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Litterfall, Accumulation and Turnover of Nutrients in the Forest Floor of Warm-Temperate Forests of Central Japan

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Abstract Litterfall, and accumulation and turnover of carbon, nitrogen, and mineral nutrients were studied in the forest floor of six subtropical/warm-temperate forests, three natural and semi-natural forests developed on contrasting topography, and *Cryptomeria* plantations of different ages, on Mt. Kiyosumi, Chiba, central Japan. Annual litter production at these sites amounted to 4.64-6.47 t/ha dry matter. The annual input of nutrient elements to the soil through litterfall was estimated to be 63-121 kg/ha for N, 2.8-7.0 kg/ha for K, 1.1-1.7 kg/ha for Na, 45.6-131.0 kg/ha for Ca, and 10.2-28.4 kg/ha for Mg. The *Abies-Tsuga* forest occurred on shallow soil on a ridge, and had the greatest accumulation of nutrients on the forest floor and surface soils (0-15 cm). The amounts of nutrients accumulated in the forest floor and surface soils (0-15 cm) of the evergreen *Quercus (Cyclobalanopsis)-Castanopsis* forest on a crest slope and the deciduous *Quercus-Cornus* forest on a valley bottom were about half those of the *Abies-Tsuga* forest, but the latter deciduous forest developed on deep soils, and nutrients were stored in the lower soil layer (15-50 cm). Turnover times of nutrient elements in the forest floor and soil system were, in order of increasing turnover time : 1.6-10.8 yr for Ca, 3.2-15.8 yr for Na, 8.6-25.1 yr for Mg, 9.5-31.7 yr for K, and 20.3-100.9 yr for N. Na was supplied mainly by rainfall. These turnover times reflect the specific behavior of nutrients, and are a useful indicator of nutrient dynamics in various forest types.

Key words : Nutrients, litterfall, turnover rates, warm-temperate forests, Kiyosumi.

The accumulation of carbon, nitrogen, and mineral nutrients in the forest floor is determined by the dynamic balance between supply through litterfall and loss due to decomposition. The process and rate of decomposition can change significantly depending on the time of year, tree species, climatic conditions, and other factors. There are also variations within a single region depending on the forest type, age of the forest, topographical habitat gradients, and other factors (Anderson *et al*., 1983 ; Vogt *et al*., 1986). The decomposed nutrients are leached out, or absorbed by the plants growing on the site.

Many previous researchers have studied turnover rates of nutrient elements in the forest ecosystems (Attiwill, 1967 ; Nihlgard, 1972 ; Lee and Park, 1981 ; Vogt *et al*., 1986). Nutrient accumulation and turnover are useful indicators of ecosystem function. In a steady-state ecosystem, input by litterfall, rainfall, decomposing roots, and other factors equates to the loss due to leaching and absorption by plants. Nutrient status affects physiognomic forest types and the pattern of forest zonation on mountains (Grubb, 1977).

The aim of this study was to clarify the nutrient contents and the amount of annual return of nutrients of forest litter in the principal warm-temperate forest types on Mt. Kiyosumi, central Japan. Furthermore, the turnover of nutrients was compared among the various forest types in similar climatic regions.

Study area

The studied forests belong to the University Forests in Chiba of the University of Tokyo, located at Mt. Kiyosumi, a small hilly region near the Pacific coast, Chiba Prefecture, Japan (Fig. 1). The area is located at 35°9′N and 140°9′E, at an altitude of ca. 300 m.

Annual rainfall amounts to 2231.9 mm and annual mean temperature is 13.7°C. The monthly mean temperature for the coldest month is 3.4°C. (January), and that for the warmest month is 24.0°C (August). A climatic diagram of Mt. Kiyosumi was prepared according to Walter *et al*. (1975) (Fig. 1). The geological bedrock is sandstone mixed with mudstone of the Tertiary Period. The soil type is brown forest soil with a somewhat low pH of 5.3-6.0 (Table 1).

