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

Reduction of inorganic matters to soil and formation of porosity resulting from root system

By

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Summary : The rotting of roots after the cutting or dying of trees is an important process that forms porosity in the soil and supplies organic or inorganic matters to the soil. These matters or porosity have physico-chemical influences on forest soils, which are helpful to forest reproduction.

The root biomass per ha of dominant and codominant trees at each stand age and the amount per ha of porosity and inorganic matters were estimated for different stand ages of *C. japonica, Ch. obtusa, P. densiflora* and *L. leptolepis.*

When the trees were cut down at a stand age of 40 years in the second site class forest of the yield table, the root biomass per ha left in the soil was 67 tons for *C. japonica*, 45 tons for *Ch. obtusa* 47 tons for *P. densiflora*, and 37 tons for *L. leptolepis.*

The total amount per ha of inorganic matters restored to the soil was as follows: Nitrogen-71 kg for *C. japonica*, 80kg for *Ch. obtusa*, 35kg for *P. densiflora*, and 39kg for *L. leptolepis* ; and Phosphorus-13kg for *C. japonica* and *Ch. obtusa*, 10kg for *P. densiflora* and 8kg for *L. leptolepis* ; Potassium-88kg for *C. japonica*, 74kg for *Ch. obtusa*, 68kg for *P. densiflora*, and 36kg for *L. leptolepis* ; and Calcium-250kg for *C. japonica*, 70kg for *Ch. obtusa*, 103kg for *P. densiflora*, and 31kg for *L. leptolepis.*

The amount per ha of porosity estimated from the root volume was 161m³ for *C. japonica*, 93 m³ for *Ch. obtusa*, 110m³ for *P. densiflora*, and 88m³ for *L. leptolepis.*

The root biomass, the amount of porosity, and the amount of inorganic matters considerably varied with species. The difference in the amount of inorganic matters was largely due to the difference in stand volumes.

The distribution of the root biomass and the amount of porosity in the soil is dependent upon how thick are the roots, such as stock, very large roots or large roots which occupy a greater part of the root biomass. The ratios of root distribution within the upper horizon 30cm deep were, to the total amount of root biomass, 80% for *C. japonica* and *L. leptolepis*, 89% for *Ch. obtusa* and 68% for *P. densiflora.* All these species except *P. densiflora* showed the high ratios of over 80% in the upper horizon. *P. densiflora* grows its tap roots into deep soil and therefore has a comparatively high ratio in the lower soil horizon.

The reduction ratios of matters in the 40 years-old stands of each species were estimated from both data of dry matters and inorganic matters in the above-and under-ground parts. The ratios for dry matter were 68% for *C. japonica*, 75% for *Ch. obtusa*, 69% for *P. densiflora*, and 67% for *L. leptolepis.*

Contents

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I Introduction

Many reports have been made on forest production in the aboveground parts. However, there has been little data available on the production in the underground parts. To throw some new light on that field, therefore, the author has made a series of studies on the root system of different tree species since 1951.

The present report is the fifth part of such a series of studies on the distribution, biomass, and functions of the root system, dealing with the production and reduction of inorganic matters by the growth and decay of roots. A study has also been made on the function of roots in the formation of porosity in the soil.

II Amount of inorganic matters in each tree part

Inorganic matters in each tree part were analyzed with the samples taken from seven stands of *C. japonica*, eight stands of *Ch. obtusa*, six stands of *P. densiflora*, and five stands of *L. leptolepis* (see the preceeding article I (KARIZUMI, 1974) for the descriptions of stands) by the following methods: Kjeldahl's method for nitrogen, colorimetric method for phosphorus, and flame photometric method for potassium and calcium. The results are shown by dry matter basis in Table 1. The variable coefficients of these values were 10-20% including some errors by sampling.

By using the data of Table 1 and the biomass of each tree part, the average amounts of inorganic matters in each tree part, a whole tree, and one hectare were examined.

1. Nitrogen (N)

(1) Average amount per tree

a. aboveground part

Examples of the standing amounts per tree of N are shown in Tables 2 and 3. In *C. japonica*, the average amount per tree of N was 78g in the 9-year-old S1 stand, 176g in the 23-year-old S2 stand, 311g in the 34-year-old S4 stand, 353g in the 45-year-old S5 stand, and 1095g in the 49-year-old S17 stand.

The amount increased with the increasing stand age. To compare the amount among four species with nearly the same basal area, the average amount per tree of N was 353g in the *C. japonica* stand (b.a. 439 ㎠), 346g in the *Ch. obtusa* stand (b.a. 427㎠), 232g in the *P. densiflora* stand (b.a. 361㎠), and 269g in the *L. leptolepis* stand (b.a. 442㎠). (Table 3)

Of all the tree parts, the leaf part showed the largest average amount per tree of N. In the mature stand of *C. japonica*, the average amount per tree of N was 100g to 150g at the basal areas of 300 to 500㎠. In the stands of almost the same basal area, the amount was 35 to 80g for *L. leptolepis*, 80 to 100g for *P. densiflora*, and 100 to 150g for *Ch. obtusa*. *L. leptolepis* had the smallest leaf biomass.

The ratio of N amount in each part is given in Tables 2 and 3 as an example.

The ratio of N in the stem part was 30-40% of the total amount of N. In the immature stand, the ratio of the stem part was lower than that of the leaf part, and shows the tendency to increase with the increasing stand age. For example, in *C. japonica*, the ratio was 9% and 34% in a 9-year-old and 45-year-old stand, respectively. The ratio in *Ch. obtusa* was very low, as compared with those of *C. japonica, L. leptolepis* or *P. densiflora* ; the ratio was only 8% in the 48-year-old stand.

The ratio of the N accumulation in the branch part to the total N accumulation per ha was 4-9% for *C. japonica*. It increased with tree age, though it did not do so as remarkably as that in the stem part. *Ch. obtusa* showed the low ratio of 3 to 6%, which was less than that of *C. japonica*. On the other hand, there were many stands of *P. densiflora* in which those ratios showed more than 10%. *P. densiflora* contained relatively much more N in the branch part.

The ratio in the leaf part was the highest of all tree parts in each species. That of *C. japonica* was over 50% of the gross amount in almost all stands surveyed. Particularly in the immature stands, a greater part of the accumulation distributed to the leaf part. The ratio went down in the

Table 1. Content of inorganic matters by tree species and tree parts, with the aboveground for five stand ages and the underground for five soil horizons. (%)

Species	Stand age	N			P_2O_5			K_2O			CaO		
		Stem	Branch	Leaf	Stem	Branch	Leaf	Stem	Branch	Leaf	Stem	Branch	Leaf
C. japonica	10	0.10	0.35	1.36	0.05	0.08	0.23	0.11	0.11	0.75	0.20	1.10	1.60
	20	0.09	0.33	1.26	0.04	0.07	0.22	0.12	0.12	0.70	0.22	1.15	1.65
	30	0.08	0.31	1.17	0.03	0.04	0.21	0.13	0.13	0.65	0.25	1.20	1.70
	40	0.08	0.28	1.08	0.02	0.03	0.20	0.14	0.13	0.60	0.26	1.25	1.75
	50	0.07	0.25	1.00	0.02	0.02	0.20	0.15	0.14	0.55	0.27	1.30	1.80
	Soil horizon	N						P_2O_5					
		f	s	m	l	L	St	f	s	m	l	L	St
	I	0.74	0.44	0.35	0.15	0.09	0.06	0.17	0.08	0.06	0.05	0.03	0.01
	II	0.60	0.43	0.30	0.14	0.08	—	0.12	0.06	0.05	0.04	0.01	—
	III	0.55	0.35	0.25	0.11	0.06	—	0.07	0.04	0.04	0.02	0.01	—
	IV	0.37	0.27	0.20	0.09	—	—	0.05	0.02	0.03	0.01	—	—
	V	0.35	0.20	0.14	0.07	—	—	0.04	0.01	0.02	0.01	—	—
	Soil horizon	K_2O						CaO					
		f	s	m	l	L	St	f	s	m	l	L	St
	I	0.43	0.32	0.25	0.12	0.13	0.13	0.92	0.60	0.55	0.46	0.40	0.35
	II	0.30	0.28	0.20	0.10	0.08	—	0.84	0.55	0.48	0.43	0.35	—
	III	0.26	0.25	0.17	0.09	0.06	—	0.75	0.45	0.40	0.34	0.30	—
	IV	0.20	0.20	0.10	0.07	—	—	0.70	0.40	0.35	0.30	0.25	—
	V	0.17	0.18	0.08	0.06	—	—	0.65	0.40	0.35	0.30	—	—

Table 1. (Continued)

Species	Stand age	N			P_2O_5			K_2O			CaO		
		Stem	Branch	Leaf	Stem	Branch	Leaf	Stem	Branch	Leaf	Stem	Branch	Leaf
	10	0.08	0.26	1.12	0.05	0.09	0.30	0.13	0.22	0.94	0.07	0.35	1.30
	20	0.07	0.20	1.05	0.04	0.08	0.29	0.14	0.23	0.90	0.08	0.37	1.25
	30	0.06	0.18	0.97	0.03	0.07	0.27	0.15	0.24	0.87	0.08	0.39	1.20
	40	0.06	0.18	0.93	0.02	0.06	0.25	0.15	0.25	0.85	0.09	0.42	1.15
	50	0.05	0.14	0.90	0.02	0.04	0.22	0.16	0.26	0.82	0.10	0.45	1.00
	Soil horizon	N						P_2O_5					
		f	s	m	l	L	St	f	s	m	l	L	St
	I	1.02	0.65	0.30	0.12	0.05	0.05	0.18	0.07	0.04	0.03	0.02	0.01
Ch. obtusa	II	1.00	0.60	0.28	0.10	0.04	—	0.16	0.05	0.03	0.02	0.02	—
	III	0.94	0.52	0.20	0.08	—	—	0.10	0.04	0.03	0.02	0.01	—
	IV	0.67	0.40	0.15	0.06	—	—	0.07	0.03	0.02	0.01	—	—
	V	0.55	0.36	0.12	0.05	—	—	0.05	0.03	0.01	0.01	—	—
	Soil horizon	K_2O						CaO					
		f	s	m	l	L	St	f	s	m	l	L	St
	I	0.42	0.30	0.25	0.19	0.14	0.12	0.50	0.25	0.20	0.18	0.15	0.12
	II	0.40	0.28	0.20	0.18	0.10	—	0.45	0.20	0.15	0.17	0.10	—
	III	0.39	0.24	0.14	0.15	0.07	—	0.40	0.18	0.10	0.15	0.08	—
	IV	0.38	0.20	0.10	0.12	—	—	0.36	0.16	0.08	0.14	—	—
	V	0.37	0.15	0.08	0.10	—	—	0.33	0.15	0.08	0.12	—	—

Table 1. (Continued)

Species	Stand age	N			P_2O_5			K_2O			CaO		
		Stem	Branch	Leaf	Stem	Branch	Leaf	Stem	Branch	Leaf	Stem	Branch	Leaf
P. densiflora	10	0.07	0.25	1.40	0.07	0.09	0.25	0.13	0.20	0.50	0.15	0.55	0.40
	20	0.06	0.20	1.35	0.06	0.08	0.24	0.14	0.22	0.47	0.18	0.60	0.35
	30	0.05	0.20	1.30	0.05	0.07	0.22	0.14	0.24	0.43	0.21	0.68	0.28
	40	0.05	0.18	1.25	0.03	0.05	0.20	0.15	0.26	0.40	0.23	0.73	0.25
	50	0.04	0.17	1.22	0.03	0.04	0.19	0.17	0.28	0.39	0.26	0.77	0.22
	Soil horizon	N						P_2O_5					
		f	s	m	l	L	St	f	s	m	l	L	St
	I	1.10	0.42	0.25	0.12	0.08	0.05	0.25	0.07	0.04	0.03	0.03	0.01
	II	0.92	0.30	0.25	0.12	0.06	—	0.20	0.06	0.03	0.03	0.02	—
	III	0.74	0.27	0.20	0.08	—	—	0.14	0.05	0.03	0.02	—	—
	IV	0.70	0.24	0.20	0.08	—	—	0.09	0.05	0.02	0.02	—	—
	V	0.68	0.21	0.15	0.04	—	—	0.08	0.04	0.02	0.01	—	—
	VI〜	0.65	0.18	0.15	0.04	—	—	0.08	0.03	0.01	0.01	—	—
	Soil horizon	K_2O						CaO					
		f	s	m	l	L	St	f	s	m	l	L	St
	I	0.45	0.31	0.25	0.10	0.14	0.15	0.45	0.34	0.20	0.16	0.23	0.25
	II	0.38	0.30	0.23	0.09	0.13	0.14	0.42	0.30	0.18	0.15	0.20	—
	III	0.32	0.25	0.18	0.07	0.11	—	0.40	0.26	0.17	0.14	0.18	—
	IV	0.30	0.20	0.17	0.05	—	—	0.37	0.23	0.15	0.13	—	—
	V	0.28	0.17	0.15	—	—	—	0.35	0.20	0.13	0.10	—	—
	VI〜	0.25	0.15	0.10	—	—	—	0.32	0.17	0.10	—	—	—

Table 1. (Continued)

Species	Stand age	N			P_2O_5			K_2O			CaO		
		Stem	Branch	Leaf	Stem	Branch	Leaf	Stem	Branch	Leaf	Stem	Branch	Leaf
L. leptolepis	10	0.11	0.32	2.22	0.03	0.05	0.18	0.11	0.35	0.85	0.05	0.25	0.45
	20	0.10	0.30	2.10	0.03	0.04	0.18	0.13	0.37	0.84	0.05	0.27	0.42
	30	0.09	0.28	2.00	0.02	0.03	0.17	0.15	0.38	0.83	0.06	0.30	0.40
	40	0.08	0.26	1.90	0.02	0.02	0.17	0.16	0.39	0.83	0.06	0.33	0.38
	50	0.06	0.25	1.84	0.01	0.02	0.16	0.16	0.40	0.81	0.07	0.35	0.36
	Soil horizon	N						P_2O_5					
		f	s	m	l	L	St	f	s	m	l	L	St
	I	0.70	0.42	0.30	0.13	0.08	0.06	0.20	0.06	0.05	0.03	0.02	0.02
	II	0.55	0.35	0.28	0.12	0.07	—	0.18	0.05	0.03	0.02	0.01	—
	III	0.40	0.30	0.24	0.10	0.06	—	0.12	0.05	0.03	0.01	0.01	—
	IV	0.34	0.27	0.16	0.08	0.05	—	0.09	0.04	0.02	0.01	0.01	—
	V	0.32	0.20	0.10	0.07	—	—	0.05	0.03	0.01	0.01	—	—
	Soil horizon	K_2O						CaO					
		f	s	m	l	L	St	f	s	m	l	L	St
	I	0.33	0.25	0.14	0.09	0.10	0.09	0.33	0.20	0.16	0.09	0.08	0.07
	II	0.30	0.20	0.12	0.08	0.08	—	0.30	0.17	0.14	0.08	0.07	—
	III	0.25	0.15	0.10	0.06	0.07	—	0.27	0.15	0.12	0.07	0.05	—
	IV	0.23	0.10	0.09	0.05	0.06	—	0.25	0.13	0.10	0.06	0.04	—
	V	0.20	0.08	0.08	0.04	—	—	0.23	0.10	0.09	0.05	—	—

Note) 1. Root size

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

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

2. Soil Horizon
I : 0~15cm, II : 15~30cm
III~V : every 30cm
3. All figures are shown by dry matter basis.

Table 2.　The total amount per tree of each inorganic matter in *C. japonica* for different basal areas, and the ratio of the amount in the fine root to the total amount.

g・(%)

Stand	S1	S2	S4	S5	S17
Basal area (cm^2)	61	249	335	439	1 042
N	78*(2.1)**	176(2.0)	311(1.4)	353(1.5)	1 095(0.9)
P_2O_5	16(2.1)	39(1.8)	61(1.4)	76(1.3)	233(0.9)
K_2O	49(1.8)	51(1.3)	303(0.8)	427(0.6)	1 205(0.5)
CaO	112(1.9)	391(1.2)	786(0.8)	1 095(0.6)	3 243(0.4)

*　The total amount per tree of each inorganic matter
**　The ratio of the amount in the fine root to the total amount

Table 3.　The amount(g) and ratio (in parentheses, %) per tree of four inorganic matters in different parts of four tree species.

