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

Root density and absorptive structure

By

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Summary : The fine root density was highest in the surface soil. The densities of the matured stands were about 200 for *C. japonica* and *L. leptolepis* about 400 for *Ch. obtusa* and about 40 for *P. densiflora* ; and those of the closely planting or dry stands, 1,000 for *C. japonica* and *Ch. obtusa*, 400 for *P. densiflora*, and 300 for *L. leptolepis*. Competition is considered to absorb nutrition and water in such a case as high root density.

The root surface area is one of the factors directly relating to the absorption of water and nutrient. The area per tree at the basal area of 500 m^2 was 22 m^2 for *C. japonica*, 35 m^2 for *Ch. obtusa*, 9 m^2 for *P. densiflora*, and 15 m^2 for *L. leptolepis*. *Ch. obtusa* was largest in the surface area of absorption, and *P. densiflora*, smallest there.

The root surface area per ha is shown as follows, where it is almost stabilized in the mature stand : 1.5 ha for *C. japonica*, 2.5 ha for *Ch. obtusa*, 0.5 ha for *P. densiflora*, and 1.0 ha for *L. leptolepis*. It was much wider for *Ch. obtusa* than any oher species, but for *P. densiflora* it rated low. This explains that *Ch. obtusa* is abundant in the fine roots which occupy the greater parts of the absorptive surface area, and *P. densiflora* is not.

The variation curve of the root surface area to the tree size came up to the maximum value in the 20 to 25-year-old stand. To cite examples of each species : 3.5 ha for *C. japonica*, 3 ha for *Ch. obtusa*, 2 ha for *P. densiflora*, and 1.5 ha for *L. leptolepis*. This makes clear that it has the tendency to increase more clearly than the root biomass. It can be estimated that the increasing root surface area has an influence on the growth of the trees through the increasing absorption of water and nutrient.

The root surface area per ha differs in the stand density and the site condition. According to the table, the examples in the conditions, such as the dry soils and the maximum stand density, are as follows : 4 ha for *C. japonica*, 5 ha for *Ch. obtusa*, 1.7 ha for *P. densiflora*, and 1.2 ha for *L. leptolepis*. In the conditions, such as the wet soils and the maximum stand density, 1.2 ha for *C. japonica*, 2.0 ha for *Ch. obtusa*, 0.4 ha for *P. densiflora*, and 0.6 ha for *L. leptolepis*.

The ratio of each part to the whole root surface area is highest in fine roots. For example, it was 58% for the fine roots and 16% for the small roots, of *C. japonica*. It follows therefrom that those two roots have a big part of the whole root surface area as is the case. This was alike in the other species. Particularly, they had 83% for *Ch. obtusa* which was abundant in the fine and the small roots.

The greater parts of the whole root biomass were the accumulated parts of large roots, very large roots or root stocks, but those of the whole root surface area were fine roots and small roots which changed with roots working. Accordingly, the root surface area must be used in this respect as an index of absorption rather than the root biomass.

The vertical distribution of the root surface area in the stand of each species is shown in Table 48. It is conceivable that nutrient and water should be taken in from each soil horizon almost by such a ratio as shown there. That of each species to the total absorption in the soil horizon 30 cm deep below the surface horizon in the stands of the basal area of about 500 cm^2 is as follows : 59% for *C. japonica*, 69% for *Ch. obtusa*, 57% for *P. densiflora*, and 73% for *L. leptolepis*. This explains that the absorptive structures are maldistributed to the lower soil horizon much more for *C. japonica* and *P. densiflora* than for *Ch. obtusa* and *L. leptolepis*.

The absorptive structure indexed by that area was maldistributed to the surface horizon in the infertile and dry sites on the residual soils with the thin surface soils or of the heavy wet sites. Those ratios came up to 80～90% in soil horizons I and II. At the same time, it was observed that the dead fine roots caused the absorptive structure to decayed in the heavy wet sites or in the deeper soils with bad aeration.

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Contents

Ⅰ Introduction

The first issue[17], "Method of investigation and estimation of the root biomass" and the second[18], "Root biomass and distribution in stands" of the present thesis were already reported in the reports of Government Forest Experiment Station No. 259 and No. 267. The relations between root density and environmental condition, and the problems on root surface area are reported in this third issue.

Such concepts as root density, absorptive structure expressed as root surface area, etc. are very important to analyse the production or growth of forest, or to know the relation between the site conditions and the root system.

This report verified these problems on the data of the sample stands used in Reports I and II. The reader may refer to this report with them.

Ⅱ Root density

When a comparative study is made of root biomass at every sample block between either trees or stands, the measured root biomass can not be used as such because each soil volume containing the roots of each tree or stand is different from each other. In this case, it is possible to halt this inconvenience if the root biomass is to be expressed as a root weight per investigated soil volume, i. e., the root weight (dry weight) per 1 m^3 of soil as the root density[10][12][16].

The root density is calculated from both the root weight in each of the horizontal and the vertical soil blocks and the volume of a soil block. The average root density in each horizon of stands is similar to the root biomass per ha. But as shown in the S 11~S 17 stands, the soil horizons are different in depth at the same stands. So the root biomass per ha is not considered to be the same as root density.

Precisely because the investigated areas differ usually by tree density, it is very effective to convert the horizontal distributions of roots into the root density if comparison is made between the stands' locations in horizon and the root biomass.

The distribution of root biomass was analysed altogether by using root density, though this was doubled in the part of root biomass to some extent.

Root density is different by the size of tree, tree density, and soil condition. And in the same stand, it is different both in the soil horizons and in the horizontal positions from trees.

Though it is possible to examine the density of each root class, that of a fine root, especially in the surface soil horizon (horizon I), has an important physiological and ecological meaning relating to the absorption of nutriment and water.

The root density of a fine root is highest in soil horizon I. In a dry forest, dense planting and with shallow surface soil, the root density becomes remarkably high in the same horizon. So it causes competition for absorption of water and nutriment, which hinders tree growth. The explanations of root density will be given hereinafter on each condition.

1) **Vertical changes in root density**

The root density decreases quickly as the soil horizon goes deeper. In the case of root biomass, the curve of root biomass distribution showed a warp between horizons I～II and III, because of the difference of the volume of the soils of sampling block. But in the case of root

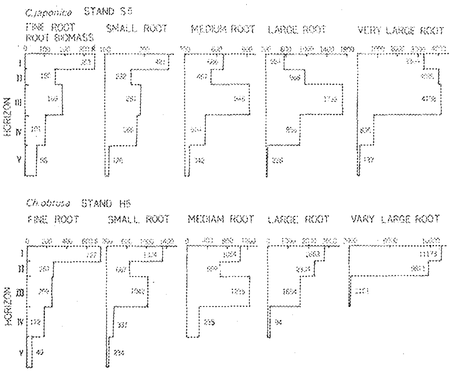
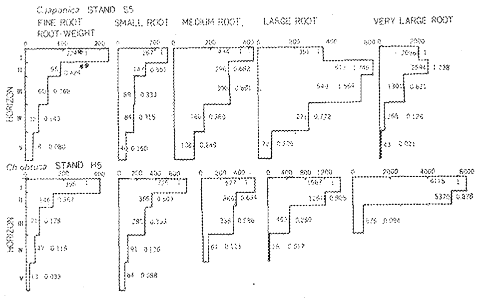


Fig. 1-1 Vertical distribution of root biomass in the typical stands.



* Root density.
** Ratio of root density to that of horizon I.

Fig. 1-2 Vertical distribution of root density in the typical stands.

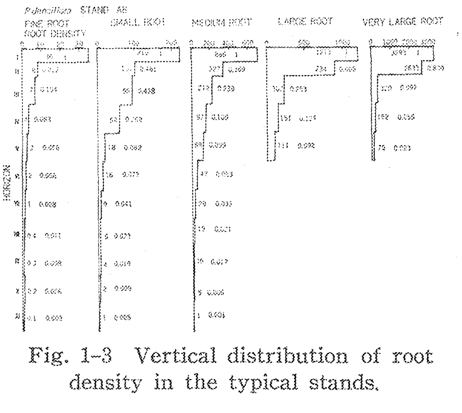


Fig. 1-3 Vertical distribution of root density in the typical stands.

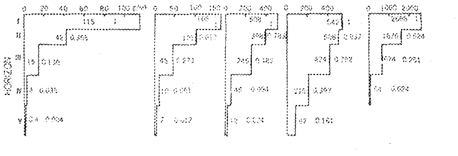


Fig. 1-4 Vertical distribution of root density in the typical stands.

density, root biomass is indicated as per volume of soil, so its curve is a gentle decreasing one[*1] (especially remarkable among fine to medium roots).

The vertical change in root density with the tree growth became stable when the basal area got to about 500 cm², as shown in Fig. 1 and as applying to the principal stands S 5, H 5, A 8, K 21, of the investigated stands. Although there was some difference, this vertical change was different from that in root size. Those changes of small and fine roots, for example, were gentle; those of large and very large roots differed with their characteristics of branching. The roots of *C. japonica* were remarkably branched in soil horizons II and III. Consequently, their root densities were high. The ratios to the root density in horison I were, in the case of the large root, 1.7, 1.6, and 0.8 in soil horizons II, III and IV respectively. This species had a great difference in the distribution pattern of root density from *Ch. obtusa* and *L. leptolepis,* the flat rooted species, the root densities of which were high in horizons I and II, and low in horizons III and IV. In the case of *Ch. obtusa,* flat rooted, the ratios to the root density of the large root were 0.8 and 0.3 in horizons II and III respectively. Those of the very large root were 0.9 and 0.1 in horizons II and III respectively. In the case of *L. leptolepis,* those of the large root were 0.9 and 0.8 in horizons II and III respectively. Those of the very large root were 0.8 and 0.1 in horizons II and III respectively. In any case, their large roots were maldistributed to the surface soil horizon.

In the case of *P. densiflora,* those of the large and the very large roots were high in the surface soil horizon. They were 0.8 in horizon II and 0.3 in horizon III. The species has the same trend as the flat-rooted species in this respect. However, the deep-rooted species is characterized either by the fact that the densities of the fine to medium roots arrive at horizon XI, or by the fact that it has tap roots.

The root density of the fine root in horizon I became lower in the order of *Ch. obtusa* in H 5 stand (398)[*2], *C. japonica* (224), *L. leptolepis* (115), and *P. densiflora* (36). *P. densiflora* had the extremely low root density for its tree's size.

The decreasing tendency of the fine root density according to soil horizon was most remarkable in *P. densiflora* of which the ratios to the root density in horizon I were 0.22 and 0.19 in horizons II and III respectively, decreasing gradually to horizon XI. The maldistribution of the fine roots to the surface soil and the tap-rootedness were two main characteristics of the root system of *P. densiflora*[1]. From the view-point of absorption, *P. densiflora* has a characteristic of shallow-rootedness.

L. leptolepis and *Ch. obtusa* had the second highest fine root density in horizon I. In the former, the ratios to the root density in horizon I were 0.365 and 0.130 in horizons II and III respectively. In the latter, they were 0.367 and 0.178 in each of these two horizons. The vertical changes were both very much alike, but *L. leptolepis* showed a more remarkable decrease than *Ch. obtusa.* The root density of *L. leptolepis* decreased rapidly in the deep horizon to 4[*3] (0.04)[*4], and that of *Ch. obtusa,* to 47 (0.118). Though they are both flat-rooted, the latter has a characteristic to develop the root system deeper even in a compact and wet soil[*5].

[*1] Compare the vertical distribution of root biomass to the root density, in the stands S 5 and H 5 of Fig. 1.

[*2] This indicates the root biomass (g/m³) in the soil of 1 m³. Units are all omitted hereafter.

[*3] 4 : Root density.

[*4] (0.04) : Ratio of the root density to that in horizon I.

[*5] *Ch. obtusa* develops the root system favourably in an aerobic condition, and it has the high root density even in a compact and wet soil of the surface soil horizon.

The ratios of the fine root density of *C. japonica* to that in horizon I were 0.42, 0.27 and 0.14 in horizons II, III and IV respectively. These ratios were all higher than those of three other species. Hence it is that *C. japonica* is deep-rooted.

In all species, the root biomass of the fine roots was maldistributed to the surface soil. In lower horizons, it decreased rapidly. As concerns the small and medium roots, it increased in the deep, so the decreasing curve went gentler. As concerns the large and the very large roots, in the deep, no increase, but it gathered in the surface. It showed, however, the thick layer's distribution if compared with the gradual decrease of a fine root.

2) **Root density and stand growth**

The root density of each root class at every sample soil block varies, as shown in Fig. 2, with tree growth.

The change in fine root density, which has the closest connection with the tree growth in each soil horizon, is shown in Fig. 2. According to the figure, each root density in soil horizon I became higher within the range of the basal areas of 100 to 200 cm². That of *Ch. obtusa*, as shown in Table 1, was 500 at the basal area of 50 cm², and that of *P. densiflora*, 250 at that of 50 cm² except in the extremely infertile and dense stands. *Ch. obtusa* and *P. densiflora* had a tendency to increase the density of the fine roots in horizon I at an earlier time than *C. japonica*. It is due either to the high tree density these stands have or to the fact that *Ch. obtusa* distributes many fine roots to the surface soil horizon at a young stage.

If compared with *C. japonica, Ch. obtusa* and *P. densiflora, L. loptolepis* does not show an increase of root density at an early stage. At the basal area of 300 cm², for example, the root

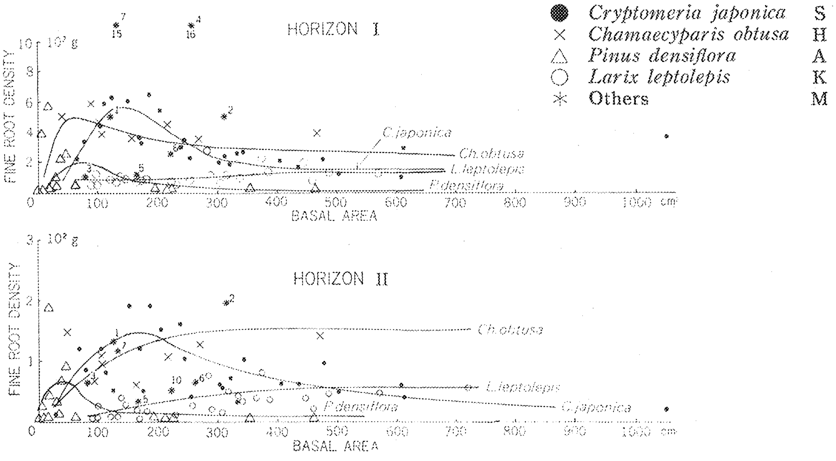


Fig. 2. Fine root density in each soil horizon.

Table 1. Changes of root density and its ratio according to the size of forest

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Maximum root density in the immature stand (A) (g/m³)	600(150)	500(50)	250(50)	—
Root density when constant (B) (g/m³)	200(300)	400(200)	50(200)	200(—)
Ratio (A/B)	3.00	1.25	5.00	—

( ) : Basal area (cm²)

density increased slightly to 200. It was not clear whether it was caused by the charactristics of root distribution of *L. leptolepis* root or by the method of choosing sample trees.

Maximum of root density differs by species. Generally down to the basal areas 300～400 cm², however, it increased temporarily at an early stage, decreasing down to the almost constant density. At an area of more than 600 cm², it became a little higher. In the S 17 stand, for example, it was 400 at basal area of 1,042 cm². At the basal area of 500 cm², where they became almost constant, they became lower in the order of *Ch. obtusa* (400), *C. japonica* or *L. leptolepis* (200), and *P. densiflora* (40) (See Fig. 2). *Ch. obtusa* had twice as high a density as *C. japonica* and *L. leptolepis*, and 10 times the high density of *P. densiflora*. Make a comparison between these densities and those at an earlier time, arriving at the maximum. The result is shown in Table 1. As is clear from it, *P. densiflora* had 1/5 of the maximum, *C. japonica* 1/3, and *Ch. obtusa* 4/5. Hence it is that the decreasing ratio of *P. densiflora* was high, and that of *Ch. obtusa* low.

The increasing density of the fine root in the surface soil is related to tree growth. When the density became higher in fertile horizon I with good aeration, the above-ground part grew vigorously (Fig. 2). It is clear that there was a close relationship between them. This step is a little bit earlier than when the leaf biomass increases to the maximum per area*. And besides, at this stage, most assimilated product is consumed for the growth of fine roots. The vigorous functions of absorption and assimilation promotes the growth of both parts until both root density and leaf biomass become constant to maintain a given relationship between absorption and assimilation. These facts suggest that there is a possibility of root competition for absorbing nutriment and water at this stage, particularly in the infertile and dry site.

The fine root density decreased to be constant at the basal areas of 300～500 cm². This is because the assimilated product is distributed largely to the larger roots for their growth, rather than to the fine and the small roots, and consequently their growth slows down. Also the number of trees decrease as they grow.

The density of the fine roots in soil horizon I, once decreasing when the trees were medium-sized, increases again when they grow further, because the fine roots, as mentioned before[18], have a property of selecting soil horizons. In the sample stands, this tendency was clear in the *L. leptolepis* K 28 stand at the average basal area of 645 cm², and in the *C. japonica* S 17 stand, at that of 1,042 cm². And in the ordinary forest also, the root density in the surface soil went higher remarkably in a large-diameter tree stand.

The maximum point of the root density moves to the larger basal area as the soil horizon becomes deeper. In the case of *C. japonica*, they were highest at the basal areas of 150 to 200 cm² in soil horizons I and II. They were, what's more, highest at those of 200 to root density.

The conclusion is either that the root density is always constant regardless of the size of trees when the roots are small and when the soil horizon is shallow, or that it becomes highest at the young stage.

The maximum point moves to the large basal area as the diameter of root becomes larger and as the soil goes lower. And finally, the root density describes a parabolic curve or such a slightly concave increasing curve upward as the very large root describe in soil horizons IV and V.

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* Compare to the changing curve[18][22] of leaf biomass per ha (See Fig. 38).

Table 2. Variation coefficients of root densities in each horizon of Stand S2

Root class		f	s	m	l	L
Horizon	I	0.12	0.18	0.41	0.55	0.74
	II	0.16	0.25	0.52	0.60	0.95
	III	0.25	0.31	0.57	0.82	—
	IV	0.82	0.70	0.92	1.95	—
	V	1.50	1.20	1.70	—	—

Table 3. Variance of root densities of fine root in horizon I (%)

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Stand	S2	H2	A2	K2
Variation coefficient	12	8	32	20

3) **Variance of root density**

The variance of the root density in a stand becomes larger as the roots become larger and the soil goes deeper. The coefficients of variation of the fine roots of *C. japonica* in the S2 stand increased, as in Table 2, gradually from 12% in soil horizon I to 82% in soil horizon IV, and then to 150% in soil horizon V. The fine and the small roots were distributed to each soil horizon with little variance, but the larger roots showed considerable variance.

Each species's coefficient of variance of the fine root in soil horizon I became, as in Table 3, smaller in the order of *P. densiflora*, 250 cm², 300 cm², and 350 cm² in soil horizons III, IV and V respectively. This is because no root system of small trees grows in the deep soils.

In the lower horizons, such as IV and V, the root density of the large-diameter tree was not so high; that of a medium-diameter tree at basal areas of 300~400 cm² was rather higher, because it had many branching tip roots there. That of the large diameter tree did not increase because the decrease of tree number caused less root density.

Up from horizon IV, only the root densities of tap-rooted *P. densiflora* and of *C. japonica* large diameter tree (S17 stand) were observed. *P. densiflora* tended to make a parabolical increase of root density with the increasing basal area.

In the small and medium roots, the tendency was almost similar to that of a fine root. A large root showed an almost parabolical increase according to the increase of basal area.

This tendency was more distinctive in a very large root. In the large root of the *C. japonica* stand, the root density tended to become higher at an earlier stage. In the very large root it was not observed in horizon I. As the basal area increased, so increased the *L. leptolepis*, *C. japonica* and *Ch. obtusa*.

Though the root density variance of *P. densiflora* spread unevenly, that of *Ch. obtusa* with the fine roots densely spread was very even. In fact, that of the former was four times as high as that of the latter.

4) **Root density and various conditions**

The root density varies with such conditions as tree density, site condition, etc. The relation between each of those conditions and the density of the fine roots in soil horizon I will be described below.

(1) Tree density

Each species's root density of fine root increased with the tree density, as shown in Fig. 3. The trend was most remarkable in *P. densiflora*. The species had the root densities of 400 to 600 in the highly dense planting stands of A10 and A6. *C. japonica* had the root densities of 250 and 450 at the tree density indices of 0.5 and 1.0 respectively. The root density increased to 1.8 times as high at twice the tree density. Each species's variance was large, as shown in

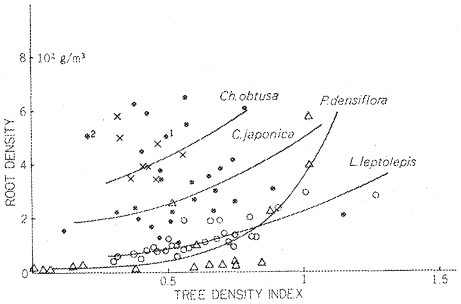

Fig. 3. Tree density and fine root density in soil horizon I.

Fig. 3. For instance, the root densities were remarkably high for tree density in such stands as S 24, S 14, S 6, S 7, S 10, S 23, H 6, H 1, A 5, etc. It was, however, low in the S 22 stand, mainly due to the site conditions.

The increase of tree density cause the size of trees to change, owing the to competitive density effect, and the root density to go up and down along with it. It is, therefore, impossible to make the same comparison between them. Here go through the root densities according to each soil horizon on the stands with the almost equal-sized trees and the different tree densities. A result is shown in Table 4. In addition, make a comparison between the close planting S 22 stand of *C. japonica* and the sparse planting S 18 one, and between the S 8 and the S 2 stand. This done, two facts emerge, namely, the root density in the low horizon is higher in a close planting stand than in a sparse planting one, and that the increasing rates tend to go higher there than in the surface soil horizon.

Table 4. Vertical variation in root density and tree density

		Close planting stand					Sparse planting stand				
Stand		S 22					S 18				
Stand age		41					32				
Basal area (cm²)		419					554				
Density index		1.158					0.545				
Site index		21.8					23.4				
Root class		f	s	m	l	L	f	s	m	l	L
Horizon	I	218	251	427	585	1,994	118	165	398	258	2,192
	II	66	234	551	615	4,719	62	73	304	440	2,708
	III	48	147	549	1,081	2,854	44	88	367	645	1,272
	IV	53	132	415	539	861	30	72	225	276	286
	V	25	83	181	297	100	12	30	56	88	82
		Close planting stand					Sparse planting stand				
Stand		S 8					S 2				
Stand age		29					23				
Basal area (cm²)		238					249				
Density index		0.898					0.652				
Site index		20.7					21.7				
Root class		f	s	m	l	L	f	s	m	l	L
Horizon	I	317	490	686	689	2,700	350	374	582	258	1,648
	II	160	167	434	499	781	108	166	336	326	805
	III	124	156	436	829	—	77	127	319	611	270
	IV	93	181	454	229	—	51	76	174	159	—
	V	32	140	231	21	—	11	28	94	—	—

This holds true not only in the case of the fine root, but also in the case of the a medium root. The working and accumulating parts had a high root density in the low horizon in a close planting stand. The tree density makes the root density increase more remarkably in the low horizon than in the surface soil horizon, possibly because of tree density effect. Precisely because interference and competition among roots, as shown in Photo. 2 of the second issue[18], are caused by the remarkably increasing root density in the surface soil horizon in a highly close planting stand, roots are prevented from growing there, and conversely, have their growth enhanced in the low horizon; furthermore, in the case of a large root, it may result from the adaptability by the supporting structure to the physical change of the above structure. The root swelling evolves weakly in a highly dense stand; in a sparse planting stand, it often grows extraordinarily to be plank-like sometimes.

As nutriment and moisture are promoted to be used in the low horizons in a highly dense stand, the influence deriving from the increase of tree density in the deep-soil site is insignificant. Root development is retarded in the site with shallow surface soils, and maldistributed to the surface soil horizon in the site with deep soil. Competition among roots is often induced in an excessively dense stand.

(2) Soil type

The root density has a closer relation to the soil type than to the tree density, as shown in Fig. 4, because it is easily affected by soil condition.

The root densities were high in the dry soils of Er-β, Er, B_A, Bl_A and Bl_C types. In the case of *C. japonica*, they were 900 in the B_A soil-typed S 24, 650 in the Bl_C soil-typed S 7, 600 in both the Bl_A soil-typed S 6 and the Bl_D(d) soil-typed S 14, 300 to 400 in the Bl_D typed soil, and 100 to 200 in the B_D typed one. This explains that the root density becomes lower as the soil becomes more moist.

This also holds true in the case of the other species. *Ch. obtusa* taken as an example, the root densities were 600 in the H 6 stand of the B_B soil type, 500 in the H 1 stand of the Bl_D(d), 400 in the H 2, H 3 and H 5 stands of the B_D, and 350 in the H 4 stand of the B_D(w). This also explains that the wetter the soils, the lower the root densities become.

Particularly in the case of *P. densiflora*, the root density was about 600 in the A 10 stand of the B_A soil type because of close planting and dryness. And it was 400 in the dry and infertile forest stand, A 6. This is very high as against the root densities of 30 to 40 in the stand of Bl_D(d) soil type or as against those of 20 to 30 in the stand of Bl_D.

This applies also to *L. leptolepis*. The root density was about 300 in the dry soils of Bl_C and Bl_D-m. It decreased, however, to about 50 to 70 in the soils of Bl_E, Bl_{E-F}, Bl_F, and Bl_G. This is because all these soils were moist and under the condition of bad aeration.

It became evident from these observations that the root densities were higher in the dry soil and lower in the moist soil. They became lower in the order of *P. densiflora*, *C. japonica*, *L. leptolepis*. and *Ch. obtusa*. Hence it is that the root densities of *P. densiflora*'s fine roots are easily affected by the quantity of water the soils contain, and that those of *Ch. obtusa*

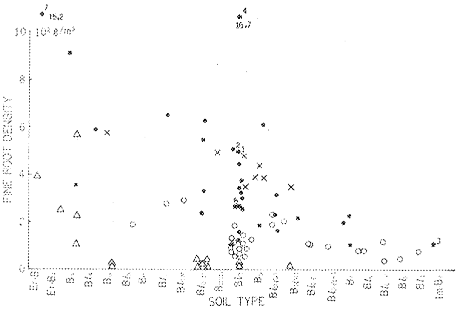

Fig. 4 Soil types and fine root densities in soil horizon I.

Table 5. Soil types and fine root densities

P. densiflora

Moist condition of soil		Dry soil	Moderately moist soil			Moist soil
Stand		A6	A2	A1	A7	A9
Soil type		Er–β	Bl_{D}(d)	Bl_{D}(d)	Bl_{D}	Bl_{D}
Horizon	I	401	44	47	28	27
	II	28	11	13	45	6
	III	8	7	4	11	3
	IV	1	2	1	6	2
	V	—	1	1	4	1
	VI	—	0.5	0.3	0.5	0.4
	VII	—	—	—	—	0.4
	VIII	—	—	—	—	0.1
	IX	—	—	—	—	0.1
	X	—	—	—	—	0.04
	XI	—	—	—	—	+

L. leptolepis

		Dry soil				Moderately moist soil				Moist soil				Very moist soil			
Stand		K16	K17	K23	K24	K21	K22	K27	K14	K27	K2	K20	K28	K4	K5	K6	K7
Soil type		Bl_{D}(d)	Bl_{D}(d)	Bl_{D}–m	Bl_{DE}–m	Bl_{D}	Bl_{D}	Bl_{D}	Bl_{D}	Bl_{D}	Bl_{D-E}	Bl_{E}	Bl_{D}	Bl_{F}	Bl_{E-F}	Bl_{E-F}	Bl_{G}
Horizon	I	198	207	291	105	115	110	93	137	93	106	87	87	54	129	46	84
	II	44	41	77	33	42	44	29	53	29	19	23	33	9	29	9	12
	III	7	19	24	8	15	12	13	29	13	7	12	15	3	5	0.8	0.9
	IV	1	4	—	2	4	3	4	7	4	2	2	1	1	—	—	—
	V	—	1	—	+	0.4	1	0.4	3	0.4	—	1	1	—	—	—	—

C. japonica

		Dry soil			Moderately moist soil			Moist soil		
Stand		S6	S7	S20	S2	S23	S26	S8	S18	S22
Soil type		Bl_{A}	Bl_{C}	B$_{A}$	Bl_{D}	B$_{D}$	Bl_{D}(w)	Bl_{D}(w)	B$_{E}$	B$_{E}$
Horizon	I	597	653	377	350	616	171	317	118	218
	II	80	193	123	103	196	65	160	62	66
	III	35	103	43	77	120	56	124	44	48
	IV	25	44	24	51	60	28	93	30	53
	V	8	14	5	11	10	10	32	12	25

Ch. obtusa

		Dry soil	Moderately moist soil		Moist soil
Stand		H6	H2	H8	H4
Soil type		B$_{B}$	B$_{D}$	Bl_{D}	B$_{D}$(w)
Horizon	I	587	395	487	359
	II	71	107	105	134
	III	21	56	56	53
	IV	2	3	5	9
	V	—	—	1	5

are not.

Table 5 shows the changes of the densities of each species's fine root according to the typical soil conditions. As is clear from the table, the root densities were high even in the deep soil in the moderately moist site, while in the dry soil they were remarkably high in the surface horizon and low in the core soil. This is cleared up by two facts : 1) that the sites of the dry soil types, such as B_A, B_B, etc., have the shallow surface soil which makes growth of roots possible, and as a result, 2) that roots are physically obliged to distribute only to the surface horizon.

The species have their own relation of soil conditions to the vertical distribution of root densities. *C. japonica*, for example, had the higher root densities in the core soil than *Ch. obtusa* and *L. leptolepis*, flat-rooted. The species had also the higher root densities in the deep soil even if in the wet soil. This originates in the property that the roots of the species stand well against the anaerobic conditions[8)11)] (See Photo 5 and 6 in the second issue[18)]). And instead, *L. leptolepis* showed a remarkable decrease of the root density in the deep soil in heavy wet soil. This comes of the aerobic property of the species's root; therefore, moisture and bad aeration impede its absorption and growth.

Ch. obtusa had a remarkably higher root density in horizon I than in the lower horizons. The roots were not prevented from growing so much in the deep soil of moist soils such as B_D(w) etc. They stood well against the anaerobic conditions.

P. densiflora and *L. leptolepis* both took the extremely high root density in the surface horizon in the dry soil. In horizon I, for example, that of *P. densiflora* was nearly ten times as high as that in the moderately moist stand, and that of *L. leptolepis* almost twice as high as that there. However, both root densities decreased rapidly in horizon II and lower.

(3) Site index (site quality index)

Fig. 5 shows the relation between the root densities of fine roots in horizon I and the site indices. According to the figure, the root densities decrease as the site indices increase. This is common to all the species. There was a high interrelation between the two. This is due to the threefold causes, first that the surface soil are dry and shallow in the sites with small site indexes, secondly that fine roots faciliate ramification and growth in such a site and finaly third that fine roots are physically obliged to distribute to the surface horizon, owing to the bad soil conditions in the deeper soils.

The site indices decreased even on the heavy wet condition. But in this case, the relation of them to root densities was the opposite to the above-mentioned relation. This was clearly observed in the case of *L. leptolepis*. The root densities, for example, were all low in the stands with small site indices and heavy humidity such as K 6, K 4, K 8, and K 5. It follows from these that the changes in site index are not always compatible with those in root density.

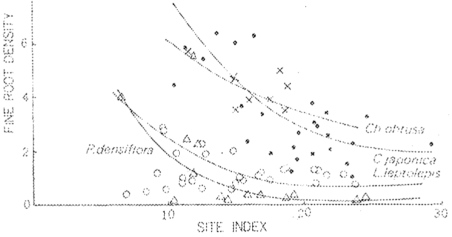

Fig. 5 Site indexes and fine root densities in soil horizon I.

By drawing the changing curves of root density—site index, using the stand where the dry condition caused low site indices, we get the result shown in Fig. 5. And the relation between site index and root density is shown

Table 6. Site index and fine root densities in horizon I

Species Site index	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
10	600	600	300	250
20	350	400	40	150

in Table 6. According to the table, *P. densiflora* had the highest changing ratio of root density by the change of site index. That is to say, the species's root density decreased to about one-eight as the site index increased twice. And the changing ratios became lower in the order of *P. densiflora, C. japonica, L. leptolepis*, and *Ch. obtusa.*

The root density was low in the stand with good growth and high in the stand with poor growth. This explains the difference in efficiency between absorption and assimilation by roots. It is therefore to be recognized that the efficiency of absorption is caused to lower, owing to the shortage of nutriment and water for the faculty of absorption of roots, because the root density is high in a dry and infertile stand.

The increasing root density has a connection with the increasing amount of absorption in a dry stand. The growth, however, does not increase for root density because the absorption efficiency is caused to lower. The root density was lower in a moderately moist soil than in a dry soil. However, the efficency of absorption makes good and the growth increases because of the sufficient supply of nutriment and water.

Soil type, site index, etc. are the general indicators of site conditions. This is described in the relation of each physical and chemical factor of soils with root density.

(4) The amount of air in the field condition

Fig. 6 shows the relation of the densities of the fine roots in horizon I with the amount of air in the field condition. As can be seen Fig. 6 from the figure, the root densities increase as the amount of air in the field condition increases. This is explained by the reason that, on the one hand, the better the aeration the more favorable growth of roots on the sufficient water condition, and on the other hand, that the root density and the amount of air in the field condition increase in a dry soil in general.

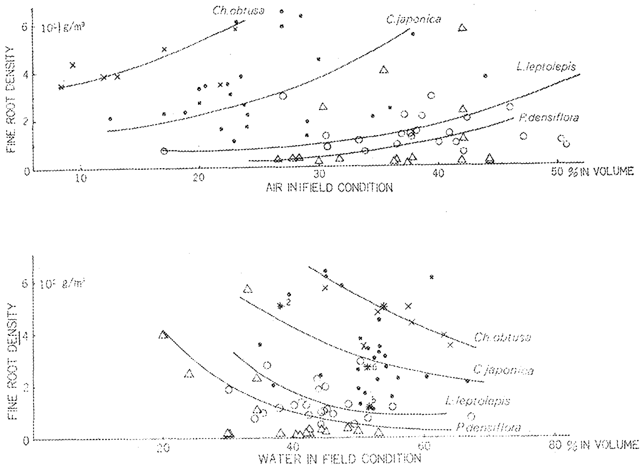

Fig. 6 Soil properties and fine root densities in soil horizon I.

There were, as in Fig. 6, all the dry soils in such stands with the large amount ofair and high root density as H 6, S 6, S 7, S 14, S 10, S 20, K 22, K 26, etc.

Among four species, *Ch. obtusa* had the highest root density as a whole. The root density of that species was 359 in the stand of H 4 with the amount of air of 8.4%*, and it was 587 in the stand of H 6 with air of 23.1%. In the case of *C. japonica*, they were 218 and 550 in the stands of S 22 with that of 12.5% and S 10 with that of 38.1% respectively. In the case of *P. densiflora*, they were 38 and 112 in the stands of A 4 with air of 26.6% and A 12 with that of 42.1% respectively. In the case of *L. leptolepis*, they were 87 and 230 in the stands of K 28 with that of 30.5% and K 25 with that of 45.9% respectively.

Compare now the amount of air of 25% in the field condition and the root density. And it will be clear that *Ch. obtusa* has the root density of 650, *C. japonica* has that of 300, *L. leptolepis* has 100, and *P. densiflora* has 30. That is to say, *Ch. obtusa*, on the one hand, had a high root density even in the soil with a small amount of air; and *L. leptolepis*, on the other hand, had a low root density in the soil with a large amount of air. As is clear Fig. 6, furthermore, *Ch. obtusa* took the higher ratio of increase of the root density to the amount of air in the field condition; however, there was no compatibility with this in the case of *L. leptolepis*.

The variance was wide in the relation between the amount of air in the field condition and the root density. At the amount of air of 25% in the field condition, *C. japonica* took the distribution area of 150 to 650. This is also applicable in the case of *L. leptolepis* and *P. densiflora*. This variance of root density was then wider than that to the soil type and the site index which put the various factors together. Precisely because the root density has been greatly changed by the other factors except for the amount of air in the field condition.

(5) The amount of water in the field condition

Fig. 6 shows the relation of the amount of water in the field condition to the root density. The root density decreased, as shown in the figure, as the amount of water increased.

This arises from a twofold reason, on the one hand, that aeration gets worse as the amount of water increases, and, on the other hand, that the branching and the growth of roots are obliged to make insufficient in the soil with much moisture. This is in reverse to the case in the dry soil with a large amount of air in the field condition.

At the amount of water of 50% in the field condition, the root densities were 550, 300, 100, and 30 for *Ch. botusa*, *C. japonica*, *L. leptolepis*, and *P. densiflora* respectively.

As already mentioned, the root density decreases as the amount of water in the field condition increases. *L. leptolepis* and *P. densiflora* took the highest ratio of increase. Their root densities decresed sharply as their amount of water in the field condition decreased to 40 to 45%. *Ch. obtusa* drew an almost straight line in change from the dry stand of H 6 to the wet stand of H 4. This is just the contrast with the case of the amount of air in the field condition.

C. japonica had a remarkably wide variance as against the other species. This also held true in the case of the amount of air in the field condition.

(6) Non-capillary pore space

The non-capillary pore space included the pore space of the pF values of 0 to 1.7 and the minimum air capcity. Fig. 7 shows the relation between the non-capillary pore space and the root density. *C. japonica* and *P. densiflora* took, as given in the figure, a very wide variance. The root density drew a concave curve slightly upward with the increasing non-capillary pore

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* This indicates the percentage of volume.

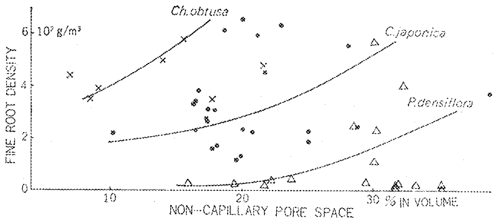


Fig. 7 Non-capillary pore spaces and fine root densities in soil horizon I.

Table 7. Fine root density and non-capillary pore space

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*
Rate of change in root density	14	25	13

Amount of change in root density per 1% of amount of non-capillary pore space.

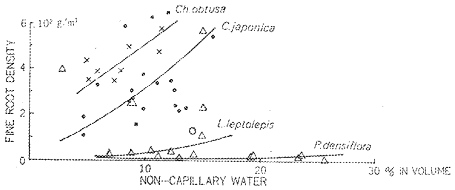


Fig. 8 Amount of non-capillary water and fine root densities in soil horizon I.

Table 8. Fine root densities in horizon I under the condition of 15% of non-capillary pore space

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*
Root density (g/m³)	220	550	30

space. This is not common to all the species. *Ch. obtusa*, for example, as in Table 7, took a higher root density than *C. japonica*, *P. densiflora*, and *L. leptolepis*. *Ch. obtusa* took the higher ratio of change of the root density to the non-capillary pore space, proving that the growth of the species's fine roots was easily affected by the changing amount of air contained in the soil, and furthermore due to the fact that the non-capillary pore space increased in a dry soil where the root density increased. It was in the soils with dryness that all species had a large non-capillary pore space and a high root density.

Ch. obtusa took the high root densities of 400 to 600 even in the site with the small non-capillary pore space of 10 to 15 % because it had a higher root density than any other species in general. The root densities of each species at the non-capillary pore space of 15% were, as in Table 8, highest and extremely low for *Ch. obtusa* and *P. densiflora* respectively. This is owing to the ramification property each fine root species has. To draw a conclusion from these figures that *Ch. obtusa* grows roots sufficiently even under an anaerobic soil conditon would therefore be inappropriate.

(7) Non-capillary water saturation

The non-capillary water saturation means the porosities at the pF values of 0 to 1.7. Fig. 8 shows the relation between the non-capillary water saturation and the root density. According to the figure, the root density increases as the non-capillary water saturation increases. This agreed nearly with the case of the non-capillary pore space, and made clear that there was a high interrelation between the growth of roots and the aeration. At the same time, this explained that roots sped up growing in the site with larger non-capillary water saturation, where aeration became more sufficient.

The ratio of root densities to the non-capillary water saturation became higher in the order of *Ch. obtusa*, *C. japonica*, and *P. densiflora*. At the non-capillary water saturation of 10%, the root densities were 500, 300, and 30 for *Ch. obtusa*, *C. japonica*, and *P. densiflora* respectively. *P. densiflora* had a lower ratio of increase of the root densities to the non-capillary water saturation than *C. japonica* and *Ch. obtusa*. That species, however, took the high root density for non-capillary water saturation in such infertile and dry stands as A 6, A 5, etc.

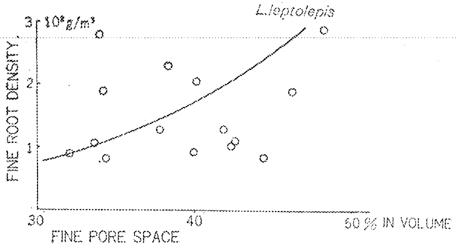


Fig. 9 Fine pore space and fine root densities in soil horizon I.

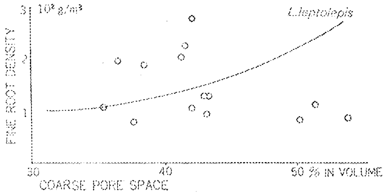


Fig. 10 Coarse pore space and fine root densities in soil horizon I.

(8) Pore space under the pF values 2.7 and above

Fig. 9 shows the relation between the pore space under the pF values 2.7 or above and the root densities of *L. leptolepis*. As the figure shows, there was a wide variance between them, and as a whole, the root densities increased as the pore spaces under the pF values 2.7 and above increased. The root densities on an average were 75, 175, and 350 at the pore spaces of 30%, 40%, and 50% respectively.

(9) Pore space at the pF values 2.7 and below

Fig. 10 shows the relation between the pore spaces at the pF values 2.7 and below and the root density. There was a wider variance than in the case of the pore spaces at the pF values 2.7 and above; for instance, the root densities had the distribution area of $\frac{200}{100-300}$ at the pore space of 4% at the pF values 2.7 and below. This explains that the pore space at the pF values 2.7 and above has a closer connection with the growth and the distribution of roots than the pore space at the pF values 2.7 and below.

(10) Minimum air capacity

The root densities increase, as shown in Fig. 11, describing a straight line or a concave curve slightly upward as the minimum air capacity increases. The sites with the large minimum air capacity held the dry soils with a large amount of air in general. There, the root densities had a tendency to go higher. This was more remarkable in the order of *Ch. obtusa*, *C. japonica*, *P. densiflora*, and *L. leptolepis*, as shown in Fig. 11.

Going through them on the stands of *Ch. obtusa*, H 3 and H 6, and on the stands of *P. densiflora*, A 1 and A 6, where that relation was observed most distinctively, we got the results shown in Table 9. According to the table, the root densities of all species increased with the minimum air capacity. For example, *Ch. obtusa* and *P. densiflora* had the increases of the root densities by 67 and 22 as the minimum air capacity increased by 1 percent respectively. The

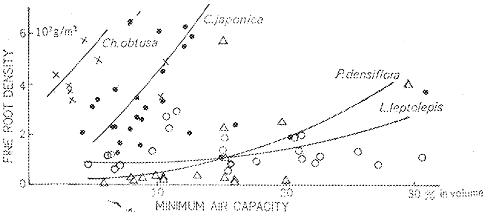


Fig. 11 Minimum air capacity and fine root densities in soil horizon I.

Table 9. Minimum air capacity and fine root density in horizon I

Stand	*Ch. obtusa*		*P. densiflora*	
	H3	H6	A1	A6
Minimum air capacity	2.1	4.2	13.1	29.6
Root density	447	587	47	401
*	67		22	

* Ratio of increase to 1% of air capacity.

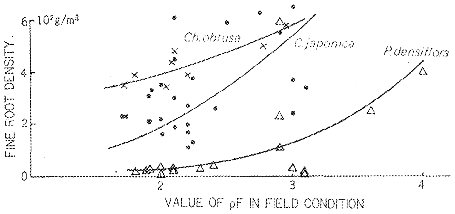


Fig. 12　Value of pF in field condition and fine root densities in soil horison I.

Table 10.　Value of pF and fine root density in horizon I.

Value of pF \ Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*
2 (A)	200	400	30
3 (B)	550	600	150
B/A	2.25	1.25	5.00

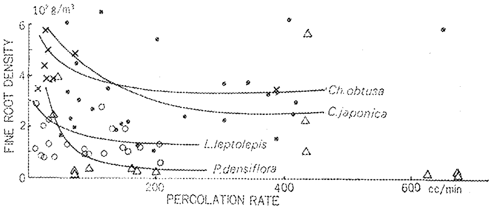


Fig. 13　Percolation rate and fine root densities in soil horizon I.

former took the higher increasing ratio than the latter; but on the other hand, *L. leptolepis* made almost no increase of the root densities although the minimum air capacity increased. This is just the contrast with the case of *Ch. obtusa*. The variance was wide in the stand of *C. japonica*. The root densities were low for the minimum air capacity in the stands of S 18, S 19, and S 20 because the density indices were low there.

(11)　pF values in the field condition

Fig. 12 shows the relation between the pF values in the field condition and the root densities. The root densities of each species increased, as shown there, as the pF values increased. *C. japonica,* for example, took the broadest variance. The species had the distribution areas of 100 to 600 at the pF value of 2.2.

Ch. obtusa had the highest root densities of 2 and 3 both, as shown in Table 10. And the root densities became lower in the order of *Ch. obtusa*, *C. japonica*, and *P. densiflora*. The ratios of increase of the root density to the pF values, however, became lower in the order of *P. densiflora* (5.00), *C. japonica* (2.25), and *Ch. obtusa* (1.25). *P. densiflora* won the highest of the three species. It is noticeable that *C. japonica* took a higher ratio of increase of root density by dryness than *Ch. obtusa*, so it can be said that the growth of the fine roots of the former is affected more easily by water condition than that of the latter.

(12)　Percolation velocity

Fig. 13 shows the badly complicated relation between the percolation velocity and the root density. In general the root density is high in the site with low percolation velocity, and low in the site with high percolation velocity and sufficient aeration.

The percolation velocity—root density curve is an upward concave decreasing curve. However, it is not always common to all species. *Ch. obtusa*, *P. densiflora*, and *L. leptolepis*, for example, were caused to increase their root densities more rapidly than *C. japonica* as their percolation velocity slowed up. The turning points of each species in the relation between the

Table 11.　Critical point of percolation ratio from the figure indicating the relation between percolation rate and fine root density

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Percolation ratio (cc/mm)	200	75	60	75

From Fig. 13.

Table 12. Fine root density in horizon I at the percolation rate of 100 cc per min

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Root density (g/m^3)	450	380	50	100

two are shown in Table 11. According to the table, *P. densiflora* did not make a great change in root density before its percolation velocity decreased to 60 cc/min. But below that velocity a change was brought about. All species were prompted to increase their root density rapidly in the site with the percolation velocity of 20 cc/min or below. This explains that the growth of roots makes a remarkable change there.

The above-mentioned relation between percolation velocity and root density is just the contrast with the growth condition that roots grow sufficiently in the condition of high percolation velocity and good aeration. This, however, is precisely in line with the tendency that the root density increases, and that the percolation velocity slows down in a dry and infertile stand. If we go through the root densities at the percolation velocity of 100 cc/min using Fig. 13, we get results shown in Table 12. According to the table, the root densities became lower in the order of *C. japonica*, *Ch. obtusa*, *L. leptolepis*, and *P. densiflora*. *C. japonica* had nine times as high a root density as *P. densiflora* at the same percolation velocity.

