up and down the slope. And besides, this difference tended to become broader with the increase of the depth of the soil horizon or the size of the roots.

4) Root distribution to the right and left sides of a slope

The root density on the right and left sides of a slope was observed up (① and ④) and down (② and ③) the slope. The average values of the root density were 203 up and right, 300 up and left, 286 down and right, and 395 down and left. They were larger on the left side both up and down the slope. But as shown in Table 28 on the result of regression calculation, variances were wide in both cases. No difference was recognized between them.

5) Horizontal changes in root biomass

The changes of the root biomass in horizontal divisions 1, 2 and 3, in relation to the basal areas are shown in Table 29. The horizontal changes of the density of the fine roots in soil horizons I and II are shown in Table 30.

Though the root density in the horizontal division did not change with the change in tree size, the difference between the root densities in horizontal divisions 1 and 3 became larger when the roots were horizontally farther away from the root stock, and so became the regression coefficients.

6) Block method recognized from the root distribution

Let us go through the root densities of fine roots in horizontal division 2 and in each sample block ① to ④ on soil horizon I. The result is shown in Table 31. According to the table, they are 280 and 316 in blocks ① and ④ upward of a slope respectively; they are 323 and 361 in block ② and ④ downward of it. These are 3 to 41 thinner or thicker than the average, 320, in the second whole horizontal division. The ratios of these differences to the average are 1 to 3 per cent.

The root densities in blocks ④ and ② were close to the average value in the second

Table 27. Root density on the upper and the lower part of the slope in the *C. japonica* stand S 13

Root class	Horizon	Upper part			Lower part		
		Regression coefficient	Regression constant	Variation coefficient	Regression coefficient	Regression constant	Variation coefficient
f	I	0.27	252	0.22	0.01	340	0.15
	III	0.15	22	0.27	0.16	37	0.14
l	I	1.13	466	0.43	2.42	878	0.50
	III	11.3	−1,204	0.40	0.40	302	0.44

Table 28. Root density on the right and the left side of the slope (Stand S 13. Fine root, Soil horizon I)

Division	Upper part		Lower part	
	Right side of the slope ①	Left side of the slope ④	Right side of the slope ②	Left side of the slope ③
Regression coefficient	0.44	0.95	0.21	0.20
Regression constant	203	300	286	395
Variance of regression S^2_{yx}	7,150	7,058	4,573	5,529
Root density g/m³	280	316	323	361
Variation coefficient	0.30	0.26	0.21	0.21
Correlation coefficient	0.40	0.09	0.25	9.21

* ①~④ : Horizontal division

Table 29. Horizontal change in fine root density in the *C. japonica* stand, S 13 (Soil horizon I)

Horizontal division	1	2	3
Regression coefficient	− 0.04	0.14	0.27
Regression constant	223	296	361
Variation coefficient	0.15	0.13	0.15
Correlation coefficient	0.10	0.26	0.44
Root density g/m³	216	320	313

Table 30. Horizontal change in fine root density in the *C. japonica* stand, S 13

Horizontal division	1				2				3			
Soil Horizon	Root density	Regression coefficient	Regression constant	Variation coefficient	Root density	Regression coefficient	Regression constant	Variation coefficient	Root density	Regression coefficient	Regression constant	Variation coefficient
I	216	0.04	223	0.15	320	0.14	296	0.13	313	0.27	361	0.15
III	34	0.09	19	1.18	57	0.16	29	0.14	23	0.12	25	0.22

Table 31. Fine root densities at the *C. japonica* stand, S 13 in each sample block (Soil horizon I)

	Upper part of the slope (A)		Lower part of the slope (A)		Average (B)
Sample block	①	④	②	③	2
Root density (A) g/m^3	280	316	323	361	320
Difference from average	40	4	3	41	
Ratio of the differece from the average to the average	0.30	0.01	0.01	0.13	

Table 32. Fine root density in the first horizon of the *C. japonica* stand S 13

	Upper part of the slope	Lower part of the slope	Average
Sample block	① + ④	③ + ②	2
Root density (g/m^3)	298	342	320
Difference from average	22	22	
Ratio of the difference from the average to the average	0.07	0.07	

Table 33 Fine root density on the right and the left side of the slope in the 2nd soil horizon of *C. japonica* stand, S 13

	Right side of the slope	Left side of the slope	Average
Sample block	① + ②	③ + ④	2
Root density (g/m^3)	301	339	320
Difference from average	19	19	—
Ratio of the difference from the average to the average	0.06	0.06	—

horizontal division. The differences between them are three to four. The ratio of them to the average is one per cent. It is not proved, however, that the root densities in blocks ④ and ② are always close to the average in every stand.

Furthermore, the large variances of these blocks indicate that the root density changes greatly.

The root densities were, as shown in Table 32, 22 less than the average value up the slope and 7 more down the slope.

It is generally observed that the root density down the slope is higher than that up the slope. It is presumable on every sample tree or stand that the roots are more densely distributed down the slope than up the slope. Therefore, the total root biomass is to become large when only the upper half is examined, while it is to become small when the lower half is examined. Neither result is desirable in measuring the root biomass.

As shown in Table 33, the difference between the root densities on the right and left sides of the slope and the average value are both 19, and their ratio to the average value is 6%. This value is less by 1% than that of the up-and-down divisions. When the slope is divided into two parts, upward and downward, there is a tendency, as pointed out before, that the root densities are always lower upward than downward. There is, however, no tendency similar to that when the slope is divided into two parts, left and right, and besides, the error of measurement has a possibility to cancel each other.

The fine root in soil horizon I has a tendency to be more uniformly distributed than any other root or to any other soil horizon. Even in this case, it still shows such differences of distribution of the root biomass as already mentioned. They tend to increase more remarkably in the other larger roots in the lower soil horizons.

From these properties of root distribution, the 1/2 block method, which divides the block into two parts, right and left, along the slope, may be suitable in examining the root biomass by the block method.

12. Variance of the measured part biomass in a stand

The part biomass of the sample trees is obtained by the soil block method. The variance changes greatly according to the methods of estimation when the partial biomass per unit area are calculated from the data in this table. The numerial calculations, which give difference as little as possible and operation as easy as possible, are desired in estimating the total biomass. For this sake, the accuracy of estimation was examined when the variables and equations (①~⑦) in Table 34 were used.

The logarithmic equation ⑤ in Table 34 has generally been used as the relative growth equation. This equation has, however, a contradiction in that the total biomass is not obtained when the equations for each part are added up, unless the coefficient of relative growth, b[*1], is 1. From this viewpoint, use of the other equations such as the semi-logarithmic or linear regressions that can be added up to obtain the total biomass are desirable. Previously Mr. YAMAMOTO[1)*2] expressed the volume of root stock in relation to the diameter of it. The numerical calculation of ⑦ is an orthogonal polynomial which has nine independent variables. These variables were calculated according to EFROYMSON's[2)] method, which is to be described later. Here, only the terms relating to the partial biomass are taken up.

As a result, the constants, coefficients, coefficients of correlation, coefficients of variation etc. were obtained as in Table 35 on each stand. The variation coefficients when each equation is applied according to the table on the S 13 stand, from which many trees sampled, are shown in Table 36.

y_1 (Stem) : The coefficients of variation of the stem by equations ①, ② and ③ were large, 19%, but by equation ⑥ it was 6% and smallest.

y_2 (Branch) : The coefficients of variation of branches were large, on the whole 21~28%, but equations ④ and ⑦ gave small ones.

y_3 (Leaf) : The coefficients of variation of leaves were large again on the whole, 18~23%, but by equation ⑦, it was 18% and smallest.

y_4 (Above-ground part) : The coefficients of variation of the above-ground part were 6~16% smaller than those of stem, and by equation ⑥ it was 6% and smallest. It is due to the

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*1 An equation of relative growth: $y=ax^b$,
y : Part biomass, x : Total biomass or D^2H, b : Coefficient of relative growth.

*2 An equation of the volume of root stock: $V=aD^b$,
V : Volumes of root stock (尺^3) 尺$=0.303$ m, D : Diameters of root stock, $a=2.314$, $b=2.45$.

1) YAMAMOTO, K. : On the root volume of *Pinus densiflora*. Bull. Gov. For. Exp. Sta., 15, 133~138, (1925).

2) EFROYMSON, M. : Multiple regression analysis. Mathematical methods for digital computers. New York, 191~203, (1965).

Table 34. Veriables and regression equations to be used in estimating each part biomass of a tree

A. Definition of variables,

Dependent variables (in unit dry weight : g)

y_1 Stem biomass
y_2 Branch biomass
y_3 Leaf biomass
y_4 Above-ground part biomass
y_5 Fine root biomass
y_6 Small root biomass
y_7 Medium root biomass
y_8 Large root biomass
y_9 Very large root biomass
y_{10} Root stock biomass
y_{11} Underground part biomass
y_{12} Total biomass of a tree (above-and under-ground parts)
y_{13} Latest annual stem growth
y_{14} Py_3 Latest annual leaf growth
y_{15} Qy_{13} Latest annual branch growth
y_{16} y_1+y_2 Above-ground part biomass excluding leaf biomass (stem, and branch biomass).
y_{17} y_5+y_6 Working part biomass of the underground part (fine root, and small root).
y_{18} $y_7+y_8+y_9+y_{10}$ Non-working part biomass of the underground part (medium root, large root, very large root, root stock).
y_{19} $y_1+y_2+y_{11}$ Above-and underground part biomass excluding leaf biomass.
y_{20} $y_{13}+y_{14}+y_{15}+\left(y_{13}\times\frac{y_{11}}{y_1}\right)$ Total of the latest annual growth of stem, branch, leaf, and root.
y_{21} Maximum depth of root (cm)

Independent variables
D DBH cm
H Tree height cm
V Volume cm^3

B. Regression equations to be used in the calculating of biomass, ①～⑦.

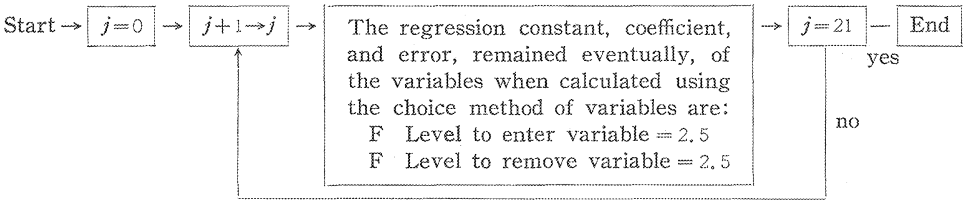
① $y=a+b\ \log D+c\ \log H$*1
② $y=a+b\ \log D$
③ $y=a+b\ \log (D^2H)$
④ $y=a+b\left(\frac{\pi D^2}{4}\right)$
⑤ $\log y=a+b\ \log (D^2H)$
⑥ $y=a+bV$
⑦ $y=a_0+a_1D+a_2H+a_3D^2+a_4DH+a_5H^2+a_6D^3+a_7D^2H+a_8DH^2+a_9H^3$

*1 The logarithms to be used in the calculations of Table 35 and 42 are all the natural logarithm.

y: y_1 to y_{21} were calculated.

Choice method of variables by the orthogonal polynomial ⑦.

$$y_j=a_0+a_1D+a_2H+a_3D^2+a_4DH+a_5H^2+a_6D^3+a_7D^2H+a_8DH^2+a_9H^3$$
$$=a_0+a_1x_1+a_2x_2+a_3x_3+a_4x_4+a_5x_5+a_6x_6+a_7x_7+a_8x_8+a_9x_9 \quad j=1\sim21$$



* The equation ⑦ differs from those of ①～⑥ in the character of equation.

Table 35. Estimating regression equations for part biomass of a tree and their accuracy in a stand, See Table 34.

C. japonica stand S 13, n : 15,
Equation ④ : $y=a+b(\pi D^2/4)$

y	a	b	r	S_{yx}
1	−3,362	204.9180	0.98	3,359
2	−112	11.6800	0.92	407
3	3,283	32.6311	0.79	2,084
4	−191	249.2291	0.97	4,410
5	349	0.6735	0.97	13
6	457	1.1508	0.94	32
7	303	6.6910	0.98	99
8	69	8.2283	0.92	278
9	−726	11.0206	0.97	195
10	−15	40.5218	0.98	1,119
11	468	68.1196	0.98	943
12	276	317.3487	0.98	5,279
13	−475	25.4746	0.96	550
14	1,149	11.4209	0.79	729
15	−166	8.9161	0.96	192
16	−3,474	216.5980	0.98	3,455
17	806	1.8243	0.96	40
18	−338	66.2952	0.98	936
19	−3,007	284.7176	0.98	4,282
20	530	54.3483	0.95	1,350
21	110	0.2046	0.94	6

C. japonica stand S 13, n : 15,
Equation ⑤ : $\log y=a+b \log (D^2H)$

y	a	b	r	S_{yx}
1	−1.4774	0.9487	0.98	3,580
2	−3.2733	0.8662	0.94	445
3	1.0232	0.6478	0.91	1,980
4	−0.3239	0.8806	0.99	3,913
5	4.1649	0.1600	0.91	23
6	4.2103	0.1839	0.86	53
7	0.0001	0.5856	0.97	133
8	−2.1296	0.7559	0.93	332
9	−13.6530	1.6503	0.95	380
10	−2.5807	0.9161	0.98	779
11	−0.4383	0.7900	0.99	868
12	0.1999	0.8590	0.99	4,471
13	−5.2267	1.0801	0.98	638
14	−0.0266	0.6478	0.91	693
15	−6.2765	1.0801	0.98	223
16	−1.3549	0.9436	0.98	3,448
17	4.8700	0.1740	0.89	68
18	−1.8068	0.8912	0.99	790
19	−0.4891	0.8994	0.99	3,751
20	−2.0514	0.9019	0.98	1,307
21	2.7832	0.1778	0.97	4

C. japonica stand S 13, n : 15,
Equation ⑦ : $y=a_0+a_1D+a_2H+a_3D^2+a_4DH+a_5H^2+a_6D^3+a_7D^2H+a_8DH^2+a_9H^3$

y		S_{yx}
1	$1,772+0.1131801D^2H$	2,574
2	$-112+9.173473D^2$	407
3	$-10,603+1,736.160D-1.573773D^3$	1,693
4	$-9,760+3.969035DH-0.01138264H^2$	3,548
5	$383+0.023573D^3$	12
6	$512+0.040811D^3$	27
7	$303+5.255078D^2$	99
8	$270+0.004564D^2H$	256
9	$-426+0.006003D^2H$	168
10	$-15+31.82572D^2$	568
11	$468+53.50097D^2$	943
12	$-5,225+2.123938DH+0.0889653D^2H$	4,573
13	$146+0.014134D^2H$	435
14	$-3,711+607.6565D-0.550821D^3$	592
15	$51+0.004947D^2H$	152
16	$1,966+0.1195779D^2H$	2,650
17	$895+0.064384D^3$	32
18	$-338+52.06815D^2$	936
19	$4,249+0.156805D^2H$	3,541
20	$-2,874+0.743688DH$	1,054
21	$97+0.002808DH$	4

Ch. obtusa stand : H 3, n : 6,
Equation ④ : $y=a+b(\pi D^2/4)$

y	a	b	r	S_{yx}
1	−3,267	297.8203	0.99	2,811
2	138	41.5874	0.98	695
3	2,463	21.2588	0.77	1,468
4	−667	360.6666	0.99	3,277
5	542	1.1741	0.89	49
6	1,290	1.7543	0.98	29
7	468	7.8013	0.99	79
8	210	12.3012	0.99	92
9	−2,238	38.5196	0.97	750
10	−732	50.8756	0.98	840
11	−460	112.4261	0.98	1,547
12	−1,126	473.0927	0.99	4,727
13	−277	17.2229	0.87	812
14	739	6.3776	0.77	440
15	−97	6.0280	0.87	284
16	−3,130	339.4078	0.99	2,293
17	1,832	2.9285	0.95	73
18	−2,291	109.4977	0.98	1,571
19	−3,589	451.8339	0.99	3,585
20	297	36.1982	0.95	1,835
21	97	0.0613	0.64	6

Table 35. (Continued)

