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

Root growth and water absorption

By

Noboru KARIZUMI(1)

Summary

The root biomass and its distribution in the ground had already been described in the previous articles. In this paper, the increment and the water absorption of roots are reported for major forest tree species. The root increment of a tree and a stand was calculated by measuring the root biomass of many stands with different ages. The maximum of annual increment was reached at the age of about 20 years for the following four species, which was 5 t/ha/yr for *Cryptomeria japonica*, 3 5 t/ha/yr both for *Chamaecyparis obtusa* and *Pinus densiflora* and 2 t/ha/yr for *Larix leptolepis*, respectively. Then, these increments decreased with the increased age, for example, at the age of 30 to 35 years it was 4.3, 2.5, 2.4, and 1.8 t/ha/yr, respectively. Both *Eucalyptus globulus* and *Acacia dealbata*, so-called fast-growing species, showed 6 t/ha/yr at the age of ca. 10 years. The root increment is influenced by stand density and site condition. The root increment of a tree was 3.1 kg at the stand of density index 1.2, but 6.5 kg at the stand of density index 0.5 at the age of 30 years for *Cryptomeria japonica*. This means the double difference between both densities. To compare the increment between the type B_A of infertile dry brown soil and the type Bl_E of slightly wetted black soil, the latter was 1.4 times of the former. The root length and surface area were calculated from the root biomass of different ages under different site conditions. The annual increment of root length of a tree at the age of 30 years under moderate site condition was 208 m for *Cryptomeria japonica*, 254 m for *Chamaecyparis obtusa*, 198 m for *Pinus densiflora*, and 200 m for *Larix leptolepis*, respectively. The water absorption for a unit area was calculated by both the annual growth and the coefficient of evaporation for several species. In case of semi-matured stand under moderate site condition, for example, it was 7,000 to 8,000 t/ha/yr for *Cryptomeria japonica*, 4,000 to 5,000 t/ha/yr for *Chamaecyparis obtusa*, 2,000 to 3,000 t/ha/yr for *Pinus densiflora*, and 1,000 to 2,000 t/ha/yr for *Larix leptolepis*, respectively. Then, the amount of water absorbed by 1 gram of fine root and by 1 cm^2 of root surface area was estimated with reference to stand age and site condition.

I Introduction ……40
II Root biomass and tree growth ……40
  1) Current annual growth of each part of tree in biomass……40
  2) Annual increment ratios by distribution ……46
  3) Average annual growth of root in length……47
  4) Average annual growth of white roots by surface area ……50
  5) Annual growth of a tree per working part ……53
  6) Ratios of leaf biomass to the fine root biomass, fine root surface

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area and total root surface area ……65
7) Average net assimilation ratio and average respiration ratio ……68
8) Total assimilated product per tree ……72
9) Assimilated product per ha ……72
10) Respiration per tree ……73
11) Respiration per ha ……74
12) Ratio of the respiration amount to the assimilated product ……74
13) Assimilation ratio ……75
14) Various conditions and the average net assimilation ratio ……77
15) Production ratio of root ……77
16) Various conditions and production ratio by root ……79
III Absorption of water by root system ……81
1) Average absorption ratio by root ……81
2) Absorbed water ……85
3) Various conditions and amount of absorbed water per ha ……86
4) Absorption ratio by root ……94
5) Various conditions and absorption ratio by fine root biomass ……94
6) Absorption ratio by surface area of white tip roots ……97
7) Surface area of lignified part and white tip roots with the difference counted in …… 101
8) Absorption ratio of every species …… 103
9) Site conditions and absorption ratio …… 108
10) Tree growth and absorption ratio by root …… 109
11) Annual absorption of water in each soil horizon from the absorptive structure of root system …… 110
12) Transpiration ratio by leaf …… 115
13) Section root area at the base of root stock …… 116
Literature cited …… 123
和文摘要 (Summary in Japanese) …… 125

I Introduction

To clarify "The mechanism and function of tree root in the process of forest production", the author has aleady reported, first¹⁾, "Method of investigation and estimation of the root biomass", second²⁾, "Root biomass and distribution in stands", and third³⁾, "Root density and root absorptive structure". In this fourth report, the author has analysed and studied the forest production, relation between water absorption and the root system, role of the root system taken in the cycle of forest materials, etc. The reader may refer to reports I, II, and III on the data of the sample stands.

II Root biomass and tree growth

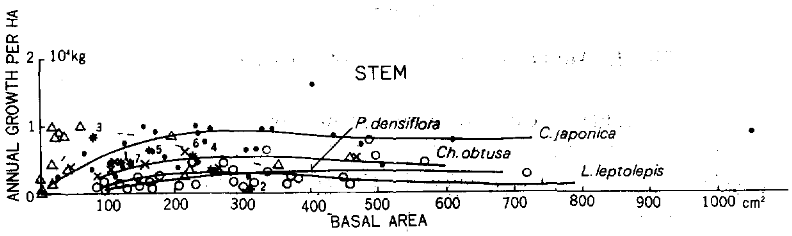
1) Current annual growth of each part of tree in biomass

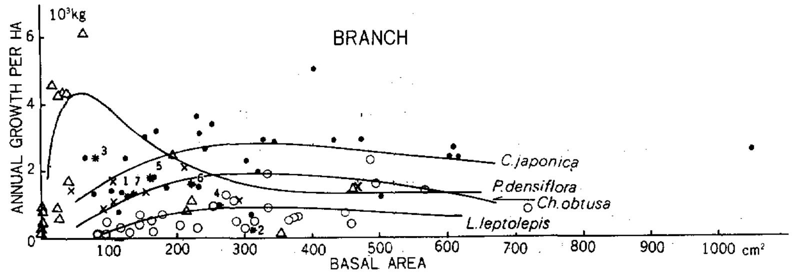
The average current annual growth per tree and that per ha (Appendix Table 2 in the report I) were calculated from the current annual growth of each sample tree (Appendix Table 1 in the report I) obtained by the method stated on page 70 in the report I. These two play a very important role to study the function of roots and leaves. In this study the annual growth of stem is measured by the stem analysis and the other parts are estimated from the ratio of the standing biomass. So the latter are greatly affected by the standing biomass of each part.

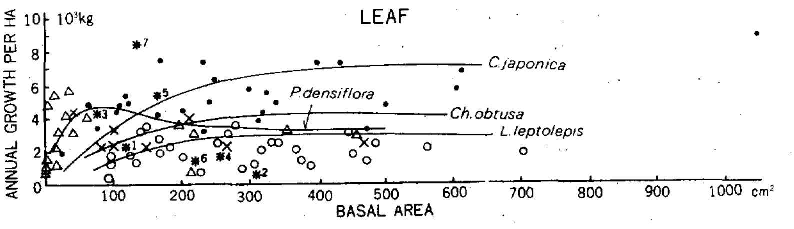
In Fig. 1, the annual growth of each prat from Appendix Table 2 in the report I is plotted with the basal area on the abscissa.

Stem: The current annual growth per ha of stems is large for the young trees at the basal area of 150 to 200cm^2. It decreases a little when the trees grow older. The same holds true in the working parts, such as leaves and fine root. The increase of the biomass of leaf and small root equalled that of the biomass of stem at this stage. This agrees well with the current annual increment pattern in the yield table (See Fig. 37 in the report Ⅲ[8]). The current annual growth per area declines when the trees grow bigger because their growth ratio and number decrease.

Table 1 shows the growth at the immature stage and the growth at the matured stage at the basal area of 500cm^2 extracted from Fig. 1. In a matured stand, the growth was 7*, 4, or 3 tons for *C. japonica*, *Ch. obtusa*, and *P. densiflora* or *L. leptolepis* respectively. It was almost 10 tons for *C. japonica* and for *P. densiflora* in the immature stand. This is because







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* It is said that the annual increment of the stem per ha in our country is 2 to 8 tons in the average[9].

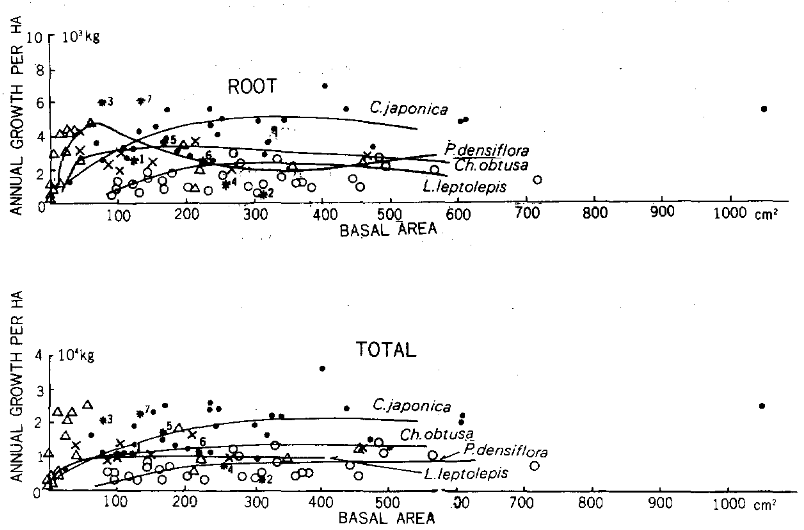

Fig. 1. Annual growth per ha of each part of a tree.

Table 1. Current annual stem growth. (t/ha)

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Maximum in the young stage	10	6	10	3
Basal area : 500cm²	7	4	3	3

they have a high tree density and grow favourably at this stage.

The growth per ha is much affected by the tree density and the soil condition. As shown in Fig. 1, the highly dense stand S22 has a growth of 17 tons, showing a large difference of 9 tons from the average, while the sparse stand S9 has a growth of only 2 tons with a large difference of 8 tons from the average.

As shown in Table 2 where a comparison has been made between the close planting S22 stand and the sparse planting S18 stand with similar soil conditions but different tree densities, the average annual increment per tree is less in a close planting stand than in a sparse planting stand. Particularly, this is so in the case of the growth of leaves ; close planting caused it to decrease greatly. The average annual increment of the stem in close planting S22 stand with the density index of 1.2, was 7.5kg per tree, while that in a sparse planting S18 stand with the density index of 0.5, was 11kg. The former index was 69% of the latter. The parts with the smallest indices, which are easily affected by density, were leaves (43%), roots (48%), branches (67%), the total weight (61%), and stems (69%). This makes clear that the growth of either leaves or roots is affected more greatly by density. As is evident in a comparison of these stands, the growth of the total weight decreased to about 60% of that in the sparse planting stand when the tree denstiy increased twice.

Table 3 shows the comparison of the annual increment with five pairs of stands as a sample. The basal area and the stand densities are almost the same, and the soil conditions

Table 2. Tree density and average annual growth (kg) of each part of tree.

	Close planting stand	Sparse planting stand
Stand	S22	S18
Stand age (yrs)	41	32
Basal area (cm^2)	419	554
Tree density index	1,158 (2.12)	0.545
Site index	21.8	23.4
Stem	7.5 (0.69)	11.0
Branch	2.2 (0.67)	3.3
Leaf	3.2 (0.43)	7.4
Root	3.1 (0.48)	6.5
Total	16.0 (0.61)	26.1

The figures in the parentheses show the ratio of the average annual growth of close planting stand to that of sparse planting stand.

Table 3. Soil types and annual growth. (t/ha)

Stand	S20	S12	S 7	S13	S10	S23	S15	S18
Basal area (cm^2)	265	267	160	196	208	152	451	554
Tree density index	0.482	0.672	0.575	0.598	0.585	0.798	0.682	0.545
Soil type	B_A	Bl_E	Bl_C	Bl_D	$Bl_{D(d)}$	B_D	Bl_D	B_E
Setm	6.2	9.9	5.1	9.4	4.0	10.2	7.9	8.1
Branch	1.9	3.5	1.5	3.3	1.2	3.1	2.8	2.4
Leaf	4.0	6.3	3.7	7.4	4.4	5.2	6.6	5.5
Root	3.8	5.2	3.2	5.6	3.0	4.7	4.8	4.8
Total	16.0	24.8	13.6	25.7	12.5	23.1	22.2	21.0

are different within each pair. Here all stands in the soils of B_A, Blc and $Bl_{D(d)}$ types show small annual growth and a difference as large as 3.7 tons is seen between the S20 stand of B_A type soil and the S12 stand of $Bl_{D(w)}$ type soil.

Branches: The annual increment of branches is similar to that of stem because it is obtained by multiplying the annual increment of stems by certain coefficient. The coefficient, however, varies according to the age. So, the gowth of branches tends to become larger than that of stems.

Table 4 shows the annual growth per ha at the young stage and the grownup stage (500 cm^2 in basal area). Here again *P. densiflora* showed large growth at the young stage for the same reason as in stems. Branches as well as stems show large growth in close planting stands. The growth was 5 tons in the stand of S22. As for soil conditions the growth of branch is large in the productive and moderately moist soils, but samall in dry soils.

Leaves: The current annual increment of leaves is obtained, as is that of branches, by multiplying their standing biomass by a certain coefficient. It varies similarly with that of their weight, although the coefficient changes a little according to their age. Table 5 gives

Table 4. Current annual branch growth. (t/ha)

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Immature stand (largest)	3.0	2.0	4.0	0.4
Basal area: 500cm^2	2.5	1.5	1.0	0.4

Table 5. Current annual leaf growth at the basal area of 500cm^2. (t/ha)

Species / Basal area	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
500 (cm^2)	5.0	3.0	3.2	2.5

Table 6. Current annual growth for different species. (t/ha)

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*Ch. pisifera*	*Eu. globulus*	*Z. serrata*	*A. firma*	*T. canadensis*	*A.decurrens* v. *dealbata*
Stand	S10	H3	A3	K29	M2	M3	M4	M5	M6	M7
Stem	4.0	6.2	8.5	1.4	0.9	8.3	3.3	6.1	5.4	4.6
Branch	1.2	2.2	2.6	0.4	0.3	2.5	1.0	1.8	1.6	1.4
Leaf	4.4	3.8	3.6	1.7	0.7	4.0	1.6	5.2	1.4	8.4
Root	3.0	3.8	3.4	1.1	0.6	6.0	1.1	3.7	2.5	6.1
Total	12.5	16.0	18.1	4.6	2.5	20.8	7.0	16.8	10.9	20.5

the annual increments per ha of four kinds of species at the average basal area of 500cm^2 extracted from Fig. 1. *C. japonica* had as shown almost twice as large a growth as *Ch. obtusa*, *P. densiflora* and *L. leptolepis*. These three kinds of species had almost the same growth. A comparison has been made as given in Table 6 between these four kinds of species and several other species. According to the table, the annual increment of *Acacia decurrens* v. *dealbata* is the largest.The annual increment of *Abies firma*, *C. japonica*, and *Eucalyptus globulus* reaches 4 to 5 tons, and that of *Larix* and *Zelkova* is only about 2 tons.

The growth of leaves is not so much affected by tree density, nor is the biomass per ha of leaves. The stands, S22 and S26, with extremely different stand density indices showed almost the same growth of only 7 tons.

As for soil conditions, the growth became large in the moderately moist soils, and small in the dry soils such as B_A and Bl_C type soils, as shown in Table 3.

Roots: The annual increment of roots is the annual increment of the above-ground parts divided by the T/R ratio. Hence, it varies in proportion to this ratio, according to the variation of the growth of the above-ground parts.

Table 7 shows the annual growth per ha of roots in the matured stand extracted from Fig. 1 showing the relation between the annual increment of roots and the basal area.

Roots also show different growth per ha under the different tree densities and the soil conditions as do the above-ground parts. They show large growth in the close planting stands and in the moderately moist soils with the large soil indices (Table 2).

Total biomass: The annual growth per ha for the total biomass of every species, as shown in Fig. 1, increases in a parabolic curve. It shows its peak at the basal area of 150 to 200 cm^2 at the young stage.

Table 8 shows the annual increments per ha of the total biomass at the young and the grown-up stage. As shown in this table, the maximum annual increment of *C. japonica* came to 21 tons at the young stage, whereas it was about 19 tons at the grown-up stage. *P. densiflora* reached its great difference in the annual increment at the young and the grown-up stage. It became two-thirds of that of the former.

At the grown-up stage, the growth became smaller in the order of *C. japonica*, *Ch. obtusa*, *P. densiflora*, and *L. leptolepis*. There was a difference of over twofold that of *P. densiflora* between *C. japonica* and *L. leptolepis*. As for some other species, both *Eucalyptus globulus* and *Acacia decurrens* v. *dealbata* showed, as given in Table 6, the growth of more than 20 tons. *Zelkova serrata*, the deciduous broad-leaved tree, had a growth of only 7 tons.

Although there is a large difference because of big variety in the stand age and site condition, as can be seen in Fig. 2, the correlation between the annual growth per ha and the density ratio is such that the growth increases in a parabola as the tree density increases, and becomes nearly constant when the density index is 0.8 and above. So it is estimated that in the close planting stands of moderately moist soils, the annual growth per ha registers about 25 tons for *C. japonica*, about 18 tons for *Ch. obtusa*, about 20 tons for *P. densiflora*, or about 12 tons for *L. leptolepis*, all of which are about as much as 130% of the actual production of the stand with the moderate tree density. Indeed, there is an increase of growth per tree in a sparse planting stand, but it is no match for the increase of growth per ha made possible by increasing the number of trees in the stand. The total production per ha at the maximum density was about 130% of those at the densities in the ordinary yield tables. It was figured out from this that the density index must always be kept above 0.8 in order to obtain the maximum production per unit area. The S22 stand, with the colluvium soil of B_E type, site quality index 22, and density index 1.16, showed the largest annual growth of 36 tons among all the investigated stands, while the average annual growth of stands with the moderate site condition and density was 18 tons when the basal area was about the same. Their difference in growth was about twice as large as that of S22 stand.

The growth is small in the dry soils of B_A, Bl_C and the other types, and large in the moderately moist one (Table 3). There were differences by 8.8 tons and 12 tons between S20, Bl_A type, and S12, $Bl_{C(w)}$ type between S7, Bl_C type, and S13, Bl_D type, respectively.

Table 7. Current annual root growth. (t/ha)

Species / Basal area	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
500 (cm^2)	4.3	2.5	2.4	1.8

Table 8. Current annual growth in the immature and mature stand. (t/ha)

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Immature stand(largest)	21	15	15	10
Basal area: 500cm^2	19	13	10	8

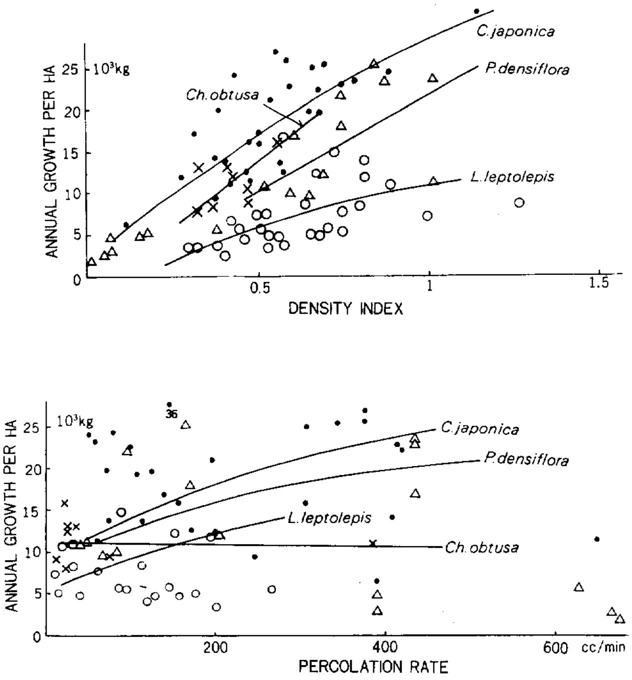

Fig. 2. Annual growth per ha for different conditions.

Examination of Fig. 2 makes clear that the growth increases as the percolation ratio increases.

2) Annual increment ratios by distribution

The production ratios by distribution in the stems, branches, leaves, and roots of *C. japonica* as given in Table 9, were 38 to 39%, 12 to 13%, 27 to 28%, and 22 to 23% respectively at the basal area of over 300cm^2. However, the ratio of annual increment of branches or leaves in an immature stand became higher than that in a mature stand.

Table 10 shows the production ratios by distribution each species takes at the basal area of 500cm^2. At this stage, 31 to 40% of the total production is distributed to the stems of all species. The ratio became lower in the order of *L. leptolepis*, *C. japonica*, *Ch. obtusa*, and *P. densiflora*. Although the proportion of the accumulated production in the stems of the matured tree is high, the proportion of the distributed production is low as compared with those in leaves and roots.

The production ratios by distribution branch take very largely from 5 to 14% according to species. They are the lowest for *L. leptolepis* and the highest for *Ch. obtusa*.

As for leaves, the second biggest proportion, 27 to 34%, of the total production is distributed. *C. japonica* and *Ch. obtusa* had a lower ratio of 27% than *L. leptolepis* and *P. densiflora*, because that proportion depends upon the duration of leaving.

The ratio of roots is 23 to 25% and does not differ very much according to species. As many points remain unsolved on the estimation of growth of leaves, branches and roots, they will form the subject of a future study.

Table 9. Production of each part of *C. japonica* stand according to tree growth (t/ha), and its ratio to the total.

Basal area (cm²)	100	200	300	400	500	700	1000
Stem	5.0 (0.38)	10.0 (0.41)	8.0 (0.39)	7.5 (0.39)	7.0 (0.38)	7.0 (0.38)	7.0 (0.38)
Branch	1.0 (0.08)	3.0 (0.13)	2.5 (0.12)	2.5 (0.13)	2.3 (0.12)	2.3 (0.12)	2.2 (0.12)
Leaf	4.0 (0.31)	6.0 (0.25)	5.5 (0.27)	5.0 (0.25)	5.0 (0.27)	2.0 (0.27)	5.0 (0.28)
Root	3.0 (0.23)	5.0 (0.21)	4.5 (0.22)	4.4 (0.23)	4.3 (0.23)	4.2 (0.23)	4.1 (0.22)
Total	13.0 (1.00)	24.0 (1.00)	20.5 (1.00)	19.9 (1.00)	18.6 (1.00)	18.7 (1.00)	18.3 (1.00)

The figures in the parentheses show the ratios to the total production.

Table 10. Production ratio by distribution of each part at the basal area of 500cm².

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Stem	0.37	0.36	0.31	0.40
Branch	0.13	0.14	0.10	0.05
Leaf	0.27	0.27	0.34	0.32
Root	0.23	0.23	0.25	0.23

3) Average annual growth of root in length

The average annual growth of roots in length (hereinafter referred to as the root-length growth) was obtained from the total root length and stand age.

As the root-length growth is different according to stand age, it would be unsuitable to make a comparison between stands taken at random. Hence, the stands with almost the same basal area are compared in Table 11.

Acacia decurrens v. *dealbata*, which grows rapidly and has many fine roots, shows the largest root-length growth of 805m. *Zelkova serrata*, whose fine roots grow long for their weight because of their thinness, shows a growth of 314m. For similar reason *Eucalyptus globulus* shows a large growth of 266m.*

The root-length growth of the broad-leaved species such as *Quercus mongolica* v. *grosseserrata*, *Betula platyphylla* v. *japonica*, and *Betula davurica* ranges from 28 to 58m, very much smaller than the above three broad-leaved species, because they all have little fine root biomass and poor growth.

Among the coniferous trees, *C. japonica* shows the greatest root- length growth of 118m and then *Ch. obtusa* with 111m. *Ch. obtusa* shows the smaller growth because of poor growth even though it has more fine root biomass. *Abies firma* and *P. densiflora*, which both have little fine root biomass, show the smaller growth of 36m and 117m respectively.

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* Kozlowski and others have reported that *Cornus* saplings show the average annual root-length growth of 51m. Kozlowski and others, Jour. Forestry, 46, 750~754, 1948.

Table 11. Average annual growth of root length a tree of each species.

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*Ch. pisifera*	*Eucalyptus globulus*
Stand	S10	H3	A3	K29	M2	M3
Average annual growth of root length (m)	118	111	17	48	94	266
Basal area (cm²)	208	254	198	200	238	177

Table 12. Average annual growth of root length a tree at the basal area of 500cm². (m)

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Average growth of root length	155	140	33	70

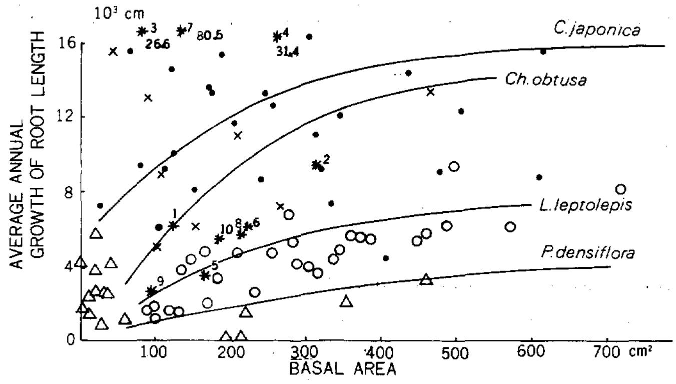


Fig. 3-1. Average annual growth of root length.

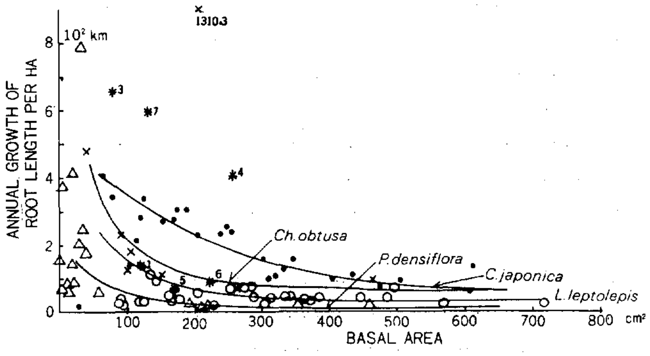


Fig. 3-2. Average annual growth of root length per ha.

Zelkova serrata	*Abies firma*	*Tsuga canadensis*	*Acacia decurrens* v. *dealbata*	*Quercus mongolica* v. *grosseserrata*	*Betula platyphylla* v. *japonica*	*Betula davurica*
M4	M5	M6	M7	M8	M9	M10
314	36	62	805	58	28	56
188	56	211	135	167	118	157

Table 13. Average annual root length growth at the basal area of 100 and 500cm². (km/ha)

Species / Basal area(cm²)	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
100	352	200	50	150
500	100	60	20	50

The average root-length growth changes according to the basal area. That per tree increases, as shown in Fig. 3, in a parabolic curve and the growth per ha decreases as the basal area increases. Table 12 shows the average root-length growth at the basal area of 500cm², when the growth per tree becomes almost constant. In the mature stands, the root-length growth per year of *C. japonica*, *Ch. obtusa*, *P. densiflora*, and *L. leptolepis* was about 155m, 140m, 30m and 70m respectively. These growths increase little after the trees have grown up to their own size. In fact, at the basal area of 1,042cm², *C. japonica* had the annual root-length growth of 150m in the stand of S17, almost the same as that at the basal area of 500cm².

The root-length growth per ha tends to decrease rapidly, as shown in Fig. 3, as trees grow. The decreasing curve is gentler for *C. japonica* than for *Ch. obtusa* and *P. densiflora*, because the latter two are both poorer in growth and lower in tree density than the former.

From the data in Table 13, showing the root-length growth when the basal area is 100 cm² and 500cm², it can be said that *C. japonica* has the largest growth, and then *Ch. obtusa*, *L. leptolepis* and *P. densiflora* in that order. The average root-length growth per ha is, as in Fig. 3, large for the small-diameter trees, and small for the large-diameter trees. For the fine and the small roots of the former occupy a greater proportion of the total root biomass, and the tree number is many; and, on the contrary, the growth per ha of the latter tends to decrease gradually. This is in part due to the unfavorable branching and poor growth of the fine roots getting the large-diameter roots to cause the diameter growth, and partly because the tree number decreases. One reason for this is the rapid increase of the annual average root-length growth per tree at the young stage.

Both the growth per tree and that per ha reach their maximum at the young stage when the root-length growth per tree and that per ha increase rapidly. They do this because the root tips have many young tissues which absorb water and nutrients vigorously at this stage (See page 110 in the report III for the variation of the current annual growth in a stand).

In order to find out the relation between the root-length growth and the tree density, two pairs of stands, S22–S18 and S8–S2, were studied. The result is shown in Table 14.

Table 14. Average annual root length growth of *C. japonica* and stand density.

Tree density	Close planting stand	Sparse planting stand	Close planting stand	Sparse planting stand
Stand	S22	S18	S8	S2
Stand age (yrs)	41	32	29	23
Basal area (cm^2)	419	554	238	249
Tree density index	1.158	0.545	0.898	0.652
Site index	21.8	23.4	20.7	21.7
per tree (m)	44	88	87	134
per ha (km)	101	66	237	255

Table 15. Average annual root length growth of *C. japonica* and soil type.

Stand	S20	S12	S 7	S13	S10	S23	S15	S18
Basal area(cm^2)	265	267	160	196	208	152	451	554
Tree density index	0.482	0.672	0.575	0.598	0.585	0.798	0.682	0.545
Soil Type	B_A	Bl_E	Bl_C	Bl_D	$Bl_{D(d)}$	B_D	Bl_D	B_E
per tree (m)	136	126	154	133	118	82	157	88
per ha (km)	283	245	316	313	234	279	140	66

According to this table, the average root-length growth per tree was smaller in the close planting stand than in the sparse planting stand of each pair. They were 44m and 88m in the close planting of S22 and in the sparse planting stand of S18 respectively.

It was also applicable to the cases of both stands, S8 and S2. And, on the contrary, the growth per ha was larger in the close planting stand of one pair. They were 101km and 66km in the stands of S22 and S18 respectively. But the growth was larger in the sparse planting stand of S2 than in the dense planting stand of S8. This is the reverse of the relation between S18 and S22.

As for the effects of soil conditions, the root-length growth is larger in the dry soils of B_A, Bl_C and $Bl_{D(d)}$ types than in the moderately moist soils, as shown in Table 15. When compared between S 20 and S12 stands at the nearly equal basal area, the average growth per tree showed 136m and 126m in the B_A soil typed stand of S20 and in the stand of S12 respectively. That per ha was 283km in the former, and 245km in the latter. So, it can be safely said that the difference of the growth per ha between close planting stands and sparse planting stands is not always dependent on tree density, though the growth per tree tends to be easily affected by it. Despite the high density ratio the root length per ha was shorter in the stand of S12 than in the dry-soil stand of S20. In the other stands this tendency was similar, that is to say, the growth was larger in the dry soil than in the moderately moist soil.

4) **Average annual growth of white roots by surface arca**

The annual growth of white tip roots by surface area calculated from the average annual diameter of white roots and the root-length growth has already been listed in the detailed data.

As is clear from Fig. 4, the average annual growths per tree and per ha of white tip roots in surface area change, as the trees grow, just like the root-length growth. The former increased in a parabolic curve, and instead the latter decreased. The surface area of white roots increased rapidly at the basal area of 100 to 200cm^2 when the average growth of white roots per tree became highest; then the growth per ha was large for the immature trees. But, with a growing tree it decreased because both the growth ratio and tree density fell off.