(13) pH (H_2O)

The potential of hydrogen (pH) is an indicator of the chemical properties of soils. An examination of the relation between the pH and root density, yields the results of Fig. 14. The variance of each species was very wide as in the figure. The root density decreased in general with the increasing pH, with an exception of a few stands of *C. japonica*.

The relation as applying to *Ch. obtusa* can be seen in Table 13. The pH of the table was 4.3 in the infertile and dry stand of H 6. This makes clear that the stand is more acid than the stand of H 7. Furthermore, the root densities changed along with it. They were 587 and 355 in the stands H 6 and H 7 respectively, making a difference of 232 between them. The root densities of each species at the pH of 5 became lower, as in Table 14, in the order of *Ch. obtusa*, *C. japonica*, *P. densiflora*, and *L. leptolepis*. There was a small differ ence among them if compared with the other factors. What has been mentioned so far is a considerably rough account. Actually, each species has

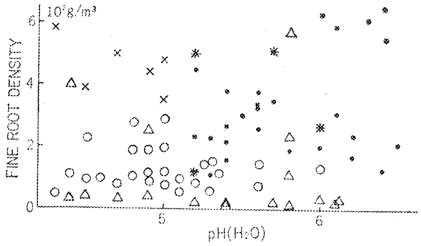


Fig. 14 pH (H_2O) fine root densities in soil horizon I.

Table 13. pH and fine root density in horizon I of the *Ch. obtusa* stands

(g/m^3)

Stand	H 6	H 7
pH	4.3	6.1
Fine root density	587	355

Table 14. Fine root density in harizon I of pH 5

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Fine root density	350	450	250	100

Table 15. Exchangeable acidity and fine root density in horizon I

Species	*C. japonica*		*Ch. obtusa*		*L. leptolepis*	
Stand	S 27	S 10	H 7	H 6	K 28	K 17
Exchangeable acidity	0.5	11.0	1.2	62.0	2.8	26.0
Fine root density	137	550	355	587	87	207
Rate of increase*	39		4		5	

* Ratio of increase: Ratio of root density to the exchangeable acidity 1.

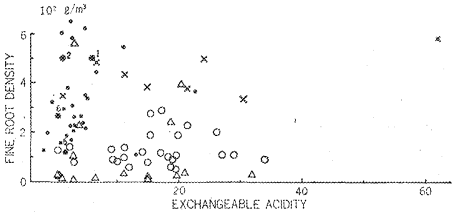


Fig. 15 Exchangeable acidity and fine root densities in soil horizon I.

Table 16. Exchangeable acidity and fine root density in horizon I of the *P. densiflora* stands

Stand	A 2	A 5	A 6
Soil type	B*l*D(d)	Er	Er-β
Ex. acidity	12	19	21
Fine root density	44	254	401
Rate of increase*	—	—	40

* Ratio of increase of root density to that of A 2.

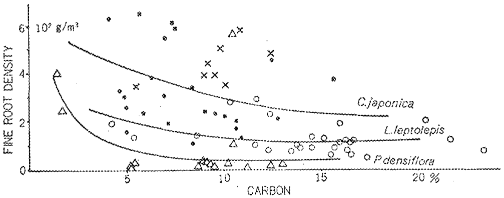


Fig. 16 Carbon and fine root densities in soil horizon I.

a very broad distribution area of the root densities even at the same pH value. The root densities of *C. japonica*, for example, ranged from 137 in the stand of S 27 to 653 in the stand of S 7.

(14) Exchangeable acidity

The root densities of each species increased, as shown in Fig. 15, with the increasing exchangeable acidity. This is observed most distinctively in the case of *C. japonica*. Inquire into this on the stands of S 27 to K 17 with the extremely different exchangeable acidity, and turn to Table 15 for results. Then the ratio of increase of the root densities to the exchangeable acidity became lower in the order of *C. japonica* (39), *L. leptolepis* (5), and *Ch. obtusa* (4). *C. japonica* greatly increased the root density in the site with increasing exchangeable acidity. *Ch. obtusa* had still a low ratio of increase. It is clear from this that the chemical property of soils exercises a greater influence on the growth and distribution of the fine roots of *C. japonica* than on those of *Ch. obtusa*.

The exchangeable acidity and the root density increased, as shown in Table 16, both remarkably in the infertile and dry stand of *P. densiflora* such as A 5 and A 6. The root densities, for example, were 44 and 401 in the B*l*D(d) soil-typed stand of A 2 and in the Er-β soil typed stand of A 6 at the exchangeable acidities of 12 and 21 respectively. That species had the root density increase of 40. This ratio, as in Table 15, was higher than that of *C. japonica*.

(15) Carbon

The relation between the amount of carbon and the root density, as shown in Fig. 16, has considerably wide variance, which is common to each species. In general the root densities, however, decreased, as the amount of carbon increased.

Roots grow sufficiently in a site with a large amount of carbon and high fertility. Root densities increase in an infertile and dry site with a small amount of carbon. It is due not only to the decrease of carbon content, but to the influence given by the other factors there. It is also owing to the fact that fine roots are caused to maldistribute to the surface horizon in the dry site with the poor physical and chemical properties.

The above-mentioned relations were, as in Fig. 16, not obvious in the case of *Ch. obtusa*, but were observed distinctively in both the infertile and dry stand and the original stand of *P. densiflora* in Table 17. The root densities were remarkably high in the Er-AB and Er-B soil-typed infertile and dry stands of A 5 and A 6 as against those in the BlD(d) soil-typed stand of A 1. The amount of carbon was larger in the latter.

Table 17. Carbon and fine root density in horizon I of the *P. densiflora* stands

Stand	A 5	A 6	A 1
Carbon	1.9	1.6	8.8
Fine root density	254	401	47
soil type	Er	Er-β	BlD(d)

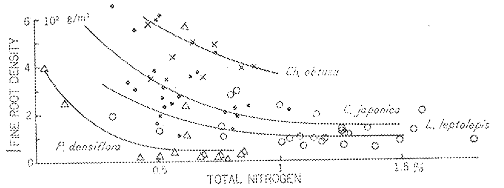


Fig. 17 Total amount of nitrogen and fine root densities in soil horizon I.

Table 18. Nitrogen and fine root density in horizon I of the *Ch. obtusa* stands

Stand	H 6	H 2
Total nitrogen (%)	0.5	0.9
Fine root density (g/m³)	587	395

The root density of each species decreased rapidly until the amount of carbon came up to 8 to 10%. It did not decrease greatly in the sites with a higher carbon content.

At the amount of carbon of 10, in Fig. 16, the root densities became lower in the order of *Ch. obtusa* (400), *C. japonica* (300), *L. leptolepis* (150), and *P. densiflora* (30).

(16) Nitrogen

The amount of N and carbon are alike in relation to the root density, as shown in Fig. 17. However, nitrogen is more closely related to the root density and the root growth than carbon. The root density of *Ch. obtusa* had little correlation with carbon. There was, however, a high correlation with N as shown in Fig. 17. Results of observations on this relation on the stands of *Ch. obtusa* of H 6 and H 2 are shown in Table 18, from which it is clear that the root density decreases as the amount of N increases.

This phenomenon is traceable to the fact that roots are induced to maldistribute in the surface horizon in the dry and barren site with a little amount of N, as in the case of the amount of carbon.

This is observed more clearly in the case of *C. japonica* and *P. densiflora* than in the case of *Ch. obtusa* and *L. leptolepis*, and that is precisely because the branching and the growth of the fine roots of the former two are easily affected by the chemical properties of soils.

The root density of *Ch. obtusa* decreased as the amount of N increased up to 1.0%. The inflection points were about 0.6% for *C. japonica*, 0.7% for *L. leptolepis*, and 0.4% for *P. densiflora*. The species were not caused to change their root densities when the N content exceeded those amounts.

(17) C/N ratio

The C/N ratio, carbon/nitrogen ratio, which indicates the fertility of soils and the root

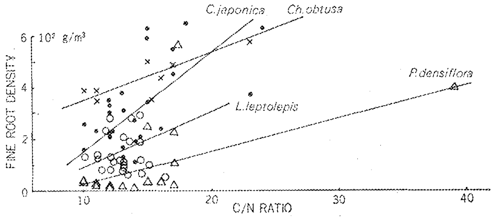


Fig. 18 C/N ratio and fine root densities in soil horizon I.

density had, as shown in Fig. 18, the closest interrelation of all chemical factors between them. And besides, their relation drew an almost straight line.

As often mentioned, this agrees very well with the fact that the root densities increase in the surface horizon in the infertile and dry stand with the high C/N ratio.

Estimate from Fig. 18 the root density of each species at the C/N ratios of 10 and 20, and turn to Table 19 for results. According to the table, the ratios of increase of root density became lower in the order of *P. densiflora*, *L. leptolepis*, *C. japonica*, and *Ch. obtusa.* It was inferred from these that if compared with the other species, *Ch. obtusa* did not make a great change of growth for chemical change, owing to the low ratios of increase of the amount of carbon and N and the C/N ratio all.

The relations between the various factors of soils and the root densities have been gone into so far, and as is clear from their correlation graphs, the interrelation of the root density with the individual factors had a remarkably wide variance as against that with the factors which put together the individual factors such as soil type, site index, etc. This comes about precisely because the root densities have been fixed upon by the interrelation among the various soil factors. The root density has a tendency to not increase where aeration, moisture, fertility, etc., faciliate the growth of trees but to increase in the infertile and dry condition. This is cleared up by a twofold reason : on the one hand, the ramification and growth of fine roots are promoted in that site, and on the other hand, roots are caused to maldistribute to the surface horizon because they are subjected to a limitation on growing in the shallow surface soil. The soil factors that have a comparatively close relation with the root density are such physical properties as the amount of air and water in field condition and the pF values, and such chemical properties as the amount of carbon and N and C/N ratio.

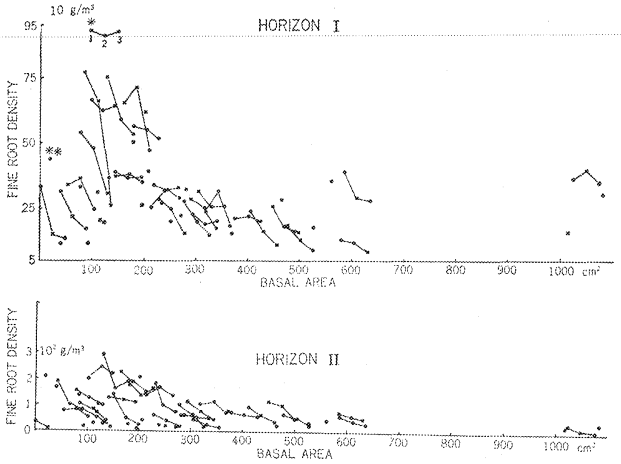
The root densities increased, as above-mentioned, in a dry and infertile stand; and at the same time, their surface areas of absorption increased. The absorbed quantity itself did not make for a great increase in root density because the absorption efficiency of roots was caused to decline either by the shortage of water by dryness or by high lignification in the tissues of fine roots.

5) **Horizontal variation of the root density in a stand**

Draw the relation between the distance from a root stock and the root density according to each root classification and each soil horizon using the detailed data. Results are shown in Fig. 19. According to the figure, the root densities got highest in horizontal division 1 near the root stock in each species, soil horizon and root classification. But they kept on decreas-

Table 19. C/N ratio and fine root density in horizon I

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
10 (A)	150	350	30	80
20 (B)	550	550	150	300
Ratio of increase (A/B)	3.7	1.6	5.0	3.8



* 1 : Root density of horizontal division 1
2 : Root density of horizontal division 2
3 : Root density of horizontal division 3

** Each isolated point indicates the root density only in the third horizontal division. The point of No. 45 is, for example, the root density in the third horizontal division of stand No. 45.

Fig. 19 Basal area and fine root density in soil horizons I and II of the *C. japonica* stand.

ing as the horizontal divisions go from 1 to 3, that is, farther from the root stock. Such ratio of decrease is not common to all species, root classification, soil horizons, tree densities, and soil conditions.

(1) Horizontal variation of the root density of each species

The ratios of decrease are shown in Fig. 19 on the fine roots in soil horizon I. According to them, the flat-rooted species, *L. leptolepis* and *P. densiflora* had the lower ratios of decrease by horizontal division than *C. japonica* and *Ch. obtusa*. This was also observed in the experiment at the Asakawa nursery. There was, that is, a small difference in root density between horizontal divisions 1 and 3. The ratio of decrease of the density of the fine root from horizontal division 1 to 3 in the soil horizon I of the stands S 5, H 5, A 4 and K 22 with similar moderate site conditions from the detailed data is shown in Table 20.

When the ratios of decrease from horizontal divisions 1 to 3 were to be expressed as the ratios to the root densities in horizontal division 1, they became lower in the order of *L. leptolepis* (0.82), *P. densiflora* (0.72), *C. japonica* (0.60) and *Ch. obtusa* (0.51).

L. leptolepis and *P. densiflora*, on the one hand, had almost the same density of the fine

Table 20. Horizontal change in fine root density in horizon I

Species	Stand	Horizontal division		
		1	2	3
C. japonica	S 5	268 (1.00)	232 (0.87)	161 (0.60)
Ch. obtusa	H 5	579 (1.00)	374 (0.65)	298 (0.51)
P. densiflora	A 4	46 (1.00)	33 (0.72)	33 (0.72)
L. leptolepis	K 22	117 (1.00)	108 (0.92)	96 (0.82)

The figures in the parentheses shows the ratios in root density when the root density in the first horizontal division is to be 1.

roots regardless of the distance from the root stock. *C. japonica* and *Ch. obtusa* on the other hand, had in horizontal division 3 near the root stock nearly twofold as high root densities as those about midway between them and their neighbour tree. This makes clear that the former two develop their roots widely along the surface horizon, and instead that the latter two collect their roots around their root stock. It became more indistinct in the lower soil horizon. The difference by horizontal distribution among species was observed most distinctly in soil horizon I. The root density of every species became particularly high in horizontal division 1 in soil horizons III and below.

(2) Tree growth and horizontal variation of root density

The root density in the horizontal division changes with the tree growth. An examination of the relation between the two on *C. japonica*, *Ch. obtusa* and *P. densiflora* as ratios of the root density in horizontal divisions 3 to 1, produces results shown in Table 21. According to the table, the ratio increased with the tree growth. The difference in density between the two divisions, after all, became smaller. And at the same time it is clear that the fine roots grow uniformly in soil horizon I as the tree grows.

(3) Tree density

Generally speaking, the higher the tree densities become the more interlocked the roots become among trees. Along with it the root densities increased to become equalized in each soil horizon. The relation between the tree density and the horizontal variation of root density in a few standard stands with different tree densities is shown in Table 22. The difference in the root density between horizontal divisions 1 and 3, became smaller as the tree density got smaller, showing the ratios of the two densities to be more than 0.9 in the close planting forest with the density indices of 0.8～1.2, and from 0.6 to 0.8 in the sparse planting stand with the density indices of 0.4～0.6. The root densities became higher around the root stock. About 70% of that density was about midway between them and their neighbour trees. Table 23 shows the comparison on the fine root densities of *C. japonica* in soil horizon I between the sparse planting stand in the Obi district and the dense planting stand in the Yoshino district. According to the table, the ratios were 0.51 to 0.64 and 0.68 to 0.72 in the sparse planting stand in the Obi district and in the close planting stand in the Yoshino district respectively. The root densities were more uniform horizontally in the latter than in the former. That is to say, the root densities were low about midway between the trees as against those near the trees in the sparse planting stand, and besides, the horizontal equalization of root density facilitated the uniform increase of root density regardless of the distance from the root stock in the close planting stand. This equalization is caused by a twofold fact; in the first place, the increasing tree densities promote the increase of the root weights contained in soils, and in the second place, the roots tend to grow from where they are of high root density to where they are of low root density.

(4) Soil

As already mentioned, a physical limitation is put on the spaces for root growing in dry and infertile forest land with shallow surface soils. Also, the root densities increase there because fine roots are caused to grow further on that condition. A horizontal analysis of the increase of root density on the fine roots in soil horizon I in the stand of *C. japonica*, produced results shown in Table 24. As is clear from the table, the ratios in horizontal divisions 3 to 1 were 0.83 10 1.00, 0.71 to 0.76, and 0.54 to 0.60 in the dry soil of B_A–B_{lc} soil types, in the moderately moist soil, and in the wet soil. From this it follows that the ratios become higher

Table 21. Horizontal change in fine root density in horizon I and basal area (g/m^3)

Basal area Species	100～200	200～300	300～500
C. japonica	(S 1) 317*～177** 0.56***	(S 3) 340～291 0.86	(S 4) 248～189 0.76
Ch. obtusa	(H 2) 442～334 0.76	(H 3) 560～382 0.68	(H 6) 530～451 0.85
P. densiflora	(A 2) 54～ 36 0.67	(A 3) 37～ 33 0.89	(A 8) 43～ 30 0.70

( ) Stand No.
* Root density in horizontal division 1 (A).
** Root density in horizontal division 3 (B).
*** B/A

Table 22. Horizontal change in root density and tree density (g/m^3)

Tree density index	0.4～0.6	0.6～0.8	0.8～1.2
C. japonica	(S 5) 268*～161** 0.60***	(S 23) 752～537 0.71	(S 22) 215～201 0.93
L. leptolepis	(K 27) 99～79 0.80	(K 22) 117～ 96 0.82	(K 26) 286～284 0.99

( ) Stand No.
* Root density in horizontal division 1 (A).
** Root density in horizontal division 3 (B).
*** B/A

Table 23. Horizontal change in fine root density in horizon I of the sparse planting stands of *C. japonica* in the Obi district and of the close planting stands in the Yoshino district

	Obi district			Yoshino district		
Stand	S 25	S 26	S 27	S 48	S 50	S 51
Tree density index	0.398	0.449	0.475	0.67	0.72	0.71
Horizontal division 1 (A)	281*	247	182	282	240	359
Horizontal division 3 (B)	151*	111	93	203	163	251
B/A	0.54	0.45	0.51	0.72	0.68	0.70

* Fine root density.

Table 24. Horizontal change in fine root density in horizon I and soil properties of the *C. japonica* stands

Soil moisture condition	Dry soil			Moderately moist soil			Moist soil		
Stand	S 7	S 20	S 24	S 23	S 4	S 15	S 5	S 12	S 25
Soil type	B_{lC}	B_A	B_A	B_{lD}	B_{lD}	B_{lD}	B_{lE}	B_{lD}(w)	B_{lD}(w)
Horizontal division 1(A)	653*	384	930	752	248	398	268	293	281
Horizontal division 3(B)	474	370	929	537	189	283	161	160	151
B/A	0.73	0.96	1.00	0.71	0.76	0.71	0.60	0.55	0.54

* Root density

Table 25. Horizontal change in each root density of the *C. japonica* stand S 5

Root class		f	s	m	l	L
Horizon	I	0.60*	0.67	0.41	0.13	+**
	II	0.44	0.57	0.48	0.06	+
	III	0.26	0.37	0.19	0.01	+
	IV	0.21	0.21	0.27	0.03	−
	V	+	+	+	+	−

* Root density in horizontal division 3/ Root density in horizontal division 1.

** The plus signs show existing only in horizontal division 1.

and the root densities get more equalized as the soil becomes drier.

(5) Root classification and root density

Each root class, say, fine, small, medium roots, etc., has its own way of horizontal distribution. By examining these relation according to each soil horizon in the S 5 stand of *C. japonica*, we got the results shown in Table 25. According to the table, the distribution of the fine and the small roots became much more uniform than that of the larger roots. The medium and the large roots, in a word, were distributed mostly around the root stock.

Such different ways of distribution of the roots indicate that the smaller roots absorb water and untriment from a far and wide area where they are distributed evenly, while the large roots are concentrated near the root stock and support the above-ground part. Distribution of the roots larger than the large root was hardly seen in horizontal division 3 of the soil horizon III and below.

(6) Horizontal variation of the root density in each soil horizon

An explanation has been practically made of the fine roots in soil horizon I so far. Furthermore, each soil horizon facilitates the horizontal change in root density. Table 25 on the stand of S 5 explains that the ratios decrease in each root classification as the soil horizons go down, and in addition, that the root biomass have a tendency to maldistribute to horizontal division 1. A distinctive line was drawn between 0 to 30 cm in depth and 30 cm above in depth in soil horizons I and II respectively. That is to say, the horizontal distribution pattern of the roots changed here. The ratio of the large roots was 0.03 in soil horizon IV, where 93% of all large root biomass were distributed to horizontal division 1. In soil horizon V, the fine to large roots were all distributed to horizontal division 1 and not to horizontal division 3.

6) **Root density and root competition**

We have so far dealt with the changing root density caused by the various conditions. We make here an effort to go through the densities of the fine roots which have the closest connection with the tree growth. The root densities became highest in the soil horizon 0 to

Table 26. Full density of the fine roots of each species

Species	Stand	Stand age (yrs)	Tree density index	Soil type	Value of pF in field condition	Horizon	Horizontal division	Root density (g/m^3)	Basal area (cm^2)
C. japonica	S 24	41	0.67	BA	2.8	I	1	930	99
Ch. obtusa	H 6	28	0.32	BB	3.0	I	1	630	91
P. densiflora	A 6	16	1.27	Er–BA	4.0	I	1	416	22
L. leptolepis	K 23	52	1.03	B*l*D-m	—	I	1	301	141

15 cm deep in the young and close planting stand in a dry and infertile site. There, competition may take place among trees when nutriment and water are absorbed.

Upon picking out from the investigated stands the highest densities of the fine roots of each species, we get the results shown in Table 26. According to the table, they were 930, 416, and 301 for *C. japonica*, *Ch. obtusa*, *P. densiflora*, and *L. leptolepis* respectively. *Ch. obtusa* had a higher root density in general. *C. japonica*, however, had a higher root density than that species in the extremely infertile and dry forest land. These stand ages ranged from 16 to 52 years, and all the planting sites were on horizontal division 1 and vertical division I in a dry and infertile forest land.

The soil condition is one of the environmental factors commonest to all stands with highest root density. The aridity of soil evoked a great influence on the density of fine roots in particular. The reasons for this are, on the one hand, that the fine roots are caused to make easier their ramification and growth on an infertile and dry condition, and on the other hand, that the roots are caused to grow only in soil horizon I because of the shallow surface soil.

7) Various soil properties and vertical variation of the root density

Fig. 20 shows the relation between the density of the fine root, which is most closely conected with the tree growth, and the physical and chemical properties of the soil as to some typical stands.

As mentioned before and seen in Fig. 20, the density of the fine root was high in the shallow soil horizon and low in the lower horizon regardless of species age and soil environment. Although the root density decreased from the shallow soil horizon to the lower one, the decreasing pattern did not always agree with vertical variation of each factor of the soil. This is because the root distribution is affected not only by a simpe factor but by the interaction of all the physical and chemical factors of the soil, such as water, air, fertility, and gravity. The relation between the root density and the vertical variation of each soil factor is shown in Fig. 20.

(1) Air in the field condition

The amount of air in the field condition is a temporary indicator of aeration of soils. Generally, it is large in the surface horizon, and small in the lower horizon. This agreed well with the change in root density by soil. The slightly wet soils like the S 22 stand etc. contained much water in the surface horizon and sometimes a less amount of air than in the lower soil horizons. In these sites, the root densities had a tendency to decrease in the surface soil horizon and to increase in the lower soil horizons with a large amount of air if compared with those in such dry stands with an extremely large amount of air as S 6, S 7, H 6, A 5, and K 16. (Refer to the stand of S 22 in Fig. 20.)

The amount of air was large in the sedimentary soil horizons with volcanic gravel, such as soil horizons I and VI, in the stands of S 13, S 16 and H 7 in Oneyama National Forest. There, the root density decreased as the amount of air increased, because both the shortage nutriment and water and the bad soil structure impede the growth of roots. This is just opposite to the change in the amount of air.

In the stand of S 16, the root densities were lower in the volcanic gravel horizon of soil horizon II than in soil horizons I and III, as shown in Table 27, although the amount of air was larger there than in soil horizons I and III. The amount of air regained increase in soil horizon IV. The root density did not, however, go into reverse as seen in soil horizons II and III, partly because the total root biomass decreased in the lower soil horizons, and partly

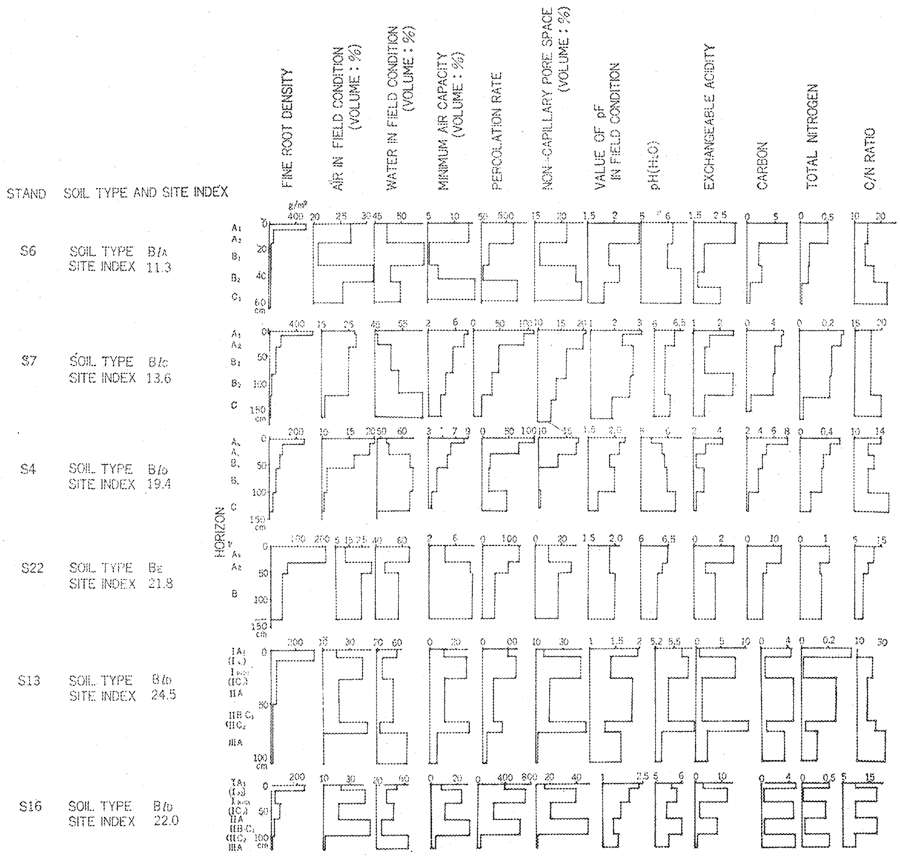


Fig. 20-1 Vertical change in fine root density, and physical and chemical properties of soil in the *C. japonica* stands.

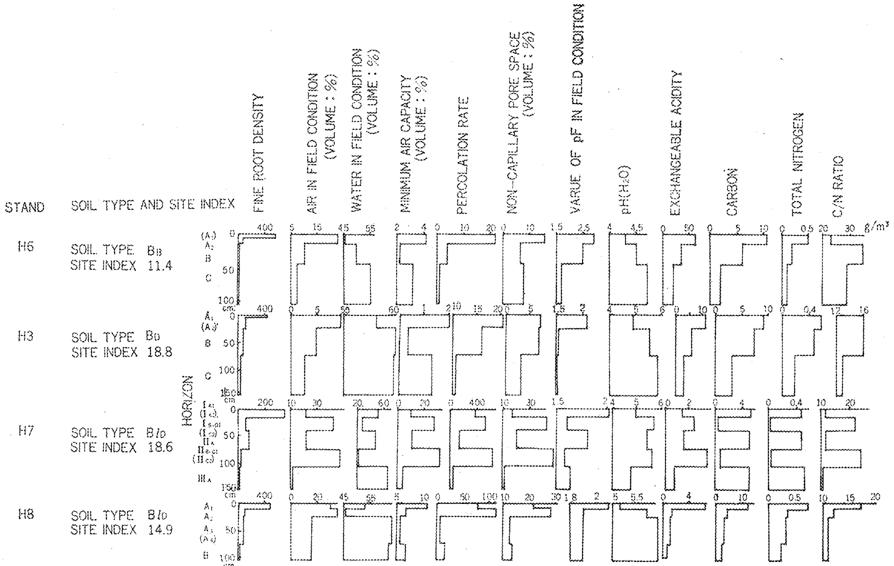


Fig. 20-2 Vertical change in fine root density, and physical and chemical properties of soil in the *Ch. obtusa* stands.

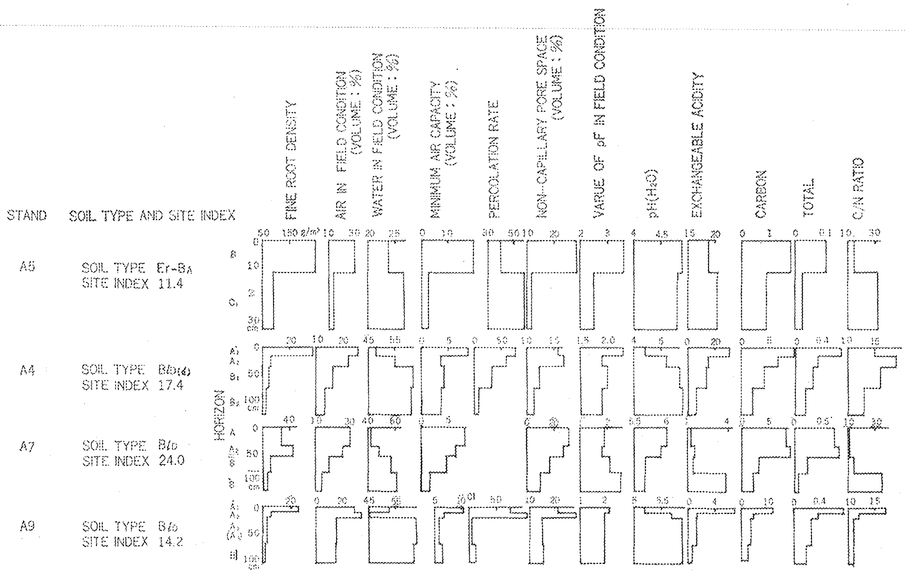


Fig. 20-3 Vertical change in fine root density, and physical and chemical properties of soil in the *P. densiflora* stands.

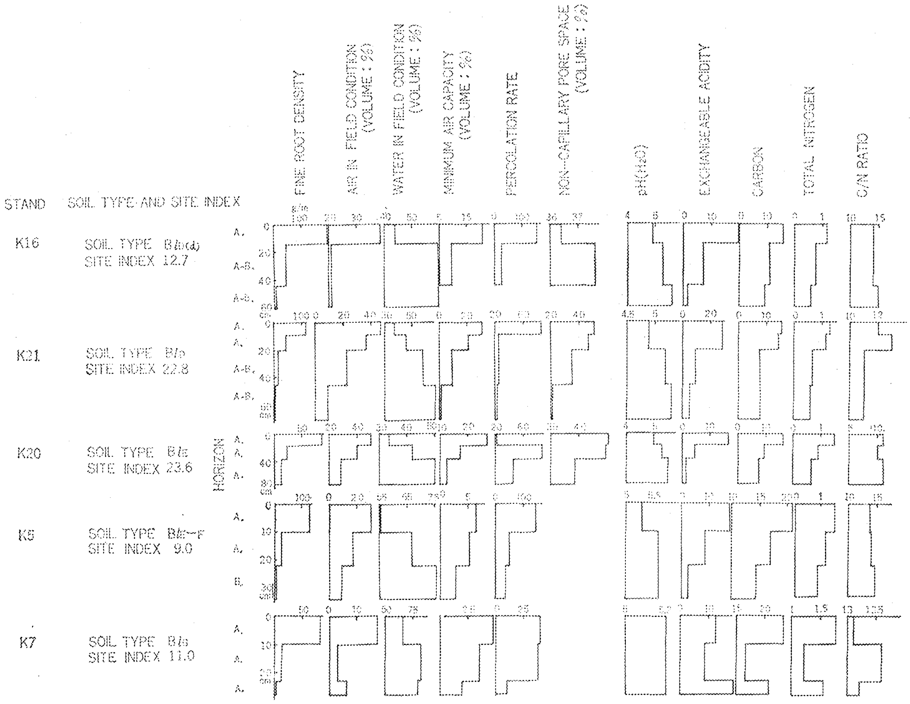


Fig. 20-4 Vertical change in fine root density, and physical and chemical properties of soil in the *L. leptolepis* stands.

Table 27. Air in field condition and fine root density of the *C. japonica* stand S 16

Horizon	Air in field condition (volume %)	Fine root density (g/m³)
I	24	268
II	41	31
III	21	73
IV	46	24
V	11	5

because the growth condition of roots equalized there. Therefore, it decreased gradually to 73 in soil horizon III, to 24 in soil horizon IV, and to 5 in soil horizon V.

The larger the amount of air becomes the better the roots grow in the soils holding a sufficient supply of water and nutriment. The vertical variation of the amount of air, for example, corresponded very well with change in root density as in the stands of S 4, H 3, A 4, and K 21. But in the soils with the small amounts of nutriment and water, the root density decreased in the soil horizon with the large amount of air.

An extraodinarily large amount of air is contained in the shallow turface soil in a dry and infertile forest land. The root densities were remarkably high in the surface soil horizon and extremely low in the lower soil horizons. This has a twofold reason; 1) that roots are deterred from growing in the firm lower soils; and 2) that roots are caused to maldistribute physically to the surface horizon. There, the root distribution depends on whether or not there exists space for roots growing in the soils, and not on the physical and chemical properties of soils.

(2) The amount of water in the field condition

The amount of water in the field condition, generally speaking, is contained much more in the lower horizons than in the surface horizon. (See Fig. 20.) This is quite different from the case of the amount of air. The change is also just contrary to that of the large and vertical distribution of the root densities in the surface horizon. These may be caused to take place because roots come to maldistribute to the surface horizon with good aeration in the moderately moist or wet soils with bad aeration, where much water is maintained in the deep place. The root densities, however, were high in the surface horizon even in dry forest land, where the surface soil was dried up remarkably and much water was held in the core soil. That is to say, it was not observed here that the root densities became higher in a core soil with much water than in the surface horizon.

Table 28 shows the relation of the amount of water in the field condition to the root den-

Table 28. Water in field condition and fine root density of the *C. japonica* stand S 27

Horizon	Water in field condition (volume %)	Fine root density (g/m³)
I	50	137
II	54	49
III	56	47
IV	61	26
V	61	10

* See Fig. 20

sities in the BA soil-typed stand of S 6. The root densities were, as shown there, remarkably high in the surface soil with a little water, and low in the lower soils with much water. They decreased rapidly with the water increasing.

The dry stand of S 6 has the soil horizon with much water contained at the depth of 20 to 30 cm. The root densities did not increase remarkably there. And also in the stand of K 16, they did not increase although the quantity of water increased remarkably at the depth of 20 cm and below. Furthermore, in Oneyama National Forest they ran parallel to the decreasing water in the volcanic gravel horizon in the stand of S 13 and S 16. This arises from either the shortage of water or the badly inferior physical and chemical properties of soil in this soil horizon.

The root densities fell off in the deeper soils in a dry stand with the exception of the special cases in Oneyama National Forest. This comes about either because of the bad aeration and soil structure, or of the firm soil and poor chemical property. Horizontally, in a dry stand, roots often grow in a concave area with almost equal soil properties of aeration, fertility, etc., and with much water. Vertically, roots nearly maldistribute to the surface horizon because the above-mentioned factors put a great limitation upon their growing. Or rather, water is one of the factors preventing their growing in this case.

The vertical distribution of roots is also affected by it because the climate condition in Japan is not like that in a desert area where there is almost no rainfall all the year round.

The vertical distribution of roots is there given a greater influence by soil structure, aeration, fertility, etc. rather than by water condition.

(3) Minimum air capacity

The minimum air capacity had a similar tendency to the vertical distribution of root density; they went on up in the surface horizon and down in the lower horizon. This does not, however, always hold true in all cases. Sometimes the minimum air capacity, for example, became smaller in the surface horizon than in the lower horizon as observed in the stands of S 22, S 13, S 16, and H 7. This is just the reverse with the case of the distribution of root density.

In the BE soil-typed stand of S 22, the minimum air capacity was smaller in the surface horizon with much water than in the lower horizon. Aeration was worse in the surface horizon as against that in the other stands. There, the root density became lower than in the dry stands S 6, S 7, etc. There was no influence to cause the decreasing trend of it going into reverse. It increased, for example, slightly only in the lower horizon with the large minimum air capacity.

Thus, this stand made little difference in the change in root density from the normal stand of S 4, despite the bad aeration in the surface horizon. It is due either to the sufficient supply of oxygen because that surface soil comes into contact with the atmosphere, or to the favorable growth of roots regardless of aeration.

In the stands of S 7, S 13, and S 16, the minimum air capacity was smaller in the surface horizon than in the lower horizon, because there existed volcanic gravel in the latter horizon. The root densities were higher there than in the lower soil horizon with the large minimum air capacity. It was contrary to the case in the other soils. This originates in the fact that the physical and chemical properies of soils are worse in this horizon.

The minimum air capacity was large and the root density was high in the surface horizons of such dry-soil stands as S 6, S 7, H 6, A 5, K 16, etc. Possibly, partly because the roots were maldistributed particularly to the surface horizon with the large minimum air capacity and good aeration, and partly because hightening the root densities caused the physical property of soils to change and the minimum air capacity to enlarge.

Thus, there may be always the causal relation between the root density and all the factors closely connected with it. Particularly, most closely connected with them is the minimum air capacity.

(4) Percolation velocity by water

Among all physical properties of soil, the percolation velocity by water is most closely connected with the distribution of root density; they make a similar change. The percolation velocity and the distribution of root density both went up in the surface horizon and down in the lower horizon. The remarkably high interrelation, as shown in Fig. 20 and in Table 29, was observed between them in the stand of S 7.

Percolation velocity indicates the number of pores and the movement of water in a soil. The high root density in the soil with high percolation velocity means that roots grow favorably in the porous soil where water moves easily.

As already mentioned, the root densities became higher as the percolation velocity became higher in the original stand. They decreased, however, remarkably in the volcanic gravel horizon like the stand of S 16 where the rest of the physical and chemical properties of soil got worse.

The vertical distribution of root density is dependent on the relativity among each soil horizon in a site, and not on the absolute quanty of each factor. The percolation velocities were, for example, 650 cc/min and 22 cc/min in the soil horizon I in the stands of S 6 and H 6 respectively. Though there was a great difference between them, it did not exert any influence on the vertical distribution of root density in each stand. (See Fig. 20.)

(5) Non-capillary porosity

The non-capillary porosity goes on up in the surface horizon, and down in the lower horizon. It is similar to the change in root density. The growth of roots is generally affected by

Table 29. Percolation ratio and fine root density of the *C. japonica* stand S 7

Horizon	Percolation rate (cc/min)	Fine root density (g/m^3)
I	115	653
II	95	193
III	47	103
IV	35	44
V	15	14

Table 30. Non-capillary pore space and fine root density of the *C. japonica* stand S 7

Horizon	Non-capillary pore space	Fine root density
I	11.9	653
II	11.8	193
III	10.4	103
IV	9.6	44
V	9.5	14

the non-capillary porosity when nutriment and water are supplied sufficiently. The root density tends to be higher in the soil horizon with high non-capillary porosity. In the stand of S 7, the non-capillary porosities were 11.9% and 9.5% in the surface soil horizon and in the lower soil horizon respectively. Corresponding to it, the root densities were, as shown in Table 30, 653 and 14 in soil horizons I and V, respectively. They decreased, that is, with great speed at the non-capillary porosity of 10% and below. They were, for example, 44 and 14 at those of 9.6% and 9.5% respectively, but this is not always common to all stands. In the stand of S 6 as in Fig. 20, the root density did not make so great an increase as to go into reverse order even when the non-capillary porosity was higher in the lower soil horizons than in soil horison I. This explains that the distribution of each root biomass in each soil horizon is dependent not only on the non-capillary porosity but on the other soil factors.

(6) pF values in the field condition

The pF values in the field condition express the amount of water which trees can absorb. They may be more closely connected with the root density than with the amount of water in the field condition in this respect. Fig. 20 shows the relation between the pF values and the root densities. According to the figure, the pF values and the root densities both go up in the surface horizon, and down in the lower soil horizon. The root densities were higher in a dry soil horizon than in a wet one.

The pF values was distinctively observed to make a change according to each soil horizon in the dry stand of S 6. Table 31 shows the relation between them there, listing the pF values of 2.5 and 1.8 in soil horizons I and IV, respectively. This makes clear that the surface soil was dried up more remarkably than the lower soils, and that the root densities were 264 and 16 in the former and latter, respectively. An extremely big difference existed between them.

Roots grew favorably in the moderately moist soils with the pF value of about 2.0 and unfavorably in the dry soil with that of about 2.5. As concerns the vertical distribution of roots biomass, fine roots grew sufficiently in the surface soil horizon with a large pF value, and insufficiently in the lower soil horizon with a small pF value. This arises from a fourfold cause; 1) that the surface soils seem, as already mentioned, to be unfavourable to the root growth under drought condition; and yet, roots grow favourably in the surface horizon when there is a sufficient supply of oxygen from the atomosphere and of water by rainfall indispensable to the growth and the function of roots; 2) that there are the more favourable chemical properties and more supply of nutriment in the surface horizon than in the lower horizon; 3) that the deeper soils stand physically well against the roots infiltrating, thanks to the insufficient aeration and firmness; and 4) possibly that the values of pF are large and the soils are dried up in soil horizon I. The root growth is, however, affected by the amount of water

Table 31. Value of pF in field condition and fine root density of the *C. japonica* stand S 6

Horizon	Value of pF	Fine root density (g/m^3)
I	2.5	264
II	1.9	47
III	2.1	19
IV	1.8	16
V	—	—

during a short period. Therefore, roots grow plenteously at the period, e. g., the rainy season, when they have a high temperature and much rainfall.

The values of pF were all small in the volcanic gravel layers of soil horizons II and IV in the stands of S 13, S 16 and H 7. Those layers contained much water, which was beneficial to root growth, and had a large amount of air, essential to the growth and the function of roots. The soil structure and the chemical properties, however, were remarkably worse there than in the other soils; consequently, roots grew very unfavourably. Hence, the root density was lower there than in the lower horizon.

In the stand of A 7, the deeper soil contains the clayey soil with strong water-holding capacity. Therefore, the pF value was 2.5 there and larger than in the surface horizon. Little water is used for plant growing although the site like that contains much physical water. It caused poor aeration and consequently roots grew insufficiently and roots densities fell off. Even when they were high in both horizons, the values of pF in the lower and surface horizons had their own properties in relation to the root density. That is to say, the root growth was given another influence by the value of pF in the dry surface horizon and by that in the moist lower horizon.

(7) pH (H_2O)

pH is related to the vertical distribution of humidification as seen in the typical stand, S 4, in Fig. 20 and Table 32. It is small in the humidified surface horizon, and large in the little humidified lower horizon. The root density is high in the former horizon. Vertically, the root density increased as pH decreased.

The humidified forest soils suitable for the root growth become less and less acidic in general. When there exist a sufficient supply of air and water on this condition, roots grow favorably and root densities go up.

Roots were not prevented from growing only by the pH values of about 5.4 to 6.3 insofar as they were not added to the chemical properties of soil which set up the pH conditions. The root growth and density are both dependent directly upon the difference of humidification in distribution which makes an inclination of the pH values 5.4 and 6.3 in the surface horizon. Aeration and water except for pH and the other chemical properties have helped root densities to go up in inclination as already explained in dealing with the other soil factors. The value of pH and the root density were 6.3 and 2 respectively in soil horizon V. There, roots are caused to grow unfavorably by the overhumidity, bad aeration, etc., along with the shortage of humus and the inorganic salts, such as N, carbon, and the like.

The value of pH increases and the root density decreases under the soil conditions that lack humus and inorganic salts. This is clearly observed in the volcanic gravel layer in the

Table 32. Value of pH and fine root density of the *C. japonica* stand S 4

Horizon	pH(H_2O)	Fine root density (g/m^3)
I	5.4	340
II	5.8	85
III	5.9	44
IV	6.0	26
V	6.3	2

Table 33. Value of pH and fine root density of the *C. japonica* stand S 16

Horizon	pH(H_2O)	Fine root density (g/m^3)
I	5.4	268
II	5.8	31
III	5.4	73
IV	6.0	24
V	5.5	5

stands of S 13, S 16, and so forth. There was, as shown in Table 33, an opposite interrelation between the value of pH and root density in that layer. The value of pH and the root density were 5.8 and 31 in soil horizon II, and 5.4 and 73 respectively in soil horizon III. This is diametrically contrary to the gradual decreasing of root density.

(8) Exchangeable acidity

The exchangeable acidities were 1 to 2 in the soil with good aeration or rich humus and inorganic salts. They were, however, more than 20 in the barren and dry soil with bad aeration. The root density, therefove, became higher when the exchangeable acidity became lower. But the root density, generally speaking, becomes higher in the surface soil horizon with higher exchangeable acidity, because of the interaction between other soil factors as observed in pH and the other soil factors. The root growth is diametrically contrary to the exchangeable acidity. The data of the S 6 stand in Fig. 20 show a very good example of this. The stand S 6 in the barren and dry surface soil of B_B type had a verv high exchangeaale acidity of 62 if compared with those in the general forest stand. Although this was not always good for the tree growth, that stand took a very high root density of 1261.

The high exchangeable acidity alone does not always facilitate root growing, as seen in the stand of S 6. The root distribution is also dependent upon the other physical factors, such as aeration, water-supply by rainfall, distribution in humus, etc.

The stands of S 13, S 16, and H 7 had an extraordinarily different property of soil in the deeper soils. There, the exchangeable acidity was higher in the volcanic gravel layer in soil horizon II than in soil horizon I in the other stands. (See Fig. 20.) The root density fell off along with it. As the exchangeable acidity increased, the root density decreased in the deeper soils in the stands of A 5 and A 7. This is opposite to the case in the above-mentioned stand of S 6. It is difficult to judge from these the relation in the vertical distribution between the exchangeable acidity and root density. In general the root density goes on up in the surface horizon, and down in the lower horizon when the exchangeable acidity trends to be higher.

(9) Carbon

Generally is there much carbon in the highly humidified surface horizon, and less in the scantily humidified lower horizon. The root density changes, corresponding to the quantity of carbon; that is to say, it goes up in the surface horizon with much carbon, and down in the lower soil horizon. There is a clear interrelation between them. Fig. 20 and Table 34 show the relation between them in the stand of S 4, from which it can be seen that the amounts of carbon and the root densities were 8% and 277 respectively in soil horizon I, and 2% and 15 respectively in the lowest horizon V, precisely because roots grow sufficiently in the surface soils with much organism and good aeration. According to the data in the investigated stand they had a decisively high correlation as against the other factors. That arises from a twofold reason; on the one hand, the factors suitable for the tree growth, such as aeration, water, nutriment, etc., have been intertwined in the surface horizon in all these stands, and on the other hand, that especially among all those factors, the distribution in

Table 34. Carbon and fine root density of the *C. japonica* stand S 4

Horizon	Carbon (%)	Fine root density (g/m³)
I	8	277
II	5	103
III	4	86
IV	3	51
V	2	15

Table 35. Carbon and fine root density in the volcanic gravel and ash soil of the *C. japonica* stand S 16

Horizon	Carbon (%)	Fine root density (g/m³)
I	5.2	257
II	0.5	20
III	4.8	44
IV	0.9	—
V	5.1	—

humus goes down all from upward to downward.