Ch. obtusa stand H 3, n : 6,
Equation ⑤ : $\log y = a + b \log (D^2H)$

y	a	b	r	S_{yx}
1	−0.7908	0.9246	0.98	4,210
2	−2.0091	0.8714	0.98	629
3	1.5786	0.5700	0.75	1,957
4	0.0018	0.8811	0.98	6,090
5	3.8089	0.2254	0.82	63
6	5.2100	0.1737	0.95	50
7	−0.3959	0.6327	0.98	128
8	−2.3294	0.8062	0.99	113
9	−8.9502	1.3799	0.98	805
10	−2.6810	0.9327	0.97	1,212
11	−1.3682	0.8962	0.98	2,113
12	0.2245	0.8847	0.98	7,968
13	−4.7888	1.0110	0.91	848
14	0.3747	0.5700	0.75	587
15	−5.8386	1.0110	0.91	297
16	−0.5631	0.9177	0.99	4,148
17	5.3831	0.1907	0.91	98
18	−2.7362	0.9943	0.98	2,102
19	−0.2006	0.9122	0.99	5,557
20	−2.2520	0.8801	0.88	2,081
21	3.6698	0.0809	0.55	7

P. densiflora stand A 2, n : 23,
Equation ④ : $y = a + b(\pi D^2/4)$

y	a	b	r	S_{yx}
1	798	242.7678	0.94	2,731
2	−1,440	71.5468	0.89	1,134
3	−623	32.8598	0.89	511
4	−1,264	347.1744	0.94	3,920
5	14	0.1471	0.89	2
6	149	1.7197	0.92	22
7	66	9.1081	0.93	109
8	−254	17.5567	0.97	133
9	−337	7.8736	0.85	142
10	−6	47.4168	0.94	520
11	−277	82.4234	0.95	808
12	−1,542	429.5978	0.94	4,708
13	174	29.3761	0.88	494
14	−374	19.7159	0.89	306
15	105	17.6257	0.88	296
16	−641	314.3146	0.94	3,558
17	163	1.8668	0.92	24
18	−440	80.5566	0.95	792
19	−919	396.7380	0.94	4,339
20	−109	76.7633	0.90	1,138
21	100	0.6363	0.70	20

P. densiflora stand A 2, n : 23,
Equation ⑤ : $\log y = a + b \log (D^2H)$

y	a	b	r	S_{xy}
1	−1.1552	0.9656	0.95	2,938
2	−8.4709	1.4559	0.91	1,355
8	−7.7365	1.3254	0.96	627
4	−1.9127	1.0534	0.95	4,139
5	−0.3666	0.3146	0.83	3
6	1.6505	0.3495	0.90	25
7	−2.5172	0.7997	0.92	129
8	−9.7036	1.4591	0.95	242
9	−19.4289	2.1696	0.90	169
10	−3.6031	1.0325	0.94	715
11	−2.9891	1.0219	0.95	988
12	−1.6283	1.0472	0.95	4,883
13	−1.8929	0.8449	0.85	682
14	−8.2473	1.3254	0.90	376
15	−2.4037	0.8449	0.85	409
16	−1.7675	1.0344	0.95	3,853
17	1.7730	0.3463	0.90	28
18	−3.7276	1.0818	0.95	974
19	−1.5105	1.0319	0.95	4,610
20	−1.9492	0.9243	0.88	1,635
21	2.1446	0.2502	0.56	33

P. densiflora stand A 2, n : 23,
Equation ⑦ : $y = a_0 + a_1D + a_2H + a_3D^2 + a_4DH + a_5H^2 + a_6D^3 + a_7D^2H + a_8DH^2 + a_9H^3$

y		S_{yx}
1	$-11,140 + 3.370515DH$	2,142
2	$4,343 - 1,360.801D + 0.140574D^2H$	763
3	$1,577 - 511.1999D + 0.057454D^2H$	416
4	$-375 - 0.000241D^2 + 0.538385D^2H$	2,869
5	$14 + 0.000121D^2H$	2
6	$150 + 0.001424D^2H$	20
7	$403 - 77.96727D + 0.012197D^2H$	84
8	$-228 + 0.014406D^2H$	118
9	$229 - 25.80116D^2 + 1.35438D^3 + 0.012585DH^2$	105
10	$-2075 + 2.370416H + 0.038136D^2H$	411
11	$-206 + 0.068387D^2H$	647
12	$-487 - 272.2183D^2 + 0.638689D^2H$	3,485
13	$262 - 27.38164D^2 + 0.052859D^2H$	424
14	$946 - 306.7201D + 0.034473D^2H$	250
15	$157 - 16.42894D^2 + 0.031715D^2H$	255
16	$171 - 222.7926D^2 + 0.492047D^2H$	2,586
17	$164 + 0.001545D^2H$	21
18	$-370 + 0.066842D^2H$	634
19	$-712 + 0.331079D^2H$	3,393
20	$3,593 - 862.7788D + 0.115063D^2H$	937
21	$65 + 8.669515D$	20

Table 35. (Continued)

L. leptolepis stand K 1, n : 9,
Equation ④ : $y=a+b(\pi D^2/4)$

y	a	b	r	S_{yx}
1	−16,065	431.8035	0.99	5,768
2	−13,483	89.2293	0.97	3,334
3	−498	10.4185	0.96	434
4	−30,046	531.4513	0.99	8,058
5	172	0.5785	0.94	30
6	556	1.2887	0.96	57
7	1,717	4.8302	0.97	169
8	−478	17.4676	0.98	407
9	−2,947	41.3862	0.99	563
10	−3,395	56.2368	0.99	1,076
11	−4,376	121.7880	0.99	1,419
12	−34,422	653.2392	0.99	8,688
13	−1,596	16.3890	0.98	364
14	−498	10.4185	0.96	434
15	−479	4.9167	0.98	109
16	−29,548	521.0328	0.99	8,211
17	728	1.8671	0.96	81
18	−5,104	119.9208	0.99	1,416
19	−33,924	642.8208	0.99	8,847
20	−3,014	36.3330	0.99	732
21	86	0.3529	0.98	11

L. leptolepis stand K 1, n : 9,
Equation ⑤ : $\log y=a+b\log(D^2H)$

y	a	b	r	S_{yx}
1	−1.9873	1.0155	0.99	5,179
2	−15.2827	1.8355	0.97	3,816
3	−8.6698	1.2298	0.96	543
4	−2.8743	1.0908	0.99	7,454
5	−0.7826	0.4954	0.95	29
6	1.5895	0.3936	0.96	59
7	2.4565	0.4194	0.96	201
8	−5.2948	1.6253	0.98	487
9	−8.4383	1.3078	0.97	1,685
10	−6.0918	1.1610	0.98	1,712
11	−3.8623	1.0607	0.99	2,567
12	−2.5732	1.0850	0.99	9,288
13	−10.2303	1.3627	0.98	589
14	−8.6698	1.2298	0.96	543
15	−11.4343	1.3627	0.98	177
16	−2.8596	1.0882	0.99	7,304
17	1.6454	0.4202	0.96	81
18	−4.3014	1.0901	0.99	2,472
19	−2.5603	1.0828	0.99	9,137
20	−8.8625	1.3256	0.98	1,416
21	−1.4533	0.5020	0.98	10

Ch. pisifera stand M 1, n : 5,
Equatian ④ : $y=a+b(\pi D^2/4)$

y	a	b	r	S_{yx}
1	5,507	193.4888	0.99	855
2	516	24.0379	0.98	144
3	1,557	22.0561	0.94	266
4	7,581	239.5827	0.99	722
5	413	0.7870	0.66	32
6	770	1.0845	0.68	41
7	228	11.4620	0.95	122
8	297	10.7160	0.98	71
9	−573	18.3091	0.96	171
10	865	35.6573	0.93	504
11	2,000	78.0158	0.99	224
12	9,580	317.5986	0.99	766
13	462	12.3127	0.98	87
14	343	4.8523	0.94	58
15	138	3.6938	0.98	26
16	6,023	217.5267	0.99	884
17	1,183	1.8715	0.68	71
18	817	76.1443	0.99	271
19	8,023	295.5425	0.99	970
20	1,112	25.8351	0.99	124
21	57	0.3734	0.97	3

Ch. pisifera stand M 1, n : 5,
Equation ⑤ : $\log y=a+b\log(D^2H)$

y	a	b	r	S_{yx}
1	3.9771	0.5214	0.97	1,760
2	1.2452	0.5708	0.97	209
3	3.0488	0.4391	0.95	256
4	4.2745	0.5162	0.98	20,769
5	4.4796	0.1452	0.75	388
6	5.5121	0.1072	0.75	470
7	0.3979	0.5786	0.94	2,476
8	0.7152	0.5514	0.98	954
9	−4.0410	0.9458	0.96	203
10	2.1394	0.5310	0.94	7,044
11	2.7193	0.5487	0.99	3,715
12	4.4537	0.5239	0.98	23,860
13	1.6634	0.4898	0.94	2,077
14	1.5347	0.4391	0.95	780
15	0.4594	0.4898	0.94	623
16	4.0259	0.5266	0.97	23,297
17	5.7969	0.1206	0.76	805
18	1.8694	0.6081	0.99	4,180
19	4.2604	0.5323	0.98	26,208
20	2.5255	0.4827	0.97	2,748
21	1.1981	0.2843	0.94	54

Table 35. (Continued)

Z. serrata stand M 4, n : 5,
Equation ④ : $y=a+b(\pi D^2/4)$

y	a	b	r	S_{yx}
1	−24,717	731.8867	0.99	8,030
2	675	31.8944	0.99	366
3	551	2.7737	0.84	360
4	−23,491	748.5547	0.99	8,257
5	1,519	0.4916	0.93	39
6	1,778	0.9726	0.95	66
7	1,030	14.1890	0.99	253
8	849	14.1095	0.99	134
9	−2,869	31.8925	0.99	411
10	−4,830	66.9103	0.99	945
11	−2,523	128.5655	0.99	1,233
12	−26,014	877.1203	0.99	9,258
13	1,731	3.0208	0.70	631
14	551	2.7737	0.84	360
15	519	0.9062	0.70	189
16	−24,042	745.7811	0.99	8,362
17	3,297	1.4642	0.96	84
18	−5,819	127.1013	0.99	1,174
19	−26,565	874.3466	0.99	9,389
20	3,203	7.0482	0.92	619
21	124	0.2682	0.95	18

Z. serrata stand M 4, n : 5,
Equation ⑤ : $\log y=a+b\log(D^2H)$

y	a	b	r	S_{yx}
1	−0.0456	0.8952	0.99	16,375
2	0.5966	0.5800	0.96	766
3	−0.0174	0.5367	0.94	278
4	0.1592	0.8827	0.99	16,927
5	6.6634	0.0564	0.94	33
6	6.5591	0.0801	0.86	101
7	1.0293	0.5558	0.98	562
8	0.4739	0.5938	0.99	314
9	−12.3158	1.5369	0.99	671
10	−6.2968	1.1614	0.99	1,488
11	−0.4470	0.8018	0.99	3,670
12	0.5025	0.8697	0.99	19,985
13	6.0523	0.1319	0.37	1,104
14	−0.0174	0.5367	0.94	278
15	4.8484	0.1319	0.37	331
16	0.1132	0.8855	0.99	16,800
17	7.2924	0.0696	0.91	147
18	−2.6248	0.9514	0.99	2,691
19	0.4652	0.8720	0.99	21,844
20	5.7742	0.2069	0.76	1,104
21	1.8572	0.2570	0.95	19

A. firma stand M 5, n : 5,
Equation ④ : $y=a+b(\pi D^2/4)$

y	a	b	r	S_{yx}
1	−4,749	165.0300	0.99	1,075
2	5,249	27.6744	0.97	390
3	6,370	23.0486	0.97	345
4	6,870	215.7530	0.99	956
5	120	0.2657	0.41	35
6	416	0.2775	0.44	34
7	42	6.9595	0.94	140
8	−956	13.1129	0.97	173
9	−1,173	13.4959	0.98	152
10	2,318	32.5658	0.98	307
11	767	66.6772	0.99	242
12	7,637	282.4302	0.99	784
13	−18	17.8342	0.97	241
14	1,592	5.7622	0.97	86
15	−5	5.3503	0.97	72
16	500	192.7044	0.99	1,028
17	536	0.5431	0.43	68
18	231	66.1341	0.99	258
19	1,267	259.3816	0.99	822
20	2,007	35.6286	0.98	327
21	211	0.7035	0.97	10

A. firma stand M 5, n : 5,
Equation ⑤ : $\log y=a+b\log(D^2H)$

y	a	b	r	S_{yx}
1	−3.7025	1.1385	0.99	1,151
2	4.3660	0.4015	0.95	495
3	5.3969	0.3188	0.94	512
4	1.6140	0.7513	0.99	864
5	1.7041	0.2814	0.47	40
6	5.0086	0.0937	0.47	32
7	−1.8948	0.7454	0.91	170
8	−9.9420	1.4111	0.96	200
9	−14.4612	1.7719	0.97	181
10	1.2589	0.6391	0.99	234
11	−0.2977	0.8034	0.99	360
12	1.7196	0.7629	0.99	1,103
13	−3.2316	0.9308	0.96	328
14	4.0106	0.3188	0.94	128
15	−4.4356	0.9308	0.96	98
16	−0.4388	0.8986	0.99	988
17	4.7356	0.1416	0.48	69
18	−0.7979	0.8403	0.99	341
19	0.1912	0.8722	0.99	898
20	1.0828	0.6558	0.97	480
21	2.0626	0.3102	0.95	10

Table 35. (Continued)

T. canadensis stand M 6, n : 5,
Equation ④ : $y=a+b(\pi D^2/4)$

y	a	b	r	S_{yx}
1	−10,844	335.9013	0.99	3,694
2	−2,859	67.9771	0.98	1,363
3	−285	18.5300	0.99	151
4	−13,988	422.4084	0.99	3,543
5	453	0.1214	0.44	32
6	2,124	1.0032	0.72	126
7	221	15.5990	0.99	161
8	115	14.7039	0.99	81
9	−2,345	29.4871	0.99	418
10	−3,449	58.1445	0.99	785
11	−2,883	119.0591	0.99	1,329
12	−16,870	541.4675	0.99	4,662
13	−1,065	21.2699	0.99	232
14	−71	4.6325	0.99	38
15	−319	6.3810	0.99	70
16	−13,703	403.8784	0.99	3,487
17	2,576	1.1246	0.69	154
18	−5,459	117.9345	0.99	1,276
19	−16,585	522.9375	0.99	4,628
20	−1,784	39.8495	0.99	391
21	87	0.2848	0.98	7

T. canadensis stand M 6, n : 5,
Equation ⑤ : $\log y=a+b\log(D^2H)$

y	a	b	r	S_{yx}
1	−1.3621	0.9646	0.99	2,561
2	−4.8192	1.1032	0.97	2,581
3	−3.4846	0.9119	0.99	154
4	−1.3566	0.9815	0.99	4,007
5	5.5413	0.0495	0.47	34
6	6.8284	0.0731	0.69	141
7	−1.7385	0.7742	0.99	296
8	−2.4430	0.8221	0.99	136
9	−10.1413	1.4286	0.98	738
10	−5.8683	1.1637	0.99	1,236
11	−1.7622	0.9187	0.99	2,365
12	−0.9054	0.9667	0.99	6,228
13	−5.9242	1.0956	0.99	147
14	−4.8709	0.9119	0.99	38
15	−7.1282	1.0956	0.99	44
16	−1.4526	0.9851	0.99	3,815
17	7.0643	0.0692	0.67	141
18	−3.8871	1.0722	0.99	2,082
19	−0.9714	0.9689	0.99	5,997
20	−4.8095	1.0605	0.99	355
21	0.5894	0.3461	0.98	6