The study area belongs to the warm-temperate forest zone with a climax of evergreen broad-leaved forest dominated by *Castanopsis cuspidata*

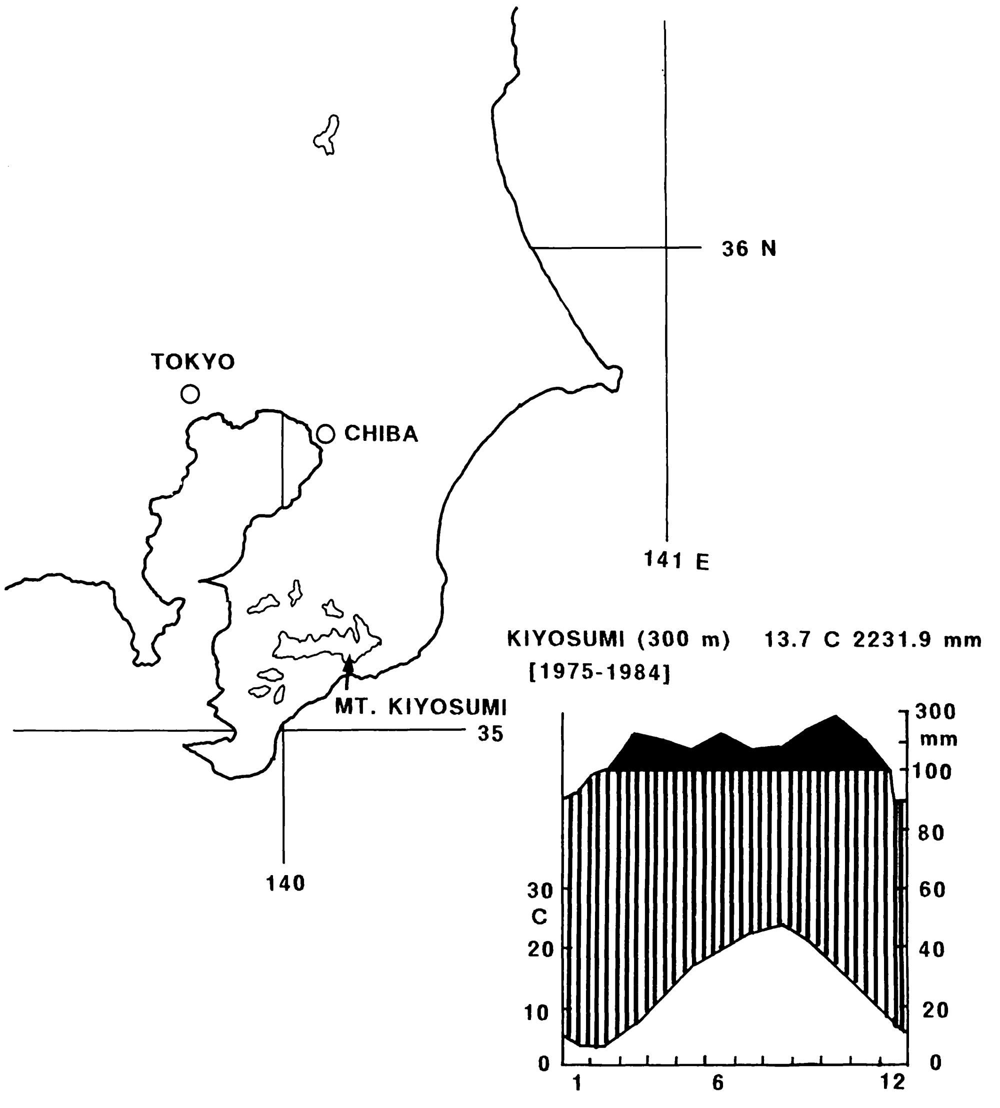

Fig. 1. Map of study area, Mt. Kiyosumi and Walter's climatic diagram for Kiyosumi (35°9′N, 140°9′E, 300 m in alt., The Tokyo University Forest in Chiba 1987).

var. *sieboldii*, *Quercus (Cyclobalanopsis) acuta, Q. (C.) salicina* and *Q. (C.) glauca*. Coniferous forests dominated by *Tsuga sieboldii, Abies firma* or *Pinus densiflora* are found on ridges, and the conifers often become emergent trees from the evergreen broad-leaved canopy of the forest. Deciduous forests dominated mainly by *Euptelea polyandra* and *Cornus controversa* are found on sites with frequent disturbances along the valley bottom. The secondary forests of deciduous trees such as *Quercus serrata, Q. acutissima* and *Carpinus tschonoskii* develop after the destruction of evergreen broad-leaved forests on hillsides facing north. This reflects the phytogeographical location of this region ; near the boundary between the southern evergreen forests and the northern deciduous forests. This zone is called the warm-temperate zone in Japan, but is equivalent to the subtropical zone of China (Song, 1988), and the latter may be a more appropriate term for this zone. Here we follow the traditional terminology used in Japan to avoid confusion. There are extensive areas of plantations of *Cryptomeria japonica* and *Chamaecyparis obtusa*.