The layers of the volcanic gravel and volcanic ash are accumulated alternatively in the stands of S 13, S 16 and H 7. Thus, the layers with much carbon and the layers with little carbon are caused to exist alternately in some of the investigated stands. The distribution of the root densities corresponds to that of carbon in this site; in other words, the root density goes up in the soil layer with much carbon, and down in the soil layer with little carbon. This relation is clearly shown in Fig. 20, and particularly so on the stand of S 16 shown in Table 35. According to the table, the amounts of carbon and the root densities were 5.2% and 257 respectively in soil horizon I, 0.5% and 20 in soil horizon II, and 4.8% and 44 in the volcanic ash layer of soil horizon III. The root density in soil horizon III was about twice as high as that in soil horizon II. Few factors had so high an interrelation with root density as the amount of carbon in the surface or lower soil horizons. It had a higher interrelation than the amount of air in the field condition and the minimum air capacity in soil horizon II.

(10) Nitrogen

Fig. 20 verifies that there is much N in the highly humidified surface soil horizon and little in the lower horizon. It has, as observed in the case of carbon, a high correlation with the root density. This comes of a twofold reason, on the one hand that roots grow unfavourably in the little humidified soil with little N, and on the other hand that N is highly connected with the root growth.

The property of selecting soils by roots is observed when the amount of nitrogen changes as that of carbon changes. The root density as in Table 36, was higher in soil horizon III with much N than in horizon II with lapilli accumulated alternatively.

That was observed distinctly, as in Table 36, between soil horizons II and III. The root density did not go into reverse between soil horizons IV and V. This is due either to the decrease of root biomass between them, or to the equalization of the environmental conditions caused by the other increasing factors to prevent roots growing. The root densities were 24 and 5 in soil horizons IV and V respectively. They decreased gradually regardless of the changing amount of N.

Table 37 shows the vertical distributions of root density in the B_E soil-typed stand of S 18 containing much N even in the lower horizon and in the B_A soil-typed stand of S 20 with little there. In the former, the root density made a low ratio of decrase. In the latter, it increased

Table 36. Nitrogen and fine root density of the *C. japonica* stand S 16

Horizon	Nitrogen (%)	Fine root density (g/m³)
I	0.52	268
II	0.03	31
III	0.46	73
IV	0.05	24
V	0.51	5

Table 37. Vertical change in N and fine root density of the *C. japonica* stands of different soil types (g/m³)

Stand	S 18		S 20	
Soil type	B$_E$		B$_A$	
Horizon	N	Fine root density	N	Fine root density
I	0.59	118	0.67	377
II	0.44	62	0.20	123
III	0.29	44	0.08	43
IV	0.29	30	0.06	24
V	0.01	12	—	5

* Vertical distribution ratio of N

remarkably in soil horizon I. In soil horizon II and below, N and root density both made a high ratio of decrease if compared with those in soil horizon I.

(11) C/N ratio

The C/N ratio is low in the fertile surface soil horizon, and high in a core soil. (See Fig. 20.)

As already mentioned, roots grow sufficiently in the firtile soils with plenty of carbon and N, and root densities go up along with it. There is, in a word, a highly close correlation between them. This holds true in the case of the C/N ratios as an indicator of the fertility of soils. The root densities, for example, increased in the surface horizon with the low C/N ratio and high fertility, and not in the lower horizon with the low C/N ratio and the unfavourable physical and chemical properties. There was, that is, a close relation here again in the root growth between the C/N ratio and the root density. The difference between the sitting soils causes the changing trend of the C/N ratios to go into reverse in the lower horizon as in the stand of S 16. There, the root densities change hand in hand with the C/N ratios. And they become higher in the lower horizon with the low C/N ratio than in the upper horizon.

As mentioned above, the root density is affected by the various physical and chemical factors of soil, especially by such a physical property as percolation velocity, or such chemical properties as carbon and N amounts and their ratios. In principal, the root density decreases from upward to downward. This tendency does not change even when there is some change in the soil properties.

The root densities go up in the surface horizon, and down in the lower horizon even when there exist the conditions unfavourable to the root growth, such as drought, bad aeration, etc., in the former. This is borne out by the detailed data and Fig. 1 showing that the root densities go down gradually from upward to downward, and yet that each soil factor does not always make a given change as the root density. Particularly in the surface horizon, roots grow more sufficiently than in the lower horizon even when the physical and chemical properties of soil are much worse there. The root densities go up with it, possibly because the root distribution is subject to the other strong influences rather than to soils.

They are atmosphere and rainfall, which respectively supply oxygen and water necessary for the growth of roots in the surface soil. These influences diminish in the lower horizons. Furthemore, dead leaves and branches supply organism which gives nutriment to the roots in the surface soil horizon. The synthetical function of the above-mentioned great influences leads to ample growth of roots and consequently their maldistribution to the surface horizon even when the analyzed values of the physical and chemical properties of soils there are conditioned by the factors unfavourable to the root growth, such as infertility, drought, insufficient aeration, and so forth.

Such environmental factors influencing roots go on diminishing gradually in the lower horizon, whereas insufficient aeration, shortage of nutriment, etc., come to be predominant there. The quality of the physical and chemical properties of soil, therefore, comes to control the root distribution. It causes the roots to pick out soils. The root densities, furthermore, go into revese as observed typically in the stands of S 13, S 16, H 7, and others; that is to say, the difference in property between soils causes the root densities to go up in the lower horizons and down in the surface horizon.

That cannot be observed distinctively insofar as the physical and chemical properties of soil do not make a conclusive difference from each other as the alternative accumulation of the volcanic gravel and volcanic ash in the stands of S 13, S 16, and H 6. Their slight change does not cause the root density to reverse the order in variation according to each soil horizon. For it is neutralized by the fundamental property of the root density in distribution that it changes from upward to downward.

The vertical variation of the root densities results from the interaction by these physical and chemical properties of soils. That is to say, the various intertwined conditions of aeration, water, nutriment, etc. either facilitate or hinder the root growth. The root growth and the analysis of the interaction between roots are the subject for a future study.

A lengthy and careful study should be made of the increase of root densities, influence to the tree growth by it, and competition by roots.

8) Root density up and down the slope around a root stock

Usually roots develop equally in all directions when a tree is on flat ground. But when a tree grows on slanted ground, the root distribution differs up and down the slope because of differences in the gravity and soil condition.

As already mentioned in regard to investigating methods, horizontal divisions 1 and 2 have been subdivided into two parts respectively; the upper side 1 and the lower side 2, and the upper sides (① + ④) and the lower sides (② + ③). A comparison on the root density up and down the slope has been made between ① and ② in horizontal division 1 and between (① + ④) and (② + ③) in horizontal division 2. This revealed the fact that the root densities were higher down the slope than up it in all species and root classification.

Selecting the stand of S 13 of *C. japonica* as an example and going through the difference

Table 38. Root density in the upper and the lower part of the slope of horizontal division 2 of the *C. japonica* stand S 2

Root class		f		s		m		l		L	
Location		Upper part	Lower part	U. P.	L. P.	U. P.	L. P.	U. P.	L. P.	U. P.	L. P.
Horizon	I	321	428	338	458	569	612	171	210	—	822
	II	98	107	167	188	265	308	60	116	43	—
	III	53	71	113	128	169	203	68	167	—	—
	IV	45	58	64	92	86	131	24	92	—	—
	V	9	13	21	43	60	137	—	—	—	—

Table 39. Ratio in root density in the lower part to that of upper part of the slope in the horizontal division 2 of soil horizon I

Species	Stand	f	s	m	l
C. japonica	S1	1.15	1.18	1.37	1.56
Ch. obtusa	H1	1.15	1.15	1.29	1.58
P. densiflora	A2	1.20	1.19	1.16	2.40
L. leptolepis	K14	1.18	1.09	1.16	1.41

in root density according to the slope, we get the results seen in Table 38. According to the table, the root densities were 321 up the slope and 428 down it. This comes under all cases of each root classification such as a fine root, a medium root, etc., or each soil horizon.

By calculating the ratios of the root density down the slope to that up the slope when the latter is to be 1, we get a more specific understanding of the relation, as is confirmed in the detailed data.

(1) Difference in ratio according to species

Table 39 shows the ratios of the root densities downward to those upward on *C. japonica*, *Ch. obtusa*, *P. densiflora*, and *L. leptolepis* out of the detailed data. According to the table, they were all more than 1 in all species. It proved that the root densities down the slope were higher than those up the slope in all species. However, no definite significance was observed on the difference between species.

(2) Root classification

Fine and small roots distribute evenly to the surface soil horizon. Distribution of the large roots, however, corresponds to the biomass distribution of the upperground parts as they relate to the supporting function. The ratio, for example, of the fine roots of *C. japonica* was, as shown in Table 39, 1.15, that of the small roots 1.18, that of the medium roots 1.37, and that of the large roots 1.56. It is clear from this that as roots become thicker, the ratio of the root density becomes higher. The same relation was also observed on *Ch. obtusa*, *P. densiflora*, or *L. leptolepis*.

The variations of the ratios by the root size are shown in Fig. 21. According to it, the ratios of the fine and the small roots were almost the same in distribution, but those of the medium and large roots increased rapidly. This explains that one group of the roots and another smaller and larger than a medium root respectively, have a great difference in root distribution to the slope.

This is partly because the fine and the small roots distribute evenly to the forest floor so as to absorb water and nutriment, and partly because the larger roots grow appropriately down the slope in order to support the above-ground parts.

Fig. 22 shows the distribution of the biomass up and down the slope according to the strata of the branches and leaves of the above-ground parts in the stand of S 15.

The ratios of distribution of the above-

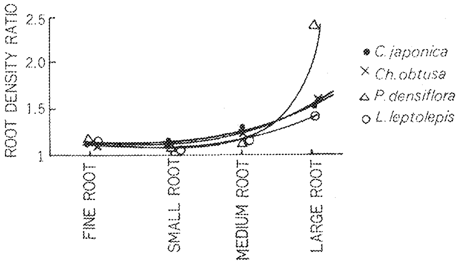


Fig. 21 Root class and ratio of root density in horizon I of the upper and lower parts of slope.

and-under ground parts by slope are shown in Table 40. They were, as shown there, 38% and 62% of the total branch biomass up and down the slope respectively at the inclination of 25° in the stand of S 15. The parts down the slope stand against gravity by this ratio. The ratios of the total root biomass by distribution were 42% and 58% up and down the slope respectively. Although their ratios are not the same, a high interrelation is recognizable between the distribution of biomass of the above-ground parts and that of the root biomass. And at the same time, the large roots grow amply down the slope in order to support the above-ground parts in particular. Such a distribution of the biomass of branches and leaves as in Table 40 is also observed in an ordinary forest. When this is added to the fact that the biomass of the underground parts are all larger downward in any stand, it is universally tenable that the biomass of the above-and-under ground parts are distributed corresponding to the slope.

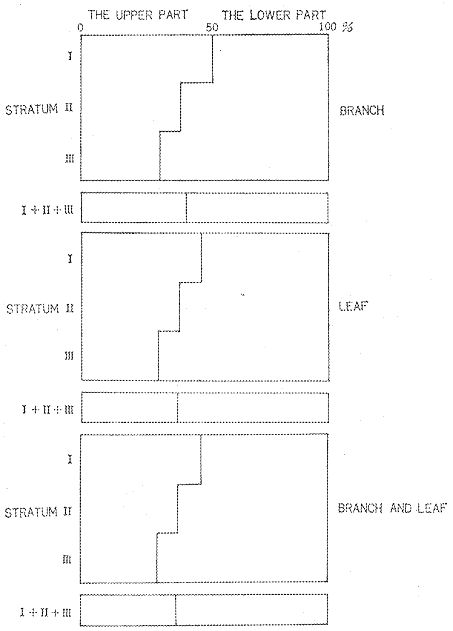


Fig. 22 Ratio of leaf and branch biomass on the upper and lower parts to the total of slope in the *C. japonica* stand, S 15.

Dr. MIYAZAKI[21] discovered that the supporting roots, called an anchorlike tap root, developed down the slope[5]. And also it is easy to know these relation from the various froms of the roots of each investigated species given in this study.

(3) Root density up and down the slope and tree growth

The tree growth causes the difference of root biomass in distribution up and down the slope. There was, however, no significant difference between the tree growth and distribution

Table 40. Ratio of the above-and-underground part biomass inthe upper and the lower part of the slope 25° in inclination in *C. japonica* stand S 15

Part		Uper (%)	Lower (%)
Above-ground part	Branch and leaf	38	62
Underground part	Root	42	58

Table 41. Distribution ratio of the root biomass in the lower part to that in the upper part of the slope of the *C. japonica* stand

Stand	Basal area (cm^2)	f	s	m	l
S 1	61	1.15	1.18	1.37	1.56
S 2	249	1.33	1.36	1.08	1.23
S 5	439	1.19	1.13	1.18	1.38

Here, the distribution ratio by root biomass upward is to be 1.

of root biomass in the detailed data. To go further into this, take from this table a few stands with different basal areas and then look over that relation. A result is shown in Table 41. There was, as shown there, no given relation between the tree grwth and the ratios in each root classification.

(4) Soil horizon

Table 42 shows the ratio of the root density down the slope to that up the slope in each soil horizon of the stand S 5, at the age of 45 years. The root density down the slope becomes higher in the lower soil horizons, because the influence on the roots by water and fertility gets weaker and that by gravity gets stronger. In the surface horizon, the roots intermingle with those of the neighbouring trees, and hence the difference between the densities of roots up and down the slope is not so clear since this intermingling does not occur in the deep soil. This is also one of those reasons.

(5) Angle of the slope and root density

The ratio of the roots by distribution down the slope becomes higher, proportionating the angle of the slope. The relation between the two in the *C. japonica* stand is shown in Table 43.

Two reasons can be conceived to understand this phenomenon. One reason is as follows: As the slope goes steeper, the weight of the above-ground becomes maldistributed down the slope. Correspondingly, the root system down the slope develops as if they support the above-ground. This holds good, especially in the case of large and very large root, and root stocks. And this is an effect of the stimulus by the difference in gravity distribution on the thickening growth of large roots. This phenomenon is one of the adaptation of roots as a supporting structure to the gravity distribution in the above-ground.

The other is an effect of gravity on the growth of root length. This is because the root tips are made to strech down the slope by the stimulus of gravity. As already mentiond, this phenomenon can be recognized in the lower horizon rather than in the surface horizon where less roots are intermingled.

Table 42. Difference in root density in the upper and the lower part of the slope in each horizon of the *C. japonica* stand S 5

Root class		f	s	m	l	L
Horizon	I	1.19	1.13	1.18	1.38	*
	II	0.98	1.15	1.14	1.33	1.31
	III	0.74	1.27	1.09	1.54	3.21
	IV	1.07	1.12	1.32	2.13	—
	V	1.73	1.59	1.17	1.86	—

Table 43. Inclination of slope and ratio in root density

Stand \ Root class	Inclination of slope	f	s	m
S 3	6°	1.07	1.02	1.09
S 13	12	1.14	1.13	1.12
S 2	20	1.24	1.26	1.18

Here, the root density in the upper part of the slope is to be 1.

Table 44. Ratio by root density in the right and the left side of the slope of the *C. japonica* stand S 13

Root class		f		s		m		l		L	
Horizontal division		2		2		2		2		2	
		①	②	①	②	①	②	①	②	①	②
Horizon	I	1.11	1.10	1.17	1.17	1.07	1.05	1.56	0.50	0.26	1.31
	II	0.75	1.00	0.79	0.95	1.06	0.85	1.12	0.82	—	*
	III	1.00	0.85	1.06	0.83	0.84	0.96	*	0.47	—	—
	IV	1.71	1.00	1.36	1.17	0.87	0.63	—	—	—	—

* No root distribution on the left side of slope.

① Ratio of the root density in the left side to that in the right side in the upper part of the sampling division.

② Ratio of the root density in the left side to that in the right side in the lower part of the sampling division.

9) Root density on the right and left parts of the root stock

The ratios of the root density on the left part to those on the right when the ratio on the latter is to be 1. As is apparent from this table, there is no difference in root biomass between the right and the left parts in all conditions such as species, stand age, root classification, soil horizon, etc.

Table 44 shows the data of the stand S 13 in the detailed table which had the most examples measured. According to the table, the fine and the small roots distributing evenly to soil horizon I had almost the ratio of about 1. There was no significant difference in root density between them. And yet, some roots did have a big difference in ratio in the lower soil horizon. However, there was no significant difference in root density between both sides on the slope because they all had an extremely large variance.

III Root surface area of the root system

The surface area of the root system does not always represent the absorptive structure because each root has its own absorptive efficiency. As previously stated, however, it is certainly a tentative index indicating the absorptive structure. The distribution of the surface area of the root system is of importance in this respect.

1) Average value of surface area per tree

The average surface area of the root system per tree was obtained by multiplying the

Table 45. Average root surface area a tree of each root class (m^2)

Species	Stand	Basal area (cm^2)	f	s	m	l	L	St	Total
C. japonica	S 5	439	12.0 (58)	3.3 (16)	1.8 (9)	1.2 (6)	1.5 (7)	0.9 (4)	20.7 (100)
Ch. obtusa	H 5	427	18.9 (55)	9.6 (28)	1.8 (5)	1.6 (5)	1.8 (5)	0.5 (2)	34.2 (100)
P. densiflora	A 8	361	1.2 (13)	2.8 (31)	2.2 (24)	1.3 (14)	1.2 (13)	0.4 (5)	9.1 (100)
L. leptolepis	K 21	506	7.0 (46)	2.2 (14)	2.3 (15)	1.7 (11)	1.5 (10)	0.5 (4)	15.2 (100)

( ) : Ratio to total (%)

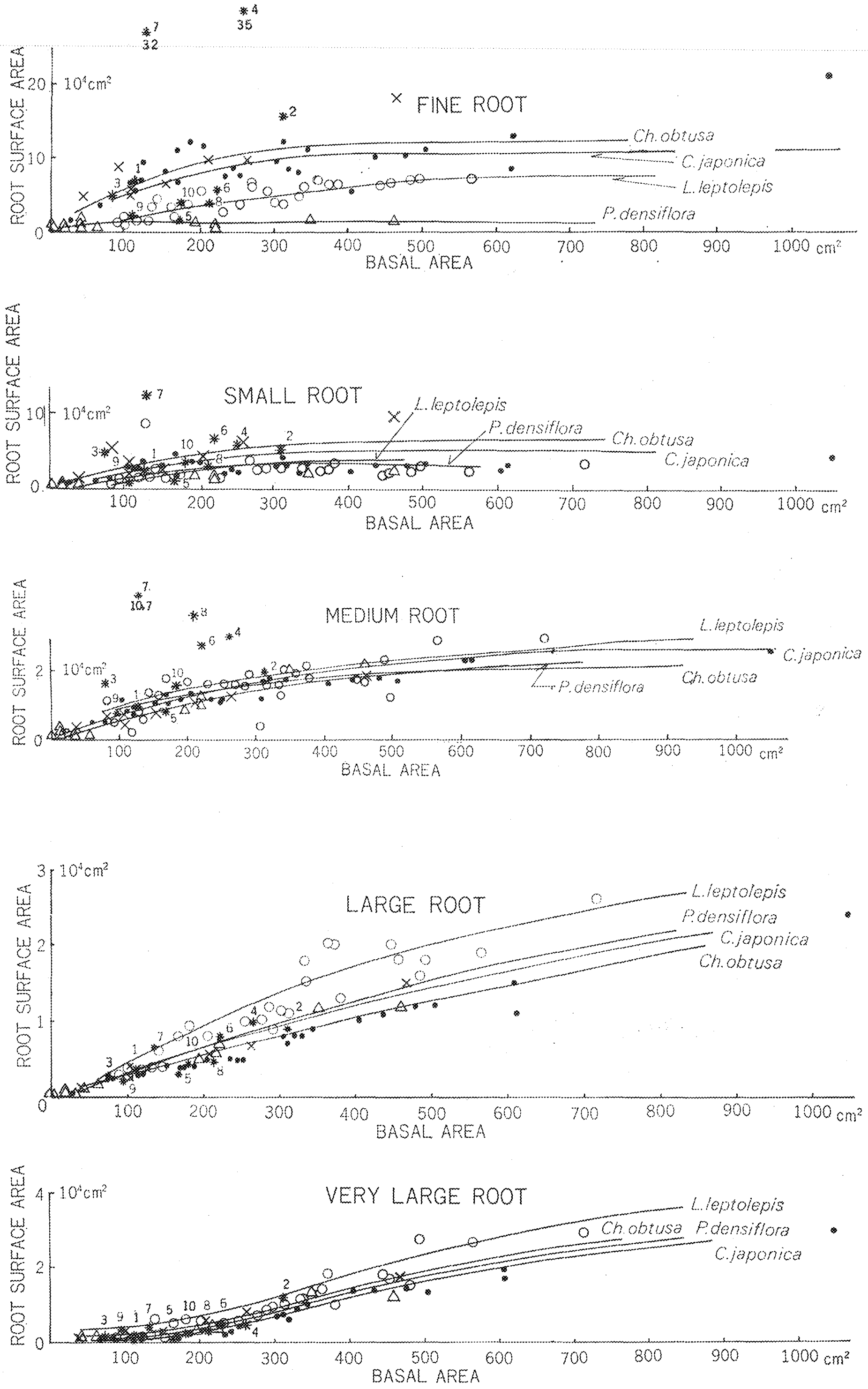


Fig. 23. Average root surface area a tree and basal area.

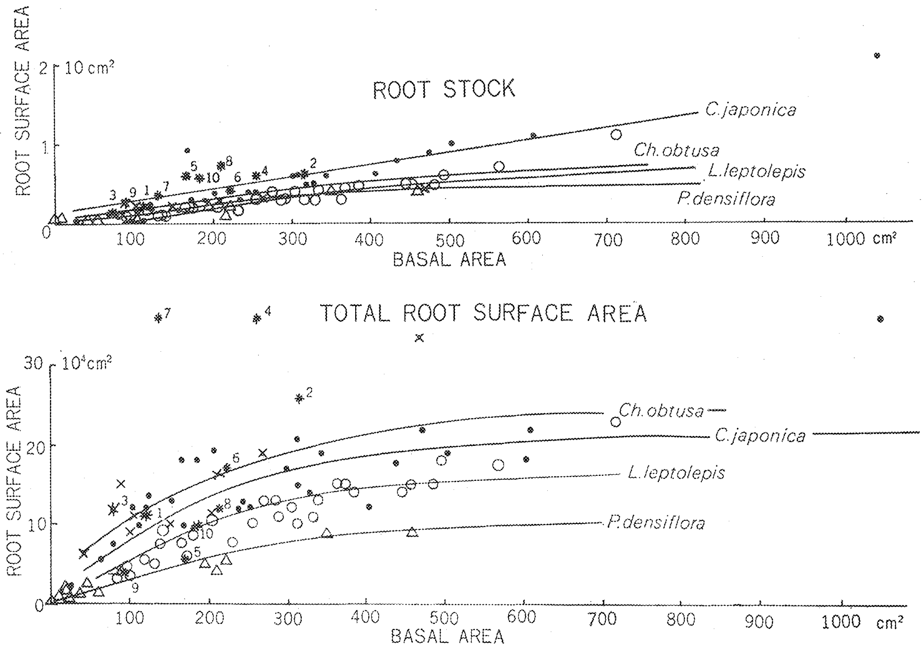


Fig. 23 (Continued)

surface area of the root system per weight by the average root biomass per tree. Results are shown in Table 45.

Each root surface area changes, as in Fig. 23, differently with increasing basal areas. Those areas of fine and small roots became constant when the basal area increased from 200 cm² to 300 cm² (at the stand age of 20 years to 25 years). Those of large root to root stocks increased describing a S-shaped curve. The upturning point of the increasing curve shifted from a narrower basal area to a brorder basal area. Hence it is that a tendency can be fixed in its movement.

A big influence is given to the surface area of all roots by those areas of fine and small roots which have a greater part of the total surface area. The increasing curve is, therefore, similar to those of the fine and small roots. It became almost constant when the basal area got to 200 cm² to 300 cm². In the second-class stand of *C. japonica*, it is equivalent, though dependent on the species and growth state, to the area at the basal area of 200 cm² to 300 cm² and at the stand age of about 20 years to 25 years. The annual growth per tree increases to the maximum of this stage. This tendency agrees roughly in the increasing tendency of the root surface area, especially of the fine and small root surface area.

The fine, small and medium roots have at their tips many young tissues excellent in absorbing. They have a high correlation with tree growth. When the absorptive efficiency of each part is considered to be constant, it can be supposed that trees are caused to grow rapidly to a certain basal area by the increasing absorption of water and nutriment with the increase of the root surface area. Although trees continue to grow further, the increase of the fine root surface area slows down for the increase of the basal area; that is to say, the absorption drops down. Then, there is a possible decrease of the growing ratio by the consumption of the assimilated products for maintaining trees, as the unassimilated products put on weight.

In this way, the change of the surface area of the root system relating to absorption (especially that of the fine root) is an important factor promoting the tree growth, along with that of the biomass of the leaves as the main assimilated part.

Among the mature trees, the growth of the surface area of the fine, small and medium roots decreases, while that of the large and very large roots or the root stock increases. For their roots grow extroadinarily to support the above-ground part, and a greater part of the assimilated products flowing into the underground part is used for the growth of the large and very large roots or the root stock. And instead, it is due to their use for the branching and growth of the fine and small roots in the case of young and small diameter trees. It is also possible to presume that the root length of large trees is so remarkable for that of small trees that the branching or extending of root tips will be restricted by the energy consumption caused by the shifting of water and nutriment. Observations at the investigated time made clear that the small diameter trees had considerably many fine roots, and that the large diameter trees had fine and small roots very sparsely.

The surface area of the root system differs according to species or to site conditions, even when the diameter at breast height is the same.

(1) Species

The general tendency in the change of the root surface area of the various species, when plotted against the basal area, is shown in Fig. 23. Among the four kinds of the main stands extracted from these investigated stands, as is evident from Table 45, *Ch. obtusa* showed the broadest fine root surface area of 18.9 m^2, then *C. japonica*, *L. leptolepis*, and *P. densiflora* the narrowest one of 1.2 m^2.

Those areas of the small root were in the same order. Those of the medium root, however, became narrower in the order of *L. leptolepis*, *P. densiflora*, *C. japonica*, and *Ch. obtusa*. Those of the large root became narrower in the order of *L. leptolepis*, *Ch. obtusa*, *P. densiflora*, and *C. japonica*. Those of the very large roots became narrower in the order of *Ch. obtusa*, *C. japonica* or *L. leptolepis*, and *P. densiflora*. These orders change greatly corresponding to the different patterns of branching and growth of each species.

The difference in the root surface area between species was large for the fine root. It became smaller as the root system put on weight.

The surface area per unit weight multiplied by the root weight is the root surface area per tree. When the two values are large, the root surface areas per tree are broader. There is, however, the bigger difference between them in general. The order in size of the root surface area was determined by the difference in root biomass. *Ch. obtusa* had, for example, example, the narrower root surface area per unit weight if compared with any other species. The species, however, had a broader area per tree because that area is affected by the root biomass, thanks to the large amount of the fine roots.

The total surface area of the root system became narrower in the order of *Ch. obtusa* (34 m^2), *C. japonica* (21 m^2), *L. leptolepis* (15 m^2), and *P. densiflora* (9 m^2). It is dependent upon the biomass of their fine and small roots, the surface area of which occupies the greater part of the root surface area.

Table 46 shows the total surface area of the root system of the trees whose basal areas are almost the same. Of the investigated trees, *Acacia decurrens* had the broadest surface area per tree of 64 m^2, as shown in Table 46, although the species had a narrower basal area of 135 cm^2 than *C. japonica* and *Ch. obtusa*. *Zelkova serrata* showed the second broadest root surface

Table 46. Average root surface area a tree of sach species (m^2)

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*Chamaecyparis pisifera*	*Eucalyptus globulus*	*Zelkova serrata*
Stand	S 10	H3	A3	K29	M2	M3	M4
Basal area (cm^2)	208	254	198	200	238	177	188
Soil Type	B*l*D(d)	BD	B*l*D(d)	B*l*B	B*l*D	Im	B*l*D
Root surface area(m^2)	19.3	16.7	5.1	11.5	26.0	12.0	46.5
Species	*Abies firma*	*Tsuga canadensis*	*Acacia decurens* v. *dealbata*	*Quercus mongolica* v. *grosseserrata*	*Betula platyphylla* v. *japonica*	*Betula davurica*	
Stand	M5	M6	M7	M8	M9	M10	
Basal area (cm^2)	156	211	135	214	96	185	
Soil Type	B*l*D	B*l*D	Er	B*l*D	B*l*D	B*l*D	
Root surface area(m^2)	5.2	17.0	63.9	12.6	4.2	9.9	

area of 47 m^2, all of which had a large amount of fine and small roots. *Zelkova serrata* had, above all, a considerably broad area for the small amount of fine roots because the thinness of the roots increased the surface area per unit weight.

The root surface areas of *P. densiflora*, *Abies firma* and *Betula platyphylla* ranged from 4 m^2 to 5 m^2. They were 1/3 to 1/4 of those of *C. japonica* and *Ch. obtusa*, and less than 1/10 of those of *Zelkova serrata* and *Acacia decurrens*. Those of *L. leptolepis*, *Eucalyptus globulus*, *Quercus mongolica*, and *Betula davurica* ranged from 10 m^2 to 13 m^2.

As already described, there is a great difference in root surface area between species; however, there is little difference in growth of the above-ground parts. It can be estimated, therefore, that *P. densiflora*, *Abies firma* and *Betula platyphylla* have a high productive efficiency per root surface area.

(2) Root surface area of a tree in each soil horizon

Fig. 24 show the relation between the basal area and the distribution of all the surface areas of the fine roots to the root stocks of a tree in each soil horizon.

The root surface area increases with the basal area in all horizons from I to XI. However, each horizon has its own pattern. In soil horizon I, for example, the root surface area tended to keep constant when the basal areas ranged from 200 cm^2 to 300 cm^2. And as soil horizons went lower, this point of inflection moved to the right, in other words, toward the larger basal areas.

In soil horizon III, it made a parabolic increasing curve for *C. japonica* and *Ch. obtusa* and a concave one upward for *L. leptolepis*.

In soil horizon IV, this tendency became more remarkable. Of the shallow-rooted species, such as *Ch. obtusa*, *L. leptolepis*, and so on, that of the small-diameter trees decreased with great speed in an upward concave and S-shaped curve for limitation of the root growth in deep soils.

In soil horizon V, there was no distribution of the root surface area in the case of the small and shallow-rooted trees of *Ch. obtusa* or *L. leptolepis*. The S-shaped curve was described clearer.

In soil horizon V or below, only the deep-rooted species, as *P. densiflora*, distributed the root system.

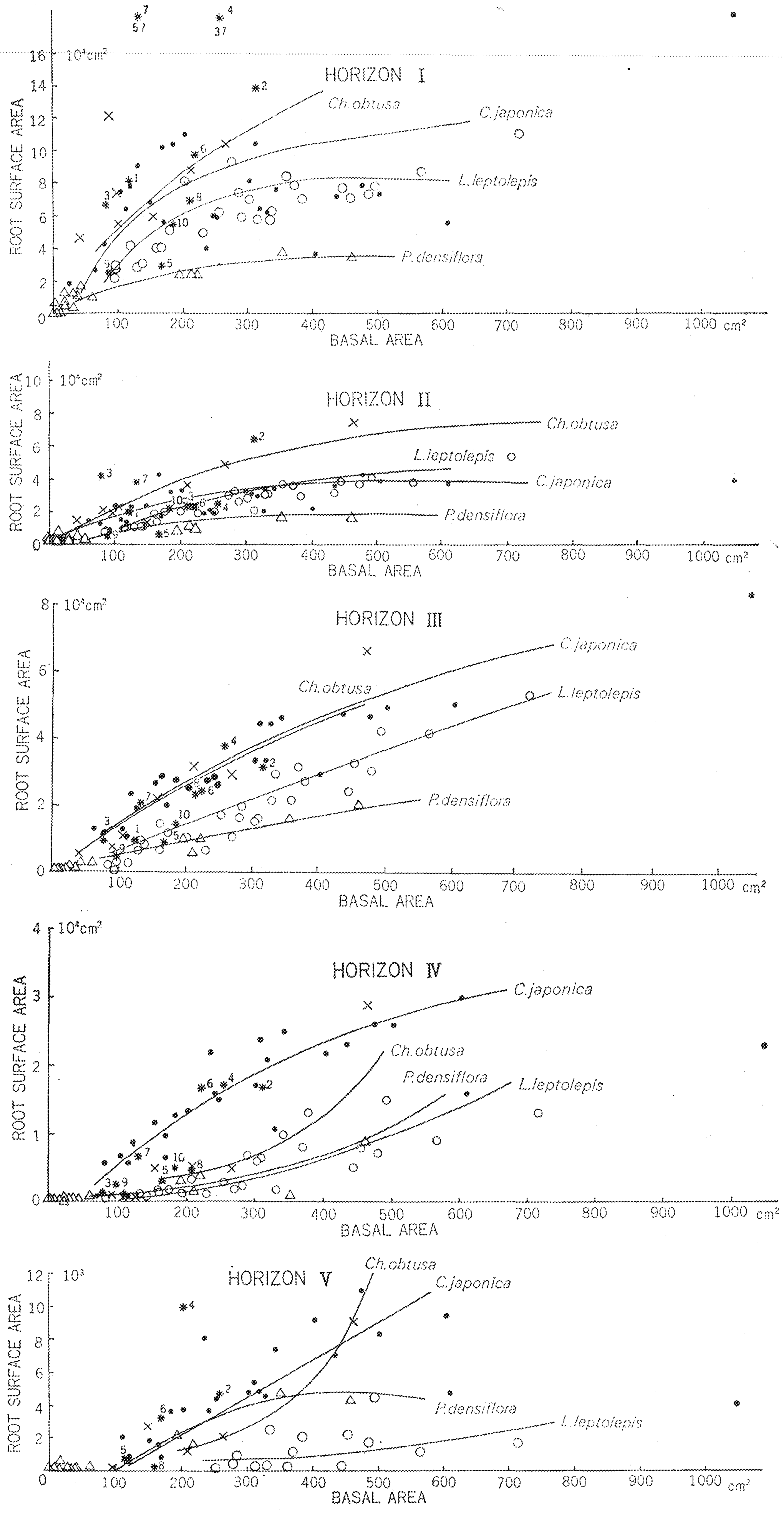


Fig. 24 Root surface area per tree in each horizon.

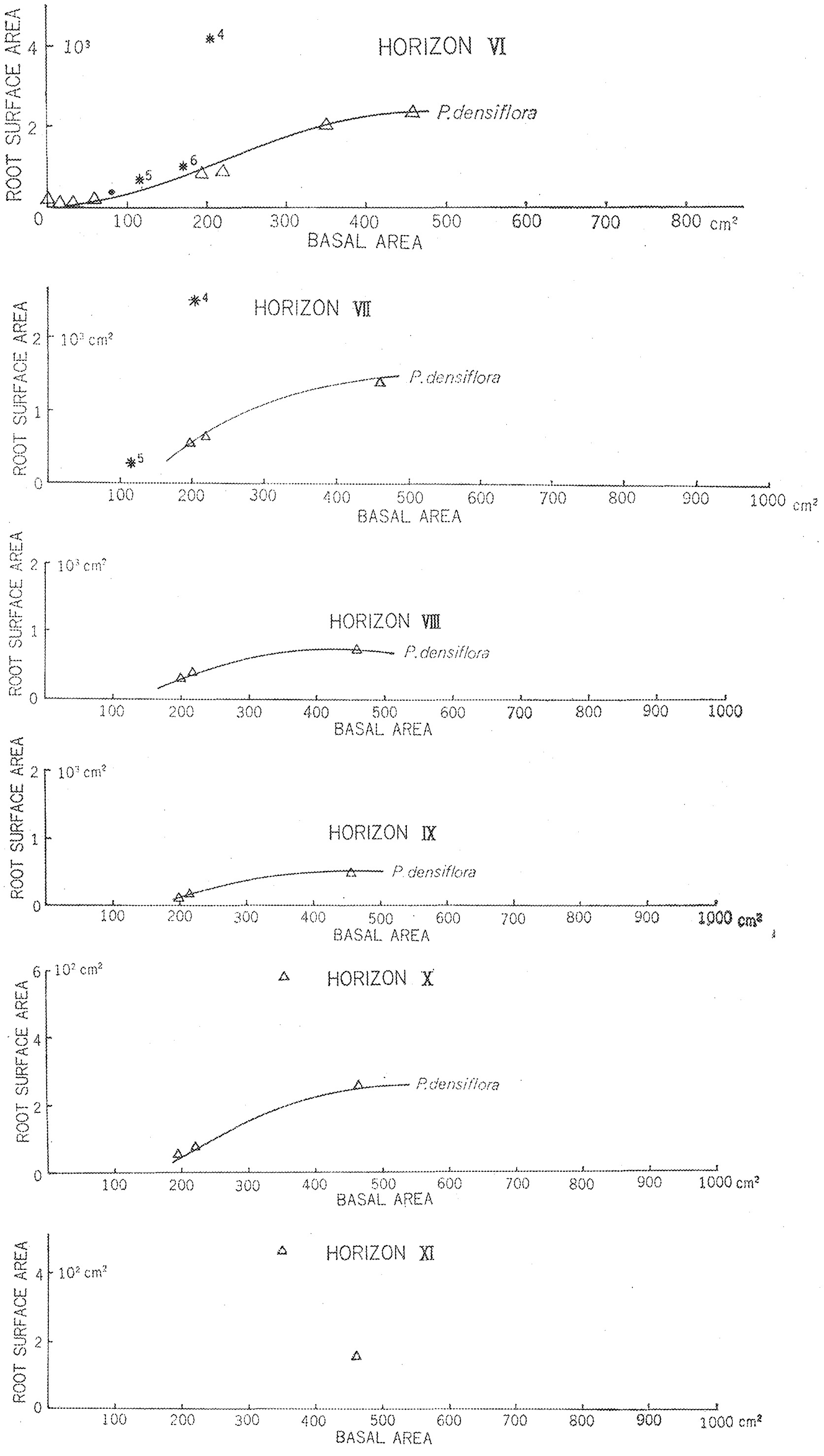


Fig. 24 (Continued)

These facts indicate that the larger trees distribute their roots to deeper soils than do the smaller trees, and in addition, that the root surface area decreases sharply in the deeper soils because of deterioration of soil conditions. A clear difference in the amount of water and nutriment absorbed there becomes apparent between the large and small trees. However, there is littie difference in the shallow horizon between the two.

They also explain that the difference in root surface area between the large and small trees is small in the surface soil with its adequate air supply and nutriment, and further, that it becomes larger in deeper soils with their insufficient aeration and poor chemical ingredients.

In the surface soil horizon, the area became constant at a comparatively earlier time, then gradually arriving at the depth with tree growth.

In soil horizons I and II, the root biomass, when plotted against the basal area, drew a somewhat concave increasing curve upward, but the surface area, as shown in Fig. 24, drew a parabolic one. There was a big difference between them for a twofold reason : first, that the root biomass depended upon the biomass of thick roots, and second, that the root surface area depended upon the biomass of fine roots. The root surface areas at the basal area of 500 cm² in soil horizon I were 14 m² eor *Ch. obtusa*, 13 m² for *C. japonica*, 8 m² for *L. leptolepis*, and 3 m² for *P. densiflora*. The fourth species' area was about one-fifth of that of *Ch. obtusa*.

In soil horizon II, they were 7 m² for *Ch. obtusa*, 4.5 m² for *L. leptolepis*, 4 m² for *C. japonica*, and 2 m² for *P. densiflora*. In soil horizon III, they were 5.5 m² for *C. japonica*, 5.0 m² for *Ch. obtusa*, 3.5 m² for *L. leptolepis*, and 2.0 m² for *P. densiflora*. In the lower horizons IV and V or below, those of *L. leptolepis* and *Ch. obtusa* decreased. The difference became clearer between the shallow-rooted and deep-roots trees.

In soil horizon V, the surface area of the deep-rooted *C. japonica* was 1 m², and that of the shallow-rooted *L. leptolepis* ranged from 0.1 m² to 0.2 m². There was a great difference between them, which became bigger in deeper soils.

There are two reasons why the surface area becomes constant in soil horizon I at an early stage, and the rate of increase in deeper soils becomes high. First, root systems are maldistributed to that horizon regardless of diameter class. Second, the root biomass of large trees is large in the deeper soils.

(3) Distribution ratio of the root surface areas to each soil horizon

Fig. 25 show the ratios of the root surface area by distribution in each horizon to the total surface area. In soil horizon I, the ratio of small roots by distribution is high in every species. It decreases as the tree grows, then increases again though slightly in a large tree. The relation is shown in Table 47. According to the table, the ratios by distribution go on decreasing until the basal area gets to about 500 cm². After that time, they increase again

Table 47. Ratio of the root surface area in horizon I to the total root surface area and basal area (%)

Basal area(cm²) / Species	100	300	500	700	900
C. japonica	65	40	35	37	40
Ch. obtusa	60	50	50	53	58
P. densiflora	56	41	37	37	38
L. leptolepis	70	52	49	49	53

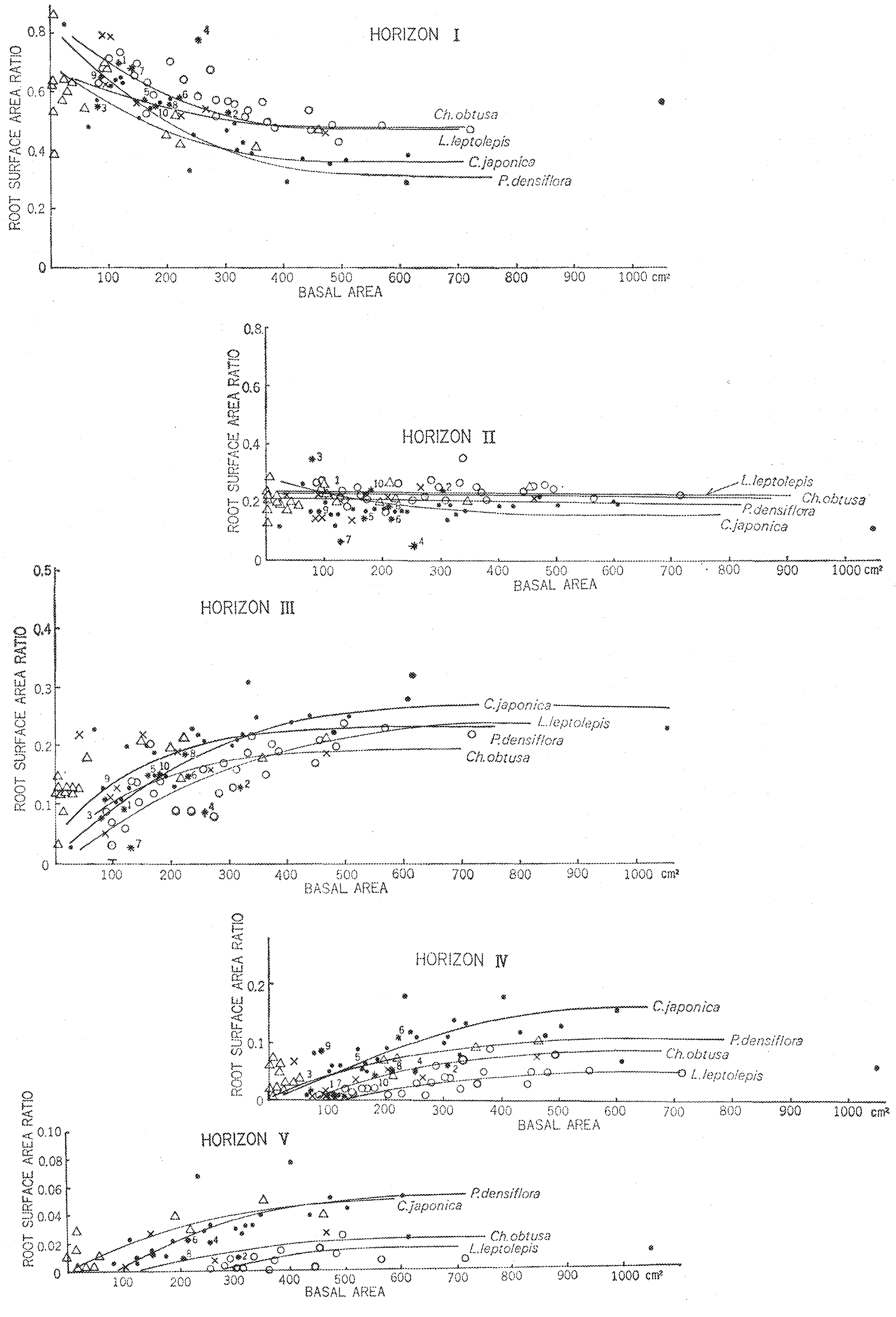
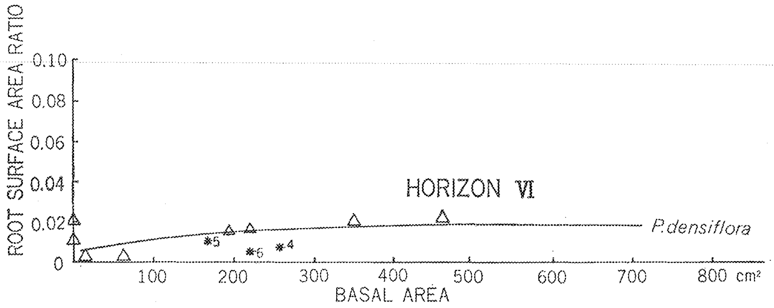
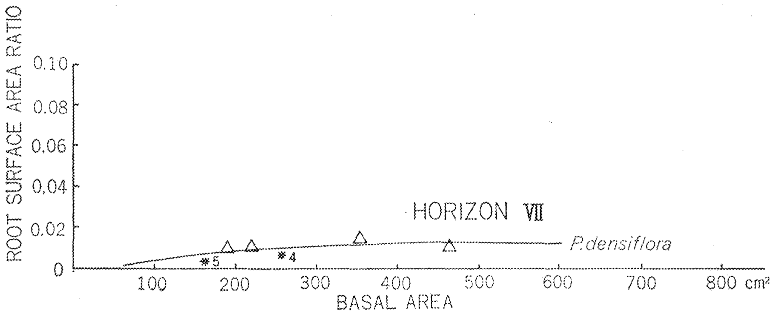
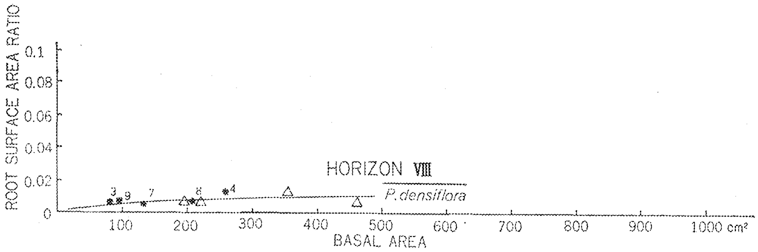
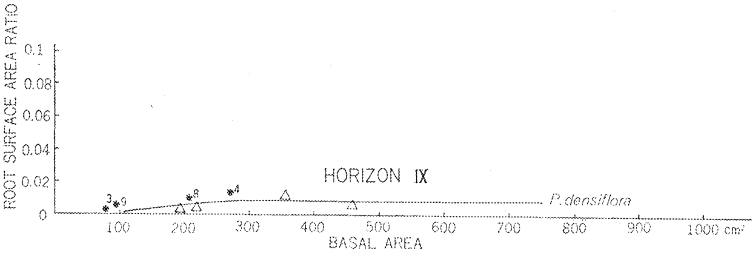


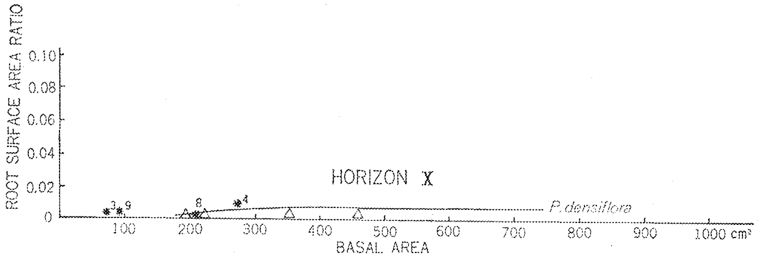
Fig. 25　Ratio of the root surface area



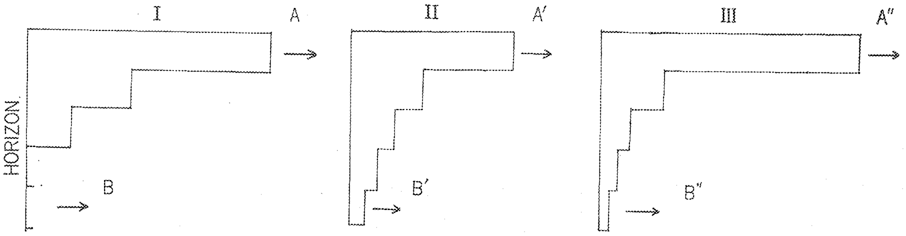








in each horizon to the total.