	N				P_2O_5			
Tree species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Stand*	S5	H5	A8	K19	S5	H5	A8	K19
Basal area (cm^2)	439	427	361	442	439	427	361	442
Stem	120.42 (34.1)	111.42 (32.1)	69.02 (29.8)	110.86 (41.3)	34.41 (45.1)	37.14 (38.4)	41.41 (57.4)	18.47 (48.5)
Branch	30.21 (8.6)	13.60 (3.9)	28.71 (12.4)	38.13 (14.2)	2.42 (3.2)	9.07 (9.4)	7.98 (11.1)	3.05 (8.0)
Leaf	149.73 (42.4)	148.73 (43.0)	93.85 (40.5)	75.26 (28.0)	29.95 (39.4)	36.36 (37.6)	15.02 (20.8)	6.54 (17.1)
Above ground part	300.36 (85.1)	273.75 (79.0)	191.58 (82.7)	224.25 (83.5)	66.87 (87.7)	82.57 (85.4)	64.41 (89.3)	28.06 (73.6)
f	5.12 (1.5)	13.94 (4.0)	1.05 (0.4)	2.51 (0.9)	0.98 (1.3)	2.14 (2.2)	0.19 (0.3)	0.73 (1.9)
s	4.80 (1.4)	20.19 (5.7)	3.36 (1.4)	2.69 (1.0)	0.65 (0.9)	1.85 (1.9)	0.59 (0.8)	0.39 (1.0)
m	7.66 (2.2)	7.85 (2.3)	7.30 (3.1)	7.64 (2.8)	1.24 (1.6)	1.04 (1.1)	1.01 (1.4)	1.06 (2.8)
l	5.03 (1.4)	7.12 (2.1)	6.25 (2.7)	7.83 (2.9)	1.13 (1.5)	1.66 (1.7)	1.25 (1.7)	1.27 (3.3)
L	9.30 (2.6)	9.51 (2.7)	8.40 (3.6)	10.40 (3.9)	1.90 (2.5)	4.40 (4.6)	2.62 (3.6)	2.22 (5.8)
St	20.42 (5.8)	14.76 (4.2)	14.25 (6.1)	13.30 (5.0)	3.40 (4.5)	2.96 (3.1)	2.10 (2.9)	4.44 (11.6)
Under ground part	52.33 (14.9)	73.37 (21.0)	40.61 (17.3)	44.37 (16.5)	9.30 (12.3)	14.05 (14.6)	7.76 (10.7)	10.11 (26.4)
Total	352.69	346.12	232.19	268.62	76.08	96.62	72.17	38.17

*　See the previous article (KARIZUMI, N. 1974. 1976. 1984) for the descriptions of the stands.

closer planting stands ; the ratio was only 40% in the stand of S22. This is due to the relative decrease of the ratio in the leaf part to the increasing accumulation in the stem part in the mature and high density stands.

b. Underground part

The average amount per tree of N in the underground part of the above-mentioned mature stands was about 52g for *C. japonica*, about 73g for *Ch. obtusa*, about 40g for *P. densiflora*, and about 44g for *L. leptolepis* as shown in Table 3. As *P. densiflora* had the markedly small biomass of the fine root, the average amount per tree of N in the underground part of *P. densiflora* was small as compared with the values of the other species.

On the other hand, the ratios which fine roots occupied in the total amount of N were 1-3% for *C. japonica*, 4-7% for *Ch. obtusa*, 1-5% for *P. densiflora* and 1-2% for *L. leptolepis*. The variation in the ratio was rather small in *C. japonica* and *L. leptolepis* as compared with *P. densiflora*. Of the four tree species, *Ch. obtusa* showed a rather high percentage. Those ratios became higher in the young stand and in the dry site of the low site index. In the small root, the differences of the N ratio

K_2O				CaO			
C. japonica	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
S5	H5	A8	K19	S5	H5	A8	K19
439	427	361	442	439	427	361	442
258.05 (60.3)	297.0 (50.6)	207.07 (61.4)	295.62 (68.1)	464 (42.5)	186 (33.9)	318 (58.4)	129 (55.0)
16.91 (4.0)	58.95 (10.0)	41.47 (12.3)	61.01 (14.1)	157 (14.3)	102 (18.7)	116 (21.4)	53 (22.7)
82.35 (19.3)	135.51 (23.1)	30.03 (8.9)	33.13 (7.6)	270 (24.6)	165 (30.2)	19 (3.5)	15 (6.2)
357.31 (83.6)	191.55 (83.7)	278.57 (82.6)	389.76 (89.8)	891 (81.4)	453 (82.8)	453 (83.3)	197 (83.9)
2.75 (0.6)	5.99 (1.0)	0.42 (0.1)	1.26 (0.3)	7 (0.6)	7 (1.3)	0.5 (0.1)	1 (0.6)
3.46 (0.8)	9.35 (1.6)	2.82 (0.8)	1.55 (0.4)	7 (0.6)	7 (1.3)	3 (0.6)	1 (0.6)
5.03 (1.2)	5.95 (1.0)	6.84 (2.0)	3.42 (0.8)	13 (1.2)	5 (0.9)	6 (1.1)	4 (1.7)
3.93 (0.9)	12.18 (2.1)	3.85 (1.1)	5.10 (1.2)	16 (1.5)	12 (2.2)	7 (1.2)	6 (2.3)
10.51 (2.5)	26.92 (4.6)	13.94 (4.1)	12.73 (2.9)	42 (3.8)	28 (5.1)	22 (4.1)	10 (4.3)
44.26 (10.4)	35.44 (6.0)	31.41 (9.3)	19.96 (4.6)	119 (10.9)	35 (6.4)	52 (9.6)	16 (6.6)
69.94 (16.4)	95.83 (16.3)	59.28 (17.4)	44.02 (10.2)	204 (18.6)	94 (17.2)	91 (16.7)	38 (16.1)
427.25	587.38	337.85	438.78	1 095	547	544	235

among the four species showed the same tendency as those in the fine root.

C. japonica, Ch. obtusa, P. densiflora, and *L. leptolepis* showed those ratios for the medium root of 2-4%, 3-5%, 1%, and 3-7% respectively. The ratios also showed a tendency to be high in stands with poor site conditions (stands K4 and K7).

C. japonica, Ch. obtusa, P. densiflora, and *L. leptolepis* showed ratios for the large root of 1-2%, 1-3%, 2-3% and 2-3% respectively.

In the roots of medium and smaller, the ratio increased as the stands were younger, while in the roots, large and above, the ratio decreased.

(2) Standing amount per ha

The standing amount per ha of N in each tree part was calculated from the above-mentioned average amounts per tree of N. The result is shown in Fig. 1.

a. Aboveground part

The amount per ha of N in the aboveground parts, including the stem, branch and leaf parts, increased with increasing of the basal area and became constant as the basal area exceeded 500㎠, as shown in Fig. 1. The N amounts of *C. japonica, Ch. obtusa, P. densiflora,* and *L. leptolepis* were 400 kg, 250kg, 200kg and 150kg at the basal area of 500㎠, respectively. *C. japonica* showed a remarkably larger amount than the other species, mainly because this species has a larger leaf biomass and higher percentage content of N.

In all species, there were larger amounts per ha of N in denser stands.

b. Underground part

In *C. japonica* and *Ch. obtusa*, the N amount of per ha in the fine root was maximum at the basal area of 150 to 200㎠, decreasing gradually with the increasing of basal area. This tendency was not clear in the case of *P. densiflora* and *L. leptolepis.* In *P. densiflora*, there was the largest amount per ha of N at very young stage, because the stands surveyed were very dense at that time.

All the stands with the comparatively large N amount, such as K25, K17, K16, etc., were the stands of small-diameter trees with basal areas of 200 to 300㎠. At the young stage when the amount reached the maximum, the average of *C. japonica, Ch. obtusa, P. densiflora* and *L. leptolepis* was about 10kg, 12kg, 2kg, and 2kg, respectively.

Thus, the great increase of the amount per ha of N in the fine roots at the young stage will reflect a high activity of the roots at this stage. A similar tendency was also observed in the cases of the small and medium roots.

The N amount per ha of the small root was larger than that of the fine root in small-diameter trees of the basal areas 150 to 200㎠. The N amount of the medium root was not large as compared with those amounts of the fine and small roots because the content of N was low in the medium root.

The large root, very large root, and root stock, as shown in Fig. 1, showed parabolic increases of the amounts per ha of N with increasing of basal area. Those roots did not show an increase of the amounts at young stage as the roots, medium and below. The N amount of the large root varied greatly with the site condition, tree density and so on.

The increase of the N amounts per ha in the roots, large and above that they function as the parts which accumulate inorganic matters.

The change of total N amount in the underground part appears as the synthesized change of all sizes of roots mentioned above. In *C. japonica*, for example, the total amount per ha of N in the underground part was greatly influenced by those amounts in the fine, small and medium roots. So,

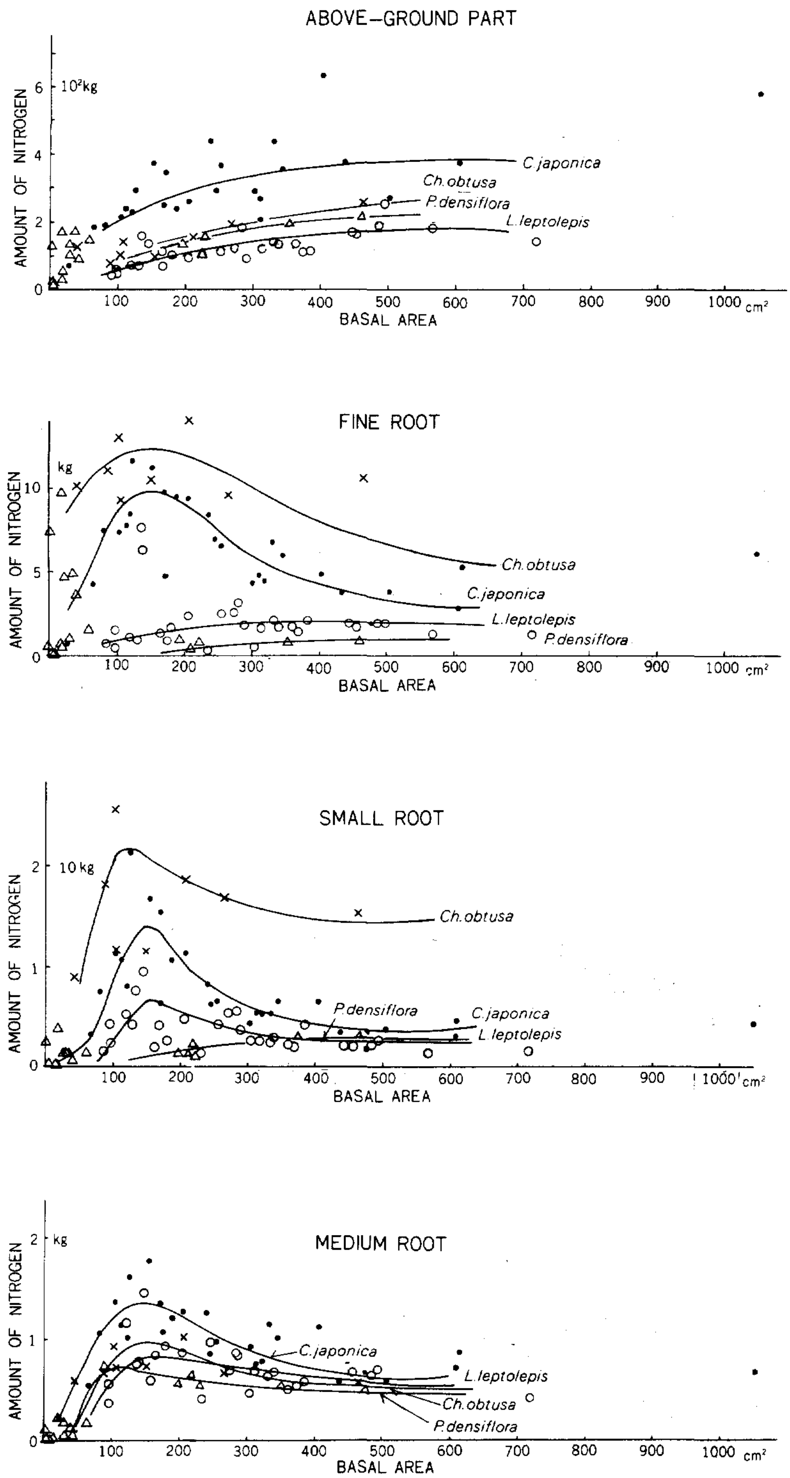


Fig. 1. The N amount per ha of different tree parts in the stands of different basal areas in four species. (One mark shows the amount of one stand.)

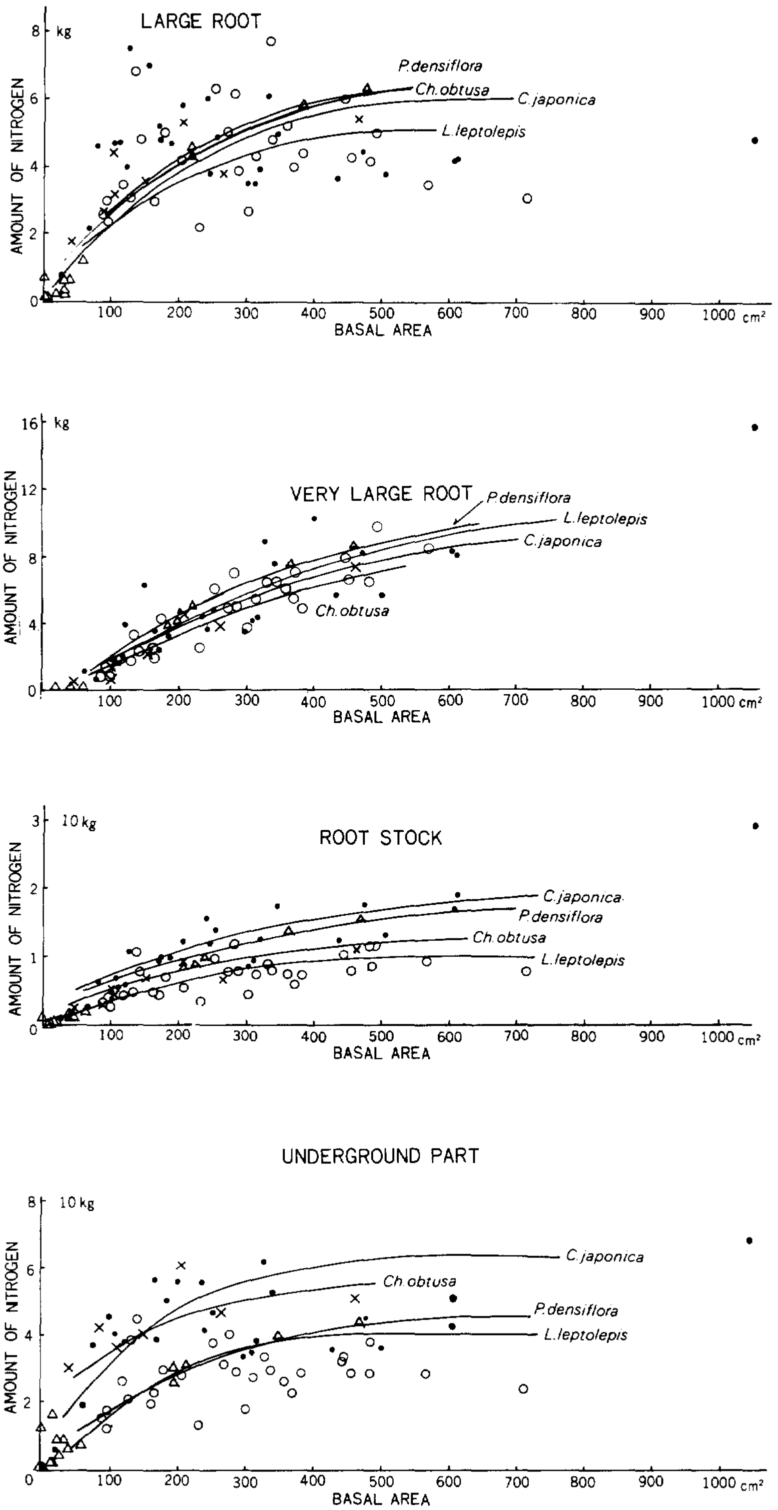


Fig. 1.　(Continued)

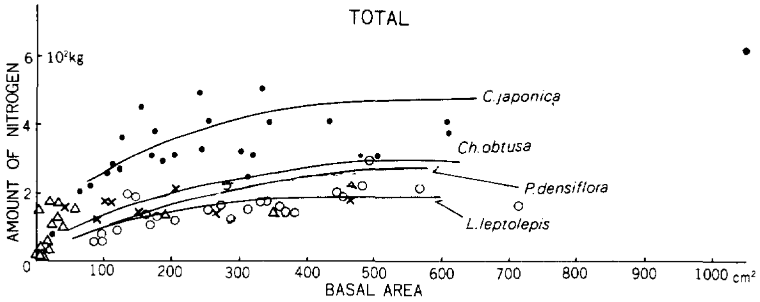


Fig. 1. (Continued)

it became almost constant at the basal areas of 300 to 400 ㎠.

The N amount in the underground part reached a constant value slightly earlier than that in the aboveground part, while the N content in the fine root was rapidly increasing. In this respect, it seems that the N amount per ha in the fine and small roots has a greater influence on the total N amount in the underground part than that of the amount in the leaf part on the amount in the aboveground part.

The amount per ha of N in the underground part showed a greater variation than in the aboveground part. The variation will be due to the soil condition which affects directly the fine root biomass. The N amount per ha in the underground part also varies with tree density as in the aboveground part.

c. Total amount

The stands surveyed of *C. japonica, Ch. obtusa, P. densiflora,* and *L. leptolepis* had, as shown in Fig. 1, total amounts of N per ha of 400 to 500kg, 300kg, 250kg, and 180kg, respectively. There was a great difference in accumulation between *C. japonica* and the other three species, largely because *C. japonica* had a large biomass of the leaf part in which the content of N was high.

The amounts per ha of N in the aboveground part occupy large part in the total accumulation per ha of N.

The total accumulation per ha of N increased in a parabolic curve before the basal area came up to 200 to 300㎠, and after that, the rate of increase slowed down very quickly. This tendency is applicable to all species.

(3) Distribution in each soil horizon

The distribution of the N amount per ha was examined for soil horizons in this section.

Examples of the results are shown in Table 4 and 5. Of the four species, *Ch. obtusa* showed a high percentage of N. The ratios of vertical distribution were high in the upper horizon at the younger stage, decreasing gradually to become almost constant at the mature stage. In *C. japonica* taken here as an example, the ratios in soil horizon I (0～15cm) were 51%, 44% and 40% in the 9-year-old stand of S1, the 34-year-old stand of S4 and the 45-year-old stand of S5, respectively.