Table 1. General description of study plots in Mt. Kiyosumi, Chiba, central Japan.

Dominance type	Life form	Stand age yrs(1985)	Tree height, m	Max. dbh, cm	Basal area land area,%	Soil pH	Compartment No.
Natural/seminatural forests							
1 *Quercus-Cornus* forest	deciduous	40	21.0	37.5	.170	5.3	C28 B4
2 *Cyclobalanopsis-Castanopsis* forest	evergreen	85	30.0	—	.320	5.7	C24 B2
3 *Abies-Tsuga* forest	conifer	93	30.0	120.0	.730	6.0	C27 A1
Cryptomeria plantations							
4 40 yrs	conifer	40	17.5	30.0	1.380	5.7	private
5 91 yrs	conifer	91	34.0	60.0	1.850	6.0	C27 C4
6 126 yrs	conifer	126	30.0	60.0	.790	5.7	C40 C5

Methods

After the growing season of 1982, three quadrats of 30 cm by 30 cm were laid on the forest floor, and samples of the L, F and H layers were taken separately (quadrat sampling method). Distinction among F, H and the surface soils was difficult in some forest types, and therefore after the analysis all of the sample data were finally grouped into three compartments, L, a pool of F, H and surface soils (0-15 cm), and lower soils (15-50 cm). In the present study, litter denotes freshly fallen litter on the forest floor (L), and forest floor nutrient mass denotes decomposing organic matter above the mineral soil plus nutrients in the mineral soils below it. The soil depths differed according to the sites. Among the six forest types, two forests, *Quercus (Cyclobalanopsis)-Castanopsis* forest and *Abies-Tsuga* forest were developed on shallow soil of up to 15 cm depth.

Litter samples were oven-dried at 80°C for 2 days. Soil samples were air-dried in the laboratory for 7 days. The contents of total carbon and nitrogen for each sample were determined by the dry combustion method with a C-N Corder (Yanaco MT 500). Exchangeable cations, Ca, Mg, K and Na in soils were extracted with ammonium acetate and their concentrations were determined with an atomic absorption spectrophotometer. The concentrations of trace elements and total cations were determined with the atomic absorption spectrophotometer after acid-digestion (hydrochloric acid-perchloric acid). The content of available phosphate was determined by the molybdophosphoric blue color method after Truogs extraction.

Results and discussion

A general description of the six sites is shown in Table 1. The sites are three natural/semi-natural forest and the three *Cryptomeria* plantations. Each of three natural/semi-natural forests corresponds to the three physiognomic types developed on contrasting topography ; i. e., deciduous forest dominated by *Quercus serrata* and *Cornus controversa* (Plot 1) at the valley bottom, an evergreen climax forest dominated by *Quercus (Cyclobalanopsis) acuta* and *Castanopsis cuspidata* (Plot 2) on a broad crest slope, and a coniferous climax forest dominated by *Abies firma* and *Tsuga sieboldii* (Plot 3) on a ridge. Three *Cryptomeria* plantations of three ages were also sampled ; young (40 yr old, Plot 4), mature (91 yr, Plot 5) and old (126 yr, Plot 6).

1. Annual return of nutrient elements

Annual litter production at the three natural/semi-natural forest sites estimated by accumulated litter in the L-layer amounted to 4.6-6.5 t/ha dry matter, and the amount for the *Cryptomeria* plantations, 5.3-5.8 t/ha, also fell within this range (Table 2). Deciduous forest showed the lowest amount, 4.6 t/ha. Using the litter trap method, Kimura *et al.* (1982) reported that a *Quercus serrata* forest under similar climatic conditions at Hachioji, west Tokyo, had a litter production of 3.64 t/ha. The other two forest types of evergreen broad-leaved and coniferous forests had similar values of 6.0-6.5 t/ha. Kabaya *et al.* (1973) reported a value of 6.4-6.9 t/ha by the litter trap method at several evergreen broad-leaved forests also in the Kiyosumi area. Ueda

Table 2. Litter standing mass and nutrient concentrations on forest floor. Percent of dry litter weight. Sampled in December, 1982.