The signs A, A' and A'' indicate root growth in the surface soil horizon. On the other hand, the signs B, B' and B'' indicate root growth in the lower soil horizons.
I : Small tree, II : Medium tree, III : Large tree

Fig. 26 Difference in root surface area ratio at the stages of selective growth by root systems.

at the basal area of 900 cm^2. This was remarkable for *C. japonica*, but not for *P. densiflora*. There are various reasons. At the young stage, roots are distributed only to the shallow upper soil; then distribution increases gradually in the deeper soils with the growth of a tree. They reach nearly the deepest parts at the basal area of about 500 cm^2. And thereafter, the growth rate of the root system picks up speed with the growth of the tree in the surface soil, but slows down in the deeper soil. In brief, there is a greater difference in growth rate between them.

The relation is shown in Fig. 26. Each sign is set up here as follows: A is the growth rate of small-diameter trees in the surface soil horizon. A' is that of medium-diameter trees. A'' is that of large-diameter trees. B is the growth rate of small-diameter trees in the lower horizons. B' is that of medium-diameter trees. B'' is that of large-diameter trees. The roots of a small-sized tree grow vigorously on the whole. The growth rates of A and B run together at a given speed to the upper soil horizon and to the under soil horizon. When a tree becomes above medium sized, the growth slows down on the whole. And at the same time, the difference of $(A'-B')$ becomes smaller in the surface horizon than at the young stage. In other words, the difference of $(A-B)$ is greater than that of $(A'-B')$. In the case of a large diameter tree, this difference of $(A''-B'')$ becomes greater again. It has two reasons. First, in soil horizon I, the growth, which once slows down in the case of a small-diameter tree, picks up speed in the case of a large diameter tree. Second, growth slows down in the lower horizon.

Suppose that absorption of water and nutriment is made at almost the same ratio of surface areas by distribution in soil horizon I in Table 47. A small-diameter tree, the basal area of which is 100 cm^2, is expected to take in 60% to 70% of the total absorption in soil horizon I. A medium-diameter tree, having a basal area of 500 cm^2, is to take in 35% to 50% of that there. It is therefore quite presumable that soil horizon I plays an important role, and that absorption is markedly influenced by the soil properties.

Thus, the growth of a tree is easily influenced by soil properties, because of such an absorption structure.

In soil horizon I, the root surface area of a young tree became narrower in the order of *L. leptolepis*, *C. japonica*, *Ch. obtusa*, and *P. densiflora*. In the same horizon, that of a large-diameter tree became narrower in the order of *Ch. obtusa*, *L. leptolepis*, *C. japonica*, and *P. densiflora*. At a young stage, *C. japonica*, deep-rooted, had the higher ratio by distribution in the surface horizon than *Ch. obtusa.* Being a large diameter tree, the species made clear the special features related to root distribution. That ratio of shallow-rooted *Ch. obtusa* or *L. leptolepis* was high in the surface horizon. That of *C. japonica* or *P. densiflora* was low. So it is not reasonable to judge the characteristics, deep rootedness or flat rootedness, of root distribution from the root distribution of a sapling.

The differences between the ratios of root surface area by distribution were 14% for a small diameter tree, 100 cm² in basal area, and 20% for a large diameter tree, 900 cm² in basal area. This verifies that the older a tree becomes, the larger that difference. It also indicates that the distribution characteristics are similar regardless of species at the young stage, but that the difference in feature becomes clear for large trees.

In soil horizon II, that ratio to the basal area drew a slightly decreasing curve in the case of *C. japonica,* as shown in Fig. 25. It decreased in an almost straight line in the case of the other species. Their rate of decrease was low. There was almost no difference by tree size between those ratios.

At the basal area of 500 cm², the ratios by root surface area were 22% for *Ch. obtusa* or *L. leptolepis,* 20% for *P. densiflora,* and 17% for *C. japonica.* There was, as shown in Fig. 25, no great difference between species.

In soil horizon III, a basal area-ratio by root surface area curve produced a parabolic increasing curve regardless of species, as shown in Fig. 25. It was the opposite with a decreasing curve in soil horizon I.

This is, as already mentioned, because the difference in root distribution between a small-diameter tree and a large-diameter tree is larger in the deeper soils. In short, the distribution of a small diameter tree is very narrow in a deep soil, and that of a large diameter tree is broad there.

The differences in trend between the changing curves are mainly due to the change in soil properties. This indicates that the growth condition of the root system changes rapidly at the depth of 30 cm and so does the distribution of the root system. Briefly stated, the selective distribution by root takes place at this horizon; the root growth is quite different up and below the depth of 30 cm.

In soil horizon III, the ratios by root surface area at the basal area of 500 cm² were 27% for *C. japonica,* 25% for *P. densiflora,* 22% for *L. leptolepis,* and 19% for *Ch. obtusa.* Those of *C. japonica* and *L. leptolepis,* deep-rooted, were higher than those of *L. leptolepis* and *Ch. obtusa,* shallow-rooted.

In soil horizons IV and below, the ratio by root surface area showed a tendency to go higher with the tree growth as in soil horizon III. In soil horizons V and below, there could be seen no root distribution of the shallow-rooted species, *Ch. obtusa* or *L. leptolepis.* To soil horizons VI and below, only the root system of *P. densiflora* could be seen to distribute.

These relations on the stands with different diameter classes are shown in Table 48. According to the table, in soil horizon I, the ratios of *C. japonica* by root surface area decreased gradually to 83% in the young S 11 stand, 55% in the S 13 stand (at the basal area of 196 cm²), and 30% in the S 18 stand (at the basal area of 554 cm²). That ratio, however, increased to 55% in the S 17 stand at the basal area of 1,042 cm². As a result, it proved that the soil-selective growth was caused by roots.

In soil horizons I and II, 30 cm deep from the surface horizon, there were distributed 50% to 90% of the total root surface area for *C. japonica,* 69% to 93% of that for *Ch. obtusa,* 57%

Table 48. Ratio of the root surface area in each horizon to the total root surface area of each species (%)

Species		*C. japonica*						*Ch. obtusa*				
Stand		S 11	S 13	S 17	S 18	S 19	S 26	H 1	H 2	H 3	H 4	H 5
Basal area (cm)		19	196	1,042	554	345	425	42	104	254	274	425
Horizon	I	83.4	54.8	55.4	30.0	40.3	38.4	70.3	62.8	53.1	54.6	47.0
	II	12.9	17.8	11.3	20.3	19.9	19.7	22.2	22.5	21.6	25.9	21.8
	III	3.7	19.6	23.2	28.1	22.4	25.8	7.5	13.9	19.3	15.7	19.9
	IV		6.8	6.3	16.4	14.2	12.5		0.8	5.2	2.7	8.6
	V		1.0	2.7	5.2	3.2	3.8			0.8	1.1	2.7
	VI			1.1								
	I + II	96.3	72.6	66.7	50.3	60.2	58.1	92.5	85.3	74.7	80.5	68.8

Species		*P. densiflora*					*L. leptolepis*					
Stand		A 1	A 2	A 3	A 4	A 8	K 6	K 10	K 11	K 13	K 20	K 28
Basal area (cm)		24	63	198	311	361	92	163	310	367	599	645
Horizon	I	60.7	54.8	45.5	41.1	37.7	70.5	62.0	51.8	48.8	48.6	47.9
	II	20.9	19.8	20.2	20.1	19.2	26.1	23.6	23.6	20.7	21.6	22.7
	III	13.5	18.7	19.6	18.4	21.7	3.4	12.4	17.6	19.6	23.8	22.9
	IV	3.6	4.7	7.1	7.3	10.8		02.0	6.2	9.4	5.3	5.8
	V	1.1	1.5	4.0	5.2	4.7			0.8	1.5	0.7	0.7
	VI	0.2	0.5	1.7	2.4	2.5						
	VII			1.0	2.0	1.5						
	VIII			0.6	1.3	0.8						
	IX			0.2	1.1	0.6						
	X			0.1	0.6	0.3						
	XI				0.5	0.2						
	I + II	81.6	74.6	65.7	61.2	56.9	96.6	85.6	75.4	69.4	70.2	70.6

Table 49. Ratio of the root surface area in horizons I and II to the total root surface area

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Stand	S 26	H 5	A 8	K 13
Basal area (cm^2)	425	425	361	367
Root surface ratio(%)	58	69	57	69

to 82% for *P. densiflora*, and 69% to 97% for *L. leptolepis*. In a medium-sized stand at the basal area of about 500 cm^2, the flat-rooted species, such as *Ch. obtusa* and *L. leptolepis*, had 69% of the total root surface area and *P. densiflora* and *C. japonica* had, as in Table 49, 57% to 58% of that in soil horizons I and II, that is, a difference of about 10% between them.

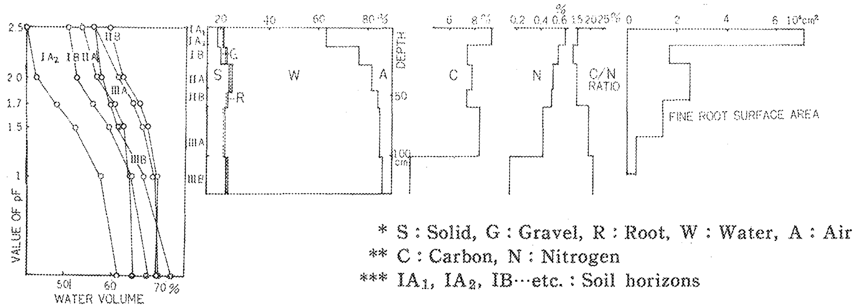
It became evident from these ratios of the root surface area by vertical distribution that first a grown-up tree took in 60% to 70% of the total absorption of water or nutriment from soil horizons I and II, and second, that it absorbed 30% to 40% of the rest from soil horizons III and below, and finally that it absorbed almost nothing in deep soils.

These characteristics of the absorptive structure related to the absorption of water and nutriment explain why the tree growth depends largely upon the properties of the surface soil.

(4) Vertical distribution of the root surface area of species

Fig. 27 shows the soil conditions and the vertical distribution of the fine root surface area on the typical stands of each species.

Although considerable differences between stands existed in water, air, carbon, N, C/N ratio,



* S : Solid, G : Gravel, R : Root, W : Water, A : Air
** C : Carbon, N : Nitrogen
*** IA_1, IA_2, IB···etc. : Soil horizons

Fig. 27-1 Vertical distribution of fine root surface area, and the physical and chemical properties of soil. (*C. japonica* stand, S 9)

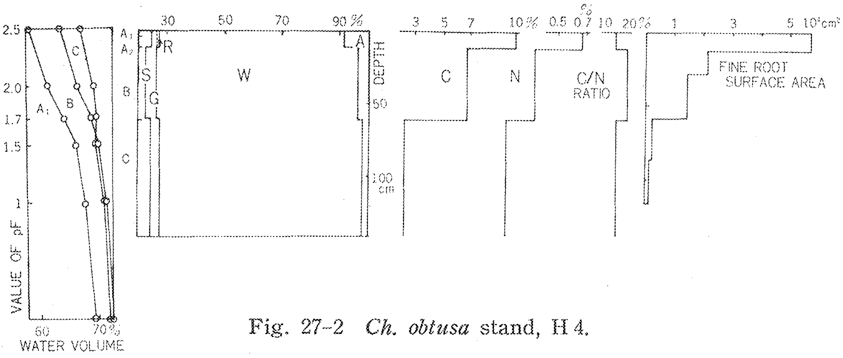


Fig. 27-2 *Ch. obtusa* stand, H 4.

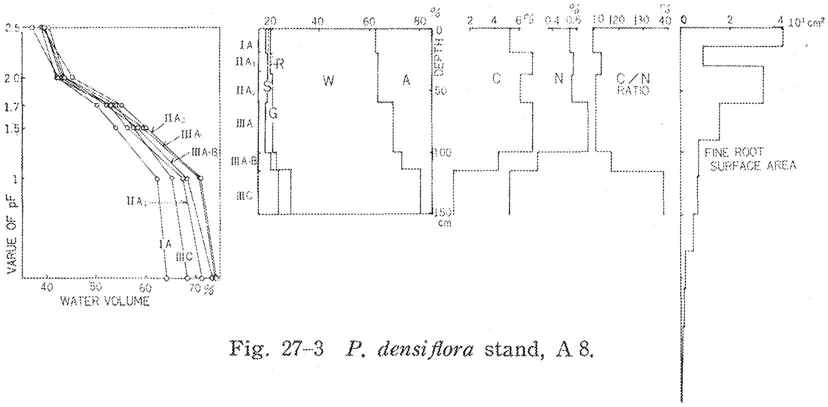


Fig. 27-3 *P. densiflora* stand, A 8.

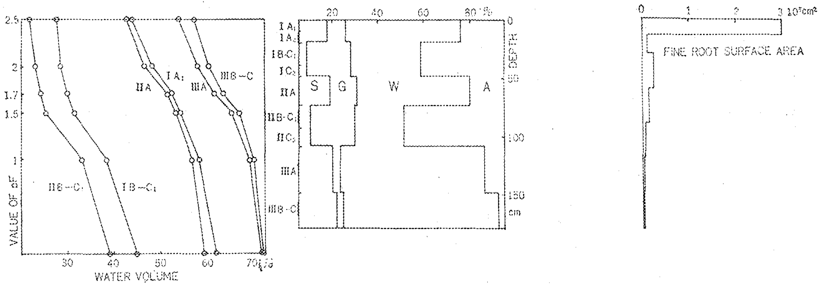


Fig. 27-4 *Zelkova serrata* stand, M 4.

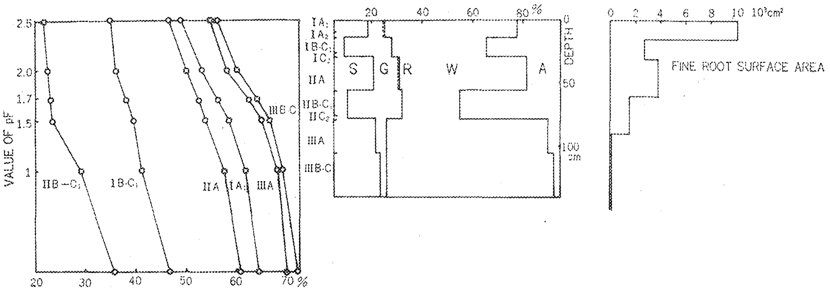


Fig. 27-5 *Abies firma* stand, M 5.

Table 50. Ratio of the fine root surface area in horizons I and II to the total root surface area

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*Zelkova serrate*	*Abies firma*
Stand	S 9	H 4	A 8	K 13	M 4	M 5
Fine root surface area per tree (m²)	21	19	9	15	46	5
Ratio of fine root surface area (%)	64	80	57	69	84	71

and pF value in field conditions, the distribution of root surface area showed the special features of each species. *L. leptolepis*, *Ch. obtusa* or *Zelkova serrata*, for example, maldistributed their root systems to the surface horizon, and yet *C. japonica* distributed the root system widely to the subsoil. To the deeper soil, *P. densiflora* also distributed its root system, reaching the depth of 3 m. To soil horizons III and IV, *Abies firma* distributed its root system more widely. The foregoing indicates the characteristics of the absorptive structures each species has[6]. And the relation is clearly recognized in Table 50 when judged from the fine root surface areas and its distribution ratio at the depth of 0~30 cm in soil horizons I and II.

(5) Tree density and absorptive structure

The changes of the absorptive structure by tree density is shown in Table 51, and as can be seen there, the ratios of the total root surface area ranged from 57% to 58% in soil horizons I and II in a sparse-planting stand, but from 49% to 51% there in a close-planting stand. In other words, the root surface area was maldistributed to the surface forizon in the former stand, but it gathered in deep horizons in the latter. The difference between them came up to 10%. The absorptive structures in a close-planting stand proved to be distributed broader by this difference in deep horizons than those in a sparse-planting stand.

Table 51. Absorptive root structures in the sparse and close planting *C. japonica* stands (Ratio by total root surface area (%))

		Sparse planting stand		Close planting stand	
Stand		S 26	S 27	S 8	S 22
Basal area (cm^2)		434	504	237	403
Tree density index		0.449	0.475	0.898	1.158
Horizon	I	38.4	37.6	33.9	29.5
	II	19.7	19.0	17.1	19.5
	III	25.8	25.6	23.5	24.7
	IV	12.3	13.5	18.7	18.7
	V	3.8	4.3	6.8	7.6

The relation of the various properties of soils to the vertical distribution of the average root surface area per tree is shown in Fig. 28. As clear from it, the same tendency with the total root surface area was recognized in the fine root surface area. The facts thus prove that the absorptive structure was larger in the lower horizons of a dense forest than of a sparse forest when the trees are of the same size.

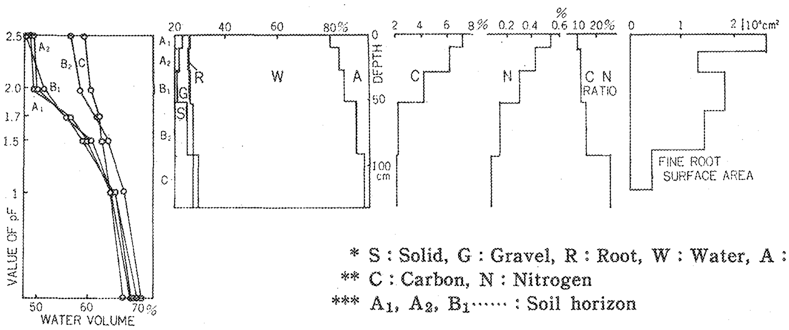
Though further deliberation is needed to determine the reason, two suggestions will be given here to aid understanding. The first is competition between roots for the increase of root density by close-planting in the surface horizon. The second is escaping growth by roots as seen in Photographs 2 of the second issue18); such roots go on spreading torard the soils with lower root density. These facts lead to the following threefold ideas; first, close-planting causes root density to increase in the surface soil; second, root interference restricts the root growth there; and finally, contrary to the second, it promotes that growth in deep soil.

When the trees are of the same size, the ones in a dense stand absorb more water or nutriment from deeper soils than the ones in a sparse stand. It is, therefore, quite possible that the fertile deeper soils with the soft and moist subsoil can be used efficiently by close planting.

As already mentioned in the chapter dealing with the root biomass distribution of a *C. japonica* immature stand in Asakawa nursery, a tree of a dense stand is smaller than that of

Table 52. Tree density and ratio by root surface area (%)

		Sparse planting stand			Close planting stand		
Stand		K 22	K 24	K 27	K 23	K 25	K 26
Stand age (yrs)		45	52	50	52	52	52
Tree density index		0.660	0.538	0.456	1.025	0.895	1.272
Basal area (m^2)		459	410	363	141	273	164
Horizon	I	46.2	56.0	49.9	65.7	57.3	69.2
	II	25.1	25.1	23.5	20.5	26.2	18.9
	III	21.6	15.1	20.3	13.8	12.8	10.5
	IV	5.6	3.7	5.5	—	3.4	1.4
	V	1.5	0.1	0.8	—	0.3	—



* S : Solid, G : Gravel, R : Root, W : Water, A : Air
** C : Carbon, N : Nitrogen
*** A_1, A_2, B_1…… : Soil horizon

Fig. 28-1 Physical and chemical properties of soil and the fine root in the close planting *C. japonica* stand, S 8. (Tree density index : 0.9.)

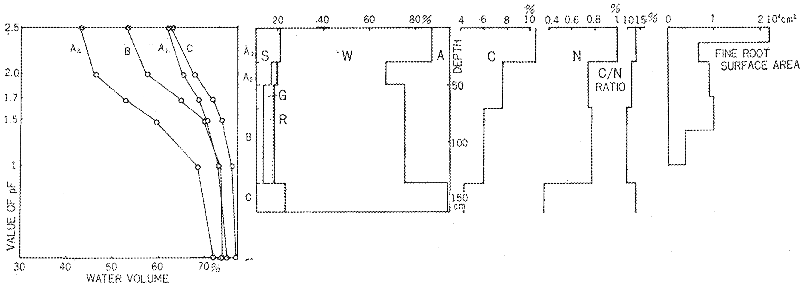


Fig. 28-2 Close planting *C. japonica* stand, S 22. (Density index : 1.2.)

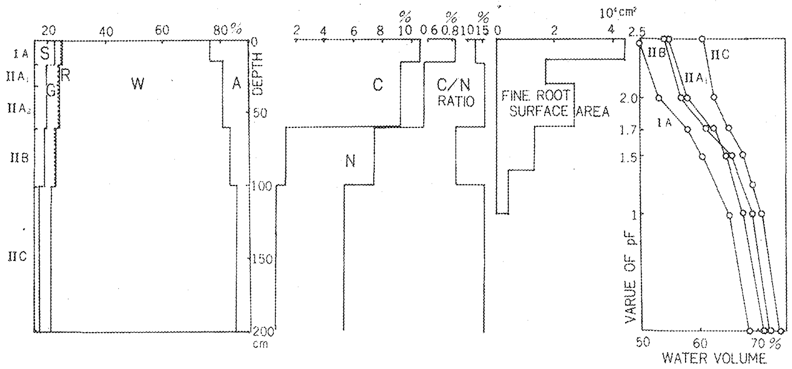


Fig. 28-3 Close planting *C. japonica* stand, S 26. (Density index : 1.3.)

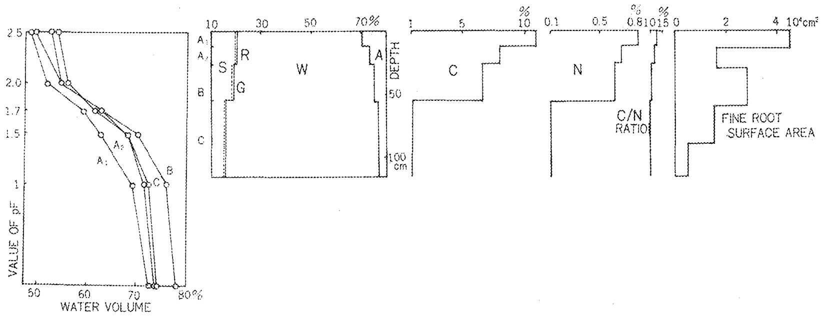


Fig. 28-4 Moderately dense planting *C. japonica* stand, S 27. (Density index : 0.5.)

a sparse stand of the same age, because of the competitive density effect. For this reason, the root systems of a dense stand are distributed more to the surface soil. The absorptive structure, therefore, is also maldistributed to the surface. This relation on both the dense stands, K 26, K 23 and K 25, and the sparse-planting stands, K 24, K 22 and K 27, is shown in Table 52. Within the ranges of the basal areas from 363 cm^2 to 459 cm^2, the sparse-planting stands with the tree densities of 0.5 to 0.7 and with large trees had the ratios of the root surface areas by distribution of 71% to 81% in soil horizon I and II. The close-planting stands with the tree densities of 0.9 to 1.3, such as K 26, K 25 and K 23, had those of 84% to 88% at the basal areas of 141 cm^2 to 273 cm^2 in the same horizons. So there was a difference of 7% to 13% between them. In the sparse-planting stands, the root surface areas equivalent to this difference were distributed to soil horizon III and downward.

To be specific, take the 18-year-old *P. densiflora* forest for density experiment in the B$_A$ soil typed site, and the result in Table 53. According to this table, the trees go on growing with decreasing tree density as the tree densities of 1.24, 0.88 and 0.62 slow down corresponding to the basal areas of 18 cm^2, 32 cm^2 and 49 cm^2 respectively in a highly dense stand. The vertical distributions of the root surface area in soil horizon I, as shown there, are 66% in the dense A 10 stand, 63% in the moderate A 11 stand, and 64% in the sparse A 2 stand. The difference between A 11 and A 12 is only 1%, but 2% or 3% between A 11 and A 10.

The surface area ratios were 88% in the A 10 stand, 82% in the A 11 stand, and 84% in the A 12 stand in soil horizon I and II 30 cm deep from the surface horizon. In a close planting stand, the individual biomass became smaller, and besides, the absorptive structure had a tendency to concentrate in the surface soil. The relationship is shown in Fig. 29, the soil properties involved. The same tendency was recognized on the fine root surface area.

Thus, an individual growth is checked by competitive density effect in a close-planting stand at a short rotation period. The absorptive structures, therefore, are expected to gather in the surface soil. And also water and nutriment are absorbed excessively from the surface soil, causing competition among the roots for water and nutriment, and a subsequent shortage of them, along with it. This is why the repetition of close planting by small trees at a short maturity term causes the deterioration of the physical and chemical properties of the surface soil and the productive power of forests.

Table 53. Tree density and absorptive structure of *P. densiflors* (Ratio by root surface area (%)

		Close planting stand	Medium planting stand	Sparse planting stand
Stand		A 10	A 11	A 12
Basal area (cm^2)		18	32	49
Tree density index		1.243	0.884	0.618
Horizon	I	66.3	63.0	64.1
	II	21.8	19.3	20.1
	III	9.9	13.5	12.5
	IV	2.0	3.6	2.7
	V	—	0.6	0.6

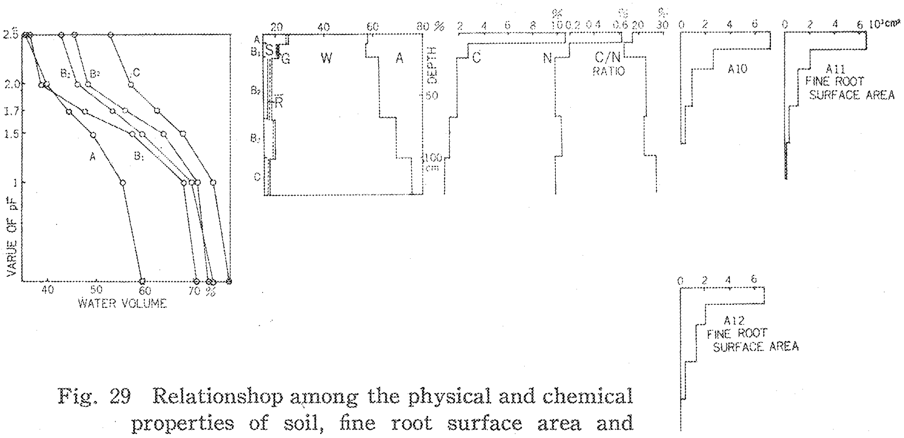


Fig. 29 Relationshop among the physical and chemical properties of soil, fine root surface area and tree density in the *P. densiflora* stands, A 10, A 11 and A 12.

Table 54. Soil types and distribution ratio by fine root surface area to each horizon of the *C. japonica* stand (%)

Stand		S 18	S 5	S 4	S 19	S 6	S 7	S 24
Soil type		BE	B*l*W	B*l*D	BD	B*l*A	B*l*c	BA
Site index		23.4	19.3	19.4	20.6	11.3	13.6	11.0
Value of pF in the field condition		2.2	2.0	2.2	2.1	2.5	3.0	2.8
Horizon	I	30.0	38.0	39.8	40.3	64.3	56.9	63.1
	II	20.3	21.1	17.9	19.9	16.2	18.1	16.7
	III	28.1	22.9	25.1	22.4	11.2	15.4	13.3
	IV	16.4	12.6	13.3	14.2	6.1	7.6	6.4
	V	5.2	5.4	3.9	3.2	2.2	2.0	0.5

(6) Soil types and ratios of root surface areas by vertical distribution

The relation between the soil types and the vertical distribution ratios of the total root surface areas extracted from the detailed table on *C. japonica* is shown in Table 54. According to the table, the ratios by distribution in soil horizon I are 30% to 38% in the BE and B*l*(w) typed soils, and 57% to 64% in the B*l*A, B*l*c and BA typed soils. In the dry soil, they are remarkably high in soil horizon I, but low in soil horizon II or below.

It is therefore expected that the root systems develop into the deeper parts in the BE, B*l*D(w), B*l*D or BD colluvial soils with the soft and moist subsoil, absorbing much water and nutriment. And it is also thought that in the dry residual soil, roots are restricted from growing in the subsoil, distributed conspicuously to the thin surface soil, and then, absorbing most of the water and nutriment from that soil.

In the moderately moist colluvial site, the growth is not so much influenced by changes of one or two of the soil conditions, and the absorption efficiency is good because each deep horizon supports the tree growth. In the dry residual soil, however, the absorption is easily affected by a temporary change of the weather, such as precipitation or aridity, being very unstable because the absorptive structure is unevely concentrated in the surface soil. The absorption efficiency, also, drops down as the surface soil is usually dried easily. These difference among absorptive structures are caused by soil conditions. Hence it is that the absorptive structures have a great influence on the growth of trees in the coming generation through changes of the physical and chemical properties of the soil. Close causality is perceived among soil conditions, changes of the absorptive structure, and the growth of trees.

Fig. 30 shows the relation between the physical and chemical properties of soil and the vertical changes of the fine root surface areas on the stands in Table 54. According to this figure, the physical and chemical properties of the deeper soils deteriorate as they become drier from BE or Bl(w) soil to the dry type BlD, BD, BlA, Blc or BA soil. The fine root surface area shows a tendency to be maldistributed to the surface area with it.

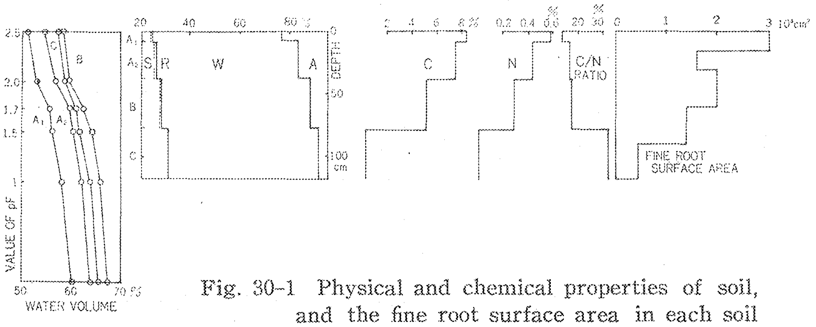


Fig. 30-1 Physical and chemical properties of soil, and the fine root surface area in each soil type. (*C. japonica* stand, S 18. Soil type BE)

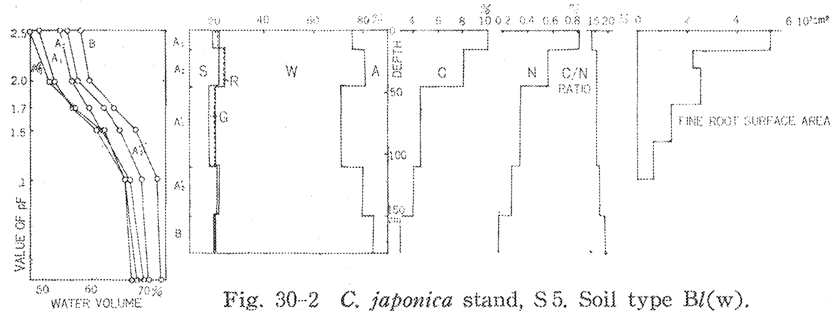


Fig. 30-2 *C. japonica* stand, S 5. Soil type Bl(w).

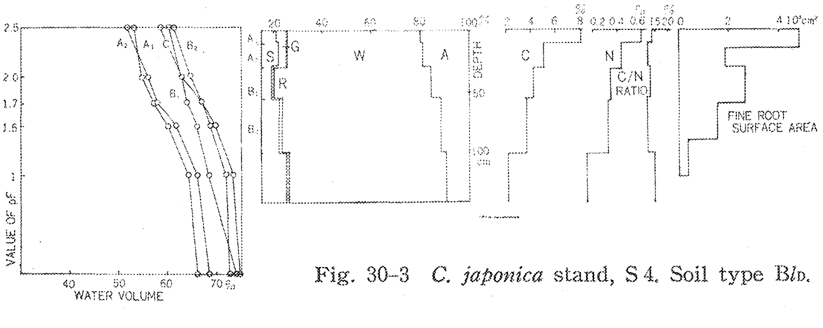


Fig. 30-3 *C. japonica* stand, S 4. Soil type BlD.

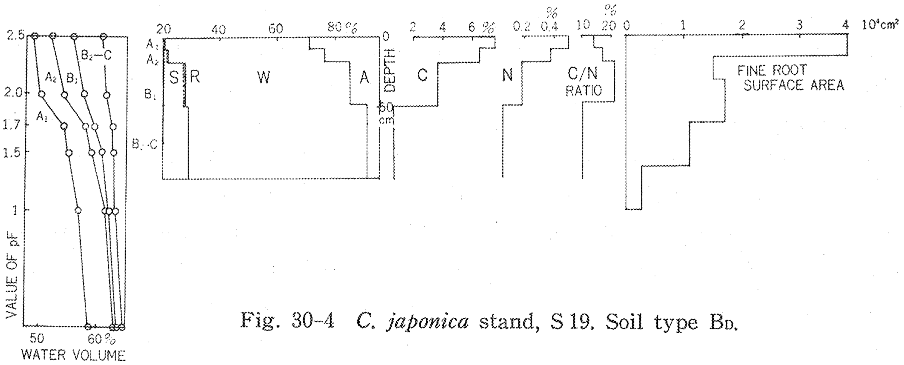


Fig. 30-4 *C. japonica* stand, S 19. Soil type Bᴅ.

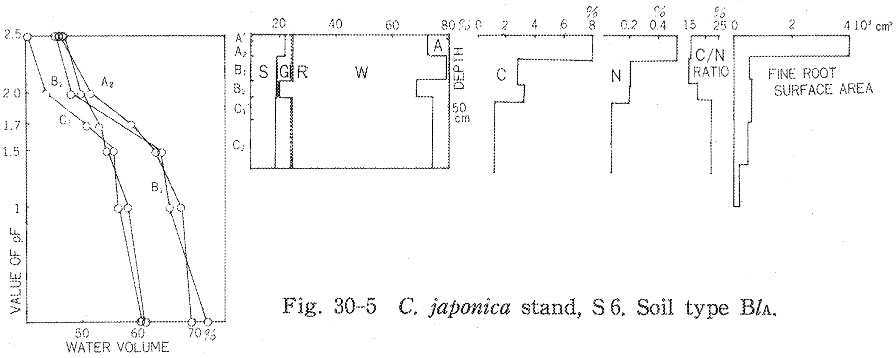


Fig. 30-5 *C. japonica* stand, S 6. Soil type B*l*ᴀ.

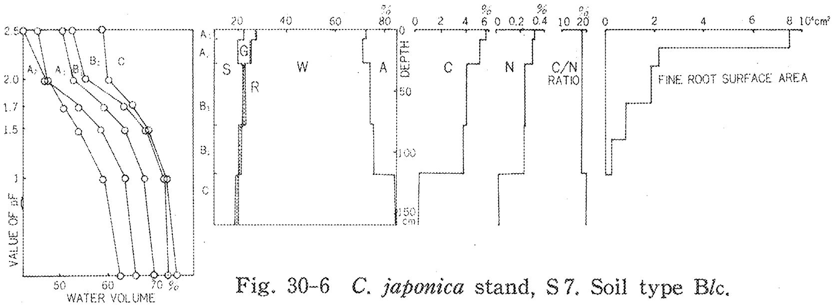


Fig. 30-6 *C. japonica* stand, S 7. Soil type B*l*ᴄ.

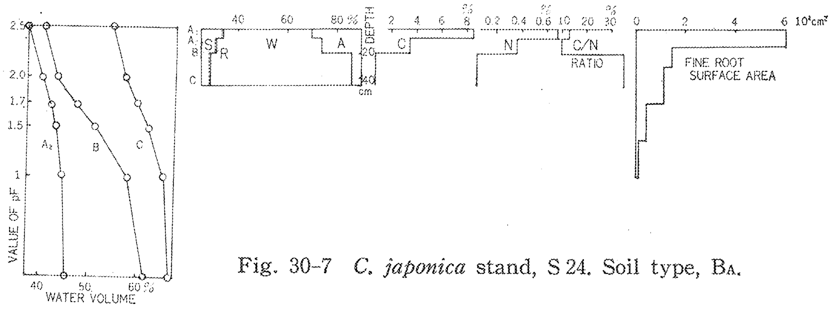


Fig. 30-7 *C. japonica* stand, S 24. Soil type, Bᴀ.

In the surface soil horizon, the absorptive structure develops more sufficiently in the residual soils than in the colluvial soils with the comparatively much pore space in the deep part.

The fine root surface area is unbalancedly maldistributed to the surface soil in a *P. densiflora* forest (A 6 stand) in the unproductive and dry soil, if compared with the A 1 stand with the B*l*D(w) type soil. That is almost the same with the distribution of the fine roots surface areas in Fig. 31. The fine root surface area ratios of the A 6 and A 1 stands are shown in Table 55.

Table 55. Difference in soil type and ratio by fine root surface area (%)

Stand		A 1	A 6
Soil type		B*l*D(d)	Er-β
Horizon	I	65.4	89.8
	II	17.8	6.4
	III	10.7	3.2
	IV	3.3	0.6
	V	2.1	—
	VI	0.7	—

The same tendency is observed in the *Ch. obtusa* stands, H 2 of the BD type and H 6 of the BB type. (See Fig. 32.)

The absorptive structure is caused to change not only by dryness but also by overhumidity. It shows, above all, a tendency to gather in the surface soil under the overhumid conditions with bad aeration as well as under dryness. This tendency was remarkable in the aerobic root ststem of *L. leptolepis*. In soil horizon I, the ratios of fine root biomass by distribution, as shown in Table 56, ranged from 71% to 77% in the dry soil of the K 16 or K 17 stand. They were higher by about 10% than those of 64% to 66% in the soils, BE to B*l*D typed. The

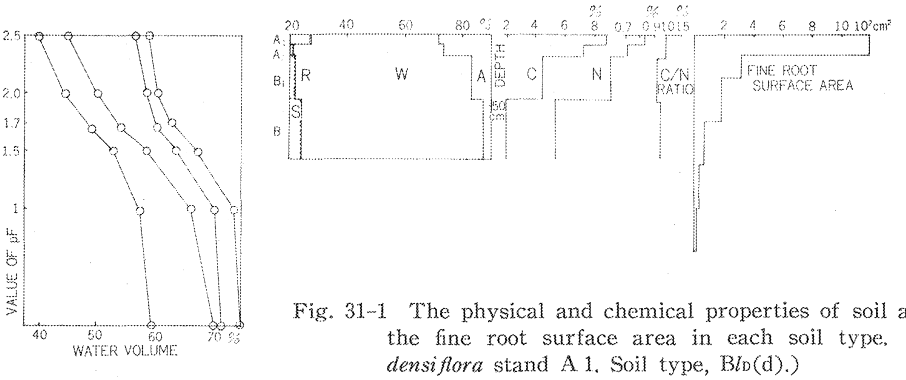


Fig. 31-1 The physical and chemical properties of soil and the fine root surface area in each soil type. (*P. densiflora* stand A 1. Soil type, B*l*D(d).)

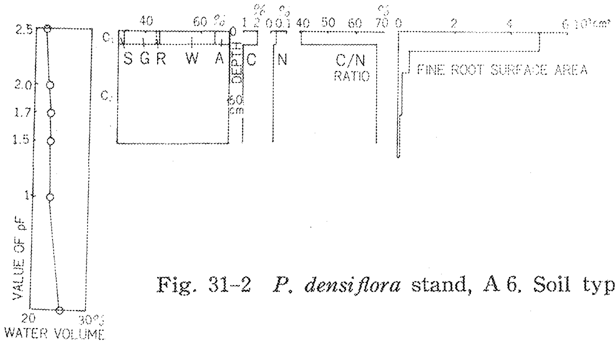


Fig. 31-2 *P. densiflora* stand, A 6. Soil type, Er-B.

Table 56. Soil properties and distribution ratio by fine root surface area to each horizon of *L. leptolepis* (%)

Stand		K16	K17	K19	K18	K20	K6	K7	K8
Soil type		Bl_D(d)	Bl_D(d)	Bl_D	B_D	B_E	Bl_{E-F}	Bl_G	Bl_D
Site index		17.4	12.7	20.7	18.4	23.6	6.8	11.0	9.8
Horizon	I	77.2	71.3	65.8	61.5	63.5	81.4	86.4	83.4
	II	17.2	14.0	21.4	23.1	17.1	16.0	11.8	15.1
	III	4.8	11.6	11.7	13.7	16.5	2.6	1.8	1.4
	IV	0.8	2.8	0.9	1.4	2.2	—	—	0.1
	V	—	0.3	0.2	0.3	0.7	—	—	—

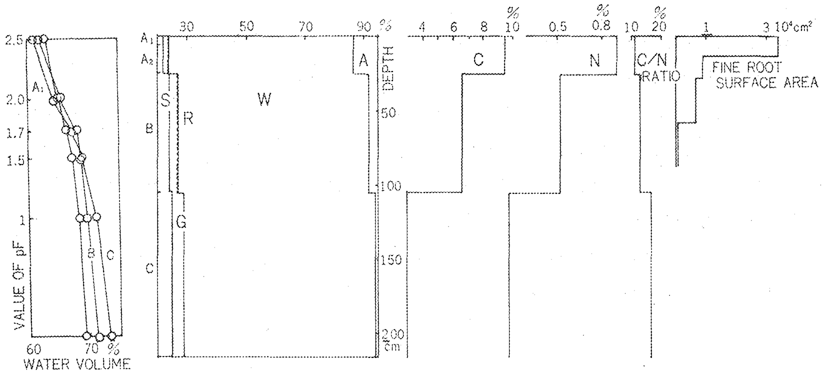


Fig. 32-1 Physical and chemical properties of soil and the fine root surface area in each soil type. (*Ch. obtusa* stand H 2. Soil type B_D.)

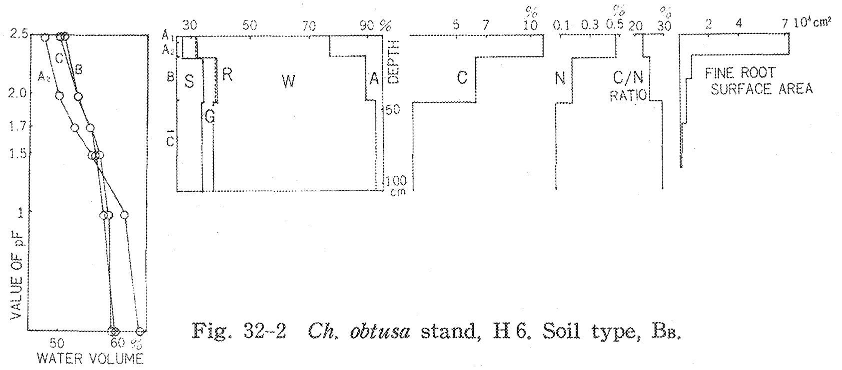


Fig. 32-2 *Ch. obtusa* stand, H 6. Soil type, B_B.

ratios of fine root surface areas by distribution increased from 81% to 86% in soil horizon I of the excessively wet soil of Nobeyama National Forest. This explains that the absorptive structure is maldistributed to the surface soil more than to the dry soil. That is to say, the root growth is strikingly restricted because the lower soil horizons contain a large amount of water and are excessively wet and anaerobic in such overhumid soils as K 6, K 7 and K 8. There the tree growth was very bad, and the site quality index ranges from 7 to 11.

Under the excessively wet or dry condition, which let the absorptive structure gather unbalancedly in the surface soil, the absorption efficiency of the root system dropped down. As a result, the tree growth became inferior.

In the soils soft and inflated in depth, having the favorable physical and chemical properties, the absorptive structure develops deep and absorbs water and nutriment from each soil horizon. When, therefore, the surface soil is dried up, it is to support the above-ground part. Thus, it is desirable for tree growth that the absorptive structure should be distributed much to the deeper soils.

(7) Vertical distribution of the root surface area and soil conditions

The root surface area, as above-mentioned, is the maximum in soil horizon I. It decreases gradually as soil horizons go lower and growth conditions get worse. This is shown in Fig. 33 as the relation between the soil factors and the fine root surface areas in each stand.

As soil horizons go lower, water content in root increases at a taken-out time in the S 3 stand, BlD(d) typed, in Fig. 33. The contrary applies to the amount of air. Strong water holding power is maintained in the deep soils. The water capacity with the pF value of 2 is 55% in soil horizon I, and 68% in soil horizon II, making a difference of 13% between them. As for the chemical properties, the amount of carbon and N decreased remarkably, if compared with the surface soil.

Thus, the physical and chemical properties of soil changed as soil horizons went lower. The root surface area decreased gradually along with it. It was 3 m^2, 62% of the total root surface area, in soil horizon I. And they were 15%, 14%, 8%, and 1% in soil horizons, II, III, IV and V respectively. In soil horizon IV or below, they decreased with rapid speed. They were 77% of the total root surface area in soil horizons I and II with favorable aeration and chemical properties. The above-mentioned distribution of the fine root surface area answering the physical and chemical change in soil is dominant in general. It changes in the moist or dry soil when the humidity in soil change in degree.

(8) The remarkably different physical and chemical properties of soil

Though the S 1 and S 11 stands, both 8 or 9 years old, show an almost similar growth, the physical and chemical properties in the S 1 stand with colluvial soils of the B_E type change gradually from the surface to the deeper soils. And the S 11 stand at the Oneyama National Forest, a habitat with volcanic ash and gravel deposited alternately, has quite different physical and chemical properties.