A. decurrens v. *dealbata* stand M 7, n : 5,
Equation ④ : $y=a+b(\pi D^2/4)$

y	a	b	r	S_{yx}
1	−960	276.5301	0.99	3,080
2	−9,462	310.4141	0.99	3,832
3	1,419	68.3567	0.98	1,199
4	−9,003	655.3009	0.99	7,695
5	441	20.6987	0.94	660
6	4	35.7067	0.96	891
7	−99	92.6304	0.96	2,121
8	−1,026	24.1985	0.97	510
9	−2,339	35.1909	0.98	527
10	−1,242	73.7735	0.99	1,187
11	−3,899	280.3527	0.99	3,427
12	−12,903	935.6536	0.99	11,037
13	−62	42.8423	0.97	863
14	1,419	68.3567	0.98	1,199
15	−18	12.8527	0.97	259
16	−10,422	586.9442	0.99	6,847
17	445	56.4054	0.95	1,544
18	−4,345	223.9473	0.99	2,247
19	−14,321	867.2969	0.99	10,243
20	831	167.4041	0.98	2,897
21	96	0.2537	0.91	10

A. decurrens v. *dealbata* stand M 7, n : 5,
Equation ⑤ : $\log y=a+b\log(D^2H)$

y	a	b	r	S_{yx}
1	−0.9329	0.9734	0.98	5,053
2	−6.6962	1.4464	0.98	9,164
3	−0.3830	0.8234	0.97	1,915
4	−1.8247	1.1138	0.98	14,514
5	−1.0098	0.7748	0.92	993
6	−2.1448	0.9038	0.92	1,801
7	−3.3762	1.0881	0.97	3,046
8	−8.0429	1.3342	0.97	639
9	−19.3071	2.2810	0.96	1,790
10	−3.8972	1.1023	0.98	1,689
11	−2.4092	1.0915	0.98	5,472
12	−1.3863	1.1069	0.98	19,497
13	−3.7120	1.0516	0.98	977
14	−0.3830	0.8234	0.97	1,915
15	−4.9160	1.0516	0.98	293
16	−2.5786	1.1650	0.98	12,599
17	−0.9978	0.8506	0.92	2,828
18	−4.0290	1.2047	0.98	5,582
19	−1.8764	1.1397	0.98	17,695
20	−1.2789	0.9655	0.98	3,991
21	2.0322	0.2443	0.97	7

Table 36. Regression equation and variation coefficient, to estimate part biomass of the *C. japonica* stand, S 13 (n : 15)

y	Equation for the estimating of part biomass						
	① %	②	③	④	⑤	⑥	⑦
1	19	19	19	10	11	6	7
2	28	27	27	21	23	22	21
3	20	19	19	23	22	22	18
4	16	16	15	10	9	6	8
5	5	5	5	3	5	4	2
6	8	8	8	5	8	6	4
7	13	13	13	7	9	6	6
8	23	23	22	18	22	15	16
9	15	17	15	14	27	9	13
10	14	17	16	16	11	14	8
11	15	14	15	8	7	7	7
12	15	15	15	9	8	6	8
13	20	20	19	14	16	7	10
14	20	19	19	23	22	22	18
15	20	20	19	14	16	7	10
16	19	19	18	10	10	6	7
17	7	6	7	4	6	5	2
18	16	15	16	8	7	7	8
19	18	18	17	9	8	6	7
20	14	15	14	13	13	9	10
21	3	3	3	4	3	4	2

offset of errors of each part as stem, branch, or leaf, that the variance of the weights of the above-ground parts was small on the whole.

y_5 (Fine root) : The coefficients of variation of the fine roots were 2～5% and smallest of all. The most accurate equation is the ⑦ one.

y_6 (Small root) : Those of the small roots were 4～8%, and that given by equation ⑦ was 4%.

y_7 (Medium root) : Those of the medium roots were 6～13%. Equations ⑥ and ⑦ gave the smallest coefficients.

y_8 (Large root) : The coefficients of variation of the large roots were larger than those of other roots by each equation. The smallest coefficient of variation was 15%, given by equation ⑥.

y_9 (Very large root) : Those of the very large roots were 9～27%, and equation ⑥ gave the smallest one.

y_{10} (Root stock) : Those of the root stock were 8～17%, and equation ⑦ gave the smallest one.

y_{11} (Underground part) : Those of the total biomass of the underground parts were 7～15 %, and equations ⑤, ⑥ and ⑦ gave small ones.

y_{12} (Total biomass of a tree) : Those of the total biomass of a tree were 6～15%, which were smaller than those of the stem, branch, leaf, or large root. The ⑥ equation showed the highest accuracy.

y_{13} (Annual growth of the stem) : Those of the annual growth of the stem were 7～20%, and were comparatively larger than those of other parts. The ⑥ equation gave the smallest error.

y_{14} (Annual growth of the leaf) : The annual growth of the leaf was based on such calculation as the leaf biomass multiplied by a certain constant ratio. Those of the annual growth of the leaf were almost the same as those of the leaf (y_3). The ⑦ equation showed the smallest coefficient of variation.

y_{15} (Annual growth of the branch) : Those of the annual growth of the branch were almost the same as those of the annual growth of the stem, y_{13}. They are those of the stem multiplied by a given ratio.

y_{16} (Unassimilated part of the above-ground) : Those of the unassimilated partial biomass of the above-ground parts were 6～19%. The ⑥ equation showed the smallest one.

y_{17} (Working parts of the underground) : Those of the weights of the working parts, the fine and small roots, were 2～7%, and smaller than those of other parts. Particularly, the ② equation showed small variance.

y_{18} (Accumulated parts of underground) : Those of the accumulated weights of the underground parts, the medium root to the root stock, were 7～16%. Equations ⑤ and ⑥ showed the smallest errors.

y_{19} (Unassimilated part weight of above-and-under ground parts) : Those of unassimilated weights of the above-and-under ground parts were 6～18%. The ⑥ equation showed the smallest variance.

y_{20} (Total annual growth) : Those of the total annual growth were 9～15%. The ⑥ equation showed the smallest variance.

y_{21} (Maximum depth of root) : Those of the maximum depth of roots were 2～4%. The ⑦ equation showed the smallest error.

When the equation with the least error is to be applied to each biomass in the S 13 stand, the coefficients of variation are 2 to 21% as shown in Table 37. The parts showing the coefficients of variation of above 10% by any equation were the branch (21%), the leaf (18%), the large root (15%), and the annual growth of leaves (18%). Those below 5% are the fine root (2%), the small root (4%), and the fine and small roots (2%). Although not a part biomass, that of the maximum depth of roots was two percent.

The equations that show the smallest coefficient of variation among the equations of ①～⑦ are those of ④, ⑤, ⑥ and ⑦. The equations of ①, ② and ③ show low accuracy as compared with the former four, as shown in Table 45. The biomass of many parts were estimated most accurately by the sixth, of all the equations that gave the smallest coefficients of variation. Here, they are the biomass of 14 parts, i. e., the stems, branches, above-ground parts, medium roots, large roots, very large roots, underground parts, total biomass, annual growth of the stem, annual growth of the branch, unassimilated above-ground parts, accumulated underground parts, unassimilated above-and-under ground parts, and total annual growth. These all had a close relationship to the volumes of a tree.

Table 37. Regression equation of the smallest error among equations ①～⑦ and variation coefficient in the *C. japonica* Stand, S 13

y	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Equation No.	⑥	④ ⑥	⑦	⑥	⑦	⑦	⑥ ⑦	⑥	⑥	⑦	⑤ ⑥ ⑦	⑥	⑥	⑦	⑥	⑥	⑦	⑤ ⑥	⑥	⑥	⑦
Variation coefficient (%)	6	21	18	6	2	4	6	15	9	8	7	6	7	18	7	6	2	7	6	9	2

The equation which was accurate next to equation ⑥ was the one chosen by equation ⑦ i. e., the orthogonal polynomial. The equations concerning such parts as leaf, fine root, and small root were accurate. All the equations to be used in ⑦ orthogonal polynomial will be described later. The equations of ④ and ⑤ were used with higher accuracy for both the total biomass of branches and underground parts, and the biomass of the accumulating underground parts.

In this way their accuracy became higher when any equation suitable for each part was used rather than when a given equation was used. For the errors were different in each part, when the ratio estimates for each partial biomass were applied. But equation ⑦ was, as a whole, accurate for all parts. And each partial biomass was highly related to the tree volumes.

13. Accuracy of the equations to be used in calculation for each stand

What has been described so far is only about the stand of S 13. Subsequently, the stands of S 6, S 9, S 24, and S 28, all investigated as detailedly as possible, were gone through in order to determine if there exists the relation like that concerning them. There, the X-axis is the equation and the Y-axis is the coefficient of variation (The data about the stand of *C. japonica* are listed up in Fig. 32).

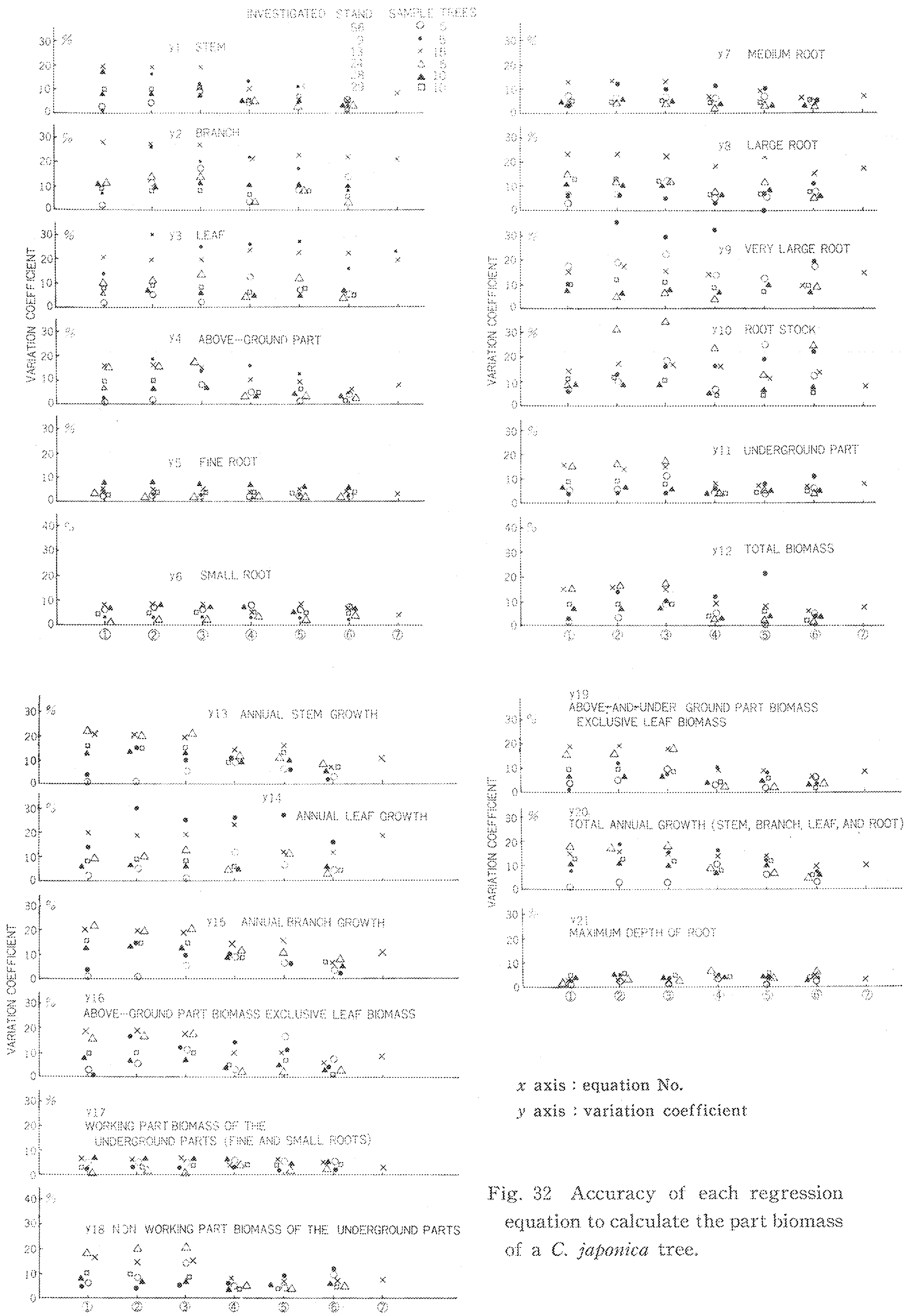
As can be judged from the detailed data where calculation has already been done, the equation which as a whole, is most accurate for the stem *C. japonica* is ⑥, which coefficient of variation ranges from 2 to 7%. And besides, the first equation, although not for S 9, is unsuitable for S 13. For the coefficient of variation amounts to nearly twenty per cent.

Thus, it is clear from Fig. 32 that almost every partial biomass can be expressed as a function of the basal area or volume, as shown in Table 38, when the equations with the highest accuracy are picked out for the *C. japonica* stand.

Table 38. Regression equation at the smallest variation coefficient for part biomass of each species

Species / y[*2]	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
1	6[*1]	4	6	6
2	4	1	6	6
3	6	6	6	3
4	6	4	6	5
5	6	4	6	5
6	6	1	1	4
7	6	4	6	4
8	4	4	6	4
9	6	4	5	4
10	1	6	6	4
11	4	5	6	4
12	6	4	6	5
13	6	4	6	4
14	6	4	6	4
15	6	5	6	4
16	6	4	6	5
17	6	1	6	4
18	4	3	6	4
19	6	5	6	5
20	6	3	6	4
21	6	6	6	4

*1 Regression equation No.
*2 y : Parts of a tree.



x axis : equation No.
y axis : variation coefficient

Fig. 32 Accuracy of each regression equation to calculate the part biomass of a *C. japonica* tree.

Also from Fig. 32 it is clear that the coefficients of variation of the parts as a branch, leaf, large root, very large root, root stock, etc. differ greatly from stand to stand; and yet, those of a fine root, small root, above-ground part, underground part, total biomass of tree, etc. differ slightly throughout each equation. This verifies that the former parts are remarkably maldistributed, although the latter parts are not. Hence it is possible to estimate by any equation the biomass of the parts, such as the fine and the small roots of small coefficients of variation, or the parts with small differences between stands, at high accuracy in any stand.

A slight discrepancy is recognized between the equation with highest accuracy for S 13 as shown in Table 37 and the equation to be used in calculation with highest accuracy chosen from all stands in Table 38. There is, however, a small difference between the two coefficients of variation. Although the coefficients of variation differ from stand to stand, the equations of ④, ⑤, ⑥ and ⑦ can be applied with comparatively high accuracy as already shown in Table 37 for S 13.

1) Accuracy of the equations to be used in calculation according to each species

The equations with the smallest errors were selected from the detailed table for *Ch. obtusa, P. densiflora, L. leptolepis* as synthetically as for *C. japonica.* The result is shown in Table 38. Those which tend to be accurate for each species are as follows; the ⑥ for *C. japonica*, the ④ for *Ch. obtusa*, the ⑥ for *P. densiflora*, and the ④ for *L. leptolepis.* Equations of ⑤ and ⑥ are accurate on the whole, and even though a slight difference exists between them there could not be supposed to exist a difference by equation between species.

2) Selection of the equations to estimate each part of a tree

To get the accurate estimates, it is necessary to use the optimum equation for each part because each part has, as already explained in Table 35 and Fig. 32, its own optimum equation. Calculations however, are more complicated.

Equation ⑥ : It is necessary to use with great care the ⑥ equation, which is most accurate on the whole; however, it is difficult to estimate the volume of stands correctly, the more so because the volume itself embraces errors. It is, therefore, better to use the equations in which the breast height diameter, tree height, etc. are the direct independent variables.

Equation ⑦ : The equation yielding the second highest accuracy is the equation from the orthogonal polynomial of the ⑦ equation. For S 13, the items and coefficients were, for example, chosen as in Table 38.

It is very desirable to produce the equation which makes it possible to estimate the part biomass within a given accuracy and to estimate the partial biomass according to those calculations. This method, however, has a great defect in that an accurate equation can not be given unless many trees are sampled, and that it requires complicated calculations to decide an equation, such as would suggest, use of an electronic computer for calculations, for example.

Let us calculate the part biomass of each species on the materials of the S 13 stand and the other stands of A 2, ST, HT, AT, KT. Results are shown in Table 39. According to this table, the items and the coefficients of variation for estimating each partial biomass are given in Table 39.