When both the growth per tree and growth per ha become almost constant, that is, when the basal area gets up to 500cm^2, the growth per tree of *C. japonica* and *Ch. obtusa* ranges, as shown in Table 16, from 2.7 to 2.9m^2, about the same. These two species also showed the largest growth per ha of 2,000m^2. *L. leptolepis* showed that of 500m^2. *P. densiflora* had both the smallest growth per tree (0.7m^2) and the smallest growth per ha (250m^2) of all these four species. ***Acacia decurrens*** v. ***dealbata*** showed the largest growth per tree of 29m^2 among all species in the detailed data. ***Zelkova serrata*** showed that of 2.4m^2, about 1/10 the growth of the former. ***P. densiflora***, ***L. leptolepis***, ***Abies firma***, ***Quercus mongolica*** v. ***grosseserrata***, ***Betula platyplylla*** v. ***japonica***, and ***Betula davurica*** showed the small growth from 0.3 to 0.8m^2 because they were poor in growth and had few fine roots. *C. japonica* and *Ch. obtusa* had 2.0 to 2.3m^2 (Table 17).

Table 18 shows the relation between the tree density and the average annual growth of white tip roots in surface area listed in the detailed data.

As is clear from that table, the growth was smaller in a close planting stand than in a

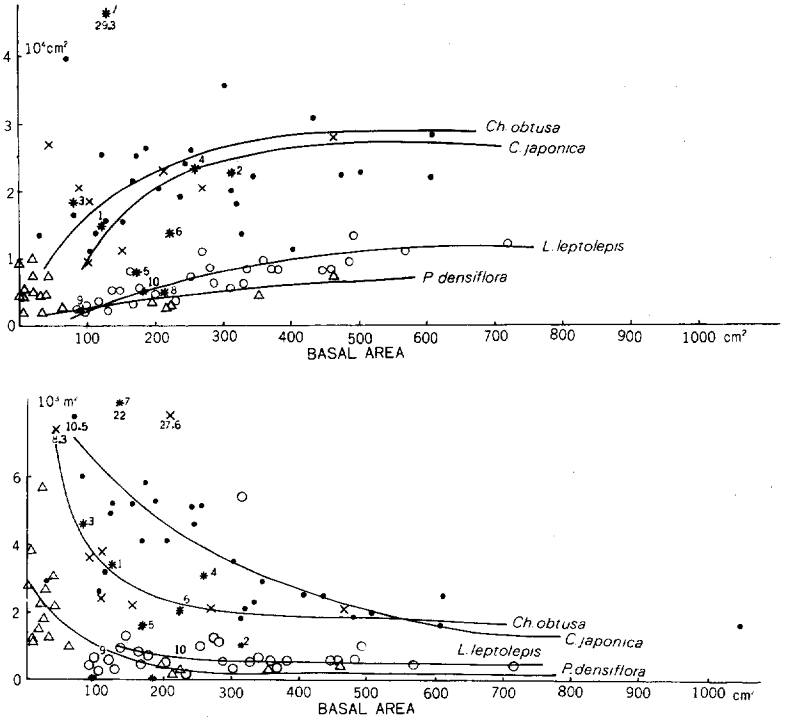


Fig. 4. Average annual growth of white tip root surface area.

Table 16. Average white tip root surface area growth at the basal area of 500cm^2. (m^2)

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
per tree	2.9	2.7	0.7	1.1
per ha	2000	2000	250	500

Table 17. Average white tip root surface area* a tree.

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*Ch. pisifera*	*Eucalyptus globulus*
Stand	S10	H3	A3	K29	M2	M3
White root surface area	2.07	2.33	0.27	0.49	2.28	1.84

* White root surface annual white root surface area growth and stand density.

Table 18. Average annual white root surface area growth and stand density.

Stand	S22	S18	S 8	S 2
Stand density	Close planting	Sparse planting	Close planting	Sparse planting
Stand age (yrs)	41	32	29	23
per tree (cm^2)	11378	21857	19178	24328
per ha (m^2)	2587	1628	5199	4647

Table 19. Average annual surface area growth of the white part of root tip and soil type. (m^2)

Stand	S20	S 3	S 7	S13	S10	S23	S15	S18
Soil type	B_A	$Bl_{D(d)}$	Bl_C	Bl_D	$Bl_{D(d)}$	B_D	Bl_D	B_E
per tree	2.0	1.6	2.6	2.5	2.1	1.5	2.8	2.2
per ha	4175	6037	5364	5894	4110	5257	2505	1628

sparse planting stand. The stands of S22 and S18 had, for example, growth of 1.1m^2 and 2.2m^2, about twice that of the former, respectively. And the growth per ha was 2,587m^2 and 1,628cm^2, respectively.

Table 19 gives the relation between the soil conditions and the average annual growth of white roots in surface area on several typical stands. According to the table, the growth per tree was larger in the dry soils than in the moderately moist wet soils. No clear relation was observed as to the growth per ha because of difference in tree density.

In addition to the average annual growth of root-length, root biomass and root surface area, those of root volume and root surface area can be determined. Here, however, the study is limited to the former three because the root volume is not very different in variation from the root biomass and the root surface area from the white root surface area.

All three kinds of growth studied so far are the annual stem growth per ha in the yield table of each species in Fig. 37 of the report III, the annual growth of each part (Fig. 1), and the root-length and annual white root growth in surface area per ha mentioned in this chapter. They reach their maximum at the young stage when the basal area is 200 to 250cm^2, decreasing when that basal area is exceeded. It was evident that the annual average root-length growth per ha and the annual average surface area of white tip root tended to go up at the young stage and down at the grown-up stage.

The increasing growth of root-length and white tip root surface area means the increase of the working parts of root whose absorptive function works most vigorously. This also means the growth of absorptive mechanism. Their pattern is similar to those of the stem

(m²)

Zelkova serrata	*Abies firma*	*Tsuga canadensis*	*Acacia decurrens* v. *dealbata*	*Quercus mongolica* v. *grosseserrata*	*Betula platyphylla* v. *japonica*	*Betula davurica*
M4	M5	M6	M7	M8	M9	M10
2.37	0.81	1.39	29.34	0.53	0.27	0.53

growth and the growth in total biomass. Those growth is all large at the young stage. Consequently, the above-mentioned is estimated to be due to the increase of both the absorption of nutrient and water and the amount of assimilation production closely connected with them.

The growth of root-length and of white tip root surface area here took place prior to that of leaves. The former was more clearly observed than the latter. The reader may refer to Fig. 1, 3, 4.

5) Annual growth of a tree per working part

The life and the growth of a tree depend on the absorption from root and on the assimilation in leaf. The production efficiency of these working parts under various conditions was calculated as follows: Only the annual growth was calculated here without taking into account the consumption of the assimilated product by respiration. Therefore, it gives only the apparent production efficiency. Nevertheless, it serves as a clue to analyse the tree growth.

The annual growth of each factor per unit is named the growth ratio to distinguish it from the production, named the production ratio, which is given when consumption by respiration is taken into account. For example, the annual growth of the fine root per unit weight, excluding consumption by respiration, is named the fine root biomass-growth ratio, and that including consumption by respiration, is named the production ratio of fine root.

The factors considered here as working parts are the fine root biomass, fine root surface area, and leaf biomass. The surface areas of a fine root etc. appear in detail later.

The annual production as a base of calculation is the annual growth of the whole tree or all parts of it such as stem, branches, leaves and roots.

(1) Annual growth ratio of each species

The growth for such factors as fine root, fine root surface area, total root surface area, leaf biomass, and so forth, in each stand is shown in Table 20. These growth ratios vary with species, stand age, or site condition. The stands showing moderate growth ratios of each species selected from the detailed data are listed up in Table 20.

The fine root biomass-growth ratio was highest, 136, for *P. densiflora*, and lowest, 3, for *Zelkova serrata*. *Betula platyphylla*, *Quercus mongolica* v. *grosseserrata*, *Abies firma*, *Betula davurica* and *L. leptolepis* showed the high growth ratios. *Ch. obtusa*, *Ch. pisifera*, *Zelkova serrata* and *Acacia decurrens* showed low ratios.

The ratios of the typical species became lower; 136 for *P. densiflora*, 34 for *L. leptolepis*, 21 for *C. japonica*, and 11 for *Ch. obtusa*. That for *Ch. obtusa* was less than one-tenth of that for *P. densiflora*. The growth ratios of *P. densiflora*, *L. leptolepis* and *C. japonica* were 13, 3 and 2 respectively when that of *Ch. obtusa* was to be 1. That of *P. densiflora* was remarkably higher.

Table 20. Annual growth ratio of each species.

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*Ch. pisifera*	*Eucalyptus globulus*
Stand	S 5	H 5	A 8	K14	M 2	M 3
Annual growth/fine root biomass (g/g)	21	11	136	34	4	31
Annual growth/fine root surface area(g/cm^2)	0.15	0.09	1.25	0.21	0.03	0.17
Annual growth/total root surface area (g/cm^2)	0.09	0.05	0.17	0.09	0.02	0.07
Annual growth/leaf biomass (g/g)	1.2	1.0	2.1	4.3	0.7	5.2

Table 21. Annual growth ratios to root surface area and biomass

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*Ch. pisifera*	*Eucalyptus globulus*
Stand	S 5	H 5	A 8	K14	M 2	M 3
Annual growth/fine root biomass (g/g)	100	52	648	162	19	148
Annual growth/fine root surface area (g/cm^2)	100	43	595	100	14	81
Annual growth/total root surface area (g/cm^2)	100	24	81	43	10	33
Annual growth/leaf biomass (g/g)	100	48	100	205	33	248

The fine root biomass-growth ratio depends largely on the fine root biomass. It was low for *Ch. obtusa*, *C. japonica*, *Ch. pisifera*, *Zelkova serrata*, and *Acacia decurrens* with a large fine root biomass, whereas for *P. densiflora*, *L. leptolepis*, *Abies firma*, *Betula platyphylla*, and *Quercus mongolica* v. *grosseserrata*, with a small fine root biomass, it was high. *P. densiflora* showed a high growth ratio for small fine root biomass, while *Ch. obtusa* showed the opposite. The difference in growth ratio went up between them.

Thus it is reasonable to say that the fine roots of the species with high growth ratio, such as *P. densiflora* and *L. leptolepis*, show a higher growth efficiency than *C. japonica* or *Ch. obtusa* with low growth ratio.

The relation of the growth ratio to the fine root surface area is shown in Table 20. The growth per unit surface area was the largest, 1.25g, for *P. densiflora*, and the smallest, 0.09 g, for *Ch. obtusa*. Among the investigated stands, the species showing growth ratios of over 20 are *P. densiflora*, *L. leptolepis*, *Abies firma*, *Quercus mongolica* v. *grosseserrata*, *Betula platyphylla*, and *Betula davurica*. The species showing ratios below 20 are *C. japonica*, *Ch. obtusa*, *Ch. pisifera*, *Eucalyptus globulus*, *Zelkova serrata*, *Tsuga canadensis* and *Acacia decurrens*. The former species have small surface areas for growth, while the latter species have large surface areas for growth.

The growth ratios to the total root surface area were, as shown in Table 20, 0.17 for *P. densiflora*, 0.16 for *Abies firma*, 0.09 for *C. japonica*, and 0.05 for *Ch. obtusa*. Since about 60% of the total root surface area was that of fine root, the order of species in the total

Zelkova serrata	*Abies firma*	*Tsuga canadensis*	*Acacia decurrens* v. *dealbata*	*Quercus mongolica* v. *grosseserrata*	*Betula platyphylla* v. *japonica*	*Betula davurica*
M 4	M 5	M 6	M 7	M 8	M 9	M10
3	50	15	8	53	68	46
0.02	0.43	0.13	0.07	0.30	0.30	0.21
0.01	0.16	0.04	0.04	0.08	0.09	0.04
4.3	0.9	1.9	2.4	3.1	5.7	5.1

of different species as compared with those of *C. japonica.*

Zelkva serrata	*Abies firma*	*Tsuga canadensis*	*Acacia decurrens* v. *dealbata*	*Quercus mongolica* v. *grosseserrata*	*Betula platy*phylla v. *japonica*	*Betula davurica*
M 4	M 5	M 6	M 7	M 8	M 9	M10
14	238	71	38	252	324	219
10	205	62	33	140	143	100
5	76	19	19	38	43	19
205	43	90	114	148	271	243

surface area was similar to that in the surface area of a fine root. The growth ratio of the total root surface area was about half that of the fine root surface area because the surface areas of the other parts were included in the calculation.

This relation is expressed in Table 21 by the ratios when the growth ratio of *C. japonica* is to be 100. As is clear from the table, the growth ratio of fine root biomass was highest for *P. densiflora*, 648, and lowest for *Zelkova serrata*, 14. These growth ratios of fine root surface area were 595 and 10 respectively. In this case, all the species were lower than in the case of fine root biomass. The growth ratios of the total root surface area were 81 and 5 respectively, 1/2 to 1/3 of the growth ratios of a fine root biomass in all species. The difference between species tended to be decreasing.

There was a great difference in fine root growth per unit weight between species. The difference, however, between species was decreasing from the surface area of a fine root to the total surface area. This is because the surface area varies with the characteristics of root branching even when the root biomass is the same. It is interesting to know that the growth ratios of the root surface area tend to be equalized whereas those of the root biomass tend to vary; this suggests equalization of the growth efficiency of every species per unit surface area. In the case of the total root surface area, the index of *P. densiflora* was 81, smaller than that of *C. japonica*. Those of *Ch. obtusa* and *L. leptolepis* were about 1/4 and 1/2 of that of *C. japonica* respectively. This is because the small and the medium roots of *P. densiflora* have wide surface areas even though its fine root has a strikingly narrow surface area.

The annual growth/leaf biomass ratio was high, 4.3 to 5.7, as shown in Table 20, for the deciduous broad-leaved species, such as ***Betula platyphylla*, *Betula davurica*, *Eucalyptus globulus*, *L. leptolepis*, *Zelkova serrata***, etc., while it was low, 1.0 to 2.1, for coniferous species, such as ***C. japonica*, *Ch. obtusa*, *P. densiflora***, etc.

This is partly because the leaf biomass of the deciduous broad-leaved species is small for growth and partly because the growth ratio of the coniferous trees becomes lower as the leaf biomass increases due to the accumulation by leaves in the few past years.

The annual growth/leaf biomass ratio of each species became lower in the order of ***Betula platyphylla*** (271), ***Eucalyptus globulus*** (248), ***Betula davurica*** (243), ***Zelkova serrata***, and ***L. leptolepis*** (both 205), as shown in Table 21. All of them were over twice as high as that of ***C. japonica***. That of ***Ch. obtusa*** was 48, about 1/5 of that of ***L. leptolepis*, *P. densiflora*** had almost the same growth ratio as ***C. japonica*** had.

(2) Tree growth and growth ratio

The relation between the tree growth and the growth ratio of each factor is shown by plotting the latter against the basal area in Fig. 5.

A wide dispersion is perceived in each growth ratio as it is greatly affected by site conditions. As a general tendency the growth ratio of every factor, however, tends to decrease in inverse proportion to the basal area.

The annual growth/fine root biomass ratios ranged from 10 to 15 in the stands with small site quality indices such as S3, S6, S7, S21, S23, S27, etc. at the basal area of about 100cm^2. Instead they were 25 to 30 in the moderately-grown young stands and 20 to 25 in the moderately matured stands. They are shown in Table 22 at the respective growth ratios at the basal areas of 1,000cm^2 and 500cm^2 listed in Fig. 5.

In Fig. 3 the fine root biomass, fine root surface area, and total root surface area all changed nearly rectilinearly. In the matured stands each growth ratio decreased. This arises from a twofold fact, on the one hand that the ratio of increase of growth is lower in the matured stand than that of the fine root biomass, fine root surface area or total root surface area, and on the other hand, that the production efficiency of roots goes up for young trees, and instead down for large-diameter trees. Furthermore, that arises from a twofold fact ; firstly, in the matured stands, both the absorption efficiency by root and

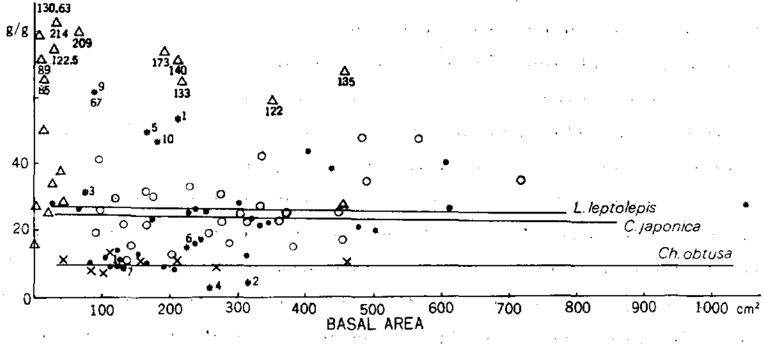


Fig. 5-1. Ratio of annual growth to fine root biomass by basal area.

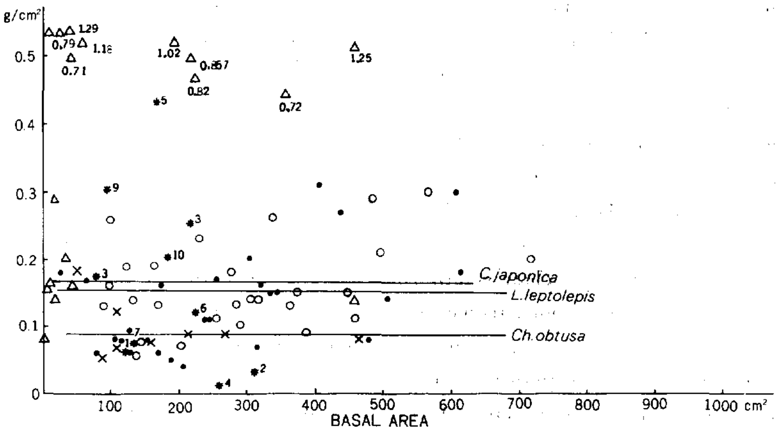


Fig. 5-2. Ratio of annual growth to fine root surface area by basal area.

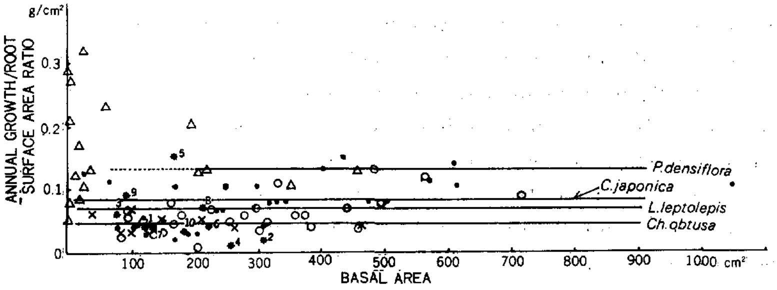


Fig. 5-3. Ratio of annual growth to whole root surface area by basal area.

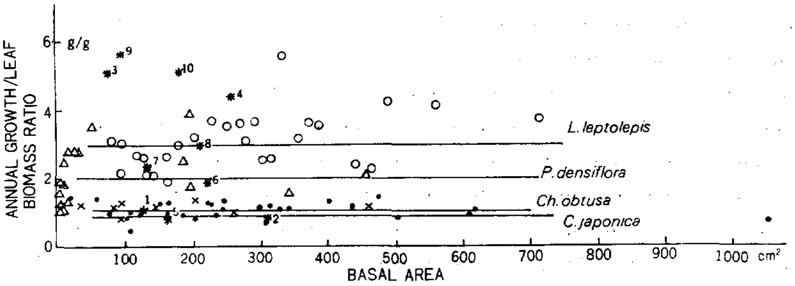


Fig. 5-4. Ratio of annual growth to leaf biomass by basal area.

Table 22. Growth ratio of *C. japonica* at the basal area of 100 and 500cm².

Basal area (cm²)	100	500
Annual growth/fine root biomass (g/g)	25 ～ 30	20 ～ 25
Annual growth/fine root surface area (g/cm²)	0.16 ～ 0.17	0.15 ～ 0.16
Annual growth/total root surface area (g/cm²)	0.08	0.07
Annual growth/leaf biomass (g/g)	1.0 ～ 1.5	1.0 ～ 1.2

assimilation-and-production efficiency by leaf go down, or consumption by respiration goes up, and secondly in the immature stands, the tissues are young, the efficiency of absorption and assimilation is high, and the production efficiency gets higher as fine and small roots have a greater part.

(3) Soil conditions and growth ratio

Each growth ratio varies with soil conditions. The relation of the annual growth/fine root biomass ratio to the soil type, site quality index, moisture condition in the field condition, and minimum air capacity is shown in Fig. 6. The data of the typical stands of *P. densiflora* which show their clear relations, are shown in Table 23 extracted from Fig. 6.

The annual growth/fine root surface area ratios, as shown in Table 23, were 0.30 in the A7 stand of moist soil, 0.72 to 1.30 in the moderately moist soil and 0.09 to 0.22 in the dry soil. The efficiency in growth went up in all the moderately moist soils and down in the dry soils. This change was remarkable in the annual growth/fine root biomass ratio and less remarkable in the total root surface area ratio. The ratios of each investigated species to the Al stand showing the highest ratios as shown in Table 24 were 0.75 to 1.00 in the moderately moist soil, 0.07 to 0.17 in the dry soil, and 0.24 in the moist soil. The annual growth/fine root surface area ratios were 0.55 to 1.00 in the moderately moist soil, 0.07 to 0.17 in the dry soil and 0.23 in the moist soil. The former ratios made an increase of difference by 1 to 2% between species. This explains that the site conditions have a greater influence on the surface area than the biomass of a fine root.

The annual growth/total root surface area ratios were 0.38 to 1.00 in the moderately moist soil, 0.16 to 0.41 in the dry siol, and 0.41 in the moist soil. The difference between species was smaller because the ratios in the dry and moist soils became higher than those of the other growth ratios.

This indicates that the absorption efficiency of the fine root surface area rather than that of the fine root biomass becomes constant. The total root surface area showed equalization of the absorption efficiency in all species and site conditions. This is because the total root surface area includes those of the roots larger than a small root, which are not easily influenced by soil conditions.

The pF values in the field condition and the annual growth/fine root biomass ratios were 1.9 and 52 respectively in the A7 stand of moist soil, 2.9 to 4.0 and 17 to 38 in the A6 to All stands of dry soil. The growth ratios decreased in both the moist soils with the pF values of 1.9 and below and the dry soils with those of 2.9 and avove.

The growth ratios went up in the moderately moist soils with the amount of water in the field condition of 42 to 49%, and down in the dry soils with that of 20 to 23%.

The growth ratios rose in the soils with minimum air capacities of 9 to 15% and fell off in the dry soils with minimum air capacities of more than 15%.

The C/N ratio was high in a devastated and dry soil, about 41 in the A6 stand. Its annual growth/fine root biomass ratio was 17. The growth efficiency of a fine root decreased remarkably in the stands with inferior chemical properties and with the C/N ratios of over 20.

Of the soil conditions, the factor most closely connected with the growth ratio is the water condition. The growth ratios go down remarkably in the dry soils, and also down in the excessively moist soils because of inferior aeration. This is because absorption by the roots is limited under both conditions.

Table 23. Soil properties and various growth ratios of *P. densiflora*.

Soil	Moist soil	Moderately moist soil				Dry soil		
Stand	A 7	A8	A1	A2	A4	A11	A12	A6
Soil type	Bl_D	Bl_D	$Bl_{D(d)}$	$Bl_{D(d)}$	Bl_D	B_A	B_A	Er_{-B}
Site index	24	16	19	17	17	7	12	12
Value of pF in field condition	1.90	2.10	2.00	2.40	2.30	4.00	2.90	2.90
Water in field condition (%)*	42.3	41.7	44.2	48.3	48.8	19.8	32.5	32.5
Minimum air capacity (%)	8.2	15.2	13.1	9.9	8.9	29.6	15.2	15.2
C/N ratio	11	10	10	16	15	17	17	41
Annual growth/fine root biomass (g/g)	52	136	214	209	122	38	35	17
Annual growth/fine root surface area (g/cm^2)	0.30	1.25	1.30	1.19	0.72	0.22	0.20	0.09
Annual growth/total root surface area (g/cm^2)	0.13	0.17	0.32	0.26	0.12	0.13	0.11	0.05
Annual growth/leaf biomass (g/g)	2.5	2.1	2.9	3.5	1.6	2.3	2.8	1.3

* Percentage in volume.

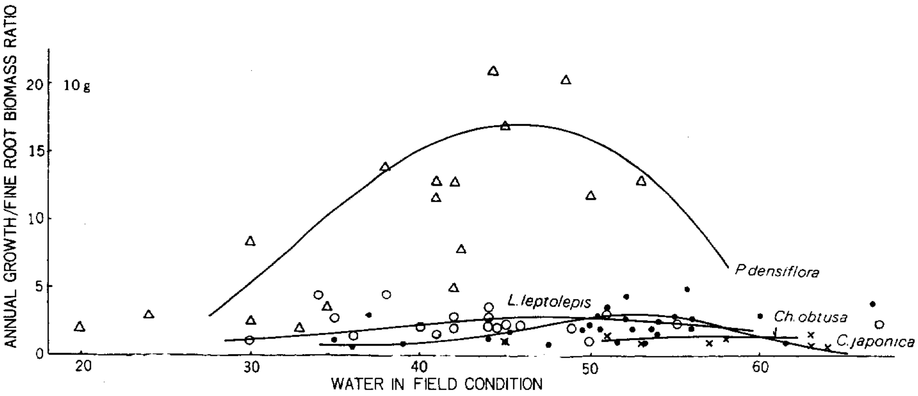


Fig. 6-1. Ratio of annual growth to unit fine root biomass, and water in field condition.

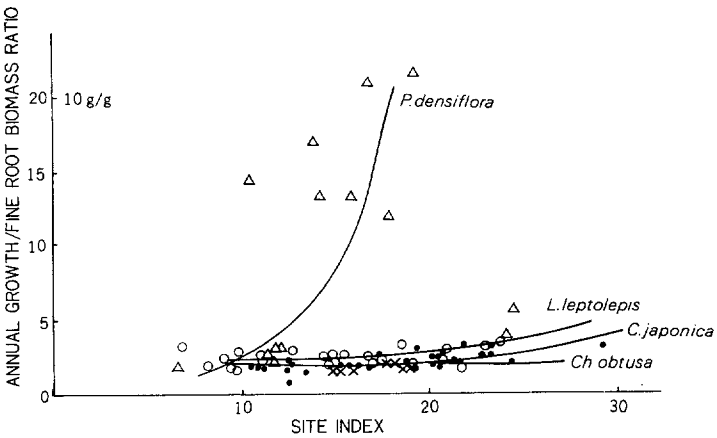


Fig. 6-2. Ratio of annual growth to fine root biomass, and site index.

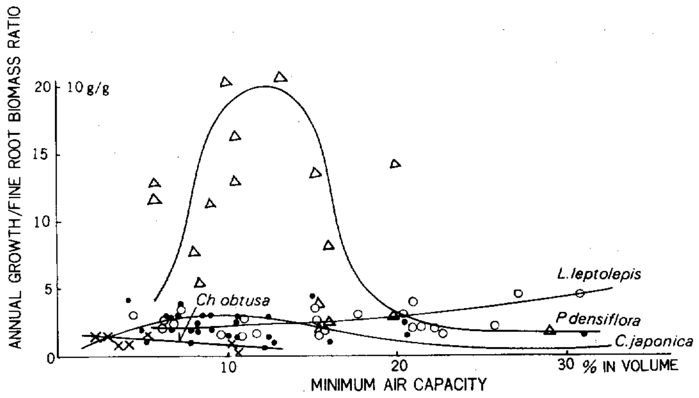


Fig. 6-3. Ratio of annual growth to fine root biomass, and minimum air capacity.

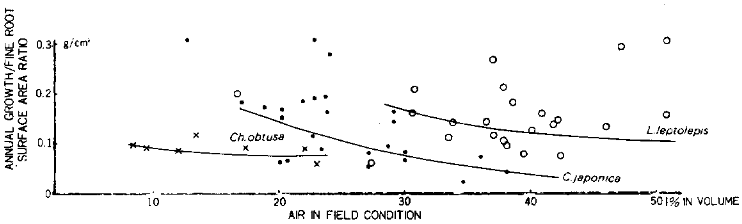


Fig. 6-4. Ratio of annual growth to fine root surface area, and air in field condition.

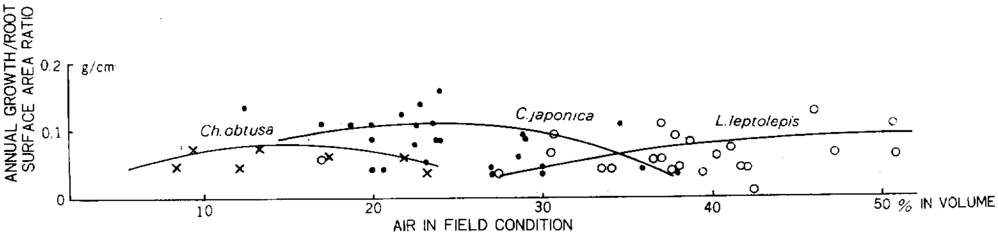


Fig. 6-5. Ratio of annual growth to total root surface area, and air in field condition.

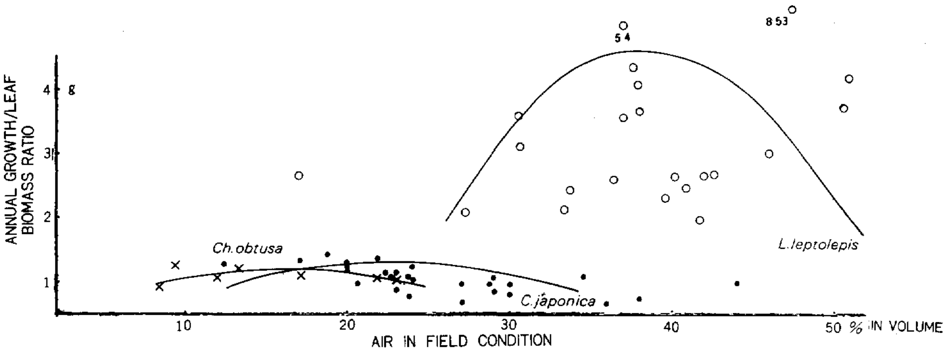


Fig. 6-6. Ratio of annual growth to leaf biomass, and air in field condition.

Table 24. Growth ratios of different stands to the stand A1 of *P. densiflora*.

Stand	A7	A8	A1	A2	A4	A11	A12	A6
Annual growth/fine root biomass (g/g)	0.24	0.64	1.00	0.98	0.57	0.18	0.16	0.08
Annual growth/fine root surface area (g/cm^2)	0.23	0.96	1.00	0.92	0.55	0.17	0.15	0.07
Annual growth/total root surface area (g/cm^2)	0.41	0.53	1.00	0.81	0.38	0.41	0.34	0.16
Annual growth/leaf biomass (g/g)	0.86	0.72	1.00	1.21	0.55	0.79	0.97	0.45

Table 25. Soil properties and various growth ratios of *C. japonica*.