The ratios of *Ch. obtusa* were 69% in the 10-year-old stand of H1, 52% in the 28-year-old stand, and 49% in the 48-year-old stand of H5. With the increasing of basal area, the ratio in soil horizon I decreased gradually in the same way as that of *C. japonica*. The distribution ratios were high in

Table 4. Ratio of inorganic matters in five soil horizons in four stands of *C. japonica* with different basal areas. (%)

Stand			S1	S2	S4	S5
Basal area cm^2			61	249	335	439
Soil horizon	I	N	51	45	44	40
	II		30	27	30	35
	III		17	19	17	17
	IV		1	7	7	6
	V		—	3	2	2
	I	P_2O_5	57	53	50	47
	II		29	26	28	33
	III		13	16	14	15
	IV		1	5	6	5
	V		—	1	1	1
	I	K_2O	53	49	48	45
	II		34	35	37	41
	III		10	11	10	10
	IV		4	4	3	3
	V		—	1	1	1
	I	CaO	51	46	46	42
	II		35	36	39	41
	III		13	13	10	12
	IV		1	4	4	4
	V		—	1	1	2

the upper horizons in the stands of low site index as compared with those in other stands of almost the same size. In stands with a high density index, where the soil was deep, the distribution ratios were 42%, 26%, 17%, 11%, and 4% in soil horizons I, II, III, IV and V respectively. This indicates that more N is distributed to lower soil horizons in those stands.

2. Phosphorus (P_2O_5)

(1) Average amount per tree

a. Aboveground part

Examples of the standing amounts per tree of P_2O_5 are shown in Table 2 and 3. The total amount per tree of P_2O_5 of the aboveground and the underground parts was 16g in the immature stand of *C. japonica* of about 60㎠ in basal area and 233g in the mature stand of S17, 49-year-old and 1042㎠ in basal area. *C. japonica* showed the increase of the accumulation per tree of P_2O_5, with a concave curve slightly upward with the increasing of basal area. As in the case of N, this curve is similar to the increasing curve of the average biomass per tree. In the 45-year-old stand of S5, the standing amount per tree of P_2O_5 was approximately 34g, 2g and 30g in the stem, branch and leaf parts respectively.

In *Ch. obtusa*, the amount per tree of P_2O_5 was 37g, 9g, and 36g in the stem, branch, and leaf parts respectively, in the stand (H5), 48 years of and 427cm in basal area. This means that a little

Table 5. The ratio of the amount of inorganic matters in each soil horizon in four tree species. (%)

Species			*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Stand			S5	H5	A8	K19
Soil horizon	I	N	40	49	45	51
	II		35	30	22	31
	III		17	16	19	15
	IV		6	4	5	3
	V		2	2	2	+
	VI		—	—	7	—
	I	P_2O_5	47	52	47	57
	II		33	35	27	33
	III		15	11	18	9
	IV		5	2	5	1
	V		1	1	2	—
	VI		—	—	1	—
	I	K_2O	45	51	40	53
	II		41	38	31	35
	III		10	10	24	10
	IV		3	2	3	2
	V		1	1	2	+
	VI				1	—
	I	CaO	42	52	39	52
	II		41	37	31	34
	III		12	9	25	12
	IV		4	2	3	3
	V		2	1	1	+
	VI		—	—	1	—
	I	Biomass	40	47	38	48
	II		41	42	31	36
	III		13	9	24	13
	IV		5	1	4	3
	V		2	+	2	+
	VI		—	—	1	—

more P_2O_5 was accumulated in the branch than other parts in *Ch. obtusa*.

P. densiflora showed larger accumulation per tree of P_2O_5 in the stem and the branch parts than other species. The amount was 41g in the stem part and 8g in the branch part in the stand of A8, 40-year-old and 361 ㎠ in basal area. These values were larger than those in the stand of *C. japonica*, S17, of larger basal area.

L. leptolepis showed the accumulation per tree of P_2O_5 of 18g, 3g, and 7g in the stem, branch, and the leaf parts respectively, and the total amount of 38g in the stand of K19 (45-year-old and 442 ㎠ in basal area). These values in the stem and leaf parts of *L. leptolepis* were smaller than those values of other species. The total accumulation per tree of P_2O_5 of 38g in the stand of K19 was equivalent only to about half the accumulation in the stand of H5 of *Ch. obtusa*.

The ratios of the amount of P_2O_5 in each tree part to the total amount of P_2O_5 are shown in Tables 2 and 3.

The ratios of the amount of P_2O_5 in the stem part to the total amount of P_2O_5 were all low, but they continued increasing gradually while the trees are growing. In a stand of *C. japonica*, the amount equal to nearly half the total amount per ha of P_2O_5 was accumulated in the stem part.

Ch. obtusa, compared with the other species, showed the low distribution ratio of P_2O_5 to the stem. That ratio was less than 40% even in the mature stand, whereas *P. densiflora* showed the high ratio which reached up to 57% in the stand of A8. In the stand of K19, *L. leptolepis* showed a little higher ratio than *C. japonica*.

C. japonica, Ch. obtusa, P. densiflora, and *L. leptolepis* showed the ratios in the branch part to the total amount of P_2O_5 of 3 to 4%, 10 to 15%, 10%to 15% and 8 to 10% respectively. *Ch. obtusa* and *P. densiflora* showed a higher percentage of distribution to the branch part.

C. japonica, Ch. obtusa, P. densiflora, and *L. leptolepis* showed the ratios in the branch part to the total amount of P_2O_5 of 45-50%, 50-60%, 20-30%, and 20-30% respectively. The former two species showed the higher percentage of distribution to the leaf part.

To the aboveground parts, *C. japonica, Ch. obtusa, P. densiflora,* and *L. leptolepis* showed those percentages of distribution of 85-90 (for the first two species), 90-95, and 65-70% respectively.

In the immature stand, each species had a large leaf biomass of which the contents of P_2O_5 were high, so each species showed the higher ratio of distribution of P_2O_5 in the aboveground part of the immature stand compared to in the mature stand.

b. Underground part

The fine root showed a fairly high rate of the accumulation of P_2O_5. In *C. japonica*, the fine, the small, the medium, the large, and the very large roots, and the root stock showed accumulations of 1.0g, 0.7g, 1.2g, 1.1g, 1.9g and 4.5g, respectively in the mature stand of S5. Although the accumulation in the root stock was more than four times that of the fine root, the root biomass in the former was more than forty times of that in the latter. But *P. densiflora*, which had a very small biomass of fine root, showed the accumulations of only 0.19g, less than one-fifth of that in the above-mentioned stand of S5 in *C. japonica*. *Ch. obtusa* and *L. leptolepis* showed 2.14g in the stand of H5 and 0.73g in the stand of K19 respectively. This shows that *Ch. obtusa* kept the largest accumulation per tree of P_2O_5 in the fine root. Because *Ch. obtusa* holds a comparatively high content ratio of P_2O_5, and in addition, it has remarkably more fine root biomass than the other species. *C. japonica* in the stand of S5, *Ch. obtusa* in the stand of H5, *P. densiflora* in the stand of A8, and *L. leptolepis* in the stand of K19 showed 9g, 14g, 8g, and 10g respectively as the total accumulation per tree of P_2O_5 in the underground parts. Of these species, *C. japonica, P. densiflora* and *L. leptolepis* showed almost equal values, while *Ch. obtusa* showed a considerably large value, compared to the other three species.

On the other hand, the distribution ratio of P_2O_5 in underground part to a whole tree was 10-15% for *C. japonica* and *Ch. obtusa*, 5-11% for *P. densiflora* and 20-30% for *L. leptolepis*. The high ratio of the P_2O_5 amount in the root system of *L. leptolepis* is due to the high accumulation of P_2O_5 in each root class, and especially to the high ratio in the root stock.

The ratios of the fine, small and medium roots were high in the immature stand, decreasing with the increasing of basal area. An example of fine root in *C. japonica*, is showed in Table 2. The very large root and the root stock showed a tendency toward increasing the ratios of the amount of P_2O_5 with increasing basal area, describing a parabolic curve.

(2) Standing amount per ha

a. Aboveground part

The change of amount per ha of P_2O_5 in the aboveground parts according to basal area showed a different pattern compared with that of N, except in *L. leptolepis*, as shown in Fig.2.

In *C. japonica*, the amount per ha was the largest at the basal area of 400 to 500㎠ and the value was about 80 to 100kg.

P. densiflora showed the second largest amount per ha of P_2O_5 after *C. japonica*. *P. densiflora* showed 50 or 60kg in the premature stand, and 70kg in the highly dense stand of A10, because this species accumulates more P_2O_5 at younger age.

Ch. obtusa showed large amount per ha of P_2O_5 next to *P. densiflora*. The amount was estimated to be almost 40kg when the species was fully grown.

Of the four species, *L. leptolepis* showed the smallest accumulation per ha of P_2O_5 of 15 to 20kg in all stands surveyed.

b. Underground part

The fine, small and medium roots of each species accumulated much P_2O_5, as well as N, in an earlier growth periods when they grow vigorously. Particularly this tendency was evidently observed in the cases of the fine and small roots. The increase of the amount of P_2O_5 at this young stage has a close connection with the increasing activity of the underground parts at this stage, as mentioned in the section of N.

After this stage, the P_2O_5 amount per ha decreased and reached almost constant level. At the level, the P_2O_5 amount in the fine root was the largest in *Ch. obtusa* and the smallest in *P. densiflora*. Regardless of a great difference in fine root biomass, *L. leptolepis* showed an amount almost as same as that of *C. japonica*. There are two reasons for this ; first *L. leptolepis* tends to distribute to the fine roots more amount of P_2O_5 than the other species ; and therefore, secondly it has a higher content per unit of P_2O_5.

The P_2O_5 amount in the small root at the constant level was the largest in *Ch. obtusa*, followed by *C. japonica, P. densiflora*, and *L. leptolepis*. The difference in the amount between the species was smaller than that in the case of the fine root. And, in the medium roots, *C. japonica* showed the largest accumulation per ha of P_2O_5. The accumulation in *Ch. obtusa, P. densiflora*, and *L. leptolepis* was a little lower.

The large, very large roots and the root stock showed the different increasing curves of the accumulations per ha of P_2O_5, with those observed in the fine to the medium roots, and the increasing curves were parabolic.

Total amount per ha of P_2O_5 in the underground part increased in a parabolic curve with the increasing basal area. The level of total accumulation per ha of P_2O_5 in the underground parts became smaller in the order of *C. japonica, Ch. obtusa, P. densiflora*, and *L. leptolepis*.

c. Total amount

The total amount of P_2O_5 per ha in each stand, as shown in Fig. 2, increased with the increasing basal area, and became almost constant at the basal area of around over 200㎠. At the basal area of 500㎠, *C. japonica, Ch. obtusa, P. densiflora*, and *L. leptolepis* showed the amount per ha of P_2O_5 of; 100 to 120kg, 40 to 60kg, 60 to 70kg, and 20 to 30kg respectively. *L. leptolepis* showed the smallest

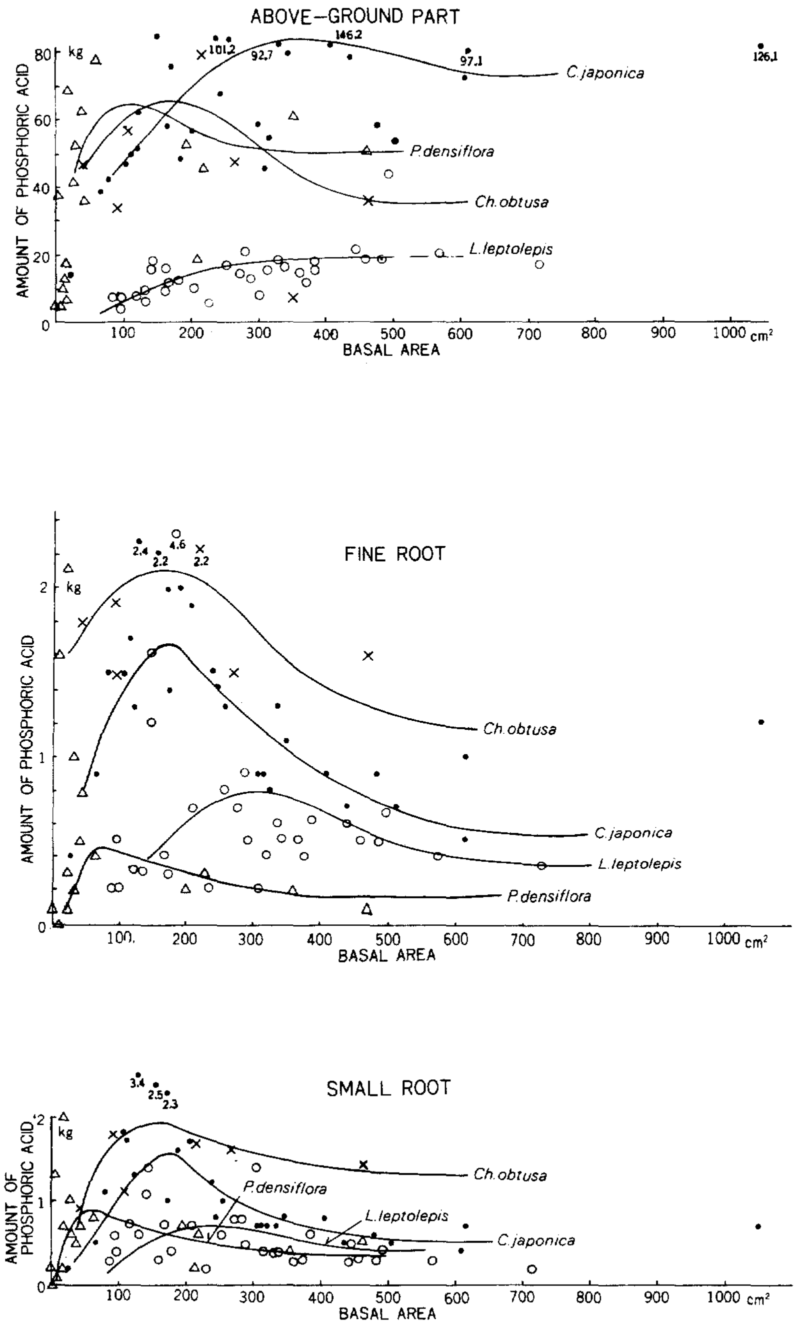
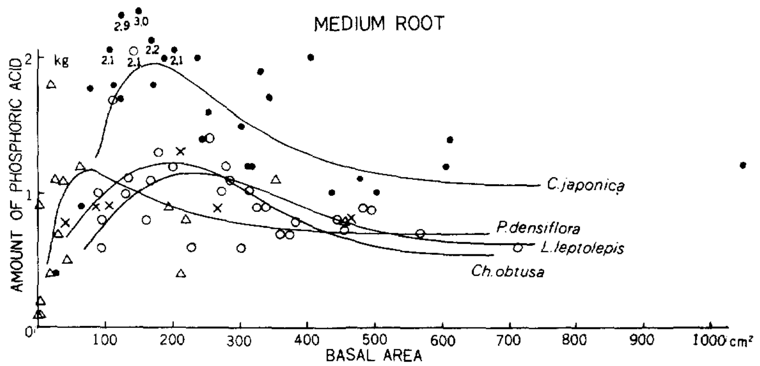
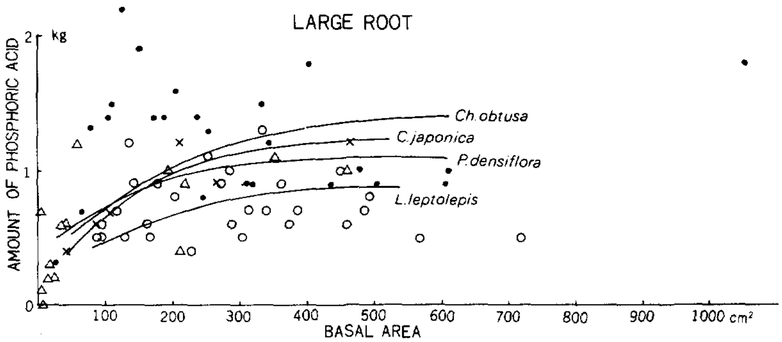


Fig. 2. The P_2O_5 amount per ha of different tree parts in the stands of different basal areas in four species. (One mark shows the amount of one stand.)