Fig. 34 shows the relation between the physical and chemical properties and the fine root surface areas. The amount of water, air, carbon, N, the pF value, and the C/N ratio in field condition, as in it, changed smoothly in the S 1 stand. As soil horizons went lower, the

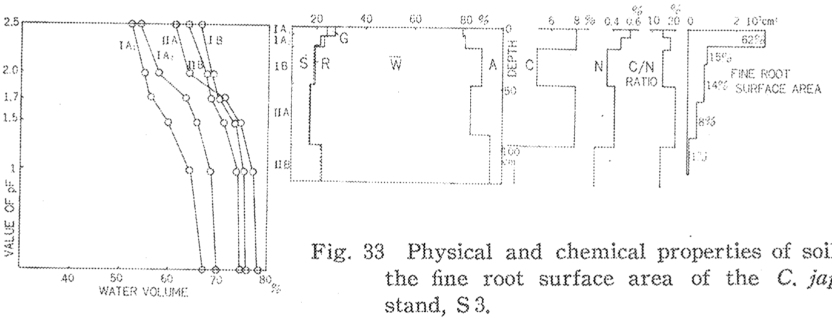


Fig. 33 Physical and chemical properties of soil, and the fine root surface area of the *C. japonica* stand, S 3.

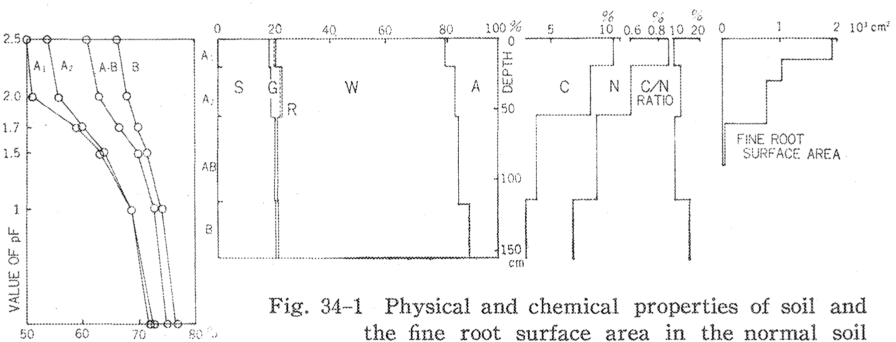


Fig. 34-1　Physical and chemical properties of soil and the fine root surface area in the normal soil texture of the *C. japonica* stand, S 1.

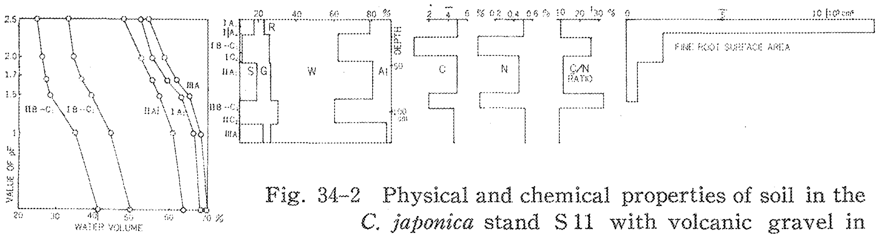


Fig. 34-2　Physical and chemical properties of soil in the *C. japonica* stand S 11 with volcanic gravel in the lower horizons, and fine root surface area.

growth conditions of the root system got worse. Along with this changing, the fine root surface area decreased gradually. They were, for example, 1.9 m² (52%) in soil horizon I, 1.0 m² (2.7%) in soil horizon II, 0.8 m² (21%) in soil horizon III, and 0.04 m² (1%) in soil horizon IV. The S 11 stand had a volcanic gravel layer near soil horizon II. This volcanic gravel layer contains a small amount of water, a remarkably large amount of air, a low water capacity against the pF values, poor water holding power, a small amount of carbon and N, and finally, a high C/N ratio. Hence it is that this layer is utterly unsuitable for developing the root system. There, the fine root surface area was maldistributed to the surface horizon, showing 84% in soil horizon I, 12% in soil horizon II, and 4% in soil horizon III. It was remarkable large in soil horizon I, probably because of restraint from root development in soil horizon II or below. It is evident from the fact that the soil conditions have a great effect on the distribution of the root system in the surface soil horizon.

The volcanic gravel layers are piled up alternatedly in the S 12 to S 17 stands at the Oneyama National Forest. The differences by soil conditions between growth rates becomes larger there as a tree grows. The root surface area became broader in soil horizon III with a favourable growth condition. Diflerence in growth increased gradually between this horizon and soil horizon II. Let us take out of it these stands; the S 12 stand, 267 cm² in basal area, stand S 15, 451 cm² in basal area and stand S 17, 1,042 cm² in basal area. It is evident from Fig. 35, that the fine root surface area decreases remarkably in soil horizon II with various inferior physical and chemical properties of soil. This decrease rate is higher in the S 17 stand with broad basal area. In the S 11 stand with small-diameter trees, the surface area ratios by distribution, as shown in Table 57, were 12% in soil horizon II and 4% in the III. Difference in ratio between both horizons enlarges as a tree grows up; for instance, the ratios were 20% in the S 15 stand, 21% in the S 16 and 16% in the S 17.

These phenomena are caused by the difference in growth rate due to the selective distri-

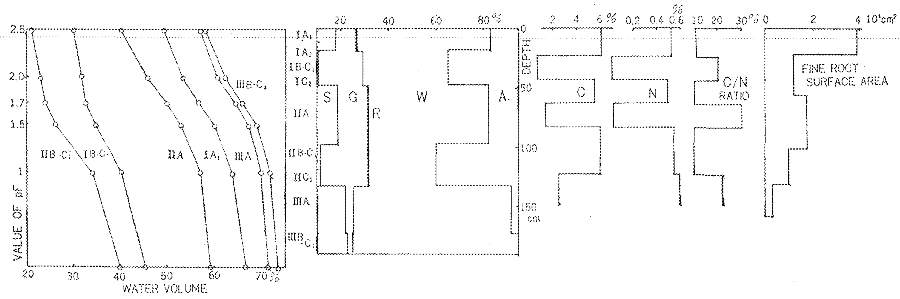


Fig. 35-1 Physical and chemical properties of soil, and fine root surface area of the *C. japonica* stand, S 12.

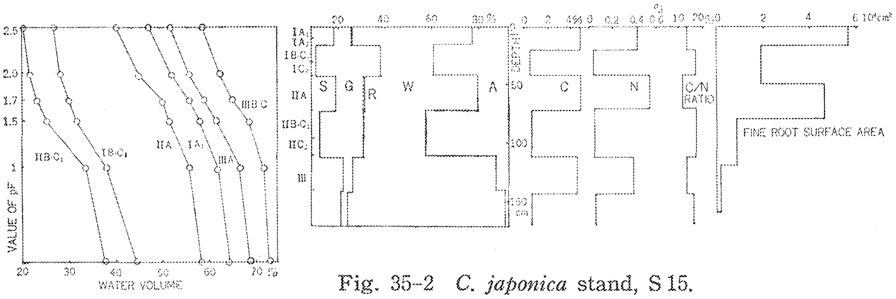


Fig. 35-2 *C. japonica* stand, S 15.

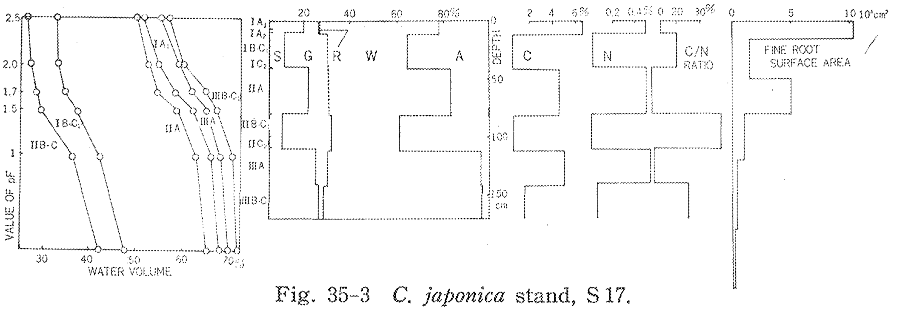


Fig. 35-3 *C. japonica* stand, S 17.

Table 57. Root surface area ratio by soil horizon in the volcanic gravel soil of the Oneyama National Forest (%)

Stand		S 11	S 12	S 13	S 15	S 16	S 17
Horizon	I	84.1	48.8	53.9	42.6	47.4	62.3
	II	12.3	14.3	16.5	14.8	10.7	7.0
	III	3.6	20.8	20.8	34.8	31.8	23.4
	IV	—	12.2	8.0	6.4	7.3	4.7
	V	—	3.9	0.8	1.4	2.8	1.7
	VI	—	—	—	—	—	0.9

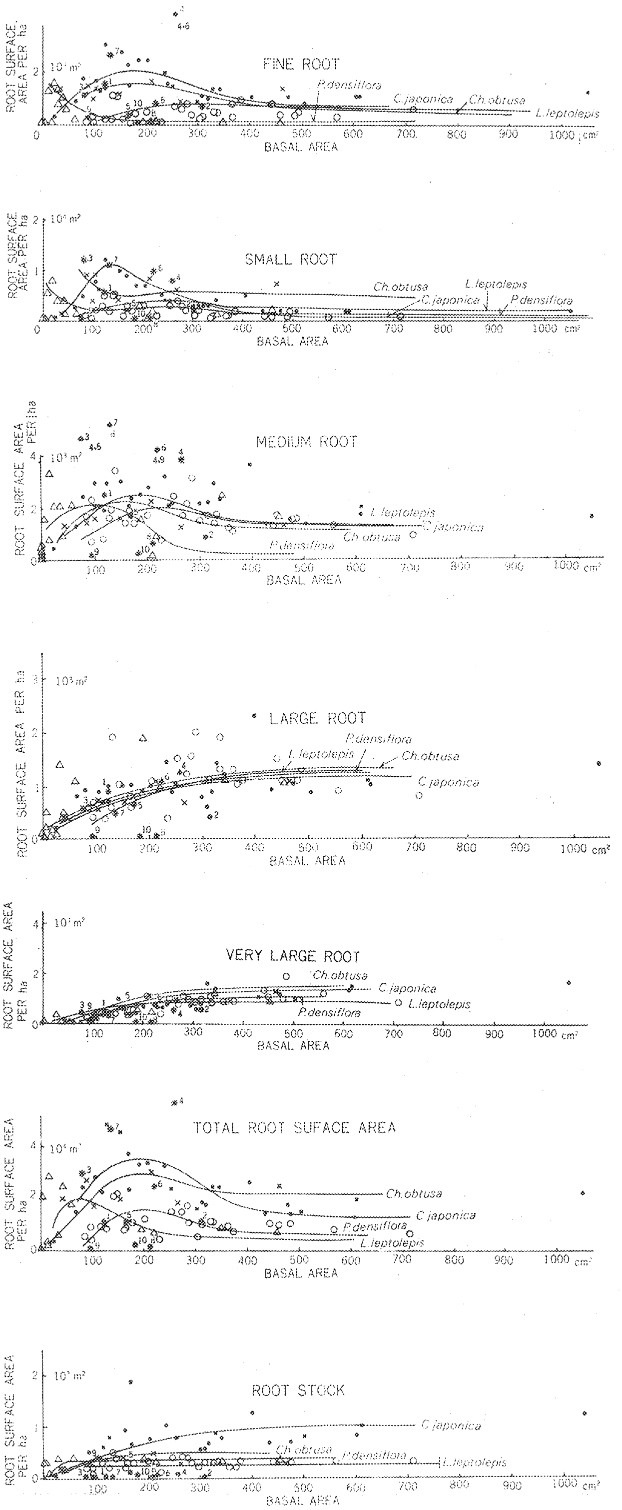


Fig. 36 Basal area and each root surface area per ha.

bution of the root system, and due to the different properties of each soil. Even in a site where the gradual and normal changes of soil properties occur, the root surface arae ratio by distribution has a tendency to become lower in soil horizon II, partly because the root systems in soil horizon II grow into soil horizon I, and partly because they branch greatly near soil horizon III.

The reader may refer to Photographs 2-8, 2-9, 3-1, 3-2, 4-1 and 4-2 in the second issue[18] on the differences in the physical and the chemical properties of soil, root growth and changes by fine root.

2) **Root surface area per ha**

The root surface area per ha was calculated by the ratio estimate of basal area from the average root surface area per tree. Its relation to basal area is shown in Fig. 36. The surface areas per ha of the fine, small or medium roots reach to the maximum when the basal area increases from 100 cm² to 200 cm² regardless of species (20 years to 25 years old). They decrease gradually as a tree grows further. This tendency is most remarkable in a fine root; it becomes less remarkable in the larger roots. The summit of increase is not observed at the young stage, when the increasing curve takes almost parabolic form.

The total root surface area draws almost the same increasing curve as the fine and small roots do, because those roots occupy a greater part of the total root surface area. This is due to the intertwined effect of the property of root branching, and to the decreases of trees in number with tree growth. To clarify the explanation, two examples are given : first in young trees, 20 years to 25 years old, the roots branched off vigorously. There were many in number per ha for many fine and small roots. Second, in old-aged trees, the number decreases greatly for increasing surface area per tree.

The reason why these relations are more remarkable in the fine, small and medium roots than in the large and very large roots is that the surface areas of fine, small and medium roots increase greatly with the increase in number of young trees, and that in the case of large trees, the rate of increase of the surface areas of large and very large roots per tree is higher than that of fine and small roots.

(1) Tree growth and root surface area

Table 58 and Fig. 37 show the annual volume growth of each species per ha according to stand age and basal area in the second class site of the yield table. As is clear from them, each rate of increase reached its maximum at the basal area of about 200 cm^2 and at the stand ages of 20 to 25 years. It had a close correlation with the change of the root surface area per ha in Fig. 36.

The same relation was also observed concerning the total biomass growth per ha for the last one year in this study ; each growth came up to the maximum at the age of 20 to 25 years. This is also relative to the growth characteristics of each species. As is clear from Fig. 37, the root surface area reached the maximum at an early stage in the case of *P. densiflora*, the annual growth of which came to the largest at an early stage ; but in the case of *Ch. obtusa*, both came to the maximum at a late stage. Their changing curves corresponded to each

Table 58. Annual stem volume growth in each yield table

	C. japonica		*Ch. obtusa*		*P. densiflora*		*L. leptolepis*	
Stand age (yrs.)	Basal area (cm^2)	Annual growth (m^3)	Basal area (cm^2)	Annual growth (m^3)	Basal area (cm^2)	Annual growth (m^3)	Basal area (cm^2)	Annual growth (m^3)
10	41	—	13	—	15	—	32	—
15	95	16.8	32	—	43	11.6	102	12.2
20	161	19.5	62	—	88	12.6	177	13.6
25	235	19.7	97	7.9	150	11.8	230	10.3
30	317	18.6	131	8.6	222	11.4	287	9.6
35	401	17.7	170	9.1	302	10.6	350	9.4
40	487	16.9	214	9.5	387	9.9	419	9.1
45	577	15.8	257	9.8	475	9.0	495	8.0
50	670	15.2	302	10.0	568	8.2	568	7.6
55	765	14.4	350	10.1	661	7.4	642	7.0
60	860	13.7	398	10.1	755	7.0	716	7.0

* Basal area of dominant trees.

** Annual stem volume growth of dominant and predominant trees.

*** For the current total production of the sample trees in this study.

C. japonica : The yield table of the *C. japonica* stand in the north Kanto and the Abukuma district, second site.

Ch. obtusa : The yield table of the *Ch. obtusa* stand in the Kiso district, second site.

P. densiflora : The yield table of the *P. densiflora* stand in the Iwaki district, second site.

L. leptolepis : The yield table of the *L. leptolepis* stand in the Shinshu district, second site.

other very distinctively.

The following are presumable when judged from the change of the growth of the root surface area or volume of a tree. First, the surface areas of fine and small roots go on increasing before the stand age gets to 20 to 25 years, owing to many young tissues. And at the same time, those roots grow and absorb water and nutriment vigorously till then. Second, the rate of increase of surface areas slows down as a tree grows older. Along with it, absorption and growth drop down.

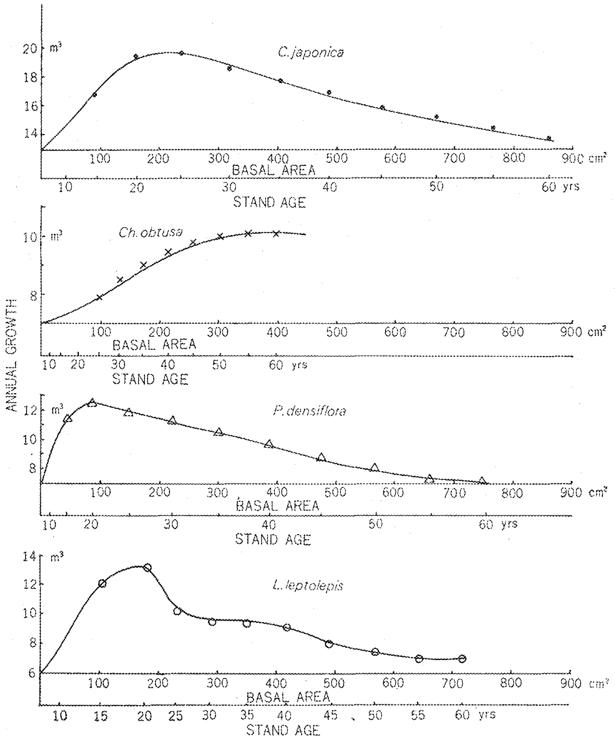
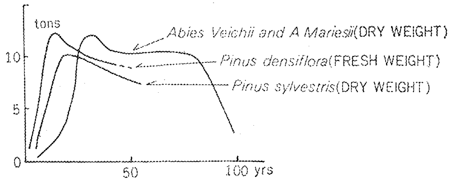


Fig. 37 Basal area, stand age, and annual growth of the stem volume per ha.

The change in root surface area per ha depends not only upon the change of trees in number, but strongly upon the increase of root surface area a tree. This is proved by three pertinent points: first, that the root surface area of a tree increases rapidly when young; second, that the trees, used in the calculations of the root surface area per ha, are unreasonably not a few in number; and third, that the same tendency is seen even at full density.



* See, leaf biomass in this study[18].

Fig. 38 Stand age and leaf biomass per ha[22].

Examining the change in leaf biomass per ha, we see in Fig. 38 that they increase temporarily and rapidly to the maximum at the stand age of 20 to 25 years when the annual volume growth reaches its maximum. This agrees well with the change in root surface area.

The reason why the root surface area increases at this stage is that as an inevitable process of root growth, the fine and small roots branch and extend actively, having a greater part of the root biomass at a young stage; in the case of the large-diameter trees, however, the thick roots of the root system play an important role as one of accumulating parts. In this respect, tree growth is a series of growing process, including a change in root surface area as a main element. Prematured root systems increase their surface area, which increases the absorption amount of nutriment and water, and this facilitates the assimilation in leaves further. This increase of assimilation promotes the growth of volume again.

As is known, the surface areas of fine and small roots increase temporarily with rapid speed as one stage of root growth. Hence it is that the increase of the leaf biomass or annual

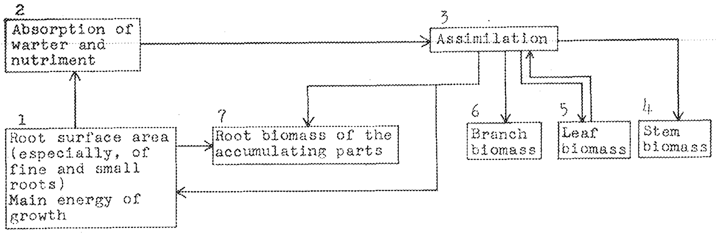


Fig. 39 Figure indicating how to grow considering root surface area as the main element of growth.

volume growth is highly related to that of the root surface area.

The change in root surface area is, in this sense, the possible main cause of a series of growth changes. The growth change caused by the change in root surface area, based on this idea, is shown in Fig. 39.

Active absorption of water and nutriment is, first, stimulated by the increase of the fine or small root in surface area at an early stage; second, this promotes the increase of the assimilated product in leaves, and third, a part of that product mainfests itself as the growth of a stem, branches or leaves, particularly followed by an increase of the annual volume growth in a stem. The assimilated product reduced to a root system is mainly used for the growth of fine roots at an early stage. As a tree grows up, it is used more for the growth of the thick roots, accumulated parts. Therefore, the growth in surface area declines, and consequently the absorption becomes less active. So does the tree growth.

When the seed begins to germinate, the main roots develop, supporting the above-ground part and at the same time, begin absorption prior to assimilation in the above-ground part. In short, the root function is the main energy for growth. It is possible to presume from these facts that the growth of the above-ground part depends upon the change in root surface area and the subsequent change of the absorptive power, assuming that there is no hindrance

Table 59. Root surface area per ha of immature stands and of mature stands (Widest root surface area of immature stands)

	Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Widest root surface area of immature stands	Root surface area (m^2)	35,000	30,000	20,000	15,000
	Basal area (cm^2)	180	200	80	170
Root surface area at the basal area of 500 cm^2		15,000	25,000	5,000	10,000

Table 60. Maximum root surface areas per ha of each species

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Stand	S 24	H 3	A 10	K 26
Soil type	$\mathrm{B_A}$	$\mathrm{B_D}$	$\mathrm{B_A}$	B*lc*
Site index	11.0	18.8	11.6	9.6
Density index	0.7	0.6	1.2	1.3
Basal area (cm^2)	99	254	18	164
Root surface area (ha)	4.9	3.1	2.9	2.3

Table 61. Root surface area

	P. Tunbergii	*P. Strobus*	*P. taeda*	*Ch. pisifera*	*E. globulus*
Stand	A13	A14	A17	M1	M3
Soil type	Bl_D	Bl_D	Bl_{D-E}	Bl_D	Im$_{-BF}$
Basal area (cm^2)	23	154	4	137	177
Root surface area (ha)	0.3	0.4	0.2	2.7	3.0

to growth of both the under-and-above ground part such as shade to assimilation of leaves.

Each root surface area per ha at an early stage, as in Table 59, is 30,000 m^2 to 35,000 m^2 at the maximum, about 3 to 3.5 times as large as the planting area, for *C. japonica* or *Ch. obtusa*, and yet 15,000 m^2 to 20,000 m^2 for *P. densiflora* or *L. leptolepis*.

At the basal area of 500 cm^2 when the growth of the surface area became stable, the root surface area per ha was 25,000 m^2, the largest, for *Ch. obtusa*, 15,000 m^2 for *C. japonica*, and 5,000 m^2, 25% of its maximum at an early stage for *P. densiflora*. The rate of decrease was the minimum for *Ch. obtusa*, only 20% off from its maximum stage. This is mainly due to the decrease of trees in number, and because the root density becomes high for *Ch. obtusa* with strong tolerance as the tree number does not decrease so much, and becomes low in the case of *P. densiflora* whose number decreases greatly.

For the other species involved, the maximum root surface areas of each species, as in Tables 60 and 59, were 4.9 ha. for *C. japonica*, 3.1 ha for *Ch. obtusa*, 2.9 ha for *P. densiflora*, and 2.3 ha for *L. leptolepis*. According to Table 61 showing the root surface areas of other species, they were 6.1 ha for *Zelkova serrata*, largest among the investigated species, and 4.8 ha for *Acacia decurrens*. It means that the former has a wide surface area per unit weight and the latter has a large amount of fine roots.

They were 0.07 ha to 0.2 ha for *Quercus mongolica*, *Betura platyphylla* or *Betula davurica*, and small if compared with those of the above-mentioned species, because they had small amount of the fine roots which had a greater part of all the root surface areas, and low tree density. Similarly, *P. Thunbergii*, *P. strobus*, *P. taeda* and *Abies firma* had a small surface area, 0.2 ha to 1.1 ha.

That of the main species, *Ch. obtusa*, as in Table 60, has a smaller root surface area than *C. japonica* can be explained as follows : first, its fine root is small in average diameter ; second, the bulk density is high ; third, its root surface area per unit weight is small, and finally, the tree density is low. *P. densiflora* has these reasons : first, the species has a small amount of the fine roots when grown up normally ; second, the bulk density is low ; and third, the root surface area per ha is slightly less than one ha, but it increases to 2.9 ha in the premature and too dense stands, as A 10. The value is near to that of *Ch. obtusa*, and it is to be noted that this increase in area is just compatible with the tendency *P. densiflora* has to grow at an early time.

(2) Toot surface area per ha according to every root class

Table 62 reveals the root surface area per ha according to every root class in the *C. japonica* stand of S 5. As is clear from it, the total root surface area per ha is 1.8 ha, of which 1 ha is equivalent to that of the fine root, 0.2 ha to that of the small root, and 0.15 ha to that of the medium root. The ratio to the total root surface area decreases as the roots become larger.

per ha of each species

Z. serrata	*A. firma*	*T. canadensis*	*A. decurrens*	*Q. mongolica* v. *grosseserrata*	*B. platyphylla* v. *japonica*	*B. davurica*
M4	M5	M6	M7	M8	M9	M10
Bl$_D$	Bl$_D$	Bl$_D$	Er-$_{BA}$	Bl$_D$	Bl$_D$	Bl$_D$
188	156	211	135	167	118	157
6.1	1.1	2.5	4.8	0.2	0.07	0.09

Table 62. Surface area per ha of each root class (m^2)

Species	Stand	f	s	m	l	L	St	Total root surface area
C. japonica	S5	10,472	2,882	1,592	1,049	1,299	789	18,083
Ch. obtusa	H5	14,210	7,189	1,354	1,170	1,387	342	25,652
P. densiflora	A8	965	2,213	1,684	1,014	974	344	7,194
L. leptolepis	K21	4,944	1,520	1,638	1,177	1,059	373	10,711

Table 63. Ratio by root surface area of each root class when the whole root surface area is to be 1 (%)

Species	Stand	f	s	m	l	L	St	Total root surface area
C. japonica	S5	57.9	15.9	8.8	5.8	7.2	4.4	100

The ratio of each root surface area to the total root surface area was calculated when the total area was to be 1. It is shown in Table 63 on the S5 stand of *C. japonica* from this table. As is clear from the table, the surface area of the fine root was equal to 58%, that of the small root to 16%, and the medium root to 9%, of the total root surface area. This ratio differed according to species or stand ages.

Fig. 40 shows the relation between the root surface area ratio and the basal area. The surface area ratio of fine and small roots was, as shown there, high for a small-diameter tree within the range of the basal areas of less than 300 cm^2 regardless of species. It decreased, however, gradually with the increase of basal area. This was remarkable for those roots. That of a medium root is almost constant regardless of the width of the basal area. Those ratios of large and very large roots increased as the basal increased, describing a parabola (*P. densiflora* or *L. leptolepis*) and an S-shaped curve respectively. The maximum points moved towards the broader basal area.

This is, as before, partly because the root growth of a small-diameter tree takes place in the form of branching and extending of the fine or small roots which occupy a greater part of the total biomass, and partly because the fine or small root surface area ratio of a large-diameter tree becomes lower as the growth rate of the large root becomes higher with tree growth. The surface area ratio of the fine roots by distribution, as in Fig. 40, was 65% for *C. japonica* or *Ch. obtusa* at the basal area of 20 cm^2 to 30 cm^2. However, it decreased gradually with the increasing basal area, showing about 55% at the basal area of 500 cm^2, a difference of 10%. In the case of *L. leptolepis*, the ratios were 45% at 100 cm^2, and 40% at 500 cm^2. In the case of *P. densiflora*, the ratios were 60% at 10 cm^2 to 20 cm^2, and about 12% at 500 cm^2.

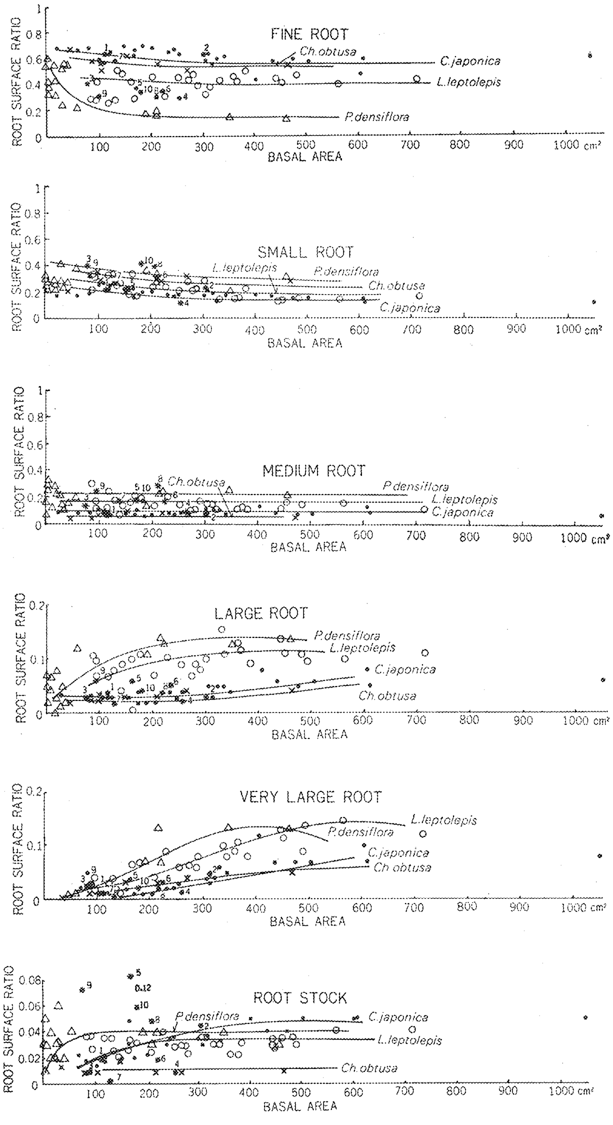


Fig. 40 Ratio of each root surface area to the whole root surface area.

Their ratios decreased strikingly, as compared with those of the other species.

This is because the growth rate of *P. densiflora* becomes more remarkable for the large roots and lower for the fine or small roots with the increasing basal area.

As above-mentioned, the surface area ratio of the fine root closely related to the absorption is high for a small-diameter tree and low for a large-diameter tree. This runs parallel with the fact that tree growth is quick at the sapling stage and slow at the matured stage.

The surface area ratios of the fine roots at the basal area of 500 cm² were 50% to 60% for *C. japonica* or *Ch. obtusa*, 40% to 45% for *L. leptolepis*, and 10% to 15% for *P. densiflora*. This explains that the fine roots of *C. japonica* and *Ch. obtusa* occupied about half of the total root surface area, and that the root of *P. densiflora* had only 10% to 15% of that.

The surface area ratio of a small root as well as that of a fine root decreased almost equally with the increase of basal area. The difference in ratio between the basal areas of 50 cm² and 500 cm² was about 5%, smaller tham that of the fine root. The ratios at the basal area of 500 cm² were 38% for *P. densiflora*, 30% for *Ch. obtusa*, 22% for *L. leptolepis*, and about 15% for *C. japonica*.

The fine root of *P. densiflora* had the lowest ratio of all, but its large root had the highest ratio of all. For the other roots grow more vigorously than the fine root.

The ratio of a medium root runs almost parallel with the increasing basal area, although that of a fine or small root makes a decreasing curve. And it goes almost constant regardless of diameter class. The surface area ratios of the medium roots were 22% for *P. densiflora*, 18% for *L. leptolepis*, 7% for *C. japonica*, and 5% for *Ch. obtusa*.

Table 64. Ratios by root biomass and by root surface area of each root class (%)

	Stand	f	s	m	l	L	St	Total
Ratio by root biomass	S5	1.5	2.4	5.3	7.8	22.3	60.7	100
	H5	2.2	5.3	4.7	10.2	34.1	43.5	100
	A8	0.3	2.7	8.2	11.3	26.0	51.5	100
	K21	1.0	2.0	8.0	13.2	30.8	45.0	100
Ratio by root surface area	S5	57.9	15.9	8.8	5.8	7.2	4.4	100
	H5	55.4	28.0	5.3	4.6	5.4	1.3	100
	A8	13.4	30.8	23.4	14.1	13.5	4.8	100
	K21	40.1	14.2	15.3	11.0	9.9	3.5	100

The ratio of the large root of *P. densiflora* or *L. leptolepis* increased before the basal area reached 200 cm², and then became constant. The increasing curve of *C. japonica* or *Ch. obtusa* went gentle, describing an S shaped curve before the basal area reached 500 cm² and then became constant. The ratios at the basal area of 500 cm² were 15% for *P. densiflora*, 12% for *L. leptolepis*, 5% for *C. japonica*, and 4% for *Ch. obtusa.*

The ratio of a very large root shows this tendency more clearly. It increases describing an S shaped curve irrespective of species. It reaches the maximum at the basal area of 350 cm² in the case of *L. leptolepis*, and at that of 600 cm² in the case of *C. japonica* or *Ch. obtusa.* The ratios, corresponding to each basal area, were 14% for *P. densiflora*, 15% for *L. leptolepis*, 8% for *C. japonica*, and 5% for *Ch. obtusa.*

The ratios of a root stock at the basal area of 500 cm² were 4.2% for *C. japonica*, 3.5% for *P. densiflora*, 3.0% for *L. leptolepis*, and about 1.0% for *Ch. obtusa.*

On the whole, the ratios of a large or very large root or root stock were high and that of a fine root was low for *P. densiflora* or *L. leptolepis* because of the characteristics of branching of root. They were the opposite to the case of *C. japonica* or *Ch. obtusa.*

The surface area ratios of the fine and small roots with young tissues are high. Their absorption efficiency is higher than that of large roots; thus it can be presumed from the facts that a larger amount of water or nutriment is absorbed through the fine and small roots.

The ratios by biomass and surface area according to every root class are shown in Table 64. As is clear from the table, the ratios by biomass were 0.3% to 2.2% for a fine root and 2.0% to 5.3% for a small root; the ratios by surface area were 13% to 58% for the former root and 14% to 31% for the latter. The latter were 30 to 40 times as high as the former in the case of fine root and 6 to 7 times in the case of a small root.

As concerns the root stock which had a greater part of the root biomass, the ratios by amount were 45% to 61% and the ratios by surface area were 1.3% to 4.8%. Contrary to the former case, they were 10 to 40 times as high as thess.

(3) Tree density and fine root surface area per ha

The surface area per ha of a fine root increases as the stand density increase. It also differs greatly by site conditions even

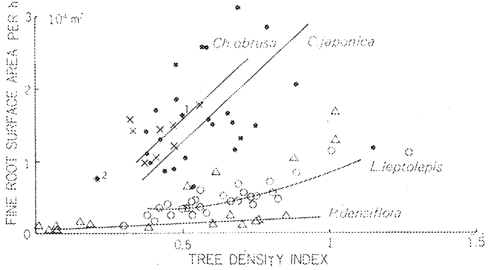


Fig. 41 Fine root surface area per ha and tree density.

Table 65. Surface area of absorption per ha in full density estimated (ha)

Soil \ Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Dry soil	4.0	5.0	1.7	1.2
Moderately moist soil	2.5	2.3	1.0	0.8
Moist soil	1.2	2.0	0.4	0.6

under the same density. Its dispersion to the density index is large as shown in Fig. 41. Therefore, no close relation can be seen between them.

The surface areas of the fine root were 1.2 ha in the S 22 stand of *C. japonica* with the stand density index of 1.2, and 3.1 ha in the S 24 stand with the index of 0.7. They were broader by 1.9 ha in the former than in the latter. For the S 24 stand is dry B_A-typed and the S 22 stand is rather moist B_E-typed. This holds good in the case of *Ch. obtusa*, *P. densiflora*, and *L. leptolepis*.

The surface area of the fine root at the full density estimated from Fig. 41 is shown in Table 65. Those areas in a dry soil were 5.0 ha, especially broad, for *Ch. obtusa*, 4.0 ha for *C. japonica*, 1.7 ha for *P. densiflora*, and 1.2 ha for *L. leptolepis*.

(4) Soil conditions and the surface area of a fine root per ha

The surface area of a fine root changes by soil conditions. The various soil factors and the surface areas of fine roots are gone through in this chapter.

a. Soil type

Fig. 42 shows the relation between the soil types and the surface areas of fine roots per ha. Regardless of species, those areas were, as in the figure, broad in such dry soils as B_A, Bl_A, B_B and Bl_C, and narrow in such wet soils as Bl_E, B_E, Bl_F and Bl_G.

The following two points prove it. First, the surface area per unit weight increases as the fine root under a dry condition is small in average diameter and is long. Second, the root biomass itself increases; as a result, the surface area increases strikingly.

From this figure, it can be estimated that the surface areas of the fine root per ha in a moderately moist site equivalent to the second-rate soil in the yield table, are 1.5 ha for *C. japonica*, 1.7 ha for *Ch. obtusa*, 0.2 ha for *P. densiflora*, and 0.8 ha for *L. leptolepis*. Table 66 shows a rough relation between the soil types and the surface areas of fine roots.

In such an ordinary forest as in Table 66, the surface areas of the fine roots in a dry forest would be 2.5 ha to 3.5 ha, widest, for *Ch. obtusa*. 2.0 ha to 3.0 ha for *C. japonica*, 0.5 ha to 2.0 ha for *P. densiflora*, and 1.0 ha to 2.0 ha for *L. leptolepis*.

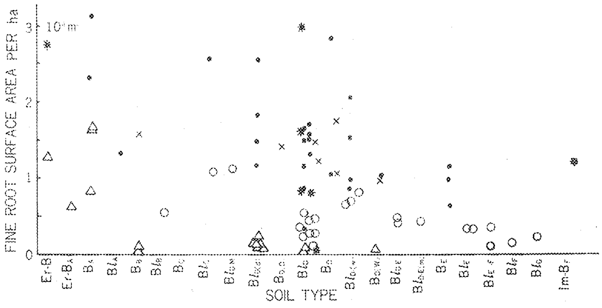


Fig. 42 Fine root surface area per ha and soil type.

Table 66. Root surface area per ha in forests, about 30 years, at the moderate density indices say, of 0.6 to 0.7 (ha)

	C. japonica	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	Soil type
Dry soil	2.0～3.0	2.5～3.5	0.5～2.0	1.0～2.0	Er・B_A・Bl_A・B_B・Bl_B・B_C・Bl_C
Moderately moist soil	1.0～2.0	1.5～2.5	0.2～0.5	0.5～1.0	Bl_D(d)・Bl_D・Bl_D(w)・B_D(w)
Moist soil	0.5～1.0	0.5～1.5	0.1～0.2	0.2～0.5	B_E・Bl_E・Bl_{EF}・Bl_F・Bl_G

Table 67. Site index and fine root surface area per ha (ha)

Species / Site index	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
10	2.7	1.6	0.9	0.6
20	1.7	1.4	0.3	0.5
25	0.8	1.2	0.1	0.3

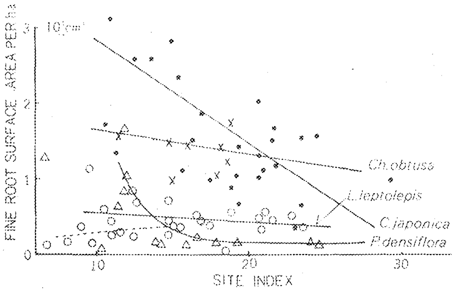


Fig. 43 Fine root surface area per ha and site index. The dotted line shows that of very moist stand.

Table 68. Fine root surface area per ha in case that the causes for decrease of site index are different

Stand	K29	K4
Site index	10.5	8.2
Soil type	Bl_B	Bl_F
Fine root surface area (ha)	0.6	0.2

In the wet soils, they were 0.1 ha to 0.2 ha for *P. densiflora* and 0.2 ha to 0.5 ha for *L. leptolepis*, both decreasing sharply. It is to be proved either by the fact that the growth of fine roots of those species with aerotropic roots, such as *P. densiflora* and *L. leptolepis*, is easily retarded under a wet condition, or by the fact that the fine roots easily decay under an overhumid condition.

b. Site index

The relation between the site index and the surface areas of fine roots is shown in Fig. 43. Those surface areas increase, generally speaking, as site index become smaller. As shown in Table 67 obtained from Fig. 43, the surface areas of *C. japonica* were 2.7 ha, 1.7 ha, and 0.8 ha respectively under the site indexes of 10, 20 and 25. Hence it is that those areas decrease in the sites with large site indices. The main reasons for this are, first, that a site with a smaller site index is generally a dry forest, and second, that the area decreases under an overhumid condition even if the site index is small.

For *C. japonica* taken here as an example, the site indices were 11.0 in stand S 24 with the dry B_A type soil, and 10.6 in stand S 21 with moist black volcanic ash. They were almost equal. The fine root surface areas, however, were 3.1 ha in the S 24 stand, and 1.7 ha in the S 21 stand, showing difference of 1.4 ha in area between them.

Also as shown in Table 68 about the *L. leptolepis* stands of K 29 and K 4, the surface areas were 0.2 ha in the K 4 stand with the smaller site index and 0.6 ha in the K 29 stand, explained by the fact that the decrease of the site index is due to excessive humidity in the K 4 stand and to dryness in the K 29 stand. Thus the surface area of a fine root is thought to be directly related not to the site index but to the water conditions in soil, which define site index.

The fine root surface area has a tendency to go wider when the site index is small according to Fig. 43, because the stands with the small site indices caused by dryness are mainly taken as a sample. This tendency is not so clear for *L. leptolepis*, because many samples are taken out of the over-humid inferior forest grounds, and because the fine root surface areas become rather reduced at the small site index (by a dotted line in Fig. 43).

c. pF value in field conditions and surface areas of fine roots

Fig. 44 shows the relation between the pF values in field condition and the fine root surface areas.

The fine root surface areas are changeable with the various factors, such as tree density, soil conditions, etc. The dispersion was wide in relation with the pF values. However, the area generally increased, as shown in Fig. 44, as the pF value increased, especially when the pF value went over 2.5. From this it is clear that the physiological function of trees, related to absorption, changes suddenly when the pF value goes over 2.5, because the tree growth changes then. The fine root surface areas per ha at the pF values 2.0, 2.5 and 3.5 from Fig. 44 are shown in Table 69. This table makes clear these relationships.

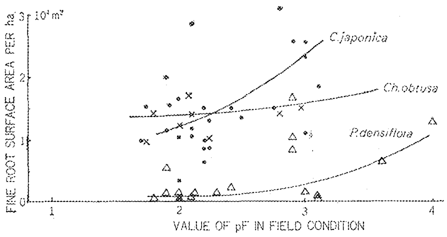


Fig. 44. Fine root surface area per ha and value of pF in field condition.

d. Percolation rate

The relation between percolation rate

Table 69. Fine root surface area per ha to each value of pF (ha)

Species Value of pF	*C. japonica*	*Ch. obtusa*	*P. densiflora*
2.0	1.5	1.3	0.2
2.5	1.7	1.4	0.3
3.5	3.5	1.8	1.0

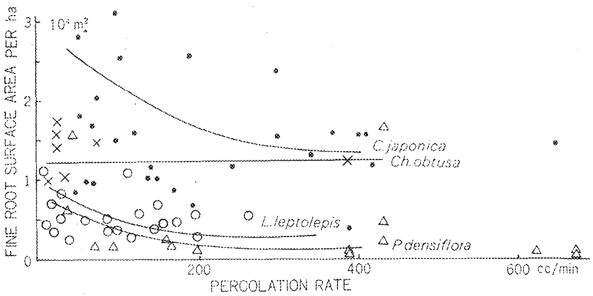


Fig. 45 Fine root surface area per ha and percolation rate.

and fine root surface area is shown Fig. 45. The figure shows that the surface area has a tendency to decrease gradually, corresponding to the increase of percolation rate.

It may be presumed that generally the surface area is wider in the soil with good aeration and high percolation rate than in the soil with bad aeration. The water percolation, however, was worse in the dry B_A or B_C type soil of the S 24 or S 7 stand in Fig. 45. And besides, it was liable to go faster in the moderately moist soils developed fully in structure. The fine root surface area had a tendency to increase in the dry soil with low percolation rate as the fine root surface area varied in proportion to the humidity in soil.

There are various reasons why percolation rate slows down. As in the case of site index, the relation between surface area and percolation rate varies to the fundamental factors relevant to percolation rate.

The fine root surface area of *C. japonica* per ha and the percolation rate in soil horizon I, were 0.9 ha and 51 cc/min respectively in the S 26 stand, Bl_D(w) soil-typed, and 0.7 ha and 40 cc/min in the K 7 stand, excessively wet Bl_G soil-typed. This is quite contrary to the above-mentioned increase of the fine root surface area by the decreasing percolation rate caused by dryness.

Thus, the fine root surface area becomes, sometimes, broader or narrower as the percolation rate decreases under the extremely wet or dry conditions. Generally, the moderately moist soil shows good percolation. The surface area is narrower there than in a dry soil.

It is therefore inappropriate to regard the percolation rate as an index of growth of the root surface area.

e. C/N ratio

The relation between the C/N ratio as an index of the chemical properties of soil and the fine root surface area is shown in Fig. 46. As is clear from it, most of the sample stands have the C/N ratios of 10 to 15.

Within this range of the C/N ratios, each species' surface area of the fine root become less in the order of *Ch. obtusa*, *C. japonica*, *L. leptolepis*, and *P. densiflora* (Table 70.). The variance, however, was very wide. As an example, that of *C. japonica* ranged from 0.6 ha to 3.0 ha.

Judging from this wide variance, there is a close correlation in the C/N ratios of 10～15 between them. The fine root surface area, however, increases as the C/N ratio increases in general.

The relation between the C/N ratio and fine root surface area per in the sample stands,

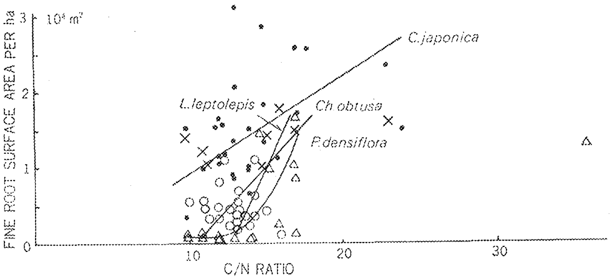


Fig. 46 Fine root surface area per ha and C/N ratio.

Table 70. Fine root surface area per ha of each species to the C/N ratios of 10 to 15 (ha)

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolipis*
Fine root surface area per ha	1.2～1.7	1.3～1.8	0.1～0.3	0.2～0.7

Table 71. C/N ratio of the *C. japonica* stand and fine root surface area per ha

Stand	S 20	S 21	S 22
Soil type	BA	BD	BE
C/N ratio	23	17	12
Fine root surface area (ha)	2.3	1.7	1.2
Site index	15.4	20.6	23.4

BE, BD or BA soil-typed, in Akita Prefecture situated in the northern part of the Main Island of Japan is shown in Table 71. Set up on the BA typed soil with a bad growth condition, the S 20 stand, as can be seen in the table, had the site index of 15.4, the C/N ratio of 23, and the surface area per ha of 2.3 ha. And as the soil types shifted from the dry BD typed soil in stand S 21 to the moist BE typed one in stand S 22, the site indices came up to 23.4 from 15.4, and the C/N ratios went down from 23 to 12. Along with it, those surface areas decreased from 2.3 ha to 1.2 ha. Hence it is that the C/N ratio and the surface area decrease hand in hand.

This change is a result of interaction among each factor. For example, the fine root surface area increases as the C/N ratio becomes higher in a dry and barren forest. It can be said in other words that the fine root surface area increases under the condition in which the C/N ratio becomes higher.

There is a tentative relationship between each soil factor and fine root surface area, but it is not clear whether each factor is directly related to the changes in fine root surface area because there is a close relation between such factors themselves.

Generally, the surface area is liable to increase in a dry and barren forest soil with sufficient aeration.

This tendency can be regarded as an adaptation of the tree to absorption of water and nutriment, which it lacks, by extension of roots and increase of the root surface area in a dry and barren soil.