Soil	Moist soil			Mderately moist Soil			Dry soil		
Stand	S22	S18	S26	S 4	S17	S19	S 7	S20	S24
Soil type	B_E	B_E	Bl_E	Bl_D	Bl_D	B_D	Bl_C	B_A	B_A
Site index	22	23	19	19	21	21	14	15	11
pF value in field condition	1.90	2.20	2.20	2.20	2.24	2.10	3.00	3.00	2.80
Water in field condition (%)*	66.5	52.2	51.6	54.1	51.4	50.0	45.0	35.2	36.2
Minimum air in field condition (%)*	4.2	15.0	7.0	8.3	6.8	20.4	8.0	31.1	20.6
C/N ratio	12	14	13	14	13	14	18	23	13
Annual growth/fine root biomass (g/g)	44	40	39	23	27	23	9	11	11
Annual growth/fine root surface area (g/cm^2)	0.31	0.30	0.28	0.15	0.19	0.16	0.05	0.07	0.06
Annual growth/total root surface area (g/cm^2)	0.13	0.14	0.16	0.09	0.11	0.09	0.04	0.04	0.04
Annual growth/leaf biomass (g/g)	1.3	0.9	1.0	1.2	0.7	1.0	0.9	1.0	1.0

* Percentage in volume.

The annual growth/leaf biomass ratios as shown in Table 23, were 2.5 in the A7 stand of moist soil, 1.6 to 3.5 in the A8, A1 and A4 stands of moderately moist soil, and 1.3 to 2.8 in the A11, A12 and A6 stands of dry soil. The great difference as seen in the growth ratio by root was not observed, although that ratio was slightly high in the moderately moist soils. The ratios to the A1 stand were 86 in the A7 stand, and 45 in the A6 stand. The production in the devastated and dry soils was about half of that in the moderately moist soils. The production efficiency by the leaf decreased with the absorption efficiency by the roots.

The above-mentioned relation to the other species is as follows :

a. *C. japonica*

The relation between the soil conditions and the growth ratios of *C. japonica* is shown in Table 25. This species did not make as great a change in ratio as *P. densiflora*.

The annual growth/fine root biomass ratios were 39 to 44 in the wet B_E to Bl_E soil-typed stands S22, S18 and S26, 23 to 27 in the moderately moist soil, and 9 to 11 in the dry soil. If converted into the values of pF, they were high at the ratios of 1.9 to 2.2. And they lessened in the dry soil with those of 2.8 to 3.0. They were high and low at the respective amount of water, 52 to 67% and 36 to 45%, in the field condition. Although they did not show a clear correlation with the minimum air capacity and C/N ratio, they were high

Table 26. Soil properties and various growth ratios of *Ch. obtusa*.

Soil	Moist soil	Moderately moist soil	Dry soil
Stand	H4	H2	H6
Soil type	$B_{D(w)}$	B_D	B_B
Site index	15	18	11
Value of pF in field condition	1.71	2.22	2.96
Water in field condition (%)*	64.1	63.1	45.2
Minimum air in field condition (%)*	3.4	3.2	4.2
C/N ratio	15	11	23
Annual growth/fine root biomass (g/g)	9	15	8
Annual growth/fine root surface area (g/cm^2)	0.10	0.13	0.05
Annual growth/total root surface area (g/cm^2)	0.05	0.07	0.03
Annual growth/leaf biomass (g/g)	1.0	1.2	1.1

* Percentage in volume.

when the minimum air capacity and the C/N ratio were less than 8 to 9% and 15%, respectively.

The annual growth/fine root surface area ratios were 0.28 to 0.31 in the moist soil, 0.15 to 0.19 in the moderately moist soil, and 0.05 to 0.07 in the dry soil. The annual growth/total root surface area ratios were 0.13 to 0.16, 0.09 to 0.11 and 0.04, respectively. As seen in the fine root biomass, they went up in the wet soil and down in the dry soil. The difference in ratio between species was, as in the case of *P. dendiflora*, smaller for the annual growth/total root surface area ratio than for the annual growth/fine root biomass ratio.

Thus the growth efficiency of the roots of *C. japanica* goes higher in the rather moist soil. The annual growth/fine root biomass ratio in the moist B_E type soil was about 4 times as high as that in the dry B_A type soil. Two reasons for this are first, that the work and the growth of the species's roots are vigorous in a wet condition, and second that they show the large growth for fine root biomass. This relation is common to the fine root surface area and the total root surface area.

The annual growth/leaf biomass ratios were 0.9 to 1.3 in the moist soil, 0.7 to 1.0 in the moderately moist soil, and 0.9 to 1.0 in the dry soil. They tended to be a little higher in a rather moist condition, though not so much as the roots. This indicates that the fine root biomass or surface area changes more markedly with site conditions than the leaf biomass.

b. *Ch. obtusa*

The annual growth/fine root biomass ratios of *Ch. obtusa*, as shown in Table 26, were 9 in the H4 stand with rather moist soil of $B_{D(w)}$ type, 15 in the H2 stand with moderately moist soil, and 8 in the H4 stand with dry soil. It decreased under both dry and wet conditions.

Ch. obtusa is a species with roots that develop in an aerobic soil. In this respect it is different from *C. japonica*, the roots of which grow even in an anaerobic soil. That ratio fell off in moist soil.

The values of pF were 1.7, 2.2, and 3.0, in the stands of H4, H2, and H6 respectively. The water conditions in the field condition were 64%, 63% and 45%, and the C/N ratios were 5, 11 and 23 in the respective stands. These ratios are remarkably high in the dry soils.

The annual growth/fine root biomass or total root surface area ratio was also highest in the moderately moist soil as seen in the annual growth/fine root biomass ratio.

The annual growth/leaf biomass ratios were 1.0 in the moist soil, 1.2 in the moderately moist soil, and 1.1 in the dry soil. They did not make as great a difference as the growth ratio by root in *P. densiflora* and *C. japonica*. It is interesting, however, that the ratio was higher in a dry soil than in a moist soil, unlike the root growth ratio.

c. *L. leptolepis*

The relation between the soil condition and the growth ratio of *L. leptolepis* is shown in Table 27. According to this, the annual growth/fine root biomass ratios were 20 to 29 in the excessively ~~moist~~ soils of Bl_F–Bl_G types, 35 to 48 in the moderately most soil, and 11 to 13 in the dry soil. As already mentioned on *Ch. obtusa*, the growth ratio was high in the moderately moist soil and low in the excessively moist or dry soil.

The annual growth/fine root surface area ratios were 0.13 to 0.20 in the excessively moist soil, 0.21 to 0.30 in the moderately moist soil, and 0.06 to 0.08 in the dry soil. The annual growth/total root surface area ratios were 0.04 to 0.07, 0.09 to 0.14, and 0.02 to 0.04 respectively. In relation to any soil factor, they were low in the heavy wet or dry condition.

The relation between the site index and the growth ratio is shown in Table 27.

The site indices were, as shown there, 8 to 11 in the excessively moist soil, 21 to 24 in the moderately moist soil, and 10 to 11 in the dry soil. This shows clearly that the annual growth/fine root biomass ratio rises in the moderately moist soil with a large site index. There was a close correlation between them.

The water in field condition was 55 to 67% in the excessively moist soil, 33 to 42% in the moderately moist soil, and 30 to 50% in the dry soil. The minimum air capacities were 4.2 to 6.4%, 15 to 31% and 11 to 15% in the respective soils. This minimum air capacity was extremely low in the excessively moist soil. Undoubtedly excessive moisture

Table 27. Soil properties and various growth ratios of *L. leptolepis*.

Soil	Moist soil			Moderately moist soil			Dry soil		
Stand	K4	K5	K7	K21	K20	K14	K23	K26	K29
Soil type	Bl_F	$Bl_{E\text{-}F}$	Bl_G	Bl_D	Bl_F	Bl_D	$Bl_{D\text{-}m}$	Bl_C	Bl_B
Site index	8	9	11	23	24	21	10	10	11
Water in field condition (%)*	56.0	55.3	67.2	37.8	33.7	41.7	49.5	36.4	30.2
Minimum air capacity (%)*	4.2	6.4	4.7	30.7	27.2	15.2	11.6	10.8	15.4
C/N ratio	16	14	13	12	11	10	14	13	14
Annual growth/fine root biomass (g/g)	20	25	29	47	48	35	11	13	13
Annual growth/fine root surface area (g/cm^2)	0.13	0.16	0.20	0.30	0.31	0.21	0.06	0.08	0.08
Annual growth/total root surface area (g/cm^2)	0.04	0.07	0.05	0.14	0.12	0.09	0.03	0.04	0.02
Annual growth/leaf biomass (g/g)	3.2	3.1	2.7	8.5	4.2	4.3	2.0	2.5	2.7

* Percentage in volume.

and inferior aeration caused the growth ratio to drop.

The C/N ratios were 13 to 16 in the excessively moist soil, 10 to 12 in the moderately moist soil, and 13 to 14 in the dry soil.

Thus, a close correlation was recognized between each soil condition, especially moisture and aeration conditions, and growth ratio.

The annual growth/leaf biomass ratios were 2.7 to 3.2 in the excessively moist soil, 4.2 to 8.5 in the moderately moist soil, and 2.0 to 2.7 in the dry soil. They were slightly high in the moderately moist soil, and low in both dry and moist conditions.

The relations mentioned above as to each spcies are shown in Fig. 6. The relations of all these factors to the annual growth/fine root biomass ratio are explained as follows :

The annual growth/fine root biomass ratio of *C. japonica* reached about 50 when the water ratio was 50 to 55% in the field condition, but about 10 in the dry conditions (water ratio of 35 to 40%) and the excessively moist conditions (water ratio of over 60%). *L. leptolepis* resembled *C. japonica* in the annual growth/fine root biomass ratio. The former, however, had a high growth ratio even in the rather dry conditions with the water ratio of 40 to 50%. Its growth ratio dropped in the dry conditions (below 30%) or excessively moist conditions (over 60%). *P. densiflora* yielded a high ratio when the moisture ratio became 40 to 50%. *Ch. obtusa* yielded a comparatively high ratio even in the moist soil with the moisture of 50 to 60%.

The growth ratios increased, as shown in Fig. 6, with the site index. They became lower in the order of *P. densiflora*, *L. leptolepis*, *C. japonica*, and *Ch. obtusa*. They depend on their fine root biomass. *L. leptolepis*, for example, had a high ratio because of the small fine root biomass, and *Ch. obtusa* had a low ratio, because of the large biomass.

The growth ratios became higher when the minimum air capacities were 10 to 14% for *P. densiflora*, 8 to 9% for *C. japonica*, 20 to 30% for *L. leptolepis*, and 4 to 5% for *Ch. obtusa* respectively. *Ch. obtusa* grew well under aerobic conditions, and its growth did not deteriorate much even in the site with a small minimum air capacity.

The relation between the annual growth/total root surface area ratio and the amount of air in the field condition is shown in Fig. 6. The ratios were, as shown there, 0.07 for *Ch. obtusa* with only about 15% of the amount of air, and 0.15 for *C. japonica* with 24%. When the amount of air went beyond this, the production decreased. This is because a site with a large amount of air is generally a dry one and even though the amount of air is good for growth the dry condition that goes with it cuts down the production. In addition, the production of *L. leptolepis* was largest (0.1) when the amount of air was 35 to 40%. Outside of this range the growth ratio decreased.

The relation between the annual growth/leaf biomass ratio and the amount of air in the field condition is shown in Fig. 6. According to the figure, the growth ratios were highest, 1.2, at 14% of air for *Ch. obtusa*, 1.5 at that of 20% for *C. japonica*, and 4.5 at that of 38% for *L. leptolepis*. They decreased in the sites with the amount of air above or below those values. Below that, respiration was restricted by excessive moisture, whereas above that, the growth was restricted by drought.

Each growth ratio changes according to site conditions. It reaches the maximum value under the most suitable conditions for each species, and therefore can be regarded as an index of the productivity of a forest.

Particularly as often pointed out, the root growth ratio changes more clearly than that of leaf biomass under the influence of soil conditions. So it is desirable for the judgment of the productivity to make use of the growth ratios by root, relating directly to site conditions.

6) Ratios of lief biomass to the fine root biomass, fine root surface area, and total root surface area

A fixed correlation exists between each growth ratio and each factor related to it.

These relations are expressed as the ratios of the leaf biomass, a working part of the above-ground parts, to the biomass and surface area of a fine root and to the total surface area of roots, working parts of the underground parts. That is to say, they are the leaf biomass/fine root biomass ratio, leaf biomass/fine root surface area ratio, and leaf biomass/total root surface area ratio. Their variations are as follows in relation to the tree growth and site conditions.

(1) Growth of a tree and leaf biomass/fine root biomass, leaf biomass/fine root surface area and leaf biomass/total root surface area ratios

The relations between the basal area and the ratios of such root factors as the leaf biomass/fine root biomass, fine root surface area, and total root surface area are shown in Fig. 7. As this figure shows, they increased parabolically to become constant in large diameter trees. The leaf biomass/fine root biomass ratio of *C. japonica* for example, as shown in Table 28, was 15 at the basal area of 100 cm². With the increasing basal area, they increased gradually to 21 at that of 300 cm², and 30 at that of 500 cm². They did not increase as much after that. This is partly because the fine root biomass of the immature tree is large for the leaf biomass, and partly because after reaching the maximum when young it goes on decreasing with the tree growth to be almost constant, while the leaf biomass increases to be almost constant. The leaf biomass/fine root surface area ratio and the leaf biomass/total root surface area ratio also increased sharply until the basal area reached 400 to 500cm²; then the increasing ratio decreased, making the ratios almost constant.

Putting this relation together with the annual growth in volume and the current total annual growth in stand, it became evident that the annual growth and total production inclined upwards at the young stage when the fine root biomass was large for the leaf biomass, and that the annual growth was on the decline with the ratio of increase of the leaf biomass/fine root biomass ratio.

They make clear firstly that the assimilation is related to the absorption of water and nutriment, secondly that the growth tends to increase on the same site condition when the fine root biomass is large even if the soil conditions or the leaf biomass is constant, and thirdly that the growing pace of matured trees drops in spite of the increase of the leaf biomass because the absorption of water or nutriment does not increase when the ratio of increase of the fine root biomass is low.

The observation of changes of leaf biomass and root biomass also indicated that insufficient absorption by the underground parts caused the assimilation efficiency of leaf to deteriorate

Table 28. Basal area and ratios of leaf biomass-root factor in *C. japonica*.

Basal area (cm²)	100	200	300	500	1000
Leaf biomass/fine root biomass (g/g)	15	18	21	30	38
Leaf biomass/fine root surface area (g/cm²)	0.10	0.12	0.15	0.21	0.30
Leaf biomass/total root surface area (g/cm²)	0.05	0.06	0.08	0.11	0.43

Table 29. Ratios of leaf biomass-root factor of each species at the basal area of 500cm^2.

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Leaf biomass/fine root biomass (g/g)	30(1.00)	13(0.43)	72(2.40)	10(0.33)
Leaf biomass/fine root surface area(g/cm^2)	0.22(1.00)	0.11(0.50)	0.76(3.45)	0.06(0.27)
Leaf biomass/total root surface area (g/cm^2)	0.11(1.00)	0.05(0.45)	0.09(0.82)	0.03(0.27)

Figures in the parentheses show the ratios to the values of *C. japonica*.

Table 30. Soil types and ratios of leaf biomass/root factor in *C. japonica*.

Stand	S18	S19	S20
Soil type	B_E	B_D	B_A
Site index	23.4	20.6	15.4
Leaf biomass/fine root biomass (g/g)	45.74	22.78	10.71
Leaf biomass/fine root surface area (g/cm^2)	0.3444	0.0136	0.0694
Leaf biomass/total root surface area (g/cm^2)	0.1607	0.0876	0.0417

and the growth to decrease. Under a given environmental condition the quantitative correspondence of the leaf and fine root was closely connected with production. The working efficiencies of them showed only a slight difference.

This tendency, as shown in Fig. 7, was comparatively clear for *C. japonica* or *P. densiflora*. For *Ch. obtusa* or *L. leptolepis*, however, the ratio of increase was low. Therefore, the ratios of the small and the large trees showed little difference.

This tendency of the relation of the basal area to the leaf biomass/fine root biomass ratio was also observed in the relation of the basal area to the leaf biomass/fine root surface area ratio. Difference between species became smaller in the rate of increase of the leaf biomass/total root surface area ratio. The leaf biomass/total root surface area ratio was the lowest for *Ch. obtusa* one-sixth as high as the highest for *P. densiflora*. The highest leaf biomass/total root surface area ratio for *C. japonica*, was about 3 times as high as the lowest for *L. leptolepis* (Table 29).

This indicates the difference of quantitative structures for the assimilative and absorptive parts of each species. Since *Ch. obtusa* or *L. leptolepis* with comparatively inferior growth show lower ratios than *P. densiflora* or *C. japonica* with good growth, the first two show a low growing efficiency for root biomass.

When the ratio of *C. japonica* was to be 1, the ratios of the leaf biomass to each root factor of *Ch. obtusa* shown in Table 29, were 0.43 to 0.50, and those of *P. densiflora* were 0.82 to 3.45. The leaf biomass/fine root surface area ratio of *P. densiflora* was much higher than that of *C. japonica*, because the fine root biomass of the former was small for the leaf biomass. Those of *L. leptolepis* were 0.27 to 0.33, about 1/3 of those of *C. japonica*.

(2) Soil conditions and each leaf biomass/root factor ratio

The fine root biomass varies with soil conditions, as do the fine root surface area, total root surface area, and each leaf biomass/root factor ratio. Table 30 shows the leaf biomass/fine root biomass ratio of the S18, 19 and 20 stands of *C. japonica* under the different soil conditions. The leaf biomass/each root factor ratio in the devastated and dry stands with a small

Table 31. Soil types and ratios of leaf biomass/root factor in *L. leptolepis*.

Stand	K6	K14
Soil type	Bl_{E-F}	Bl_D
Site index	6.8	21.0
Leaf biomass/fine root biomass (g/g)	19.03	7.98
Leaf biomass/fine root surface area(g/cm²)	0.1224	0.0486
Leaf biomass/total root surface area (g/cm²)	0.0353	0.0207

site index, as shown there, has a tendency to become lower as the fine root biomass increases. The leaf biomass/fine root biomass ratios were 46 in the B_E type soil, 23 in the B_D type soil, and 11 in the B_A type soil. The B_E soil had four times as great a difference in ratio as the B_A soil. This holds true in the case of the ratios of the fine roots and total roots by surface area.

The above-mentioned are as follows; 1), the leaf biomass/fine root biomass ratio drops in a dry soil; 2), the assimilation efficiency by leaf increases in the B_A dry soil if the absorptive efficiency by fine root is the same for every stand; 3), the insufficient growth at the site index of 15.4 means that despite the large fine root biomass the absorptive efficiency drops remarkably due to either the lignification of fine roots or to the lack of water and nutrient. In summation, therefore, an increase of the growth such as already mentioned does not take place hand in hand with the fine root biomass.

In this respect, as the environmental conditions are quite different in moderately moist soil and dry soil, the effects of the leaf biomass/root factor ratio on growth are quite different.

The trees in a barren and dry stand have similar structures in the partial biomass to the small trees in a moderately moist stand. Their own efficiencies, however, cause the difference in growth to fall in between the two. The relations mentioned above are generally observed between stands with large and small site quality indices.

Table 31 shows the ratios of *L. leptolepis*, which are caused to be comparatively unchangeable by site conditions. According to the table, the ratio was 8 at the site index of 21 in the Bl_D soil-typed stand of K14, while it increased strikingly to 19 in the K6 stand of the Bl_{E-F} type soil because overhumidity caused a fine root to die. This means that the aerobic fine roots of *L. leptolepis* rot and die under an excessively moist condition, which causes the absorption structure to break up.

(3) Tree density and leaf biomass/various root factors ratio

The relation between the density index and the leaf biomass/each root factor ratio is shown in Fig. 7. The leaf biomass/fine root biomass ratio out of the figure was 40 at the density index of 1.2 in the dense stand of S22, and 38 at that of 0.4 in the stand of S26 with almost the same diameter. The leaf biomass/total root surface area ratio was, on the contrary, higher in the S26 stand than in the S22 stand. Judging from the fact that the S22 stand is of B_E type soil and the S26 stand of B_D type soil, no distinct difference between the leaf weight/root factor ratios caused by difference in density was supposed to exist.

The leaf biomass/root factor ratios in S29, S8 and S28 stands with almost the same basal area and the different density ratios are shown in Table 32. The ratios were lower in the S8 stand with a larger density index than in the stands of S28 and S29 with a smaller density index in this case. It was therefore difficult to judge whether the tree density caused a distinctive difference to come out between the ratios.

7) Average net assimilation ratio and average respiration ratio

From each average partial biomass per tree the average assimilation ratio and the average respiration ratio are figured out as follows:

$\Delta W = aW_L - RWc$

ΔW=growth of an individual (dry weight) per year

W_L=dry weight of the leaf

Wc=total dry weight of the unassimilated part

a=average assimilation ratio of the leaf

R=average respiration ratio of the unassimilated part

The average net assimilation ratio will be called the assimilation ratio hereafter, and the average respration ratio the respiration ratio.

The above equation divided by Wc is $\frac{\Delta W}{Wc} = a\frac{W_L}{Wc} - R$ and there exists a linear regression between $\frac{\Delta W}{Wc}$ and $\frac{W_L}{Wc}$ (Fig. 8). As is clear from the large variance of those measured values, errors become larger even when the constant (respiration ratio of the unassimilated part: R) and the coefficient (assimilation ratio: a) are calculated by the method of least squares according to the above-mentioned regression equation. It is therefore difficult to get accurate respiration ratios or assimilation ratios. This is because even the respiration ratio or assimilation ratio of the same species varies with the stand age, tree density and soil condition. Many complete samples classified by stand age, tree density and soil condition are necessary to calculate these values accurately from the standing stock of stand.

Although the above samples show a low accuracy in this sense, it is possible to plot $\Delta W/Wc$ against W_L/Wc by taking the average of sample stands. Hence, regression lines as shown in Fig. 8, were drawn when the stands of the medium tree density and soil conditions were considered as a temporary standard. Table 33 gives the assimilation ratios and the respiration ratios thus acquired. According to the table, the former ratio in decreasing order is *L. leptolepis* (4.3), *P. densiflora* (3.0), *C. japonica* (1.4), and *Ch. obtusa* (1.3). The respiration ratios of *C. japonica* and *P. densiflora* are 0.04, about twice as high as those of *Ch. obtusa*

Table 32. Tree density indexes and ratios of leaf biomass-root factor in *C. japonica*.

Stand	S 29	S 28	S 8
Basal area (cm²)	117	229	238
Soil type	Bl_D	Bl_D	Bl_E
Tree density index	0.287	0.566	0.898
Leaf biomass/fine root biomass (g/g)	20.29	19.75	16.67
Leaf biomass/fine root surface area (g/cm²)	——	——	0.1192
Leaf biomass/total root surface area (g/cm²)	——	——	0.0753

Table 33. Average net assimilation ratio of leaf and average respiration ratio of non-assimilatory parts.

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Assimilation ratio of leaf (g/g/yr)	1.35	1.26	2.96	4.26
Respiration ratio of non-assimilatory parts (g/g/yr)	0.044	0.016	0.044	0.021

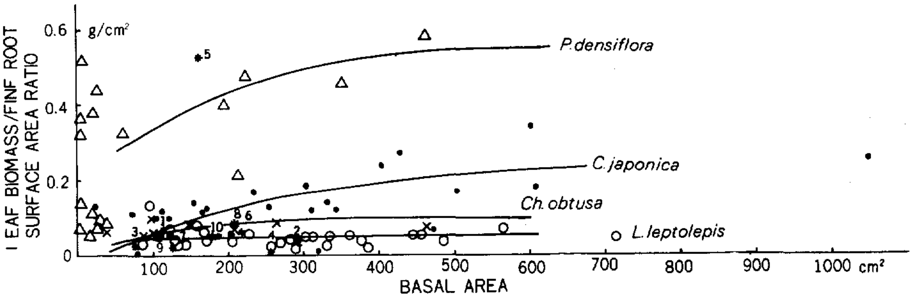


Fig. 7-1. Basal area, and ratio of leaf biomass to fine root biomass.

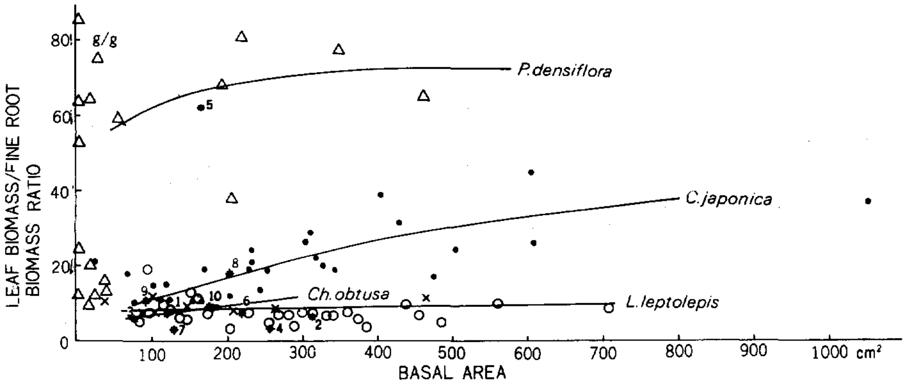


Fig. 7-2. Basal area, and ratio of leaf biomass to fine root surface area.

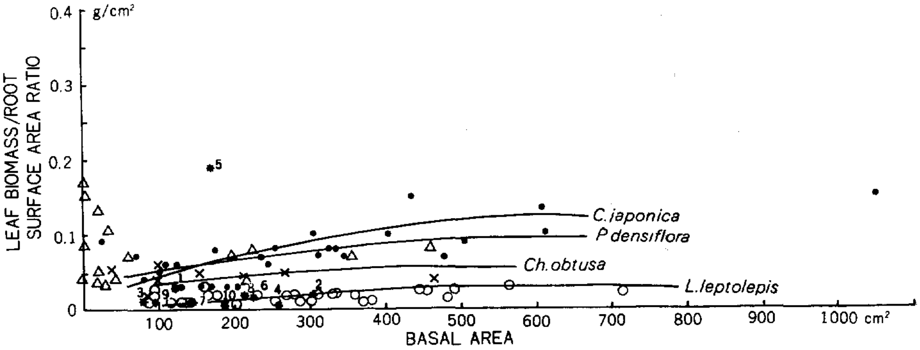


Fig. 7-3. Basal area, and ratio of leaf biomass to root surface area.

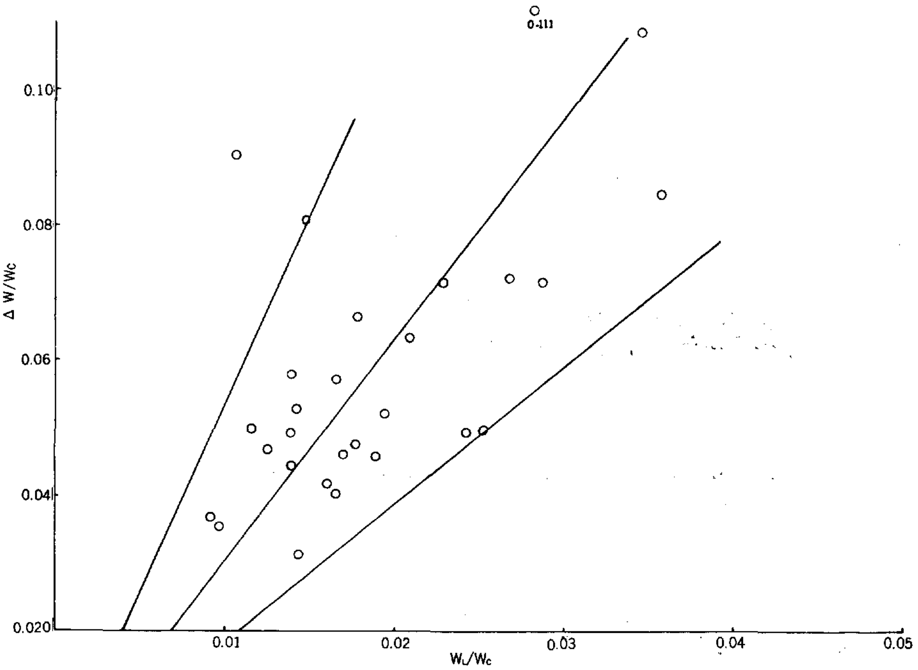


Fig. 8-1. Average net assimilation ratio of leaf and average respiration ratio of non-assimilatory parts of *C. japonica*, *Ch. obtusa*, *P. densiflora* and *L. leptolepis*.

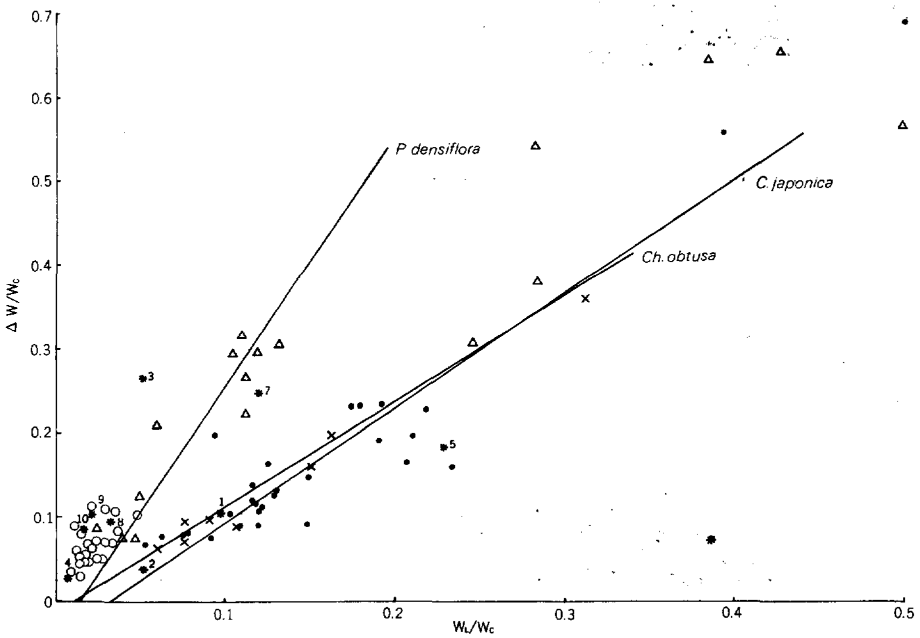


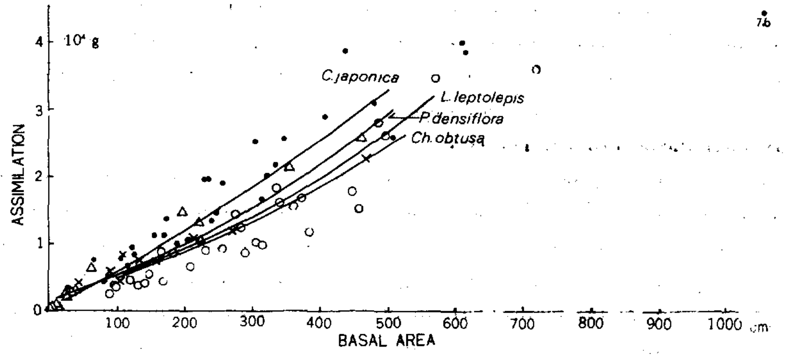
Fig. 8-2. Average assimilation ratio and average respiration ratio of non-assimilatory parts of *L. leptolepis*.