	Litterfall ton/ha	N	P	K	Na	Mg	Ca	Mn	Cr	Zn	Al	Fe
Natural/seminatural forests												
1 *Quercus-Cornus* forest	4.6	1.600	.01	.110	.030	.240	1.78	.030	.0020	.010	.010	3.800
2 *Cyclobalanopsis-Castanopsis* forest	6.0	2.000	.01	.110	.030	.320	.76	.020	.0010	.002	.020	.060
3 *Abies-Tsuga* forest	6.5	1.300	.01	.070	.040	.440	1.27	.080	.0004	.010	.240	.130
Mean (1—3)	5.7	1.633	.01	.097	.033	.333	1.27	.043	.0010	.007	.090	1.330
Cryptomeria plantations												
4 40 yrs	5.8	1.600	.01	.120	.020	.240	1.39	.004	.0010	.010	.004	.050
5 91 yrs	5.3	1.200	.01	.050	.030	.190	1.96	.004	.0010	.010	.020	.040
6 126 yrs	5.6	1.200	.01	.070	.030	.280	2.35	.004	.0010	.020	—	.020
Mean (4—6)	5.6	1.333	.01	.080	.027	.237	1.90	.004	.0010	.013	.012	.037
Total mean (1—6)	5.6	1.483	.01	.088	.030	.285	1.59	.024	.0011	.010	.059	.683

and Tsutsumi (1980) reported litterfall of about 5.8-7.8 t/ha from evergreen broad-leaved forest dominated by *Persea (Machilus) thunbergii* in Shikoku, southwest Japan. Katagiri *et al.* (1978) reported a similar figure, 5.13-6.86 t/ha, for a warm-temperate evergreen oak forest in the Minamata Research Area of the JIBP, Kyushu, Japan. The amount of annual litter production estimated from the accumulated litter on the forest floor is within a similar range to that obtained by the litter trap method. The annual standing crop of forest floor litter measured by the quadrat method was 6.11 t/ha in a subtropical mixed forest dominated by *Annogeissus, Lannea* and *Flacourtia* in the Siwalik, northern India (Rout and Gupta, 1990).

Nutrient concentrations in litter were variable and seemed to show no systematic differences among the forest types for each nutrient element (Table 2). Katagiri *et al.* (1978) also stated that there was no systematic difference in nutrient concentration among trees. The nutrient concentrations in the litter of the natural/semi-natural forests fell within the range 1.3-2.0 % of dry weight for N, 0.01 % for P, 0.07-0.11 % for K, 0.3-0.4 % for Na, 0.24-0.44 % for Mg, 0.76-1.78 % for Ca, 0.02-0.08 % for Mn, 0.0004-0.002 % for Cr, 0.002-0.01 % for Zn, 0.01-0.24 % for Al, and 0.06-3.80 % for Fe. The nutrient concentrations for *Cryptomeria* plantations were also within and around the range for natural/semi-natural forests, except for some elements such as Mn and Fe, which showed a lower content than those of natural/semi-natural forests.

Most of these values are similar to those of the other subtropical/warm-temperate forests in Japan. The concentration of P differs markedly from the other forest, but this was due to the fact that only available phosphate was measured in the present study. The amount of K was 1/5 to 1/6 of that reported in *Persea (Machilus) thunbergii* forests in Shikoku. On the other hand, the amount of Mg was double that of the same forests (Ueda and Tsutsumi, 1980). These differences may reflect the decomposition or leaching processes acting on fallen litter on the forest floor.

Based on these data, the annual input of some nutrient elements to soils through litterfall in the natural/semi-natural forests was estimated, as shown in Table 3. The amounts of annual input were 74-121 kg/ha for N, 4.6-6.4 kg/ha for K, 45.6-82.5 kg/ha for Ca, and 11.1-28.4 kg/ha for Mg. The amounts in the three *Cryptomeria* forests were within and around the amounts for the natural/semi-natural forests (Table 3). These values are similar to those of comparable forests in Tokushima (Ueda and Tsutsumi, 1980) and in the Minamata JIBP area (Katagiri *et al.*, 1978).