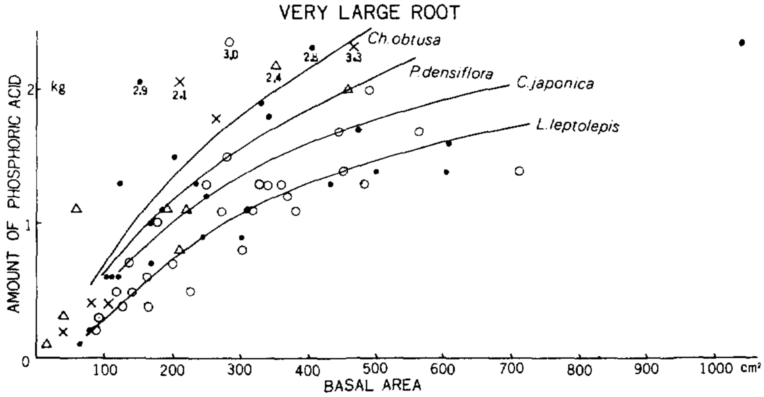


Fig. 2. (Continued)

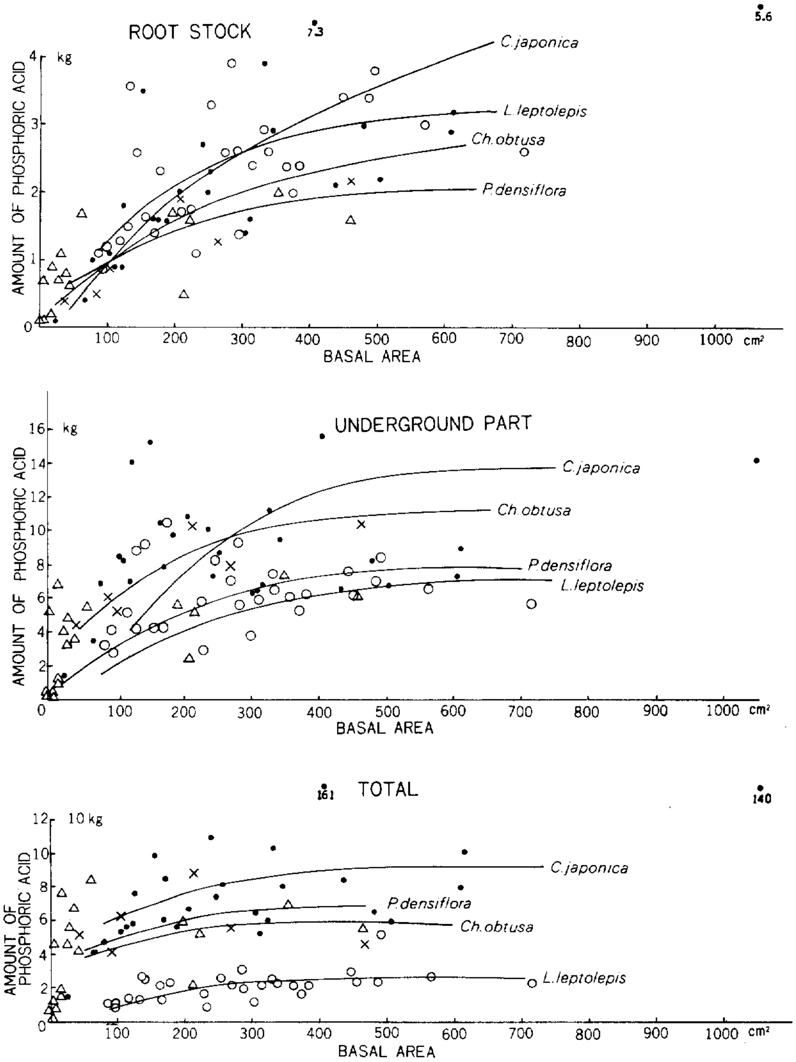


Fig. 2. (Continued)

amount. It is due to the large amount in the leaf part that *C. japonica* showed the largest amount of P_2O_5.

(3) Distribution in each soil horizon

In the mature stands of each species, the ratios of the P_2O_5 amount in each soil horizon to the total amount per ha of P_2O_5 were 50 to 60%, 25 to 35%, 10 to 20%, 2 to 5%, and 0.5 to 2% in soil horizons I, II, III, IV, and V respectively (Table 5).

The amount of P_2O_5 had a tendency to be high in the upper soil horizon and to be low in the lower soil horizons. Therefore, the ratios of distribution of P_2O_5 in each soil horizon became higher in the upper horizon than the ratios of root biomass in each horizon. In the immature stand and in the poor and dry stand, as root biomass was biased to the upper soil horizon in those stands, the ratios of distribution to soil horizons Ⅰ and Ⅱ were high.

The ratios of distribution of the P_2O_5 amount in each soil horizon were examined in four stands of *C. japonica*, S1 to S5, as shown in Table 4. Those ratios showed a tendency to decrease gradually with the increasing basal area in soil horizon Ⅰ. The tendency was similar to that of root biomass. The percentages of distribution in soil horizons Ⅰ and Ⅱ were 86% in the small-diameter stand of S1, and 79% in the large-diameter stand of S5.

This tendency was the same with that of N. As already mentioned, a greater part of the amount of P_2O_5 and N elements as the energy for root growth distributes within the upper horizon down to 30cm depth.

As a rule, tree growth depends largely upon the soil condition in the upper soil horizon because the roots that have higher activity for nutrient absorption distribute more to the upper soil horizon.

The accumulation of N and P_2O_5 in roots is useful to improve the chemical property of the surface soil and the productivity of a forest land by the decaying of roots.

3. Potassium (K_2O)

(1) Average amount per tree

a. Aboveground part

The average amount per tree of K_2O in each aboveground part of the large-diameter tree is shown in Table 3.

The amount in the stem part was 207g in *P. densiflora* and 258g in *C. japonica*. The amount of *Ch. obtusa* and *L. leptolepis* was larger than that in *C. japonica* and *P. densiflora.*

The average amount per tree of K_2O in the branch part decreased in the order of *L. leptolepis, Ch. obtusa, P. densiflora,* and *C. japonica*. The difference in average amount between each species was larger in the branch part than in the stem part. This difference depends upon branch biomass. *C. japonica* with fewer branches than the other tree species, showed less than one-third of the amount of *Ch. obtusa.*

In the leaf part, *Ch. obtusa* showed the largest amount per tree of K_2O, 136g, and *C. japonica* the second largest amount per tree, 82g. There was a considerable difference in amount between these two species. *P. densiflora* and *L. leptolepis* showed almost the same amounts, 30-33g. This means that both *P. densiflora* and *L. leptolepis* have remarkably small leaf biomass, as compared with the former two species. The difference in the amount of K_2O was larger than that in N.

The ratios of the K_2O amounts in each tree part to the total amount of K_2O are given in Table 3. *C. japonica, Ch. obtusa* and *P. densiflora* showed those ratios of 80 to 85% and 15 to 20% for the aboveground and the underground parts respectively, while *L. leptolepis* showed slightly higher ratios of 85 to 90% for the aboveground part and had a the standing amount of K_2O equivalent to percentages of 50 to 60 in the stem part.

The ratios of the K_2O amount in the leaf part to the total amount per ha of K_2O were 15-25% for *C. japonica*, 20-30% for *Ch. obtusa*, 10-20% for *P. densiflora*, and 8-15% for *L. leptolepis*. The ratio in *L. leptolepis* showed a tendency to be low in the leaf part and to be high in the stem part. The ratios in the branch part decreased, in the order of *L. leptolepis* (14%), *P. densiflora, Ch. obtusa,* and *C. japonica* (4%).

The ratios of the amount of K_2O in the aboveground part to the total amount per ha of K_2O were almost the same in *C. japonica, Ch. obtusa,* and *P. densiflora. L. leptolepis* showed a slightly higher percentage, resulting from the accumulation of much K_2O in the stem and branch parts.

b. Underground part

As shown in Table 3, the ratios of the amounts of K_2O in the fine root to the total amount of K_2O decreased in the order of *Ch. obtusa* (1.0%), *C. japonica* (0.6%). *L. leptolepis* (0.3%), and *P. densiflora* (0.1%). This order accorded with the order in root biomass. There was ten times of the difference in ratio between *Ch. obtusa* and *P. densiflora*. In the root stock, *C. japonica* showed the highest ratio of 10%, and *L. leptolepis* showed the lowest ratio of 5%. Those ratios in the small root, medium root, large root, very large root, and root stock were 0.4 to 1.6%, 0.8-2.0%, 0.9-2.1%, 3-5%, and 5-10% respectively. This shows that those ratios gradually increase with roots thickening.

The ratios of the amounts of K_2O in the underground part to the total amount per ha of K_2O were 17% for *P. densiflora*, 16% for *C. japonica* and *Ch. obtusa*, and 10% for *L. leptolepis*.

(2) Standing amount per ha

a. Aboveground part

As shown in Fig. 3, the standing amount per ha of K_2O in the aboveground part increases, describing a parabolic curve, owing to the influence of the stem and branch biomass. And it was estimated that at the basal area of 500㎠, *Ch. obtusa, C. japonica*, and *P. densiflora* or *L. leptolepis* had amounts of about 450kg, 400kg, and 250kg of K_2O respectively.

The standing amount per ha of K_2O in the aboveground part did not show such great differences between each species as observed in the leaf part. These amounts became smaller in this order of *Ch. obtusa, C. japonica, P. densiflora*, and *L. leptolepis*.

b. Underground part

As in the cases of N and P_2O_5, the standing amounts per ha of K_2O in the fine, small and medium roots reached their maximum at young stage (100-200㎠ in basal area).

At young stage when the standing amounts per ha of K_2O in the fine root reached a maximum, *C. japonica, Ch. obtusa, L. leptolepis*, and *P. densiflora* showed those amounts of 5kg, 5.5kg, 1.5kg, and 2.5kg respectively. The amounts in the latter *L. leptolepis* and *P. densiflora*, were much smaller than those of the former two species.

A similar tendency was also clearly observed in the small and medium roots. In the large root, very large root and the root stock, the amount increased parabolically with the increasing of basal area.

In earlier age, there were many fine roots containing much K_2O and distributing to the upper soil horizon. The increase of K_2O amounts in the fine, small and medium roots in the early stages of growth, as well as the increasing of N and P_2O_5, is an indicator for the increasing activity of the underground parts in the young stages that the growth is vigorous.

c. Total amount

The total amounts per ha of K_2O increased with the increasing of basal area, resembling a parabolic curve. At the basal area of 500㎠, *Ch. obtusa, C. japonica*, and *P. densiflora* or *L. leptolepis* showed the amounts of about 500kg, 400kg, and 300kg respectively. In the stand of the highest tree density in *C. japonica*, the amount of nearly one ton per ha was estimated (Fig. 3).

(3) Distribution in each soil horizon

In the mature stand, the distribution ratios of the amounts of K_2O at each soil horizon to the total amount per ha of K_2O in the underground parts were 40 to 60% in soil horizon Ⅰ, 30 to 40% in soil horizon Ⅱ, 10 to 25% in soil horizon Ⅲ, 3 to 10% in soil horizon Ⅳ, and 1% in soil horizon Ⅴ (Table 4). This shows that the amount of K_2O, over 80% of the total amount, distributes to the

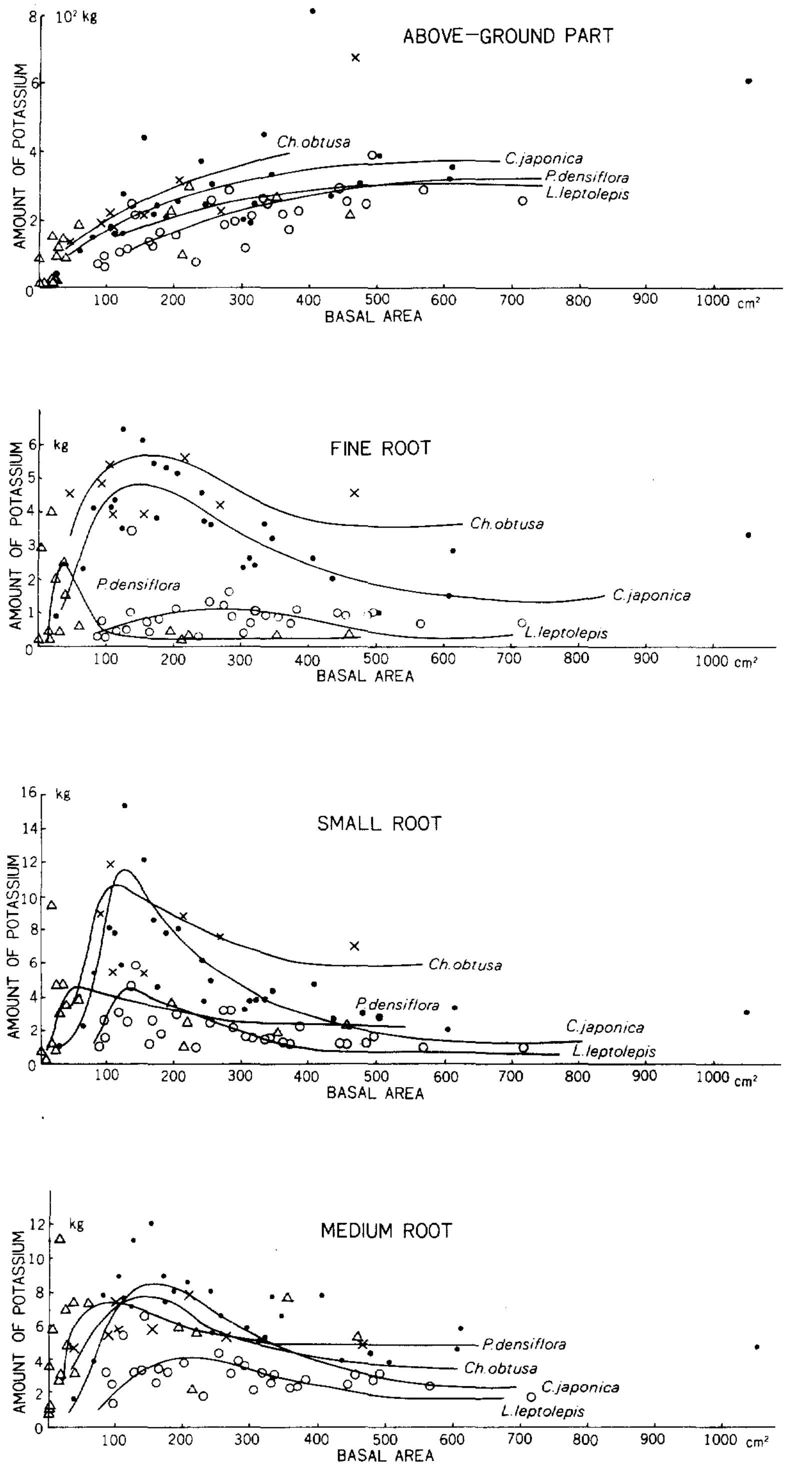
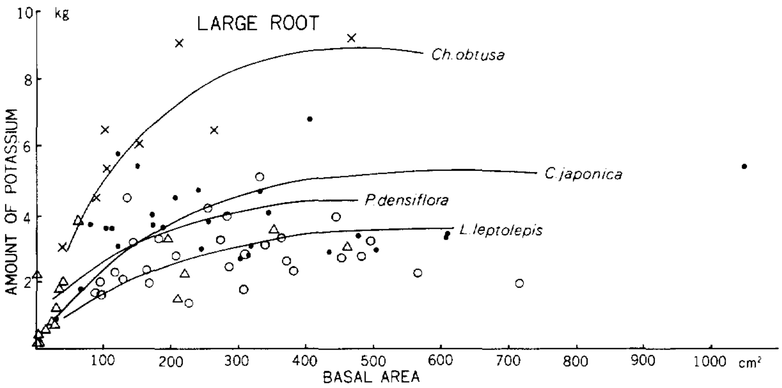
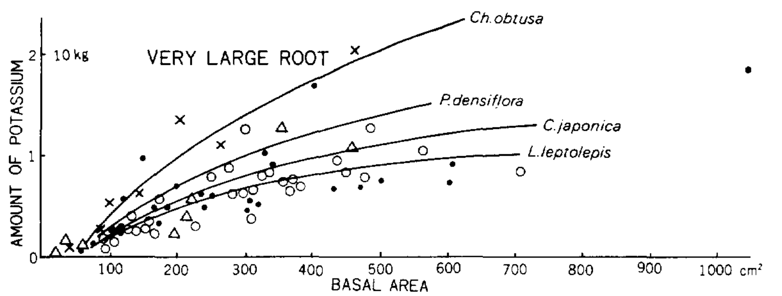
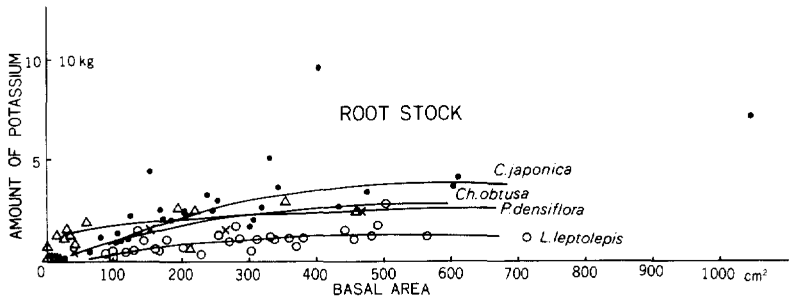


Fig. 3. The K_2O amount per ha of different tree parts in the stands of different basal areas in four species. (One mark shows the amount of one stand.)







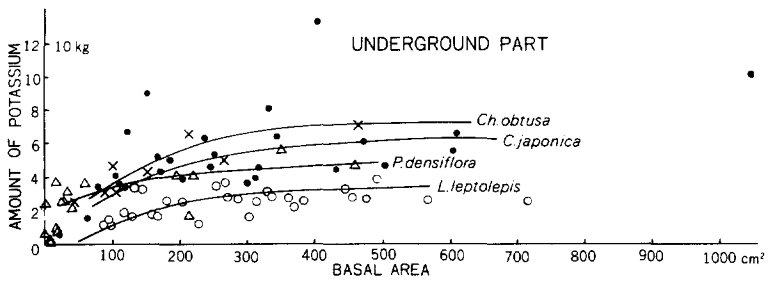


Fig. 3.　(Continued)

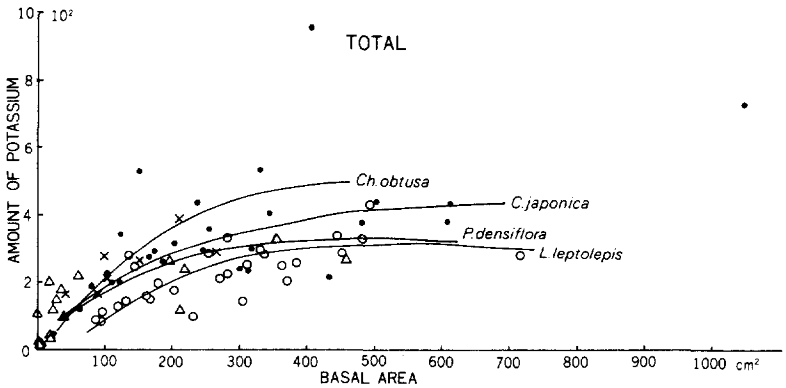


Fig. 3. (Continued)

soil horizon of 0 to 30cm in depth.