As clearly shown in it, there are many various items picked out for estimating each part biomass both within and between stand. It follows from the fact that the given terms, constants, and coefficients of variation are not to be fixed for given parts of a tree.

The total biomass of the sample tree of y_{12} was examined to choose the following items: DH and D^2H for the S 13 stand, H^2 and D^2H for the ST stand, H^2, D^2H and DH^2 for the A 2

Table 39. Application of the orthogonal polynomial to estimate the part biomass of a sample tree in a stand

Part	Term									Variation coefficient					
	D	H	D^2	DH	H^2	D^3	D^2H	DH^2	H^3	S 13	A 2	S_T	H_T	A_T	K_T
1	—	—	—	×	—	△	● ○	*	◉	8	14	5	5	4	9
2	—	—	●	—	—	○	× * ◉ △	—	—	21	26	24	12	19	39
3	—	—	◉	—	—	●	× * ○	—	△	19	31	24	8	18	33
4	—	—	—	—	●	△	× ○ ◉	*	—	8	15	6	2	5	10
5	—	○	—	○	—	● *	× ◉	—	—	3	—	5	4	4	15
6	—	—	× *	—	—	●	—	△	◉ ○	4	28	8	3	5	13
7	—	—	● ◉	○	—	—	× △	*	—	7	13	11	4	6	12
8	—	—	○	—	—	—	● ◉ × *	—	△	17	26	13	6	5	16
9	—	—	○	—	—	△	● * ×	◉	—	14	40	17	13	3	15
10	—	—	—	—	—	—	× ○ ◉ *	—	△	8	15	7	4	5	9
11	—	—	●	—	—	—	◉ * ○	—	× △	8	13	8	4	4	11
12	—	—	—	—	—	△	● ◉	× *	○	8	12	6	3	5	10
13	—	—	◉	—	—	○	● △ ×	*	—	11	23	28	24	5	25
14	—	—	—	◉	—	●	×	*	○ △	19	31	24	8	44	33
15	—	—	◉	—	—	○	● △ ×	*	—	11	22	28	26	13	3
16	—	—	—	—	—	△	● ◉	*	○	8	14	6	2	5	10
17	—	—	—	○	—	●	× *	△	◉	3	8	6	5	5	12
18	—	—	●	—	—		◉ *	○	× △	8	13	8	5	4	10
19	—	—	—	—	—	△	● ◉	*	× ○	8	12	6	2	5	10
20	—	—	—	● ◉	—	○	×	* ○	—	10	22	27	18	16	25
21	×	—	○	● *	◉	△	—	—	—	3	14	7	3	7	18

S 13 ● S_T ◉ H_T ○ A 2 × A_T * K_T △

Table 40. Accuracy of the ratio estimate equation.

y	part	z	$\sqrt{V_z}$	$\frac{\sqrt{V_z}}{z}$
1	Stem	187.12	20.33	0.1086
2	Branch	11.12	2.23	0.2005
3	Leaf	51.75	15.01	0.2900
4	Above-ground part	249.99	25.98	0.1039
5	f	2.68	0.93	0.3470
6	s	3.78	1.23	0.3254
7	m	8.47	0.87	0.1027
8	l	8.69	1.59	0.1830
9	L	7.30	1.68	0.2301
10	St	40.74	3.21	0.0788
11	Uuderground part	70.41	5.63	0.0800
12	Total	320.40	31.23	0.0975

*1 Retio estimate equation

$$V_z \fallingdotseq Z^2 \frac{N-n}{N-1} \frac{1}{n}\left(\frac{\sigma x^2}{\bar{x}^2}+\frac{\sigma y^2}{\bar{y}^2}-Z\frac{cov(x \cdot y)}{\bar{x}\bar{y}}\right) \qquad Z=\frac{\sum y}{\sum x}$$

*2 y_9 : $n=13$, Others : $n=15$

stand and DH^2 for the A_T stand. Thus, the different items were applied even to the same parts in the different stands. However, the items D^2 and D^2H were chosen for most stands. This makes clear that the biomass of each part has a high correlation with the basal area or volume.

When the above-mentioned method is accepted, it is possible to set up the equations with higher accuracy to be used in estimating each part biomass. More closely scrutinized materials are necessary, however, for establishing the equations to be calculated with given accuracy.

Equation ⑤ : As already mentioned, the logarithmic equation has been accepted as the equation which is most applicable or as the equation of relative growth up to now. Theoretically it may be unreasonable to apply it to the weight of each part with different coefficients. Also from the viewpoint of accuracy, equation ⑤, a logarithmic equation, is never a good one as compared with the others in Table 35. This is also applicable to the result on the S 13 stand. The coefficients of variation of the stem biomass in Table 36 were 19% by the equations ①, ② and ③, 10% by the ④, 11% by the ⑤, 6% by the ⑥, and 7% by the ⑦. Those errors were larger according to the ⑤ than according to the equations ④, ⑥ and ⑦.

The accuracy of the equations changes according to each part or to each stand. It is therefore very unreasonable to presume that what was already mentioned on equation ⑤ holds true in every case. As a result of synthetical examination according to Table 35 and the other detailed table, that equation was not the one with much higher accuracy. And at the same time, it is obvious that calculation becomes complicated because of logarithmic change, calculation of errors, and so on.

Equation ④ : The equation ④ is comparatively accurate among those seven equations, and gives higher accuracy than equation ⑤, a logarithmic equation. This is borne out by Table 43 and the others. Its method of calculation is much simpler and easier to use than the logarithmic equation and orthogonal polynomials.

Thus, there are many regressions to estimate the partial biomass as stated so far. But the simple equation ④ with comparatively high accuracy is most suitable, because accuracy does not become much higher even when more complicated equations are used.

As previously mentioned, it is possible to improve accuracy in estimating part biomass if various kinds of equations are used in calculation. In this study, however, the ratio estimate method by basal area similar to the equation ④, was used to avoid involved calculation though the accuracy was slightly lower. The errors between them were calculated on the materials of the S 13 stand. A result is shown in Table 40.

3) Decision of the number of sample trees in a stand

As mentioned repeatedly, the accuracy of estimation of each part biomass changes according to the equations to be used in calculation or to the properties of variance each part has. Many sample trees are needed when their number is decided according to the parts in which errors are large, such as leaf, branch, and large root. Investigation requires much expenditure. But not many sample trees are necessary for fine roots when estimation is carried out to obtain given accuracy, since variance is very narrow. On the other hand, the errors in leaves or branches become much greater.

This granted, great attention should be focussed on estimating any special part biomass to decide the number of sample trees. Generally speaking, the number of sample trees has been decided to make constant the estimation errors of th total biomass.

The number of sample trees is given by the following equation to be used in calculation when the coefficients of variation, permitted errors, and levels of significance, are given.

$$n_0=\left(\frac{tc}{p}\right)^2$$

n_0 : Number of sample tree, p : Aimed accuracy,

c : Coefficient of variation

The coefficients of variation of the total biomass of each species calculated by the equation ④ from Fig. 32 range from six to ten percent. Let us give the following conditions, taking as an aim the coefficient of variation of 10%, the greatest of them. Then the number of necessary sample trees are to be 5 when the coefficient is 10%, t is 2, and the aimed accuracy is 10% in average.

When calculated according to the above-mentioned equation, 16 sample trees are necessary to estimate the leaf biomass of *C. japonica* as its coefficient of variation is about 20%. This means that 16 sample trees are necessary for estimating the branch biomass by the equation ④ at the level of significance of 90% and the aimed accuracy of 10%, while about five trees are enough for estimating the total biomass.

From a result of actual measurements of the various stands changing the number of sample trees, it is evident that the coefficients of variation were not constant, as shown in Fig. 32. This means that some of the stands with fewer sample trees showed fewer errors than the stands with more sample trees. The stands S 6 and S 9 of *C. japonica*, from which 5 sample were taken, both showed the coefficients of variation smaller than 10%.

14. The equations to be used in calculation and their accuracy when all sample trees are run altogether

What has been dealt with so far is the relation among sample trees in a stand. Let us select such stands with normal growth as shown in Table 41 out of these sample stands and calculate the number of them, run together, according to the equations from ① to ⑦. Their constants, coefficients, coefficients of correlation, and coefficients of variation are shown in Table 42 and Table 43 (S_T for the sample trees of *C. japonica* stands in gross, H_T for those of *Ch. obtusa*, A_T for those of *P. densiflora*, K_T for those of *L. leptolepis*).

From comparisons between this table and Table 42 giving variances in the same stand, it is clear that the variances of different stands in gross are far bigger than those of the same stand.

Proceed now to a comparison between the stems of the stands S 13 and S_T according to both tables. Table 35, 42 gives the result. As shown clearly there, the coefficient of variation for S_T increased by over 6 times that for S 13 according to the equations ①, ② and ③ with low adaptability, by about 3 times that for S 13 according to those of ④ and ⑤, and by about 1.5 times that for S 13 according to the equation ⑥. According to the equation ⑦, however, that of S_T became smaller than that of S 13.

Equations ①, ②, and ③ are inaccurate for the sample trees in the same stands, but much more inaccurate for the S_T stand with sample trees run together.

The equation which is least inaccurate is the equation chosen by the orthogonal polynomial of the equation ⑦ when the sample trees are run altogether. They ranged, for example, from 5 to 28% for *C. japonica*. Equations ④, ⑤ and ⑥ showed the next smallest errors. According to the equation ④, the coefficients of variation of each part ranged from 15 to 45%, and that of the total weight got up to 24%.

Table 41. Investigated stands, calculated in a lot, and number of tree

Number of stand	Species							
	C. japonica		*Ch. obtusa*		*P. densiflora*		*L. leptolepis*	
	Stand No.	Trees	Stand No.	Trees	Stand No.	Trees	Stand No.	Trees
1	1	5	1	5	1	8	1	9
2	2	5	2	5	2	23	3	5
3	3	5	3	6	3	5	11	3
4	4	5	4	5	4	5	13	3
5	5	5	5	5	7	5	15	3
6	11	8	7	5	8	2	18	3
7	12	8	8	5	9	5	19	3
8	13	15	—	—	11	10	20	3
9	15	5	—	—	—	—	21	3
10	17	8	—	—	—	—	22	3
11	29	10	—	—	—	—	23	4
12	—	—	—	—	—	—	27	3
13	—	—	—	—	—	—	28	3
14	—	—	—	—	—	—	24	3
Total	11	79	7	36	8	63	14	51

This relation was also recognized in *Ch. obtusa* (HT), *P. densiflora* (AT), and *L. leptolepis* (KT).

From these results, it is clear that the variances become generally larger when the sample trees are run altogether. Application to a polynomial equation is desirable in such cases. Even in this case, however, the partial biomass can be more accurately estimated by the linear regression, the independent variable of which is basal area.

These relations almost correspond to those of estimation of the sample trees in the same stand.

Many measurements of stands are still needed for deciding which equations to use for the partial biomass; hence much has been left that will have to be taken up in future studies.

Table 42. Estimating regression equations for part biomass of a tree and their accuracy in the sample trees of the typical stands, See Table 34

C. japonica stands, n : 79
Equation ④ : $y = a + b\,(\pi D^2/4)$

y	a	b	r	S_{yx}
1	−33,157	407.5583	0.98	23,995
2	−3,884	36.1043	0.96	3,162
3	−1,420	50.8742	0.97	4,248
4	−38,462	494.5369	0.98	28,945
5	274	1.0782	0.93	141
6	441	1.3582	0.91	198
7	868	3.3356	0.92	473
8	125	7.9440	0.98	406
9	−5,776	37.1923	0.98	2,861
10	−7,309	86.1185	0.98	5,273
11	−10,209	135.3535	0.98	7,763
12	−48,670	629.8903	0.98	36,453
13	1,317	13.4439	0.93	1,762
14	−323	12.7672	0.94	1,561
15	275	4.1277	0.87	755
16	−37,041	443.6626	0.98	26,526
17	715	2.4364	0.93	324
18	−10,923	132.9171	0.98	7,879
19	−47,250	579.0161	0.98	33,978
20	1,884	34.6366	0.96	3,106
21	106	0.1859	0.89	32

C. japonica stands,
Equation ⑤ : $\log y = a + b \log (D^2H)$

y	a	b	r	S_{yx}
1	−1.3484	0.9473	0.99	13,513
2	−2.0937	0.8032	0.94	4,486
3	1.9517	0.5718	0.95	5,021
4	0.3275	0.8396	0.99	21,400
5	0.6900	0.4389	0.97	111
6	1.3439	0.4163	0.97	148
7	1.0232	0.4999	0.98	270
8	−1.2881	0.6893	0.98	557
9	−11.5069	1.4800	0.98	2,699
10	−2.7657	0.9360	0.99	3,616
11	−0.7104	0.8216	0.99	6,243
12	0.6320	0.8352	0.99	27,315
13	0.9772	0.5762	0.91	3,021
14	1.7429	0.4971	0.92	1,810
15	0.4496	0.5335	0.90	1,062
16	−1.0332	0.9290	0.99	16,660
17	1.7593	0.4252	0.97	238
18	−1.4798	0.8738	0.99	5,646
19	−0.3158	0.8966	0.99	21,917
20	2.5286	0.5223	0.92	5,747
21	2.0807	0.2344	0.94	25

C. japonica stands, n : 79,
Equation ⑦ : $y = a_0 + a_1D + a_2H + a_3D^2 + a_4DH + a_5H^2 + a_6D^3 + a_7D^2H + a_8DH^2 + a_9H^3$

y		S_{yx}
1	$-2,786 + 0.007211H^2 + 0.002433DH^2 - 0.000013H^3$	3,703
2	$419 + 0.008653D^2H$	1,149
3	$1,160 + 26.50084D^2$	2,176
4	$-813 + 0.010154H^2 + 0.124916D^2H$	4,734
5	$-140 + 20.35371D + 0.300918H - 0.000088D^2H$	29
6	$50 + 0.000721H^2 - 0.0000002H^3$	65
7	$-701 + 71.22093D + 1.010366H$	191
8	$56 + 48.39827D + 0.002449D^2H$	277
9	$1,783 - 3.410608H + 0.000170DH^2$	740
10	$3 + 0.026707D^2H$	968
11	$1,146 - 1.094685D^3 + 0.056828D^2H$	1,725
12	$-578 + 0.011752H^2 + 0.163608D^2H$	6,121
13	$360 + 13.59972D^2$	1,228
14	$830 + 15.71455D^2 - 0.124782DH$	609
15	$269 + 3.896653D^2$	403
16	$-4,498 + 0.010641H^2 + 0.112255D^2H$	4,176
17	$37 + 18.77669D + 0.000963H^2 - 0.0000003H^3$	81
18	$377 - 0.960623D^3 + 0.054030D^2H$	1,690
19	$-4,263 + 0.012239H^2 + 0.150948D^2H$	5,402
20	$1,668 + 27.75559D^2$	2,697
21	$-40 + 2.656472D + 0.178699H - 0.000044H^2$	11

Ch. obtusa stands, n : 36,
Equation ④ : $y = a + b\,(\pi D^2/4)$

y	a	b	r	S_{yx}
1	−19,282	410.8639	0.98	10,518
2	−730	48.0616	0.98	1,267
3	1,586	30.1924	0.96	1,228
4	−18,426	489.1180	0.98	11,362
5	289	2.2979	0.92	141
6	564	5.9858	0.87	508
7	704	5.7941	0.96	240
8	−178	14.5957	0.99	259
9	−4,714	55.6824	0.97	1,874
10	−2,564	64.5887	0.98	1,529
11	−5,508	147.7548	0.98	3,443
12	−23,934	636.8728	0.98	14,685
13	395	14.2372	0.96	625
14	726	5.9541	0.91	404
15	205	4.1491	0.93	242
16	−20,012	458.9256	0.98	10,839
17	853	8.2837	0.89	623
18	−6,361	139.4711	0.98	3,285
19	−25,520	606.6804	0.98	14,141
20	1,706	28.9966	0.95	1,425
21	83	0.1251	0.76	16

Table 42. (Continued)