The amount of K is similar to that at Minamata, but the amount in Tokushima is more than six times these values. This results from differences in the concentration of nutrients, and not in the amount of litter.

The annual input of nutrients in a subtropical mixed forest of northern India was within a similar range, i. e., 84.1 kg/ha for N, 5.81 kg/ha for P,

Table 3. Input and accumulation of carbon and nutrient elements in the study sites.

	Litter ton/ha	C ton/ha	N kg/ha	K kg/ha	Na kg/ha	Mg kg/ha	Ca kg/ha
Annual input by rain water		—	—	2.0	18.2	2.4	2.2
Natural/seminatural forests							
1 *Quercus-Cornus* forest							
Annual input by litterfall	4.6	2.4	74.0	4.9	1.4	11.1	82.4
Accumulation in forest floor and upper soil (0—15 cm)		39.4	2153.0	66.0	72.3	105.4	424.5
Accumulation in lower soil (15—50 cm)		67.6	5310.0	84.3	12.2	10.2	491.0
Total accumulation F + H + soil (0—50 cm)		106.9	7463.0	150.3	84.5	115.6	915.5
Total input/total accumulation (%)		2.3	1.0	4.6	23.1	11.6	9.2
Turnover times (yrs)		44.0	100.9	21.9	4.3	8.6	10.8
2 *Cyclobalanopsis-Castanopsis* forest							
Annual input by litterfall	6.0	3.1	121.0	6.4	1.7	19.5	45.6
Accumulation in forest floor and soil (0—15 cm)		38.2	2458.0	79.8	64.2	221.0	77.9
Turnover times (yrs)		12.4	20.3	9.5	3.2	10.1	1.6
3 *Abies-Tsuga* forest							
Annual input by litterfall	6.5	2.8	84.0	4.6	2.5	28.4	82.4
Accumulation in forest floor and soil (0—15 cm)		55.6	5957.0	208.5	325.9	772.0	240.3
Turnover times (yrs)		20.1	70.9	31.7	15.8	25.1	2.8
Cryptomeria plantations							
4 40 yrs							
Annual input by litterfall	5.8	3.1	92.0	7.0	1.1	13.7	79.7
Accumulation in forest floor and upper soil (0—15 cm)		43.9	3836.0	70.2	43.6	142.5	329.1
Accumulation in lower soil (15—50 cm)		130.4	12770.0	19.0	4.7	14.4	92.6
Total accumulation F + H + soil (0—50 cm)		174.2	16606.0	89.1	48.3	157.0	421.7
Total input/total accumulation (%)		1.8	.6	10.1	39.8	10.2	19.4
Turnover times (yrs)		55.5	180.5	9.9	2.5	9.8	5.1
5 91 yrs							
Annual input by litterfall	5.3	2.9	63.0	2.8	1.5	10.2	103.0
Accumulation in forest floor and upper soil (0—15 cm)		50.3	2652.0	96.0	57.9	158.0	465.3
Accumulation in lower soil (15—50 cm)		62.8	5670.0	51.2	11.8	83.2	280.6
Total accumulation F + H + soil (0—50 cm)		113.0	8322.0	147.2	69.7	241.2	745.9
Total input/total accumulation (%)		2.5	.8	3.2	28.2	5.2	14.1
Turnover times (yrs)		39.7	132.1	31.2	3.5	19.2	7.1
6 126 yrs							
Annual input by litterfall	5.6	3.0	67.0	4.0	1.7	15.8	131.0
Accumulation in forest floor and upper soil (0—15 cm)		49.6	3312.0	54.4	51.5	189.5	630.7
Accumulation in lower soil (15—50 cm)		154.5	14540.0	43.4	11.5	60.5	285.0
Total accumulation F + H + soil (0—50 cm)		204.1	17852.0	97.8	63.0	250.0	915.7
Total input/total accumulation (%)		1.5	.4	6.1	31.5	7.3	14.6
Turnover times (yrs)		67.6	266.4	16.4	3.2	13.8	6.9