Table 34. Estimates of average net assimilation ratio of leaf and average respiration ratio of non-assimilatory parts[12].

Species	Assimilation ratio of leaf (g/g/yr)	Respiration ratio of non-assimilatory parts (g/g/yr)	References
C. japonica	1.14 (1.46~0.81)	0.023	SHIDEI and others
Ch. obtusa	2.42 (3.35~1.88)	0.030	〃
P. densiflora	2.05 (2.83~1.59)	0.055	YOSHINO (seedlings)
L. leptolepis	3.29 (4.12~2.45)	0.027	SHIDEI and others

Table 35. Average respiration ratio of each species.

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Respiration ratio of non-assimilatory parts (g/g/yr)	0.044	0.016	0.044	0.021
Respiration ratio of a tree (g/g/yr)	0.05	0.02	0.05	0.03



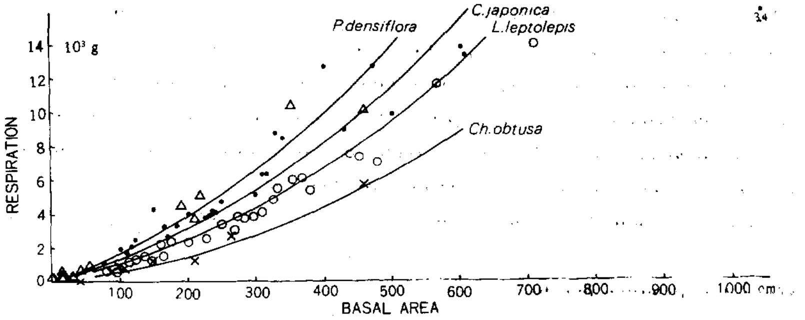


Fig. 9. Total assimilation and respiration a tree.

or *L. leptolepis* (0.02). As mentioned before, however, these relations differ with the accuracy of the measurements of standing stocks. The average net assimilation ratio and the average respiration ratio acquired from a rough estimate of standing stocks are very inaccurate as Shidei and others$^{11)}$ admitted. As seen by the two assimilation ratios of *P. densiflora* in Table 34, 0.030 and 0.055, even within the same species there is a large difference on the various conditions. When calculating of the assimilation ratio of the leaf, the respiration ratio of the unassimilated part is regarded to be constant. But as it also varies with various environmental conditions, the assimilation ratio cannot always be determined with the respiration ratio as a constant. Such physiological experiments as measuring respration and assimilation as well as analyzing the stand with many complete samples are necessary for determining these values. As a clue to analyse growth of the stand and as comparative values, however, even these values acquired from such samples are meaningful. The assimilation ratios became lower in order of *L. leptolepis, P. densiflora and C. japonica* and the values were almost the same both in Table 33 (by the author) and Table 34 (by Shidei).

In this calculation the average respiration ratio of *C. japonica* was 0.044 in Table 33, nearly twice as high as that in Table 34.

The reason why such a striking difference should appear is the subject for a future study. But here the respiration ratios of the unassimilated part and of the whole tree shown in Table 35 were used for calculation. When it is supposed that the assimilation ratios in Table 35 do not change in the various conditions, Fig. 9 shows respiration of the unassimilated part, the total respiration of the tree, the total assimilated product, and the assimilation ratio in each stand calculated from the detailed data.

8) Total assimilated product per tree

The total assimilated product, which is the sum of the annual respration and annual production of the whole tree, is shown in Fig. 9 in relation to the size of tree. The assimilated product increases describing a straight line or a concave curve slightly upward with the increase of the basal area. With *C. japonica*, as an example, it is 7kg in the immature stand of S1, and 31kg in the matured stand of S5. The annual assimilated product per tree and per year was about 10kg in the stand of S17, which had the broadest basal area of all investigated stands, and 30kg in the stand with grown-up trees and a basal area of about 500 cm^2.

Though this basal area-production curve is similar to the basal area-annual growth curve, the increasing curve of the assimilated product runs steeper than that of the annual growth as the respiration ratio among the assimilated product becomes higher for the large-tree (Fig. 9).

The assimilated product varies with species. It became smaller in the order of *C. japonica, P. densiflora, L. leptolepis*, and *Ch. obtusa*, regardless of stand age. The assimilated product of trees, for example, at a basal area of 500cm^2 was 32kg for *C. japonica*, 29kg for *P. densiflora*, 26kg for *L. leptolepis*, and 24kg for *Ch. obtusa*. The product of these species ranged from 20 to 30kg.

9) Assimilated product per ha

The assimilated product per ha calculated from the assimilated product per tree is shown in Fig. 10 in relation to the basal area. All species gave large assimilated products in their sapling stage. They were 35 tons for *C. japonica*, 30 tons for *P. densiflora*, and 20 tons each for *Ch. obtusa* and *L. leptolepis*, at the basal area of 200cm^2. At the basal area of about 500 cm^2, the assimilated products were about 30 tons for *C. japonica*, about 20 tons for *P. densiflora*,

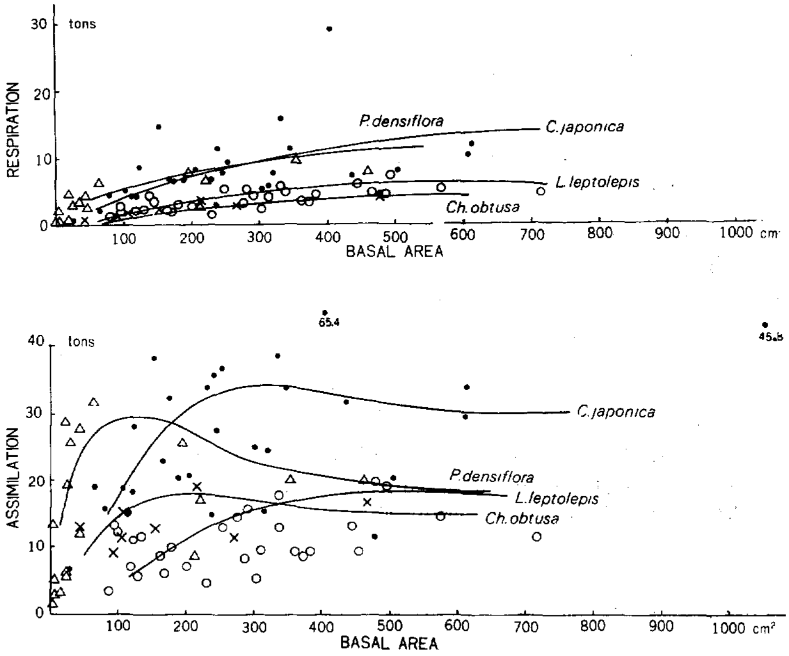


Fig 10. Total assimilation and respiration per ha in each tree size.

about 15 tons for *Ch. obtusa*, and about 13 tons for *L. leptolepis*. That is to say, the latter in a mature stand was smaller than the former in an immature stand. This is partly because the leaf biomass and the fine root biomass of every species increase at the young stage and the physiological metabolism works vigorously, and partly because the tree density is comparatively high in the sapling stage. Among these four species *C. japonica* showed comparatively large values. They were about twice as high as those of *L. leptolepis* and *Ch. obtusa*.

P. densiflora gave large assimilated product (25 to 30 tons) in the stands of A1, A10, A11 and A2. It became clear from the investigation that density was facilitated in these stands by natural regeneration, and that under those conditions the assimilated product of *P. densiflora* per area had a tendency to increase temporarily with the increase of assimilating efficiency in the sapling stage. Once grown up, the ratio of decrease in the number of *P. densiflora* is higher than those of other species; consequently the assimilated product decreased more sharply to about 20 tons.

10) Respiration per tree

The respiration per tree was obtained by multiplying the average respiration ratios of a whole tree in Table 35 by the total biomass of a tree. Respiration varies in proportion to the total biomass of a tree. That is to say, it increases as the total biomass of a tree increases with the increase of the basal area. The curve of increase of the respiration plotted against the basal area, different from that of assimilation, is a concave curve upward. It shows a tendency to rise sharply as the basal area becomes wider (Fig. 8).

The respirations at the basal area of 500cm² were 14kg for *P. densiflora*, 11.5kg for *C. japonica*, 9.5kg for *L. leptolepis* and 6.5kg for *Ch. obtusa*. They were 34kg in the S17 stand with the largest basal area of 1,040cm² and 13kg in the close planting stand of S22 (tree

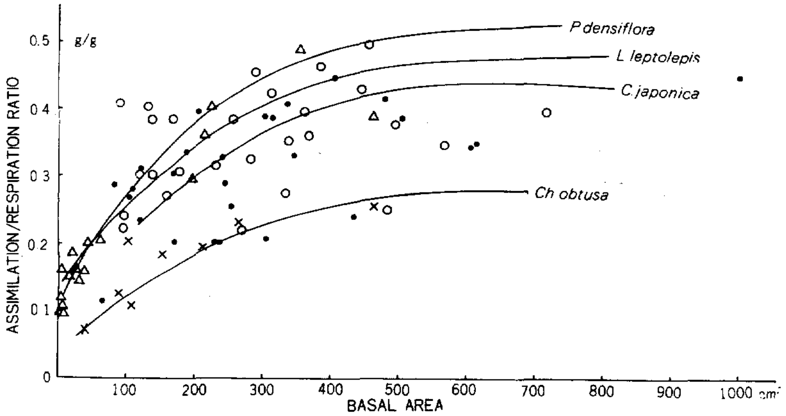


Fig. 11. Ratio of total respiration* to total assimilation**.

* Amount of respiation was calculated from the average respiration ratio table.

** Total assimilation : annual growth and total respiration of a tree.

density ratio; 1.2).

11) Respiration per ha

Respiration per ha increases gradually as shown in Fig. 10, and becomes almost constant at a basal area of about 300cm². At a basal area of 500cm² they were 13 tons for *C. japonica*, 12 tons for *P. densiflora*, 6 tons for *L. leptolepis*, and 4 tons for *Ch. obtusa*. *Ch. obtusa* gave one-third less than the respiration per ha of *C. japonica*. This species as well as *L. leptolepis* was smaller in respiration than *C. japonica* and *P. densiflora*. These in the S17 stand of large trees with a large proportion of the unassimilated part and in the dense planting S22 stand are large, nearly 20 tons and 30 tons respectively. The respiration, therefore, in a stand 23cm in average breast height diameter and at a density ratio of 1 was expected to range from about 25 to 30 tons. Since the unassimilated partial biomass is large as compared to the leaf biomass in dense planting stand of large trees, the respiration is large compared to the assimilated product. In the stand of S22, the assimilated product per ha was 65 tons and the respiration per ha was 30 tons. Therefore, almost 50% of the assimilated product was used for respiration.

12) Ratio of the respiration amount to the assimilated product

The ratio of the respiration to the total assimilated product is shown in Fig. 11. It increased with the increase of basal area because the respiratory part increased with it. For *C. japonica*, as an example, in the young S1 stand (61cm² in basal area), the respiration was 11% of the assimilated product and the remaining 89% was for growth, while in the S17 stand of large trees (1,040cm² in basal area) the respiration was 45% of the total assimilated product and the growth was 55%. The difference in growth between the two was 34%. The ratio of the respiration to the assimilated product increased rather sharply in a concave curve upward until the basal area came to 400 to 500cm². After that, it was almost constant.

At the young stage below 400 or 500cm² in basal area, the accumulation is much larger than the consumption of the assimilated product by respiration. This leads to the rapid growth at this stage. After that, the growing pace slows down because the ratio of the respiration to the assimilated product increases. This is another reason why the growth of a tree is active at the young stage and not at the grown-up stage (See Fig. 1). The rate of increase of this

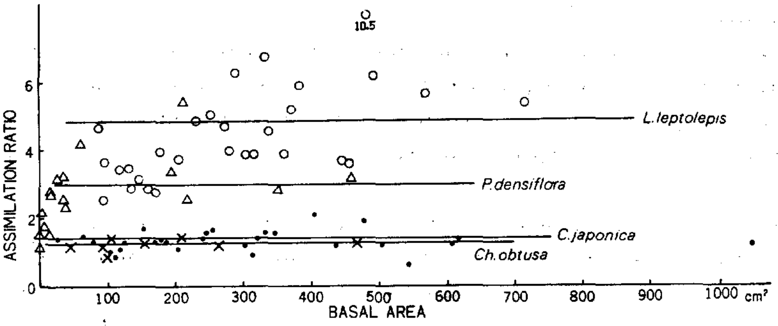


Fig. 12. Average net assimilation ratio* of leaf and basal area.
* Average net assimilation ratio : ratio of net assimilation to leaf biomass.

Table 36. Annual growth/leaf biomass ratio (A) and average net assimilation ratio of leaf (B) in *C. japonica* stand of different basal areas.

Stand	S 1	S 3	S2	S 4	S 5	S17
Basal area (cm²)	61	109	249	335	439	1042
A	1.4	1.0	1.2	1.2	1.2	0.7
B	1.2	1.3	1.6	1.6	1.9	1.2
B/A	1.1	1.3	1.3	1.3	1.6	1.7

ratio of respiration to assimilation varies with species. It usually is lower in the order of *P. densiflora*, *L. leptolepis*, *C. japonica* and *Ch. obtusa*. At an basal area of 500cm², where the rate of respiration to the total assimilated product became nearly constant, the ratios were 50% for *P.* densiflora, 45% for *L. leptolepis*, 43% for *C. japonica*, and 25%, comparatively low, for *Ch. obtusa*. In particular, *Ch. obtusa* gave the lowest rate.

At the young stage, the ratio of respiration to assimilated product is low. At a basal area of 100cm², for example, the ratios were 27% for *P. densiflora*, 26% for *L. leptolepis*, 20% for *C. japonica*, and 10% for *Ch. obtusa*. At both young and grown-up stages, the ratios were high for *P. densiflora* and lowest for *Ch. obtusa*.

13) Assimilation ratio

The assimilation ratio of each stand calculated from the respiration ratio (Table 35) is shown in Fig. 12.

The assimilation ratio varies with either stand age or soil condition. Within the limits of the investigated stand for this study, the ratios range from 0.9 to 2.1 for *C. japonica*, 1.0 to 1.5 for *Ch. obtusa*, 1.5 to 3.2 for *P. densiflora*, and 2.8 to 10.5 for *L. leptolepis*. The average ratios were the highest, 5.0, for *L. leptolepis*, about 4 times as high as that of *C. japonica*, of *Ch. obtusa* (1.3), and 2.5 for *P. densiflora*. This explains why the leaf biomass of *L. leptolepis* and *P. densiflora* is small for growth. This tendency is also observed as in Table 34 by Shidei and others. In this table, for example, the ratios to the assimilation ratio (1.1) of *C. japonica* were 2.0 to 2.4 for *P. densiflora* and 3.3 for *L. leptolepis*. The following also proved to be true; among the data obtained up to now, the higher assimilation ratios were 4 to 5 for deciduous broad-leaved trees such as *Betula platyphylla* v. *japonica*, *Betula ermanii* and *Betula maximowicziana*, which had characteristics similar to those of *L. leptolepis*. The assimilation ratio of a deciduous tree, coniferous or broad-leaved, is higher than that of an ever-green tree.

Assimilation ratios vary with various conditions. As is clear from Fig. 12, they showed a small variance in *C. japonica*, *Ch. obtusa* and *P. densiflora* and a large variance in *L. leptolepis*. This depends partly on the accuracy of the estimate of the leaf biomass but largely on the characteristic of assimilation efficiency that is very easily changed by the environmental conditions.

All species' assimilation ratios are almost constant in relation to the basal area. Even if the tree size changes, the productive efficiency of its leaf shows little change. It can be safely said that the growth ratio decreases for a large tree either because of the decrease of the ratio of the leaf biomass to the unassimilated part, or the decrease of the assimilated and accumulated product caused by the increase of respiration in the unassimilated part with the tree growth.

This average net assimilation ratio runs parallel to the annual growth per leaf biomass or the annual growth/leaf biomass ratio (Fig. 5). The former is higher, however, than the latter because the respiration of the unassimilated part is added to the assimilated product of the former ratio. The difference becomes much larger for the large trees as the respiration increases with a growing tree. This relation on the S1 stand, 9 years old, and the S17 stand, 49 years old, is shown in Table 36. According to the table, the ratio of the assimilation ratio to the annual growth/leaf biomass ratio, i. e., $\left(\frac{\text{average net assimilation ratio}}{\text{annual growth/leaf biomass ratio}}\right)$, increases with the increase of the basal area. They were 1.1 in the S1 stand and 1.7 in the S17 stand. Though the difference between the two was only 0.1 in the S1 stand, it went up to 0.5 in the S17 stand; the ratio of leaf biomass by growth was 0.7 and the average net ratio by assimilation was 1.2. This explains why the annual growth/leaf biomass ratio drops down

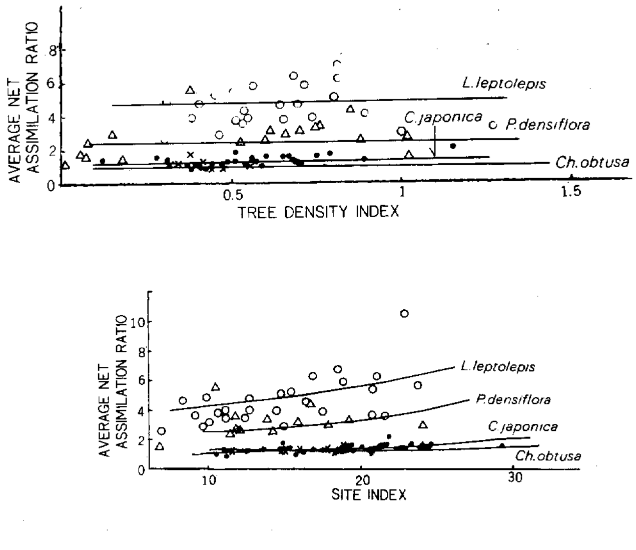


Fig. 13. Site conditions and average net assimilation ratio* of leaf.
* Average net assimilation ratio : ratio of net assimilation to leaf weight.

as the respiration increases with the growing tree.

14) Various conditions and the average net assimilation ratio

The assimilation ratio varies with soil conditions as well as with species. It shows variation similar to that of the leaf weight production ratio. Its relations to the stand density and site index are shown in Fig. 13.

(1) Tree density

The tree density has no close relation with the assimilation ratio. The assimilation ratio is almost constant both in a sparse planting stand and in a close planting stand. The reason for this is that the leaf biomass as well as the growth per tree increases in a sparse planting stand, while they both decrease in a close planting stand. It was clear from this that there was a certain relation between them, and that the assimilation efficiency of the leaf had no great difference. In the stands of *C. japonica* under similar soil conditions, their assimilation ratios were 2.1 in the S22 stand (density ratio: 1.2) and 1.9 in the S5 stand (density ratio: 0.5). For *P. densiflora* given as an example, the ratios were 2.8 in the close A10 stand (density ratio: 1.2), 2.6 in the A11 stand (density ratio: 0.88) and 3.2 in the A12 stand (density ratio: 0.62). As seen in *C. japonica*, no close correlation between the density and the assimilation ratio was observed. This holds true in the case of *L. leptlepis* and *C. japonica*.

(2) Site index

The assimilation ratio of all the species increases, as shown in Fig. 13, as the site index becomes larger. This tendency is greatest for *L. leptolepis*. Its ratios were, for example, about 6 and 3 at the site indices of 24 and 10 respectively. They decreased still more sharply with the decrease of the site quality index. *Ch. obtusa* did not show such a great change. Its ratios were, for example, 0.6 and 0.4 at those of 20 and 10 respectively. The assimilation ratios at the site index of 20 were 5.5 for *L. leptolepis*, 3.2 for *P. densiflora*, 1.4 for *C. japonica*, and 1.3 for *Ch. obtusa*. That of *L. leptolepis* was nearly four times as high as that of *C. japonica*, or *Ch. obtusa*. This difference varies with the site index.

15) Production ratio of root

When the fine root biomass, fine root surface area, or total root surface area, relative to absorbing nutriment and water, is considered to be closely related to the annual production, just as in the assimilation ratio of the leaf, their relations with those root factors will be expressed as follows:

$$\Delta W = aW_R - bW$$

$$\frac{\Delta W}{W} = a\frac{W_R}{W} - b$$

W=total biomass of a tree

ΔW=growth in dry weight per year

W_R=root factors such as the fine root biomass, fine root surface area or total root surface area

a=average production rate by root

b=respiration rate by total biomass

There are, of course, other root fartors such as the total root biomass. But in this study only the fine root biomass (W_F), the fine root surface area (A_F) and the total root surface area (A_R), which are considered to be most closely connected with the absorption of water and nutriment, were examined. The production ratio by root to each factor is calculated from the average respiration ratio by total biomass (b) in the Table 35. Here, of all prod-

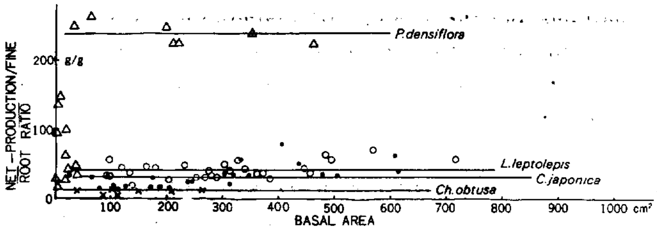


Fig. 14. Ratio of net production to fine root biomass, and basal area.

Table 37. Ratios of production-root factor of each species at the basal area of 500cm².

Species	Production/fine root biomass (g/g)	Production/fine root surface area (g/cm²)	Production/total root surface area (g/cm²)
C. japonica	33	0.23	0.14
Ch. obtusa	13	0.13	0.06
P. densiflora	235	1.42	0.24
L. leptolepis	42	0.27	0.10

uction ratios by root, the production ratio by fine root, the production ratio by fine root surface area and the production ratio by total root surface area represent the ratios of the assimilated biomass to the fine root biomass, to the fine root surface area, and to the total root surface area respectively.

This production ratio by root is, as in the case of the leaf biomass, almost constant regardless of tree size (Fig. 14). Difference between stands is thought to be caused mainly by soil conditions. The production ratios of each species by root at the basal area of 500cm² are shown in Table 37. According to this table the amount which the fine root by unit weight produces was the largest, 235g, for *P. densiflora*, 33g for *C. japonica*, 42g for *L. leptolepis*, and the lowest, 13g for *Ch. obtusa*. The production efficiency of the fine root of *Ch. obtusa* was the lowest, about 1/20 of that of *P. densiflora*. This explains why the fine root biomass of *P. densiflora* is small for the assimilated biomass. And vice versa in the case of *Ch. obtusa*.

The amount of the fine root produced by unit surface area was 1.42g for *P. densiflora*, 0.27g for *L. leptolepis*, 0.23g for *C. japonica*, and 0.13g for *Ch. obtusa*. The production efficiency of *P. densiflora* was about ten times as high as that of *Ch. obtusa*. This ratio was half of that of the fine root biomass. Differences between species were smaller for the fine root surface area than for the fine root biomass. The reason for this is that the fine root of *P. densiflora* is thinner and its surface area per unit dry weight is wider than those of *Ch. obtusa*. It is likely that the absorbing efficiency of *P. densiflora* is ten times as high as that of *Ch. obtusa* and 6.5 times as high as that of *C. japonica* or *Ch. obtusa* if the absorbing power which sustains the growth is proportionate to the fine root surface area (Fig.15).

The assimilated product per unit area which the whole root system produced was 0.14g for *C. japonica*, 0.06g for *Ch. obtusa*, 0.24g for *P. densiflora*, and 0.10g for *L. leptolepis*. This was different from the production ratio by fine root biomass or the production ratio by fine root surface area. That is to say, they became smaller in the order of *P. densiflora*, *C. japonica*,

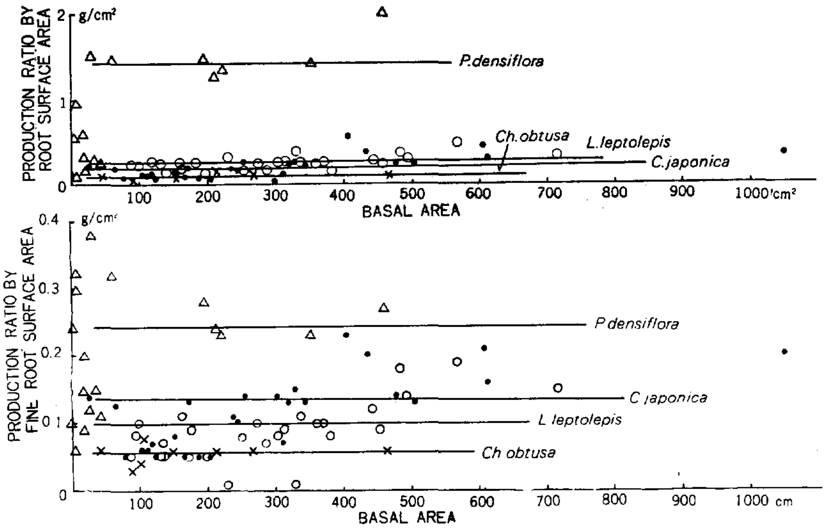


Fig. 15. Production ratio by fine root surface area* and production ratio by root surface area** in each basal area.

* Production ratio by fine root surface area : ratio of the net production to fine root surface area.

** Production ratio by root surface area : ratio of net production to root surface area.

Table 38. Ratios of the annual growth and production to various root factors.

Stand	S 1	S 3	S 2	S 4	S 5	S 17
Basal area(cm²)	61	109	249	335	439	1042
Annual growth/fine root biomass (g/g)	26.14	10.03	17.58	22.75	21.20	27.35
Production/fine root biomass (g/g)	29.4	14.0	24.7	34.1	36.2	49.5
Annual growth/fine root surface area (g/cm²)	0.17	0.06	0.12	0.15	0.09	0.19
Production/fine root surface area (g/cm²)	0.19	0.09	0.17	0.23	0.26	0.35
Annual growth/total root surface area (g/cm²)	0.11	0.04	0.08	0.09	0.09	0.11
Production/total root surface area (g/cm²)	0.13	0.06	0.11	0.13	0.15	0.21

L. leptolepis, and *Ch. obtusa* (Fig. 15).

As compared with the growth per root, the production ratio by root surface area includes the respiration. Accordingly, the difference between the production ratio and the growth ratio becomes larger for the larger trees with the respiration holding a greater part. Table 38 shows the production ratio by fine root biomass, production/fine root surface area ratio and the production/total root biomass ratio in some stands of *C. japonica*. In the S1 stand with a small basal area, the growth per fine root was 26 and the fine root ratio by production was 29, higer by the added amount of respiration. This also holds true in the case of the production/fine root surface area ratio and the production/total root surface area ratio. This difference between the two went up hand in hand with the tree growing. In the stand of S17, there was nearly a twofold difference between the growth per root and the production ratio by fine root. That difference became, if not so remarkable, smaller in the order of the total root surface area, fine root surface area, and fine root biomess.

16) Various conditions and production ratio by root

The production ratio by root as well as the assimdlation ratio by leaf varies with various

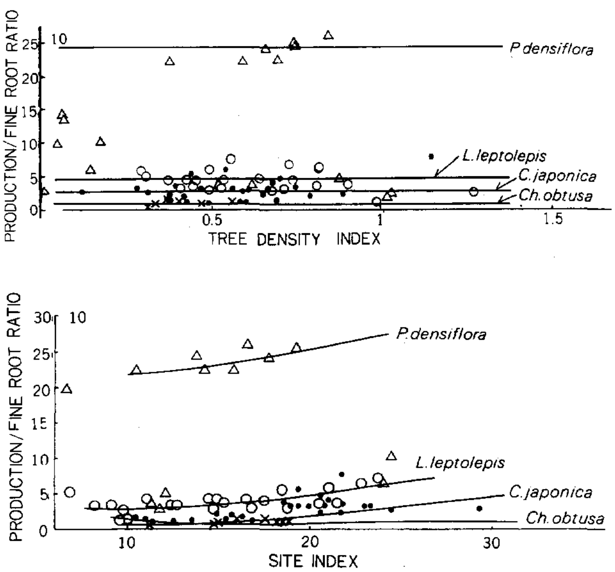


Fig. 16. Ratio of production to fine root biomass under soil conditions.
Production-fine root ratio: net-assimilation (g)/fine root weight (g).

environmental conditions.

(1) Tree density

The production ratio by fine root biomass as well as the assimilation ratio, does not change so greatly when the tree density of every species changes (Fig. 16). The production ratio was higher in the dense S22 stand of *C. japonica* (density index: 1.2) than in the other stands. This is due to good soil conditions and high productivity by stand. It is not likely that the production efficiency was caused to go higher by reason of density. On the other hand, the ratio in the dense A10 stand (density index: 1.2) was 30, far lower than the average production/fine root biomass ratio of ***P. densiflora*** (235). Here again it did not seem that the productive efficiency varies with stand density. This comes under the case of ***L. leptolepis*** and ***Ch. obtusa***. Besides, this may lead to the fact that density does not cause all species to increase the production efficiency by fine root. It is all common to the production ratio by surface area and the total root production ratio by surface area.

(2) Site index

The production/fine root biomass ratio increased, as shown in Fig. 16, with the site index. The ratios of *C. japonica* were 10-15 at a site index of 10 and 50-60 at that of 20. In other words they are 4 or 5 times higher when the site index is doubled.

Those of ***P. densiflora*** were 220 and 250 at those indices of 10 and 20 respectively. Those of ***L. leptolepis*** were 10 to 20 and 40 to 50 at those indices of 10 and 20 respectively. Those of ***Ch. obtusa*** were 5 and 10 at the same ratios as the former respectively. The production ratios varied more widely for *C. japonica* and ***L. leptolepis*** than for ***Ch. obtusa*** and ***P. densiflora***. The ratio of ***Ch. obtusa*** varies only slightly, as compared with the other species and so does the producton effiiciency of the fine root.

These relations apply also to the production/fine root surface area ratio, and production/total root surface area ratio. The production ratios of each species by root in the typical

Table 39. Production ratios to various root factors corresponding to soil types and site indexes.

Species	Stand	Soil type	Site index	Production/fine root biomass (g/g)	Production/fine root surface area (g/cm²)	Production/total root surface area (g/cm²)
C. japonica	S 22	B_E	21.8	78.4	0.562	0.235
	S 4	Bl_D	19.4	34.1	0.226	0.134
	S 6	Bl_A	11.3	13.6	0.116	0.066
Ch. obtusa	H 4	$B_{D(w)}$	15.0	12.3	0.122	0.062
	H 1	$B_{D(d)}$	18.2	12.7	0.095	0.065
	H 6	B_B	11.4	8.9	0.062	0.035
P. densiflora	A 1	$Bl_{D(d)}$	19.2	251.7	1.517	0.380
	A11	B_A	12.0	45.6	0.268	0.154
	A 6	E_r-B	6.6	19.9	0.106	0.064
L. leptolepis	K20	Bl_F	23.6	72.8	0.473	0.190
	K15	Bl_D	17.4	40.0	0.249	0.095
	K26	Bl_C	9.6	18.6	0.110	0.053

soil conditions selected from the detailed data are shown in Table 39.

III Absorption of water by root system

1) Average absorption ratio by root

Water absorbed from the surface of roots, after being used for the life and growth of a tree, is transpired from the leaves or other parts.