Ch. obtusa stands, n : 36,
Equation ⑤ : $\log y = a + b \log (D^2H)$

y	a	b	r	S_{yx}
1	−1.0564	0.9454	0.99	5,241
2	1.4211	0.6001	0.90	3,515
3	3.7903	0.4067	0.87	2,378
4	1.1358	0.7937	0.98	12,198
5	1.9413	0.3722	0.92	147
6	1.0846	0.5060	0.91	517
7	2.1716	0.4271	0.97	231
8	−0.8692	0.6910	0.98	424
9	−7.4537	1.2516	0.97	2,738
10	−1.0306	0.8034	0.98	1,888
11	0.2135	0.7724	0.98	4,156
12	1.4667	0.7886	0.98	15,892
13	1.8850	0.4876	0.86	1,260
14	4.0927	0.2725	0.65	864
15	1.5575	0.4229	0.79	484
16	−0.0022	0.8739	0.99	8,257
17	2.0583	0.4579	0.92	614
18	−0.6111	0.8266	0.98	3,920
19	0.6569	0.8452	0.99	11,947
20	4.0706	0.3818	0.78	3,220
21	2.3726	0.1864	0.90	12

Ch. obtusa stands, n : 36,
Equation ⑦ : $y = a_0 + a_1D + a_2H + a_3D^2 + a_4DH + a_5H^2 + a_6D^3 + a_7D^2H + a_8DH^2 + a_9H^3$

y		S_{yx}
1	$1,477 - 0.724141DH + 0.238735D^2H$	564
2	$1,410 + 2.434044D^3$	456
3	$1,212 + 59.668630D^2 - 0.036002D^2H$	349
4	$50,033 - 15,179.03D + 1,622.169D^2 - 44.37958D^3 + 0.077509D^2H$	325
5	$183 + 0.351556H$	17
6	$-1,274 + 6.087116H - 0.397190DH + 0.000557DH^2 - 0.000006H^3$	21
7	$292 + 1.783950D^2 + 0.085913DH$	35
8	$-90 + 11.15868D^2$	55
9	$-400 + 11.21464D^2$	88
10	$34 + 15.37086D^2 + 0.021338D^2H$	117
11	$-1,337 + 508.9747D + 0.048739D^2H$	271
12	$5,957 - 12.75398D^3 + 0.686018D^2H - 0.000035H^3$	707
13	$698 + 1.151490D^3$	449
14	$1,006 + 9.921627D^2 - 0.000001H^3$	130
15	$302 + 0.378093D^3$	179
16	$1,716 + 0.268357D^2H - 0.000010H^3$	336
17	$173 + 1.050588H - 0.047590DH$	52
18	$-414 + 55.05780D^2 - 0.000170DH^2$	260
19	$3,427 + 348,823D^2H - 0.000011H^3$	486
20	$2,834 + 2.269659D^3$	913
21	$58 + 0.181419D^2$	2

P. densiflora stands, n : 63,
Equation ④ : $y = a + b\,(\pi D^2/4)$

y	a	q	r	S_{yx}
1	−6,564	367.9310	0.97	10,460
2	−225	50.5105	0.93	2,640
3	267	19.0441	0.95	810
4	−6,522	437.4857	0.97	12,327
5	24	0.1721	0.79	18
6	121	2.3089	0.96	87
7	116	8.9460	0.95	392
8	−70	12.4435	0.97	367
9	−3,575	36.6932	0.93	2,193
10	−402	54.8712	0.98	1,289
11	−1,770	109.1770	0.97	3,101
12	−8,293	546.6626	0.97	15,365
13	908	12.3797	0.88	888
14	220	9.3680	0.94	447
15	628	3.0300	0.63	495
16	−6,790	418.4415	0.97	11,929
17	145	2.4811	0.96	90
18	−1,915	106.6959	0.97	3,121
19	−8,560	527.6185	0.97	14,969
20	2,070	28.3450	0.90	1,781
21	118	0.4794	0.93	24

P. densiflora stands, n : 63,
Equation ⑤ : $\log y = a + b \log (D^2H)$

y	a	b	r	S_{yx}
1	−0.5455	0.9098	0.99	10,066
2	−0.4264	0.7479	0.90	4,959
3	0.1738	0.6363	0.88	1,971
4	0.3685	0.8531	0.98	13,828
5	0.8920	0.2393	0.52	52
6	0.6894	0.4471	0.93	135
7	−0.2758	0.6115	0.92	661
8	−4.5603	0.9782	0.96	627
9	−12.1500	1.5659	0.94	2,883
10	−1.8544	0.8755	0.98	2,074
11	−0.6792	0.8226	0.98	4,054
12	0.6673	0.8463	0.98	18,024
13	0.9774	0.5763	0.93	2,528
14	−0.1072	0.6088	0.88	467
15	1.6544	0.4469	0.82	902
16	0.0342	0.8751	0.98	13,111
17	1.1802	0.4149	0.91	175
18	−1.2815	0.8681	0.98	4,184
19	0.4142	0.8627	0.98	16,586
20	2.1947	0.5437	0.92	2,370
21	2.8245	0.2033	0.84	42

Table 42. (Continued)

P. densiflora stands, n : 63,
Equation ⑦ : $y = a_0 + a_1D + a_2H + a_3D^2 + a_4DH + a_5H^2 + a_6D^3 + a_7D^2H + a_8DG^2 + a_9H^3$

y		S_{yx}
1	$-5,908 + 0.002939DH^2$	1,877
2	$-4,401 + 0.001018DH^2$	1,246
3	$-1,677 + 0.000420DH^2$	525
4	$-11,986 + 0.004377DH^2$	3,168
5	$22 - 0.264582D^2 + 0.027308D^3$	2
6	$154 + 0.001379D^2H$	22
7	$-232 + 0.000118DH^2$	81
8	$-162 - 13.31422D^2 + 0.027759D^2H$	79
9	$229 - 25.801160D^2 + 1.354380D^3 + 0.012585D^2H$	105
10	$209 - 44.90808D^2 + 0.083258D^2H$	389
11	$238 - 90.65707D^2 + 0.157998D^2H$	593
12	$-14,731 + 0.005406DH^2$	3,920
13	$-813 + 0.000390DH^2$	339
14	$-1,006 + 0.000252DH^2$	315
15	$-488 + 0.000234DH^2$	203
16	$-10,309 + 0.003957DH^2$	2,750
17	$168 + 0.001495D^2H$	24
18	$61 - 89.495731D^2 + 0.155352D^2H$	573
19	$-13,055 + 0.004985DH^2$	3,504
20	$-2,680 + 0.001013DH^2$	924
21	$94 + 0.006153DH$	14

L. leptolepis stands, n : 51,
Equation ⑤ : $\log y = a + b \log (D^2H)$

y	a	b	r	S_{yx}
1	−0.2988	0.8822	0.89	57,779
2	−4.8389	1.0493	0.82	13,019
3	−2.6676	0.7733	0.74	2,191
4	−0.3848	0.8989	0.93	47,103
5	0.7385	0.3797	0.86	70
6	3.2403	0.2626	0.71	210
7	1.1847	0.5019	0.88	731
8	0.0029	0.6285	0.89	1,522
9	−6.5184	1.1558	0.96	3,264
10	−1.1486	0.7948	0.95	3,936
11	−0.3421	0.7962	0.96	6,994
12	0.1149	0.8794	0.95	45,050
13	−6.4281	1.0656	0.86	2,711
14	−2.6676	0.7733	0.74	2,191
15	−7.6321	1.0656	0.86	813
16	−0.4561	0.9025	0.93	47,756
17	3.1269	0.2961	0.79	256
18	−0.7347	0.8221	0.96	7,140
19	0.0579	0.8824	0.95	44,369
20	−3.9471	0.9511	0.86	5,192
21	0.7074	0.3310	0.78	42

L. leptolepis stands, n : 51,
Equation ④ : $y = a + b\,(\pi D^2/4)$

y	a	b	r	S_{yx}
1	−42,416	494.9767	0.95	29,752
2	−10,758	74.9090	0.87	8,070
3	−313	9.0036	0.87	985
4	−53,486	578.8892	0.96	31,833
5	168	0.5443	0.86	61
6	558	0.9701	0.71	186
7	1,243	4.9526	0.87	539
8	485	13.6093	0.91	1,139
9	−6,646	51.2517	0.96	2,864
10	−4,339	58.9886	0.97	2,817
11	−8,529	130.3166	0.97	5,526
12	−62,016	709.2058	0.96	35,870
13	−2,131	17.3287	0.81	2,399
14	−313	9.0036	0.87	995
15	−639	5.1986	0.81	720
16	−53,174	569.8856	0.96	31,477
17	727	1.5144	0.79	224
18	−9,256	128.8022	0.97	5,559
19	−61,703	700.2022	0.96	35,455
20	−3,554	36.2150	0.87	3,888
21	110	0.2010	0.74	35

L. leptolepis stands, n : 51,
Equation ⑦ : $y = a_0 + a_1D + a_2H + a_3D^2 + a_4DH + a_5H^2 + a_6D^3 + a_7D^2H + a_8DG^2 + a_9H^3$

y		S_{yx}
1	$21,233 + 10.72649D^3$	9,507
2	$-11,988 + 15.70471H + 8.183507D^3 - 0.101338D^2H$	4,473
3	$2,400 + 0.335226D^3 - 0.000001H^3$	801
4	$19,924 + 12.69070D^3$	12,078
5	$492 + 0.008131DH$	47
6	$316 + 0.000011DH^2$	116
7	$-3,209 + 436.6589D - 0.003300D^2H$	359
8	$2,028 + 0.460620D^3 - 0.000001H^3$	711
9	$796 + 0.976770D^3$	1,254
10	$1,082 + 0.404035DH + 0.914715D^3 - 0.000002H^3$	1,216
11	$-22,015 + 31.56659H + 3.123020D^3 - 0.000005H^3$	3,195
12	$27,984 + 15.50351D^3$	14,813
13	$1,181 + 0.946350D^3 - 0.008883D^2H$	696
14	$2,400 + 0.335226D^3 - 0.000001H^3$	801
15	$345 + 0.283904D^3 - 0.002665D^2H$	209
16	$18,889 + 12.51122D^3$	11,604
17	$430 + 0.000014DH^2$	147
18	$-22,814 + 31.95270H + 3.097191D^2 - 0.00001H^3$	2,732
19	$26,949 + 15.32402D^3$	14,293
20	$4,362 + 1.410014D^3 - 0.000154DH^2$	1,708
21	$263 - 0.098577H + 0.010282D^3$	33

Table 43. Accuracy of each regression

Species	ST n : 79*1 *C. japonica*							HT n : 36 *Ch. obtusa*					
Equation No. / y	①	②	③	④	⑤	⑥	⑦	①	②	③	④	⑤	⑥
1	99*2	102	104	25	14	7	5	52	52	57	17	9	28
2	120	124	127	42	59	30	24	37	42	49	15	41	31
3	80	86	88	29	34	27	24	30	33	37	17	32	24
4	97	101	103	24	18	9	6	47	48	53	15	16	27
5	31	31	32	23	18	26	5	24	24	25	19	20	26
6	25	25	25	23	17	26	8	31	31	31	29	30	35
7	25	26	27	24	14	30	11	13	14	19	13	13	23
8	60	62	65	15	21	18	13	36	37	43	10	16	22
9	133	137	140	41	39	26	17	73	75	81	28	42	35
10	101	105	108	26	18	16	7	48	51	57	17	19	29
11	96	99	102	24	18	12	8	48	49	54	15	18	26
12	97	100	103	24	18	9	6	47	48	54	15	16	27
13	49	53	55	32	54	35	28	29	35	42	20	40	30
14	65	71	74	28	43	30	24	25	33	37	22	46	26
15	44	49	51	34	57	39	28	27	36	42	24	48	32
16	100	103	106	25	16	8	6	50	50	56	16	12	28
17	27	27	27	22	16	25	6	28	28	28	25	25	31
18	99	103	106	25	18	13	8	51	52	58	16	19	27
19	99	102	105	25	16	9	6	49	50	55	15	13	27
20	49	54	57	25	42	29	27	26	34	40	19	44	28
21	21	21	22	19	15	21	7	9	12	10	15	11	16

*1 n : Number of samples.
*2 Variation coefficient of regression : $(S_{yx}/\bar{y})$, %

森林生産の場における根系の機構と機能 I

根系調査と根量推定の方法

苅　住　昇[1]

和文摘要

主表題である「森林生産の場における根系の機構と機能」のもとに森林の地上部，地下部の各部分の現存量と生産量，およびこれをとりまく各種の環境条件との関係が研究の対象としてとりあげられ，また林業技術との関係が検討された。とくに，未知の問題が多い地下部について，根系の機構と機能の解析に重点をおき，根量・根長・根系表面積・根系体積・根密度などの根系の諸因子を通じて，量的に根系の働きを明らかにしようと考えた。この研究の一環として，まず根量調査法，根量および生産量の推定法が研究された。この論文では，とくにこの問題をとりあげた。

養・水分の樹体内への吸収は根系表面積に関係しており，根系表面積は林木の吸収構造を示すものと考えられる。また，根長は根系の広がりや分布を考察するための重要な因子である。これらの諸因子を明らかにするために，根系を太さによって細根，小径根，中径根，大径根，特大根，根株に7区分し，各区分の根量，平均直径，容積密度数などを測定した。根系表面積や根長はこの3因子によって計算された。

1973年8月14日受理

(1) 造林部

on the all sample trees

	At n : 63 *P. densiflora*							Kt n : 51 *L. leptolepis*						
⑦	①	②	③	④	⑤	⑥	⑦	①	②	③	④	⑤	⑥	⑦
5	—	65	64	22	21	—	—	39	39	40	22	42	17	9
12	—	69	71	39	74	—	—	59	68	74	49	79	52	39
8	—	51	53	27	66	—	—	40	44	48	34	74	35	33
2	—	63	63	21	24	—	—	39	39	42	20	30	17	10
4	—	37	38	29	82	—	—	18	17	18	17	19	18	15
3	—	35	35	19	29	—	—	20	20	21	20	23	21	13
4	—	51	50	27	38	—	—	17	16	17	18	24	19	12
6	—	57	57	22	37	—	—	24	26	30	21	28	25	16
13	—	109	109	70	92	—	—	47	47	50	24	27	20	15
4	—	54	54	17	27	—	—	35	36	39	16	23	16	9
4	—	64	64	21	28	—	—	32	33	36	14	18	14	11
3	—	63	63	21	25	—	—	37	38	40	18	23	15	10
24	—	14	15	14	41	—	—	70	70	70	58	65	54	25
8	—	105	109	62	65	—	—	40	44	48	34	74	34	33
26	—	27	27	32	63	—	—	70	70	70	58	65	54	3
2	—	64	64	22	24	—	—	39	39	42	20	31	17	10
5	—	64	34	17	33	—	—	18	18	19	18	20	19	12
5	—	35	65	22	29	—	—	33	34	37	15	19	15	10
2	—	64	64	22	24	—	—	38	38	40	18	23	15	10
18	—	32	34	30	40	—	—	54	54	55	40	54	38	25
3	—	18	18	13	22	—	—	18	18	18	19	23	20	18

根量調査法には全量掘り上げ法，土壌ブロックサンプリング法があるが，この調査では土壌層位，根株からの距離，傾斜の上下，左右など，水平的・垂直的に根量がわかるように設計された土壌ブロックサンプリング法を用いた。土壌ブロックの面積は胸高断面積で重味づけをしたものを用いると，調査木の根量にほぼ近くなることがわかった。この方法によると，林分の根量は理論的な矛盾なく推定することができる。土壌の表層部では，また細い根系ほど根量の分散が小さく，一定精度で推定するには小数のブロックをサンプリングすればよいが，根量全体をサンプリングの対象とした場合，危険率10%，総量の10%の誤差で林分の根量を推定するには5～10本の調査木を選べば十分であることがわかった。ブロックの全量を掘り上げることは多大の労力を要するので，その半分をサンプリングすると労力は全量サンプリングの60%程度になる。この場合，傾斜の下部の根量は上部より20%程度多いので，傾斜に沿って分割する方法がよい。傾斜の左右では根量の差はなかった。

根系区分において小根の区分には時間がかかるが，比推定法を用いると容易に根量を誤差内で推定することができる。細根と小径根を精度10%で推定するためには，資料はスギでは110gでよかった。この量は小径根と中径根，分散が異なる樹種ごとに確かめられた。