15.7 kg/ha for K, 92.2 kg/ha for Ca and 21.3 kg/ha for Mg (Rout & Gupta, 1990). The annual return of nutrients in deciduous forests at high latitudes, e. g., in Belgium (Duvigneaud and Denaeyer De Smet, 1970) was 50 kg/ha for N, 2.4 kg/ha for P, 21 kg/ha for K, 110 kg/ha for Ca, and 6 kg/ha for Mg. The annual return in temperate deciduous forests in Sweden was estimated by Nihlgard (1972) to be 69 kg/ha for N, 5.0 kg/ha for P, 14.4 kg/ha for Ca, and 4.3 kg/ha for Mg. The present estimates are within a similar range to these values, except for a small value for K and a large value for Mg, reflecting the different contents of these elements in the fallen litter. The amount of Ca varies among sites.

The annual input of nutrients by precipitation was calculated based on the data of Kabaya (unpublished data), and is shown in Table 3. The amount of Na in rainwater is nearly ten times larger than the content in litterfall. The amount of K is comparable to that in litter. The other elements have smaller amounts in rainwater, and are mainly returned by litterfall. The input ignored in the present study was that of detritus from root systems.

2. Accumulation of nutrients in the forest floor

The amount of nutrients accumulated on the forest floor and in the soils varied depending on site and horizon (Table 3). Two sites of natural forest, the *Quercus (Cyclobalanopsis)-Castanopsis* forest on a crest slope and the *Abies-Tsuga* forest on a ridge, had somewhat shallow soils compared to the other sites, the deciduous forest on the valley and three *Cryptomeria* plantations, and the soil samples were collected only above depths of 15 cm for the two.

The total amount of nutrients in the forest floor and surface soils (0-15 cm) of the evergreen *Quercus (Cyclobalanopsis)-Castanopsis* forest on a crest slope and the deciduous *Quercus-Cornus* forest on a valley bottom were about half those of the *Abies-Tsuga* forest on a ridge, but the latter deciduous forest developed on deep soils, and nutrients were stored in the lower soil layer (15-50 cm)(Table 3). The different accumulation pattern of nutrients at different topographical locations reflects the characteristic morphological sequence or the catena principle in geomorphology, consisting on ridge top of an eluvial, in the middle slope of a steep colluvial and at the valley of an alluvial zone, which eventually controlling water and mass movements along the catena (Scheidegger, 1986). Ridges are mainly flat and materials accumulate and/or washout, slopes are steep and transport or throughput of material, and valleys are flat and deposition of materials.

The relative abundance of nutrients in each compartment, such as litterfall and accumulation in the forest floor, showed nearly the same pattern for all sites (Fig. 2). Nutrient contents in the forest floor and soils in the natural/semi-natural forests were 2458-7463 kg/ha for N, 79.8-208.5 kg/ha for K, 64.2-325.9 kg/ha for Na, 115.6-772.0 kg/ha for Mg, and 77.9-915.5 kg/ha for Ca.

If the system concerned is in a steady state, although it is not a true climax forest, activities of nutrient pools can be measured by turnover times or mean residence time expressed as the contents of a particular element in the forest floor including soils (F + H + total soils) divided by annual inputs by litterfall and rainfall for that particular element (Table 3). The turnover times were specific to the elements and were similar among the three natural/semi-natural forest types, i. e., in order of increasing turnover time, Ca, Na, Mg, K, C, and N. The shortest turnover time was 1.6-10.8 yr for Ca, followed by 3.2-15.8 yr for Na, 8.6-25.1 yr for Mg, 9.5-31.7 yr for K, 12.4-44.0 yr for C, and the longest one was 20.3-100.9 yr for N. This order is the same as that for an oak forest in Minnesota (Reiners and Reiners, 1970). Attiwill (1967) reported that the loss of nutrient elements follows the order Na, K, Ca, Mg, P and N, and the order is nearly the same as the increasing order of turnover times for the nutrients in the present study. The order of abundance of nutrients in the forest floor was P < K < Mg < N < Ca in the subtropical mixed forest in northern India (Rout and Gupta, 1990). The most variable nutrient is Ca among the three regions: Mt Kiyosumi, Minnesota, and northern India. Thus, the order of increasing accumulation and stable residence is Na, K, Mg and N (except Ca), and is almost constant at the three sites. This order may reflect the general behavior of nutrients in the forest floor.