Those distribution ratios vary with species and stand ages. In fact, *Ch. obtusa*, and *L. leptolepis* showed a tendency to distribute much of K_2O to soil horizons I and II, while *C. japonica* and *P. densiflora* showed a tendency to distribute much of K_2O to the lower soil horizons.

Under the poor and dry soil conditions, the ratios were 62% and 57% in the stands of S6 and S7 with the low site index, respectively, and 70% in the stand of H6. Particularly in these stands, the fine roots distributed with the higher ratio to the upper soil horizon.

4. Calcium (CaO)

(1) Average amount per tree

On the sample stands of S5, H5, A8, and K19, the average amounts per tree of CaO in each aboveground and underground part are given in Table 3.

In the stem part, *C. japonica* showed the amount per tree of 464g, which was nearly four times the amount of 129g in *L. leptolepis*. This difference is mainly due to the difference of CaO content in the stem part between each species. Also in the branch part, *C. japonica* showed a large average amount per tree of CaO of 157g, while *L. leptolepis* showed a small one of 53g for large branch biomass.

The above-mentioned tendency was more distinctly in the leaf part. *C. japonica* showed the largest average amount per tree of 270g, while in *P. densiflora* and *L. leptolepis* the amount was 15 to 19g. This difference in the leaf part results from two reasons, first, that *C. japonica* and *Ch. obtusa* hold much larger leaf biomass than *P. densiflora* and *L. leptolepis*, and second, that the former species have higher contents of CaO than the latter two species.

The total amount per tree of CaO in the aboveground parts was 891g for *C. japonica*, which was four times for *L. leptolepis* and twice for *Ch. obtusa* and *P. densiflora*.

Such a tendency as the above-mentioned was also observed on the total amount per tree of CaO in the underground parts. The amounts per tree of CaO in the underground parts were 204g for *C. japonica* and 38g for *L. leptolepis*. The large difference between two species reflects the difference of K_2O amount in root stock.

The total amounts per tree of CaO were around 1kg for *C. japonica*, 544-547g for *Ch. obtusa* or *P. densiflora*, and 235g for *L. leptolepis*.

The total amount per tree of CaO increased with the growing of tree. The example in the stands of *C. japonica* is shown in Table 2.

The distribution of CaO was examined in terms of the ratios of the CaO amounts in each tree part to the total amount of CaO.

The ratios to the stem parts were 35-45% for *C. japonica*, 30-35% for *Ch. obtusa*, 50-60% for *P. densiflora*, and *L. leptolepis*. The ratio to the stem part in *P. densiflora* was higher than those in the other species.

The distribution ratios to the branch parts were 10-15% for *C. japonica*, 20% for *Ch. obtusa*, 25% for *P. densiflora* and 30% for *L. leptolepis*. *P. densiflora* and *L. leptolepis* showed the higher ratios to the branch parts than the other two species. The ratios of the leaf parts were 30-35% for *C. japonica*, 30% for *Ch. obtusa*, 12% for *P. densiflora*, and 6% for *L. leptolepis*. The distribution ratios of CaO to the aboveground parts were 81%, 83% and 84% in the stands of S5, H5 or A8, and K19 respectively.

On the other hand, the fine root showed the amount equal to the percentage from 0.1 to 1.3. The ratios to the root stocks were 11% for *C. japonica*, 6% for *Ch. obtusa*, 10% for *P. densiflora*, and 7% for *L. leptolepis*.

As mentioned above, the amount or ratio of inorganic matter depends on the biomass and concentration of inorganic matter. Since the ratio of CaO in the heartwood was higher than that N and P_2O_5, its change is influenced by such accumulating parts as the stem part, large root and root stock.

(2) Standing amount per ha

a. Aboveground part

The amounts of CaO per ha in the aboveground parts to the increasing basal area increased with parabolic curve and reached constant level, at the young stage (150-200㎠ in basal area) as shown in Fig. 4. The amount of CaO at the basal area of 400 to 500㎠ was 900kg for *C. japonica*, 400 kg for *P. densiflora*, 350kg for *Ch. obtusa* and 150 kg for *L. leptolepis*.

b. Underground part

CaO, as well as the other inorganic matters, was abundant in the fine and small roots in the immature stands (100-200㎠ in basal area). The standing amount per ha of CaO was 12kg in the fine roots of *C. japonica*. The amount decreased to about 5kg at 500㎠ of the basal area. The tendency to increase the amount at the young stage was not so clear for *Ch. obtusa*, of which the largest amount was 6kg. Even in the mature stand, the standing amount per ha of this species was about 4 kg. In the fine roots of *P. densiflora* and *L. leptolepis*, the amount per ha was very small, and less than 2kg in most stands.

In the mature stands, the CaO amounts were larger in the large root or root stock than in the fine and small root. For example, in S5 stand of *C. japonica* these amounts were 6.1kg for the fine root, 13.9kg for the large root and 104.1kg for the root stock. The total amounts per ha of CaO in the underground part were 178g for *C. japonica*, 71kg for *Ch. obtusa* or *P. densiflora*, and 29kg for *L. leptolepis*.

c. Total amount

The last figure in Fig. 4 shows the total amounts per ha of CaO in both the aboveground and the underground parts in all. As shown in the figure, those amounts per ha in the mature stands were about 1000kg for *C. japonica*, 500kg for *P. densiflora* or *Ch. obtusa*, and 200 kg for *L. leptolepis*. These amounts are much affected by tree density. In the S22 stand, for example, the amount was more than

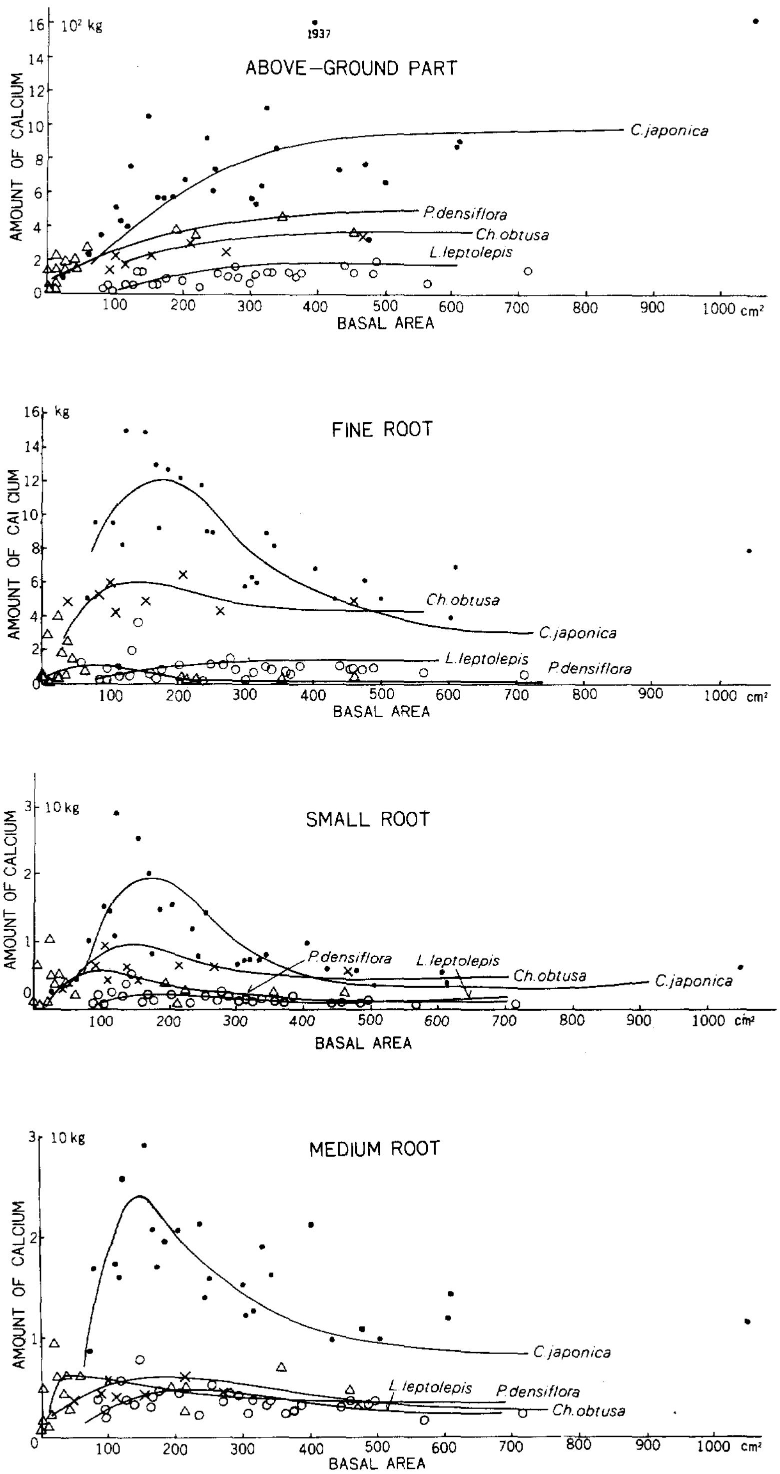


Fig. 4. The CaO amount per ha of different tree parts in the stands of different basal areas in four species. (One mark shows the amount of one stand.)

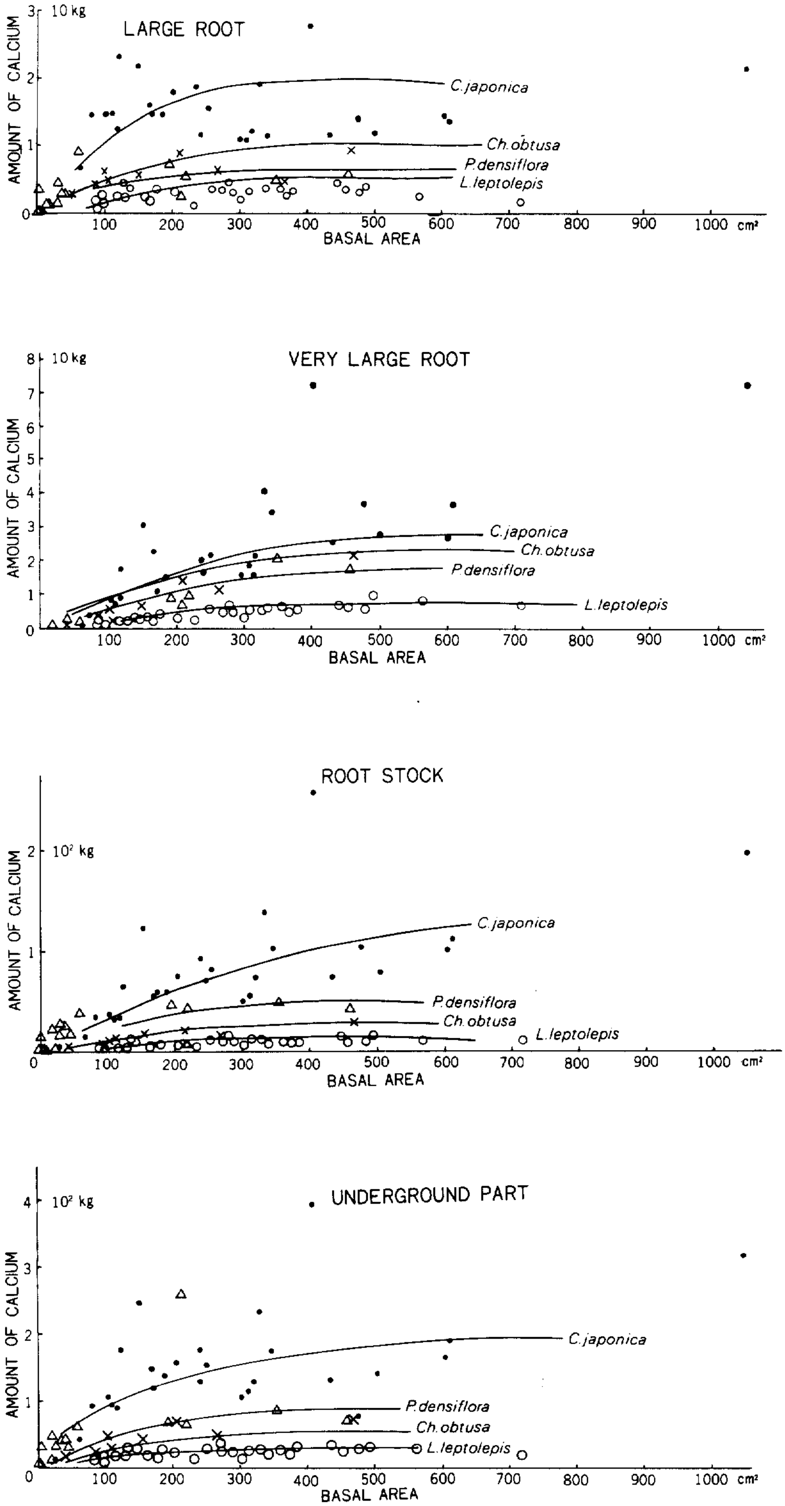


Fig. 4.　(Continued)

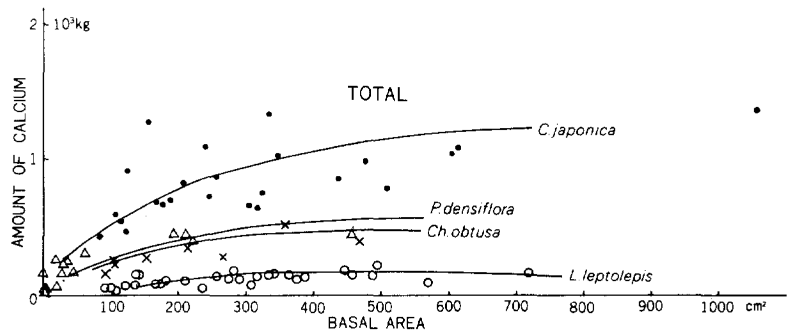


Fig. 4. (Continued)

2 tons.

(3) Distribution in each soil horizon

The distribution ratios of CaO in each soil horizon to the total amount of CaO was examined on the stands of S5, H5, A8, and K19. The result is shown in Table 5. In such flatrooted species as *Ch. obtusa* and *L. leptolepis*, the distribution ratio to soil horizon I was the high percentage of more than 50 of the total amounts per ha of CaO. Furthermore, the ratios distributed to soil horizons I and II, 0-30cm in depth, were 82% for *C. japonica*, 89% for *Ch. obtusa*, 70% for *P. densiflora*, and 86% for *L. leptolepis*.

III Total production amount and reduction amount of matters

1. Total production of dry matters per ha

The standing biomass of each part of sample stands have been dealt with in the second issue (KARIZUMI, N. 1974) of this study. Since those sample stands, however, have their own sites and stand densities which differ from each other, the accurate estimation of each part biomass can not be expected. And also those stands are not appropriate for estimating the production of the suppressed trees. The estimation of the total production (net production), therefore, has not been based here on the standing biomass reported in the second issue, but on the stem volume increment of the dominant and suppressed trees in the second class site in the yield table of each species.

Accordingly, a scrupulous comparison has been made between the standing biomass of the sample stands surveyed and the standing biomass from the yield table, on the 40-year-old stands. (Only the dominant trees were picked out in either case.)

A result is shown in Table 6. The ratio of each part biomass was obtained from Fig. 29 in the second issue.

The total production in the above- and underground parts was obtained from the values in the second class site of the stand yield table for each species. In this case, the total production includes the integrated amount of the dominant and suppressed trees at each stand age of 10, 20, 30, 40, and 50 years, and the integrated amount of fallen leaves and dead branches in each year.

The method of estimation was as follows. First, the biomass of the dominant trees was estimated by multiplying the volume of the dominant trees per ha in the yield table of each species by the apparent basic density of the stem part. Then, each biomass of tree parts such as branch, leaf, fine to very large roots, or root stock was estimated by multiplying the stem biomass obtained thereby by the ratio of each tree part corresponding to each basal area, which was obtained from the basal areas and tree part ratios by the biomass given in Fig. 29 in the second issue of this study.

The apparent basic density of the stem part used in estimating the stem biomass of the dominant trees was given by the average stem volume and weight in the sample stands. The relationship between the basal area and those densities is shown in Fig. 5. This figure gives the values of the basic densities corresponding to the average basal areas at each stand age listed in the yield table, and those values were used in the actual estimation. The tree volumes used in estimating the basic densities were those volumes with bark, which were obtained from stem analysis. This method had a tendency to give somewhat higher values than was actually the case, and as a result, the estimated densities became somewhat lower.

The biomass of the suppressed trees was estimated from the stem volumes of the suppressed trees per ha in the yield table by the same method which was taken to estimate the biomass of the dominant trees. Then, each tree part biomass was estimated.

It was here decided that the biomass taken out of the forest land by logging is equivalent to 75% of the stem biomass of the dominant and suppressed trees.