つぎに胸高直径，樹高などの変数として根量を求める数式の利用が検討された。比較的精度が高くて，計算しやすいのは胸高断面積を変数とする一次式であることがわかった。単に一定精度で推定するためには直径と樹高を用いた直交多項式の利用が考えられた。

Appendix　　Table 1. Table of

Species	Stand No.	Local No.		Stand age Years	Investigated			
					Area m²	Trees	Tree height m	H. B*1 m
C. japonica	S. 1	Onokoyama	A	9	178	51	6.8	1.8
	2		B	23	270	51	13.3	8.1
	3		C	21	263	73	9.6	5.3
	4		D	34	264	36	16.2	10.0
	5		E	45	378	36	19.3	13.5
	6		F	28	200	50	8.3	4.8
	7		G	34	270	65	11.5	8.1
	8		H	29	203	55	15.4	11.0
	9		I	45	462	40	15.7	8.5
	10		J	48	400	79	12.8	8.0
	11	Oneyama	A	8	327	95	3.7	1.0
	12		B	21	244	45	13.4	7.4
	13		C	17	456	95	11.5	6.1
	14		D	20	351	74	8.9	4.3
	15		E	29	477	58	15.5	9.6
	16		F	38	286	42	18.0	10.9
	17		G	49	630	40	21.7	8.9
	18	Akita	A	32	549	45	18.6	11.5
	19		B	32	416	47	16.4	10.6
	20		C	32	382	51	12.3	7.3
	21	Yasato	A	45	187	44	10.6	7.2
	22	Chiba	A	41	314	69	20.6	17.8
	23		B	41	141	49	14.5	11.4
	24		C	41	127	55	10.2	8.3
	25	Obi	A	21	509	47	10.1	2.4
	26		B	25	727	61	12.8	3.5
	27		C	31	698	47	14.9	6.6
	28	Oneyama	V	24	286	50	12.8	7.5
	29	Obi	D	17	324	50	7.1	—
	30		E	40	131	60	18.2	—
	31	Oneyama	H	33	609	79	18.9	—
	32		I	62	981	60	26.5	—
	33		J	62	875	95	19.2	—
	34		K	29	513	73	12.7	—
	35		L	29	634	87	17.0	—
	36		M	28	418	63	10.4	—
	37		N	22	423	68	12.5	—
	38		O	22	142	25	14.0	—
	39		P	40	546	67	21.0	—
	40		Q	40	570	99	16.0	—
	41		R	22	412	80	13.5	—
	42		S	22	508	121	12.0	—
	43		T	17	204	46	10.0	—
	44		U	17	108	28	9.0	—
	45	Yoshino	A	10	37	45	5.3	2.0

*1 H. B : Height to the first main branch.

*2 Site index : Estimated height of 45 year old tree.
Following yield tables were used for estimating site indexes.

C. japonica : Yield table of North Kanto and Abukuma district.
Ch. obtusa : Yield table of Kiso district.
P. densiflora : Yield table of Iwaki district.
L. leptolepis : Yield table of Shinshu district.

all the investigated stands

sample stand			per ha			Site index*2	Tree density index*3	Soil type
D. B. H cm	Basal area cm²	Volume m³	Trees	Total basal area m²	Volume m³			
8.8	61	0.024	2,857	17.4	68.6	29.3	0.313	BlE
17.8	249	0.168	1,887	47.0	317.0	21.7	0.652	BlD
11.7	109	0.055	2,770	30.2	152.4	17.0	0.482	BlD(d)
20.7	335	0.270	1,360	45.6	367.2	19.4	0.600	BlD
23.6	439	0.410	950	41.7	389.5	19.3	0.519	BlD(w)
11.5	105	0.050	2,500	26.3	125.0	11.3	0.423	BlA
14.2	160	0.105	2,407	38.5	252.7	13.6	0.575	BlC
17.4	238	0.204	2,700	64.3	550.8	20.7	0.898	BlD(w)
20.7	337	0.275	864	29.1	237.6	15.7	0.381	BlD(d)
16.2	208	0.149	1,975	41.1	294.3	12.5	0.585	BlD(d)
4.9	19	0.005	2,897	5.5	14.5	23.0	0.122	BlD
18.4	267	0.183	1,844	49.2	337.5	23.4	0.672	BlD(w)
15.8	196	0.114	2,083	40.8	237.5	24.5	0.592	BlD
12.0	115	0.055	2,107	24.2	115.9	16.2	0.382	BlD(d)
24.0	451	0.368	1,214	54.8	446.8	20.8	0.682	BlD
22.7	406	0.374	1,465	59.5	547.9	22.0	0.752	BlD
36.4	1,042	1.131	634	66.1	717.1	20.6	0.703	BlD
26.6	554	0.510	819	45.4	417.7	23.4	0.545	BE
21.0	345	0.287	1,128	38.9	323.7	20.6	0.510	BD
18.3	265	0.172	1,333	35.3	229.3	15.4	0.482	BA
11.8	110	0.066	2,350	25.9	155.1	10.6	0.415	BlD
23.1	419	0.404	2,193	91.9	886.0	21.8	1.158	BE
13.9	152	0.123	3,460	52.6	425.6	15.0	0.798	BD
11.2	99	0.058	4,298	42.6	249.3	11.0	0.697	BA
20.4	328	0.170	923	30.3	156.9	17.5	0.398	BlD(w)
23.3	425	0.278	838	35.6	233.0	19.4	0.449	BlD(w)
27.6	599	0.450	673	40.3	302.9	18.9	0.475	BlD
17.1	229	0.162	1,750	40.1	283.5	20.2	0.566	BlD
12.2	117	0.045	1,541	18.0	69.8	15.7	0.287	BlD
36.0	1,018	0.826	458	46.6	378.3	19.8	0.498	BlD
24.4	468	0.438	1,297	60.7	567.0	23.4	0.701	BlD(w)
38.0	1,134	1.410	611	69.3	862.0	22.5	0.664	BlD(w)
26.8	564	0.729	1,083	61.1	792.0	16.6	0.677	BlD(d)
16.2	206	0.153	1,423	29.3	219.0	17.1	0.407	BlD(d)
15.8	196	0.139	1,372	26.9	191.3	22.9	0.395	BlD(w)
15.2	181	0.106	1,507	27.3	161.2	14.4	0.386	BlD(d)
17.3	235	0.162	1,608	37.8	259.8	21.0	0.510	BlD
18.0	254	0.196	1,761	44.7	342.9	23.3	0.607	BlD(w)
26.0	531	0.527	1,227	65.2	645.8	22.8	0.722	BlD
19.0	284	0.263	1,737	49.3	456.7	17.5	0.643	BlD
18.6	272	0.203	1,942	52.8	392.0	23.0	0.681	BlD(w)
13.0	133	0.094	2,382	31.7	223.7	20.2	0.486	BlD
11.0	95	0.052	2,255	21.4	117.7	21.9	0.358	BlD
12.0	113	0.061	2,593	29.3	157.6	19.7	0.463	BlD
5.0	20	0.290	12,019	24.0	78.7	23.8	0.532	BB

*3 Density index : Ratio of standing trees to full density calculated by following equations by REINEKE's method.

C. japonica stand : $\log N_m = -1.6307 \log D + 5.5010$

Ch. obtusa stand : $\log N_m = -1.3563 \log D + 5.1365$

P. densiflora stand : $\log N_m = -1.6383 \log D + 5.3330$

L. leptolepis stand : $\log N_m = -1.7273 \log D + 5.3773$

N_m : Trees per ha in full density

D : D. B. H, cm

Appendix-Table 1. (continued)

Species	Stand No.	Local No.	Stand age Years	Investigated			
				Area m^2	Trees	Tree height m	H. B m
C. japonica	S. 46	Yoshino B	15	80	55	7.1	3.7
	47	C	19	102	46	10.5	6.6
	48	D	24	212	73	12.3	7.4
	49	E	31	156	40	14.5	8.1
	50	F	45	251	39	18.6	11.8
	51	G	51	348	46	21.3	13.7
	52	H	60	714	70	21.9	10.5
Ch. obtusa	H. 1	Gero A	10	142	44	4.6	2.3
	2	B	18	232	48	7.7	5.8
	3	C	28	104	16	12.8	10.0
	4	D	38	522	51	13.0	10.3
	5	E	48	901	74	16.9	12.1
	6	F	28	293	51	7.4	3.6
	7	Oneyama W	31	265	46	13.5	7.0
	8	Yasato B	38	205	43	13.0	7.5
P. densiflora	A. 1	Takahagi A	11	42	42	5.4	3.5
	2	B	19	400	200	9.3	6.5
	3	C	36	230	40	12.3	7.5
	4	D	38	400	42	16.3	13.1
	5	Okayama A	16	119	89	4.7	3.0
	6	B	16	25	56	1.9	1.0
	7	Meguro A	5	60	15	5.1	1.4
	8	Komoro A	35	370	37	14.0	8.7
	9	Yasato C	35	392	49	12.6	8.6
	10	Masiko A	18	73	155	5.8	3.1
	11	B	18	75	69	6.1	2.5
	12	C	18	53	24	6.0	1.9
P. thunbergii	13	Meguro B	5	60	15	5.6	1.4
P. strobus	14	C	42	108	12	10.2	8.1
P. thunbergii	15	Izu A	3	112	45	1.1	0.2
P. taeda	16	B	3	112	45	1.9	0.4
	17						
	18	C D	3	112	45	2.0	0.6
L. leptolepis	K. 1	Tanzeyama A	51	900	74	17.6	9.2
	2	B	51	1,000	107	11.8	6.7
	3	C	31	414	70	11.7	8.1
	4	D	31	759	97	6.4	4.6
	5	Nobeyama A	47	223	47	9.1	5.5
	6	A′	48	450	55	7.0	2.3
	7	B	45	402	58	11.0	6.4
	8	C′	48	932	71	10.1	2.9
	9	D	47	438	59	12.6	7.1
	10	D′	47	311	45	11.7	7.4
	11	E	47	603	57	17.0	10.4
	12	E′	47	746	42	14.7	8.4
	13	F	48	612	53	19.2	13.3
	14	Komoro A	33	482	41	17.8	11.4
	15	Ueda A	44	377	35	17.2	11.4
	16	B	44	449	49	12.7	7.3
	17	C	45	230	36	14.7	10.3
	18	D	45	611	61	18.4	13.2

sample stand			per ha			Site index	Tree density index	Soil type
D. B. H cm	Basal area cm²	Volume m³	Trees	Total basal area m²	Volume m³			
7.1	40	0.970	6,865	27.5	121.3	17.8	0.534	B_D
10.1	80	2.340	4,503	36.0	229.0	20.2	0.603	B_B
12.5	123	6.560	3,438	42.3	309.0	19.4	0.665	B_D
16.1	204	6.250	2,557	52.2	400.0	18.3	0.727	B_C
21.8	373	14.540	1,557	58.1	580.4	18.6	0.716	B_E
23.7	441	22.050	1,321	58.3	633.3	20.0	0.708	B_E
28.3	629	48.460	980	61.6	678.3	19.0	0.671	B_D(w)
7.3	42	0.011	3,086	13.0	33.9	18.2	0.334	B_D(d)
11.5	104	0.042	2,066	21.5	86.8	17.6	0.414	B_D
18.0	254	0.177	1,538	39.1	272.2	18.8	0.566	B_D
18.7	274	0.187	977	26.8	182.7	15.0	0.379	B_D(w)
23.3	427	0.368	821	35.1	302.1	16.0	0.429	B_D
10.8	91	0.036	1,736	15.8	62.5	11.4	0.320	B_B
14.4	162	0.114	1,736	28.1	197.9	18.6	0.472	Bl_D
12.6	126	0.091	2,100	26.5	191.1	14.9	0.477	Bl_D
5.5	24	0.007	10,000	24.0	70.0	19.2	0.758	Bl_D(d)
9.0	63	0.038	5,000	31.5	190.0	16.6	0.850	Bl_D(d)
15.9	198	0.128	1,737	34.4	222.3	13.8	0.750	Bl_D(d)
19.9	311	0.267	1,050	32.7	280.4	17.4	0.655	Bl_D(d)
5.3	22	0.008	7,417	16.3	59.3	11.4	0.529	Er–B_A
4.6	17	0.001	22,400	38.1	22.4	6.6	1.268	Er–B
4.8	18	0.006	2,500	45.0	15.0	24.0	0.152	Bl_D
21.4	361	0.250	1,000	36.1	250.0	15.8	0.703	Bl_D
17.1	228	0.144	1,250	28.5	180.0	14.2	0.608	Bl_D
4.7	18	0.005	21,200	38.2	106.0	11.6	1.243	B_A
6.4	32	0.010	9,100	29.1	91.0	12.0	0.884	B_A
7.9	49	0.012	4,500	22.1	54.0	11.8	0.618	B_A
5.4	23	0.008	2,500	57.5	20.0	24.4	0.184	Bl_D
14.0	154	0.088	1,111	17.1	97.8	10.4	0.389	Bl_D
1.0	1	—	4,000	0.4	—	—	0.019	B_B
2.0	3	—	4,000	1.2	—	—	0.058	B_B
2.3	4	—	4,000	1.6	—	—	0.073	B_D(w)
20.9	343	0.321	822	28.2	263.9	16.6	0.647	Bl_{D-E}
16.2	206	0.136	1,070	22.0	145.5	11.0	0.534	Bl_{D-E}
15.3	183	0.115	933	17.1	107.3	14.8	0.426	Bl_E
10.4	86	0.032	1,520	13.1	48.6	8.2	0.408	Bl_F
10.7	90	0.044	2,100	18.9	92.4	9.0	0.511	Bl_{E-F}
10.7	92	0.040	1,221	11.2	48.8	6.8	0.307	Bl_{E-F}
12.8	128	0.073	1,440	18.4	105.1	11.0	0.467	Bl_G
14.6	169	0.101	761	12.9	76.9	9.8	0.314	Bl_D
14.1	155	0.106	1,347	20.9	142.8	12.4	0.533	Bl_D
14.4	163	0.108	1,445	23.6	156.1	11.5	0.585	Bl_D
19.9	310	0.271	945	29.3	256.1	16.8	0.682	Bl_D
19.5	297	0.248	563	16.7	139.6	14.5	0.389	Bl_D
21.6	367	0.353	865	31.7	305.3	18.9	0.715	Bl_D
23.2	422	0.369	850	35.9	313.7	21.0	0.814	Bl_D
20.6	332	0.285	927	30.8	264.2	17.4	0.749	Bl_D
18.6	271	0.175	1,089	29.5	190.6	12.7	0.699	Bl_D(d)
17.4	238	0.164	1,563	37.2	256.3	14.7	0.807	Bl_D(d)
21.0	346	0.294	997	34.5	293.1	18.4	0.811	Bl_D

Appendix-Table 1. (continued)

Species	Stand No.	Local No.	Stand age Years	Investigated Area m²	Trees	Tree height m	H. B m
L. leptolepis	K. 19	E	45	556	43	20.7	13.7
	20	Ueda F	45	788	35	23.6	15.4
	21	G	43	499	33	22.6	11.8
	22	H	45	809	53	21.5	14.8
	23	I	52	188	52	10.1	6.8
	24	J	52	771	44	15.7	8.9
	25	K	52	315	44	13.5	8.9
	26	L	52	323	68	9.9	6.2
	27	M	50	579	32	16.1	9.9
	28	N	51	1,144	42	21.8	13.6
	29	O	53	347	40	11.2	5.8
Ch. pisifera	M 1	Yasato A	38	171	36	12.0	6.5
	2	Meguro C′	57	160	10	14.4	8.3
E. globulus	3	Okayama C	9	288	32	15.0	10.7
Z. serrata	4	Oneyama X	55	539	97	15.1	13.1
A. firma	5	Y	20	168	37	8.1	2.0
T. canadensis	6	Z	38	296	46	12.9	6.9
A. *	7	Okayama A′	13	—	8	7.4	3.8
Q. *	8	Nobeyama C′	34〜46	932	17	7.5	1.8
B. *	9	C′	19〜39	932	16	7.7	3.2
B. davurica	10	C′	32〜40	932	9	8.6	3.6