The turnover times of nitrogen in natural/semi-natural forests ranged from 20.3 to 100.9 yr, and those in *Cryptomeria* forests ranged from 132.

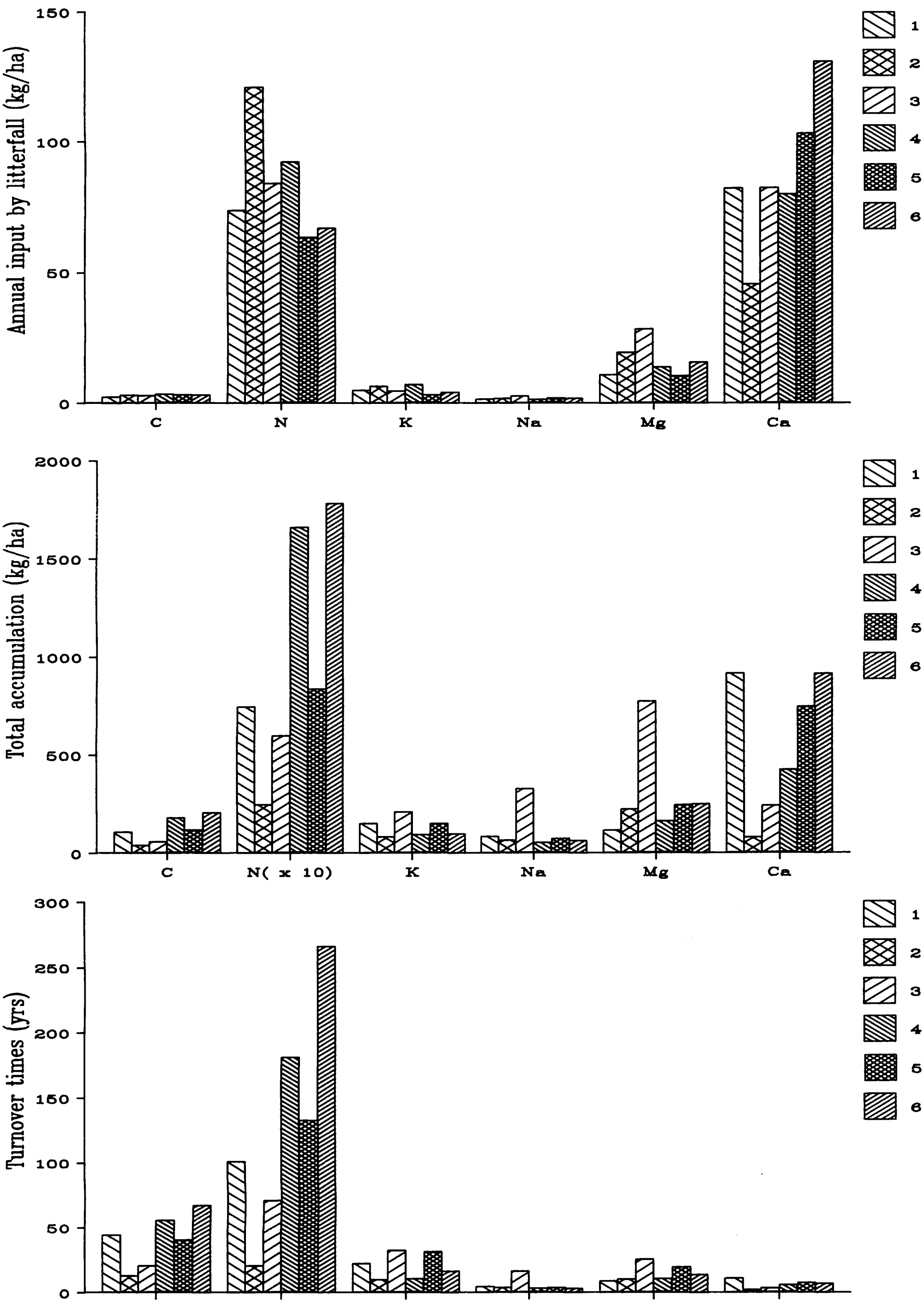

Fig. 2. Spectra of nutrients, input by litterfall, forest floor and soil accumulation, and turnover times (years, total accumulation including soils divided by input by rain water and litterfall) in t/ha, 1, *Quercus-Cornus* forest ; 2, *Quercus (Cyclobalanopsis)-Castanopsis* forest ; 3, *Abies-Tsuga* forest ; 4, *Cryptomeria* plantation (40 ry) ; 5, *Cryptomeria* plantation (91 yr) ; 6, *Cryptomeria* plantation (126 yr).