The amount of dead branches was estimated by using the MÖLLER's equation. After then, the amount per ha was estimated by multiplying the ratio of the basal area by the amount of dead branches per tree which was obtained from the figure of the basal area-annual accumulated dead branch biomass corresponding to each stand age in the yield table.

The following indicates how to estimate the accumulated leaf biomass of the dominant trees at

Table 6. Average standing biomass per ha of the sample stands surveyed and the standing biomass obtained from the volume in the second class site of the yield table. (40-year-old stand)

Species	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Basal area (cm²)	487	214	387	419
Biomass of sample stands surveyed : A (tons)	220	120	210	170
Biomass in the 2nd class site of the yield table : B (tons)	193	140	134	115
Biomass : Stem, branch, leaf, and root biomass B/A (%)	88	117	64	68

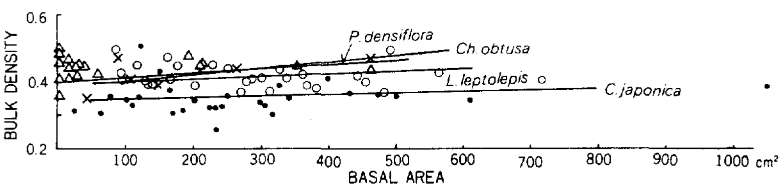


Fig. 5. Bulk densities obtained from the stem volume and weight of the sample tree of different basal areas in four species.

given stand ages. The annual accumulated leaf amount per ha was estimated on the basis of the leaf biomass per ha of the dominant trees at each stand age of 10, 20, 30, 40, and 50 years. Supposing that the ratios of fallen leaves in a year are to be 25% for *C. japonica* and *Ch. obtusa* and 50% for *P. densiflora*, based on the leaf-duration of each species, the annual amounts of fallen leaves will be the accumulated biomass of leaves multiplied by the falling ratio. The following equations to estimate the fallen leaves were developed :

1) As to the amounts* of the fallen leaves accumulated for ten years ;

$$\sum_{n=1}^{10} y_f = \left(\sum_{n=1}^{10} \frac{y_{10}}{10} - \frac{y_{10}}{2}\right) \times R_L = 5y_{10}R_L$$

2) As to those for twenty years ;

$$\sum_{n=1}^{20} y_f = \{5y_{10} + 10y_{10} + 5(y_{20} - y_{10})\} \times R_L$$

3) As to those for thirty years ;

$$\sum_{n=1}^{30} y_f = \{5y_{10} + 10y_{10} + 5(y_{20} - y_{10}) + 10y_{20} + 5(y_{30} - y_{20})\} \times R_L$$
$$= \{15y_{10} + 10y_{20} + 5(y_{20} - y_{10}) + 5(y_{30} - y_{20})\} \times R_L$$

Those for 40 or 50 years were estimated in a like manner on the leaf amount at every ten years, which were assumed to increase rectilinearly by every 1/10 annually for the terms. The meaning of symbols is as follows :

y_f : annual amount of fallen leaves

$\sum_{n=1}^{10} y_f$: accumulated amount of fallen leaves up to the stand age of 10 yrs

Y_{10} : leaf biomass at the stand age of 10 yrs

Y_{20} : leaf biomass at the stand age of 20 yrs

R_L : falling ratio, i.e., $\frac{\text{amount of fallen leaves}}{\text{leaf biomass}}$
(0.25 for *C. japonica* and *Ch. obtusa*, 0.5 for *P. densiflora*)

The amount of dead branches and fallen leaves of the suppressed trees was estimated by multiplying the accumulated biomass of the dominant trees by the ratios of branch and leaf biomass.

The accumulated amounts of fallen leaves increased with the increasing stand age as shown in Fig 6.

In the 40-year-old stands, the total amounts per ha of fallen leaves were 110 tons for *C. japonica*, 98 tons for *Ch. obtusa* and *P. densiflora*, and 84 tons for *L. leptolepis*. Furthermore, the ratios of the accumulated amounts of fallen leaves to the leaf biomass at each stand age were, in *C. japonica* taken here as an example, one time at a stand age of 10 years, 3 times at that of 20 years, 6 times at that of 30 years, 8 times at that of 40 years, and 10 times at that of 50 years. This interrelation (between the accumulated amount of fallen leaves and the leaf biomass at each stand age) is shown in Table 7 for the 40-year-old stands of four species. This table shows that the accumulated amounts of fallen leaves of *P. densiflora* and *L. leptolepis* (24-37 times) are much larger than those of *C. japonica* and *Ch. obtusa* (8, 9 times).

The ratios of the accumulated amounts of fallen leaves to the total production of each stand

* They means here the leaf amount accumulated for the middle of a year. If the leaf biomass at the end of growing period is taken in estimating, the first equation is thus $\sum_{n=1}^{10} y_f = 5.5y_{10}R_A$.

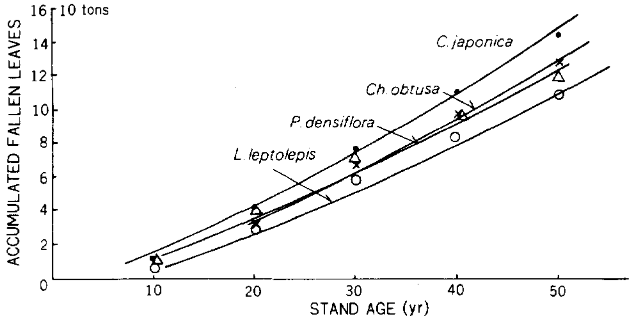


Fig. 6. The accumulated amount per ha of fallen leaves at different stand ages in four species.

Table 7. The ratio of accumulated amount of fallen leaves and branches to the standing biomass of leaves and branches in four tree species (40-year-old stands).

Species	Ratio of fallen leaves*	Ratio of fallen branches*
C. japonica	8	7
Ch. obtusa	9	4
P. densiflora	24	5
L. leptolepis	37	5

* The ratio to 1 of standing biomass of leaves and branches

Table 8. Ratio of the accumulated amount of the fallen leaves to the total production in the 40-year-old stands of four tree species, including dominant and suppressed trees.

Species	Total production (A)	Accumulated fallen leaves (B)	B/A (%)	Accumulated leaves (C)	C/A (%)
C. japonica	439	110	25	135	31
Ch. obtusa	313	98	31	115	37
P. densiflora	347	98	28	109	31
L. leptolepis	293	85	29	89	30

Unit for A, B, & C : ton/ha

were 24-26% at the stand ages of 10-50 years, being equal to about 1/4 of their total production. And also, in the 40-year-old stands of four species, those ratios were 25-31%, as shown in Table 8.

This indicates that about 1/3 to 1/4 of the total production was reduced again to the forest land as fallen leaves.

The ratios of accumulated leaves to total prodution at the stand age of 40 years were almost same values for *C. japonica, P. densiflora*, and *L. leptolepis*. *Ch. obtusa* showed the somewhat higher ratio of 37% than the other species.

The ratios of the partial biomass to the total production per ha are shown in Table 9. As shown in the table, those ratios of leaf biomass decreased sligtly for *C. japonica* and *L. leptolepis* as the stand age advanced.

Table 9 also gives the detailed data on the branch part of each species. This table shows that the branch amount is equivalent to 12-16% of the total production per ha in the 40-year-old stands. The ratio of the stem biomass to the standing biomass of *C. japonica* was 66% at the stand age of 40 years, while its ratio to the total production, including the amounts of dead leaves and branches, decreased to 43%, as shown in Table 9. The ratio of the stem biomass to the total production decreased in the following order : *L. leptolepis, C. japonica, P. densiflora,* and *Ch. obtusa*. The ratio of the stem biomass to the total production showed a tendency to increase with stand age. Particularly, *P. densiflora* showed a marked tendency to increase the ratio with age. The ratios in *C. japonica* or *L. leptolepis*, however, did not increase once they reach the stand age of 20 years.

The total production per ha for the whole aboveground part, including the biomass of the leaf, branch and stem part, is also shown in Table 9. In the 40-year-old stands, the production per ha was 373 tons for *C. japonica*, 268 tons for *Ch. obtusa*, 300 tons for *P. densiflora*, and 256 tons for *L.*

Table 9. The total production per ha and the ratio of the part biomass to the former in the stands of five ages of four species.

Species	Stand age(yrs)	10	20	30	40	50
Stem	*C. japonica*	11(21)	67(37)	128(41)	187(43)	242(43)
	Ch. obtusa	—	33(23)	66(30)	104(33)	117(36)
	P. densiflora	10(15)	56(33)	101(39)	142(41)	179(46)
	L. leptolepis	7(23)	54(43)	90(43)	127(43)	160(43)
Branch	*C. japonica*	12(23)	23(13)	35(11)	51(12)	66(12)
	Ch. obtusa	—	36(25)	39(18)	49(16)	58(14)
	P. densiflora	37(51)	38(22)	40(15)	49(14)	52(13)
	L. leptolepis	9(30)	17(14)	30(14)	40(14)	53(14)
Leaf	*C. japonica*	22(42)	63(35)	99(32)	135(31)	173(31)
	Ch. obtusa	—	50(36)	85(38)	115(37)	148(36)
	P. densiflora	18(25)	52(31)	85(33)	109(31)	126(32)
	L. leptolepis	11(35)	35(28)	64(30)	89(30)	114(31)
Aboveground part	*C. japonica*	45(86)	153(85)	262(84)	373(86)	481(86)
	Ch. obtusa	—	119(84)	190(86)	268(86)	354(86)
	P. densiflora	65(91)	146(86)	226(87)	300(86)	357(91)
	L. leptolepis	27(88)	106(85)	184(87)	256(87)	327(88)
Underground part	*C. japonica*	7(14)	28(15)	47(16)	67(14)	85(14)
	Ch. obtusa	—	21(16)	34(14)	45(14)	60(14)
	P. densiflora	7(9)	22(14)	35(13)	47(14)	35(9)
	L. leptolepis	4(12)	18(15)	28(13)	37(13)	46(12)
Total production	*C. japonica*	52	180	309	439	567
	Ch. obtusa	—	140	224	313	414
	P. densiflora	72	168	261	347	392
	L. leptolepis	31	124	212	293	373

Figures without parentheses : ton/ha ; Figures in parentheses : %

leptolepis, which equalled 85 to 87% of the total production per ha including the production of the underground parts.

Both the root biomass per ha and the ratios of the biomass to the total production per ha are also shown in Table 9. As shown in table, the root biomass of each species increased rapidly with the increasing stand age. In the 40-year-old stands, the root biomass was 37 to 67 tons. In terms of the standing biomass, the ratio of the root biomass to the total production was 20-25%, but 13-14% was the ratio of the root biomass to the total production per ha, including the amounts of fallen leaves and dead branches. These ratios to the total production per ha decreased with the increasing stand age. One reason of the decrease would be that annual accumulation of dead roots is not taken into account. Supposed that the underground parts grow in proportion to the ratios of the underground part biomass that the amount of dead roots annually accumulates in the same manner with the annual accumulation of fallen leaves and dead branches in the aboveground parts, it can be expected that the integrated root biomass is larger by 50-10% of the total production per ha by rough estimate.

The ratios of root biomass in each root class to the total production per ha varied with species. The ratios in the 40-year-old stands of four species and in the *C. japonica* stands of different ages are shown in Table 10(1) and (2). The ratio was the lowest in the fine root and increased in the larger root classes. For example, the ratio was 0.2-0.7% in the fine root and 2.9-3.4% in the very large root.

In *C. japonica*, the ratio in the root stock was larger than in the other tree species. This is because that *C. japonica* has a tendency to make assimilation products accumulate in the root stock rather than in the large and the very large roots.

As shown in Table 10(2), in each root class, the ratio of each root class to the total production

Table 10. Ratio of the production of each root class to the total production.

(1) Ratio in the 40-year-old stands of four species.

Tree species \ Root class	f	s	m	l	L	St
C. japonica	0.3	0.6	1.2	1.4	2.9	8.7
Ch. obtusa	0.7	1.5	1.4	1.7	3.2	5.9
P. densiflora	0.2	0.4	1.4	1.7	3.2	6.6
L. leptolepis	0.2	0.4	1.3	1.7	3.4	5.6

(2) Ratio in the *C. japonica* stands of different ages.

Root class \ Stand age (yrs)		10	20	30	40	50
Root	f	0.9	0.7	0.4	0.3	0.3
	s	1.8	1.3	0.7	0.6	0.5
	m	3.6	2.5	1.6	1.2	1.1
	l	2.4	2.0	1.6	1.4	1.2
	L	0.5	1.5	2.5	2.9	3.2
	St	5.0	7.6	8.6	8.7	8.7

varied with stand age. The ratios in the 10-year-old stands were about three times the ratios in the 50-year-old stands for fine, small, and medium roots. By contrast, the ratios of the very larger root and the root stock increased with stand age.

The total tree production per ha as the sum of each part biomass of the above-and underground parts is shown in Table 9. As shown in the table, at a stand age of 40 years, the total production per ha was 439 tons for *C. japonica*, 347 tons for *P. densiflora*, 313 tons for *Ch. obtusa*, and 293 tons for *L. leptolepis*.

2. Total production of inorganic matters per ha

The total production in dry weight per ha for each inorganic matter of N, P_2O_5, K_2O, and CaO was examined for each species and each stand age.

The total production per ha inorganic matters was obtained by multiplying the production of each tree part in dry weight (Table 9) by the ratio of each inorganic matter per unit dry weight (Table 1). In estimating the total production, the contents of N and P_2O_5 per unit dry weight in the fallen leaves and branches were estimated to be 60% of those in the fresh materials, considering the decrease of those contents after falling.

As a result, the total production of inorganic matters and the ratios in each tree part to the total production were obtained for the 40-year-old stands as shown in Table 11. As shown in the table, the distribution ratios of inorganic matters differed from those of each tree part biomass, because the content of each inorganic matter differed among tree parts.

(1) Nitrogen

Of the four species, *C. japonica* showed the largest total production per ha of N of 1304kg. The amount produced in *L. leptolepis, Ch. obtusa* and *P. densiflora* were 1245kg, 914kg and 958kg respectively. There are three reasons for a small production of N per ha in *Ch. obtusa*. Firstly, *Ch. obtusa* grows poorly in comparison with the other species ; secondly, it has a small production in dry weight, and thirdly, it has a low content of N in each tree part.

The leaf part of every species showed a high ratio of 76% to 89% of the total amount of production per ha of N. This ratio was about 2 to 3 times as high as the ratios of the dry weight of 30-37%.

The distribution ratios of N for the stem parts ranged from 4.4% in *P. densiflora* to 11.4% in *C. japonica*. This suggests that the production of the stem part per unit dry weight is more easily influenced by the growth pattern of each species rather than by leaf biomass.

The ratios of N accumulated in the stem part were equal to only 5% to 10% of that in the leaf part; and therefore, even if the whole amount of the stem part were to be cut down and taken away from a forest stand, the greater part of N would be left within the land.

The ratios in the branch part were 3-8%, and were higher in *C. japonica, Ch. obtusa,* and *L. leptolepis* than *P. densiflora*.

The ratios of N for the aboveground parts were equivalent to 91-97% of the total production of N. This shows that a greater amount of N distributes for the aboveground parts, in contrast with the ratios by dry weight of 70-75%.

In each underground part, the distribution ratio was 0.2-2.2% for the fine roots, 0.3-3.2% for the small root, 0.3～1.2% for the medium root, 0.2-0.7% for the large root and 0.4-0.8% for the very large root. The ratios for the large root and above showed almost the same value. This tendency differed from that in root biomass.

The distribution ratios of N for each underground part of each species were 5.5% for *C. japonica*, 8.7% for *Ch. obtusa*, 3.4% for *P. densiflora*, and 3.1% for *L. leptolepis*.

Total amount per ha of N increased parabolically with the increasing stand age. In particular, these amounts increased remarkably between the stand ages of 10 and 20 years. This can be explained by both facts, firstly that trees grow vigorously at these stages, and secondly, that the young tissues of the stem, the leaf part or the fine roots with the higher content of N are producted with remarkable speed.

(2) Phosphorus

The total production per ha of P_2O_5 in the 40-year-old stands, as shown in Table 11, became smaller in the order of *Ch. obtusa* (245 kg), *C. japonica* (243kg), *P. densiflora* (210kg), and *L.leptolepis* (131kg).

The distribution ratio of P_2O_5 for each tree part is made up as follows : 66～77% for the leaf part, 9～20% for the stem part, 4.5～9.0% for the branch part.

The distribution ratio of P_2O_5 for the whole aboveground part was 95% for *P. densiflora, Ch. obtusa* and *C. japonica*, and 94% for *L. leptolepis*. Therefore, these four species distribute only about 5% of P_2O_5 for the underground parts. This low ratios for the underground parts are due to the lower ratios of the P_2O_5 content and to the smaller biomass of the underground parts, which does not include the amount of dead roots.

Table 11. Distribution ratio of the amount of each inorganic matter to the total production in the 40-year-old stands.