In fact, the absorbed weight by a tree rises in response to the increase of an absorbing surface of fine roots. It varies with the water conditions of soil or property of the roots. When these conditions are invariable, the more plentiful the absorbed weight, the wider the surface area. Tree growth declines as the absorbing surface area lessens, answering the decrease of the fine root amount by excessive wet, disease, and insects. A suitable surface area of the fine root is necessary for satisfactory tree growth.

3) **Disintegration of absorptive structure**

As a whole, the absorptive structure is distributed unbalancedly to the surface soil under a dry condition. There, the root systems are lignified to stand against an excessively dry condition. And thereby, the white parts of the root tips branch off from the lignified fine roots in a rainy season.

Thus the absorptive structure rarely breaks down, if not by an excessive dryness; at most the absorption efficiency per unit root surface area deteriorates. That structure, however, often breaks down by decay of the root system under an excessively moist condition with bad aeration.

The process of breakdown of the absorptive structure of *L. leptolepis*, which has little resistance against an excessively moist condition and a bad aeration, is shown in Table 72 on

Table 72. Site conditions and absorptive structures of *L. leptolipes* (%)

Stand		K 3	K 23	K 26	K 6	K 7	K 4
Basal area (cm^2)		183	141	164	92	128	86
Soil type		Bl_E	Bl_D–m	Bl_C	Bl_{E-F}	Bl_G	Bl_F
Site index		14.8	9.5	9.6	6.8	11.0	8.2
Fine root surface area (m^2)		3.3	4.0	4.6	1.1	1.5	1.1
Horizon	I	67.9	70.9	74.4	81.4	86.4	77.6
	Ⅱ	17.1	18.8	14.5	16.0	11.8	13.1
	Ⅲ	13.6	10.3	9.8	2.6	1.8	8.0
	Ⅳ	1.4	—	1.3	—	—	1.3
	Ⅴ	—	—	—	—	—	—

each stand, dry, moderately moist, and wet.

Findings listed in the table give the following for the stands of K 3, K 23, and K 26. In the stand of K 3, where the root system grew favourably, the fine roots were 3.3 m^2 in surface area, showing 68% distributions in soil horizon I, but in the dry-soild stands of K 23 and K 26, the whole fine root surface area increased from 4.0 m^2 to 4.6 m^2. And 71% to 74% of them maldistributed excessively to the surface soil horizon.

In these stands the site index ranged from 9.5 to 9.6. The roots grew insufficiently. The fine roots maldistributed unbalancedly to the surface soil. The absorptive structure was in no normality, if compared with that in stand K 3. The surface area, however, was broader there than that in stand K 3. Accordingly, tentatively favourable and continuous growth was expected though the absorption efficiency was low.

On the other hand, the decay of fine roots in the lower horizons caused those surface areas to increase distribution to soil horizon I in the excessively moist stands with insufficient aeration, K 6, K 7, and K 4. And those surface areas decreased to about one-third of that in a normal stand. It was evident from the facts that breakdown of the absorptive function went

Soil condition	Fine root surface area	Ratio of fine root surface area in the surface horizon	Growth of tree
Dry	Large ——→	High ——→	Tree growth is stable, though poor, because the absorbing efficiency decrease.
	Small ——→	Low ——→	Trees die as the absorptive structures are decayed in case that soil is dry excessively.
Moist and moderately moist	Medium →	Moderate →	Trees grow normally.
Very moist	Small ——→	High ——→	Trees grow poor and die because of the decrease of absorption efficiency and decay of the absorptive structure.

Fig. 47 Schematic presentation indicating the decay of absorptive structure.

on in the lower soil horizons.

The relation bentween the change in absorptive structure with the changing soil conditions and the tree growth is shown in Fig. 47.

Absorption efficiency goes generally worse under a dry condition. The breakdown of absorptive function and the subsequent death of the tree do not take place so easily as under an excessive moist condition. It is conceivable, however, that the absorptive structure is gradually ruined as a result of a vicious cycle of low absorption efficiency and growth rate. For the root system is prevented from reproducing, owing to the limit of absorption and assimilation when the excessively dry condition continues for a long time. In this case, the absorptive structure is small in the surface soil with severe dryness and large in the deeper soils.

The function and growth of fine roots decline due to bad aeration under an excessively moist condition. Fine roots are caused to die gradually from the lower horizons. And the absorptive structure is maldistributed to the surface soil. After that, it breaks down gradually from the lower soil horizons.

Effects of the water condition on the breakdown of the absorptive structure differ depending on species. The root systems of such wet-endurance species as *Salix* spp. or *Alnus japonica* do not easily break down even in excessively moist ground, but those of such species with a small wet-endurance as *L. leptolepis* etc., break down such condition easily.

Another breakdown of the absorptive structure is also caused by the damage by disease and insects. In this case, that structure does not always maldistribute to the surface soil.

Table 73 shows the process of breakdown of the absorptive structure in an inferior *L. leptolepis* forest at Nobeyama National Forest.

The decaying ratios of the small and medium roots in soil horizon I of the K 7 stand with excessively wet soils, as in Table 73, were 48% and 40% respectively. These ratios rose irrespective of stands as soils went deeper, because the conditions for development of the root system deteriorated in the lower soil horizons.

At Nobeyama National Forest, the withering ratio was high even in the B*l*D typed soil due

Table 73. Death ratio of the small and the medium root of *L. leptolepis* at the unproductive stands of the Nobeyama National Forest (%)

Stand		K7	K9	K10	K5	K6	K11	K12	K13	K8
Site index		10.6	12.4	11.5	9.0	6.8	16.8	14.5	18.7	9.0
Soil type		B*l*G	B*l*D	B*l*D	B*l*E-F	B*l*E-F	BD	B*l*D	B*l*D	B*l*D
Small root	I	48	16	35	27	27	20	25	26	18
	II	51	28	34	42	47	63	30	32	30
	III	60	44	66	51	70	49	71	35	55
	IV	—	40	47	—	61	86	85	37	42
	V	—	75	—	—	—	—	—	—	—
Medium root	I	40	23	30	33	57	26	20	24	27
	II	43	39	29	39	41	43	22	20	21
	III	59	43	46	54	55	33	11	14	37
	IV	—	63	54	—	34	58	53	38	53
	V	—	70	—	—	—	47	—	—	—

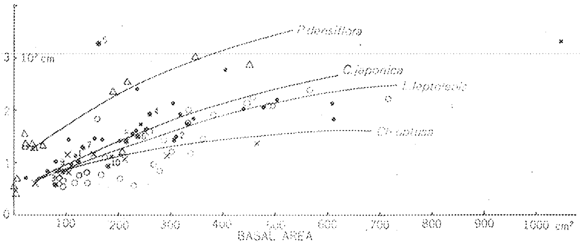


Fig. 48 Maximum root depth and basal area.

to the poor growth caused by overhumidity, and particularly higher in the Bl_G and Bl_{EF} type soils than in the Bl_D type soil. In the normal stands, the withering ratio of the root system was very low.

Table 74 shows the ratios by biomass of the young parts to the lignified parts, of the fine root, 50 g in weight. and less than 2 mm in diameter. ($\frac{f}{f+F}\times 100$, f : the biomass of the fresh tissues, F : the biomass of the lignified parts). According to the table, the ratios in soil horizon I were higher (18% to 29%) in the excessively moist Bl_G or Bl_{E-F} type soil than (34% to 59%) in the Bl_D type soil. There was a difference of 16% to 30% between them. It was evident from the facts that the growth of fresh fine roots in the excessively moist Bl_G type soil was checked, even in soil horizon I with good conditions for growth.

The decrease of absorption efficiency caused by that of the fresh fine roots leads to decreased growth; thus proving the cause for the lowering absorptive structure and bad growth.

This ratio decreased gradually in the deeper soil where the conditions for the growth of fine roots became worse. It got down to 4% to 5% in soil horizons IV and V.

The foregoing is an extreme illustration of the deterioration and breakdown of the absorptive structure in the inferior forests with an excessively moist soil in a high and cold district. It derives from the facts that in the normal stands, the soil conditions affect the absorptive structure related to absorption and assimilation efficiency, and that tree growth varies by interactions among them.

Though an extreme decay of root is not caused in a dry stand as in excessively moist ground, the fine and small roots are so much lignified from bad growth of root that its absorption efficiency deteriorates.

Generally in a dry stand, the fine and small roots remain lignified and inactive until the water in soil is supplied sufficiently at the time, as a rainy season, when they shoot out many fresh white root tips and work actively.

The states of the root system are quite different under an excessively moist condition and under a dry condition, even when their site indexes are both small. Photographs 4-3, 4-4, 5, 6 in the second issue[18] illustrate the difference.

IV Maximum depth of roots

Fig. 48 shows the relation between the basal area and the average maximum depth of root per tree including the main and oblique roots. According to the figure, the maximum depth of root increased, describing an almost parabolic curve regardless of species, and corresponding to the increase of the basal area. Particularly in the young tree, 100 cm² in basal area, it increased rapidly.

Tree growth : Table 75 shows the maximum depth of root at basal areas of 100 cm² and 500 cm². The ratios of increase of root length at the basal area of 100 cm² are shown in Table 75. The root length ranged from 90 cm to 175 cm at the basal area of 100 cm², and from 25 cm to 45 cm per basal area 100 cm² within the range of the basal areas of 100 cm² to 500 cm². The growth velocity was one-half to one-fifth that at the area of 100 cm^2 or below.

Species : The maximum depth of root is different from one species to anther. At the basal area of 100 cm^2, it was, for example, 1.2 m for *C. japonica*, 1 m for *Ch. obtusa*, 1.75 m for *P. densiflora*, or 0.9 m for *L. leptolepis*. Although only *P. densiflora* had remarkably long roots since its sapling stage, there was no great difference in length among *C. japonica*, *Ch. obtusa* and *P. densiflora*. At the basal area of 500 cm^2, for example, it was 2.2 m for *C. japonica*, 1.5 m for *Ch. obtusa*, 3.5 m for *P. densiflora*, or 2.0 m for *L. leptolepis*. Characteristics of each species appear clearer and differences between species become bigger as roots become larger. The average maximum depth of *P. densiflora* reached 3.5 m because its main roots grew into a tap shape. The maximum depth of the sample tree No. 4 of the A 4 stand, 29 cm in DBH grew to 4 m, longest among the trees investigated.

The root system of *Ch. obtusa* made similar growth to those of *C. japonica* and *L. leptolepis* at the young stage. After that, the main root grew less in length. A characteristic of the shallow-rooted species was apparent. The maximum depth of the root systems of these and other species, though at different basal areas and soil conditions, was as shown in Table 76,

Table 74. Ratio of the fresh tissues of fine roots (Ratio by dry weight)

Stand	K7	K9	K10	K5	K6	K11	K12	K13	K8
Site index	10.6	12.4	11.5	9.0	6.8	16.8	14.5	18.7	9.0
Soil type	Bl_G	Bl_D	Bl_D	Bl_{E-F}	Bl_{E-F}	B_D	Bl_D	Bl_D	Bl_D
I	22.8	39.7	34.6	28.9	17.9	44.0	44.9	58.9	37.0
II	8.6	12.8	21.3	15.6	16.5	27.2	21.5	46.8	15.6
III	5.0	14.6	25.0	2.8	5.4	21.9	12.3	38.0	6.0
IV	—	8.0	16.8	—	4.0	11.8	8.7	14.9	9.5
V	—	4.0	3.1	—	—	3.6	5.0	7.3	—

The values were calculated by the equation $\frac{f}{f+F}\times 100$

F : Weight of the lignified parts of fine roots.

f : Root weight of fresh tissues, almost occupied by the fine roots of this year's growing.

Table 75. Maximum depth of root in each tree size (cm)

Species / Basal area (cm^2)	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
100	120	100	175	90
500	220 (63)	150 (43)	350 (100)	200 (57)

( ) : Shows ratio to *P. densiflora* (%)

Table 76. Maximum depth of roots

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*Ch. pisifera*	*E. globulus*
Stand	S10	H3	A3	K29	M2	M3
Basal area (cm^2)	208	254	198	200	238	177
Soil type	Bl_D(d)	B_D	Bl_D(d)	Bl_B	Bl_D	Im
Maximum depth of root	142	110	227	70	149	60

230 cm to 330 cm for the tap-rooted *P. densiflora* or *Abies firma*, and 60 cm to 110 cm for *Ch. obtusa*, *L. leptolepis*, *Eucalyptus globulus*, *Betula platyphylla*, and *Betula devurica*.

This maximum depth is comparatively shallow because the ordinary stand ground has a shallower efficient soil horizon than a nursery soil or seashore sand with deep subsoil. It is due to the shallow sufficient horizons in an ordinary stand. Generally, the growth of roots is checked in an excessively moist and compact clay soil with bad aeration, but not in a slightly dry sandy soil with good aeration and small physical resistance; the roots grow in deep soils.

Soil conditions : As already mentioned, the maximum depth of root varies with soil conditions. Root growth is extremely restricted, physically and physiologically, in an excessively wet soil or soil with a shallow base rock. The average maximum depth of roots in the stands, almost the same in basal area, and different in soil conditions in Fig. 48, is shown in Table 96. According to the table, it is 214 cm in the S 25 stand of the Bl_D(w) type soil with deep collubial subsoil, or 150 cm in the S 9 stand of large trees in the Bl_D(d) type sedentary soil with shallow surface soil. There was, that is, a difference of 60 cm between them. A difference of 30 cm lay between the Bl_D typed stand of H 8 and B_B typed stand of H 6, of *Ch. obtusa*.

A difference of 64 cm lay between the Bl_D typed of K 11 and the Bl_D(d) typed stand of K 25 with shallow effective soil horizon, of *L. leptolepis*.

So far the case of dry soil with shallow and available soil horizon has been mentioned. The same phenomenon is also recognized under an excessively moist condition. The maximum root depth was, for example, 184 cm in the Bl_E soil-typed stand of K 3. However, the root system was prevented greatly from growing in the lower flooded soil horizon of the Bl_G soil-typed and heavy wet stand of K 7.

Tree density : Table 78 shows the relation between the tree density and the maximum depth of root. The maximum depth was 278 cm in the S 22 stand with high density, but 205 cm in the sparse S 26 stand of also moderately moist collubial soil, making a difference of 70 cm between them. That in the A 10 stand was 155 cm and deeper by 20 cm than those in the less dense stands, A 11 and A 12, with larger trees and the same habitat conditions.

Thus it is conceivable that the horizontal root growth is restricted while the vertical

Table 77. Soil properties and maximum depth of root of each species

Species	*C. japonica*		*Ch. obtusa*		*L. leptolepis*				*Z. serrata*	*A. firma*	*T. canadensis*	*A. decurrens* v. *dealbata*	*Q. mongolica* v. *grosseserrata*	*B. platyphylla* v. *japonica*	*B. davurica*
Stand	S 25	S 9	H 8	H 6	K 11	K 25	K 3	K 7	M 4	M 5	M 6	M 7	M 8	M 9	M 10
Basal area (cm^2)	328	337	126	91	310	273	183	128	188	156	211	135	214	96	185
Soil type	Bl_D(w)	Bl_D(d)	Bl_D	B_B	Bl_D	Bl_D(d)	Bl_E	Bl_G	Bl_D	Bl_D	Bl_D	Er	Bl_D	Bl_D	Bl_D
Maximum depth of root (cm)	214	150	118	87	145	81	184	62	193	329	151	133	145	80	95

Table 78. Tree density and maximum depth of root

Species	*C. japonica*		*P. densiflora*		
Stand	S 22	S 26	A 10	A 11	A 12
Basal area (cm^2)	419	425	18	32	49
Soil type	B_E	$Bl_D(w)$	B_A	B_A	B_A
Density index	1.2	0.4	1.2	0.9	0.6
Maximum depth of root (cm)	278	205	155	134	134

Table 79. Errors of the regression equations for maximum depth of root (%)[17]

Species	Stand	Trees	Equation						
			①	②	③	④	⑤	⑥	⑦
C. japonica	S 13	15	3	3	3	4	3	4	3
	S_T	79	21	21	22	19	15	21	7
Ch. obtusa	H 3	6	6	6	6	6	6	5	—
	H_T	36	9	12	10	15	11	16	3
P. densiflora	A 2	23	15	15	15	15	24	15	14
	A_T	63	—	18	18	13	22	—	7
L. leptolepis	K 1	9	7	8	7	5	5	8	—
	K_T	51	18	18	18	19	23	20	18

growth is promoted as the stand density increases.

Expressions for the maximum depth of roots and their errors : When the maximum depth is calculated according to equations ① to ⑦ as a function of the basal area and the tree height, the coefficients, constants, and errors of the regression equations are shown in the preceding number. The variation coefficients in a stand and all the stands of each species are shown in Table 79. The errors each equation had within a stand were 3% or 4%. However, they were 15% to 22%, and 5 to 7 times larger in equation ⑦ because the soil condition and density, which had an influence on the depth of roots, were different from one stand to another. The error was 7% by equation ⑦. When the items, relative to the maximum depth, were chosen, it was much smaller than those errors by the others.

The largest variation coefficient was that of *P. densiflora*, followed by those of *L. leptolepis*, *Ch. obtusa* and *C. japonica* in that order. The variation was large for *P. densiflora* as its main roots grew remarkably long with large variation. *L. leptolepis* showed the second largest be-

Table 80. Regression coefficients of equation ④ applied to the investigated trees of each stand in a lot

Species	Stand	Sample tree	Regression coefficient (%)
C. japonica	S_T	79	19
Ch. obtusa	H_T	36	13
P. densiflora	A_T	63	48
L. leptolepis	K_T	51	20

cause the growth of roots was easily affected by the habitat conditions.

When the maximum depth of roots in a stand was expressed as a function of the basal area with equation ④, the largest regression coefficient was that of *P. densiflora*, followed by those of *L. leptolepis*, *C. japonica*. *P. densiflora* with a tap root had a strikingly large coefficient (Table 80).

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森林生産の場における根系の機構と機能 III

根密度と根系の吸収構造

苅住　昇(1)

摘要

森林の生産を支える根系の構造と働きについて，さきに林業試験場研究報告第259号17)では「根系調査と根量推定の方法」について，第267号18)ではスギ，ヒノキ，アカマツ，カラマツ林その他の林分における「根量とその分布」について報告した。この号では以上の研究に関連し，これらの資料から林分の根密度と吸収構造を解析，研究した。

地下部の構造の解析において一定土壌体積当たり根量としての根密度の考え方は有効な手がかりとなる。根密度の考えを取入れることによつて調査土壌体積がそれぞれ異なる部分の根量についてもこれを同じウェイトで比較検討することが可能であり，林床の一部の根密度測定から林分の根量分布を推定することができる。

林木の生産に関係が深い細根について，その分布が最も多いI層の根密度は成木安定林分でスギ・カラマツ200，ヒノキ400，アカマツ40，幼齢最大時にはスギ・ヒノキ600，アカマツ200，カラマツ100程度となった。

密植・乾燥林分では細根の根密度は増加するがスギ・ヒノキ1,000，アカマツ400，カラマツ300以上になることはきわめて少なく，このような高い根密度になる林分は一般には表土の浅い乾燥土壌で，このような立地では生産の低下と根系の競争が考えられた。

I層の細根の根密度は閉鎖した成木林ではほぼ一定になるが，これはha当たり細根量のところでも述べたように地上部の同化生産の担い手である葉量と地下部の養・水分吸収の主体をなす細根量が一定の均衡を保つことを示すもので，特に腐植と無機塩類に富むI層の根密度でこれらの対応が明らかであることは表層の一定の細根量が森林の生産を支えていることを意味するものである。

林分内における根密度は幼齢時には根株の周囲で高いが林分の成長に伴って根株から離れた隣接木の中間付近の根密度が高まり，通常の林分では林齢20～25年で水平区分による差がほとんど無くなる。

この林分の成長に伴う根密度の平均化は先ず表層でおこって次第に深部に達するが，III層以下では根系の交錯は著しく少なくなる。またこの傾向は細根・小径根で著しく，大根以上ではほとんど見られない。林分内における根密度の平均化傾向は高密度林分や表土が浅い乾燥林分で顕著である。

養水分は根系の表面を通って樹体内にとり入れられる。このため根系の表面積は林木の生長の基礎となっている養・水分の吸収作用と密接に関係している。このため土壌中の根系表面積分布を明らかにすることによって林木の吸収構造を解析すをことができる。

1976年5月8日受理

(1)　造林部

根系表面積は養・水分の吸収に関係する直接的な因子であるが単木の根系・表面積は胸高断面積500cm^{2}でスギ22m^2，ヒノキ35m^2，アカマツ9m^2，カラマツ15m^{2}となり，ヒノキは最も吸収表面積が大きくて，アカマツは小さい。

ha当たり根系表面積は成木安定林分のほぼ一定になったところでスギは1.5ha，ヒノキ2.5ha，アカマツ0.5ha，カラマツ1.0haとなり，ヒノキは他の樹種に比べて著しく大きくてアカマツは小さい。これはヒノキは吸収表面積の大部分を占める細根が多く，アカマツは少ないことによっている。

林木の大きさに対する根系表面積の変化曲線は，林齢20〜25年生で最大となり，スギは3.5ha，ヒノキは3ha，アカマツ2ha，カラマツ1.5haで，根量よりも著しい増加傾向が見られた。この根系表面積の増加は養・水分の吸収量の増加を通じて直接林木の成長に影響しているものと推察できた。

ha当たり根系表面積は本数密度・立地条件によって異なり，乾燥・最多密度でスギは4ha，ヒノキ5ha，アカマツ1.7ha，カラマツ1.2haとなり，湿潤・最多密度条件でスギ1.2ha，ヒノキ2.0ha，アカマツ0.4ha，カラマツ0.6ha，適潤条件ではスギ2.5ha，ヒノキ2.3ha，アカマツ1.0ha，カラマツ0.8haとなった。

全根系表面積を構成する各部分の割合は細根が最大でスギでは細根が58%，小径根が16%を占め，両者で全根系表面積の74%を占めた。他の樹種も同様であるが特に細根・小径根が多いヒノキはその表面積が83%を占める。

総根量では大径根以上の蓄積部分がその大部分であったが，根系表面積では細根・小径根が大部分で根の働きに対応した変化を示し，この点でも林木の吸収作用を指標するには根量よりも根系表面積が適当であることがわかった。

平均胸高断面積500cm^{2}程度の大きさの林分の根系表面積の垂直分布は地表から15cmのⅠ層にはスギ38%，ヒノキ47%，アカマツ38%，カラマツ48%が，Ⅰ・Ⅱ層の30cmの間にはスギは59%，ヒノキ69%，アカマツ57%，カラマツ73%が分布し，スギ，アカマツの吸収構造はヒノキ，カラマツよりも下層で大きいことがわかった。深さ150〜180cmのⅤ層ではスギ5.4%，ヒノキ2.7%，アカマツ4.7%，カラマツ1.2%で上記のことが一層明らかであった。

この根系表面積が指標する吸収構造は表土の浅い残積土のせき悪乾燥地や過湿地では表層に片寄って，Ⅰ・Ⅱ層での割合は何れも80〜90%に達する。また過湿地や，通気が悪い下層土では細根の枯死による吸収構造の崩壊が認められた。

Appendix　Table 1. Ratio of each root biomass in each soil horizon to the total (%)

* Horizon	f ***	s	m	l	L
S 1**					
Ⅰ	49.6	41.5	44.7	46.8	100
Ⅱ	25.6	28.9	30.1	24.9	
Ⅲ	23.6	27.3	22.1	28.3	
Ⅳ	1.2	2.3	3.1		
S 2					
Ⅰ	47.8	37.2	27.8	12.4	55.1
Ⅱ	14.1	16.6	16.1	15.3	26.9
Ⅲ	21.1	25.4	30.5	57.4	18.0
Ⅳ	13.9	15.2	16.6	14.9	
Ⅴ	3.1	5.6	9.0		
S 3					
Ⅰ	59.8	47.1	46.5	37.6	53.6
Ⅱ	14.9	14.6	20.1	33.1	31.8
Ⅲ	15.6	23.5	23.7	28.7	14.6
Ⅳ	9.1	13.6	9.3	0.6	
Ⅴ	0.6	1.2	0.4		
S 4					
Ⅰ	40.7	33.8	29.1	21.2	40.1
Ⅱ	15.1	13.5	14.4	24.3	27.9
Ⅲ	25.1	29.7	30.1	36.1	28.4
Ⅳ	14.9	15.8	15.7	15.1	3.6
Ⅴ	4.2	7.2	10.7	3.3	
S 5					
Ⅰ	41.5	31.8	23.2	12.8	26.5
Ⅱ	17.7	17.5	15.9	22.3	32.8
Ⅲ	22.3	21.2	32.1	39.9	32.9
Ⅳ	11.9	20.0	17.1	19.7	6.7
Ⅴ	6.6	9.5	11.6	5.3	1.1
S 6					
Ⅰ	73.5	54.4	46.6	60.2	100
Ⅱ	9.8	19.2	29.4	39.8	
Ⅲ	8.6	14.4	21.0		
Ⅳ	6.1	7.2	1.3		
Ⅴ	2.0	4.8	1.7		
S 7					
Ⅰ	56.0	50.9	36.4	40.4	100
Ⅱ	16.5	13.9	19.6	33.4	
Ⅲ	17.6	17.6	24.4	21.3	
Ⅳ	7.6	12.8	13.4	4.9	
Ⅴ	2.3	4.8	6.2		
S 8					
Ⅰ	32.5	30.4	20.4	20.6	77.6
Ⅱ	16.4	10.4	12.9	14.9	22.4
Ⅲ	25.5	19.3	25.9	49.6	
Ⅳ	19.0	22.5	27.0	13.7	
Ⅴ	6.6	17.4	13.8	1.2	
S 9**					
Ⅰ	51.6	37.6	34.0	29.1	57.0
Ⅱ	11.7	12.9	13.5	25.7	21.9
Ⅲ	21.5	27.4	29.8	38.8	20.1
Ⅳ	12.0	15.4	19.3	6.4	1.0
Ⅴ	3.2	6.7	3.4		
S 10					
Ⅰ	57.7	50.3	35.4	38.4	92.1
Ⅱ	16.6	15.4	17.0	27.9	7.9
Ⅲ	14.3	14.4	25.8	29.2	
Ⅳ	9.1	15.1	15.9	4.5	
Ⅴ	2.3	4.8	5.9		
S 11					
Ⅰ	83.3	80.4	80.4	98.8	
Ⅱ	12.8	13.7	15.0	1.2	
Ⅲ	3.9	5.9	4.6		
S 12					
Ⅰ	46.3	42.6	40.6	35.3	49.2
Ⅱ	14.1	13.0	16.8	20.1	24.3
Ⅲ	21.5	23.9	24.1	31.9	24.0
Ⅳ	13.4	14.5	17.7	10.1	2.5
Ⅴ	4.7	6.0	0.8	2.6	
S 13					
Ⅰ	52.1	57.1	55.8	42.5	72.5
Ⅱ	16.3	14.4	15.2	32.1	17.3
Ⅲ	21.6	21.0	19.9	18.7	10.2
Ⅳ	8.9	6.1	5.8	5.6	
Ⅴ	1.1	1.4	3.3	1.1	
Ⅵ	1.2	1.9	1.5	1.9	2.0
S 14					
Ⅰ	61.8	67.1	63.7	51.0	88.2
Ⅱ	13.1	9.3	9.1	29.5	11.8
Ⅲ	22.7	21.5	25.3	18.4	
Ⅳ	1.4	1.0	0.4	0.3	
Ⅴ	1.0	1.1	1.5	0.8	
S 15					
Ⅰ	40.6	37.6	29.1	15.6	21.8
Ⅱ	14.5	18.7	17.9	20.8	35.0
Ⅲ	36.2	32.7	34.2	38.5	36.7
Ⅳ	6.9	7.9	10.6	19.0	5.9
Ⅴ	1.8	3.1	8.2	6.1	0.6
S 16					
Ⅰ	45.1	41.3	32.3	18.2	30.3
Ⅱ	10.5	8.5	15.2	26.2	29.6
Ⅲ	32.6	35.5	28.7	38.8	34.4
Ⅳ	8.2	9.3	15.3	12.0	5.3
Ⅴ	3.6	5.4	8.5	4.8	0.4

* Horizon : Ⅰ 0～15 cm, Ⅱ 15～30 cm, Ⅲ 30～60 cm, Ⅳ 60～90 cm, Ⅴ 90～120 cm……each horizon 30 cm, see page 10 in the literature No. 17

** Stand No. See appendix-Table in the literature No. 17

*** f : Fine root, s : Small root, m : Medium root, l : Large root, L : Very large root. See page 15 in the literature No. 17

Appendix-Table 1. (continued)

Horzion	f	s	m	l	L	Horizon	f	s	m	l	L
S 17						S 25					
Ⅰ	59.7	53.4	40.6	41.0	32.7	Ⅰ	49.6	42.8	28.9	30.0	61.6
Ⅱ	7.0	8.8	10.9	13.2	18.5	Ⅱ	15.7	16.0	21.8	29.4	22.4
Ⅲ	24.7	26.2	31.9	23.9	25.4	Ⅲ	20.0	22.6	28.3	32.0	15.2
Ⅳ	5.3	5.7	8.5	10.7	17.6	Ⅳ	11.2	13.5	14.0	8.2	0.8
Ⅴ	2.1	4.0	6.6	9.3	3.8	Ⅴ	3.5	5.1	7.0	0.4	
S 18						S 26					
Ⅰ	33.5	20.8	13.1	9.5	26.8	Ⅰ	40.3	32.7	26.1	17.2	40.8
Ⅱ	17.6	19.3	16.9	16.2	33.1	Ⅱ	15.2	15.9	19.0	25.0	32.6
Ⅲ	25.1	24.3	33.5	47.5	31.1	Ⅲ	26.5	27.7	31.4	40.2	22.9
Ⅳ	17.0	21.8	25.4	20.3	7.0	Ⅳ	13.1	16.7	17.0	14.1	3.0
Ⅴ	6.8	13.8	11.1	6.5	2.0	Ⅴ	4.9	7.0	6.5	3.5	0.7
S 19						S 27					
Ⅰ	42.9	34.5	25.0	20.0	47.8	Ⅰ	39.0	30.8	24.4	15.2	39.9
Ⅱ	17.5	15.3	18.2	22.0	24.2	Ⅱ	14.0	15.3	16.2	24.4	33.8
Ⅲ	21.3	23.3	32.9	43.0	24.5	Ⅲ	26.8	27.1	33.4	41.0	22.0
Ⅳ	14.3	21.4	19.1	11.5	3.1	Ⅳ	14.6	19.2	18.5	15.0	3.1
Ⅴ	4.0	5.5	4.8	3.5	0.4	Ⅴ	5.6	7.6	7.5	4.4	1.2
S 20						H 1					
Ⅰ	58.5	47.0	34.0	35.0	72.0	Ⅰ	70.8	68.4	62.9	64.4	100
Ⅱ	19.0	23.6	25.5	33.7	28.0	Ⅱ	21.3	20.2	28.0	33.7	
Ⅲ	13.4	25.1	32.0	29.1		Ⅲ	7.9	11.4	9.1	1.9	
Ⅳ	7.4	3.9	8.0	2.2							
Ⅴ	1.7	0˙4	0.5								
S 21						H 2					
Ⅰ	65.1	60.8	41.7	51.1	92.7	Ⅰ	63.5	57.5	56.7	60.8	76.9
Ⅱ	18.3	19.4	18.8	36.6	7.3	Ⅱ	17.3	27.4	27.3	30.5	23.1
Ⅲ	11.0	11.1	30.5	11.8		Ⅲ	18.1	14.0	15.7	8.7	
Ⅳ	5.6	8.7	9.0	0.5		Ⅳ	1.1	1.1	0.3		
S 22						H 3					
Ⅰ	40.5	20.8	13.1	11.6	13.9	Ⅰ	55.0	44.7	41.8	38.8	62.5
Ⅱ	12.3	19.3	16.9	12.2	32.9	Ⅱ	14.4	27.7	25.4	37.0	32.5
Ⅲ	18.0	24.3	33.5	43.0	39.8	Ⅲ	21.2	22.2	31.5	22.6	5.0
Ⅳ	19.9	21.8	25.4	21.4	12.0	Ⅳ	8.0	4.2	1.3	1.6	
Ⅴ	9.3	13.8	11.1	11.8	1.4	Ⅴ	1.4	1.2			
S 23						H 4					
Ⅰ	51.7	42.7	32.0	34.5	83.5	Ⅰ	57.1	50.1	44.1	45.2	56.0
Ⅱ	16.4	16.3	18.0	28.1	15.5	Ⅱ	21.4	26.5	26.7	38.2	38.4
Ⅲ	20.1	27.9	31.7	27.5	1.0	Ⅲ	17.0	17.3	27.3	15.5	5.6
Ⅳ	10.1	10.7	13.7	9.1		Ⅳ	2.9	4.1	1.9	1.1	
Ⅴ	1.7	2.4	4.6	0.8		Ⅴ	1.6	2.0			
S 24						H 5					
Ⅰ	62.8	60.6	42.6	49.7	97.5	Ⅰ	49.3	36.8	33.0	41.4	48.4
Ⅱ	15.6	13.8	15.4	35.5	2.5	Ⅱ	18.1	18.5	21.0	33.3	42.5
Ⅲ	15.0	14.7	28.7	10.3		Ⅲ	17.6	29.0	38.6	23.9	9.1
Ⅳ	6.2	9.9	11.0	4.5		Ⅳ	11.7	9.2	7.4	1.4	
Ⅴ	0.4	1.0	2.3			Ⅴ	3.3	6.5			

Appendix-Table 1. (continued)

Horizon	f	s	m	l	L
H6					
I	83.4	75.0	64.7	55.7	88.7
II	10.0	15.0	27.9	43.6	11.3
III	6.1	8.5	7.1	0.7	
IV	0.5	1.5	0.3		
H7					
I	52.3	60.1	49.5	43.9	67.1
II	10.0	13.0	17.4	39.1	26.5
III	26.0	22.4	29.1	16.1	6.4
IV	7.3	1.9	4.0	0.9	
V	4.4	2.6			
H8					
I	68.0	62.2	58.2	52.0	85.1
II	14.7	25.2	23.0	41.5	14.9
III	15.7	11.2	17.6	5.9	
IV	1.4	1.1	1.2	0.6	
V	0.2	0.3			
A1					
I	63.7	54.4	64.3	87.8	
II	17.3	22.8	18.3	12.2	
III	11.8	15.8	13.0		
IV	3.6	5.2	3.5		
V	2.7	1.8	0.9		
VI	0.9				
A2					
I	57.4	47.4	57.2	54.8	71.2
II	14.3	18.6	20.5	21.3	15.8
III	17.4	24.5	14.1	22.2	13.0
IV	6.1	6.7	5.0	1.7	
V	3.5	2.0	2.6		
VI	1.3	0.8	0.6		
A3					
I	50.7	35.8	45.7	37.3	60.9
II	14.3	16.6	19.2	28.3	20.1
III	13.8	23.6	18.0	24.4	16.6
IV	8.5	10.0	6.0	6.5	1.4
V	6.8	6.0	6.3	3.5	1.0
VI	2.5	3.7	2.5		
VII	1.8	2.1	1.4		
VIII	1.0	1.2	0.8		
IX	0.3	0.7	0.1		
X	0.3	0.3			
A4					
I	61.1	25.0	35.8	36.7	44.7
II	10.0	18.9	14.1	22.9	32.9
III	11.7	18.1	20.0	24.0	13.0
IV	5.6	10.8	6.4	9.3	6.5
V	3.2	8.3	8.6	6.0	2.9
VI	1.8	5.1	4.9	1.1	
VII	2.1	5.0	3.9		
VIII	1.2	3.3	2.4		
IX	1.6	2.5	2.1		
X	0.9	1.6	1.0		
XI	0.7	1.4	0.8		

Horizon	f	s	m	l	L
A5					
I	59.1	72.0	66.7	61.4	75.6
II	21.8	13.6	19.4	24.0	24.4
III	14.9	10.6	9.5	14.6	
IV	3.3	3.8	4.4		
V	0.9				
A6					
I	89.3	82.9	89.7	58.1	
II	6.3	10.3	8.4	32.7	
III	3.7	5.7	1.9	9.2	
IV	0.7	1.1			
A7					
I	30.0	27.2	25.7	17.8	87.1
II	48.0	40.3	45.2	43.4	12.9
III	11.5	17.2	17.6	16.8	
IV	5.9	7.3	7.7	11.0	
V	4.0	7.3	3.8	11.0	
VI	0.5	0.7			
A8					
I	47.1	29.5	39.5	39.2	46.6
II	10.4	13.7	14.6	23.8	37.2
III	18.3	25.9	18.9	20.0	9.0
IV	8.7	16.1	8.7	9.8	5.1
V	4.9	4.8	7.9	7.2	2.1
VI	4.5	4.4	4.2		
VII	3.2	2.3	2.6		
VIII	1.1	1.4	1.7		
IX	0.8	1.0	1.4		
X	0.6	0.5	0.4		
XI	0.4	0.4	0.1		
A9					
I	56.4	32.7	43.6	34.5	55.8
II	12.1	21.6	18.4	28.8	26.0
III	13.5	22.0	19.0	26.1	16.5
IV	8.8	9.2	6.5	7.2	1.7
V	4.8	5.3	5.0	3.4	
VI	1.7	4.0	3.1		
VII	1.7	2.3	2.2		
VIII	0.5	1.6	1.5		
IX	0.3	0.8	0.7		
X	0.2	0.5			
A10					
I	64.9	67.2	69.0	100	
II	22.2	18.6	21.3		
III	9.7	12.7	9.7		
IV	3.2	1.5			
A11					
I	61.2	59.7	66.7	78.6	
II	19.4	17.2	15.4	17.2	
III	13.6	18.9	12.5	4.2	
IV	5.0	3.0	3.6		
V	0.8	1.2	1.8		

Appendix-Table 1. (continued)

Horizon	f	s	m	l	L
A12					
Ⅰ	63.3	61.3	67.9	74.5	
Ⅱ	20.2	17.3	17.5	25.5	
Ⅲ	11.8	17.8	11.9		
Ⅳ	3.7	2.6	2.4		
Ⅴ	1.0	1.0	0.3		
A13					
Ⅰ	52.8	49.0	55.4	83.1	
Ⅱ	16.3	24.6	24.9	16.9	
Ⅲ	16.7	12.3	10.3		
Ⅳ	8.8	8.8	7.3		
Ⅴ	5.4	5.3	2.1		
A14					
Ⅰ	59.2	46.6	52.1	47.2	70.2
Ⅱ	24.5	29.4	24.1	32.2	21.3
Ⅲ	10.2	17.5	15.7	20.6	8.5
Ⅳ	6.1	6.5	8.1		
A15					
Ⅰ	54.3	42.4	68.8		
Ⅱ	20.0	30.5	23.0		
Ⅲ	16.3	20.3	8.2		
Ⅳ	9.4	6.8			
A16					
Ⅰ	54.4	56.2	88.4	91.9	
Ⅱ	20.0	21.9	7.7	8.1	
Ⅲ	18.6	15.6	2.6		
Ⅳ	4.3	3.1	0.8		
Ⅴ	1.4	1.6	0.5		
Ⅵ	1.3	1.6			
A17					
Ⅰ	37.3	39.4	33.1	47.1	
Ⅱ	25.0	27.3	28.0	34.3	
Ⅲ	12.5	3.0	19.7	12.7	
Ⅳ	11.3	3.0	10.4	5.9	
Ⅴ	8.8	21.2	5.2		
Ⅵ	3.8	6.1	3.6		
Ⅶ	1.3				
A18					
Ⅰ	55.0	61.8	73.3	90.9	
Ⅱ	23.3	19.1	25.6	9.1	
Ⅲ	21.7	19.1	1.1		
A19					
Ⅰ	87.8	63.8	81.6		
Ⅱ	7.3	17.2	18.4		
Ⅲ	3.3	13.8			
Ⅳ	1.6	5.2			

Horizon	f	s	m	l	L
K1					
Ⅰ	58.9	40.0	27.6	15.4	45.1
Ⅱ	17.4	27.9	20.9	28.6	29.5
Ⅲ	17.4	23.8	29.8	38.0	23.8
Ⅳ	6.0	7.5	12.9	13.3	1.6
Ⅴ	0.3	0.8	8.8	4.7	
K2					
Ⅰ	74.8	51.4	40.6	35.6	74.6
Ⅱ	13.1	27.1	34.4	35.0	16.9
Ⅲ	9.6	18.8	20.4	25.3	8.1
Ⅳ	2.5	2.7	4.6	4.1	0.4
K3					
Ⅰ	66.8	44.0	36.1	28.3	51.2
Ⅱ	16.8	28.2	28.4	33.1	27.8
Ⅲ	14.9	24.3	29.1	34.5	20.1
Ⅳ	1.5	3.5	6.4	4.1	0.9
K4					
Ⅰ	76.9	66.3	51.5	43.5	71.3
Ⅱ	13.0	18.5	38.6	37.2	24.2
Ⅲ	8.7	13.9	8.0	19.3	4.5
Ⅳ	1.4	1.3	1.9		
K5					
Ⅰ	76.7	73.2	47.9	50.9	67.3
Ⅱ	17.5	17.6	39.9	41.6	26.5
Ⅲ	5.8	9.2	12.2	7.5	6.2
K6					
Ⅰ	81.2	76.2	58.2	48.6	74.2
Ⅱ	15.9	19.7	36.7	47.2	25.8
Ⅲ	2.9	4.1	5.1	4.2	
K7					
Ⅰ	86.2	78.9	60.1	48.9	83.5
Ⅱ	11.8	14.7	27.6	36.4	16.5
Ⅲ	2.0	6.4	12.3	13.2	
Ⅳ				1.5	
K8					
Ⅰ	71.8	64.1	46.3	35.2	66.0
Ⅱ	13.0	18.9	36.2	31.9	34.0
Ⅲ	14.1	15.4	13.5	29.1	
Ⅳ	1.1	1.6	4.0	3.8	

Appendix-Table 1. (continued)

Horizon	f	s	m	l	L
K9					
Ⅰ	71.5	66.6	40.2	25.8	56.4
Ⅱ	15.3	18.4	32.5	37.0	32.0
Ⅲ	12.2	14.0	21.1	26.6	11.6
Ⅳ	1.0	1.0	6.2	10.6	
K10					
Ⅰ	84.7	57.7	43.5	36.2	65.0
Ⅱ	6.8	25.7	33.0	36.4	26.5
Ⅲ	8.5	14.5	18.4	22.2	8.5
Ⅳ		2.1	5.1	5.2	
K11					
Ⅰ	70.3	42.9	35.1	22.9	38.8
Ⅱ	13.4	25.8	27.0	25.0	40.0
Ⅲ	12.0	20.7	27.4	32.8	21.2
Ⅳ	3.9	10.1	9.0	14.3	
Ⅴ	0.4	0.5	1.5	5.0	
K12					
Ⅰ	73.1	55.0	39.7	31.2	50.0
Ⅱ	18.1	24.9	25.9	30.6	34.9
Ⅲ	4.6	14.4	27.0	26.7	15.1
Ⅳ	4.2	5.7	7.4	11.5	
K13					
Ⅰ	61.8	44.4	28.8	18.5	35.0
Ⅱ	15.2	20.7	16.8	25.8	36.9
Ⅲ	14.5	22.1	30.0	34.2	27.1
Ⅳ	8.0	11.8	16.0	18.2	1.0
Ⅴ	0.5	1.0	8.4	3.3	
K14					
Ⅰ	51.2	36.0	26.7	22.1	44.5
Ⅱ	19.7	22.0	26.1	15.9	21.5
Ⅲ	22.1	31.7	30.1	31.8	23.5
Ⅳ	5.1	7.2	12.0	20.5	10.5
Ⅴ	1.9	3.1	5.1	9.7	
K15					
Ⅰ	63.8	61.8	49.4	30.0	46.5
Ⅱ	17.3	16.2	16.8	22.5	32.0
Ⅲ	12.5	14.3	23.3	30.1	21.5
Ⅳ	6.0	7.4	10.5	17.4	
Ⅴ	0.4	0.3			
K16					
Ⅰ	76.8	70.2	52.9	37.7	60.4
Ⅱ	17.1	19.4	30.1	31.8	23.9
Ⅲ	5.3	8.5	13.8	23.8	15.7
Ⅳ	0.8	1.9	3.2	6.7	
K17					
Ⅰ	69.7	53.9	44.3	35.4	47.9
Ⅱ	13.7	18.4	25.0	28.1	32.1
Ⅲ	13.0	21.5	25.2	30.0	20.0
Ⅳ	3.2	5.9	5.5	6.5	
Ⅴ	0.4	0.3			
K18					
Ⅰ	60.5	52.6	44.2	30.3	38.0
Ⅱ	22.7	19.5	21.6	32.5	39.0
Ⅲ	14.9	25.1	30.8	29.2	23.0
Ⅳ	1.6	2.2	3.0	8.0	
Ⅴ	0.3	0.6	0.4		
K19					
Ⅰ	65.3	51.8	41.6	28.7	56.7
Ⅱ	21.1	26.1	22.4	22.5	24.0
Ⅲ	12.4	19.0	29.4	34.3	18.0
Ⅳ	1.0	2.1	6.0	14.5	1.3
Ⅴ	0.2	1.0	0.6		
K20					
Ⅰ	62.4	44.3	32.8	20.3	44.3
Ⅱ	16.7	22.4	25.5	15.4	22.3
Ⅲ	17.8	27.7	32.0	35.0	30.2
Ⅳ	2.3	4.6	7.1	19.2	3.2
Ⅴ	0.8	1.0	2.6	10.1	
K21					
Ⅰ	58.8	43.6	33.5	21.6	46.0
Ⅱ	21.5	26.7	26.2	20.4	28.7
Ⅲ	15.6	23.5	32.3	33.8	23.1
Ⅳ	3.6	5.3	6.4	17.2	2.2
Ⅴ	0.5	0.9	1.6	7.0	
K22					
Ⅰ	59.2	42.4	31.1	19.5	43.0
Ⅱ	23.8	26.6	24.2	18.3	25.1
Ⅲ	13.2	25.0	35.3	34.6	29.5
Ⅳ	3.1	5.3	7.6	19.2	2.4
Ⅴ	0.7	0.7	1.8	8.4	
K23					
Ⅰ	69.9	70.1	52.3	44.9	61.9
Ⅱ	18.6	17.9	25.1	30.6	12.6
Ⅲ	11.5	12.0	22.6	24.5	25.5
K24					
Ⅰ	65.8	54.4	43.5	35.0	55.1
Ⅱ	20.9	26.3	29.9	25.6	26.5
Ⅲ	10.2	14.1	23.5	29.6	18.4
Ⅳ	3.1	4.8	3.1	9.8	
Ⅴ		0.4			

Appendix-Table 1. (continued)