A. * : *A. decurrens* v. *dealbata*　　*Q.* * : *Q. mongolica* v. *grosseserrata*　　*B.* * : *B. platyphylla* v. *japonica*

Appendix Table 2. Average part biomass of

Species	Stand No.	No. of sample trees	D.B.H cm	Basal area cm²	Tree height cm	H. B cm	Average diameter of crown cm	Volume cm³	Above-ground part Stem	Branch	Leaf	Total
C. japonica	S. 1	5	9.0	66.11	684	182	182	23,262	7,174	868	4,522	12,564
	2	5	17.5	246.34	1,329	796	244	162,198	53,130	3,736	8,587	65,453
	3	5	10.0	81.82	892	533	185	41,372	14,744	965	3,196	18,905
	4	5	20.7	344.50	1,753	995	275	321,819	110,855	8,449	14,675	133,979
	5	5	24.4	476.61	2,066	1,309	313	489,680	172,030	12,082	14,973	199,085
	6	5	11.8	112.68	859	472	189	52,375	17,296	3,586	7,026	27,908
	7	5	15.3	188.19	1,254	812	222	126,898	39,595	4,080	7,193	50,868
	8	5	17.2	237.08	1,611	1,098	250	216,607	56,014	3,991	9,033	69,038
	9	5	19.9	314.92	1,472	840	276	241,650	73,958	6,866	16,445	97,269
	10	5	16.1	206.72	1,280	803	234	147,558	50,395	3,497	8,797	62,689
	11	8	5.2	24.71	399	97	1,676	7,015	2,237	608	2,159	5,004
	12	8	17.5	253.96	1,353	702	240	179,947	63,138	3,405	10,820	77,363
	13	15	14.5	173.82	1,167	590	206	105,329	32,547	1,935	9,001	43,483
	14	8	12.1	122.68	931	419	219	65,803	23,113	2,538	7,608	33,259
	15	5	27.7	613.48	1,828	1,050	345	514,345	170,326	14,106	24,806	209,238
	16	8	20.2	336.23	1,895	1,322	2,410	321,839	122,576	7,348	12,253	142,177
	17	8	36.9	1,099.97	2,276	957	428	1,191,908	438,168	39,008	57,134	534,310
	18	5	27.6	609.12	2,037	1,120	345	645,299	165,561	17,709	29,547	212,817

sample stand			per ha			Site index	Tree density index	Soil type
D. B. H cm	Basal area cm^2	Volume m^3	Trees	Total basal area m^2	Volume m^3			
23.7	442	0.437	773	34.2	337.8	20.7	0.751	Bl_D
27.6	599	0.708	444	26.6	314.4	23.6	0.567	Bl_E
25.4	506	0.568	661	33.4	375.4	22.8	0.730	Bl_D
24.2	459	0.485	655	30.1	317.7	21.5	0.660	Bl_D
13.4	141	0.076	2,762	38.9	209.9	9.5	1.025	Bl_D–m
22.8	410	0.326	570	23.4	185.8	14.8	0.538	Bl_{DE}(m)
18.6	273	0.188	1,395	38.1	262.3	12.4	0.895	Bl_D(d)
14.4	164	0.076	2,099	34.4	159.5	9.6	1.272	Bl_C
21.5	363	0.295	552	20.0	162.8	15.4	0.456	Bl_D
28.6	645	0.683	367	23.7	250.7	20.8	0.500	Bl_D
15.9	200	0.106	1,152	23.0	122.1	10.5	0.569	Bl_B
13.2	137	0.084	2,100	28.8	176.4	13.8	0.508	Bl_D
17.4	238	0.180	625	14.9	112.5	13.0	0.218	Bl_D
15.0	177	0.107	1,111	19.7	118.9	—	—	Im–B$_F$
15.5	188	0.184	1,800	33.8	331.2	—	—	Bl_D
14.1	156	0.067	2,200	34.3	147.4	—	—	Bl_D
16.4	211	0.125	1,554	32.8	194.3	—	—	Bl_D
13.1	135	0.054	749	10.1	40.4	—	—	Er–B$_A$
13.6	167	0.066	182	3.0	12.1	—	—	Bl_D
12.3	118	0.066	172	2.0	11.3	—	—	Bl_D
14.1	157	0.076	97	1.5	7.4	—	—	Bl_D

sample trees in stand　(Dry weight : g)

Underground part							Total biomass	T/R ratio	Maximum depth of root cm	Latest annual growth				
Fine root	Small root	Medium root	Large root	Very large root	Root stock	Total				Stem	Branch	Leaf	Root	Total
246	308	670	626	77	1,526	3,453	16,017	3.638	86	2,311	924	1,809	1,387	6,431
582	797	1,662	1,688	2,379	10,476	17,584	83,037	3.722	175	4,062	1,422	2,576	2,171	10,231
308	515	953	952	280	2,826	5,834	24,739	3.240	102	1,038	363	950	728	3,088
753	1,220	2,758	3,145	7,417	21,884	37,177	171,156	3.604	185	7,492	2,248	3,669	3,723	17,131
849	1,325	2,945	4,339	12,485	34,044	55,987	255,072	3.556	208	8,010	2,403	3,743	3,843	17,999
488	1,147	1,505	1,400	800	3,837	9,177	37,085	3.041	95	1,105	387	2,108	1,183	4,783
727	1,360	2,067	1,706	1,849	8,069	15,778	66,646	3.224	114	2,507	752	1,798	1,568	6,625
542	895	1,867	1,858	1,934	9,785	16,881	85,919	4.086	243	3,323	1,163	2,710	1,754	8,950
819	1,532	2,914	2,978	5,576	17,109	30,928	128,197	3.145	150	2,804	841	4,111	2,450	10,207
725	1,449	2,294	2,200	2,731	10,192	19,591	82,280	3.200	142	1,998	600	2,199	1,502	6,299
102	153	306	252	—	582	1,395	6,399	3.587	70	1,010	404	863	633	2,910
559	933	1,746	1,980	3,158	11,999	20,375	97,738	3.797	165	5,107	1,787	3,246	2,673	14,063
467	658	1,476	1,511	1,206	7,086	12,404	55,887	3.505	146	3,989	1,396	3,150	2,402	10,938
491	982	1,625	1,468	1,186	4,734	10,484	43,743	3.172	115	2,056	720	2,663	1,714	7,152
937	1,349	3,544	4,182	12,301	35,601	57,914	267,152	3.613	185	8,896	3,114	7,442	5,399	24,851
608	798	2,389	2,840	6,734	22,129	35,498	177,675	4.005	172	5,568	1,670	3,064	2,566	12,868
1,540	1,879	4,118	9,131	36,654	93,081	146,403	680,713	3.650	333	14,432	4,330	14,284	9,077	42,122
646	1,131	3,663	4,975	14,982	38,300	63,697	276,514	3.341	211	10,925	3,278	7,387	6,468	26,058

Appendix-Table 2. (continued)

Species	Stand No.	No. of sample trees	D.B.H cm	Basal area cm²	Tree height cm	H. B cm	Average diameter of crown cm	Volume cm³	Above-ground part			
									Stem	Branch	Leaf	Total
C. japonica	S. 19	5	20.1	320.44	1,684	1,070	268	272,963	80,583	6,359	13,554	100,496
	20	5	14.5	169.56	1,194	724	226	110,292	41,528	1,980	7,767	51,275
	21	5	11.6	106.16	1,060	736	196	65,047	22,744	1,558	7,076	31,378
	22	5	22.3	403.58	2,122	1,621	301	460,564	184,283	9,545	12,786	206,614
	23	5	13.7	154.21	1,460	1,120	207	141,532	60,240	2,778	6,051	69,069
	24	5	12.2	124.54	1,100	706	199	59,558	30,772	2,659	5,792	39,223
	25	5	19.5	303.45	1,048	214	395	147,804	49,298	10,989	18,894	79,181
	26	5	23.4	434.89	133	350	426	271,793	97,170	13,097	29,084	139,351
	27	5	25.2	504.58	1,462	664	396	342,733	119,740	14,513	19,358	153,611
	28	10	16.8	228.58	1,272	631	222	145,082	45,920	2,708	11,831	60,459
	29	10	17.0	233.44	1,288	637	224	148,499	46,727	2,647	11,689	61,063
Ch. obtusa	H. 1	5	7.3	41.86	460	224	179	14,616	5,168	2,507	3,542	11,217
	2	5	11.5	105.58	757	567	250	47,841	19,570	5,267	5,568	30,405
	3	6	16.2	212.91	1,265	979	346	137,417	60,141	8,992	6,989	76,122
	4	5	18.0	266.01	1,337	903	361	190,665	83,261	11,670	9,564	104,495
	5	5	24.2	466.16	1,853	1,393	385	402,340	185,684	22,673	16,525	224,882
	6	5	10.5	87.93	741	375	202	35,988	17,088	3,305	4,457	24,850
	7	5	13.7	151.10	1,263	719	310	99,064	38,853	5,759	5,376	49,988
	8	5	11.5	104.88	1,193	799	232	71,269	29,000	3,050	4,532	36,582
P. densiflora	A. 1	8	5.5	25.53	556	357	200	10,458	4,437	1,347	819	6,603
	2	23	8.5	60.41	926	676	204	36,520	15,465	2,883	1,362	19,710
	3	5	15.5	197.63	1,179	773	287	121,527	57,261	10,106	4,096	71,463
	4	5	20.6	350.36	1,707	1,294	420	325,892	144,222	17,450	6,914	168,586
	5	10	6.7	38.17	520	296	221	13,113	5,835	2,518	1,271	9,624
	6	10	1.7	2.75	172	108	58	1,083	453	595	390	1,438
	7	5	4.6	18.36	492	141	159	7,057	3,152	1,590	764	5,506
	8	2	24.0	462.01	1,505	857	447	323,007	138,048	15,951	7,508	161,507
	9	5	16.7	220.38	1,262	854	298	151,934	67,373	11,669	4,647	83,689
	10	9	5.2	24.55	559	270	—	8,097	3,768	870	651	5,289
	11	10	5.9	31.46	568	236	—	10,747	4,857	1,450	1,070	7,377
	12	10	5.7	27.11	540	217	—	9,625	4,296	918	721	5,935
P. thunbergii	13	5	4.6	17.20	472	136	182	5,062	2,088	1,755	1,544	5,387
P. strobus	14	3	16.4	212.43	1,158	812	561	132,078	58,306	5,234	1,878	65,418
P. thunbergii	15	5	1.2	1.12	104	15	70	406	196	275	395	866
P. taeda	16	5	2.2	3.83	200	43	97	1,039	474	175	374	1,023
	17	5	2.6	5.52	217	59	200	1,592	737	334	684	1,755
	18	5	2.5	5.03	197	60	108	1,547	697	347	384	1,428
	19	3	3.9	11.76	173	523	115	872	409	452	383	1,244
	20	2	3.9	14.78	276	57	81	3,588	1,640	823	869	3,332
L. leptolepis	K. 1	9	20.3	337.06	1,751	919	483	321,319	129,478	16,592	3,014	149,084
	2	9	14.7	178.13	1,263	667	450	125,978	55,754	7,939	1,928	65,621
	3	5	14.4	164.77	1,241	773	700	111,071	51,503	6,516	2,692	60,711
	4	5	10.3	88.12	752	418	347	39,990	19,487	3,711	433	23,631
	5	3	10.9	95.66	843	547	260	43,269	18,173	2,593	957	21,723
	6	3	11.0	96.05	743	230	263	37,401	15,017	4,560	1,313	20,890
	7	3	12.1	118.11	1,037	640	247	63,926	26,643	3,687	1,113	31,443
	8	2	17.1	230.79	1,205	285	390	131,229	58,945	8,990	1,605	69,540
	9	3	12.7	130.23	1,237	707	277	82,787	33,433	3,417	900	37,750
	10	3	14.6	168.11	1,227	737	267	96,289	38,803	3,177	1,360	43,340
	11	3	19.1	289.94	1,637	1,037	420	234,060	93,913	7,740	1,183	102,836

Underground part							Total biomass	T/R ratio	Maximum depth of root cm	Latest annual growth				
Fine root	Small root	Medium root	Large root	Very large root	Root stock	Total				Stem	Branch	Leaf	Root	Total
595	1,189	2,342	2,667	4,548	17,120	28,461	128,957	3.531	192	5,615	1,685	3,389	3,036	13,725
725	1,812	2,155	1,857	1,978	7,618	16,145	67,420	3.176	143	3,005	902	1,942	1,844	7,693
447	1,117	1,757	1,368	849	4,486	10,024	41,402	3.130	146	1,918	576	1,769	1,361	5,624
367	827	2,236	3,445	9,811	32,248	48,934	255,548	4.222	278	7,471	2,241	3,196	3,080	15,988
517	1,272	1,882	1,567	2,303	10,168	17,709	86,778	3.900	147	2,984	895	1,513	1,381	6,774
514	1,543	1,620	1,586	1,294	5,271	11,828	51,051	3.316	128	2,242	673	1,448	1,319	5,682
686	1,166	3,352	2,724	4,250	14,215	26,395	105,576	3.000	214	6,787	2,375	5,668	4,935	19,765
761	1,217	2,689	3,723	8,825	25,336	42,551	181,902	3.275	205	10,243	3,585	8,725	6,866	29,420
781	1,290	2,804	3,968	9,975	27,533	46,351	199,962	3.314	224	5,098	1,529	4,840	3,355	14,822
599	827	1,804	2,086	1,741	10,354	17,410	77,869	3.473	158	5,790	2,027	3,549	3,271	14,637
576	781	1,826	2,130	1,760	10,389	17,461	78,524	3.497	161	5,873	2,056	4,091	3,440	15,460
343	466	683	513	240	1,428	3,673	14,890	3.054	68	1,286	450	1,063	1,054	3,853
452	939	1,277	1,419	1,082	4,279	9,448	39,853	3.281	82	2,452	858	1,670	1,550	6,731
792	1,663	2,129	2,829	5,963	10,100	23,476	99,598	3.242	110	3,390	1,187	2,097	2,062	8,736
964	2,729	2,581	3,587	9,024	12,944	31,829	136,324	3.283	114	3,759	1,128	2,104	2,126	9,117
1,474	3,598	3,193	6,915	23,085	29,533	67,798	292,680	3.317	138	7,074	2,122	3,636	3,865	16,697
608	1,611	1,349	1,348	1,209	3,015	9,140	33,990	2.719	87	1,378	482	1,337	1,276	4,473
588	1,029	1,521	1,832	2,722	7,265	14,957	64,945	3.342	120	2,580	774	1,183	1,360	5,897
511	1,647	1,328	1,399	1,504	3,974	10,363	46,945	3.530	118	1,466	440	997	824	3,728
11	114	230	139	—	1,108	1,602	8,205	4.122	124	965	483	451	461	2,359
23	253	616	806	146	2,859	4,703	24,413	4.192	139	1,949	975	749	925	4,598
60	767	1,568	2,211	2,372	9,785	16,763	88,226	4.263	227	4,911	1,473	2,048	1,981	10,414
89	868	4,236	4,584	10,665	20,929	41,371	209,957	4.075	301	4,703	1,411	3,457	2,345	11,916
87	264	315	500	266	1,521	2,953	12,577	3.260	126	816	408	699	592	2,515
30	87	107	98	—	222	544	1,982	2.645	66	98	49	215	136	497
37	151	494	292	93	610	1,677	7,183	3.282	136	630	378	459	447	1,914
114	1,109	3,360	4,628	10,618	20,947	40,776	202,283	3.961	289	6,606	1,982	3,755	3,115	15,457
58	731	2,054	2,708	3,475	12,571	21,597	105,286	3.875	258	2,962	888	2,324	1,594	7,768
63	204	310	3	—	588	1,168	6,457	4.527	155	603	302	359	272	1,536
64	169	337	192	—	998	1,760	9,137	4.190	134	917	459	589	475	2,440
59	191	377	94	—	939	1,660	7,595	3.575	134	735	368	397	541	2,040
24	114	478	313	—	640	1,569	6,956	3.433	151	418	250	927	465	2,060
49	429	1,513	2,005	3,788	6,470	14,254	79,672	4.590	122	3,639	1,092	939	1,234	6,904
16	59	61	—	—	149	285	1,151	3.045	53	65	39	237	106	428
7	32	78	62	—	144	323	1,346	3.168	51	158	95	224	151	628
8	33	193	102	—	193	529	2,284	3.321	69	245	147	411	242	1,045
6	21	90	44	—	153	314	1,742	4.542	42	232	139	230	133	735
12	57	37	—	—	207	314	1,558	3.961	71	103	61	230	99	493
19	64	259	34	—	615	991	4,323	3.361	90	410	246	521	351	1,528
367	991	3,345	5,409	11,002	15,560	36,674	185,758	4.065	205	3,928	1,178	3,014	1,995	10,115
198	623	2,745	3,442	4,632	9,095	20,735	86,356	3.165	111	2,031	609	1,928	1,439	6,007
202	536	2,161	3,085	3,693	7,752	17,429	78,140	3.483	184	1,718	515	2,692	1,417	6,342
69	302	1,745	1,451	840	3,605	8,012	31,643	2.949	72	457	137	433	349	1,376
120	567	1,037	1,237	920	3,068	6,949	28,672	3.126	57	1,013	304	957	730	3,003
69	538	1,143	1,646	1,267	3,716	8,379	29,269	2.493	67	561	168	1,313	816	2,859
102	821	2,600	1,834	1,606	4,341	11,304	42,747	2.781	62	840	252	1,113	793	2,998
184	790	2,671	3,367	5,827	9,565	22,404	91,944	3.104	58	2,247	674	1,605	1,461	5,987
98	686	1,678	1,737	1,676	4,847	10,722	48,472	3.521	72	610	183	900	480	2,173
118	828	2,150	1,852	1,917	5,078	11,943	55,283	3.629	79	575	173	1,360	579	2,686
283	1,014	3,137	3,595	7,173	13,037	28,239	131,075	3.642	145	1,963	589	1,183	1,014	4,748