	N				P_2O_5			
	C. japonica	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
Stem	11.4	6.9	4.4	8.2	15.3	8.5	20.3	19.3
Branch	7.6	7.2	3.0	6.3	4.5	9.1	8.6	4.6
Leaf	75.5	77.2	89.2	82.4	75.0	77.4	66.3	69.7
Above ground part	94.5 (1 233)	91.3 (834)	96.6 (923)	96.9 (1 206)	94.8 (230)	95.0 (233)	95.2 (200)	93.6 (123)
f	0.5	2.2	0.6	0.2	0.5	1.3	0.6	0.7
s	0.7	3.2	0.4	0.3	0.5	1.1	0.4	0.5
m	1.1	1.2	0.3	0.8	1.0	0.6	0.7	1.0
l	0.6	0.7	0.2	0.4	0.7	0.5	0.7	0.6
L	0.8	0.4	0.6	0.6	0.9	0.8	1.3	1.1
St	1.8	1.0	1.3	0.8	1.6	0.7	1.1	2.5
Under ground part	5.5 (71)	8.7 (80)	3.4 (35)	3.1 (39)	5.2 (13)	5.0 (12)	4.8 (10)	6.4 (8)
Total amount of inorganic matters (kg/ha)	(1 304)	(914)	(958)	(1 245)	(243)	(245)	(210)	(131)

(1) Biomass data were taken from Table 9, 10.
(2) Figures without parentheses show percentage.
(3) Figures in parentheses show the amount of inorganic matters in kg/ha.

(3) Potassium

Table 11 shows the total production per ha of K_2O of each species in the 40-year-old stands and the ratio of distribution for each tree part.

The total production per ha of K_2O was the largest 1331kg in *Ch. obtusa*, and the smallest production of 844kg was in *P. densiflora*.

The distribution ratio of K_2O was comparatively high in the stem and the branch parts, as compared with that of N and P_2O_5.

The whole aboveground part occupied 92 to 97% of the total production per ha of K_2O. This ratio was almost the same with that of N and that of P_2O_5.

The total production per ha of K_2O in each species increased almost parabolically with the increasing stand age.

(4) Calcium

The total production per ha of CaO and the distribution ratio at the stand age of 40 years are shown in Table 11. This table shows that the total production in *C. japonica* was 3735 kg of the largest amount, which was seven times of the amount in *L. leptolepis*.

The distribution ratios of CaO were very high for such parts as the stem, branch and very large root, while the ratios were low for such young and new tissues as the leaf and fine root, as well as in K_2O.

Ninety to Ninetysix % of the total production per ha of CaO distributed for the aboveground part and the remaining 4 to 10% for the underground part.

K_2O				CaO			
C. japonica	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*	*C. japonica*	*Ch. obtusa*	*P. densiflora*	*L. leptolepis*
21.3	11.8	25.3	18.0	13.0	5.6	26.5	13.2
5.4	9.1	15.1	14.2	16.9	12.1	34.0	23.6
66.1	73.5	51.5	64.6	63.5	78.2	29.6	57.9
92.8 (1 139)	94.4 (1 257)	91.9 (776)	96.8 (1 093)	93.4 (3 486)	95.9 (1 622)	90.1 (958)	94.7 (546)
0.3	0.6	0.3	0.2	0.3	0.6	0.3	0.3
0.5	1.0	0.4	0.2	0.3	0.6	0.5	0.3
0.8	0.7	1.2	0.4	0.6	0.4	0.8	0.9
0.5	0.7	0.6	0.3	0.6	0.5	0.8	0.6
1.0	0.9	1.7	0.8	1.2	0.7	1.7	1.2
4.1	1.7	3.9	1.3	3.6	1.3	5.8	2.0
7.2 (88)	5.6 (74)	8.1 (68)	3.2 (36)	6.6 (249)	4.1 (70)	9.9 (103)	5.3 (31)
(1 227)	(1 331)	(844)	(1 129)	(3 735)	(1 692)	(1 061)	(577)

The total production per ha of CaO increased parabolically with the stand age in a similar way to the total production of the other inorganic matters.

3. Reduction ratio of matters

(1) Reduction ratio of dry matters

Reduction ratio of each matter was estimated from the total production of biomass and each inorganic matter corresponding to second site of the yield table, which had been estimated for each stand age in the previous papers (KARIZUMI, N. 1974).

The reduction ratio of dry matter is given as the ratio of the amount of matter returned into the forest land to the total production. Supposing that 75% of the stems of the dominant and the co-dominant trees is taken out of the forest land, Table 12 shows the reduction ratio of biomass and inorganic matters in each stand age of four species. Also, Fig.7 shows the relations of stand age with the total production of biomass, the amount to be returned to the forest land, and the reduction ratios.

In the case of *C. japonica* and *Ch. obtusa*, the total production increased in an almost straight line with the increasing stand age. The amount left behind in the forest land also increased in a similar way.

The reduction ratio of biomass decreased with the increasing stand age and was 68% for *C.*

Table 12. The reduction ratio of matters by stand age and species. (%)

Species	Matter	Stand age (yrs)				
		10	20	30	40	50
C. japonica	Biomass	84.5*	72.3	68.9	68.1	68.0
	N	97.2	93.9	92.5	90.8	91.7
	P_2O_5	92.6	86.4	85.6	88.5	90.3
	K_2O	95.6	89.8	86.4	84.0	82.1
	CaO	97.0	93.0	90.8	90.3	90.1
Ch. obtusa	Biomass	—	82.6	77.9	74.9	73.3
	N	—	96.8	95.9	94.8	95.0
	P_2O_5	—	93.5	92.9	93.6	95.8
	K_2O	—	94.5	92.5	91.1	89.6
	CaO	—	97.6	96.9	95.8	94.4
P. densiflora	Biomass	89.2	75.1	71.0	69.2	65.8
	N	98.3	96.9	97.1	99.7	—
	P_2O_5	91.7	78.8	81.3	84.8	—
	K_2O	94.7	86.7	83.8	81.2	—
	CaO	96.2	86.6	80.2	76.9	—
L. leptolepis	Biomass	82.8	67.5	67.9	67.4	67.9
	N	97.1	93.2	93.7	93.9	95.3
	P_2O_5	91.7	82.1	81.2	85.5	91.7
	K_2O	95.7	82.6	87.3	86.5	86.6
	CaO	96.7	91.6	90.3	90.1	88.8

* The figures in the table show the ratios of the remainings in each stand to the total production.

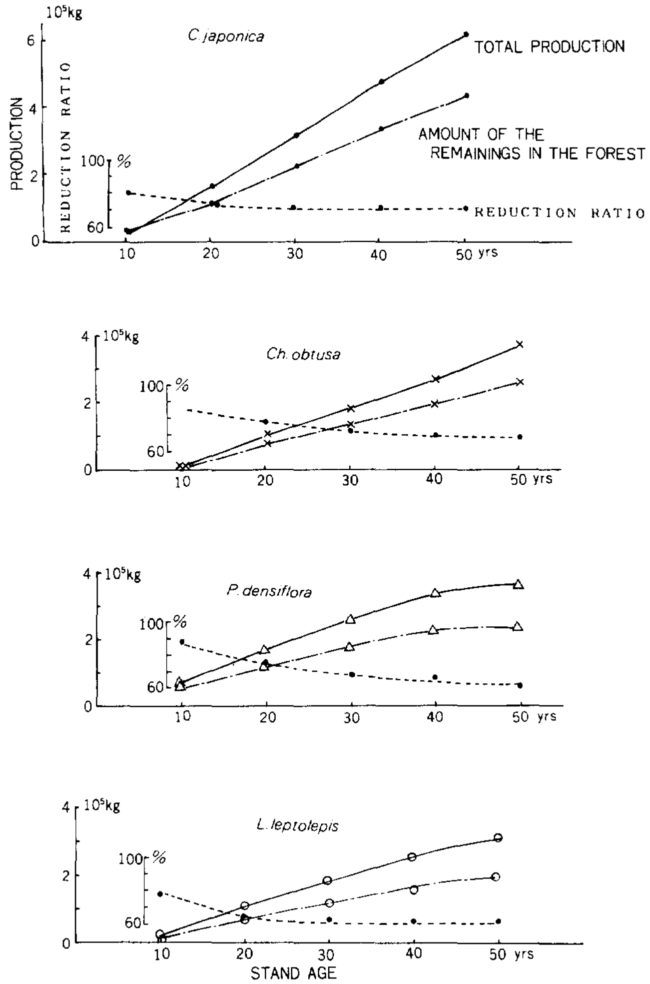


Fig. 7. The total production per ha, the amount remaining in the forest land, and the ratio of the latter to the former, reduction ratio by stand age and species.

japonica, 75% for *Ch. obtusa*, 69% for *P. densiflora*, and 67% for *L. leptolepis* in the 40 year old stands. The high ratio of *Ch. obtusa* is due to the large production in the leaf and branch parts.

(2) Reduction ratio of inorganic matters

As is clear from Table 12, all the reduction ratios of each inorganic matter were very high regardless of the species and stand ages. This is explained from facts that most of the physiologically active parts such as leaves and fine roots, which contain much inorganic matters, are reduced to the forest land, and then that the stems showing low contents of inorganic matters are taken away therefrom.

Of all the inorganic matters, K_2O and CaO, which were much accumulated in the stem part showed slightly lower reduction ratios than N and P_2O_5, of which the contents were high in the leaf or the fine roots. Clear difference, however, was not observed between these two ratios.

The reduction ratios of biomass and inorganic matters were the highest in *Ch. obtusa* among four species, as shown in Table 12. As already mentioned, this is due to the large amount of fallen leaves and dead branches which *Ch. obtusa* produces.

The reduction ratio of biomass and each inorganic matter decreased as the stand age increased. Every species showed a high reduction ratio at the young stage and a low reduction ratio at the advanced stage. However, the decrease in the ratios of the inorganic matters is less than that of biomass. This is due to the greater distribution of inorganic matters to such parts as the leaf, branch, or fine root. This is explained for the interrelation between each of the inorganic matters; N and P_2O_5, which accumulate mainly in the working parts, showed lower ratios of decreasing (3-5%), whereas K_2O and CaO showed somewhat higher ratios (7-13%).

Some examples of the reduction ratios are shown in Table 13. To compare these ratios with the data of Table 12, the reduction ratio of the latter was considerably higher than that of the former.

The difference between both data may be due to the difference in the contents of inorganic matters and in the methods of estimating. From these data, 80~90% of the total production of inorganic matters, will be reduced to the forest land, and the ratio is high as compared to that in agricultural plant.

These reduction ratios, however, were estimated without taking into account the loss of inorganic matters by erosion or the amount of branches taken away from the forest land after logging. But the recent logging causes the disturbance of forest land and the whole tree logging brings branches and leaves out. If these are to be taken into account, the ratios decrease to about 50 to 60%.

When the reduction ratio of matter is assumed to be 90% without taking into account the loss of inorganic matters by erosion and so on, the forest land will suffer no lack of inorganic matters by the repeated forest operations.

4. Production and reduction ratio of matters when the amount of dead roots is taken into consideration

The total production of the underground part at a given stand age can be obtained by multiplying the total production of the aboveground part —— which means the standing biomass of the aboveground parts of the dominant and the co-dominant trees plus the annual accumulation of fallen leaves and dead branches —— by the root biomass ratio to the whole tree biomass, when the assimilated products are distributed to the roots in proportion to the root biomass ratio.

As the total production thus estimated includes the amount of dead roots, which corresponds to

Table 13. The reduction ratios of introganic matters in the forest lands.
(after TSUTSUMI, 1962)　(%)

Species	N	P_2O_5	K_2O	Researcher
C. japonica	74	88	51	TSUTSUMI, 1962
P. densiflora	69	65	73	
European red pine	78	77	65	DENGLER, 1935
European beech	80	77	67	
Trees	80	80	73	BAKER, 1950
Agricultural plant	25	20	71	

the amount of fallen leaves and branches, it will be larger by the amount of dead roots than the root biomass given in Table 9.

The result of an estimate on the *C. japonica* stands is shown in Table 14. Here the ratios of root biomass are set, on the basis of Fig 7, as 24% at the stand age of 10 years, and 23% at the stand ages of 20 to 50 years.

According to Table 14, when the amount of the dead roots was not taken into account, the underground part biomass in the 40-year-old stand of *C. japonica* was 67 tons per ha which was equivalent to 15% of the total production; but it was 111 tons per ha when the amount of dead roots was taken into account and the ratio of the root biomass was estimated to be 23%. There was a difference of 44 tons between both numerical values, which was equivalent to the annual accumulated amount of dead roots taken in the present study. The amount of dead roots was equivalent to 10% of the total production including that amount. The reduction ratio of dry matter was 71%, increasing by 3% from the ratio of 68% obtained by ignoring the dead roots.

The above-mentioned idea of taking into account the ratio of dead roots was also applicable in estimating the amount of each inorganic matter. The production and reduction ratio of N was examined by using the data of the 40-year-old stand of *C. japonica*, and the result is shown in Table 15. The production of N in the underground parts was 125kg per ha increasing by 53kg per ha, the ratio to the total production of N increased from 6 to 9%. That increase of 53kg corresponded to 4% of the total production including the amount of dead roots. The ratio of increase was lower than that in the dry matter. This is due to the lower content of N in the root system rather than the content in the aboveground parts.

The reduction ratio of N was 91% when the dead roots was taken into account. The percentage was almost equal to the percentage obtained when the rate of dead roots was not taken into account. This shows that the amount of N which is taken out of the forest land is small for the total production of N. This is also applicable in the cases of the other forms of inorganic matters.

Table 14. The reduction ratios of dry matter in *C. japonica* when the amount of dead roots is taken into account.

Part \ Stand age	10 (yrs)		20 (yrs)		30 (yrs)		40 (yrs)		50 (yrs)	
Aboveground part	44 239 (0.858)	44 239 (0.760)	152 450 (0.844)	152 450 (0.770)	261 915 (0.857)	261 915 (0.770)	372 461 (0.849)	372 461 (0.770)	481 618 (0.850)	481 618 (0.770)
Underground part	7 313 (0.142)	13 970 (0.240)	28 000 (0.156)	45 537 (0.230)	47 373 (0.143)	78 234 (0.230)	66 760 (0.151)	111 254 (0.230)	85 133 (0.150)	143 860 (0.230)
Total	51 552 (1.000)	58 209 (1.000)	180 450 (1.000)	197 987 (1.000)	309 288 (1.000)	340 149 (1.000)	439 221 (1.000)	483 715 (1.000)	566 751 (1.000)	625 478 (1.000)
Amount taken away from the forest land	7 998 (0.155)	7 998 (0.137)	50 031 (0.277)	50 031 (0.253)	96 154 (0.311)	96 154 (0.283)	139 902 (0.319)	139 902 (0.289)	181 365 (0.320)	181 365 (0.290)
Amount left behind in the forest land	43 554 (0.845)	50 211 (0.863)	130 419 (0.723)	147 956 (0.747)	213 134 (0.689)	243 995 (0.717)	299 319 (0.681)	343 813 (0.711)	385 386 (0.680)	444 113 (0.710)

For each stand age :
right column : in cluding dead roots
left column : not including dead roots
Figures without parentheses : dry weight in kg/ha
Figures in parentheses : percentage

Table 15.　Production and reduction ratio of N in the 40-year-old stand of *C. japonica*, considering dead roots.

Part	Case not to include dead roots	Case to include dead roots
Aboveground	1232.7 (0.94)	1232.7 (0.91)
Underground	71.2 (0.06)	124.6 (0.09)
Total	1303.9 (1.00)	1357.3 (1.00)
Amount taken away from the forest land	119.9 (0.09)	119.9 (0.09)
Amount left behind in the forest land	1184.0 (0.91)	1237.4 (0.91)

Ⅳ Accumulation of matters in each soil horizon and formation of porosity by roots

1. Root biomass and accumulating amount of inorganic matters

The root biomass and accumulating amount of inorganic matters were estimated by the following method.

The distribution of the root biomass in each soil horizon was calculated by multiplying the total root biomass of the dominant and the co-dominant trees by the distribution ratio of the root biomass in each soil horizon. The amount of inorganic matter of root in each soil horizon was calculated by multiplying the root biomass in each soil horizon and each root class by the ratio by dry weight of inorganic matter located in each soil horizon and each root class, respectively. The result is shown for the 40-year-old stands in Table 16.

(1) Root biomass

In the 40-year-old stands, the root biomass per ha in soil horizon Ⅰ was 28 tons for *C. japonica*, 23 tons for *Ch. obtusa*, 18 tons for *P. densiflora*, and 11 tons for *L. leptolepis*. In soil horizon Ⅴ, they were 1.1 tons for *P. densiflora*, 1.0 tons for *C. japonica*, 0.4 tons for *L. leptolepis*, and 0.1 tons for *Ch. obtusa*. The difference in the root biomass among soil horizons reflects the property of the shallow-rooted *L. leptolepis* and *Ch. obtusa* and the deep-rooted *P. densiflora* and *C. japonica*. The taprooted *P. densiflora* accumulated the root biomass in soil horizon XI, over 3m of depth, showing a considerable root biomass in soil horizon Ⅵ and below.

C. japonica, accumulated also the large root biomass not only in the upper soil horizon but also in the lower soil horizon. The shallow-rooted *Ch. obtusa* accumulated a larger root biomass in soil horizons Ⅰ and Ⅱ but not as much in soil horizon Ⅲ and below. The root biomass of *L. leptolepis* distributed in the upper soil horizons rather than in the lower soil horizons. The root biomass increased with the increasing stand age, showing a difference of 34 tons in soil horizon Ⅰ between ages of 10 and 50 years in *C. japonica*. As the tree density decreases with the growing of stand, in the stand age of over 40 years, the accumulation of the root biomass dose not increase with such speed as before.

(2) Accumulating amount of inorganic matters

a. Nitrogen

The accumulating amounts per ha of N in the roots were calculated for each soil horizon. The result is shown in Table 16.

Table 16. The amount per ha of biomass, root volume and inorganic matters in roots by soil horizon in the 40-year-old stands.