Horizon	f	s	m	l	L
K25					
I	67.0	55.5	41.7	26.7	57.5
II	24.1	26.8	26.5	24.8	25.3
III	7.3	14.4	23.1	32.5	16.5
IV	1.4	3.0	8.2	14.1	0.7
V	0.2	0.3	0.5	1.9	
K26					
I	73.2	72.1	54.0	45.6	70.4
II	14.3	16.0	29.5	32.5	16.3
III	11.0	9.9	14.7	21.9	13.3
IV	1.5	2.0	1.8		
K27					
I	59.2	43.0	39.9	25.7	55.1
II	18.4	28.9	25.5	22.7	21.9
III	17.2	20.8	27.0	35.3	22.4
IV	4.7	6.7	6.6	13.0	0.6
V	0.5	0.6	1.0	3.3	
K28					
I	56.4	47.9	44.4	27.5	40.4
II	21.4	23.2	29.3	14.1	18.7
III	19.3	22.9	20.0	37.1	31.9
IV	1.9	3.9	5.9	20.1	9.0
V	1.0	2.1	0.4	1.2	
K29					
I	83.4	68.9	52.4	42.6	60.9
II	9.6	20.8	23.3	31.5	25.9
III	6.4	9.9	19.8	20.3	13.2
IV	0.6	0.4	4.5	5.6	
M1					
I	70.6	65.2	60.9	68.5	100
II	17.8	27.0	26.5	17.7	
III	11.0	7.4	11.9	13.8	
IV	0.6	0.4	0.7		
M2					
I	55.1	47.0	45.1	43.1	65.0
II	20.7	27.1	25.3	40.0	35.0
III	11.4	20.3	25.6	16.9	
IV	9.5	5.0	4.0		
V	3.3	0.6			
M3					
I	58.1	48.6	67.3	66.1	84.3
II	31.3	41.1	28.8	33.9	15.7
III	9.1	9.2	3.9		
IV	1.5	1.1			
M4					
I	84.6	77.0	37.7	47.6	52.6
II	3.2	4.4	16.7	27.2	12.2
III	6.5	10.8	18.3	11.8	25.6
IV	2.9	4.0	11.4	7.8	8.6
V	1.8	1.8	9.0	4.1	1.0
VI	0.6	1.3	4.4	1.5	
VII	0.4	0.7	2.5		
M5					
I	52.8	52.5	65.4	58.0	100
II	13.3	10.8	7.1	16.5	
III	18.8	17.9	14.9	8.2	
IV	7.3	10.6	3.5	6.4	
V	3.0	4.3	4.0	5.2	
VI	2.4	2.8	3.4	5.7	
VII	2.4	1.1	1.7		
M6					
I	55.7	57.2	51.3	58.2	100
II	10.2	11.4	23.3	24.6	
III	16.3	15.9	18.3	14.9	
IV	13.3	12.4	6.1	2.3	
V	3.5	2.3	0.8		
VI	1.0	0.8	0.2		
M7					
I	88.7	91.0	92.9	65.2	57.9
II	6.6	4.4	4.3	20.1	28.0
III	3.6	3.6	2.2	11.4	12.6
IV	1.1	1.0	0.6	3.3	1.5
M8					
I	60.2	61.3	45.2	32.1	28.4
II	12.4	11.4	19.4	45.0	52.2
III	24.5	21.5	25.0	21.1	19.4
IV	2.3	5.3	10.4	1.8	
V	0.6	0.5			
M9					
I	71.5	70.2	61.2	41.0	51.2
II	12.3	13.0	10.8	20.5	36.5
III	10.5	10.2	15.2	31.2	12.3
IV	5.7	6.6	12.8	7.3	
M10					
I	62.5	60.8	54.5	40.5	45.2
II	20.1	18.5	15.3	31.2	50.0
III	15.3	16.0	17.2	25.0	4.8
IV	2.1	4.7	13.0	3.3	

Appendix

Table 2. Physical and chemical properties

Location	Stand	Soil type	Horizon	Thickness of horizon (cm)	Volume weight (g/100cc)	Specific gravity of fine soil	Volume composition of soil in the field condition (%)					Min. air capacity (%)
							Solid			Water	Air	
							Fine soil	Gravel	Root			
Onokoyama	S 1	Bl_E	A_1	20	51.7	—	18.3	2.5	0.2	60.2	18.8	6.5
			A_2	35	52.0	—	19.2	3.7	0.1	61.5	15.5	5.0
			A-B	60	55.3	—	20.2	1.0	—	64.7	14.1	4.2
			B	40+	59.2	—	20.8	0.4	—	68.0	10.8	2.1
	S 2	Bl_D	A_1	15	52.3	—	20.2	1.6	0.4	53.0	24.8	8.4
			A_2	25	53.0	—	18.0	1.0	0.2	59.1	21.7	7.2
			A-B	40	55.2	—	19.5	2.5	0.1	60.4	17.5	5.4
			B	40+	60.7	—	21.2	—	—	64.5	14.3	4.0
	S 3	Bl_D(d)	IA_1	7	61.4	2.47	24.0	3.2	0.3	51.7	20.8	5.4
			IB_2	10	56.9	2.62	21.3	1.8	0.1	56.8	20.0	6.7
			IB	30	49.7	2.59	19.1	0.1	0.6	66.9	13.3	4.3
			ⅡA	50	46.6	2.62	17.8	—	0.1	64.7	17.4	3.6
			ⅡB	30+	56.9	2.59	21.5	0.6	0.2	68.0	9.7	3.1
	S 4	Bl_D	A_1	10	54.4	2.49	20.7	4.8	0.2	54.1	20.2	8.3
			A_2	20	57.1	2.56	21.5	3.2	0.7	55.4	19.2	6.3
			B_1	25	51.7	2.67	19.3	0.4	0.1	63.8	16.4	5.7
			B_2	45	63.1	2.75	22.8	0.3	0.2	64.8	11.9	4.1
			C	35+	71.6	2.77	25.7	0.5	0.1	63.6	10.1	3.3
	S 5	Bl_D(w)	A_1	15	50.7	2.51	19.5	2.4	0.9	52.9	24.3	8.0
			A_2	30	56.7	2.52	22.0	2.1	0.3	56.4	19.2	6.9
			A'_1	25	47.7	2.66	17.5	2.5	0.1	50.8	29.1	9.0
			A'_2	40	57.2	2.73	20.8	0.2	—	57.8	21.1	7.0
			B	30+	58.4	2.91	20.1	0.5	0.1	62.4	16.9	4.9
	S 6	Bl_A	A_2	10	57.0	—	22.1	2.3	1.1	47.3	27.2	12.8
			B_1	17	51.7	—	19.0	5.7	0.1	54.2	21.0	5.1
			B_2	12	50.6	—	18.9	1.2	0.1	48.0	31.8	6.9
			C_1	15	51.2	—	18.5	6.1	0.2	49.7	25.5	13.9
	S 7	Bl_C	A_1	8	48.8	—	21.5	5.4	0.5	45.0	27.6	8.0
			A_2	20	50.7	—	19.3	5.2	0.2	46.4	28.9	7.5
			B_1	50	55.8	—	21.5	1.1	0.2	51.6	25.6	5.7
			B_2	40	54.5	—	20.6	0.1	0.1	54.0	25.2	4.5
			C	40+	53.3	—	19.6	0.1	0.1	63.9	16.3	3.9
	S 8	Bl_D(w)	A_1	10	58.1	—	22.7	2.7	0.1	54.2	20.3	4.9
			A_2	17	57.0	—	21.5	4.0	0.2	57.2	17.1	4.0
			B_1	25	55.8	—	20.6	5.1	0.2	58.9	15.2	3.9
			B_2	40	71.3	—	24.4	2.1	—	63.3	10.2	1.8
			C	40+	77.9	—	27.0	1.1	—	64.1	7.8	3.6
	S 9	Bl_D(d)	IA_2	10	50.1	—	19.1	2.2	0.2	42.2	36.3	16.0
			IB	15	55.0	—	20.7	2.0	0.2	53.5	23.6	8.5
			ⅡA	20	61.9	—	23.9	1.0	0.1	56.7	18.3	9.2
			ⅡB	15	60.6	—	23.0	—	0.1	61.6	15.3	6.5
			ⅢA	40	59.6	—	22.1	—	0.1	62.9	14.9	7.0
			ⅢB	30+	63.8	—	23.1	0.1	0.1	62.6	14.1	3.2
	S 10	Bl_D(d)	IA_2	5	49.2	—	19.0	3.2	0.3	39.4	38.1	12.2
			IB	15	55.3	—	20.5	4.5	0.2	54.2	20.6	7.5
			ⅡA	20	60.2	—	22.8	1.0	0.1	54.0	22.1	10.1
			ⅡB	15	61.7	—	23.5	—	0.1	56.3	20.1	8.5
			ⅢA	40	60.8	—	23.0	—	—	62.0	15.7	7.2
			ⅢB	45+	63.8	—	24.0	—	—	65.2	10.8	4.0
Oneyama	S 11	Bl_D	IA_1	7	—	2.77	18.0	5.2	0.1	55.0	21.7	8.5
			IB-C_1	20	—	2.83	11.2	14.8	+	35.8	38.2	24.5
			ⅡA	40	—	2.65	19.3	7.3	—	53.2	20.2	9.7
			ⅡB-C_1	15	—	2.81	10.5	20.0	—	27.5	42.0	28.4
			ⅢA	1	—	2.61	22.5	4.0	—	61.0	12.5	3.2
	S 12	Bl_D(w)	IA_1	12	—	2.80	17.5	9.3	0.2	56.4	16.6	6.5
			IB-C_1	20	—	2.84	10.4	19.2	+	35.2	35.2	25.2
			ⅡA	50	—	2.75	18.5	12.8	0.1	50.6	18.0	9.3
			ⅡB-C_1	20	—	2.83	11.5	20.1	+	28.3	40.1	28.4

of soil in investigated stands

Value of pF in the field condition	Percolation rate (cc/min)	pF (Water in volume : %)						Non-capillary water (%)	Non-capillary pore space (%)	pH		Exchangeable acidity	Carbon (%)	Total nitrogen (%)	C/N ratio
		0	1	1.5	1.7	2.0	2.5			H_2O	KCl				
1.7	67	72.5	69.0	63.5	59.0	51.3	50.2	13.5	20.0	5.3	4.4	3.41	9.52	0.87	11
1.6	45	72.0	68.7	64.0	60.1	56.0	54.1	11.9	16.9	5.5	4.8	2.35	7.84	0.61	13
1.9	32	74.6	73.0	70.0	66.7	63.5	61.4	7.9	12.1	5.7	4.7	2.04	4.00	0.37	11
2.0	8	76.7	74.2	71.6	70.0	68.1	66.5	6.7	8.8	6.0	5.2	1.56	3.25	0.20	16
2.0	125	69.4	66.5	62.0	57.2	53.0	49.3	12.2	20.6	5.7	4.7	4.95	7.82	0.64	12
2.0	84	73.6	71.7	67.2	64.3	59.0	57.2	9.3	16.5	5.6	4.9	3.41	6.57	0.50	13
1.9	40	72.5	70.0	66.5	63.4	58.7	57.7	9.1	14.5	5.9	5.2	2.50	3.21	0.21	15
1.8	28	74.8	73.8	69.4	66.2	62.0	60.6	8.6	12.6	6.2	5.3	1.94	3.00	0.13	23
3.1	61	67.1	64.4	59.7	56.1	54.9	52.1	11.0	16.4	5.6	4.6	5.30	8.35	0.54	15
2.2	64	70.1	68.7	65.7	63.4	57.9	54.2	6.7	13.4	5.8	5.0	2.76	8.30	0.46	18
2.4	7	75.9	75.4	73.4	70.2	68.9	66.4	5.7	10.0	5.9	4.7	2.54	5.17	0.35	15
2.0	17	78.5	77.4	74.5	71.1	63.9	61.4	7.4	11.0	5.9	5.1	2.32	8.24	0.42	20
1.9	14	74.6	74.0	71.2	68.6	67.5	63.7	6.0	9.1	6.1	5.1	2.43	3.46	0.25	14
2.2	100	66.0	63.9	60.0	57.1	54.9	53.1	8.9	17.2	5.4	4.5	4.2	8.04	0.59	14
2.1	72	68.3	66.0	61.7	57.7	55.9	51.7	10.6	16.9	5.8	5.3	2.9	5.05	0.43	12
1.9	16	74.5	73.2	69.6	66.9	62.4	60.1	7.6	13.3	5.9	4.9	2.2	4.32	0.34	13
2.0	14	72.6	71.8	68.6	66.7	64.5	61.2	5.9	10.0	6.0	5.3	2.8	3.71	0.31	12
1.7	47	70.4	68.4	65.8	63.6	62.5	58.5	6.8	10.1	6.3	5.0	2.2	2.20	0.15	15
2.0	157	69.2	66.8	61.4	56.5	52.9	50.0	12.7	20.7	5.4	4.9	5.04	10.01	0.82	12
2.0	89	68.7	66.9	62.9	60.0	56.4	54.2	8.7	15.6	5.7	4.8	5.07	8.20	0.57	14
2.1	190	70.9	68.0	62.4	57.0	51.7	48.2	13.9	22.9	6.0	5.4	2.80	4.73	0.35	14
2.0	24	71.9	70.4	66.1	62.9	57.6	55.9	9.0	16.0	6.1	5.5	2.82	4.07	0.28	15
1.9	20	74.4	73.3	69.2	65.0	60.0	58.3	9.4	14.3	5.9	5.2	1.17	3.05	0.18	17
2.5	650	61.7	58.7	55.0	53.5	50.5	47.2	8.2	21.0	6.1	4.9	3.08	7.50	0.50	15
1.9	65	70.1	68.1	63.5	59.2	51.9	46.6	10.9	16.0	6.0	5.3	2.24	2.37	0.17	14
2.1	95	72.9	66.0	64.4	57.0	48.7	45.7	15.9	22.8	6.5	5.9	1.68	2.74	0.16	17
1.8	722	61.3	57.2	56.0	51.4	44.0	41.0	9.9	23.8	6.5	5.7	2.52	0.65	0.03	22
3.0	115	64.6	61.2	55.7	52.7	49.4	47.2	11.9	19.9	6.4	5.8	2.51	5.8	0.32	18
2.3	95	67.8	65.5	60.2	56.0	49.0	44.2	11.8	19.3	6.4	5.7	1.68	5.3	0.30	18
2.7	47	71.5	69.5	65.4	61.1	54.9	52.5	10.4	16.1	6.2	5.3	1.40	4.2	0.23	18
2.6	35	74.7	73.7	69.7	65.1	57.4	54.7	9.6	14.1	6.2	5.3	2.52	4.0	0.22	18
1.9	15	76.3	74.0	69.8	66.8	62.4	61.0	9.5	13.4	6.3	5.7	1.40	0.4	0.02	20
1.9	40	69.6	66.2	60.2	57.1	53.0	49.6	12.5	17.4	—	—	—	—	—	—
1.7	34	70.3	66.7	60.8	57.9	51.2	50.8	12.4	16.4	—	—	—	—	—	—
1.6	37	70.2	66.6	61.1	57.8	51.0	50.3	12.4	16.3	—	—	—	—	—	—
1.7	8	71.7	68.6	65.4	63.0	60.1	58.5	8.7	10.5	—	—	—	—	—	—
1.5	27	68.3	66.2	64.4	63.6	62.2	61.0	4.7	8.3	—	—	—	—	—	—
3.0	245	62.5	58.9	53.4	49.9	45.7	43.9	12.6	28.6	6.2	4.7	4.76	9.01	0.56	16
2.2	74	68.6	65.0	60.4	57.2	54.0	52.4	11.4	19.9	6.0	4.6	4.00	7.08	0.50	14
2.2	80	65.8	64.7	63.2	61.4	57.9	55.1	4.4	13.7	5.9	4.7	3.08	7.52	0.46	16
2.3	37	70.4	70.0	68.4	66.9	63.3	60.6	3.5	10.0	5.9	4.7	2.80	7.10	0.45	16
1.9	45	70.8	69.5	67.2	65.2	62.3	57.6	5.6	12.6	5.7	4.8	2.52	8.15	0.38	21
1.4	28	73.5	67.5	62.1	60.9	58.7	57.5	12.6	15.8	6.1	5.6	1.40	2.50	0.11	23
2.9	200	65.3	59.0	53.7	49.5	44.0	41.8	15.8	28.0	6.4	4.9	10.71	7.05	0.41	17
2.5	85	67.3	64.5	63.2	61.5	57.3	54.0	5.8	13.3	6.2	4.7	8.42	5.13	0.23	22
2.1	92	66.0	64.4	62.0	60.0	54.7	51.0	6.0	16.1	5.9	4.5	6.34	7.52	0.46	16
2.1	63	67.9	66.8	63.5	62.0	56.8	53.2	5.9	14.4	6.0	4.8	4.20	4.66	0.29	16
2.0	52	69.8	68.0	66.1	64.2	61.7	60.0	5.6	12.8	5.9	4.6	3.48	6.49	0.37	18
1.9	31	72.0	70.0	67.5	66.8	64.6	63.1	5.2	9.2	6.2	5.7	2.00	2.07	0.09	23
2.00	390	68.2	66.5	62.7	59.0	55.3	52.0	9.2	17.7	5.4	4.4	1.82	5.02	0.50	10
1.81	620	49.5	44.1	39.0	36.5	34.6	33.2	13.0	37.5	5.6	5.5	10.21	0.51	0.02	26
1.91	174	63.7	60.7	57.1	55.2	52.4	47.6	8.5	18.2	5.4	4.6	1.54	4.92	0.45	11
1.62	382	41.1	35.0	28.2	27.0	26.1	24.7	14.1	42.5	5.7	5.6	8.73	0.95	0.03	32
1.75	47	70.3	68.1	65.0	61.5	58.3	54.1	8.8	12.0	5.0	4.3	2.12	4.55	0.51	9
1.73	307	66.5	64.0	60.1	56.7	53.2	49.3	9.8	16.3	5.2	4.2	2.52	6.15	0.53	12
1.45	647	45.2	40.1	34.6	32.5	31.7	30.2	12.7	37.9	5.5	5.4	15.32	0.62	0.03	21
1.65	135	59.3	57.1	52.6	50.0	45.7	40.3	9.3	18.6	5.3	4.5	2.00	5.43	0.50	11
1.37	450	40.0	34.2	26.2	24.0	22.9	21.2	16.0	44.4	5.6	5.4	12.19	1.25	0.04	31

Appendix-Table 2. (continued)

Location	Stand	Soil type	Horizon	Thickness of horizon (cm)	Volume weight (g/100cc)	Specific gravity of fine soil	Volume composition of soil in the field condition (%)					Min. air capacity (%)
							Solid			Water	Air	
							Fine soil	Gravel	Root			
Oneyama	S12	Bl$_D$(w)	ⅢA	40	—	2.65	22.0	3.2	—	66.4	8.4	3.5
			ⅢB-C$_1$	—	—	2.61	22.7	2.1	—	69.7	5.5	2.0
	S13	Bl$_D$	ⅠA$_1$	8	55.2	2.80	17.1	10.0	0.1	52.8	20.0	10.5
			ⅠB-C$_1$	20	38.0	2.98	10.6	18.1	—	29.9	41.4	28.3
			ⅡA	40	56.8	2.83	18.2	13.7	0.1	45.3	22.7	11.6
			ⅡB-C$_1$	10	42.7	2.96	12.2	19.0	—	25.6	43.2	30.2
			ⅢA	30	63.1	2.89	21.0	3.2	—	65.0	10.8	4.7
			ⅢB-C	—	54.3	2.62	19.1	2.4	—	70.8	7.7	3.6
	S14	Bl$_D$(d)	ⅠA$_1$	4	—	2.75	16.5	9.5	0.2	45.2	28.6	12.3
			ⅠB-C$_1$	15	—	2.84	9.2	19.2	—	22.5	49.1	30.2
			ⅡA	35	—	2.80	19.1	12.8	0.1	43.0	25.0	11.7
			ⅡB-C$_1$	17	—	2.90	12.0	19.0	—	19.0	50.0	34.5
			ⅢA	25	—	2.84	22.5	4.1	—	58.2	15.2	6.6
			ⅢB-C	—	—	2.70	23.0	3.0	—	59.7	14.3	5.4
	S15	Bl$_D$	ⅠA$_1$	10	—	2.75	17.4	8.7	0.1	51.2	22.6	9.0
			ⅠB-C$_1$	15	—	2.94	10.0	18.0	—	32.5	39.5	27.5
			ⅡA	30	—	2.80	18.6	12.5	0.1	48.3	20.5	10.2
			ⅡB-C$_1$	24	—	2.93	11.5	19.4	—	26.0	43.1	31.2
			ⅢA	30	—	2.86	22.0	4.2	—	61.2	12.6	4.5
			ⅢB-C	—	—	2.80	20.6	3.0	—	67.7	8.7	3.0
	S16	Bl$_D$	ⅠA$_1$	10	—	2.79	18.0	8.5	0.2	49.5	23.8	8.7
			ⅠB-C$_1$	25	—	2.85	9.5	16.4	+	33.0	41.1	24.7
			ⅡA	30	—	2.70	20.0	9.3	0.1	49.2	21.4	11.3
			ⅡB-C$_1$	30	—	2.94	11.2	17.0	+	26.3	45.5	30.5
			ⅢA	25	—	2.67	20.5	2.5	+	66.5	10.5	3.1
			ⅢB-C	—	—	2.65	21.3	1.4	—	70.0	7.3	1.5
	S17	Bl$_D$	ⅠA$_1$	7	—	—	18.2	6.4	0.5	51.4	23.5	6.8
			ⅠB-C$_1$	20	—	—	9.8	18.7	+	34.4	37.1	23.6
			ⅡA	40	—	—	20.2	8.2	0.2	52.5	18.9	6.0
			ⅡB-C$_1$	20	—	—	9.0	21.3	+	28.8	40.9	27.4
			ⅢA	30	—	—	23.4	5.0	+	65.7	5.9	2.0
			ⅢB-C	—	—	—	24.8	2.0	—	68.1	5.1	1.1
Akita	S18	B$_E$	A$_1$	8	—	2.36	24.5	—	0.4	52.2	22.9	15.0
			A$_2$	30	—	2.54	26.2	0.2	0.2	56.7	16.7	9.2
			B	40	—	2.65	27.9	+	0.2	59.9	12.0	4.0
			C	40+	—	2.71	31.0	+	—	60.4	8.6	3.2
	S19	B$_E$	A$_1$	7	—	2.36	20.3	0.1	0.4	50.0	29.2	20.4
			A$_2$	10	—	2.47	21.4	0.1	0.1	54.7	23.7	15.2
			B$_1$	30	—	2.61	27.6	0.1	0.1	58.0	14.2	8.6
			B$_2$-C	50+	—	2.68	28.5	—	—	62.2	9.3	7.0
	S20	B$_E$	A-M	4	—	2.40	19.1	—	1.4	35.2	44.3	31.1
			B$_1$	20	—	2.54	20.4	—	0.5	52.6	26.5	18.0
			B$_2$	30	—	2.60	32.7	—	0.1	52.8	14.4	9.2
			C	—	—	2.72	41.7	—	0.1	47.7	10.5	8.4
Yasato	S21 H8 M1 A9	Bl$_D$	A$_1$	9	40.7	—	16.6	+	0.2	53.2	30.0	10.5
			A$_2$	10	47.3	—	18.5	0.1	+	45.8	35.6	6.7
			A$_3$	30	53.6	—	19.9	0.1	+	63.4	16.6	5.7
			B	35	55.7	—	21.2	+	—	62.3	16.5	6.5
			C	—	58.6	—	23.0	+	—	67.8	5.7	3.5
Chiba	S22	B$_E$	A$_1$	30	47.7	—	20.6	0.3	0.1	66.5	12.5	4.2
			A$_2$	20	43.7	—	16.5	3.1	0.1	47.5	32.8	8.2
			B	85	38.2	—	13.1	4.6	0.1	57.7	24.5	8.4
			C	—	54.7	—	20.3	—	0.1	73.8	5.8	2.7
	S23	B$_D$	A$_1$	10	35.8	—	14.4	0.4	0.8	61.3	23.1	10.2
			A$_2$	15	39.2	—	14.6	0.2	0.1	53.8	31.3	7.0
			B	35	43.5	—	15.9	—	0.1	65.0	19.0	4.1
			C	—	44.4	—	16.0	0.2	0.1	68.8	14.9	3.8

Value of pF in the field condition	Percolation rate (cc/min)	pF (Water in volume : %)						Non-capillary water (%)	Non-capillary pore space (%)	pH		Exchangeable acidity	Carbon (%)	Total nitrogen (%)	C/N ratio
		0	1	1,5	1,7	2,0	2,5			H_2O	KCl				
1,57	32	71,3	70,0	67,2	64,8	60,7	57,2	6,5	10,0	5,0	4,4	1,56	6,00	0,57	11
1,37	11	73,2	71,8	69,0	66,0	62,2	58,0	7,2	9,2	5,5	5,3	9,35	1,40	0,06	23
1,92	378	62,3	60,7	57,8	56,5	51,5	46,0	5,8	16,3	5,6	4,7	0,95	4,65	0,38	12
1,40	490	43,0	36,1	28,4	26,5	25,0	23,7	16,5	44,8	5,7	5,5	7,62	0,45	0,02	23
1,80	163	56,4	53,0	50,2	47,4	40,8	37,2	9,0	20,6	5,4	4,4	1,43	4,80	0,25	19
1,30	277	38,6	31,0	22,1	20,0	18,2	17,0	18,6	48,8	5,8	5,7	10,50	0,75	0,03	25
1,62	51	71,1	69,4	66,5	64,0	59,0	55,4	7,1	11,8	5,3	4,2	2,41	3,49	0,11	32
1,50	36	74,9	73,2	71,1	68,5	65,3	61,2	6,4	10,0	5,5	5,2	12,38	0,92	0,06	15
2,75	407	61,5	58,1	53,8	51,0	48,5	46,3	10,5	22,8	6,0	5,2	4,85	4,07	0,17	24
2,31	680	41,4	35,2	26,5	24,3	22,0	20,8	17,1	47,3	6,2	6,0	15,72	0,32	0,01	32
2,07	185	56,3	54,1	48,6	46,0	43,6	41,9	10,3	22,0	5,8	4,7	5,62	4,21	0,22	19
1,70	932	34,5	29,3	20,5	19,0	17,6	16,3	15,5	50,0	5,9	5,5	17,35	0,40	0,02	20
1,84	65	66,8	64,2	62,5	60,1	56,0	51,2	6,7	13,3	5,6	4,4	4,12	3,58	0,09	40
1,70	60	68,6	66,6	62,7	59,6	54,7	50,9	9,0	14,4	6,0	5,6	9,58	0,57	0,02	29
2,10	420	64,8	62,4	58,4	56,0	52,1	47,5	8,8	17,8	5,5	4,5	1,82	4,95	0,41	12
1,43	534	44,5	38,2	31,6	30,0	28,3	27,0	14,5	42,0	5,8	5,7	5,42	0,47	0,03	16
1,81	282	58,6	56,1	51,7	50,2	45,2	40,3	8,4	18,6	5,6	4,5	0,95	5,00	0,52	10
1,45	627	37,9	33,8	25,1	23,0	21,5	20,2	14,9	46,1	5,9	5,6	6,34	0,64	0,04	16
1,56	43	69,3	67,2	62,0	59,2	56,0	52,3	10,1	14,6	5,7	5,5	1,25	4,72	0,38	12
1,56	28	73,4	72,0	68,8	65,1	62,7	59,0	8,3	11,3	5,8	5,6	7,81	0,77	0,05	15
2,41	415	64,6	62,7	57,7	56,0	51,3	49,1	8,6	17,3	5,6	4,4	3,25	5,15	0,52	10
2,00	720	49,4	43,5	36,2	34,0	33,0	32,0	15,4	40,1	5,8	5,7	12,51	0,54	0,03	18
1,70	230	59,3	56,3	51,7	49,2	47,8	45,3	10,1	21,4	5,4	4,4	1,43	4,82	0,46	10
1,40	642	41,3	33,4	24,5	22,0	19,8	17,9	19,3	49,8	6,0	5,7	8,52	0,92	0,05	18
1,68	45	73,9	72,7	69,5	66,2	64,0	61,3	7,7	10,8	5,5	4,3	0,92	5,09	0,51	10
1,56	10	75,8	73,9	71,0	67,7	65,0	62,6	8,1	9,6	5,9	5,8	9,43	1,24	0,04	31
2,24	342	68,1	66,1	62,3	58,3	54,8	51,2	9,8	16,6	5,4	4,3	2,02	6,24	0,49	13
1,72	810	47,9	42,2	37,0	34,5	33,0	32,3	13,4	37,0	5,8	5,0	16,13	0,60	0,03	20
2,00	215	65,4	62,7	58,7	57,0	52,5	50,0	8,4	14,4	5,3	4,5	1,85	4,74	0,50	9
1,60	541	42,3	36,3	29,4	28,2	27,0	26,1	14,1	41,5	5,7	5,4	13,04	0,77	0,02	39
1,42	37	69,6	68,1	65,2	62,0	59,1	55,0	7,6	9,6	5,2	4,4	2,61	5,16	0,52	10
1,40	14	72,1	70,6	67,5	65,0	60,0	56,6	7,1	8,2	5,0	4,1	5,32	1,75	0,07	25
2,2	198	60,1	58,0	56,1	55,5	52,7	51,1	4,6	19,6	5,3	3,6	13,2	8,32	0,59	14
2,0	63	64,2	62,2	60,5	59,5	56,8	54,6	4,7	13,9	5,4	3,8	10,8	7,40	0,44	17
2,0	5	67,9	66,0	63,7	62,4	59,4	58,1	5,5	9,5	5,7	3,7	28,6	5,04	0,29	17
1,8	4	65,8	63,7	61,8	61,0	58,7	57,2	4,8	8,0	6,0	4,5	45,7	0,32	0,01	32
2,1	140	58,8	56,9	55,0	54,2	50,2	48,9	4,6	25,0	5,8	4,1	2,2	7,06	0,51	14
1,9	70	63,2	61,4	58,9	57,8	53,8	51,9	5,4	21,6	5,7	4,3	8,5	6,57	0,38	17
1,9	12	63,6	61,8	60,7	59,6	57,6	55,7	4,0	12,6	5,6	4,0	11,7	3,72	0,18	21
1,8	6	64,5	63,2	62,8	62,5	61,4	60,8	2,0	9,0	5,7	3,6	18,9	0,61	0,06	10
3,0	305	48,4	46,1	41,5	40,4	37,4	36,1	8,0	39,1	5,6	3,7	22,9	15,60	0,67	23
2,7	127	61,1	59,0	56,9	55,6	53,2	52,3	5,5	23,5	5,5	3,6	35,3	2,63	0,20	13
2,5	82	58,0	56,0	54,9	54,5	53,4	52,8	3,5	12,7	5,5	3,4	76,7	1,14	0,08	14
1,9	5	59,8	48,5	48,3	48,2	47,4	46,9	11,6	20,0	5,6	3,5	67,3	0,79	0,06	13
2,1	77	72,7	70,5	66,4	61,6	54,3	48,9	11,1	21,6	5,2	4,3	6,52	12,42	0,74	17
1,9	111	74,7	71,5	63,3	52,7	43,3	40,4	22,0	28,7	5,7	4,6	1,37	4,40	0,36	12
1,9	6	74,3	73,6	70,6	67,3	62,5	57,4	7,0	12,7	5,9	4,8	1,20	3,72	0,33	11
1,9	14	72,3	72,3	68,8	65,5	61,0	59,1	6,8	13,3	5,9	4,9	0,68	2,56	0,23	11
1,5	5	70,0	69,0	67,5	64,3	60,0	56,2	5,7	9,2	6,1	5,0	0,50	1,83	0,10	18
1,9	144	74,8	73,0	70,4	68,9	65,5	62,4	5,9	10,1	6,5	5,4	3,04	12,8	1,04	12
1,9	101	72,1	68,9	59,9	53,0	46,3	43,2	19,1	27,3	6,4	6,1	0,91	7,3	0,75	10
2,0	51	73,8	73,8	70,0	64,8	57,7	53,4	9,0	17,4	6,3	6,2	1,60	5,9	0,77	8
1,5	29	76,9	76,0	74,0	71,9	68,0	63,3	5,0	7,7	6,2	6,4	0,46	4,2	0,35	12
2,1	60	74,2	71,7	68,5	65,8	61,8	59,0	8,4	18,6	6,3	6,0	1,37	7,4	0,51	15
2,0	98	78,1	75,4	68,3	60,9	53,5	50,3	17,2	24,2	6,2	5,8	1,17	1,1	0,16	7
2,1	23	79,9	78,8	74,2	68,3	65,7	61,9	11,6	15,7	6,1	4,6	8,95	1,0	0,05	20
1,8	61	79,9	78,0	74,0	69,5	66,9	62,8	10,4	14,2	6,0	4,4	8,67	0,8	0,04	20

Appendix-Table 2. (continued)

Location	Stand	Soil type	Horizon	Thickness of horizon (cm)	Volume weight (g/100cc)	Specific gravity of fine soil	Volume composition of soil in the field condition (%)					Min. air capacity (%)
							Solid			Water	Air	
							Fine soil	Gravel	Root			
Chiba	S 24	B_A	A_2	8	79.5	—	33.3	—	0.5	36.2	30.0	20.6
			B	12	80.2	—	30.5	—	0.1	43.5	25.9	7.9
			C	25	79.2	—	28.6	—	0.1	57.5	13.8	4.7
Obi	S 25	Bl_D(w)	IA_1	4	65.4	—	27.4	0.1	0.8	37.0	34.7	12.3
			IA_2	7	62.0	—	24.7	0.1	0.4	43.4	31.4	2.2
			IB-C	6	51.5	—	20.0	0.3	0.1	53.1	26.5	6.2
			ⅡA	40	61.5	—	17.4	0.1	0.4	59.2	22.9	5.5
			ⅡB	45	40.6	—	15.8	0.2	+	63.9	20.1	5.6
			ⅢC	—	—	—	—	—	—	—	—	—
	S 26	Bl_D(w)	IA	15	53.7	—	22.2	1.9	0.2	51.6	24.1	7.0
			ⅡA_1	15	50.8	—	19.5	3.6	0.1	57.0	19.8	4.7
			ⅡB	40	54.0	—	18.6	3.6	0.1	60.6	17.1	6.4
			ⅡC	100	60.5	—	16.5	4.2	+	64.5	14.8	5.2
	S 27	Bl_D	A_1	12	48.2	—	20.3	0.2	0.4	50.1	29.0	6.8
			A_2	14	50.4	—	20.1	0.3	0.2	54.0	25.4	5.5
			B	30	47.7	—	18.6	0.1	0.2	56.3	24.8	7.7
			C	60	37.1	—	15.5	+	0.1	60.9	23.5	6.3
	S 29	Bl_D	A_2	12	49.0	—	19.6	5.5	0.1	48.3	26.5	7.0
			C	25	51.0	—	20.0	1.2	0.1	50.8	27.9	5.6
	S 30	Bl_D	A_2	8	43.7	—	18.4	0.1	0.7	49.2	31.6	9.4
			B	18	39.8	—	15.8	0.1	0.7	51.4	32.0	8.2
			C	30	40.5	—	15.6	0.9	0.9	51.1	31.5	4.4
			C	—	36.2	—	14.1	—	0.1	58.3	27.5	4.5
Yoshino	S 45	B_B	B_1	15	69.5	2.46	24.7	12.2	0.4	35.4	27.3	19.9
			B_2	35	70.6	2.53	23.5	14.4	1.4	40.7	20.0	11.0
			C	—	79.9	2.55	27.4	11.8	1.6	39.4	19.8	5.0
	S 46	B_D	A_1	7	—	2.40	20.4	14.5	0.5	35.2	29.4	10.2
			A_2	20	—	2.51	21.3	16.7	0.4	38.4	23.2	6.7
			B	27	—	2.49	23.5	20.3	0.1	41.1	15.0	4.5
			C	—	—	2.60	24.7	19.5	—	43.7	12.1	4.0
	S 47	B_B	A_1	4	48.7	—	16.0	18.7	0.5	35.0	29.8	13.4
			A_2	10	77.0	—	20.7	14.4	0.1	37.9	26.9	9.5
			B_1	20	73.9	—	23.6	19.3	0.1	42.9	14.1	1.2
			B_2	20	75.8	—	26.5	16.0	—	43.5	14.0	1.0
	S 48	B_D	A_1	7	66.3	—	22.4	16.7	0.3	34.8	25.8	7.5
			A_2	25	91.2	—	27.0	20.4	0.1	35.5	17.0	5.0
			B	45	78.8	—	24.3	21.6	0.3	41.0	12.8	2.8
			C	—	80.4	—	25.6	18.5	0.1	44.0	11.8	2.0
	S 49	B_C	A_1	4	—	2.37	14.7	6.4	1.2	35.0	42.7	12.8
			B_1	20	—	2.51	18.0	11.1	0.1	40.3	30.5	6.1
			B_2	27	—	2.60	22.5	15.6	0.1	42.3	19.5	4.2
			C	—	—	2.54	24.4	18.0	—	45.6	12.0	1.5
	S 50	B_E	A	15	—	2.45	19.6	21.1	0.3	40.2	18.8	5.2
			B_1	20	—	2.57	22.4	18.4	0.1	42.0	17.1	4.2
			B_2	30	—	2.60	27.8	17.2	0.1	40.3	14.6	3.1
			C	—	—	2.58	27.5	15.0	—	48.6	8.9	2.2
	S 51	B_E	A_1	15	—	2.34	20.0	24.6	0.3	35.8	19.3	4.2
			A_2	15	—	2.40	20.9	20.1	0.1	46.2	12.7	1.7
			B	40	—	2.52	24.5	15.2	0.1	45.3	14.9	1.0
			C	—	—	2.60	27.0	16.7	—	49.0	7.3	0.8
	S 52	B_D(w)	A_1	15	—	2.41	18.7	10.8	1.8	41.9	26.8	7.1
			A_2	15	—	2.53	22.7	13.4	0.1	51.6	12.2	1.0
			B	30	—	2.61	23.9	15.2	0.1	51.8	9.0	2.0
			C	—	—	2.57	24.0	19.0	—	50.7	6.3	0.9
Gero	H 1	B_D(d)	A_1	4	—	2.38	23.2	2.0	0.2	57.4	17.2	5.4
			B	40	—	2.32	24.2	2.5	—	59.1	14.2	4.0
			C	70	—	2.56	25.5	4.4	—	61.6	8.5	2.5

Value of pF in the field condition	Percolation rate (cc/min)	pF (Water in volume : %)						Non-capillary water (%)	Non-capillary pore space (%)	pH		Exchange-able acidity	Carbon (%)	Total nitrogen (%)	C/N ratio
		0	1	1.5	1.7	2.0	2.5			H_2O	KCl				
2.8	104	45.6	44.8	43.4	42.3	40.5	37.8	3.3	23.9	6.4	5.8	0.91	8.5	0.68	13
2.0	75	61.5	58.2	51.5	47.5	43.5	40.8	14.0	21.9	6.3	6.4	0.90	3.4	0.34	10
2.0	55	66.6	65.3	62.2	60.0	57.5	54.8	6.6	11.3	6.2	6.6	0.85	0.7	0.02	35
2.2	74	59.4	58.5	52.6	46.6	38.5	35.3	12.8	25.1	6.0	4.9	0.59	10.62	0.78	14
2.0	69	72.6	71.0	65.7	56.3	43.1	39.7	16.3	18.5	5.8	4.8	2.50	8.50	0.65	13
2.3	10	73.4	71.5	68.1	62.9	55.1	51.1	10.5	16.7	5.4	4.3	5.11	1.95	0.30	7
2.0	32	76.6	73.0	69.2	64.3	59.5	57.0	12.3	17.8	5.8	5.3	0.46	2.70	0.22	12
1.9	28	78.4	75.8	70.8	66.3	61.4	58.9	12.1	17.7	5.4	4.0	0.44	1.50	0.04	38
—	—	—	—	—	—	—	—	—	—	5.0	4.1	0.50	0.92	0.02	46
2.2	51	68.7	65.1	60.6	57.9	53.2	49.9	10.8	17.8	6.2	5.2	2.34	10.75	0.82	13
2.0	34	72.1	69.1	65.2	61.3	57.0	54.0	10.8	15.5	5.9	5.0	3.15	9.32	0.60	16
1.8	36	71.3	67.5	64.6	62.5	58.0	54.8	8.8	15.2	5.3	4.?	1.12	1.56	0.25	6
1.7	22	74.1	71.0	69.2	65.0	62.4	60.5	9.1	14.3	4.8	4.0	0.50	0.80	0.05	16
2.2	174	72.3	69.2	62.8	59.4	51.7	48.3	12.9	19.7	6.4	5.1	0.46	10.92	0.81	13
2.1	15	73.9	72.1	68.1	6?.9	54.5	49.3	11.0	16.5	6.0	4.9	0.50	8.01	0.67	12
2.0	28	73.4	71.4	67.9	61.5	56.0	54.1	11.9	19.6	6.2	5.0	0.37	6.65	0.62	11
1.8	43	78.1	75.9	70.0	62.5	54.9	52.5	15.6	21.9	5.9	6.6	0.82	1.10	0.11	10
2.5	130	67.8	64.8	59.7	51.3	49.3	48.0	16.5	23.5	5.8	5.0	1.79	9.00	0.81	11
2.2	65	73.1	70.2	64.3	58.3	52.1	48.7	14.8	20.4	5.4	4.2	0.95	1.40	0.07	20
3.4	149	71.4	68.0	62.4	57.8	53.6	50.4	13.6	—	5.7	4.4	2.7	12.62	0.87	15
2.1	47	75.2	72.4	67.2	61.3	52.7	47.6	13.9	—	5.7	4.5	2.0	10.27	0.80	13
2.4	56	78.2	76.6	70.9	63.6	53.6	50.3	14.6	—	5.9	4.6	1.4	8.63	0.73	12
2.2	51	81.3	78.5	73.2	66.3	60.0	56.2	15.0	—	6.0	5.6	0.2	2.51	0.14	18
3.3	740	42.8	40.5	39.0	38.5	38.0	37.0	4.3	24.2	5.6	4.5	4.2	5.2	0.47	11
2.2	460	49.7	47.0	43.3	42.0	41.3	39.5	7.7	18.7	5.4	4.7	1.4	6.7	0.42	16
1.8	94	54.2	49.0	42.5	40.7	37.0	36.0	13.5	18.5	5.8	4.6	10.2	7.5	0.16	9
3.1	325	54.4	50.0	45.2	42.1	38.0	36.7	12.3	22.5	6.0	5.8	1.5	7.0	0.51	14
2.0	120	54.9	52.1	47.6	43.0	37.5	35.8	11.9	18.6	5.8	5.0	3.2	4.6	0.37	12
1.8	56	51.6	48.1	43.5	42.5	39.3	37.8	9.1	13.6	6.1	5.0	9.7	3.1	0.20	16
1.9	24	51.8	50.0	46.3	45.1	42.5	41.1	6.7	10.7	6.2	4.8	14.6	0.3	0.01	30
2.8	688	51.4	48.9	43.2	40.2	38.2	36.2	11.2	24.6	5.2	4.4	3.2	9.0	0.64	14
2.1	197	55.3	51.8	45.3	41.3	38.3	36.4	14.0	18.1	5.3	4.6	9.0	8.9	0.52	17
1.8	98	55.8	54.3	49.3	43.5	40.3	37.5	12.3	13.5	5.7	4.7	15.8	3.1	0.30	10
1.9	25	56.5	54.5	50.0	46.2	41.7	40.3	10.3	11.3	5.8	4.7	17.5	1.0	0.05	20
2.0	320	53.1	48.1	41.0	37.8	34.8	34.0	15.3	22.8	6.7	5.8	0.8	6.2	0.45	14
1.9	106	47.5	44.5	40.5	37.0	34.2	33.1	10.5	15.5	6.4	4.6	0.9	2.2	0.24	9
1.8	43	51.0	48.2	43.4	41.5	39.9	38.5	9.5	12.3	5.8	4.5	1.4	1.7	0.22	8
1.7	20	53.8	51.0	46.2	44.0	41.5	41.0	9.8	11.8	6.0	4.7	8.2	0.5	0.02	25
2.9	330	64.9	60.5	53.2	49.5	46.7	40.7	15.4	28.2	5.0	4.2	9.7	8.9	1.16	8
2.4	194	64.7	59.2	50.0	48.4	44.8	39.3	16.3	22.4	5.2	4.5	7.6	4.7	0.44	11
1.8	52	57.6	54.0	47.2	44.0	37.8	36.0	13.6	17.8	5.6	5.0	8.2	3.0	0.22	14
1.8	8	56.1	53.2	49.1	47.1	43.1	42.0	9.0	10.5	5.8	5.3	12.5	0.7	0.02	35
1.8	187	53.8	52.0	45.3	41.5	37.0	35.7	12.3	17.3	6.1	5.8	1.6	6.5	0.55	12
1.7	65	54.9	52.6	45.0	42.1	40.5	37.5	12.8	17.0	5.7	4.6	2.5	8.5	0.45	19
1.9	42	51.8	49.2	46.5	41.3	39.5	38.4	10.5	13.6	5.1	4.4	10.9	4.1	0.23	18
1.7	13	55.3	54.0	51.0	48.1	46.5	45.7	7.2	9.4	5.4	4.5	15.2	0.5	0.02	25
1.9	85	50.9	46.5	40.0	37.1	35.2	34.5	13.8	18.0	6.5	4.7	1.2	3.9	0.32	12
1.9	24	57.2	53.4	49.1	47.0	45.8	43.5	10.2	11.9	6.7	4.8	0.7	5.8	0.45	13
2.0	5	59.2	56.0	50.0	49.2	45.5	43.0	10.0	11.0	6.4	5.0	10.2	3.0	0.21	14
1.9	4	55.5	54.2	51.0	49.6	48.7	48.0	5.9	6.7	5.9	4.9	13.4	1.0	0.01	100
2.1	422	61.6	55.0	47.3	45.2	42.4	40.7	16.4	23.5	5.0	4.2	15.8	10.3	0.83	12
2.0	51	62.8	60.7	57.7	54.2	51.6	51.0	8.6	9.6	5.7	4.4	11.1	4.9	0.47	10
1.9	12	58.8	58.0	55.5	53.4	51.0	47.8	5.4	7.4	5.4	4.6	3.5	2.1	0.14	15
1.7	4	56.1	53.0	51.5	50.5	48.0	46.5	5.6	6.5	5.5	4.3	16.2	0.5	0.02	25
2.78	23	69.2	66.2	63.3	60.6	59.1	58.0	8.6	14.0	4.7	3.62	24.21	9.85	0.65	15
2.40	8	69.3	66.8	64.2	62.2	60.3	58.8	7.1	11.1	4.9	3.77	15.00	7.00	0.42	17
1.96	5	67.6	66.2	65.0	63.3	61.3	59.1	4.3	6.8	5.0	3.90	8.35	2.15	0.12	18

Appendix-Table 2. (continued)