This relation can be expressed as follows:

The amount of annual water absorption is equal to (the amount of annual transpiration +the amount of water contained in the annual production+the amount of water contained in the annually fallen leaves or dead branches). The following relations are to be set up between the amount of transpiration and leaf biomass and between the absorption of water and such root factors as the fine root biomass, fine root surface area, and total surface area:

$$\Delta W_W = aR - b(W_L)$$

ΔW_W=(the amount of water in the annual growth)+(the amount of water in the annually fallen leaves or dead branches)

R =root factor

W_L =total leaf biomass

a =average water absorption ratio (absorption ratio)

b =average transpiration ratio by leaf (transpiration ratio)

The above equation will be $\frac{\Delta W_W}{W_L} = a\frac{R}{W_L} - b$, as in the assimilation ratio.

Each ratio will be named hereafter as follows: The absorption ratio for the average water absorption ratio, the amount of absorption for the amount of water absorption, the absorption ratio by fine root biomass for the amount of water absorption per fine root biomass, the absorption ratio by fine root surface area for the amount of water absorption per fine root surface area, the absorption ratio by total root surface area for the amount of water absorption per total root surface area, and finally the absorption ratio by root for the amount of water absorption per root factor such as the absorption ratio by fine root, the absorption ratio by fine root surface area and the absorption ratio by total root surface area. The relation between $\frac{\Delta W_W}{W_L}$ and $\frac{aR}{W_L}$ about the absorption ratio by total root surface area is shown in Fig. 17.

(The amount of water contained in the annual growth+the amount of water in the annually fallen leaves or dead branches) [ΔW_W] is extremely small as against the amount of water absorption (aR) and the amount of transpiration [$b(W_L)$]. It is, therefore, impossible to obtain the transpiraion ratio accurately because $\Delta W_W/W_L$ is highly scattered and because there is no high correlation between them as in the assimilation ratio.

So, the following process was used to calculate the amount of water equivalent to ΔW_W, aR and b(W_L), and to obtain the absorption and transpiration ratios.

The amount of water in the annual growth is the sum of each amount of water obtained by multiplying the growth of each part, such as a stem, branch, leaf, etc., by the moisture ratio calculated from the average dry weight ratio of these parts (Table 40). The amount of water in the fallen leaves per year was also calculated by multiplying the amount of fallen leaves of each species by the moisture ratio in Table 40. Here, the amount of fallen leaves of each species is the one calculated from the amount of leaves in the stands, assuming the defoliation ratios of *C. japonica* or *Ch. obtusa*, *P. densiflora*, and *L. leptolepis* to be 25%, 50% and 100% respectively. The amount of fallen leaves was calculated according to MÖLLER's expression[7].

MÖLLER's expression for estimating the amount of dead branches.

$A=0.3M\ (1\text{-}K)$

A=the amount of leaves died up to that time (unit: gram)

M=the amount of stems and branches (unit: gram)

$$K=\frac{\text{diameter of tree crown (cm)}}{\text{tree hieght (cm)}}$$

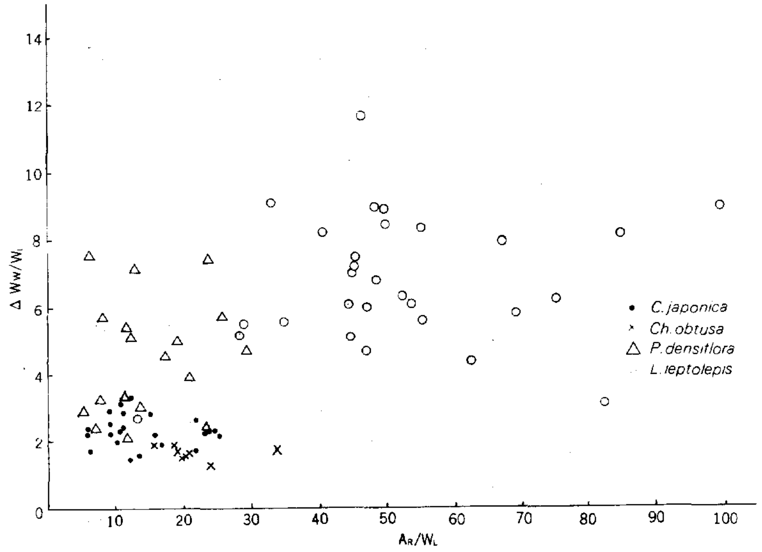


Fig. 17. Average water absorption ratio.

Table 40. Dry weight ratios and moisture ratios of current annual growing parts.
(1) Dry weight ratios (**R**)

Species	Stem*	Branch	Leaf	Root
C. japonica	0.32	0.32	0.30	0.26
Ch. obtusa	0.40	0.40	0.45	0.30
P. densiflora	0.33	0.33	0.40	0.29
L. leptolepis	0.35	0.35	0.28	0.27

* Averaged value for sap wood of sample trees. Dry weight ratio of fallen leaves and branches is considered as 0.77.

(2) Moisture ratios $\left(\frac{1-\mathbf{R}}{\mathbf{R}}\right)$

Species	Stem	Branch	Leaf	Root
C. japonica	2.13	2.13	2.33	2.85
Ch. obtusa	1.50	1.50	1.22	2.33
P. densiflora	2.03	2.03	1.50	2.45
L. leptolepis	1.86	1.86	2.57	2.70

Value for fallen leavea and branches : 0.30.

Table 41. Transpiration coefficients of each species.

Speicies	Transpiration coefficient	References
C. japonica	400 (388～433)	SHIBAMOTO10)
Ch. obtusa	350 (334～386)	
P. densiflora	194	KOYAMA4)
L. leptolepis	225	

Table 42. Estimates of transpiration of each species.

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*
Leaf biomass (dry weight) (t/ha)	12.0	11.0	4.4
Transpiration (t/ha/yr)	12270	10620	8790
Transpiration ratio*	1023	965	1998

* Ratio of transpiration to leaf biomass.

After that, the amount of water in the amount of fallen leaves was calculated by multiplying the amount of fallen leaves divided by stand age (the annual average amount of fallen leaves) by the moisture ratio in Table 40. The ratio of the water content to the amount of fallen leaves and dead branches was then conjectured to be 30% of the absolute dry weight.

ΔW_W is the sum of the amount of water in the annual growth and the amounts of water contained in the fallen leaves and dead branches. There are a few methods for estimating the amount of transpiration $b(W_L)$. But as they were all difficult to carry out in the actual

Table 43. Average transpiration calculated from leaf biomass and annual product.

Species	Stand	A (kg)	B (kg)	A/B	Species	Stand	A (kg)	B (kg)	A/B
C. japonica	S 1	4626	2527	1.83	*Ch. obtusa*	H 1	3418	1425	2.40
	S 2	8785	4092	2.15		H 2	5373	2356	2.28
	S 3	4006	1235	3.24		H 3	6744	3058	2.21
	S 4	15013	6852	2.19		H 4	9229	3191	2.89
	S 5	15317	7200	2.13		H 5	15947	5844	2.73
	S 6	7188	1913	3.76		H 6	4301	1660	2.59
	S 7	7358	2650	2.78		H 7	5188	2064	2.51
	S 8	9241	3580	2.58		H 8	4373	1305	3.35
	S 9	16823	4083	4.12	*P. densiflora*	A 1	1636	458	3.57
	S 10	8999	2520	3.57		A 2	2721	933	2.92
	S 11	2207	1164	1.90		A 3	8184	2020	4.05
	S 12	11069	5625	1.97		A 4	13814	2118	6.52
	S 13	9208	4375	2.10		A 5	2539	488	5.20
	S 14	7783	2861	2.72		A 6	779	96	8.11
	S 15	25377	9940	2.55		A 7	1526	371	4.11
	S 16	12535	5147	2.44		A 8	15001	2999	5.00
	S 17	58448	16849	3.47		A 9	9285	1507	6.16
	S 18	30227	10423	2.90		A 10	1301	298	4.37
	S 19	13866	5490	2.53		A 11	2138	478	4.47
	S 20	7946	3077	2.58		A 12	1441	396	3.64
	S 21	7239	2250	3.22		A 13	3085	400	7.71
	S 22	13086	6395	2.05		A 14	3752	1339	2.80
	S 23	6190	2710	2.28		A 15	789	83	9.51
	S 24	5925	2273	2.61		A 16	747	122	6.12
	S 25	19329	7960	2.44		A 17	1367	203	6.73
	S 26	29753	11768	2.53		A 18	767	143	5.36
	S 27	19803	6316	3.14					
	S 28	12103	6146	1.97					
	S 29	11958	6184	1.93					

A : Transpiration calculated from leof biomass.
B : Transpiration calculated from annual product.

stands, the data here were all estimated from the results of experiments in the nursery. Thus, there is the possibility of producing considerable discrepancies by some calculations. We hope this kind of study will be performed in greater detail.

The amount of transpiration in each stand was calculated from the transpiration coefficient and transpiration ratio (Table 43). Here. the transpiration coefficient is the amount of water necessary for producing the substance of one gram, as in Table 41, and the transpiration ratio is the amount of transpiration per leaf biomass, as in Table 42. Now, according to Table 43, it is observed in all stands that the amount of transpiration calculated from the leaf biomass increases. *C. japonica* and *Ch. obtusa*, for example, gave about two to three times the difference, and *P. densiflora* gave about four to five times the difference. It is difficult, however, to ascertain whether either value is true or not, because all these values are the estimated values. In this study the amount of transpiration was calculated using the transpiration coefficient in Table 41.

The amount of absorbed water per tree and per ha thus calculated is shown in Table 44 and 45. And out of the amount of water absorbed, the absorption ratios by such root factors as fine root biomass, fine root surface area, total root biomass, white root surface area, and white root were calculated according to the following expression (the absorptive efficiency at the lignified parts was counted there). Results are given in Table 44.

$$\text{Absorption ratio by root} = \frac{\text{Amount of absorbed water}}{\text{Root factors for absorption}}$$

The transpiration ratios by leaf were calculated by the following expression, which is shown in Table 44.

$$\text{Transpiration ratio by leaf} = \frac{\text{Amount of transpiration}}{\text{Leaf biomass}}$$

2) Absorbed water

(1) Average absorbed water per tree

Table 44 shows the annual average amount of the water absorbed per tree. It is the sum of the amount of water in the annual growth of the stem, branch and leaf, and in the annually fallen leaves and branches, and the annual transpiration, which occupies the greatest part of it. Let us study their ratios in each typical stand according to Table 44. A result is shown in Table 46. In all species as in Table 46, the amount of transpiration holds 99% of the total absorbed water and the amount of water in the annual growth, 0.5-1.0%. The amount of water in the fallen leaves and dead branches holds only 0.2-0.5%. It is, therefore, possible as an estimate to regard the transpiration as the total absorbed water. The transpiration, occupying a greater part of that amount of absorbed water in calculation, is related to the average annual growth. Its variation to the basal area shows, as in Fig. 18, a curve similar to that of the annual growth. That curve is an increasing concave curve slightly upward with the increase of basal area. Taking *C. japonica* here as an example, the annual amounts of transpiration per tree were 2 tons, 14 tons, and 18 tons at a basal area of 100cm^2, 400cm^2, 800cm^2, and 1,000cm^2 respectively.

This amount varies with species. At the basal area of 500cm^2, they were 8 tons for *C. japonica*, 6 tons for *Ch. obtusa*, 5.5 tons for *P. densiflora*, and 3.5 tons for *L. leptolepis*. There was more than twice the difference between the first species and the fourth.

The amount of absorbed water is smaller in the close planting stands of S22 and S23 or in the stands on the dry B_A type of residual soil of S6, S20 and S24 than in the sparse planting stands of S25, S26 or S27 or in the moderately moist stand (e.g., the S1 stand).

Table 47 shows the comparison of the amount of absorbed water per tree in some of

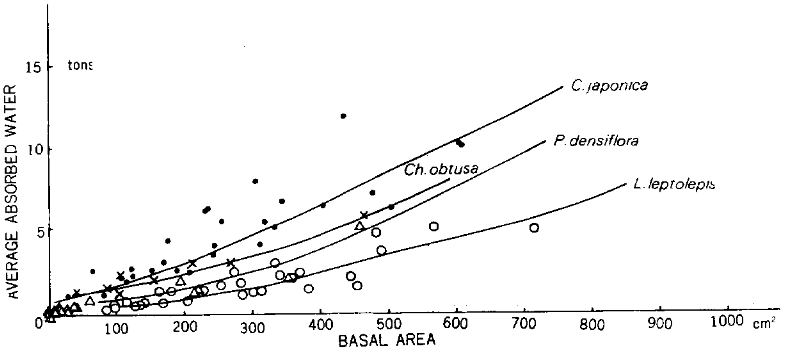


Fig. 18. Average absorbed water a tree.

the stands at different soil conditions and almost the same basal area.

(2) Absorbed water per ha

The amount of absorbed water per ha calculated from the average per tree in Table 44 is shown in Table 45 or in Fig. 19. It increased by 10,000 tons at a basal area of 100 to 300 cm² in the young stand of *C. japonica*. Across that basal area it became almost constant, for example, ranging from 7,000 to 8,000 tons at the basal area of 500-600cm². It went up to nearly 5,000 tons in the young and dense planting stand of *P. densiflora*, but down to 2,000 tons in the grown-up stand.

The amount of absorbed water for *Ch. obtusa* or *L. leptolepis* at the young stage did not increase as much as that of *C. japonica* or *P. densiflora*. However, in the H4 stand of *Ch. obtusa* it was the largest, 6,000 tons, of all the stands investigated at a basal area of 250 cm². And in a *L. leptolepis* stand at a basal area of 150cm², it was larger than in the other stands, about 2,000 tons. That of *C. japonica* was the largest of all these four species, about twice that of *Ch. obtusa* and over fivefold those of *P. densiflora* and *L. leptolepis*.

The amount of absorbed water per ha varies with species. In the mature stands, it ranged from 7,000 to 8,000 tons for *C. japonica*, from 4,000 to 5,000 tons for *Ch. obtusa*, from 2,000 to 3,000 tons for *P. densiflora*, and from 1,000 to 2,000 tons for *L. leptolepis*.

When the annual precipitation per ha in a forest ground is taken to be 15,000-20,000 tons, it follows that 40-47% of it is absorbed by the grown-up trees in a *C. japonica* stand, 25-30% in a *Ch. obtusa* stand, 13-15% in a *P. densiflora* stand, and 7-10% in a *L. leptolepis* stand. In the young stand of *C. japonica*, which absorbs the most water, 50-67% of the precipitation is absorbed. It follows from this that a considerably large amount of water is absorbed in a young close planting stand.

Thus, it is quite reasonable to assert that the shortage of water in soil is caused by the water absorption by roots in the close planting stand on dry soil. This phenomenon is remarkable, particularly in the surface soil because the roots in a young stand do not grow deep. And at the same time it is possible to estimate a change in physical and chemical properties caused by the root competition and absorption of water in the surface soil in a dry and barren forest.

3) **Various conditions and amount of absorbed water per ha**

The amount of absorbed water per ha varies in keeping with the environmental conditions such as tree density, soil conditions, etc.

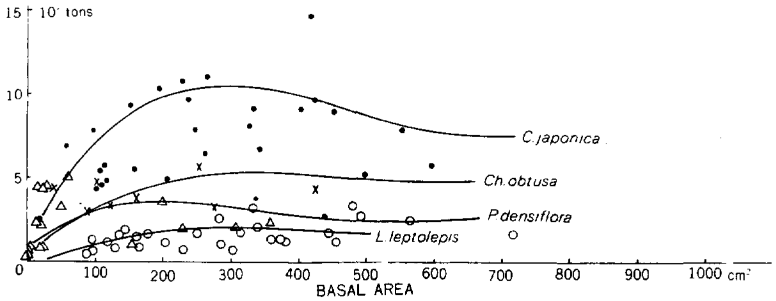


Fig. 19. Absorbed water per ha, and basal area.

(1) Tree density

The amount of absorbed water per ha increases sharply as in Fig. 20 before the tree density index gets up to 0.6–0.7. Across those ratios, it increases very little and becomes almost constant.

It ranged from 10,000 to 12,000 tons for *C. japonica*, 8,000 to 10,000 tons for *Ch. obtusa*, 4,000 to 6,000 tons for *P. densiflora*, and 2,000 to 4,000 tons for *L. leptolepis* at the tree density index of 1 (Fig. 21). The amount of absorption of *C. japonica* was the largest of the four, and that of *L. leptolepis* was the smallest, about 1/3–1/5 that of the former species. That of *Ch. obtusa* was about 4,000 tons higher than that of *P. densiflora*.

It tends to become constant in a highly dense planting stand partly because the annual growth from which it is calculated becomes almost constant, and partly because the leaf biomass closely connected with the transpiration which occupies the greater part of absorbed water becomes almost constant in a dense planting stand.

The ratio of increase of the absorbed water is high for tree density index in the case of *C. japonica* or *Ch. obtusa* as shown in Fig. 21 and low for *P. densiflora* or *L. leptolepis*. This explains why the leaf biomass of the latter does not increase much even when the tree density becomes higher as with *C. japonica* or *Ch. obtusa*.

(2) Soil type

The amount of absorbed water of *C. japonica* was the largest, nearly 15,000 tons, in the colluvium soil of B_E type (S22 stand), 10,000 tons in the moderately moist Bl_D soil, and 5,000–6,000 tons in the dry Bl_A–B_A soils. It decreased in both moist and dry soils, more so in dry soils.

For *Ch. obtusa* it was about 5,000 tons in the H3 stand with B_D soil, decreasing to about 3,000 tons in the B_B or $B_{D(w)}$ soil. Difference in site condition did not cause as much variation as in other species.

For *L. leptolepis* it was the largest, about 3,000 tons, in the Bl_D–$Bl_{D(w)}$ soils, about 1,000 tons in the dry Bl_B soil, and 500 tons in the moist Bl_F soil (K4 stand). The absorptivity of *L. leptolepis* became remarkably lower in the moist soils with insufficient aeration. In this respect, this species was quite different from *C. japonica* whose ratio of decrease of absorption was higher in the dry soil than in the moist soil.

The amount of absorbed water for *P. densiflora*, unlike that of *C. japonica* or *L. leptolepis*, was about 5,000 tons in rather dry $Bl_{(d)}$ soil, and nearly 2,000 tons in the devastated and dry stands of A5 and A6, just half of that in the stands of A1 and A2.

(3) Site index

The amount of absorbed water of every species increases with the site index. For *C. japonica*, as an example, it was practically 2,000 tons and 8,000–9,000 tons at the site indices of 10 and 20 respectively (Fig. 21).

At the site index of 20, the amounts of absorbed water were about 5,000 tons for *Ch. obtusa*, about 4,000 tons for *P. densiflora*, and about 2,000 tons for *L. leptolepis*. They varied greatly according to the site index in *C. japonica* or *L. leptolepis*. However, it was clear that the site condition does not exert a great influence on the absorptivity by *Ch. obtusa* as compared with that of *P. densiflora*, *C. japonica* and *L. leptolepis*; that amount of water absorbed was not scattered so highly by the site index.

The amount of absorbed water was comparatively little in the S1 and S11 stands for

Table 44. Water absorption and its efficiency of root and transpiration.

Stand	Water in annual growth (g)					Wate in fallen leaves (g)
	Stem	Branch	Leaf	Root	Total	
S 1	4922	1968	4215	3953	15058	543
S 2	8665	3029	6002	6187	23883	773
S 3	2211	773	2214	2075	7273	285
S 4	15958	4788	8549	10611	39906	1101
S 5	17061	5118	8721	10953	41853	1123
S 6	2354	824	4912	3372	11462	632
S 7	5340	1602	4189	4469	15600	539
S 8	7078	2477	6314	4999	20868	813
S 9	5973	1791	9579	6983	24326	1233
S 10	4256	1278	5124	4281	14939	660
S 11	2151	861	2011	1804	6827	259
S 12	10878	3806	7563	7618	29865	974
S 13	8497	2973	7340	6846	25656	945
S 14	4379	1534	6205	4885	17003	799
S 15	18948	6633	17340	15387	58308	2233
S 16	11860	3557	7139	7313	29869	919
S 17	30740	9223	33282	25869	99114	4285
S 18	23270	6982	17212	18434	65898	2216
S 19	11960	3589	7920	8653	32112	1020
S 20	6401	1921	4525	5255	18102	583
S 21	4085	1227	4122	3879	13313	531
S 22	15913	4773	7447	8778	36911	959
S 23	6356	1906	3525	3936	15723	454
S 24	4775	1433	3374	3759	13341	434
S 25	14456	5059	13206	14065	46786	1700
S 26	21818	7636	20329	19568	69351	2618
S 27	10859	3257	13530	9562	37208	1742
S 28	12333	4392	9649	9322	35696	1242
S 29	12509	4379	9532	9804	36224	1227
H 1	1929	773	1729	2456	6887	425
H 2	3678	1287	2037	3612	10614	501
H 3	5085	1781	2558	4804	14228	629
H 4	5639	1692	2567	4954	14852	631
H 5	10611	3183	4436	9005	27235	1091
H 6	2067	828	1631	2973	7499	401
H 7	3870	1161	1443	3169	9643	355
H 8	2199	660	1216	1920	5995	299
A 1	1959	980	677	1129	4745	135
A 2	3956	2373	1148	2266	9743	230
A 3	9969	2990	3072	4853	20884	614
A 4	9547	286	5186	5745	20764	1037
A 5	1656	828	1049	1450	4983	210
A 6	199	99	323	333	954	65
A 7	1279	767	689	1095	3830	138

Water in fallen branches (g)	Transpiration (kg)	Absorption (kg)	Absorption /fine root bipmass (kg/g)	Absorption/ fine root surface area (kg/cm^2)	Absorption/ total root surface area (kg/cm^2)	Absorption/ white tip root surface area (kg/cm^2)	Transpiration/leaf diomass (g/g)
59	2572	2588	10.5	0.068	0.045	0.065	572
182	4092	4117	7.1	0.048	0.031	0.169	479
53	1235	1243	4.0	0.025	0.016	0.076	389
266	6852	6893	9.2	0.061	0.036	0.311	470
309	7200	7243	8.5	0.060	0.035	0.323	484
52	1913	1925	3.9	0.034	0.019	0.138	274
95	2650	2666	3.7	0.021	0.014	0.102	371
158	3580	3602	6.6	0.048	0.030	0.188	399
131	4083	4109	5.0	0.032	0.019	0.205	250
88	2520	2536	3.5	0.020	0.013	0.122	288
19	1164	1171	11.5	0.075	0.050	0.088	542
235	5625	5656	10.1	0.072	0.044	0.213	523
150	4375	4402	9.4	0.066	0.043	0.175	489
29	2861	2879	5.9	0.038	0.024	0.115	378
464	9940	10001	10.7	0.076	0.044	0.394	403
269	5147	5178	8.5	0.061	0.036	0.185	423
712	16849	16953	11.0	0.078	0.046	0.251	297
428	10423	10492	16.2	0.122	0.057	0.383	355
206	5490	5523	9.3	0.065	0.036	0.253	407
99	3077	3096	4.3	0.028	0.017	0.171	399
40	2250	2254	5.0	0.032	0.019	0.112	319
365	6395	6433	17.5	0.126	0.053	0.584	503
119	2710	2726	5.3	0.033	0.020	0.240	451
60	2273	2287	4.4	0.025	0.016	0.149	395
161	7906	7955	11.6	0.081	0.046	0.512	421
269	11768	11840	15.6	0.112	0.063	0.334	407
284	6316	6355	8.1	0.058	0.032	0.206	328
150	6146	6183	10.3	—	—	0.239	523
216	6184	6222	10.8	—	—	0.230	532
42	1425	1432	4.2	0.031	0.021	0.076	404
83	2356	2367	5.2	0.046	0.026	0.102	425
125	3058	3073	3.9	0.032	0.018	0.147	440
164	3191	3207	3.3	0.033	0.017	0.112	335
309	5844	5873	4.0	0.031	0.017	0.205	355
48	1660	1668	2.7	0.019	0.011	0.082	374
98	2064	2074	3.5	0.032	0.019	0.173	386
61	1305	1311	2.6	0.022	0.012	0.135	289
30	458	463	42.1	0.254	0.064	0.231	565
68	933	943	41.0	0.233	0.051	0.352	692
128	2020	2042	34.0	0.201	0.040	0.533	499
96	2118	2140	24.0	0.142	0.023	0.450	310
27	488	493	5.7	0.033	0.018	0.067	388
4	96	97	3.2	0.017	0.010	0.040	249
58	371	375	10.1	0.058	0.025	0.028	491

Table 44. Continued

Stand	Water in annual growth (g)					Water in fallen leaves (g)
	Stem	Branch	Leaf	Root	Total	
A 8	13410	4023	5633	7632	30698	1127
A 9	6013	1803	3486	3905	15207	697
A10	1224	613	539	666	3042	108
A11	1862	932	917	1164	4875	183
A12	1492	747	596	1325	4160	119
A13	849	508	1391	1139	3887	278
A14	7387	2217	1409	3023	14036	282
A15	132	79	356	260	827	71
A16	321	193	336	370	1220	67
A17	497	298	617	593	2005	123
A18	471	282	345	1801	2899	69
K 1	7306	2191	7746	5387	22630	904
K 2	3778	1133	4955	3885	13751	578
K 3	3195	958	6918	3826	14897	808
K 4	850	255	1113	942	3160	130
K 5	1884	565	2459	1971	6879	287
K 6	1043	312	3374	2203	6932	394
K 7	1562	469	2860	2141	7032	334
K 8	4179	1254	4125	3945	13503	482
K 9	1135	340	2313	1296	5084	270
K10	1070	322	3495	1563	6450	408
K11	3651	1096	3040	2738	10525	355
K12	3445	1032	5842	3667	13986	682
K13	4884	1466	4428	3259	14037	517
K14	13697	4109	9655	7925	35386	1127
K15	3435	1027	5654	3086	13202	660
K16	7818	2345	7192	7725	25179	851
K17	4042	1213	4035	3173	12463	471
K18	11785	3536	6304	6969	28594	736
K19	5760	1728	10511	5103	23102	1227
K20	18594	5578	13904	11013	49089	1623
K21	20973	6292	6314	10403	43982	737
K22	3852	1155	8995	3821	17823	1050
K23	1036	311	3174	1507	6028	371
K24	5496	1650	8941	5319	21406	1044
K25	5247	1574	6990	4890	18701	816
K26	1892	567	3673	2160	8292	429
K27	7905	2372	7360	6248	23885	859
K28	16920	5076	14921	10746	47663	1742
K29	2353	705	3950	2533	9541	461

Water in fallen branches (g)	Transpiration (kg)	Absorption (kg)	Absorption /fine root biomass (kg/g)	Absorption/ fine root surface area (kg/cm²)	Absorption/ total root surface area (kg/cm²)	Absorption/ white tip root surface area (kg/cm²)	Transpiratipn/leaf diomass (g/g)
278	5999	3031	26.6	0.245	0.033	0.408	404
155	1507	1523	26.3	0.163	0.027	0.437	328
—	298	301	4.8	0.028	0.016	0.057	462
—	478	483	7.5	0.044	0.026	0.102	451
—	396	400	6.8	0.039	0.021	0.085	555
43	400	404	16.8	0.102	0.034	0.040	262
70	1339	1353	27.6	0.158	0.030	0.504	720
5	83	84	5.3	0.031	0.017	0.008	213
10	122	123	17.6	0.105	0.043	0.025	329
2	203	205	25.6	0.156	0.054	0.035	300
14	143	146	24.3	0.143	0.058	0.033	380
187	2276	2300	6.3	0.038	0.017	0.274	763
72	1352	1366	6.9	0.040	0.016	0.241	709
74	1449	1465	7.3	0.044	0.019	0.175	544
36	310	313	4.5	0.030	0.009	0.106	723
28	676	683	5.7	0.037	0.016	0.218	714
24	643	650	9.4	0.061	0.017	0.316	495
46	675	682	6.7	0.045	0.012	0.191	613
86	1347	1361	7.4	0.054	0.017	0.349	848
18	489	494	5.0	0.032	0.010	0.220	549
63	604	611	5.2	0.032	0.009	0.199	449
145	1068	1079	3.8	0.024	0.009	0.172	912
149	1359	1374	5.8	0.034	0.011	0.228	604
223	1427	1442	3.5	0.022	0.010	0.175	837
500	3660	3697	7.8	0.048	0.020	0.265	984
173	1291	1305	5.3	0.033	0.001	0.237	593
101	2511	5237	7.1	0.041	0.018	0.227	894
135	1253	1266	4.4	0.026	0.012	0.171	806
215	2986	3016	9.4	0.061	0.027	0.485	1230
308	2251	2276	5.7	0.036	0.016	0.282	556
525	5059	5110	10.8	0.070	0.028	0.466	945
307	4718	4763	10.8	0.068	0.031	0.521	1939
311	1712	1731	4.1	0.026	0.011	0.206	495
49	566	572	2.5	0.014	0.007	0.108	463
188	2090	2113	5.0	0.031	1.014	0.214	607
130	1845	1865	5.1	0.030	0.014	0.215	686
47	799	808	3.0	0.017	0.008	0.146	565
215	2408	2433	5.6	0.036	0.015	0.295	850
476	4863	4913	7.8	0.047	0.021	0.407	846
71	927	937	3.0	0.018	0.008	0.190	610

Table 45. Water absorption of root. (t/ha)