Species	Soil horizon	Biomass (kg/ha)	Root volume ($x10^3cm^3$/ha)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	CaO (kg/ha)
C. japonica	I	27 931	66 726	29.0	6.1	40.6	108.5
	II	26 566	62 999	22.3	3.8	33.4	96.8
	III	8 151	20 297	13.1	2.0	9.6	29.7
	IV	3 023	7 781	5.2	0.6	3.3	10.7
	V	1 090	2 800	1.5	0.2	1.0	3.8
Ch. obtusa	I	22 580	47 083	43.7	7.3	40.3	39.4
	II	17 715	35 515	22.2	3.6	25.6	23.9
	III	3 767	8 749	11.1	1.3	6.8	5.9
	IV	526	1 440	2.2	0.2	1.3	1.2
	V	140	390	0.6	0.1	0.3	0.3
P. densiflora	I	17 761	41 917	17.5	4.8	28.5	41.4
	II	13 954	32 405	6.3	2.4	19.6	31.2
	III	11 079	26 003	6.3	1.8	15.4	25.2
	IV	1 832	4 529	2.1	0.5	2.2	3.9
	V	1 127	2 789	1.1	0.2	1.2	1.6
	VI	294	790	0.7	0.1	0.4	0.4
	VII	179	482	0.4	tr	0.2	0.3
	VIII	109	289	0.2	tr	0.1	0.1
	IX	87	230	0.2	tr	0.1	0.1
	X	30	82	0.2	tr	tr	tr
	XI	14	40	tr	tr	tr	tr
L. leptolepis	I	11 003	37 931	17.7	4.3	16.7	14.2
	II	10 443	31 945	12.4	2.7	12.5	10.7
	III	4 668	13 626	7.1	1.0	4.5	4.4
	IV	1 568	3 401	1.3	0.2	0.8	0.9
	V	424	1 057	0.3	0.1	0.2	0.3

In soil horizon I, *Ch. obtusa* showed the largest N accumulation of 43.7kg per ha ; and *P. densiflora* showed the smallest of 17.5kg per ha, which was about 2/5 of the amount in *Ch. obtusa*. It seems that the largest N accumulation in *Ch. obtusa* is due to its nature of having a lot of fine roots with high N content.

The accumulating amounts per ha of N in soil horizon II were 22.3kg for *C. japonica*, 22.2kg for *Ch. obtusa*, 12.4kg for *L. leptolepis*, and 2.7kg for *P. densiflora*. The shallow-rooted *Ch. obtusa* showed the second largest amount after *C. japonica*.

Both of the shallow-rooted *Ch. obtusa* and the deep-rooted *P. densiflora* distributed to the upper soil horizon the amounts which corresponded to 82% and 67% of the total amounts of N respectively. The distribution ratio of N in the upper soil horizon is not so high as that of the root biomass, because the large root or the root stock which have a low content of N, occupies most of the root biomass.

The amounts of N accumulated in the underground parts increased with the increasing stand age in each soil horizon. In the horizons deeper than soil horizon III, the accumulation of N was little in the stands which were younger than 10 years old.

b. Phosphorus

The accumulation amounts per ha of P_2O_5 are also shown in Table 16. In soil horizon I, *Ch. obtusa* which has the most fine roots showed the largest P_2O_5 accumulation of 7.3 kg per ha, and *L. leptolepis* which has the least fine roots showed the smallest amount 4.3 kg per ha.

In soil horizon II, the P_2O_5 amounts corresponded to almost 50% of those amounts in soil horizon I. In the horizons deeper than soil horizon III, the deep-rooted *C. japonica* and *P. densiflora* showed large accumulations of P_2O_5. Particularly, this phenomenon was distinctive in soil horizon IV.

The ratios of the accumulation per ha of P_2O_5 in soil horizons I and II to the total amount per ha were 77% for *C. japonica*, 87% for *Ch. obtusa*, 74% for *P. densiflora*, and 85% for *L. leptolepis*. *Ch. obtusa* and *L. leptolepis* showed the characteristics of shallow-rooted species in both of amount and ratio.

The amounts in soil horizons I and II increased with the increasing stand age in all the species.

c. Potassium

The amounts per ha of K_2O in each soil horizon are also shown in Table 16. *C. japonica* had the largest amount per ha in each soil horizon. The difference among species showed a tendency to become smaller in the upper soil horizon than in the lower ones.

The ratios of the amount per ha of K_2O in soil horizons I and II, from 0 to 30cm depth, to the total amount of K_2O were 84% for *C. japonica*, 89% for *Ch. obtusa*, 71% for *P. densiflora*, and 84% for *L. leptolepis*. *P. densiflora* showed a higher ratio in the lower soil horizons.

d. Calcium

As shown in the Table 16, the amount of CaO per ha in *C. japonica* was the largest of 109kg in soil horizon I, and in *L. leptolepis* the smallest of only 14kg, which was equivalent to about one -seventh times in *C. japonica*. *Ch. obtusa* which had large root biomass showed the amount per ha of 39kg, which was equivalent to about 40% of the amount of *C. japonica*. From these results it follows that *C. japonica* has the higher content of CaO in the root system than *Ch. obtusa* and that *C. japonica* accumulates large amounts of CaO even in the thick roots.

In soil horizon V, the shallow-rooted *Ch. obtusa* and *L. leptolepis* accumulated amount of 0.3kg per ha, and the deep-rooted *C. japonica* showed the amount of 3.8kg per ha.

In each species, the amount distributed to soil horizon I and II occupied over 70% of the total amount.

2. Porosity in soil resulting from dead roots

After cutting both the dominant and the co-dominant trees, then, the humus is accumulated and the pore is formed by the decay of roots. The pores improve the aeration and physical properties of the soil, and in turn improve the productivity of the site. To estimate amount of pores, the root volume was calculated by using both the distribution of root biomass in each soil horizon and the average values of bulk density. As shown in Table 16, the root volumes per ha in soil horizon I were 67m³ for *C. japonica*, 48m³ for *Ch. obtusa*, 42m³ for *P. densiflora*, and 38m³ for *L. leptolepis*. In soil horizons I and II, 0 to 30cm depth, the volumes were 129m³ for *C. japonica*, 83m³ for *Ch. obtusa*, 74m³ for *P. densiflora*, and 70m³ for *L. leptolepis*. The ratios of the root volume in soil horizons I and II to the total root volume per ha were 80% for *C. japonica*, 89% for *Ch. obtusa*, 68% for *P. densiflora*, and 80% for *L. leptolepis*. More than 80% of the root volume was accumulated in soil horizons I and II in all species except *P. densiflora*.

The pores formed by roots in the 40-year-old *C. japonica* stand were classified by size. It was estimated that in soil horizon I there would be 1.6m³ per ha for the pores of less than 2mm in diameter, 2m³ per ha for those of 2 to 5mm in diameter, 3.4m³ per ha for those of 5 to 20mm in diameter, 2.7m³ per ha for those of 20 to 50 mm in diameter, 57m³ per ha for those of more than 50mm in diameter. The large pores formed by the root stock or very large roots can be found only in the upper soil horizon, while pores formed by the fine and the small roots can often be found in the very hard and massive deep soil.

The deep-rooted species, *C. japonica* or *P. densiflora*, function to improve the physical properties of the soil more effectively than the shallow-rooted species, *L. leptolepis* or *Ch. obtusa* if they be cut at the age of 40 years or over.

3. Contribution of roots to physical and chemical properties of soil

As mentioned in the previous sections, the humus of roots and the accumulation of inorganic matters take place largely in the upper soil horizons which the large root biomass distributes. Therefore, the physical and chemical properties of upper soil horizons are much more easily changed than those of lower soil horizons. Thus the roots greatly influence the condition of the upper soil horizon. Such an interaction is decreased rapidly in the lower soil horizons. As a result, vertical variation is caused both in the roots biomass and in the physical and chemical properties of the soil. Hence there is a close interrelation between the vertical variation of the root distribution and the vertical variation of the physical and chemical properties of soil.

The above-mentioned relationships will be able to be verified from the existing data, which show the relation between the physico-chemical properties of soil and the surface areas of fine root. Here, the relation between the root densities of fine roots and the physico-chemical properties of soil is shown in Fig. 8, by using the data of the S8 stand of *C. japonica*. The vertical distribution of the root density agrees well with the variation of the condition of the air in soil, the minimum air, the percolation rate, and the non-capillary pore space.

The changes of the chemical properties, such as pH, exchangeable acidity, carbon, total N, and C/N ratio, correspond to the variation of the root density. Those changes are also in accordance with the distribution of humus resulting from the root system.

As mentioned before, those properties of soil determine the distribution of roots, and in turn they are affected by root growth. Consequently, a high correlation was observed between these factors.

The vertical changes in the physical and chemical properties of the soil are greatly influenced by the humus that has accumulated in the upper horizon, as well as by the root system. The present vertical distribution of soil properties, furthermore, reflects the results of the past distribution and development of roots from the point of view of the function of the roots which form the humus and the pores. In other words, the present distribution of the root system helps the development of the root system itself.

From the above results, roots contribute to improvement of the physical and chemical properties of soil through the supply of inorganic matters and the formation of porosity, and the

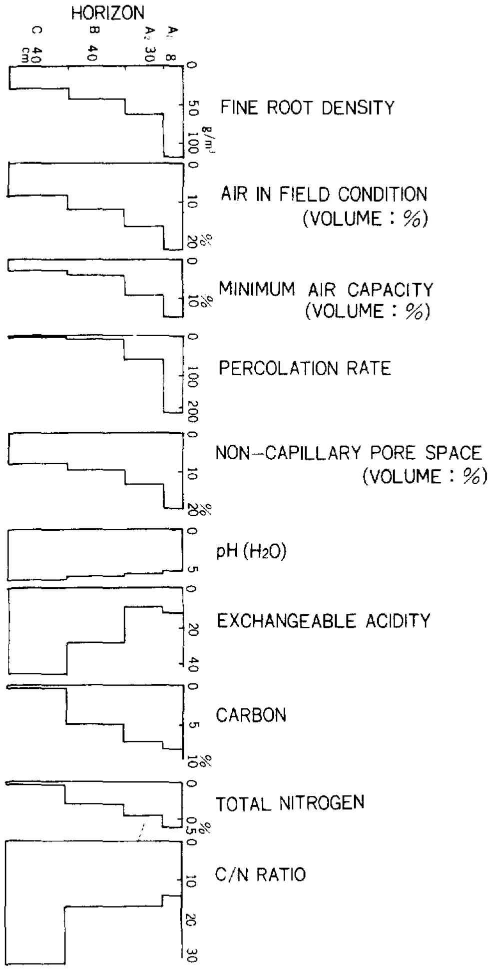


Fig. 8. Fine root density and physico-chemical properties of soil. Stand S18, soil type B_B, site index 23.4. (See : Bull. Gov. For. Exp. Sta. 138～139, No 285, 1976)

contribution is related to the growth pattern of root system which each species has.

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森林生産の場における根系の機構と機能　第５報

土壌への物質還元と孔隙形成

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摘　　要

立木の伐採や枯損によって根系が腐朽して，これが土壌へ還元する無機塩類や有機物，また土壌中に形成する孔隙は，土壌の理化学性や物質循環に影響して森林の再生産に役立っているものと考えられる。こうした根系のもつ機能を定量的に解明することは，森林生産力の評価予測に必要な情報として欠かせないが，報告はきわめて少ない。

本研究では，根系のもつ土壌の理化学性の改善機能を明らかにするための基礎資料を得るため，前の４報告で調査した種々の林齢からなるスギ，ヒノキ，アカマツ及びカラマツの各林分の根系の現存量と分布に関するデータ及び各林分から選定した試料木について器官別に分析した無機塩類(窒素，リン酸，カリ，カルシウム）濃度を用いて，各林分の塩類量及び伐採したときに地下部に残る根量と塩類量を推定した。また，根系がつくる孔隙量も試算した。結果の概要は以下のとおりである。

1　林分の器官別無機塩類の現存量

標準木の器官別塩類濃度と器官別のバイオマス量からha当たり林分の塩類量を求めた。地上部と地下部のha当たりの量は，いずれの塩類についても根元断面積が大きくなるにつれて増加して，ほぼ一定となる。樹種間ではスギの量が最も多く，次いでヒノキで，アカマツ，カラマツは少ない。例えば，一定となったときの地上部と地下部の窒素量は，おおよそスギで400kgと60kg，ヒノキで250kgと50kg，アカマツで200kgと45kg，カラマツで150kgと40kgである。地下部の量を根の大きさ別にみると，太い根では地上部と同じ傾向であるが，細根のような小さな根では断面積が大きくなるにつれて増加したのち減少する。これは成長の盛んな若い林分では細根の養分吸収が非常に活発で大きく，バイオマス量も相対的に多いことによる。

2　物質の総生産量と還元率

(1)　バイオマスと無機塩類量の総生産量

落葉量を各樹種ごとの年平均落葉率から，落枝量をMöllerの式から算出し，現存量とあわせてバイオマス総生産量とした。ha当たりのバイオマス総生産量は林齢が大きくなるに従い多くなるが，器官別の生産量割合は各樹種とも20年生以上の林分ではほぼ同じである。例えば，スギでは20年生と40年生の総生産量はそれぞれ180トンと439トンであるが，割合はいずれも地上部約86%，地下部約14%である。また，地上部では葉の割合がヒノキで37%と他樹種の約30%に比べて大きい。地下部では細い根(0.5cm以下）の占める割合がヒノキ，スギで大きい。一方，これらのバイオマス生産量をベースにして算出した無機塩類の総生産量は，バイオマスの場合とほぼ同様の傾向である。総生産量はいずれの塩類もスギで

1986年10月１日受理

(1)　元造林部

多く，例えば40年生林分の窒素は，ha当たりスギ1304kg，ヒノキ914kg，アカマツ958kg，カラマツ1245kgである。また，塩類の間では濃度を反映していずれの樹種もリン酸が最も少なく130～245kgである。器官別の生産量割合ではいずれの樹種も塩類濃度の高い葉部で大きく，従って全体に占める地上部の割合も90%以上である。地下部では細い根ほど塩類濃度は高いがバイオマス量を反映して太さ5cm以上の根を除いて太さ別の割合には大きな違いはない。

(2)　物質の還元率

還元率は総生産量に対する林地への還元量の割合で表される。今，伐採によって幹の75%が林外に持ち出されたと仮定して還元率を検討した。伐採後，林地に残されるバイオマス量は林齢に比例して直線的に増加するが，還元率は減少する。これは葉量の占める割合が若い林分で大きいことによる。例えば，10年生と40年生の林分の還元率はそれぞれ80～90%と65～73%である。一方，この時の無機塩類の還元率もバイオマスと同じ傾向であるが，値は高い。例えば，窒素では各樹種とも90%以上の率である。これは塩類を多く含む葉や枝が林地に残されるためである。特に，ヒノキは落葉と枯枝の占める割合が多いため，還元率が他の樹種に比べて大きい特徴をもつ。

現実には還元率は枯死した根量を考慮しなければならないが，枯死量を正確に把握することは極めてむつかしい。ここでは次のような算定によって枯死量を推定した。落葉落枝を含めた地上部のバイオマス総生産量と地下部のバイオマス量の合計値に地上部のバイオマス量に対する地下部のバイオマス量の割合を掛けた。この根拠は光合成生産物が器官の割合に比例して配分されることを前提としている。この結果，スギ40年生の林分の例では，枯死した根量はha当たり45トンとなり，総生産量の10%に相当する。還元率も68%から71%に増える。窒素は，53kg増え総生産量の4%に相当するが，還元率はほとんど変わらない。

3　土壌層位別の塩類集積と根による孔隙形成

(1)　層位別の根の現存量と塩類集積量

根のバイオマス量と層位ごとのバイオマスの分布割合から算出した層位別の根のバイオマス量は，いずれの樹種も表層ほど多いが，深い層でのバイオマス量はヒノキ，カラマツで極めて少なく，アカマツで多い。これらはそれぞれ浅根性，深根性樹種の特徴を示している。各層位のバイオマス量は林齢の進行とともに増加する。増加割合は若齢林で著しい。層位別の塩類量は根のバイオマス量の分布に対応している。表層30cm（層位Ⅰ～Ⅱ）までに分布する根に蓄積される無機塩類量はスギ，ヒノキ，カラマツで80%以上であるが，アカマツで約70%と少ない。こうした傾向は塩類を多く含む細根量の多少によっている。例えば，表層での窒素量はヒノキで最も多く，スギ，カラマツ，アカマツの順に少ないが，下層になるとヒノキの量は急に減少してスギの量が上まわる。これは細根量の減少に対応している。

(2)層位別の根の容積と孔隙量

伐採後の根の腐朽によって腐食質の蓄積とともに孔隙が形成される。孔隙量の推定をするため，根の容積を土壌層位別の根のバイオマス量と平均密度から算出した。表層からの深さが30cmまでのあいだで，孔隙量は40年生のスギ，ヒノキ，アカマツ，カラマツでそれぞれ129，83，74，70m^3である。これらの量はアカマツを除いて全孔隙量の80%以上を占めている。アカマツは深根性のため孔隙の垂直分布の

幅が広い。また根の大きさによって孔隙の大きさも異なる。40年生スギの例では，層位Ⅰにおいて2mm以下の孔隙量は1.6m³，2～5mmは2m³，5～20mmは3.4m³，20～50mmは2.7m³，50mm以上は57m³である。

以上の点から根系は無機塩類を供給し孔隙を形成することによって土壌の物理・化学的性質の改善に大きく寄与している。その寄与は特に表層土壌に対して大きい。このことは細根密度の分布と土壌の諸特性値との関係からも示される。すなわち層位による細根密度の大きさの違いと土壌の容気率，孔隙率，全窒素，置換酸度などの層位間の違いとよく一致している。