Location	Stand	Soil type	Horizon	Thickness of horizon (cm)	Volume weight (g/100cc)	Specific gravity of fine soil	Volume composition of soil in the field condition (%)					Min. air capacity (%)
							Solid			Water	Air	
							Fine soil	Gravel	Root			
Gero	H2	B$_D$	A$_1$	5	—	2.35	22.0	1.5	0.2	63.1	13.2	3.2
			B	80	—	2.34	24.0	3.0	0.1	64.7	8.2	1.5
			C	110	—	2.53	25.1	4.0	+	65.6	5.3	1.7
	H3	B$_D$	A$_1$	4	—	2.39	24.7	7.2	0.6	58.1	9.4	2.1
			B	50	—	2.37	33.0	2.0	0.1	60.0	4.9	0.4
			C	75	—	2.55	25.7	11.8	+	59.9	2.6	1.3
	H4	B$_D$(w)	A$_1$	4	—	2.36	25.0	2.2	0.3	64.1	8.4	3.4
			B	50	—	2.38	22.5	4.0	+	70.1	3.4	0.9
			C	80	—	2.49	24.6	3.2	—	70.2	2.0	0.4
	H5	B$_D$	A$_1$	16	—	2.39	23.4	1.5	0.5	62.5	12.1	3.1
			A$_2$	30	—	2.37	22.9	3.0	0.4	65.7	8.0	3.2
			B	80	—	2.50	24.0	2.5	0.1	67.4	6.0	2.5
			C	140	—	2.58	26.9	1.4	+	67.9	3.8	1.3
	H6	B$_B$	A$_2$	10	66.7	2.39	27.0	4.2	0.5	45.2	23.1	4.2
			B	30	85.5	2.41	34.1	4.0	0.6	50.7	10.6	2.2
			C	60	89.6	2.60	33.7	3.8	+	55.1	7.4	3.2
Oneyama	H7	Bl$_D$	ⅠA$_1$	8	55.3	2.80	17.3	9.7	0.2	51.0	21.8	10.4
			ⅠB–C$_1$	15	37.4	2.98	9.7	19.0	+	28.6	42.7	28.5
			ⅡA	35	56.8	2.80	19.7	10.2	0.1	47.6	22.4	11.2
			ⅡB–C$_1$	10	40.5	2.98	11.5	18.7	—	22.5	47.3	32.6
			ⅢA	40	62.5	2.86	21.4	2.6	—	65.8	10.2	4.2
			ⅢB–C	—	58.0	2.62	19.7	1.5	—	71.1	7.7	3.0
	M4	Bl$_D$	ⅠA$_1$	10	—	—	17.7	8.5	0.7	49.0	24.1	11.4
			ⅠB–C$_1$	20	—	—	8.7	19.7	+	30.5	41.1	26.7
			ⅡA	25	—	—	19.5	11.4	0.3	48.8	20.0	9.5
			ⅡB–C$_1$	20	—	—	10.4	20.0	+	21.4	48.2	30.6
			ⅢA	40	—	—	20.7	3.1	—	62.6	13.6	4.8
			ⅢB–C	—	—	—	22.4	3.0	—	67.2	7.4	2.7
	M6	Bl$_D$	ⅠA$_1$	8	—	—	18.0	7.5	0.7	50.5	23.3	10.0
			ⅠB–C$_1$	15	—	—	8.4	16.8	0.1	32.5	42.2	25.3
			ⅡA	27	—	—	20.2	9.5	0.4	51.8	18.1	8.6
			ⅡB–C$_1$	15	—	—	9.7	20.6	+	21.3	48.4	31.8
			ⅢA	35	—	—	21.4	5.2	—	62.5	10.9	6.2
			ⅢB–C	—	—	—	23.0	4.4	—	63.3	9.3	5.0
Takahagi	A1	Bl$_D$(d)	A$_1$	7	—	—	21.6	5.1	0.8	44.2	28.3	13.1
			A$_2$	8	—	—	21.5	—	0.4	51.3	26.8	7.5
			B$_1$	30	—	—	21.7	—	0.1	61.6	16.6	3.2
			B$_2$	40	—	—	23.4	0.4	0.1	63.3	12.8	4.3
	A2	Bl$_D$(d)	A$_1$	5	—	—	22.3	0.1	1.5	48.3	27.8	9.9
			A$_2$	25	—	—	21.8	0.2	0.4	51.2	26.4	7.4
			B$_1$	40	—	—	20.9	0.1	0.1	59.4	19.5	3.5
			B$_2$	55	—	—	26.1	6.6	0.6	56.0	10.7	3.7
	A3	Bl$_D$(d)	A$_1$	5	—	—	22.5	0.2	0.4	45.2	31.7	10.5
			A$_2$	10	—	—	21.0	0.1	0.1	52.4	26.4	5.3
			B$_1$	50	—	—	20.4	—	—	59.3	20.3	4.2
			B$_2$	45	—	—	25.3	0.4	—	60.7	13.6	3.4
			C	—	—	—	26.5	0.5	—	62.5	10.5	0.7
	A4	Bl$_D$(d)	A$_1$	15	—	—	24.0	0.1	0.5	48.8	26.6	8.9
			A$_2$	20	—	—	22.2	—	0.1	55.0	22.7	3.6
			B$_1$	40	—	—	21.4	0.1	0.1	62.0	16.4	4.2
			B$_2$	50	—	—	25.4	—	0.1	61.2	13.3	3.7
			C	—	—	—	26.5	0.1	0.1	67.0	6.2	0.4
Okayama	A5	Er–B$_A$	B	12	—	—	22.8	22.4	0.5	23.9	30.4	19.7
	M7		C$_1$	21	—	—	41.3	17.9	0.1	26.3	14.4	2.7
	A6	Er–β	C$_1$	10	—	—	31.8	11.7	1.2	19.8	35.5	29.6
	M3	Im–B$_D$	B	32	—	—	45.3	10.9	0.5	35.0	8.3	5.6
	M3	Im–B$_F$	B	20	—	—	37.2	12.9	0.2	45.2	4.5	2.8

Value of pF in the field condition	Percolation rate (cc/min)	pF (Water in volume : %)						Non-capillary water (%)	Non-capillary pore space (%)	pH		Exchangeable acidity	Carbon (%)	Total nitrogen (%)	C/N ratio
		0	1	1.5	1.7	2.0	2.5			H_2O	KCl				
2.22	35	73.1	71.1	69.0	67.2	64.4	61.4	5.9	9.1	4.5	3.92	15.13	9.50	0.90	11
2.10	30	71.4	69.8	68.7	67.7	65.4	62.0	3.7	5.2	4.9	4.10	8.24	6.52	0.52	13
1.86	10	69.2	68.2	67.4	66.3	65.0	62.9	2.9	4.6	5.7	4.22	6.51	3.00	0.18	17
2.08	21	65.4	63.6	61.8	60.5	58.6	55.9	4.9	7.0	4.9	4.02	11.69	9.04	0.57	16
1.54	16	64.5	63.2	60.5	58.1	54.8	51.2	6.4	6.8	5.5	4.19	6.29	7.38	0.47	16
1.52	11	61.2	60.5	60.0	59.1	57.6	55.6	2.1	3.4	5.8	4.22	3.15	3.04	0.23	13
1.71	14	69.1	67.4	66.1	64.0	61.2	57.9	5.1	8.5	4.4	3.60	31.91	10.12	0.69	15
1.40	24	72.6	71.3	69.8	68.7	66.7	63.6	3.9	4.8	5.2	3.90	15.73	6.72	0.36	19
1.35	2	71.8	70.9	69.9	69.6	69.0	67.1	2.2	2.6	5.7	4.18	6.29	2.41	0.16	15
1.79	25	71.5	68.7	65.7	63.6	60.0	56.4	7.9	11.0	4.5	3.75	21.57	8.82	0.85	10
1.70	18	70.5	68.6	67.1	65.8	63.8	60.5	4.7	7.9	4.8	3.99	13.48	4.51	0.62	7
1.51	6	70.9	69.4	67.6	66.0	63.8	61.4	4.9	7.4	5.0	4.10	7.19	2.02	0.24	8
1.07	4	70.4	68.1	66.6	65.0	62.8	60.2	5.4	6.7	5.6	4.07	4.82	2.00	0.12	17
2.96	22	64.1	61.1	55.6	52.7	49.6	47.3	11.4	15.6	4.3	3.25	62.15	10.85	0.47	23
2.51	4	59.1	57.6	56.1	55.0	53.2	50.7	4.1	6.3	4.5	3.40	36.17	6.25	0.18	35
1.70	1	59.3	58.5	56.7	55.2	53.1	50.0	4.1	7.3	4.7	3.90	21.45	2.00	0.07	29
2.03	385	62.4	60.0	56.7	55.1	51.3	46.3	7.3	17.7	5.0	4.0	1.50	5.46	0.48	11
1.60	530	42.8	37.5	29.0	28.2	25.4	23.6	14.6	43.1	5.7	5.4	2.42	0.43	0.02	22
1.82	145	58.8	54.6	51.2	50.0	44.2	40.3	8.8	20.0	5.4	4.6	1.65	5.20	0.47	11
1.59	635	37.2	32.2	23.6	21.1	19.7	18.0	16.1	48.7	5.6	5.1	3.41	0.72	0.03	24
1.63	42	71.8	70.0	67.2	65.0	60.9	57.1	6.8	11.0	4.8	4.3	0.95	5.24	0.51	10
1.57	30	75.8	74.2	72.0	69.3	65.2	60.8	6.5	9.5	6.2	5.6	1.48	5.95	0.24	25
1.95	315	61.7	58.2	54.3	52.5	48.3	44.0	9.2	20.6	5.4	4.5	1.42	4.92	0.47	10
1.64	710	44.9	38.2	31.5	30.0	28.5	27.6	14.9	41.6	5.7	5.2	4.32	0.40	0.02	20
1.87	180	59.3	56.7	53.4	51.6	46.6	43.0	7.7	17.2	5.3	4.7	1.56	5.33	0.53	10
1.50	560	39.0	33.2	25.4	24.1	23.0	22.0	14.9	45.5	5.9	5.1	4.00	0.62	0.03	21
1.64	82	71.4	69.0	65.1	61.5	58.3	54.2	9.9	14.7	5.0	4.4	0.88	5.14	0.47	11
1.47	35	71.9	70.0	67.0	63.4	60.4	57.5	8.5	11.2	5.1	4.7	1.50	5.00	0.30	17
2.17	300	63.8	62.0	59.1	56.5	52.1	47.3	7.3	17.3	6.0	5.1	1.20	4.51	0.50	9
1.80	674	49.4	42.2	35.1	33.0	31.4	30.0	16.4	41.7	6.1	5.8	5.32	0.38	0.01	38
1.75	164	61.3	58.2	55.0	52.7	47.5	41.4	8.6	17.2	5.8	4.9	1.65	4.75	0.49	10
1.65	527	37.9	30.4	23.2	20.7	19.0	18.4	17.2	49.0	5.9	5.4	7.02	0.51	0.02	26
1.70	43	67.2	65.0	62.5	60.0	56.1	50.7	7.2	13.4	5.6	4.6	3.00	5.00	0.44	11
1.51	20	67.6	66.0	63.4	61.2	57.3	52.1	6.4	11.4	5.4	5.0	11.43	4.65	0.31	15
2.0	93	59.4	57.1	52.7	48.9	44.4	39.9	10.5	23.6	4.5	3.8	21.57	8.82	0.85	10
1.9	43	70.6	66.2	58.6	54.0	50.0	45.2	16.6	24.1	4.7	3.7	13.48	7.25	0.73	10
1.9	30	75.0	73.7	67.5	62.5	60.7	59.3	12.5	15.7	5.5	4.0	7.19	4.51	0.62	7
1.7	28	71.8	70.4	66.4	63.0	58.4	56.5	8.8	13.1	5.8	4.1	5.00	2.02	0.24	8
2.4	162	66.2	64.1	57.8	54.0	49.9	47.6	12.2	22.1	4.9	4.0	11.69	9.04	0.57	16
2.0	130	70.2	67.5	63.8	57.1	51.2	48.5	13.1	20.5	5.5	4.2	8.42	7.38	0.47	16
1.7	74	75.4	73.1	66.7	60.1	52.5	50.1	15.3	18.8	5.8	4.2	6.29	3.04	0.23	13
1.5	45	63.0	60.1	55.7	51.6	47.3	44.8	11.4	15.1	5.8	4.1	3.15	2.08	0.09	23
3.0	170	66.4	65.1	60.7	57.6	51.1	48.1	8.8	19.3	4.7	3.8	20.34	9.15	0.84	11
2.1	84	73.5	71.2	66.3	61.2	51.8	47.4	12.3	17.6	4.8	3.7	11.25	6.84	0.72	10
2.2	40	75.4	74.3	70.4	65.8	61.4	55.1	9.6	13.8	5.2	4.1	5.72	4.02	0.33	12
1.9	28	70.9	69.9	66.9	64.1	58.6	56.3	6.8	10.2	5.8	4.2	4.35	3.00	0.21	14
2.1	12	72.3	71.0	68.9	66.8	62.9	60.5	5.5	6.2	5.8	4.0	3.02	0.53	0.02	27
2.3	77	66.5	60.6	59.0	55.6	51.0	47.4	6.9	15.8	4.4	3.6	31.91	10.12	0.69	15
1.9	61	74.1	69.2	65.5	60.7	52.7	48.0	13.4	17.0	5.2	3.9	15.73	6.72	0.36	19
2.0	33	74.2	72.0	70.0	66.0	61.4	56.2	8.2	12.4	5.7	4.0	10.45	4.35	0.27	16
1.9	9	70.8	68.7	65.4	63.2	59.5	57.3	7.6	11.3	5.8	4.2	6.29	2.05	0.16	13
1.7	4	72.8	70.6	68.5	66.7	62.9	61.2	6.1	6.5	6.0	4.5	2.84	0.67	0.03	22
3.6	40	34.6	29.0	26.8	25.8	25.2	25.1	8.8	28.5	4.9	3.6	18.70	1.85	0.12	15
2.5	54	38.0	34.9	31.9	29.3	27.2	26.2	8.7	11.4	4.8	3.3	20.45	0.92	0.03	31
4.0	45	25.7	23.4	23.2	23.1	22.6	21.9	2.6	32.2	4.9	3.2	20.07	0.68	0.01	68
1.7	80	37.7	36.3	35.5	34.9	32.6	32.4	2.8	8.4	5.3	3.8	12.13	0.73	0.05	15
0.9	76	46.9	44.4	41.1	39.2	35.4	33.4	7.7	10.5	4.0	3.2	28.43	0.80	0.03	27

Appendix-Table 2. (continued)

Location	Stand	Soil type	Horizon	Thickness of horizon (cm)	Volume weight (g/100cc)	Specific gravity of fine soil	Volume composition of soil in the field condition (%)					Min. air capacity (%)
							Solid			Water	Air	
							Fine soil	Gravel	Root			
Meguro Nursery	A7	Bl_D	A	35	—	2,30	21,2	—	0,2	42,3	36,3	8,2
	A13		A_2	20	—	2,34	20,7	—	0,1	48,0	31,2	6,5
			B	30	—	2,40	22,5	—	—	57,2	20,3	4,6
			B	35	—	2,44	23,6	—	—	61,3	15,1	1,5
Komoro	A8	Bl_D	ⅠA	20	—	2,20	18,0	2,0	0,5	41,7	37,8	15,2
	K14		ⅠA_1	15	—	2,22	18,5	2,1	0,2	42,3	36,9	8,0
			ⅡA_2	25	—	2,35	18,3	—	—	45,0	36,7	7,5
			ⅢA	40	—	2,41	17,5	3,0	—	48,6	30,9	5,5
			ⅢA-B	24	—	2,53	20,0	2,1	—	50,5	27,4	4,7
			ⅢC	—	—	2,61	22,8	5,0	—	52,1	20,1	4,0
	A8	Bl_D	A_1	15	—	2,31	20,5	1,5	1,3	40,8	35,9	14,5
	K14		A_2	20	—	2,25	20,0	1,0	0,4	44,5	34,1	10,4
			B_1	45	—	2,40	23,5	3,2	—	45,0	28,3	9,0
			B_2	40	—	2,52	22,7	2,0	—	45,2	30,1	8,4
			C	—	—	2,65	24,5	4,3	—	49,5	21,7	5,2
Mashiko	A10, 11, 12	B_A	A	7	—	—	24,3	—	1,1	32,5	42,1	15,2
			B_1	12	—	—	20,8	0,1	0,4	36,2	42,5	8,4
			B_2	50	—	—	18,3	0,2	0,2	44,0	37,3	7,6
			B_2	—	—	—	19,6	—	0,1	49,3	31,0	7,3
			C	—	—	—	17,4	0,1	0,1	57,7	24,7	5,0
Meguro	A14	Bl_D	A_1	25	—	2,36	18,0	—	1,9	38,1	42,0	20,1
	M2		A_2	25	—	2,38	19,4	—	1,2	42,4	37,0	8,5
			B	60	—	2,50	18,9	—	0,5	54,8	25,8	5,4
			B	—	—	2,58	21,1	—	—	62,6	16,3	2,7
Izu	A15, 16	B_B	A_1	4	—	2,25	24,5	0,9	0,3	30,0	44,3	15,7
			A_2	15	—	2,40	23,8	2,4	0,1	42,5	31,2	6,2
			B	55	—	2,38	23,2	4,5	—	43,7	28,6	2,5
	A17, 18	B_D(w)	A_1	15	49,7	2,39	20,6	0,7	0,1	41,2	37,4	5,9
			A_2	25	49,5	2,53	19,5	0,1	0,1	51,3	29,0	4,5
			B	70	46,1	2,74	19,7	0,5	—	59,6	20,2	2,7
			C	—	49,3	2,76	17,5	0,9	1,1	64,2	16,3	0,8
Tanzeyama	K1	Bl_{D-E}	A_1	8	—	—	17,5	—	0,6	69,9	12,0	0,0
			A_2	17	—	—	16,4	1,4	—	59,2	23,0	5,0
			B	13	—	—	18,0	1,5	—	61,3	19,2	3,0
			(A/B)′	19	—	—	—	—	—	—	—	—
			B′	20+	—	—	—	—	—	—	—	—
	K2	Bl_{D-E}	A_1	4	—	—	—	—	—	—	—	—
			A_2	9	—	—	19,0	0,8	0,5	33,0	35,0	1,8
			B	28	—	—	16,0	1,5	0,2	53,3	29,0	6,0
			(A/B)′	10	—	—	10,0	—	0,7	63,3	26,0	1,0
			C	30+	—	—	20,0	3,5	—	46,5	30,0	10,0
	K3	Bl_E	A_1	15	—	—	23,0	—	1,0	44,0	32,0	4,0
			A_2	15	—	—	19,0	—	0,5	53,5	27,0	2,0
			B_1	14	—	—	17,2	0,7	0,2	57,9	24,0	6,0
			B_2	23	—	—	20,0	1,0	—	57,0	22,0	5,0
			(A/B)′	40	—	—	17,0	1,0	—	61,0	21,0	4,5
			B	20+	—	—	—	—	—	—	—	—
	K4	Bl_F	A_1	5	—	—	16,0	—	—	56,0	28,0	4,2
			A_2	11	—	—	16,0	0,5	0,5	64,0	19,0	2,0
			B	24	—	—	18,0	2,0	1,0	68,0	11,0	4,0
			(A/B)′	40+	—	—	16,0	—	—	76,0	8,0	1,0
Nobeyama	K5	Bl_{E-F}	A_1	10	—	—	8,8	2,8	2,6	55,3	30,5	6,4
			A_2	12	—	—	14,1	0,9	1,4	66,7	16,9	5,3
			B_1	12+	—	—	15,4	0,1	0,3	75,2	9,0	2,8
	K7	Bl_G	A_1	10	—	—	14,1	0,7	1,0	67,2	17,0	4,7
			A_2	13	—	—	11,9	0,3	0,7	83,8	3,3	− 2,7
			A′	5	—	—	15,0	+	0,7	78,3	6,0	1,9

Value of pF in the field condition	Percolation rate (cc/min)	pF (Water in volume : %)						Non-capillary water (%)	Non-capillary pore space (%)	pH		Ex-changeable acidity	Carbon (%)	Total nitrogen (%)	C/N ratio
		0	1	1.5	1.7	2.0	2.5			H_2O	KCl				
1.9	—	70.4	62.5	53.0	47.0	37.8	33.2	23.4	31.6	6.1	—	1.20	8.45	0.75	11
1.8	—	72.7	66.0	55.8	51.7	42.4	37.0	21.0	27.5	6.0	—	1.52	9.22	0.84	11
2.1	—	72.9	69.0	62.4	60.0	58.3	55.7	12.9	17.5	5.7	—	1.45	3.31	0.24	14
2.5	—	74.9	72.6	67.4	65.8	63.5	61.5	9.1	10.6	5.7	—	3.90	2.45	0.07	35
2.1	200	64.3	62.3	54.0	50.1	42.2	37.0	14.2	29.4	6.0	5.0	0.65	5.32	0.51	10
2.1	75	71.2	67.0	56.2	52.7	43.4	39.5	16.7	25.0	5.9	5.0	0.57	7.05	0.54	13
2.0	57	74.2	71.0	60.0	55.1	45.0	39.2	19.1	26.2	6.1	5.2	0.42	6.07	0.53	11
1.8	42	74.0	70.7	59.5	53.0	42.0	39.0	21.0	26.5	5.7	4.9	0.44	7.15	0.65	11
1.8	35	73.2	68.4	58.4	52.1	43.0	39.5	21.1	25.8	5.6	4.7	0.30	4.32	0.25	17
1.8	20	68.2	65.3	57.5	54.0	43.5	40.3	14.2	18.2	5.4	4.5	0.15	0.75	0.02	38
2.2	257	62.2	59.5	51.0	48.2	42.7	38.5	14.0	28.5	6.1	5.1	0.50	6.00	0.53	11
2.0	80	68.2	66.1	55.7	52.0	43.7	39.0	16.2	26.6	6.0	4.9	0.47	5.42	0.48	11
1.9	58	64.3	62.0	53.5	50.1	40.5	38.3	14.2	23.2	5.7	5.0	0.35	3.25	0.27	12
1.9	40	66.9	64.1	55.0	46.3	44.2	40.0	20.6	29.0	5.8	4.8	0.28	1.45	0.08	18
1.8	32	66.0	64.0	54.5	45.4	43.4	39.5	20.6	25.8	5.5	4.4	0.10	0.66	0.02	33
2.9	436	59.4	55.5	49.2	44.4	39.9	35.9	15.0	30.2	5.8	4.6	3.0	10.7	0.62	17
2.5	95	70.8	68.0	57.4	47.8	39.0	36.5	22.5	30.9	5.8	5.8	2.5	2.7	0.20	14
2.4	82	73.7	69.7	59.5	53.5	45.0	43.2	20.2	27.8	6.0	6.0	1.8	1.8	0.08	23
2.1	70	73.0	70.3	63.9	55.7	48.4	45.5	17.3	24.6	6.0	5.8	1.8	1.3	0.06	22
2.0	32	77.4	74.0	67.7	62.4	57.0	33.2	15.0	20.0	6.0	6.0	1.2	0.8	0.03	27
1.8	628	60.0	57.2	51.4	47.0	37.7	31.2	13.0	33.1	5.70	—	1.35	8.73	0.68	13
2.0	245	70.9	67.5	55.1	50.0	42.5	35.3	20.9	29.4	5.82	—	1.72	6.20	0.54	11
2.1	62	75.2	71.4	65.7	62.1	55.0	50.1	13.1	18.5	5.45	—	3.40	3.53	0.20	18
2.1	25	76.2	72.5	69.4	66.9	63.5	58.9	9.3	12.0	5.50	—	8.52	1.57	0.06	26
3.1	675	58.6	55.4	42.3	39.2	34.0	32.1	19.4	35.1	5.4	4.7	15.20	5.24	0.43	12
2.1	420	67.5	65.0	53.5	50.0	41.5	37.6	17.5	23.7	5.6	4.9	10.56	4.15	0.35	12
2.0	94	69.8	67.8	62.0	57.5	43.0	35.6	12.3	14.8	5.9	4.7	4.35	1.95	0.08	24
2.0	390	72.7	65.1	55.0	47.1	41.0	38.2	25.6	31.5	5.8	4.8	3.08	11.3	0.79	14
2.0	379	75.8	72.0	65.5	60.0	51.7	46.0	15.8	20.3	6.0	5.0	2.24	8.8	0.54	16
1.9	89	77.1	74.6	67.0	62.5	58.2	54.0	14.6	17.3	5.9	5.9	1.40	2.9	0.16	18
1.9	24	79.7	77.0	69.5	66.0	63.2	60.0	13.7	14.5	6.0	5.8	1.11	0.9	0.03	30
—	—	—	—	—	—	—	—	—	—	4.4	4.0	19.6	16.44	1.28	13
—	—	—	—	—	—	—	—	—	—	4.8	4.3	6.6	12.96	0.95	15
—	—	—	—	—	—	—	—	—	—	5.2	4.8	1.2	5.06	0.45	11
—	—	—	—	—	—	—	—	—	—	5.3	4.8	0.9	7.62	0.52	15
—	—	—	—	—	—	—	—	—	—	5.9	5.0	0.6	3.26	0.24	14
—	—	—	—	—	—	—	—	—	—	4.6	4.2	11.5	13.77	1.08	13
—	—	—	—	—	—	—	—	—	—	4.9	4.4	6.3	11.66	0.94	13
—	—	—	—	—	—	—	—	—	—	5.2	4.9	0.6	7.41	0.52	14
—	—	—	—	—	—	—	—	—	—	5.3	4.9	1.2	8.78	0.56	16
—	—	—	—	—	—	—	—	—	—	5.7	5.3	0.6	0.86	0.09	10
—	—	—	—	—	—	—	—	—	—	4.7	4.2	10.1	12.38	1.01	12
—	—	—	—	—	—	—	—	—	—	5.0	4.4	7.2	12.68	0.97	13
—	—	—	—	—	—	—	—	—	—	5.2	5.0	0.9	6.86	0.51	13
—	—	—	—	—	—	—	—	—	—	5.2	4.9	1.2	7.41	0.54	14
—	—	—	—	—	—	—	—	—	—	5.3	4.9	0.9	8.88	0.54	16
—	—	—	—	—	—	—	—	—	—	5.7	5.0	1.3	1.15	0.13	9
—	—	—	—	—	—	—	—	—	—	4.3	4.0	20.4	17.39	1.38	16
—	—	—	—	—	—	—	—	—	—	4.6	4.2	10.6	15.03	1.13	13
—	—	—	—	—	—	—	—	—	—	4.9	4.9	1.2	7.14	0.51	14
—	—	—	—	—	—	—	—	—	—	5.4	4.7	0.9	12.24	0.66	19
—	145	79.6	—	—	—	—	—	—	—	5.3	4.1	17.2	21.3	1.54	13
—	50	78.2	—	—	—	—	—	—	—	5.6	4.4	8.7	17.0	1.22	13
—	37	81.5	—	—	—	—	—	—	—	5.6	4.6	2.7	14.3	0.98	14
—	40	79.5	—	—	—	—	—	—	—	5.2	4.2	12.4	23.5	1.79	13
—	39	89.8	—	—	—	—	—	—	—	5.2	4.3	8.4	16.6	1.22	13
—	10	82.3	—	—	—	—	—	—	—	5.2	4.3	19.0	20.8	1.57	13

Appendix-Table 2. (continued)

Location	Stand	Soil type	Horizon	Thickness of horizon (cm)	Volume weight (g/100cc)	Specific gravity of fine soil	Volume composition of soil in the field condition (%)					Min. air capacity (%)
							Solid: Fine soil	Solid: Gravel	Solid: Root	Water	Air	
Nobeyama	K 9	Bl_D	A	25	—	—	16.4	0.1	0.9	48.8	33.8	6.8
			B	30+	—	—	18.2	0.7	0.4	70.0	10.7	0.4
	K 10	Bl_D	A	20	—	—	13.6	1.2	1.7	41.7	41.8	15.5
			B	30+	—	—	17.2	0.2	1.5	63.5	17.6	4.3
	K 11	B_D	A	13	—	—	15.2	0.4	1.3	45.3	37.8	6.2
			A-B	8	—	—	16.9	0.4	0.4	56.7	25.6	7.8
			B	20+	—	—	16.3	+	1.5	58.9	23.3	9.1
	K 12	Bl_D	A	14	—	—	13.9	1.1	1.3	41.7	42.0	15.3
			A-B	11	—	—	13.9	1.0	2.1	53.4	29.6	5.1
			B	25+	—	—	15.9	0.2	3.4	59.0	21.5	4.5
	K 13	Bl_D	A	15	—	—	19.9	0.6	2.2	39.1	38.2	9.7
			A-B	10	—	—	23.5	0.7	0.5	52.5	22.8	2.6
			B	15+	—	—	16.8	0.3	0.6	49.0	33.3	9.5
Ueda	K 15	Bl_D	A	11	—	—	16.3	0.5	0.3	46.4	36.5	22.3
			A_2	10	—	—	18.5	1.5	0.1	60.3	19.6	10.4
			A-B	50+	—	—	19.4	1.6	0.0	68.6	10.4	4.6
	K 16	Bl_D(d)	A	14	—	—	15.5	1.1	0.9	44.0	38.5	20.5
			A-B_1	30	—	—	18.2	0.6	0.4	59.7	21.1	9.5
			A-B_2	15+	—	—	18.2	0.6	0.4	59.7	21.1	—
	K 17	Bl_D(d)	A_1	15	—	—	16.9	0.2	1.4	44.5	37.0	21.1
			A_2	15	—	—	16.2	1.8	0.2	63.8	18.0	6.6
			B	10+	—	—	—	—	—	—	—	—
	K 18	Bl_D	A_1	10	—	—	14.4	0.4	0.4	47.8	37.0	21.2
			A_2	13	—	—	15.9	0.3	0.6	59.9	23.3	10.0
			B	15+	—	—	—	—	—	—	—	—
	K 19	Bl_D	A_1	14	—	—	17.4	1.8	0.2	39.7	40.9	25.7
			A_2	38	—	—	17.5	0.4	0.4	63.8	17.9	3.7
	K 20	Bl_E	A_1	16	—	—	14.7	0.5	0.3	33.7	50.8	27.2
			A_2	20	—	—	14.4	2.6	0.1	42.2	40.7	17.7
			A_3	35	—	—	18.0	2.3	0.1	50.8	28.8	12.4
	K 21	Bl_D	A_1	9	—	—	13.6	0.7	0.8	37.8	47.1	30.7
			A_2	11	—	—	15.2	1.0	0.7	46.0	37.1	21.5
			A-B_1	25	—	—	17.0	1.4	0.2	58.0	23.4	9.0
			A-B_2	25	—	—	22.0	1.4	0.1	67.4	9.1	0.8
	K 22	Bl_D	A	18	—	—	18.7	3.3	0.2	44.4	33.4	22.5
			A-B_1	16	—	—	18.8	2.7	0.2	59.8	18.5	8.7
			A-B_2	26	—	—	18.4	3.7	0.1	62.2	15.6	5.8
			C	10+	—	—	—	—	—	—	—	—
	K 23	Bl_D-m	A_1	8	—	—	20.8	1.9	0.7	49.5	27.1	11.6
			A_2	45	—	—	25.8	3.5	0.2	59.8	10.7	1.3
	K 24	Bl_{DE}(m)	A_1	18	—	—	15.0	0.3	0.4	44.0	40.3	21.3
			A_2	24	—	—	15.3	0.3	4.2	52.0	28.2	7.3
			$A_{3(A')}$	50	—	—	20.8	0.1	0.1	61.9	17.1	4.4
	K 25	Bl_D(d)	A_1	8	—	—	17.6	2.5	0.2	33.8	45.9	11.0
			A_2	15	—	—	22.2	1.5	0.1	60.2	16.0	5.0
			A_3	17	—	—	19.5	3.0	0.1	56.6	20.8	8.4
			C	15+	—	—	—	—	—	—	—	—
	K 26	Bl_C	A	10	—	—	14.0	0.3	9.9	36.4	39.4	10.8
			B	20	—	—	21.8	2.0	0.4	44.9	30.9	12.6
	K 27	Bl_D	A_1	10	—	—	13.3	—	0.8	35.3	50.6	17.9
			A_2	10	—	—	16.6	—	0.2	47.5	35.7	16.9
			A_3	30	—	—	17.3	—	0.1	73.0	9.6	1.4
			A/B	20	—	—	—	—	—	—	—	—
			B	20+	—	—	—	—	—	—	—	—

Value of pF in the field condition	Percolation rate (cc/min)	pF (Water in volume : %)						Non-capillary water (%)	Non-capillary pore space (%)	pH		Exchangeable acidity	Carbon (%)	Total nitrogen (%)	C/N ratio
		0	1	1.5	1.7	2.0	2.5			H_2O	KCl				
—	200	75.8	—	—	—	—	—	—	—	5.3	4.3	9.5	15.3	1.10	13
—	33	80.2	—	—	—	—	—	—	—	5.5	4.7	1.7	7.8	0.62	12
—	119	68.0	—	—	—	—	—	—	—	5.1	4.2	10.0	15.5	1.18	13
—	51	67.7	—	—	—	—	—	—	—	5.5	4.5	2.3	8.5	0.66	12
—	175	77.0	—	—	—	—	—	—	—	5.0	4.2	14.1	16.4	1.26	13
—	67	74.5	—	—	—	—	—	—	—	5.2	4.4	5.0	14.4	0.94	15
—	60	73.1	—	—	—	—	—	—	—	5.3	4.5	2.7	10.4	0.72	14
—	—	68.4	—	—	—	—	—	—	—	5.1	4.2	18.5	16.3	1.27	12
—	102	77.9	—	—	—	—	—	—	—	5.2	4.4	5.5	11.2	0.91	12
—	65	76.0	—	—	—	—	—	—	—	5.3	4.6	3.2	9.1	0.77	11
—	265	67.6	—	—	—	—	—	—	—	5.6	4.6	2.5	8.6	0.76	11
—	135	72.7	—	—	—	—	—	—	—	5.7	4.8	0.8	5.0	0.41	12
—	120	72.7	—	—	—	—	—	—	—	5.8	4.8	0.7	3.7	0.27	12
—	93	60.6	—	—	—	—	—	39.8	43.1	4.6	—	34.2	14.4	1.14	13
—	49	69.0	—	—	—	—	—	41.3	38.7	5.1	—	15.8	10.2	0.74	14
—	15	74.4	—	—	—	—	—	53.1	25.6	5.3	—	10.2	9.1	0.66	14
—	152	62.0	—	—	—	—	—	46.1	36.4	4.9	—	19.8	15.9	1.15	14
—	28	71.4	—	—	—	—	—	43.3	37.6	5.3	—	7.1	10.7	0.79	14
—	—	—	—	—	—	—	—	—	—	5.6	—	1.7	9.2	0.61	15
—	21	60.5	—	—	—	—	—	40.3	41.3	5.0	—	26.3	20.3	1.58	13
—	13	75.3	—	—	—	—	—	51.8	30.1	5.5	—	3.0	12.1	0.80	15
—	—	—	—	—	—	—	—	—	—	5.5	—	1.5	6.0	0.41	15
—	32	63.6	—	—	—	—	—	41.8	43.0	5.3	—	8.5	15.2	1.36	11
—	51	73.3	—	—	—	—	—	41.3	42.0	5.5	—	2.3	10.1	0.89	11
—	—	—	—	—	—	—	—	—	—	5.7	—	0.9	6.4	0.64	10
—	60	54.9	—	—	—	—	—	37.8	42.8	5.3	—	11.0	14.5	1.26	12
—	35	78.1	—	—	—	—	—	52.3	29.5	5.4	—	2.5	10.1	0.87	12
—	21	53.7	—	—	—	—	—	34.3	50.2	5.0	—	16.7	16.3	1.49	11
—	87	65.3	—	—	—	—	—	33.3	49.7	5.3	—	4.5	9.4	0.90	10
—	46	67.3	—	—	—	—	—	41.5	38.2	5.5	—	1.5	7.6	0.67	11
—	86	54.3	—	—	—	—	—	33.6	51.4	4.9	—	28.8	15.6	1.27	12
—	25	61.9	—	—	—	—	—	36.8	46.6	4.9	—	28.5	14.5	1.15	13
—	25	72.5	—	—	—	—	—	45.7	35.8	5.2	—	9.3	7.4	0.68	11
—	23	75.7	—	—	—	—	—	56.4	20.1	5.3	—	5.1	7.4	0.67	11
—	15	55.3	—	—	—	—	—	42.5	35.3	4.9	—	26.6	16.2	1.25	13
—	15	69.9	—	—	—	—	—	51.5	27.1	5.4	—	8.8	8.6	0.66	13
—	18	72.0	—	—	—	—	—	54.2	23.6	5.5	—	5.9	8.5	0.57	15
—	—	—	—	—	—	—	—	—	—	5.5	—	1.1	3.1	0.30	10
—	10	65.0	—	—	—	—	—	48.1	28.5	5.0	—	17.5	11.8	0.82	14
—	11	69.3	—	—	—	—	—	46.8	23.8	5.3	—	5.1	7.0	0.48	15
—	158	63.0	—	—	—	—	—	42.3	42.0	4.8	—	18.1	11.5	0.77	15
—	193	72.9	—	—	—	—	—	50.4	29.8	4.7	—	14.0	9.5	0.66	14
—	68	74.6	—	—	—	—	—	57.7	21.3	4.8	—	14.8	10.7	0.71	15
—	31	68.1	—	—	—	—	—	38.3	41.4	4.5	—	20.9	12.4	0.99	13
—	53	71.2	—	—	—	—	—	52.7	23.5	4.6	—	13.8	11.2	0.86	13
—	30	68.9	—	—	—	—	—	50.5	26.9	4.8	—	6.9	8.7	0.62	14
—	—	—	—	—	—	—	—	—	—	5.0	—	1.8	1.4	0.15	9
—	116	65.0	—	—	—	—	—	33.9	41.9	4.8	—	15.3	10.3	0.80	13
—	85	63.2	—	—	—	—	—	41.1	34.7	4.9	—	6.1	6.5	0.47	14
—	88	68.0	—	—	—	—	—	32.1	53.8	4.9	—	18.4	13.8	1.04	13
—	66	66.3	—	—	—	—	—	46.3	36.9	4.7	—	18.6	13.3	0.89	15
—	37	81.2	—	—	—	—	—	64.7	17.9	4.8	—	10.5	10.1	0.69	15
—	—	—	—	—	—	—	—	—	—	5.0	—	4.8	5.2	0.42	12
—	—	—	—	—	—	—	—	—	—	5.2	—	1.5	1.5	0.20	8

Appendix-Table 2. (continued)

Location	Stand	Soil type	Horizon	Thickness of horizon (cm)	Volume weight (g/100cc)	Specific gravity of fine soil	Volume composition of soil in the field condition (%)					Min. air capacity (%)
							Solid			Water	Air	
							Fine soil	Gravel	Root			
Ueda	K28	Bl_D	A_1	16	—	—	17.2	0.4	0.6	51.3	30.5	7.0
			A_2	15	—	—	17.2	1.2	1.1	53.8	26.7	9.6
			A-B	30	—	—	21.7	1.1	0.2	57.9	19.1	6.9
	K29	Bl_B	A_1	10	—	—	22.1	2.8	2.5	30.2	42.4	15.4
			A-B	15	—	—	26.5	2.0	1.5	33.3	36.7	16.6
			A′	20+	—	—	26.3	2.0	0.5	64.4	6.8	5.6
Oneyama	M5	Bl_D	IA_1	9	—	—	18.5	6.7	1.0	51.8	22.0	9.5
			IB-C_1	20	—	—	9.0	18.6	+	38.0	34.4	26.0
			ⅡA	27	—	—	21.1	10.0	0.2	50.8	17.9	8.0
			ⅡB-C_1	20	—	—	10.6	21.2	—	23.0	45.2	32.4
			ⅢA	27	—	—	22.0	4.0	—	64.3	9.7	4.0
			ⅢB-C	—	—	—	23.7	2.3	—	66.8	7.2	2.1
Meguro forest experiment	*Abies*—*Quercus* forest	Bl_D	A_1	25	—	2.34	23.5	—	0.5	39.1	36.9	15.2
			A_2	35	—	2.40	23.0	—	0.2	45.0	31.8	8.1
			A_3	25	—	2.28	19.4	—	0.1	57.6	22.9	6.7
			A_4	100	—	2.37	21.5	—	—	60.0	18.5	4.4
			A_4	100	—	2.51	20.4	—	—	61.1	18.5	2.3
			B	15	—	2.60	18.6	—	—	69.0	12.4	2.5
			C	10	—	2.61	24.0	—	—	64.4	11.6	1.7
Asakawa nursery	A*	—	Ⅰ	15	—	—	24.7	1.3	0.1	41.7	32.2	5.2
			Ⅱ	15	—	—	25.0	0.9	0.1	45.2	28.8	4.3
			Ⅲ	30	—	—	23.9	—	—	52.1	24.0	3.2
			Ⅳ	30	—	—	22.4	0.6	0.1	53.8	23.1	3.8
			Ⅴ	30	—	—	21.5	—	—	60.6	17.9	2.1
	B*	—	Ⅰ	15	—	—	22.9	—	0.1	47.2	29.8	9.2
			Ⅱ	15	—	—	24.0	0.3	0.1	48.6	27.0	10.0
			Ⅲ	30	—	—	24.3	1.9	0.2	45.1	28.5	6.4
			Ⅳ	30	—	—	25.0	1.7	—	54.5	18.8	4.7
			Ⅴ	30	—	—	22.3	—	—	62.7	15.0	1.4
	C*	—	A_1	25	—	—	25.1	—	0.2	42.1	32.6	5.6
			A_2	30	—	—	24.3	—	0.1	46.7	28.9	4.2
			B_1	30	—	—	23.0	—	—	55.4	21.6	3.5
			B_2	60	—	—	21.5	—	—	58.7	19.8	2.4
			B_2	—	—	—	20.8	—	—	66.5	12.7	1.2
Meguro nursery	B*	—	A	35	—	2.32	20.5	—	0.2	40.3	39.0	7.8
			B_1	20	—	2.37	22.3	—	0.1	47.5	30.1	4.7
			B_2	60	—	2.45	23.0	—	—	58.0	19.0	3.2
			B_2	—	—	2.51	24.3	—	—	62.6	13.1	2.5
Root box	A*	—	Ⅰ・Ⅳ	10	—	2.34	22.3	—	—	40.4	37.3	11.2
	B*	—	Ⅱ・Ⅴ・Ⅶ	20	—	2.60	20.4	—	—	59.0	20.6	5.3
	D*	—	Ⅲ・Ⅵ	20	—	2.72	40.6	11.2	—	7.2	41.0	7.5

* A : Surface soil, B : Subsurface soil, C : Nursery soil, D : Sandy soils

Value of pF in the field condition	Percolation rate (cc/min)	pF (Water in volume : %)						Non-capillary water (%)	Non-capillary pore space (%)	pH		Exchangeable acidity	Carbon (%)	Total nitrogen (%)	C/N ratio
		0	1	1.5	1.7	2.0	2.5			H_2O	KCl				
—	21	74.9	—	—	—	—	—	44.3	37.6	5.6	—	2.8	13.6	1.17	12
—	11	71.0	—	—	—	—	—	47.8	32.8	5.5	—	4.5	12.4	1.05	12
—	29	70.1	—	—	—	—	—	47.7	29.3	5.9	—	1.1	6.1	0.62	10
—	127	57.2	—	—	—	—	—	34.2	38.4	4.8	—	13.3	4.3	0.31	14
—	77	53.4	—	—	—	—	—	32.9	37.1	5.1	—	4.1	3.9	0.29	13
—	45	76.8	—	—	—	—	—	43.4	27.8	5.0	—	10.7	5.0	0.38	13
2.15	350	64.3	61.6	58.4	56.2	53.0	49.1	8.1	17.6	5.2	4.3	1.75	6.00	0.58	10
1.70	575	46.4	41.0	39.5	38.0	36.0	35.0	8.4	34.4	5.5	5.3	11.20	0.52	0.02	25
1.90	152	60.7	57.4	53.7	52.3	50.0	46.5	8.4	16.4	5.1	4.5	1.62	4.84	0.47	10
1.65	647	35.8	29.0	23.5	22.8	22.5	21.8	13.0	45.4	5.6	5.5	9.50	0.82	0.03	27
1.54	54	70.0	68.0	64.8	62.3	58.1	55.1	7.7	11.7	5.0	4.2	1.75	4.57	0.42	11
1.42	28	71.9	69.0	66.4	64.0	60.2	56.0	7.9	10.0	5.9	5.7	5.62	5.00	0.32	16
2.0	340	60.8	57.7	50.7	44.2	39.1	34.4	16.6	31.8	5.54	—	1.12	10.52	0.62	17
1.9	105	68.7	66.1	57.9	51.6	43.7	37.8	17.1	25.2	5.47	—	1.05	9.71	0.60	16
1.8	43	73.8	67.5	63.7	59.1	54.0	50.1	14.7	21.4	5.70	—	2.73	9.90	0.57	17
1.8	40	74.1	72.2	67.0	62.8	57.5	53.3	11.3	15.7	6.00	—	3.45	7.21	0.45	16
2.0	28	77.3	74.2	69.3	66.1	60.8	57.5	11.2	13.5	6.05	—	3.40	6.05	0.41	15
1.7	19	78.9	75.9	72.0	69.1	64.2	62.3	9.8	12.3	5.02	—	15.75	2.54	0.07	36
1.6	25	74.3	72.1	65.2	63.4	61.1	59.9	10.9	12.6	4.80	—	28.00	0.82	0.02	41
2.0	72	68.7	65.1	56.5	51.3	41.6	36.0	17.4	22.6	6.6	5.5	1.12	8.35	0.47	18
1.9	65	69.7	65.0	57.0	52.5	44.7	40.0	17.2	21.5	6.5	5.5	1.15	7.80	0.43	18
1.8	83	72.9	67.5	57.5	53.2	44.6	40.3	19.7	22.9	6.6	5.6	1.10	10.32	0.53	19
1.8	80	73.1	67.8	59.1	55.0	46.0	42.2	18.1	21.9	6.6	5.9	3.93	9.65	0.44	22
2.0	23	76.4	69.0	60.2	55.1	51.2	48.3	21.3	23.4	6.6	5.9	1.12	6.41	0.19	34
3.0	130	67.8	65.1	62.0	58.5	53.6	50.3	9.3	18.5	6.7	5.8	2.23	0.90	0.02	45
2.1	124	65.6	62.3	56.5	52.5	49.6	46.0	13.1	23.1	6.6	5.3	1.78	4.65	0.27	17
2.2	92	67.2	65.0	60.5	56.3	53.2	48.3	10.9	17.3	6.7	6.1	1.15	7.31	0.42	17
2.1	32	68.6	66.0	61.5	58.7	55.5	50.6	9.9	14.6	6.5	5.7	0.62	7.80	0.46	17
2.1	15	76.3	63.0	69.4	66.2	63.6	58.2	10.1	11.5	6.6	5.7	1.15	7.82	0.47	17
2.0	80	69.1	63.6	56.7	51.2	42.2	36.0	17.9	23.5	6.6	5.9	1.20	9.24	0.60	15
1.9	57	71.4	67.0	59.3	54.2	45.0	41.5	17.2	21.4	6.5	5.4	1.10	7.00	0.45	16
2.2	26	73.5	69.6	64.2	61.1	56.5	53.7	12.4	15.9	6.7	5.7	3.45	5.31	0.30	18
1.8	24	76.1	71.2	64.7	60.0	56.8	54.0	16.1	18.5	6.4	5.6	8.52	3.26	0.14	23
2.1	10	78.0	75.0	72.5	70.0	67.2	64.8	8.0	9.2	6.5	5.6	7.40	2.14	0.10	21
1.9	384	71.5	62.8	53.2	48.1	38.3	33.7	23.4	31.2	6.0	—	1.02	9.42	0.72	13
1.9	256	72.9	66.5	55.7	51.5	42.5	37.1	21.4	26.1	6.2	—	1.45	7.31	0.50	15
2.0	83	73.8	70.0	63.8	61.0	58.0	55.5	12.8	16.0	5.4	—	0.90	5.25	0.37	14
2.0	46	73.2	71.5	67.4	64.5	62.9	61.0	8.7	11.2	5.6	—	1.31	2.52	0.09	28
2.3	75	66.5	63.5	55.4	51.4	43.4	37.7	15.1	26.3	6.0	—	1.14	10.25	0.86	12
2.6	12	74.3	71.7	68.6	67.2	63.7	59.9	7.1	12.4	4.5	—	5.72	2.08	0.09	23
3.2	204	40.7	32.4	19.9	13.2	11.1	9.5	24.3	31.8	5.7	—	20.35	0.05	+	—