Stand	Water in annual growth					Water in fallen leaves	Water in fallen branches	Trans-piration	Absor-ption
	Stem	Branch	Leaf	Root	Total				
S 1	13.0	5.2	11.1	10.4	39.7	1.4	0.2	6792.7	6834.0
S 2	16.6	5.8	11.5	11.8	45.7	1.5	0.3	7815.7	7863.2
S 3	8.4	2.8	8.2	7.6	27.0	1.0	0.2	4547.3	4575.5
S 4	21.1	6.3	11.3	14.0	52.7	1.5	0.4	9051.5	9106.1
S 5	14.9	4.5	7.6	9.6	36.6	1.0	0.3	6292.8	6330.4
S 6	5.5	1.9	11.4	7.8	26.6	1.5	0.1	4443.9	4472.1
S 7	10.9	3.3	8.6	9.2	32.0	1.1	0.2	5429.9	5463.2
S 8	19.2	6.7	17.1	13.6	56.6	2.2	0.4	9705.4	9764.6
S 9	5.5	1.7	8.9	6.5	22.6	1.1	0.1	3772.7	3796.5
S 10	8.4	2.5	10.2	8.5	29.6	1.3	0.2	4999.7	5030.8
S 11	4.7	1.9	4.4	4.0	15.0	0.6	0.4	2563.1	2579.1
S 12	21.1	7.4	14.7	14.8	58.0	1.9	0.5	10901.3	10961.7
S 13	19.9	7.0	17.2	16.1	60.2	2.2	0.4	10263.8	10326.6
S 14	8.6	3.0	12.2	9.6	33.4	1.6	0.1	5636.2	5671.3
S 15	16.9	5.9	15.5	13.7	52.0	2.0	0.4	8876.4	8930.8
S 16	21.0	6.3	12.6	12.9	52.8	1.6	0.5	9110.2	9165.1
S 17	18.5	5.5	20.0	15.5	59.5	2.6	0.4	10126.2	10188.7
S 18	17.3	5.2	12.8	13.7	49.0	1.7	0.3	7765.1	7816.1
S 19	14.5	4.4	9.6	10.5	39.0	1.2	0.3	6675.8	6716.3
S 20	13.3	4.0	9.4	10.9	37.6	1.2	0.2	6394.0	6433.0
S 21	10.0	3.0	10.1	9.5	32.6	1.3	0.1	5487.8	5521.8
S 22	36.2	10.9	16.9	20.0	84.0	2.2	0.8	14542.2	14629.2
S 23	21.7	6.5	12.0	13.4	53.6	1.6	0.4	9254.7	9310.3
S 24	16.3	4.9	11.5	12.8	45.5	1.5	0.2	7737.3	7784.5
S 25	14.4	5.1	13.2	14.1	46.8	1.7	0.2	7898.1	7946.8
S 26	17.9	6.3	16.6	16.0	56.8	2.1	0.2	9638.0	9697.1
S 27	8.7	2.6	10.8	7.6	29.7	1.4	0.2	5040.2	5071.5
S 28	21.6	7.7	16.9	16.3	62.5	2.2	0.3	10755.5	10820.5
S 29	9.7	3.4	7.4	7.6	28.1	0.9	0.2	4786.4	4815.6
H 1	6.0	2.4	5.3	7.6	21.3	1.3	0.1	4397.6	4420.3
H 2	7.5	2.6	4.1	7.3	21.5	1.0	0.2	4775.6	6798.3
H 3	9.3	3.3	4.7	8.8	26.1	1.2	0.2	5608.4	5635.9
H 4	5.7	1.7	2.6	5.0	15.0	0.6	0.2	3210.1	3225.9
H 5	8.0	2.4	3.3	6.8	20.5	0.8	0.2	4394.7	4416.2
H 6	3.7	1.5	2.9	5.3	13.4	0.7	0.1	2979.7	2993.9
H 7	7.2	2.2	2.7	5.9	18.0	0.7	0.2	3843.2	3862.1
H 8	5.5	1.7	3.1	4.8	15.1	0.8	0.2	3288.6	3304.7
A 1	18.1	9.0	6.2	10.4	43.7	1.2	0.3	4227.8	4273.0
A 2	20.8	12.5	6.0	11.9	51.2	1.2	0.4	4898.3	4951.1
A 3	17.3	5.2	5.3	8.4	36.2	1.1	0.2	3508.7	3546.2
A 4	8.9	0.3	4.8	5.4	19.4	1.0	0.1	1976.1	1996.6
A 5	7.1	3.6	4.5	6.2	21.4	0.9	0.1	2095.5	2117.9
A 6	4.5	2.2	7.2	7.5	21.4	1.5	0.1	2150.4	2173.4
A 7	3.2	1.9	1.7	2.7	9.5	0.3	0.1	927.5	937.4

Table 45. Continued (t/ha)

Stand	Water in annual growth					Water in fallen leaves	Water in fallen branches	Trans-piration	Absorptiou
	Stem	Branch	Leaf	Root	Total				
A 8	10.5	3.1	4.4	6.0	24.0	0.9	0.2	2342.2	2367.3
A 9	7.8	2.3	4.5	5.1	19.7	0.9	0.2	1951.6	1972.4
A10	18.7	9.4	8.2	10.2	46.5	1.6	—	4548.7	4596.8
A11	17.5	8.8	8.6	10.9	45.8	1.7	—	4490.3	4537.8
A12	12.2	6.1	4.9	10.8	34.0	1.0	—	3234.1	3269.1
A13	2.1	1.3	3.5	2.8	9.7	0.7	0.1	1000.0	1010.5
A14	6.0	1.8	1.1	2.4	11.3	0.2	0.1	1080.1	1091.7
A15	0.5	0.3	1.4	1.0	3.2	0.3	0.02	332.0	335.52
A16	1.3	0.8	1.3	1.5	4.9	0.3	0.04	488.0	493.24
A17	2.0	1.2	2.5	2.4	8.1	0.5	0.01	812.0	820.61
A18	1.9	1.1	1.4	7.2	11.6	0.3	0.1	572.0	584.0
K 1	6.1	1.8	6.5	4.5	18.9	0.8	0.2	1905.0	1924.9
K 2	4.7	1.4	6.1	4.8	17.0	0.7	0.1	1673.8	1691.6
K 3	3.3	1.0	7.2	4.0	15.5	0.8	0.1	1499.9	1516.1
K 4	1.3	0.4	1.7	1.4	4.8	0.2	0.1	460.4	465.5
K 5	3.7	1.1	4.8	3.9	13.5	0.6	0.1	1331.0	1345.2
K 6	1.2	0.4	3.9	2.6	8.1	0.5	0.03	752.3	760.9
K 7	2.4	0.7	4.5	3.3	10.9	0.5	0.1	1054.4	1065.93
K 8	2.3	0.7	2.3	2.2	7.5	0.3	0.05	750.3	758.15
K 9	1.8	0.5	3.7	2.1	8.1	0.4	0.03	785.3	793.83
K10	1.5	0.5	4.9	2.2	9.1	0.6	0.1	846.8	856.6
K11	3.7	1.1	3.1	2.8	10.7	0.4	0.1	1078.7	1089.9
K12	1.9	0.6	3.2	2.0	7.7	0.4	0.1	752.9	765.1
K13	4.1	1.2	3.7	2.7	11.7	0.4	0.2	1195.8	1208.1
K14	9.9	3.0	7.0	5.8	25.7	0.8	0.4	2657.2	2684.1
K15	3.4	1.0	5.5	3.0	12.9	0.6	0.2	1265.2	1278.9
K16	8.5	2.5	7.9	8.4	27.3	0.9	0.1	2714.4	2742.7
K17	5.9	1.8	5.9	4.6	18.2	0.7	0.2	1835.6	1854.7
K18	12.3	3.7	6.6	7.3	29.9	0.8	0.2	3111.4	3142.3
K19	4.4	1.3	8.0	3.9	17.6	0.9	0.2	1719.8	1738.5
K20	8.7	2.6	6.5	5.2	23.0	0.8	0.2	2367.6	2391.6
K21	14.7	4.4	4.4	7.3	30.8	0.5	0.2	3316.8	3348.3
K22	2.5	0.8	5.9	2.5	11.7	0.7	0.2	1119.6	1132.2
K23	2.9	0.9	9.0	4.3	17.1	1.0	0.1	1597.3	1615.5
K24	3.5	1.1	5.7	3.4	13.7	0.7	0.1	1337.6	1352.1
K25	7.0	2.1	9.3	6.5	24.9	1.1	0.2	2464.9	2491.1
K26	4.5	1.4	8.8	5.2	19.9	1.0	0.1	1910.4	1931.4
K27	4.2	1.3	4.0	3.4	12.9	0.5	0.1	1293.1	1306.6
K28	5.6	1.7	4.9	3.5	15.7	0.6	0.2	1599.9	1616.4
K29	2.6	0.8	4.4	2.8	10.6	0.5	0.1	1041.9	1053.1

Table 46. Distribution ratio of annuallv absorbed water.

Stand	Water in annual growing parts					Water in fallen leaves	Water in fallen branch	Transpir-ation	Total absorption
	Stem	Branch	Leaf	Root	Total				
S 5	0.0024	0.0007	0.0012	0.0015	0.0058	0.0002	+	0.9940	1.000
H 5	0.0018	0.0005	0.0008	0.0015	0.0046	0.0002	0.0001	0.9951	1.000
A 4	0.0045	0.0010	0.0024	0.0027	0.0097	0.0005	+	0.9898	1.000
K 1	0.0032	0.0010	0.0034	0.0023	0.0099	0.0004	0.0001	0.9896	1.000

Table 47. Annual water absorption per tree as affected by stand density and soil type.

(Stand density)

	Stand	
	S 22	S 26
Tree density index	1.16	0.45
Basal area (cm²)	419	425
Water absorbed (ton)	6.4	11.8

(Soil type)

	Stand	
	S 1	S 3
Soil type	Bl_E	$Bl_{D(d)}$
Basal area (cm²)	61	109
Water absorbed (ton)	2.6	1.2

their large site indices because in these immature stands their tree densities were low (0.31 and 0.12 respectively), whereas in the S22, S23 and S24 stands, where the amount of absorbed water was large, the tree density index ranged from 0.7 to 1.2. The same is true in the A10 and A11 stands of *P. densiflora.*

4) **Absorption ratio by root**

The relation between the tree size and the absorption ratio* by fine root biomass in Table 44 (Absorbed water (kg)/fine root biomass (g)) is shown in Fig. 21. For *C. japonica, Ch. obtusa* and *L. leptolepis,* the ratio was, as shown there, almost constant regardless of tree size, but of *P. densiflora* it was over 4,000 in the immature stands of A1 and A2, and about 2,500 in the mature stand of A4. This means that the absorptive efficiency decreases proportionately with tree size.

At the basal area of 500cm², the annual amounts of the absorbed water by fine root of unit weight, as shown in Table 48, were 22kg for *P. densiflora* (largest of all four species), 4.5kg for *Ch. obtusa* (smallest of all and practically one-fifth that of the former), and 7.0 to 8.5kg for *C. japonica* or *L. leptolepis* (one-third of that of *P. densiflora*).

5) **Various conditions and absoption ratio by fine root biomass**

The fine root biomass and the amount of absorbed water both vary with various environmental conditions and so does the absorption ratio by fine root biomass.

(1) pF value of soil in the field condition

The relation between the absorption ratio by fine root and the pF value which clearly represents the moisture conditon of soil is shown in Fig 22. As the soil gets drier and the pF value increases, the absorption ratio by fine root, decreasing gradually becomes very inefficient. Because the amount of the absorbed water decreases, the fine root biomass increases.

In the dry condition, the fine root biomass increases, and the surface area for absorption becomes broader. Its absorption efficiency, however, decreases in the moderately moist soil. Therefore, the amount of the absorbed water does not make larger for increasing fine root biomass.

Let us go through the annual amounts of the absorbed water of each species per gram of fine root at the values of pF 2,3 and 4, from Fig. 23. Results appear in Table 49. According to the table, those of *P. densiflora*, *C. japonica* and *Ch. obtusa* were 40kg, 10kg and 4kg at a value of pF 2. Those of *C. japonica* and *Ch. obtusa* were one-fourth and one-tenth that of *P. densiflora*, respectively. At a value of 3, those of *P. densiflora*, *C. japonica* and *Ch. obtusa* were taken to be 20kg, 5kg and 2kg, respectively. At a value of 4, those of each species were reckoned here to be 2kg and 1 kg (in the latter two), respectively. This explains that the characteristics of absorption for each species are very distinct on a moderately moist condition. It was, however, obscure in the dry soils with large pF value, where the difference in absorbing efficiency between species became smaller.

As shown in Table 49 and Fig. 23, the changes of the absorption/fine root biomass ratio with pF values are greatest for *P. densiflora*, then less for *C. japonica*, and for *Ch. obtusa*. The absorptoin ratio of *P. densiflora* at a pF value of 4 was about 1/20 that at a value of 2, but for *Ch. obtusa*, it was only 1/4. The absorption ratio of *Ch. obtusa* was not dependent on the water condition.

(2) Site index

The relation between the absoption ratio by fine root biomass and the site index is shown in Table 50 and Fig. 22. The absorption ratio increases with the site index. At a site index

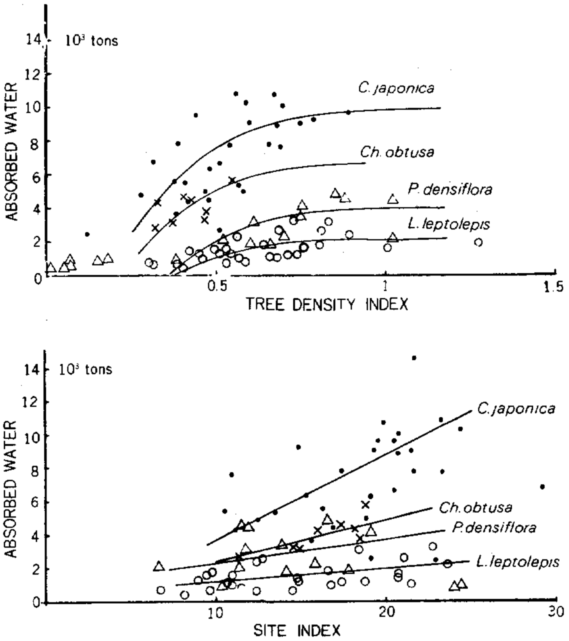


Fig. 20. Absorbed water per ha under various conditions.

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* This ratio indicates annual absorption(g) per fine root weight.

of 10, for example, the fine roots per unit weight and per year absorb 25kg of water for *P. densiflora*, 6kg for *L. leptolepis*, 4kg for *C. japonica*, and 1.5kg for *Ch. obtusa*. At an index of 20, they absorb 40kg of water for *P. densiflora*, 10kg for *C. japonica*, 8kg for *L. leptolepis*, and 5kg for *Ch. obtusa*. This clearly shows that when the site index is doubled, the absorption ratio becomes 2 or 3 times as high.

(3) Soil type

P. densiflora has the highest absorptive efficiency and the amount of absorbed water per gram of fine root was 40kg in the slightly dry $Bl_{D(d)}$ typed soil, but the species had only 5 or 6kg in the infertile and dry soils of B_A to Er−B, and Er−B_A. This was one-eighth or -nineth that of the former soil. It originates in the fact that the amount of absorbed water is small for many fine roots owing to the sufficient branching and growth by root there, although it is large for few fine roots in moderately moist soil. The variation of absorption ratio by soil conditions is greatest for *P. densiflora*, then for *C. japonica*, *L. leptolepis* and *Ch. obtusa*. This applies also to various environmental conditions.

Since the species had the highest absorption ratio by fine root in the B_E typed soil, *C. japonica* absorbed the amount of 18kg in that soil, and 10kg in the Bl_D typed soil. But it had only 4 or 5kg in the soils of B_A to Bl_C, just as did *P. densiflora*. The absorptive efficiency of that fine root decreased as the soils became drier. The rate of decrease, however, was less than that of *P. densiflora*.

Since the absorption ratio went up, *L. leptolepis* absorbed 10kg in the Bl_E−Bl_D soils, but only 4 to 6kg and 2 to 3kg in the moist Bl_G−Bl_F soils and in the dry $Bl_{D\text{-}m}$, Bl_C and Bl_B soils, respectively. This reveals that the absorption efficiency decreases both in the dry and moist soils. Like *C. japonica*, the absorption efficiency of *L. leptolepis* goes higher in the moderately or rather moist soils; but in the excessively moist soil it decreased a great deal more than the ratio of *C. japonica* because the species 's fine root had a less active metabolic function there.

Ch. obtusa had that of 5kg in the B_D soil, and 2.5kg in the B_B soil. Although the absorption ratio of *Ch. obtusa* decreased in the dry soil, it did not vary as greatly as that of *P. densiflora*, *C. japonica* or *L. leptolepis*. The absorption ratio of *Ch. obtusa* was prevented from changing greatly by the soil conditions.

The idea applied to the fine root biomass holds true in the case of the absorption ratio by fine root surface area or by total root surface area. The interrelation in absorption ratio between species, however, differs somewhat This is in part because each surface area will account for some difference on certain site conditions when the same fine root biomass is considered, and also because the absorption ratio by total surface area, as a matter of course comes to be connected with the surface area of the other roots, except for a fine root. These are shown in Fig. 23 in relation to each absorption ratio by root to the tree size.

The absorption ratio by fine root surface area varies similarly with that by fine root biomass. That of *P. densiflora* decreased in inverse proportion to basal area. In the immature stand of A1 and A2, the amount of water absorbed per unit fine root surface area reached 240g. In the A4 stand of the large-diameter trees, it decrased to 140g. Those of *C. japonica*, *L. leptolepis* and *Ch. obtusa* were all practically constant regardless of tree size. At a basal area of 500cm^2, the absorption ratios of *C. japonica*, *L. leptolepis* and *Ch. obtusa* were about 60g, 40g and 30g, respectively. This order is nearly the same as that of the fine root biomass.

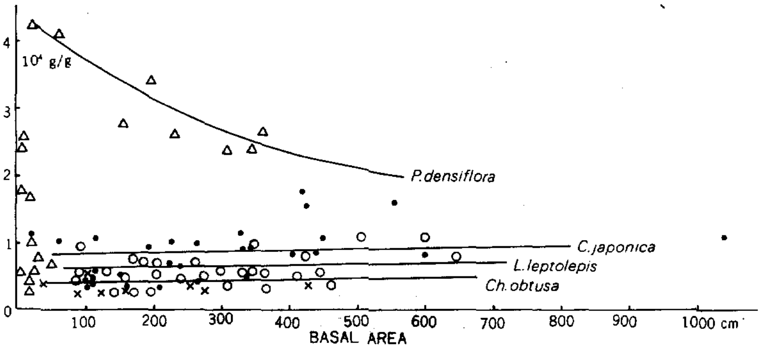

Fig. 21. Ratio of absorbed water to fine root biomass and tree growth.

This is precisely because fine root weight is sililar to fine root surface area on the average.

The absorption ratio by total root surface area is slightly different. It was high for *C. japonica* and *Ch. obtusa*, for which the fine root surface area was higher in percentage than the surface area of the rest, such as small and medium roots. On the other hand, the absorption ratio of *P. densiflora* was lower, though it had large surface areas of the small, medium and large root as compared to that of the fine root. At a basal area of 500cm^2, for example, the annual amounts of absorbed water per unit total root surface area of *C. japonica*, *P. densiflora*, and *Ch. obtusa* or *L. leptolepis* were 50g, 35g and 20g, respectively. Compared with the absorption ratio by fine root surface area, *P. densiflora*, *C. japonica* or *Ch. obtusa*, and *L. leptolepis* decreased by 105g, 10g and 20g, respectively. Those of the extensive root-typed species, such as *P. densiflora*, *L. leptolepis*, etc. decreased makedly.

The absorption ratio by fine root weight depends largely upon the fine root biomass. Therefore, *P. densiflora*, having a decidedly small fine root biomass for amount of absorbed water, showed a high absorption efficiency. In the case of total root surface area, on the other hand, the difference in absorption ratio between each species decreased because the surface area of all roots, except fine roots obviated the property of absorption by a fine root.

6) Absorption ratio by surface area of white tip roots

The surface area of white tip roots calculated by the annual average growth in root length is shown in Table 51. When water is assumed to be absorbed mainly by white roots, Table 44 shows results of calculation of the ratio of absorbed water to that surface area.

The absorption ratio of the surface of the white tip root increased, as shown in Fig 24, describing a concave curve upward as a tree grows. This phenomenon has not been observed on the absorption ratio by fine root, absorption ratio by fine root surface area, or absorption ratio by total root surface area.

It is probable that the current annual growth of the white tip root surface area is greater in the young trees than in the large trees, as compared with the average growth. The increasing curve of the absorption ratio, its steeper incline, and the higher ratio in the large tree

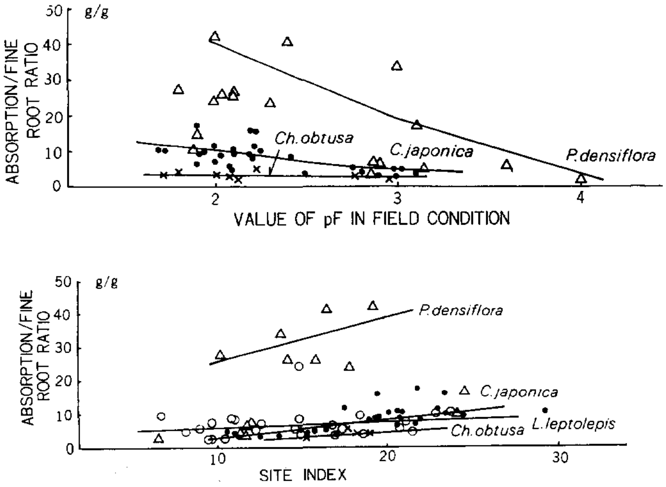

Fig. 22. Ratio of absorbed water to fine root biomass ratio under various conditions.

Table 48. Ratio of annually absorbed water/fine root biomass in each species at the basal area of 500cm².

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Ratio* (g/g)	8500	4500	22000	7000

* The ratio indicates the amount of annually absorbed water per unit fine roat biomass.

Table 49. Rotio of annually absorbed water/fine root biomass and value of pF. (kg/g)

Value of pF Species	2	3	4
P. densiflora	40	20	2
C. japonica	10	5	1
Ch. obtusa	4	2	1

Table 50. Ratio of annually absorbed water/fine root biomass ratio and site index. (kg/g)

Site index Species	10	20
C. japonica	4	10
Ch. obtusa	1.5	5
P. densiflora	25	40
L. leptolepis	6	8

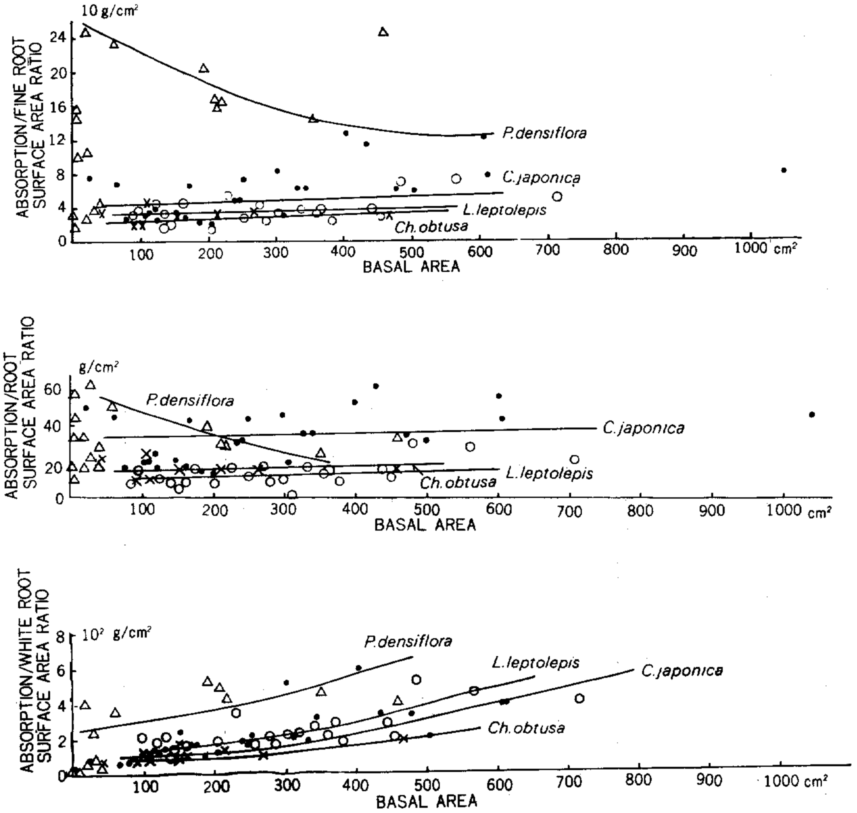

Fig. 23. Ratio of absorbed water to various root factors.

are shown in Fig. 24 when the absorption ratio was calculated from that growth. Frankly speaking, it depends largely on the outcome of future studies to answer whether or not the absorption efficiency of the white tip root surface area actually becomes so great as this increasing curve shows. Even if the absorptivity of those roots becomes, in some degree, stronger as a tree grows, it is still not likely that the absorptive efficiency of the same tree becomes several times higher as shown in Table 52 with the increase of transpiration. Indeed, the absorption through the lignified parts is thought to exist.

The absorption ratio (g/cm^2) of the white tip root surface area of each species was the highest for *P. densiflora* of all the species, irrespective of roots, as shown in Table 52. At the basal area of 100cm^2, for example, it was 300, but 600 at that of 500cm^2. These values were nearly twice as high as those of *C. japonica* and *Ch. obtusa*. This is, as in the above-mentioned absorption ratio by root, because the fine root biomass of *P. densiflora* is much less than those of *C. japonica* and *Ch. obtusa*. The surface area of white tip roots requires an adjustment in calculation when a tree has hair roots.

The surface area for absorption of *P. densiflora* having hair roots, for example, has been calculated when the surface area of the white tip root is presumed to make a 1.4 times

Table 51. Average annual growth of root length and white tip root surface area.

Stand	Average annual growth of root in length	Diameter of white tip root	White tip root surface area		Stand	Average annual growth of root in length	Diameter of white tip root	White tip root surface area	
	(cm/yr)	(cm)	(cm²)			(cm/yr)	(cm)	(cm²)	(cm²)
S 1	15618	0.81	39723	—	9	1523	0.52	2487	3482
2	13358	0.58	24328	—	10	2777	0.43	3750	5250
3	9494	0.55	16396	—	11	2686	0.40	3374	4724
4	12180	0.58	22182	—	12	2561	0.42	3377	4728
5	9144	0.78	22395	—	13	3826	0.60	7208	10091
6	9274	0.48	13978	—	14	1018	0.60	1918	2685
7	15439	0.54	26178	—	15	4109	0.55	7096	9934
8	8725	0.70	19178	—	16	1841	0.60	3468	4855
9	11184	0.57	20017	—	17	2061	0.64	4142	5799
10	11781	0.56	20716	—	18	1590	0.64	3195	4473
11	7310	0.58	13313	—	19	2518	0.58	4586	6420
12	12622	0.67	26554	—	K 1	4866	0.55	8404	—
13	13336	0.60	25125	—	2	3221	0.56	5664	—
14	14694	0.55	25377	—	3	4671	0.57	8360	—
15	15676	0.57	28057	—	4	1566	0.60	2950	—
16	7443	0.58	13555	—	5	1718	0.58	3129	—
17	15036	0.58	27384	—	6	1129	0.58	2056	—
18	8811	0.79	21857	—	7	1673	0.68	3572	—
19	9276	0.62	18059	—	8	2640	0.47	3896	—
20	13613	0.47	20090	—	9	1555	0.46	2246	—
21	6043	0.58	11006	—	10	2078	0.17	3067	—
22	4491	0.82	11378	—	11	4167	0.48	6281	—
23	8171	0.60	15394	—	12	4081	0.47	6023	—
24	10100	0.49	15540	—	13	5579	0.47	8233	—
25	16367	0.69	35461	—	14	9446	0.47	13940	—
26	14218	0.69	30805	—	15	3737	0.47	5515	—
27	12406	0.58	25894	—	16	6724	0.53	11190	—
H 1	15662	0.55	27048	—	17	4702	0.50	7382	—
2	8929	0.67	18785	—	18	4217	0.47	6223	—
3	11072	0.67	23293	—	19	5461	0.47	8059	—
4	7339	0.91	20970	—	20	2126	0.57	10964	—
5	13427	0.68	28669	—	21	6192	0.47	9138	—
6	13014	0.50	20432	—	22	5704	0.47	8418	—
7	6151	0.62	11975	—	23	3755	0.45	5306	—
8	5068	0.61	9707	—	24	5621	0.56	9884	—
A 1	860	0.53	1431	* 2003	25	5303	0.52	8659	—
2	1195	0.51	1914	2680	26	4296	0.41	5531	—
3	1677	0.52	2738	3833	27	5589	0.47	8276	—
4	2080	0.52	3396	4754	28	8171	0.47	12059	—
5	4172	0.40	5240	7336	29	4750	0.33	4922	—
6	1706	0.32	1714	2400	M 1	6294	0.75	14822	—
7	5798	0.52	9467	13254	2	9410	0.77	22751	—
8	3376	0.50	5300	7420	3	26584	0.22	18364	—

Continued

Stand	Average annual growth of root in length	Diameter of white tip root	White tip root surface area		Stand	Average annual growth of root in length	Diameter of white tip root	White tip root surface area	
	(cm/yr)	(cm)	(cm²)			(cm/yr)	(cm)	(cm²)	
4	31436	0.24	23690	—	8	5789	0.29	5271	—
5	3568	0.72	8067	—	9	2783	0.31	2709	—
6	6249	0.71	13932	—	10	5587	0.30	5263	—
7	80545	1.16	293377	—					—

* In case of pine, ordinary surfce area of white tip roots is multiplied by 1.4 to include the surface orea of root hairs.

Table 52. Ratio of annually absorbed water/white root surface area ratio by basal area.

Species	Basal area (cm²)			
	100	300	500	800
C. japonica	100	120	250	600
Ch. obtusa	100	110	200	400
P. densiflora	300	400	600	900
L. leptolepis	150	180	400	700

increase owing to the existing hair root.

7) **Surface area of lignified part and white tip roots, with the difference counted in**

The white tip roots which are full of young and active tissues, and the lignified parts, have different absorption efficiencies, therefore they absorbed different amounts of water according to their own absorption efficiencies. The following experiment was carried out in order to observe the difference in absorption efficiency of white tip roots and lignified parts.

Experiment: Measuring the amount of water absorbed by the white tip roots and the lignified parts of fine root.

Smaples: One-year-old seedlings of *C. japonica* from Daigo, Ibaraki Prefecture.

Period: July-August, 1965.

From a sample of 100 one-year-old seedlings 20 normal ones (12cm in height and 2.5mm in the base diameter) were picked out and placed one by one in a 200 c.c. triangular flask filled with water. Prior to this all the superfluous fine and white tip roots were cut off since the section of the white tip roots was very difficult to treat because the roots were very complicated. After two weeks, when the white tip roots had grown and the base began to lignify, the amount of absorbed water was measured. First, the amount of transpiration was measured for 5 days to get the average transpiration per day on the remaining condition, Next, after the tips of the wite tip roots, i,e., the youngest tissues, were cut off, their length, diameter and dry weight were measured and the cuts were closed up with an adhesive, so that the trees would not absorb water through them, The cut-off roots were drawn on papers for measuring their root length, and their dry-weight was measured after their diameters were measured with a micrometer.

The same treatment was done about the brownish and partly lignified parts of those roots. Thus, the average amount of water absorbed in a day by the tips of the white tip roots, partly or completely lignified, was calculated in connection with the weight and surface area.

The sample weights and each amount of absorbed water are shown in Table 53.The amounts of water absorbed by unit root weight per day were 180cc by the white tip roots, 22cc by a little lignified part, and 17cc by the completely lignified part. This explains why the absorptivity decreases to almost 1/8 from the tip to a little lignified part. Although its absorption efficiency is much less than that of the tips, the ilgnified part, we can assume, absorbs much water in a grown-up tree. When the absorption by the tips or white tip roots is taken to be 1, that by a slightly old white tip root is 0.12, and that by the lignified part is 0.09. The amounts of absorbed water per unit surface area were 0.613g by the tips of the white tip roots, 0.09g by the older white tip roots, and 0.077g by the lignified part. The ratios to the tip were 1.00, 0.15 and 0.13 respectively. The absorption ratio based on surface area was higher than that based on weight. As a result of this experiment, the absorption ratio of the lignified root turned out to be about 13% of that of the white tip roots. Therefore, the total surface areas of the lignified roots, multiplied by 0.13, were converted into the absorptive surface area equivalent to the absorption ratio of the surface area of the white tip roots.