Table 4. C/N ratio for the six study sites.

	Litter	F + H + soil (0-15 cm)	soil (15-50 cm)
Natural/semi-natural forests			
1. *Quercus-Cornus* forest	32.8	16.8	13
2. *Cyclobalanopsis-Castanopsis* forest	25.6	14.9	—
3. *Abies-Tsuga* forest	32.9	12.9	—
Cryptomeria plantations			
4. 40 yrs.	34.1	13.1	8.9
5. 91 yrs.	45.0	14.4	9.3
6. 126 yrs.	45.2	15.3	10.4

1 to 266.4 yr in the present study. The estimated turnover time in cool-temperate forests was 279 yr in a Japanese beech forest, and that in warm-temperate evergreen oak forests of Kyushu, Japan was 119 years (Tsutsumi *et. al.*, 1978). In the present study, the wider range of turnover times seems to reflect variations in the nutrient stock in soils due to the varying depths of the soils, different ages of the stands and the phenological variation due to different physiognomic types of forest.

The longest turnover times for most of the elements except Ca, C and N occurred in the *Abies-Tsuga* forest on ridge. This indicates the high accumulation or slow decomposition of nutrients such as K, Na, and Mg in the forest floor of *Abies-Tsuga* forest. It is generally found that coniferous forests have greater accumulation of organic matter than hardwood forests (Rodin & Bazilevich, 1967). The longer turnover times for Ca, C and N in the *Quercus-Cornus* forest are partly due to the highest accumulation of these nutrients in the lower soil strata (15-50 cm) at the valley bottom. The amount of these elements in the lower strata amounted to 63-71 % of the total accumulation in the forest floor. The shortest turnover times for all the elements except Mg occurred in the *Quercus (Cyclobalanopsis)-Castanopsis* forest on a slope. This indicates the high throughput or low accumulation of nutrients on a steep slope.

3. Relationship between carbon and nitrogen in the forest floor

The ratio of carbon to nitrogen reflects the decomposition processes of organic matter in the forest floor and soils (Kawahara and Tsutsumi, 1972). Table 4 shows the C/N ratio for the six study sites. In a steady-state soil system, the ratio is said to approach to 10, which is the value for soil micro-organisms (Waksmsman and Jenny, 1927). The C/N ratios of mineral soils at the study sites ranged from 8.9 to 13.0, showing that the soil systems are almost in a steady state at these sites.

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清澄山の暖温帯林におけるリター量，栄養塩の蓄積と循環

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千葉県清澄山の東京大学千葉演習林と隣接地で，自然林(アカガシ-スダジイ林，モミ-ツガ林)，半自然林（コナラ-ミズキ林)，人工林（スギ林，40，91，126年生)を合計6林分を選び，地表に堆積した新鮮リター量，A_0層と地表から15cmまでの表層土壌，15-50cmまでの下層土壌にわけて生育期の終わりにサンプリングし（1982年12月)，主要栄養塩を分析した．リター量は4.64-6.47t／ha，リターによる栄養塩の供給量はNが63.0-121.0kg／ha，Kが2.8-7.0kg／ha，Naが1.1-1.7kg／ha，Caが45.6-131.0kg／ha，Mgが10.2-28.4kg／haであった．尾根のモミ-ツガ林と斜面上部のアカガシ-スダジイ林は土壌が薄く，15cmまでしかサンプルが得られなかった．モミ-ツガ林はF・H層から15cmまでの土壌中に蓄積されている栄養塩がアカガシ-スダジイ林の約2倍あった．コナラ-ミズキ林は土壌が厚く，15-50cmの下層土に蓄積されている栄養塩の量が多く，総量にすると最も大きかった．結局，堆積性の斜面下部，残積性の尾根，匍行性の斜面の順に栄養塩の蓄積は少なくなる．栄養塩の種類による回転率についても述べた．