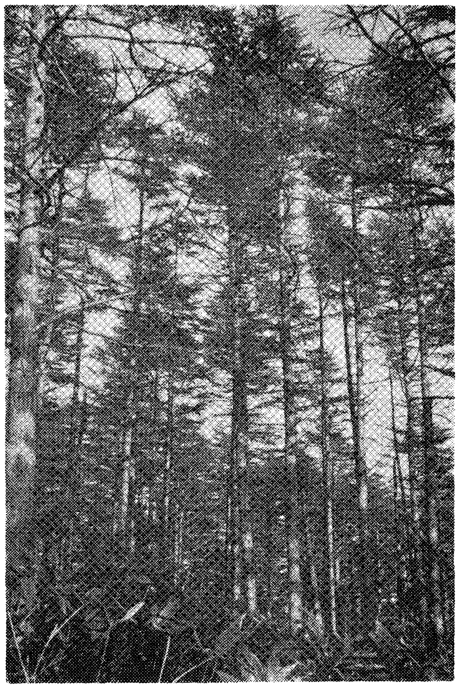
Appendix-Table 2. (continued)

Species	Stand No.	No. of sample trees	D.B.H cm	Basal area cm^2	Tree height cm	H. B cm	Average diameter of crown cm	Volume cm^3	Above-ground part			
									Stem	Branch	Leaf	Total
L. leptolepis	K. 12	3	19.4	301.68	1,560	840	380	227,552	91,840	10,810	2,273	104,923
	13	3	21.9	378.92	1,980	1,330	360	369,244	135,807	9,300	1,723	146,830
	14	5	24.9	494.31	1,806	1,142	570	478,620	233,064	34,777	3,757	271,598
	15	3	19.7	313.61	1,736	1,200	397	271,495	98,553	10,800	2,200	111,553
	16	3	18.5	272.94	1,287	717	433	171,868	61,873	12,313	2,837	77,023
	17	3	17.8	253.75	1,517	1,017	370	189,710	82,713	6,600	1,570	90,883
	18	3	20.3	331.03	1,873	1,290	350	291,459	123,870	8,087	2,453	134,410
	19	3	23.6	446.92	2,183	1,310	503	455,080	184,763	15,253	4,090	204,106
	20	3	26.7	567.88	2,420	1,437	427	702,586	288,763	29,683	5,410	323,856
	21	3	24.4	476.25	2,230	1,470	500	502,199	176,773	12,073	2,457	191,303
	22	3	24.1	459.53	2,160	1,357	460	459,516	180,127	17,676	3,500	201,303
	23	5	12.9	137.99	1,035	675	287	86,947	33,571	5,640	1,235	40,446
	24	3	20.9	364.85	1,562	900	457	308,932	126,693	26,845	3,479	157,017
	25	5	18.8	284.59	1,443	900	363	220,894	86,922	13,602	2,720	103,244
	26	4	13.2	143.88	1,003	604	279	78,377	31,192	6,710	1,429	39,331
	27	3	21.2	373.11	1,677	1,000	413	342,778	133,339	24,597	2,864	160,800
	28	3	29.7	718.94	2,237	1,345	637	838,571	327,043	49,955	5,806	382,804
	29	3	15.8	204.66	1,180	598	367	131,216	50,256	10,387	1,537	62,180
Ch. pisifera	M. 1	5	12.4	123.15	1,148	648	268	74,740	29,336	3,477	4,274	37,087
	2	3	19.8	310.42	1,535	831	622	140,283	86,938	17,405	7,022	111,365
E. globulus	3	3	10.2	78.14	1,142	844	349	42,227	20,185	1,496	1,596	23,277
Z. serrata	4	5	17.2	257.50	1,954	1,308	482	252,501	163,747	4,253	1,265	169,265
A. firma	5	5	14.5	168.29	806	203	281	65,644	23,025	9,906	10,249	43,180
T. canadensis	6	5	16.4	222.85	1,340	962	404	155,603	64,013	12,290	3,844	80,147
A. *	7	5	13.1	134.76	729	378	463	53,138	38,868	35,245	11,264	85,377
Q. *	8	2	16.5	213.76	885	175	—	83,774	46,355	23,300	3,150	72,805
B. *	9	2	10.6	95.80	775	320	—	41,529	19,120	4,425	685	24,230
B.davurica	10	2	15.2	184.61	945	355	—	89,152	46,405	15,630	1,295	63,330

A. * : *A. decurrens* v. *dealbata*　　*Q.* * : *Q. mongolica* v. *grosseserrata*　　*B.* * : *B. platyphylla* v. *japonica*

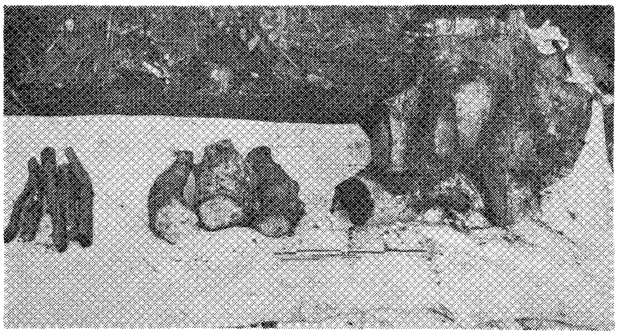
Underground part							Total biomass	T/R ratio	Maximum depth of root cm	Latest annual growth				
Fine root	Small root	Medium root	Large root	Very large root	Root stock	Total				Stem	Branch	Leaf	Root	Total
238	1,333	3,232	4,256	9,167	12,526	30,752	135,675	3.412	122	1,852	555	2,273	1,358	6,038
414	1,350	2,945	4,947	10,111	14,579	34,355	181,185	4.274	190	2,626	788	1,723	1,207	6,344
471	1,136	3,875	6,685	20,877	26,389	59,433	331,031	4.570	212	7,364	2,209	3,757	2,935	16,265
248	755	2,750	4,003	7,918	12,218	27,892	139,445	4.000	120	1,847	552	2,200	1,143	5,736
356	1,264	2,349	3,993	6,261	12,116	26,339	103,361	2.924	97	4,203	1,261	2,837	2,861	11,162
285	785	2,444	3,760	5,831	11,091	24,196	115,079	3.756	163	2,173	652	1,570	1,175	5,570
322	677	2,248	6,492	8,748	13,902	32,389	166,799	4.150	178	6,336	1,901	2,453	2,581	13,271
402	720	2,846	7,114	14,256	22,180	47,518	251,624	4.295	212	3,097	929	4,090	1,890	10,006
472	997	4,346	7,386	26,298	32,280	71,779	395,635	4.512	240	9,997	2,999	5,410	4,079	22,486
442	862	3,442	5,682	13,247	19,304	42,979	234,282	4.451	213	11,276	3,383	2,457	3,853	20,968
424	941	4,075	6,391	15,018	19,297	46,146	247,449	4.362	227	2,071	621	3,500	1,415	7,607
226	698	949	2,009	1,574	6,292	11,748	52,194	3.443	84	557	167	1,235	558	2,517
421	934	2,835	7,152	13,126	18,960	43,428	200,445	3.616	145	2,955	887	3,479	1,970	9,290
369	1,071	2,429	4,152	7,127	14,510	29,658	132,902	3.481	81	2,821	846	2,720	1,811	8,199
273	1,039	2,167	1,673	1,275	5,378	11,805	51,136	3.332	61	1,017	305	1,429	800	3,551
432	1,035	3,690	6,847	14,032	18,367	44,403	205,203	3.622	177	4,250	1,275	2,864	2,314	10,703
631	1,407	4,526	8,722	32,651	38,765	86,702	469,506	4.415	232	9,097	2,729	5,806	3,980	21,612
311	1,118	2,761	3,197	3,637	7,506	18,530	80,710	3.356	70	1,265	379	1,537	938	4,119
510	904	1,640	1,617	1,682	5,257	11,610	48,697	3.195	103	1,978	593	940	1,103	4,615
1,171	2,029	3,064	3,897	10,010	11,886	32,057	143,422	3.474	149	1,927	578	1,545	1,165	5,215
266	1,579	2,247	969	1,348	2,989	9,398	32,675	2.477	60	3,296	989	1,596	2,380	8,261
1,645	2,028	4,684	4,483	5,344	12,400	30,584	199,849	5.535	193	2,509	753	1,265	845	5,379
165	463	1,213	1,251	1,099	7,799	11,990	55,170	3.602	329	2,984	895	2,562	1,787	8,229
480	2,347	3,697	3,392	4,226	9,509	23,651	103,798	3.389	151	3,676	1,103	961	1,692	7,431
3,423	5,146	13,242	2,459	2,825	9,383	36,478	121,855	2.340	133	6,109	1,833	11,262	8,205	27,409
180	1,325	5,096	2,329	3,021	18,312	30,263	103,068	2.406	145	2,811	844	3,150	2,823	9,628
58	363	1,222	1,104	1,049	5,908	9,704	33,934	2.497	80	1,590	477	685	1,172	3,924
143	1,209	3,048	1,864	2,216	12,254	20,734	84,064	3.055	95	2,844	854	1,295	1,649	6,641

Photo. 1　The conditions of the investigated stand

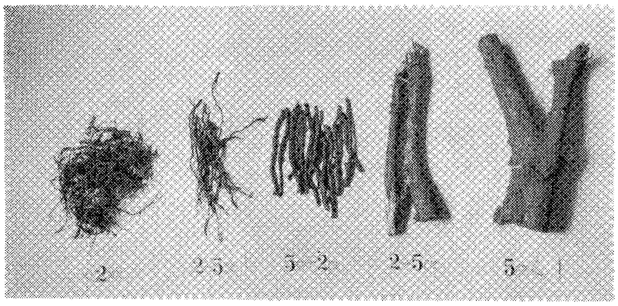


1—1. *L. leptolepis* stand K 28, D. B. H 29 cm, tree height 22 m, site index 21, density index 0.5.

Photo. 2　Classification of root

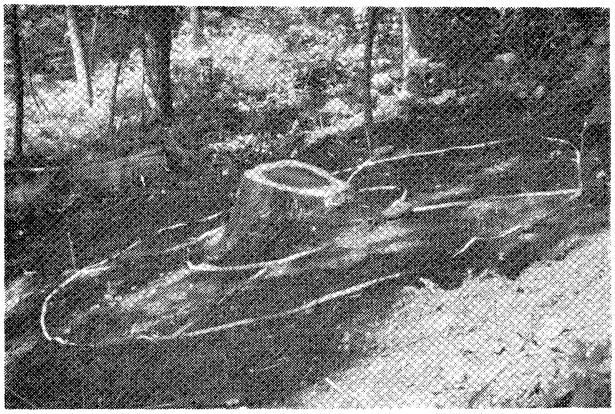


2—1. Large, very large and root stock of *C. japonica*. Inclination of root growth is observed at the base of roots.

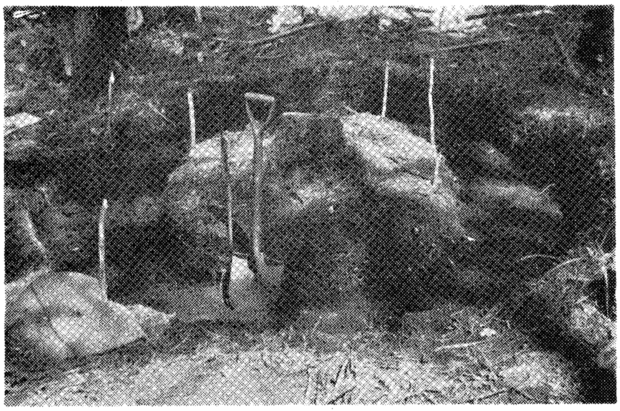


2—2. Root class of *C. japonica*.

Photo. 3 Method for measuring root biomass



3—1. Horizontal divisions before digging up, *C. japonica* stand S 15.



3—2. Digging up of each soil block-digging horizontal division 2 of horizons I and II in *L. leptolepis* stand, K 25.

Photo. 4 Measurment of root biomass

4—1. *C. japonica* S 17, tree No. 7, D. B. H 48 cm, tree height 25 m, aboveground part biomass 914 kg, underground part biomass 253 kg, digging up horizontal division 1 of soil horizon V.

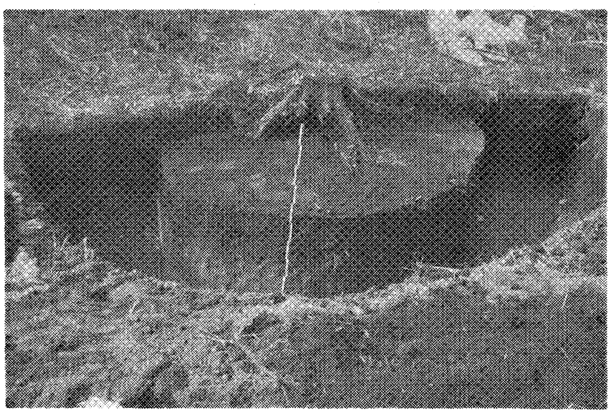
4—2. *C. japonica* stand S 2, D. B. H 18 cm, tree height 13 m, digging up of ② and ③ of horizontal division 1 of soil horizon I. Cutting off the root in soil horizon I.

4—3. Picking up the roots from the soil on the mat.

4—4. Root samples taken out from the soil before classifing roots.

4—5. Measurment of root biomass.

Photo. 5 Measurment of root biomass by a half soil block sampling method.



5—1. Digging up horizontal division 1 and 2 of soil horizons I, II, and III.

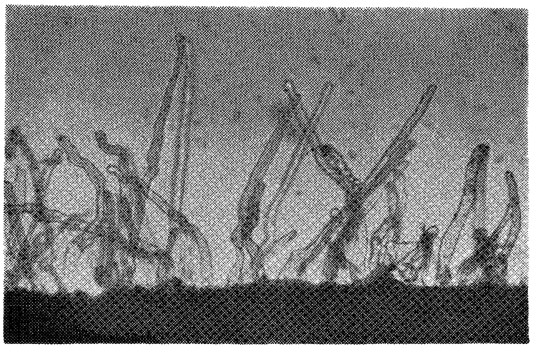


Photo. 6 Root hairs

6—1. Root hairs of *Picea jezoensis* v. *hondoensis*