The surface area of the lignified roots was converted into the surface area of the white tip roots; the ratio of that surface area to the total absorptive surface area is shown in Fig. 24. According to the table, it decreased as the basal area increased. According to the results in Table 55, water of 84% was taken in through white tip roots at a basal area of $61cm^2$ in the stand of S1, but only 36% through them at a basal area of $1,042cm^2$ in the stand of S17, showing an apparent difference of 50% between them. At the basal area of $300\sim400cm^2$, about 50% of water was absorbed through the white tip roots, and the other 50% through the lignified roots. This explains why the lignified roots and the ratio of water absorbed by the lignified roots increase as the tree gets larger. The result of calculating the amount of absorbed water according to the ratio of the absorptive surface area is shown in Table 56. We see that 2.2 tons are equivalent to 84% of the amount of the total absorbed water of 2.6 tons per tree to be absorbed through the white tip roots, and 0.4 ton through the lignified roots in the stand of S1.

That water is presumed to be taken in according to the ratio by white tip root surface area; so the large diameter tree with plenty of lignified parts, we can assume, takes in a great deal of water through these parts. That tree, for example, took in 6 tons per tree through the white tip roots in the stand of S17, and yet took in 11 tons through the lignified parts. These parts absorbed almost twice the amount of water absorbed by those parts. To investigate further, let us divide this amount of absorbed water, according to the root surface area of the lignified parts and calculate each absorptive efficiency, the surface area, and absorptive efficiency of a white tip root counted in. And having done this, we get the results shown in Table 54.

The relation between the absorption ratio and the basal area is shown in Fig. 25. As is clear from the figure, the ratio tends to increase according to the growth of trees regardless of species. Table 57 shows this in greater detail for *C. japonica*. Both the white tip root absorption ratio by surface area and the lignified root absorption ratio by surface area increased rapidly, describing an almost parabolic curve, as in Fig. 26, before the basal area reached about 200cm^2. But it is not always common to all species. For example, the absorption ratio at the basal area of 500cm^2 became lower in the order of *C. japonica* (180), *P. densiflora* (140), *L. leptolepis* (100), and *Ch. obtusa* (50). *P. densiflora* showed different absorption characteristics in that its absorption ratio dropped a little as the basal area became wider; for instance, 180 and 140 at the basal area of 100cm^2 and 500cm^2 respectively.

8) Absorption ratio of every species

There exists a certain relation between each root factor on which calculation of the absorption ratio is based. This relation varies, however, according to the characteristics of each root. The root surface area, for example, of *Ch. obtusa* with intricately ramified fine roots is larger than that of *P. densiflora* with sparsely branching fine roots, even when their root biomass is the same. This being so, it is natural that the interrelation in absorption ratio shows a difference due to certain root factors.

The absorption ratios of the principal species in the typical stands from the detailed table are shown in Table 58. Suppose that each ratio of *C. japonica* is to be 1. Then all fine root absorption ratios by weight and surface area, and the white tip root absorption ratio by surface area became lower in the order of *P. densiflora, C. japonica, L. leptolepis,* and *Ch. obtusa*. This is applicable to each root factor. Each absorption ratio was highest for *P. densiflora*, which has a large amount of absorbed water for a fine root biomass, but vice versa for *Ch. obtusa*. But each root factor made some difference. It became, for example, lower in the order of the absorption ratio by fine root biomass, the absorption ratio by fine root surface area, and the abrorption ratio by white tip root surface area. It is clear from this that the

Table 53. Water absorption by different parts of root system in *C. japonica*.

	White root (A)	White root (B)	Lignified root	Total
Daily absorbed water* (g)	1.03	0.60	1.39	3.02
Root weight (g)	0.006	0.027	0.081	0.114
Root surface area (mm^2)	168	664	1806	2638
Daily absorbed water per root weight (g/g)	172	22	17	26
Ratio to white root (A)	1.00	0.13	0.10	—
Daily absorbed water per root surface area (g/mm^2)	0.613	0.090	0.077	0.114
Ratio to white root (A)	1.00	0.15	0.13	—

* Average for three days
Period of experiment : from July to August, 1965
Matrejal : one-year-old seedlings from Daigo Natl. For.
Number of samples : 15
White root (A) : white root from a root tip to an elongation zone
White root (B) : prematured to matured zone
Average size of seedlings :
Height : o2.5cm; Basal diameter : 2.4mm
Above-ground : 2.182g)leaf : 0.458g; stem : 1.724g) Underground : 0.114g (main root : 0.09g; lignified fine root : 0.032; whitte root(A) 0.006g; white roo(B) : 0.027g)
Total weght : 2.296g; T/R ratio : 19.140

Table 54. Absorption ratio of lignified and white root.

Species	Stand	Root surface area (cm²)		Root surface area considering absorptive efficiency. Absorption effciency of lignified root is calculated as 0.13 of that of white tip root. (cm²)	Root surface area 0.13 white tip root surface area. (cm²)
		Fine root	Total		
C. japonica	S 1	37825	57224	7439	47162
	2	86660	132954	17284	41612
	3	49872	75633	9832	26228
	4	113527	191073	24839	47021
	5	119812	206885	26895	49290
	6	57268	100968	13126	27104
	7	124748	183916	23909	50087
	8	75743	120000	15600	34778
	9	128819	210912	27419	47436
	10	128701	193052	25097	45813
	11	15540	23471	3051	16364
	12	78665	127454	16569	43123
	13	66375	103017	13392	38517
	14	75810	120684	15689	41066
	15	131501	227193	29535	57592
	16	84612	145286	18887	32442
	17	218157	367936	47832	75216
	18	85790	183819	23896	45753
	19	85041	154803	20124	38183
	20	111838	186134	24197	44287
	21	69833	121221	15759	26765
	22	51161	122448	15918	27296
	23	83300	135042	17554	32948
	24	91553	145200	18876	34416
	25	97683	172711	22452	57913
	26	105453	188169	24462	55267
	27	110497	196429	25536	51430
Ch. obtusa	H 1	45940	67545	8781	35829
	2	51989	90081	11711	30496
	3	95837	167333	21753	45046
	4	97276	191368	24878	45848
	5	188968	341119	44345	73014
	6	87852	153934	20011	40443
	7	64740	107470	13971	25946
	8	58612	113037	14695	24402
P. densiflora	A 1	1825	7290	948	2951
	2	4054	18327	2383	5063
	3	10183	51538	6700	10533
	4	15090	91253	11863	16617
	5	14876	26755	3478	10814
	6	5649	9276	1206	3606
	7	6439	1488	1935	15189

White tip root surface area/(root surface area 0.13 white tip root surface area).	Absorption from root. (kg)	Absorption from lignified root. (kg)	Absorption fatio of white root. (g/cm²)	Adsorbtion ratio of lignified root. (g/cm²)
0.84	2174	414	54.7	7.2
0.58	2388	1729	98.2	13.0
0.63	783	460	47.8	6.1
0.47	3240	3653	146.1	19.1
0.45	3259	3984	145.5	19.3
0.52	1001	924	71.6	9.2
0.52	1386	1280	52.9	7.0
0.55	1981	1621	103.3	13.5
0.42	1726	2383	86.2	11.3
0.45	1141	1395	55.1	7.2
0.81	949	222	71.3	9.5
0.62	3507	2149	132.1	16.9
0.65	2861	1541	113.9	15.0
0.62	1785	1094	70.3	9.1
0.49	4900	5101	174.6	22.5
0.42	2175	3003	160.5	20.7
0.36	6103	10850	222.9	29.5
0.48	5036	5456	230.4	29.7
0.47	2596	2927	143.8	18.9
0.45	1393	1703	69.3	9.1
0.41	924	1330	84.0	11.0
0.42	2702	3731	237.5	30.5
0.47	1281	1445	83.2	10.7
0.45	1029	1248	66.2	8.7
0.61	4853	3102	136.9	18.0
0.56	6630	5210	215.2	27.7
0.50	3178	3177	122.7	16.2
0.75	1074	358	39.7	5.3
0.62	1468	899	78.1	10.0
0.52	1598	1425	68.6	8.5
0.46	1475	1732	70.3	9.1
0.39	2290	3583	79.9	10.5
0.51	851	817	41.7	5.3
0.46	954	1120	79.7	10.4
0.40	524	787	54.0	7.0
0.68	315	148	157.3	20.3
0.53	500	443	186.6	24.2
0.36	735	1307	191.8	25.4
0.29	621	1519	130.6	16.6
0.68	335	158	45.7	5.9
0.67	65	32	27.1	3.4
0.87	326	49	24.6	3.3

Table 54. Continued

Species	Stand	Root surface area (cm^2)		Root surface area considering absorptive efficiency. Absorption efficiency of lignified root is calculated as 0.13 of that of white tip ro. (cm^2)	Root surface area 0.13 white tip root surface area. (cm^2)
		Fine root	Total		
	A 8	12351	92106	11974	19394
	9	9361	55774	7251	10733
	10	10825	19200	2496	7746
	11	10907	18914	2459	7183
	12	10174	18951	2463	7191
P. thunbergii	13	3961	18949	1540	11631
P. strobus	14	8569	44704	5812	8497
P. thunbergii	15	2715	4801	624	10558
P. taeda	16	1166	2876	374	5229
	17	1311	3823	497	6296
	18	1024	2501	325	4798
	19	2187	4262	554	6974
L. leptolepis	K 1	60321	137047	17816	26220
	2	34356	87434	11366	17030
	3	33372	78038	10145	18505
	4	10502	35665	4636	7586
	5	18400	43240	5621	8750
	6	10724	37168	4832	6888
	7	15239	58502	7605	11177
	8	25163	79448	10328	14224
	9	15291	50324	6452	8788
	10	19286	64572	8394	11461
	11	45739	115554	15022	21303
	12	40329	122727	15955	21978
	13	66270	145688	18939	27172
	14	77353	181578	23605	37545
	15	39777	104108	13534	19049
	16	61736	139035	18075	29265
	17	47959	106287	13817	21199
	18	49426	113803	14794	21017
	19	63433	142277	18496	26555
	20	72600	180417	23454	34418
	21	70324	152359	19807	28945
	22	65851	155873	20263	28681
	23	39957	77780	10111	15417
	24	68721	150424	19555	29439
	25	61445	130668	16987	25646
	26	46344	95642	12433	17964
	27	67560	158054	20547	28795
	28	104083	236874	30794	42853
	29	52909	115134	14967	19889
Ch. pisifera	M 1	65659	113501	14755	29577

White tip root surface area/(root surface area 0.13 white tip root surface area).	Absorption from root. (kg)	Absorption from lignified root. (kg)	Absorption fatio of white root. (g/cm²)	Absorption ratio of lignified root. (g/cm²)
0.38	1152	1879	155.3	20.4
0.32	487	1036	139.9	18.6
0.68	205	96	39.0	5.0
0.66	319	164	67.5	8.7
0.66	264	136	55.8	7.2
0.87	351	53	34.8	4.5
0.32	433	920	161.3	20.6
0.94	79	5	8.0	1.0
0.93	114	9	23.5	3.1
0.92	189	16	32.6	4.2
0.93	136	10	30.4	4.0
0.92	—	—	—	—
0.32	736	1564	87.6	11.4
0.33	451	915	79.6	10.5
0.45	659	806	78.8	10.3
0.39	122	191	41.4	5.4
0.36	246	437	78.6	3.1
0.30	195	455	94.8	12.2
0.32	218	464	61.0	7.9
0.27	367	994	94.2	12.5
0.26	128	366	57.0	7.3
0.27	165	446	53.8	6.9
0.29	313	766	49.8	6.6
0.27	371	1003	61.6	8.2
0.30	433	1009	52.6	6.9
0.37	1368	2329	98.1	12.8
0.29	378	927	68.5	8.9
0.38	964	1573	86.1	11.3
0.35	443	823	60.0	7.7
0.30	905	2111	145.4	18.5
0.30	683	1593	84.7	11.2
0.32	1635	3745	149.1	19.3
0.32	1524	3239	166.8	21.3
0.29	502	1229	59.6	7.9
0.34	194	378	36.6	4.9
0.34	718	1395	72.6	9.3
0.34	634	1231	73.2	9.4
0.31	250	558	45.2	5.8
0.29	706	1727	85.6	10.9
0.28	1376	3537	114.1	14.9
0.25	234	703	47.5	6.1
0.50	—	—	—	—

Table 54. Continued

Species	Stand	Root surface area (cm²)		Root surface area considering absorptive efficiency. Absorption efficiency of lignified root is caiculated as 0.13 of that of white tip root. (cm²)	Root surface area 0.13 white tip root surface area. (cm²)
		Fine root	Total		
	M 2	158292	260306	33840	56591
E. globulus	3	47918	120285	15637	34001
Z. serrata	4	353321	464608	60399	84089
A. firma	5	19000	51759	6729	14796
T. canadensis	6	57329	170308	22140	36072
A. decurrens	7	368866	639469	83131	376508
Q. mongolica v. *grosserrata*	8	37669	125697	16341	21612
B. platyphylla v. *japonica*	9	13042	41573	5404	8113
B. davurcia	10	31785	99076	12880	18143

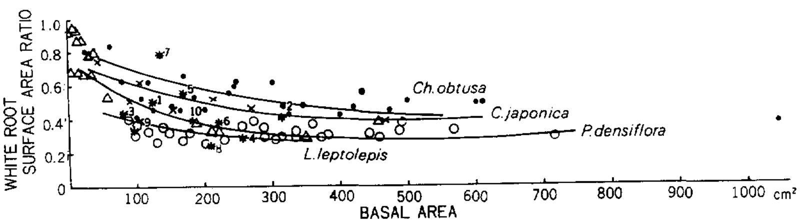

Fig. 24. Ratio of white root surface area to total absorptive surface area in each tree size when absorptive efficiency is considered.

absorption ratio comes to differ little among each species as the surface area of each root is highly related to the absorptive efficency rather than to the root biomass. As for the white tip root surface area, absorption efficiency tends to be more or less similar in each species. The total root absorption ratio by surface area and the white tip absorption ratio by surface area, in which the absorptive efficiency counted become lower in the order of *C. japonica*, *P. densiflora*, *L. leptolepis*, and *Ch. obtusa*, different from the former case. The total root absorption ratio by surface area of *P. densiflora* became almost 70% of that of *C. japonica*. As compared with the former, *Ch. obtusa* and *L. leptolepis* has a lower ratio because those species had plenty of thick roots for fine roots.

9) Site conditions and absoption ratio

It is conceivable that the absorption ratio by each root factor varies with site conditions. With the stands of *C. japonica* taken here as an example, let us examine the absorption ratios by root in the typical stands ranging from dry to moist. The result is shown in Table 59; according to the table, each absorption ratio went down in a dry soil-typed stand with a large pF value and small site index. The variation ratio differs, however, with each root factor. The fine root absorption ratio by weight in the S18 stand of the B_E-type soil with the site index of 23 was 4.15, about 4 times as high as that in the Bl_A type soil. The variation ratio decreased in the order of the fine root absorption ratio by surface area, revised

White tip root surface area/(root surface area 0.13 white tip root surface area).	Absorption from root. (kg)	Absorption from lignified root. (kg)	Absorptoin fatio of whitd root. (g/cm²)	Absorption ratio of lignified root. (g/cm²)
0.40	—	—	—	—
0.54	—	—	—	—
0.28	—	—	—	—
0.55	—	—	—	—
0.39	—	—	—	—
0.78	—	—	—	—
0.24	—	—	—	—
0.33	—	—	—	—
0.29	—	—	—	—

Table 55. White root absorption ratio of *C. japonica*.

Stand	Basal area (cm²)	White root-absorption ratio
S 1	61	0.84
S 13	196	0.65
S 4	335	0.47
S 5	439	0.45
S 16	406	0.42
S 17	1042	0.36

Table 56. Absorbed water per tree from the white roots and lignified roots of *C. japonica*.

Stand	S 1	S 13	S 4	S 5	S 17
Basal area (cm²)	61	196	335	439	1042
Absorption from white roots (ton)	2.2	2.9	3.2	3.3	6.1
Absorption from lignified roots(ton)	0.4	1.5	3.7	4.0	10.9
Total (ton)	2.6	4.4	6.9	7.3	17.0

white tip root absorption ratio by surface area, the total root absorption ratio by surface area, and the white tip root absorption ratio by surface area, and the white tip root absorption ratio by surface area was only 2.8 times high. This clearly shows that the root absorption ratio by weight varies more greatly than the absorption ratio by surface area, when the site condition changes. This is so because the root surface area varies with the site conditions even within the same species.

10) **Tree growth and absorption ratio by root**

The relation between the basal area and each root factor in the *C. japonica* stand is

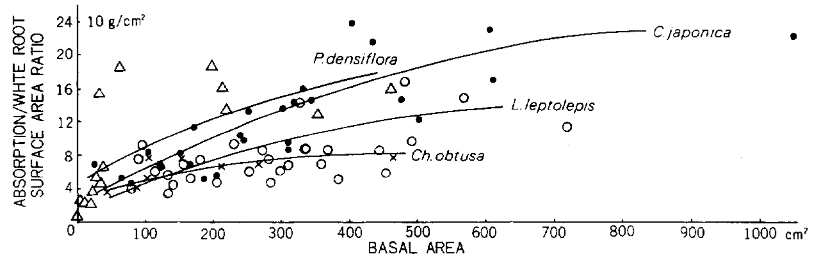

Fig. 25. Absorption-white root surface area ratio when absorptive efficiency is considered.

Table 57. Ratio of absorbed water to the surface area of white roots and lignified roots in each tree size.

Stand	Basal area (cm²)	Absorptive efficiency of roots considered	
		Absorption-white root surface area ratio (g/cm²)	Absorption-lignified root surface area ratio (g/cm²)
S 1	61	55	7
S 13	196	114	15
S 4	335	146	19
S 5	439	146	19
S 27	599	123	16
S 17	1042	223	30

shown in Table 60. The absorption ratio by weight, the fine root absorption ratio by surface area, and the total root absorption ratio by surface area, respectively, indicate certain values regardless of tree-size. The order of ratios between species was similar. The white root absoption ratio by surface area, revised ratio, and lignified root absorption ratio by surface area increased as the tree grew larger. Those in the S17 stand of the large-diameter trees, for example, were 3-4 times as high as those in the S1 stand of the small-diameter trees. This is because the white tip roots of the large diameter tree do not increase in proportion to the absorption. It proves, therefore, that water is actively absorbed through the white tip roots as the amount of transpiration increases in the large-diameter trees. This absorption is not due to the active work by roots but to the negative pressure in the vessel caused by transpiration. That such a tendency is observed in the lignified roots indicates that the absorption by the lignified root surface area is also affected by the transpiration of the above-ground part.

From these facts, as an index of the absorptive structure of roots, the revised white tip root absorption ratio by surface area or lignified root absorption ratio is more adequate than the fine root absorption ratio by weight or the fine root absorption ratio by surface area. Its calculation, however, is so tedious that it is better to substitute the total root absorption ratio by surface area for those ratios. Assuming that absorption takes place in each part of the root corresponding to the distribution of the total root surface area, the amount of water absorbed from each soil horizon should be as follows:

11) Annual absorption of water in each soil horizen from absorptive structure of root system

Table 58. Absorption-various root factor ratios by species and their ratios to the values of *C. japonica*.

Species	Stand	Basal area	Absorption-fine root weight ratio	Absorption-fine root surface area ratio	Absorption-root surface area ratio	Absorption-white root surface area ratio	Absorption efficiency considered	
							Abrorption-white root ratio	Absorption-lignified root surface area ratio
		(cm²)	(g/g)	(g/cm²)	(g/cm²)	(g/cm²)	(g/cm²)	(g/cm²)
C. japonica	S 5	439	8.5	60	35	323	146	19
Ch. obtusa	H 5	427	4.0	31	17	205	80	11
P. densiflora	A 4	311	24.0	142	23	450	131	17
L. leptolepis	K 1	343	6.3	38	17	274	88	11
Ratio to the ratios of *C. japonica* as 1								
C. japonica	S 5	—	1.00	1.00	1.00	1.00	1.00	1.00
Ch. obtusa	H 5	—	0.47	0.52	0.49	0.63	0.55	0.58
P. densiflora	A 4	—	2.82	2.37	0.66	1.39	0.90	0.89
L. leptolepis	K 1	—	0.74	0.63	0.49	0.85	0.60	0.58

Each absorption per ha in the second-class stands at the stand ages (yrs) of 10,20,30,40, and 50 in the yield table was calculated from the basal area and the annual absorption of water in Table 45 and Fig. 20. After that, the annual amount of water absorbed from each soil horizon was calculated, as in Table 61, by multiplying those values by the distribution ratio accorcing to each soil horizon in every stand of the yield table from the ratio curve of the basal area-total root surface area of every soil horizon. But here absorption is supposed to take place in proportion to the total root surface area.

The amounts of absorption increase in the immature stands. Here, they will be examined in the 50-year-old stand for which the curve of the breast height basal area-water absorbed per ha is stable as in Fig. 20. The amounts of absorbed water from soil horizon I were, the most, 3,208 tons for *C. japonica*, 2,521 tons for *Ch. obtusa*, 961 tons for *P. densiflora*, and 915 tons for *L. leptolepis*, which took in the least water of all from the surface area. *Ch. obtusa* had about 700 tons less water than *C. japonica* although the species took more fine roots there.

The water absorbed from soil horizon II was 1,283 tons for *C. japonica*, 1,156 tons for *Ch. obtusa*, 517 tons for *P. densiflora*, and 424 tons for *L.* leptolepis. The differnces between species become smaller here than from soil horizon I. The difference between *C. japonica* and *Ch. obtusa*, for example, was 2,300 tons from soil horizon I, while it was 800 tons here.

The amounts from soil horizon III were 2,326 tons for *C. japonica*, 934 tons for *Ch. obtusa*, 623 tons for *P. densiflora*, and 413 tons for *L. leptolepis*. The differences between species became larger here again. *C. japonica* and *L. leptolepis*, for example, showed a difference of 1,900 tons. Those of *C. japonica*, the deep-rooted species with much branched roots, increased more rapidly in soil horizon III (30–60cm in depth).

The amounts absorbed from soil horizon IV were 962 tons for *C. japonica*, 394 tons for *Ch. obtusa*, 313 tons for *P. densiflora*, and 91 tons for *L. leptolepis*. Those by the shallow-rooted *L. leptolepis* decreased markedly here. As the decrease was quite large regardless of species, differences between species became much smaller. For example, the difference between

Table 59. Soil properties and absorbed water-various root factor ratios.

Stand	Soil type	Site index	pF	Absorbed water-fine root weight ratio	Absorbed water-fine root surface area ratio	Absorbed water-root surface area ratio	Absorbed water-white root surface area ratio	*Absorbed water-white root surface area ratio	*Absorbed water-lignified root surface area ratio
				(g/g)	(g/cm^2)	(g/cm^2)	(g/cm^2)	(g/cm^2)	(g/cm^2)
S 6	Bl_A	11.3	2.5	3.9	34	19	138	72	9
S 7	Bl_C	13.6	3.0	3.7	21	14	102	53	7
S 4	Bl_D	19.4	2.2	9.2	61	36	311	146	19
S 26	$Bl_{D(w)}$	19.4	2.2	15.6	112	63	334	215	28
S 22	B_E	21.8	1.9	17.5	126	53	584	238	31
S 18	B_E	23.4	2.2	16.2	122	57	383	230	30

* Diffeerence in absorption cfficiency by the parts of a root is counted in. Ratios of factors of various soil types to factors of soil type Bl_A

S 6	—	1.00	—	1.00	1.00	1.00	1.00	1.00	1.00
S 7	—	1.20	—	0.95	0.62	0.74	0.74	0.74	0.78
S 4	—	1.72	—	2.36	1.79	1.89	2.25	2.03	2.11
S 26	—	1.72	—	4.00	3.29	3.32	2.25	2.99	3.11
S 22	—	1.93	—	4.49	3.71	2.79	4.23	3.31	3.44
S 18	—	2.07	—	4.15	3.59	3.00	2.78	3.19	3.33

Table 60. Basal area and absorption-various root fartor ratios in the *C. japonica* stands.

Stand	Basal area	Absorbed water-fine root ratio	Absorbed water-fine root surface area ratio	Absorbed water-root surface area ratio	Absorbed water-white root surface area ratio	Absorption efficiency considered	
						Absorbed water-white root surface area ratio	Absorbed water-lignified root surface area ratio
	(cm^2)	(g/g)	(g/cm^2)	(g/cm^2)	(g/cm^2)	(g/cm^2)	(g/cm^2)
S 1	61	10.5	68	45	65	55	7
S 13	196	9.4	66	43	175	114	15
S 4	335	9.2	61	36	311	146	19
S 5	439	8.5	60	35	323	146	19
S 27	599	8.1	58	32	206	123	16
S 17	1042	11.0	78	46	1251	223	30

Ratio of factors in various stands to those in S1.

S 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S 13	3.21	0.90	0.97	0.96	2.69	2.07	2.14
S 4	5.49	0.88	0.90	0.80	4.78	2.65	2.71
S 5	7.20	0.81	0.88	0.78	4.97	2.65	2.71
S 27	9.82	0.77	0.85	0.71	3.17	2.24	2.29
S 17	17.08	1.05	1.15	1.02	19.25	4.05	4.29

C. japonica and *L. leptolepis* was only about 900 tons.

The amounts from soil horizon V were 241 tons for *C. japonica*, 133 tons for *P. densiflora*, 45 tons for *Ch. obtusa*, and 7 tons for *L. leptolepis*. Here, the distinct difference was caused by the distribution property of each root. It became, for example, very slight for the shallow-rooted *Ch. obtusa* and *L. leptolepis*.

No absorption was observed in soil horizons VI and below on *C. japonica*, *Ch. obtusa* or *L. leptolepis*, but more than 100 tons of water was absorbed by *P. densiflora*.

In soil horizons I and II of these 50-year-old stands, the amount of water absorbed by *C. japonica* was 4,500 tons, about 3-4 times as much as that absorbed by *P. densiflora* (1,500 tons) or *L. leptolepis* (1,300 tons). The amonnt absorbed by *Ch. obtusa* was 3,700 tons. If we assume that this water absorbed from horizons I and II is utilized for growth, it becomes clear that adequate growth of *C. japonica* can be expected only in areas where the surface soil contains much water.

On the other hand, *L. leptolepis* or *P. densiflora* is known to grow rather well even in the ground with less water.

The amount of water absorbed from soil horizons I and II by *C. japonica* corresponds

Table 61. Absorbed water per ha in each soil horizon and tree growth.

(ton/ha/yr)

Species		*C. japonica*					*Ch. obtusa*				
Stand age (yrs)		10	20	30	40	50	10	20	30	40	50
Bssal area (cm²)		52	204	404	620	853	18	79	166	272	384
Horizon	Ⅰ	3245	5132	3625	2916	3208	573	1571	3055	2735	2521
	Ⅱ	1116	1822	1542	1296	1283	179	545	1150	1125	1156
	Ⅲ	318	1822	2699	2252	2326	27	190	600	810	934
	Ⅳ	71	867	1398	1296	962	1	59	175	300	394
	Ⅴ	+	207	376	340	241	+	5	20	30	45
Total		4750	9850	9640	8100	8020	780	2370	5000	5000	5050

Species		*P. densiflora*					*L. leptolepis*				
Stand age (yrs)		10	20	30	40	50	10	20	30	40	50
Basal area (cm²)		17	112	282	493	724	41	225	365	534	724
Horizon	Ⅰ	984	1775	1269	991	961	359	1229	1008	912	915
	Ⅱ	323	718	631	539	517	100	436	428	429	424
	Ⅲ	112	512	655	595	623	1	248	361	417	413
	Ⅳ	20	154	254	295	313	+	59	86	103	91
	Ⅴ	6	62	112	134	133	+	8	17	19	7
	Ⅵ	1	16	42	48	45	—	—	—	—	—
	Ⅶ	1	16	6	35	21	—	—	—	—	—
	Ⅷ	1	10	21	16	16	—	—	—	—	—
	Ⅸ	1	10	21	16	16	—	—	—	—	—
	Ⅹ	1	7	9	11	5	—	—	—	—	—
Total		1450	3280	3020	2680	2650	460	1980	1900	1880	1850

to about 1/3 of the precipitation of 1,500mm. Such a large proportion of the water in the surface soil going into roots promotes the change of the physical properties of the surface soil.

When the trees are young, the amount of water absorbed from the surface soil is very large for their age, because the roots, regardless of species, are concentrated there at the younger stage. The amount of water absorbed by the rapid-growing *C. japonica*, for example, was 3,245 tons at the age of 10 yrs. in soil horizon I, although it decreased to 3,208 tons at the age of 50 yrs. The amount of water absorbed by *P. densiflora* was 984 tons and 961 tons at the stand age of 10 and 50 yrs. respectively. It was similar to the case of *C. japonica*. The amounts absorbed by the slow-growing species, *Ch. obtusa* and *L. leptolepis*, became constant at the age of 20.

As the amount of water absorbed from soil horizon II, III and lower of the young stand decrease strikingly, the difference between this and the absorption by the mature stand becomes larger. The amounts, for example, absorbed from soil horizons III and IV were 318 tons and 71 tons respectively in the 10-year-old *C. japonica* stand, while they were 2,326 tons and 1,296 tons in the 50-year-old stand. This is common to almost all species. In the immature stand, most of the water is absorbed from the surface soil, which leads to the conclusion that the amount of water absorbed from soil horizon I becomes extraordinarily large in a close planting and young stand, and that deficiency of water is a contingency easily caused there in the dry condition. The large-diameter tree, on the other hand, can absorb a comparatively large amount of water not only from the surface soil but from the deeper soils; hence, it is probable that the absorption of water from the lower soil horizons sustains the growth of trees even when the surface soil lacks water. It is possible in this respect to estimate that the young small-diameter trees are more easily influenced by the physical and chemical properties of the shallow soil horizons than the large diameter trees. This tendency is very clear in the flatrooted species, *Ch. obtusa* and *L. leptolepis*. *P. densiflora* is not so much influenced by the dryness of the surface soil because its roots grow into the deep soil even when young. This characteristics of absorptive structure probably gives *P. dendiflora* its strong resistance against drought.

As already mentioned, the amount of absorbed water per ha is the maximum in the younger stand of 20 to 30 years old. This is also true in each soil horizon. For *C. japonica*, as an example, the amounts of absorbed water were 5,132 tons and 1,822 tons from soil horizons I and II in the 20-year-old stand, and 2,699 tons and 1,398 tons from soil horizons III and IV in the 30-year-old stand. In short, the old trees absorb much water as the soil becomes lower. This is the result of both vigorous absorption at the active young stage and the growth of roots in the deeper soils; this causes the older trees to show the maximum of basorption.

Vertical growth of roots is physically restricted. Therefore, once they are grown up, the absorption ratio is higher in the surface soil than in the lower soil, when they grow sufficiently owing to the property of their selecting some favourable soils that enables their tips to pick up growing in the surface soil.

The distribution of root surface area depends mainly on the aeration of the soil. Although there is much water in the lower soil, there is little oxygen for root respiration which is needed in its function, there is much carbonic acid gas which restricts the root's function. So when the surface soil is moderately moist and contains plenty of water, the absorption efficiency becomes higher there than in the deeper soil, and the amount of absorbed water becomes larger as in Table 60. In the dry condition, the amount of water absorbed from the surface soil decreases, increasing in the deeper soil. In the lower soil, however, the absorptive surface area of the roots is too small to supply the tree with sufficient water. As a result, the growth of the tree decreases. Since the roots grow favourable in the deep colluvial soil and absorb water to compensate for the lack of water in the surface soil, the growth does not decrease much even in the dry condition. What is the best for the tree growth, however, is that the surface soil, where there is the highest proportion of root surface area, is always constantly and moderately moist.

12) **Transpiration ratio by leaf**

A result of calculations of the amount of transpiration per leaf biomass is shown in Fig. 27 in relation to the basal area.

Every species has, as in Fig. 27, a constant transpiration ratio regardless of stand age, though the ratio increases a little at the young stage. The ratios were, for example, 700 for *L. leptolepis*, 500 for *P. densiflora*, 400 for *C. japonica*, and 350 for *Ch. obtusa*. *L. leptolepis* with the small leaf biomass showed the highest ratio, about twice as high as that of *Ch. obtusa*. As compared with the transpiration ratios calculated by Satoo in Table 42, those ratios were 1,023 for *C. japonica*, 965 for *Ch. obtusa*, and 1,998 for *P.* densiflora, all equivalent to two or four times transpiration ratios from the transpiration coefficients. There was a remarkable difference between them. Although these ratios are very much different from those by Satoo (Table 42) owing to the different calculating and measuring methods, their order of *P. densiflora, C. japonica, Ch. obtusa* remains the same. *P. densiflora* has a higher ratio than *C. japonica*, and *L. leptolepis* had the lowest ratio of all. The transpiration ratios are, we can assume as a matter of course, closely connected with the tree growth because the calculation of the amount of transpiration, which is basis of the transpiration ratio, depends on the transpiration coefficient. Their relation is similar to the variation of the ratio of the leaf biomass growth. Precisely because the transpiration ratio is the ratio of leaf biomass growth multiplied by the transpiration coefficent. As a matter of course, the ratios on the various conditions are similar in variation to the ratio of the leaf biomass growth, but each species has its own transpiration coefficent. It has, therefore, its own relativity between the production ratio and the transpiration ratio. The production ratios were, for example, 0.70 for *P. densiflora*, 0.03 for *C. japonica* or *Ch. obtusa*, while the transpiration ratios were 0.71 for *P. densiflora*, 0.50 for *C. japonica*, and 0.57 for *Ch. obtusa*, when the values of *L. leptolepis*, which were the height of both ratios, were considered to be 1. The differences of the latter ratios between species become surprisingly small compared to those of the former ratios.

The variance of transpiration ratio is shown in Fig. 26. According to the figure, *L. leptolepis* had the broadest variance, viz. 500 to 1,200. The variance of each species became narrower in the order of *L. leptolepis*, *P. densiflora*, *C. japonica*, and *Ch. obtusa*, which had the least variance of all. It is unclear whether it is due to errors in measuring the leaf biomass or to the difference in site condition and tree density. The relation between these factors and the transpiration ratio is as follows:

The transpiration ratio of each species, as in Fig. 27, increased slightly, if not clearly, as the tree density increased. The variance of the evaporation ratio in Fig. 28 is extremely large, due mainly to difference in site condition, but concerning site index it is small as in Fig. 28. The relation between the site index and the transpiration ratio is clearly seen in

Fig. 28 (they increase in direct proportion). The transpiration ratios of *C. japonica* were 250 and 450 at the site indices of 10 and 20 respectively.

The ratio of increase was 1.8. The ratios of increase of *L. leptolepis*, *P. densiflora*, and *Ch. obtusa* were 1.64, 1.15 and 1.09 respectively. *C. japonica* and *L. leptolepis* had a higher ratio than the rest.

The above-mentioned relation was not observed distinctly on *P. densiflora* because of the broad variance in ratio, and there was no great variation in the dry condition; however, the species showed a quite low ratio of 249 in the A6 stand of the devastated and dry soil of E_{r-B} type at a site index of 6.6. *Ch. obtusa* showed a small variation in ratio by the site condition as well as low transpiration ratio. The species had, for example, a slight difference in transpiration ratio of only 66 between the dry B_B soil-typed stand of H6 and the moderately moist B_D soil-typed stand of H3, though the difference in site index was 7.4.

The transpiration ratio, as mentioned above, depends on the soil conditions. It goes down in the dry or excessively moist soil with small site indices, and up in the moderately moist soil; in the fromer case, this is because roots take in water insufficiently owing to the shortage of water, air, etc., and in the latter case, because adequate absorption by root causes the transpiration ratio to go higher.

13) Section root area at the base of root stock

The section area of roots at the base of the root stock is connected functionally with the above-ground parts or their biomass as the vascular tissues for nutriment and water.

A result of measuring the basal area of the upper part of a root stock and the root section area made clear that most horizontal roots incline to grow thick one-sidedly in the vertical as in Fig. 28. It is therefore impossible to determine their section area by simply measuring the major and minor axes.

The section areas of root were actually measured and their ratio to the calculated values were obtained in order to revise the actually measured section areas of roots. After that, those calculated values were revised nearest to the actual section areas, by multiplying them by the calculated values.

This root section area ratio differs depending on how much a root inclines to grow thick one-sidedly. And this inclination differs with species, sizes, site conditions, tree densities,

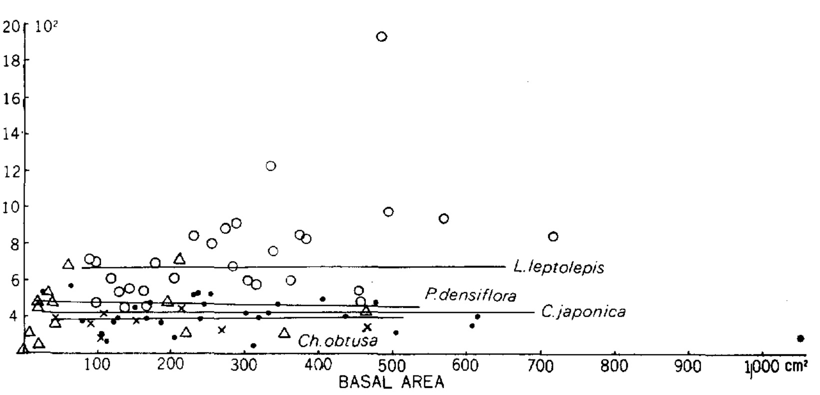

Fig. 26. Transpiration ratio of leaf.
Transpiration ratio: ratio of transpired water to leaf weight.

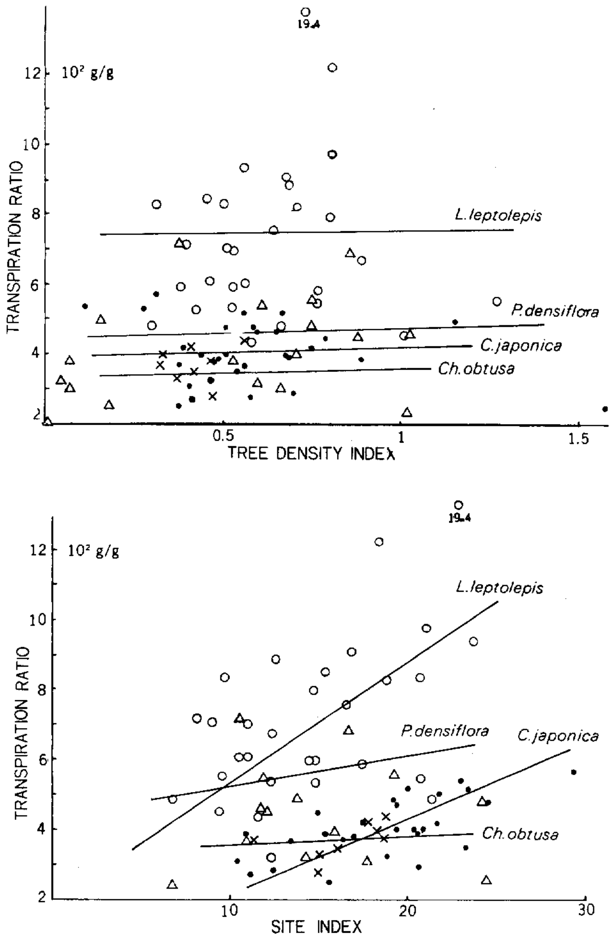

Fig. 27. Site conditions and transpiration ratios.

etc. The relation both between the inclination and the ratio by root section area on various conditions and between the basal areas of the root stock and of the root are as follows:

(1) Section root area and inclination ratio of a root

It is conceivable that the root section area varies with its inclination when the inclination ratio is expressed as follows:

$$\text{Inclination ratio}=\frac{a-b}{\frac{a+b}{2}}$$

a: major axis

b: minor axis

The ratios of the area of an ellipse, its major axis (a) and its minor axis (b), and an actual area of the horizontal root of *L. leptolepis* to the area of a circle having the diameter of $\frac{a+b}{2}$ are shown in Fig. 29. This figure explains why the horizontal root ratio by surface area is decreasing in a slightly concave curve as the inclination ratio rises.

When the inclination ratio was 0.5, the actual section root area had, as in the figure, an approximate percentage of 75 of the area of a circle, the diameter of which was the average of the major and minor axes.

The section area ratios become lower for the shallow-rooted species, such as *Ch. obtusa* and *L. leptolepis* than for the deep-rooted species, because their inclination ratio is steeper.

The basal area, root stock basal area and section root area of a sample tree in each stand were measured. Here, to measure the root stock basal area is to measure, as in Fig. 28, the diameter of the base of a branching root nearest to a root stock. As each section area was irregular, it was calculated as the area of a circle, of which the diameter was the average of the major and minor axes. But, especially when the horizontal roots, occupying a greater part of a root basal area inclined to have a far longer major axis (Fig. 30, B), by this method the root basal area became much larger that it actually was.

Fig. 31 shows the relation between the calculated area and the actual area of *L. leptolepis* in Nobeyama, where the inclination ratio of the horizontal root is remarkable. The total section area measured exactly with a planimeter was 687cm^2, while it was 769cm^2 when calculated from the average of the major and minor axes. The difference by 82cm^2 was equivalent to 12% of the exact section area, which was 89% of that was calculated from the major and minor axes.

(2) Section root area ratio on various conditions

The section root area ratio is influenced by inclination, species, sizes, tree densities, or soil conditions.

Species: Fig. 30 shows the section root area at the basal area of 500cm^2. According to the table, it was 91–92% for shallow-rooted species such as *Ch. obtusa* and *L. leptolepis*, and 96–97% for deep-rooted species such as *P. densiflora* and *Ch. obtusa.* This explains why the shallow-rooted species have a steeper inclination ratio than the deep-rooted species.

Tree growth: The section root area ratio has a tendency to decrease with tree growth. The inclined growth was, as in Fig. 31, slight at the young stage, when the basal area was still small. The section root area ratio, though nearly one at the young stage, decreased sharply at the basal area of 200–300cm^2. The curve became gentle for large-diameter trees.

This is partly because at the young stage of rapid growth, the above-ground biomass of a large tree rises sharply and so does the power necessary to sustain it, and partly because the inclined growth of roots is stimulated.

The section root area ratio of *L. leptolepis* went down rapidly to 99% at the basal area

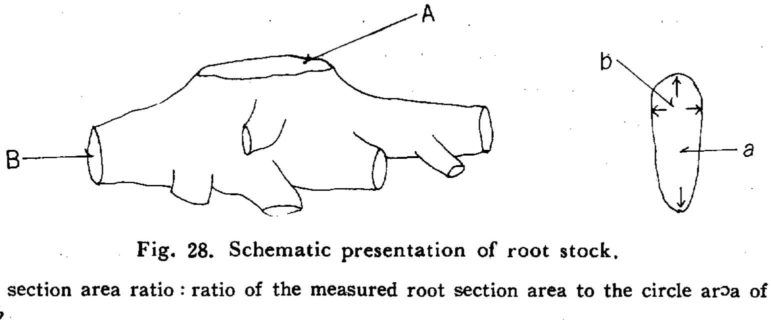

Fig. 28. Schematic presentation of root stock.

* Root section area ratio : ratio of the measured root section area to the circle area of diameter $\frac{a+b}{2}$

** Inclination ratio : ratio shown as $\frac{a-b}{a+b}$ which shows the inclination of the growth of root diameter

a : longest diameter of root section, b : shortest diameter of root section.

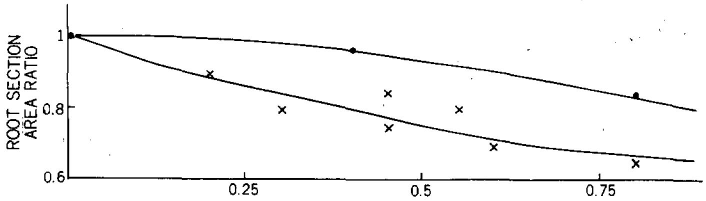

Fig. 29. Inclination growth of root and root section area ratio.

A : section area of root stock, *B* : section area of lateral root.
a : longest diameter, *b* : shortest diameter.

of $150cm^2$, though it was 89% at that of $700cm^2$. This implies that the inclined growth of roots of *L. leptolepis* takes place at an earlier stage than that of other species.

The variation of the section root area ratio of the tap-rooted species *P. densiflora* was gentle and the inclined growth occurred gently.

Tree density: The variation of the section root area ratio with the tree density is shown in Fig. 31 on the close planting stands S22 and S8 and the sparse planting stands S26 and S27. The ratios as shown there were almost 1 in the former stands and lower in the latter.

This is due to the difference of the root growth (especially horizontal roots) by tree density. A twofold reason is further added to this. The inclination ratio of roots is gentle in a close planting stand because roots do not extend so widely and rather vertical roots develop. In a sparse planting stand, it is steep because roots extend widely which is highly influenced by the external forces. This difference in ratio is seen in Fig. 30, which shows the comparison between the dense and sparse stand with almost the same basal area. The ratio is seen to be increasing slightly in the former rather than in the latter.

Thus, since trees have roots with large inclination ratio and supporting power in a sparse planting stand, they are not easily blown down by winds, while trees in a dense stand are easily blown down because they have roots with weaker supporting power.

Soil condition: The section root area ratio changes here again with the soil condition. The comparison in ratio by root basal area of the *C. japonica* stands of the dry B_A or B_B soil with the moderately moist soil is shown in Fig. 31. The result shows a distinct difference between them. The ratio was, on the whole, lower in the devastated and dry stand than in the moderately moist stand of the deep subsoil.

There are two causes for this. In the devastated and dry stand the horizontal roots, on the one hand, are greatly affected by the external forces to grow one-sidedly because they develop in the shallow surface soil, supporting the above-ground parts. In the moderately moist soil of the deep subsoil, on the other hand, the vertical roots develop well to support the above-ground parts, and consequently they do not grow so one-sidedly there.

Vertical roots and horizontal roots: About 10 horizontal and 10 vertical roots of the same size, 5cm in diameter, were taken out as samples and their section area measured with a planimeter (A). The area of a circle with the average of the major and minor axes as its diameter was (B). And then, the ratio of A to B (A/B) and its variation coefficient were calculated, as shown in Table 62.

Since all species had the horizontal roots growing one-sidedly and the vertical roots not

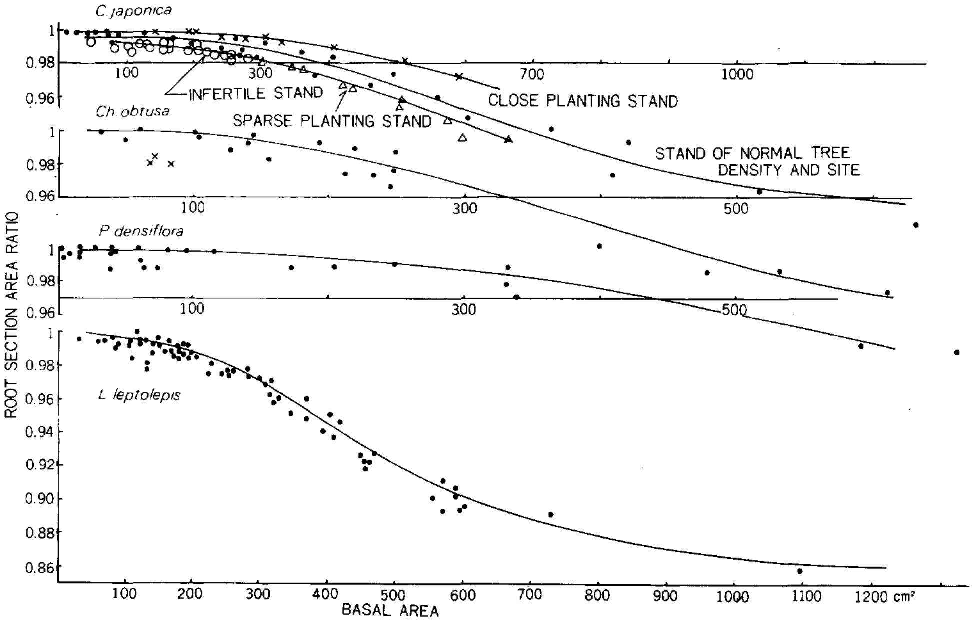

Fig. 30. Basal area and root section area ratio.

growing so one-sidedly, the former root's ratio of A to B was lower, 0.8 to 0.9, than the latter 's (nearly 1).

The difference with the root properties was remarkable in the horizontal roots. For example, the ratios of *Ch. obtusa* and *L. leptolepis*, shallow-rooted, were 0.38, for *C. japonica*, deep-rooted, the ratio was 0.87, and for *P. densiflora*, tap-rooted, 0.91. Of the broad leaved species, these with many large roots branching from the blocky root stock, such as *Quercus mongolica*, *Betula platyphylla*, and *Acacia decurrens*, had the high ratios of 0.92 to 0.95.

Root inclination ratio according to each soil horizon: The inclination ratio was investigated in five *C. japonica* stands, in depths of 0—30cm and 30—60cm. In these stands, the inclination ratio was high in soil horizons I and II. In the S4 stand, for example, it was 55% there, and 17% in soil horizon III. This can be accounted for as follows; in the surface soil, on the one hand, the horizontal roots grow thick in the vertical as in Fig. 30 to be plank-like owing to the difference in vertical condition. In the lower soil, on the other hand, roots do not grow so one-sidedly, because of the uniform condition around them.

Adaptation to the biomass of the above-ground part, though various reasons apply for the root inclination, stands out as the most inportant reason when it is recognized that this tendency is very large in the excessively moist soil or in the devastated and dry stand of the thin surface soil or in the shallow-root species. The horizontal roots near the root stock are inclined to grow thick vertically to be plank-like in adjustment to the biomass of the above-ground part. The horizontal roots of the flat-rooted species are given incentive like this in the shallow site, so their inclination ratio becomes larger.

The inclination ratio of roots is high in the upper soils where the stimulus by the weight is strong, and gentle in the deeper soil because the growth is highly checked there.

(3) Root stock basal area and section root area

It is conceivable that there exists a certain biological law as to the absorption and supporting function among the root basal area, root stock basal area, and section root area, which sustain the work and biomass of the above-ground part. Therefore, the relation between the root stock basal area and the section area of roots at the closest part of the root stock, where most of the nutriment and water concentrate, was examined.

The relation between the revised section root area and the root stock basal area is shown in Fig. 31. Their relation, as shown there, produced a straight line for *C. japonica*, *P. densifora* and *L. leptolepis*, and a concave curve upward for *Ch. obtusa*. The section root area at the basal area of 500cm^2, was wider by 10—70% than the root stock basal area. Those areas

Table 62. Errors of the estimated section area by the growth inclination of horizontal and tap roots.

Species	Sample roots	Root class	Average diameter	Average of A/B***	Variation coefficient
C. japonica	10	H*	9.7	0.8721	0.082
	7	P**	8.6	0.8845	0.054
Ch. obtusa	8	H	10.0	0.8253	0.077
	9	P	9.6	0.9742	0.060
P. densiflora	10	H	9.1	0.9051	0.102
	12	P	10.5	0.9051	0.031
L. leptolepis	11	H	8.4	0.9342	0.057
	13	P	9.2	0.9842	0.065
Ch. pisifera	7	H	9.0	0.8012	0.080
	6	P	8.5	0.9563	0.072
Eucalyptus globulus	5	H	7.7	0.8700	0.095
	5	P	5.0	0.9646	0.080
Zelkova serrata	7	H	8.5	0.8551	0.064
	7	P	8.0	0.9724	0.052
Tsuga canadensis	5	H	10.0	0.8721	0.081
	5	P	8.2	0.9653	0.065
Acacia decurrens v. *dealbata*	5	H	7.5	0.9215	0.082
	5	P	8.0	0.9845	0.095
Abies firma	5	H	8.5	0.8500	0.094
	5	P	9.2	0.9875	0.076
Q. mongolica v. *grosseserrata*	7	H	9.5	0.9532	0.074
	7	P	7.2	0.9867	00056
Betula platyphylla v. *japonica*	10	H	8.0	0.9624	0.068
	10	P	7.3	0.9932	0.050

* H : horizontal root
** P : tap root
*** A/B : see text.

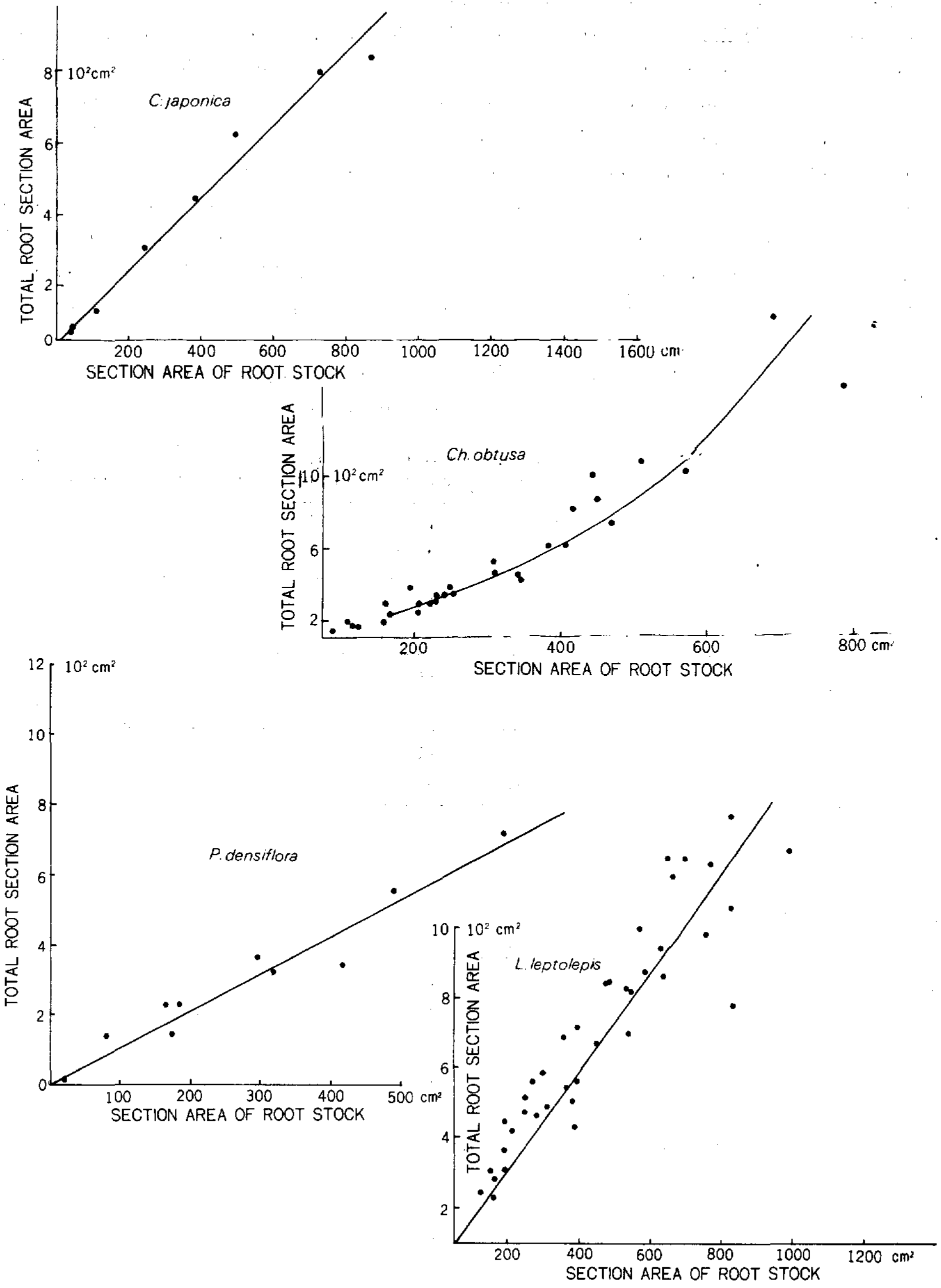

Fig. 31. Average section area of root stock.

were, for example, 550cm^2 for *C. japonica* and *P. densiflora*, 750cm^2 for *L. leptolapis*, and 850cm^2 for *Ch. obtusa*.

When the transportation of absorbed materials is considered to be in proportion to the basal area of both roots and a root stock, the current of absorbed or produced materials slows down as the section of the vessels becomes broader near the root stock ; hence, the root stock possibly has a regulative function for storage and transportation of absorbed and produced materials.

In the relationship between the two basal areas, there is a core where no transportation is efficient and old sapwood where it gets lower. But the same phenomenon is observed among the young trees which have no core. The two basal areas are quite similar in their structure when located closely. And the transporting efficiency of the two is not much different in the sapwood. So, a root stock and the nearby root system are quite close in transporting efficiency.

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森林生産の場における根系の機構と機能 Ⅳ

根系の生長と水分の吸収

苅　住　　昇(1)

摘　要

森林の生産を支える根系の，林内における分布状態や根量およびその働きについて，これまで３報にわたって報告してきた。本報では主に根系の生長と，林木の生長に大きな役割を果している根系の水分吸収について報告する。

これまで幹，枝，葉など地上部の各部分の生長量については多くの報告があるが，根についてはほとんどみられない。ここでは立地，林齢の異なる多数の林分の根量測定資料から根の生長量を計算して，林分の生長段階や各種立地条件における根の生長を量的に示した。

根の生長量はスギ，ヒノキ，アカマツ，カラマツ共に林齢20年頃最大となり，この時期には毎年ha当たりスギ５t，ヒノキ，アカマツ3.5t，カラマツ２t程度であった。ユーカリノキ，フサアカシアは10年生前後で６tに達した。ケヤキ(55年生)は２t弱であった。根の生長量は林齢が高くなると減少し，林齢30～35年ではスギは4.3t，ヒノキ2.5t，アカマツ2.4t，カラマツ1.8tとなった。林齢による生長量の変化は地上部のそれに類似した。根の生長量は林分の密度や立地条件によって異なり，単木の場合，地上部重と同様に密植林分では小さく，疎植林分では大きくなった。いまこの関係を30年生のスギ林についてみると，密度比数が1.2の林分の単木の根の生長量は3.1kgであったが，比数が0.5の疎植区は6.5kgで前者のほぼ２倍であった。立地条件についてみると，B_A型土壌とBl_E型土壌に成立したスギ林では後者の根の生長量が大きく，胸高直径25cmの林分で前者の1.4倍程度であった。林木全体の生長量に対する根の生長量の割合はほぼ一定で，全体の23％程度であった。

根長の生長量は，中庸の立地条件の30年生の壮齢林で，スギは208m，ヒノキは254m，アカマツは198m，カラマツは200mと推定された。また根端数の測定に基いて単木の根端表面積を推定したところでは，年間の根端（白根）表面積の生長量は胸高直径25cm程度の林木で，スギ2.9m^2，ヒノキ2.7m^2，アカマツ0.7m^2，カラマツ1.1m^{2}であった。ha当たりではスギ・ヒノキは2,000m^2，アカマツは250m^2，カラマツは500m^{2}となった。以上の根長・根端表面積生長量も立木密度や立地条件によって変化する。

林木の生長は葉量や細根量と密接な関係がある。細根量１g当たりの林木の生長量，細根の表面積１cm^{2}当たりの生長量，全体の根系表面積当たりの生長量，細根量と葉量との割合なども林分密度，立地条件など各種の因子によって変化する。いまスギについて細根量１g当たりの林木（地上＋地下部）の生長量を見ると幼齢木では25～30g，壮齢木では20～25g，細根表面積１cm^{2}当たりでは0.16～0.17g（幼齢木），0.15～0.16g（壮齢木）という値がえられ，幼齢木の方がやや大きい傾向は認められたが，壮齢林では各林齢に対してほぼ類似の値がえられた。胸高直径25cm程度の調査木について樹種別にみると，細根

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(1) 造林部

表面積1 cm²当たりの生長量はスギは0.23g，ヒノキ0.13g，アカマツ1.4g，カラマツ0.27gとなり，アカマツは細根の物質生産効率が大きく，ヒノキは小さいことがわかった。これを林木全体の根系表面積についてみるとスギは0.14g，ヒノキ0.06g，アカマツ0.24g，カラマツ0.10gとなった。この根系による物質生産量の割合は幼齢時にはやや大きいが，林齢を通じてそれほど大きな変化は見られなかった。つぎに土壌条件との関係をスギについて見ると，B_E型で0.235g，Bl_D型で0.134g，Bl_A型で0.066gとなり，乾燥土壌では根系の生産能率は著しく低下してB_E型立地の1/4になった。

同化作用や吸収作用を通じて葉量と根系表面積は林木の生産に直接関係する因子であるが，両者の比はスギ0.11，ヒノキ0.5，アカマツ0.09，カラマツ0.03となり，スギでは根系表面積1 cm²は0.11gの葉量を支えていることとなり，ヒノキは根系表面積の割合に葉量が多く，カラマツは少なかった。乾燥土壌では葉量に比べて根系表面積の増加が著しくて，地位指数15のB_A型土壌では0.04となり，地位指数23のB_E型土壌では0.16となった。同様な解析を各樹種，林木の生長段階，立地条件などについて行った。

さらに林木の生長に直接関係する水の動きを根系の面から解析した。各樹種の蒸散係数から林分当たりの吸水量を試算すると，中庸の壮齢安定林分ではスギは毎年ha当たり7,000〜8,000 t，ヒノキは4,000〜5,000 t，アカマツは2,000〜3,000 t，カラマツは1,000〜2,000 tとなった。林齢20〜25年の幼齢林では最も多くて，スギは15,000〜20,000 tに達した。この吸水量は土壌条件によって変化し，B_E型土壌では15,000 t，Bl_D型で10,000 t，Bl_A型は5,000〜6,000 tで，適潤土壌で多く乾燥土壌では減少した。乾燥立地のヒノキ・カラマツ・アカマツなどの林分では1,000〜3,000 tになる。

この吸水量と根量から細根吸水率を計算すると細根1g当たり年間吸水量は30年生の壮齢林でスギ8.5 kg，ヒノキ4.5kg，アカマツ22kg，カラマツ7kgとなり，アカマツは最も大きい吸水割合を示し，ヒノキは小さい。B_E型土壌のスギ林の例では18kg，Bl_D型では10kgであったが，B_A，Bl_Cなどの乾性または弱乾性の土壌では4〜5kgであった。

つぎに以上の吸水量が土層ごとの根系表面積比によって各土層から吸収されるものとすると，スギ20年生林分では年間総吸水量9,850 t/haのうちⅠ層から5,100 t，Ⅱ層からは1,800 tが吸水され，Ⅰ・Ⅱ層で6,900 tが吸収されることになる。この量は総吸水量の70％に相当する。両層の吸水量はヒノキ4,200 t，アカマツは1,900 t，カラマツは1,700 tである。