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Nutrient Elements in the Litterfall of Deciduous Broad-leaved Forests and Evergreen Coniferous Forests in Northern Hokkaido, Japan *

By

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北海道北部の落葉広葉樹林と常緑針葉樹林のリターフォールの養分*

スルヨ　ハルディウィノト**

Abstract

Contents of such nutrient elements as nitrogen (N), phosphorus (p), potassium (K), magnesium (Mg) and calcium (Ca) in the litterfall of deciduous broad-leaved forests (DBF) and evergreen coniferous forests (ECF) were studied.

Fractions of the litterfall showed differences in their nutrient concentrations; for example, the concentrations of N, P and K were high in the seed litter, while they were low in the branch litter. The concentrations of nutrient elements in the leaf litter of coniferous tree species were generally lower than those of deciduous broad-leaved tree species. Seasonal changes of N, P and K concentrations in the leaf litter of the dominant tree species were similar each other, with high rates occurring in summer, and low rates in autumn. The concentrations of N, P and K in the leaf litter were obviously lower than those in the growing leaves.

Since the amounts of nutrients returned to the forest floor fluctuated seasonally in similar trends with the fluctuation of the litterfall rates in all investigated forests, it is suggested that the seasonal changes of nutrient input were largely controlled by the rates of litterfall. The total amounts of nutrients returned to the floor of the forests were probably more affected by the concentrations of nutrient elements in the litterfall. Ranges of nutrient amounts in the litterfall of the DBF obtained in this study were 27.3-30.9kg/ha·yr for N, 0.8-1.8Kg/ha·yr for P, 5.60-5.63Kg/ha·yr for K, 23.7-35.1kg/ha·yr for Ca and 2.4-4.3kg/ha·yr for Mg; while those of the ECF were 28.3-28.4kg/ha·yr for N, 1.4-1.6kg/ha·yr for P, 4.0-4.3kg/ha·yr for K, 29.76-29.81kg/ha·yr for Ca and 2.1-2.6kg/ha·yr for Mg.

Key words: Nutrient elements, Litterfall, Deciduous broad-leaved forests, Evergreen coniferous forests.

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1. Introduction

A forest ecosystem depends on a continued recycling of minerals for continued growth (DANIEL et al., 1980). An understanding of nutrient cycling is an essential prerequisite for understanding and predicting the effects of nutrition on the forest growth (TURNER et al., 1976; LANDSBERG, 1986). Litterfall as a major nutrient cycling pathway which transfers a significant proprortion of the nutrient uptake and net primary production of forests to the forest floor (MAGGS, 1985), is composed of various fractions with different concentrations of nutrient elements between each fraction (TSUTSUMI, 1977).

Low concentrations of N, P and K were found in branch litter of evergreen broad-leaved forests in Kyushu (KATAGIRI et al., 1978) and of *Chamaecyparis obtusa* stands on Mt. Hiei, Shiga Prefecture (TSUTSUMI et al., 1983). TSUTSUMI (1977) reported that the concentration of nutrient elements in leaf litter of coniferous forests was lower than that in leaf litter of deciduous broad-leaved forests. The high N concentration in leaf litter of *Chamaecyparis obtusa* in summer decreased gradually to a minimum in autumn when the amount of leaf litter reached the maximum (UEDA and TSUTSUMI, 1979). RAUNEMAA et al. (1983) reported that the concentrations of P and K in leaf litter of Scots pine were much lower than those in the growing needle-leaves.

Amounts of nutrient elements supplied to the forest floor fluctuated seasonally, depending on the rates of litterfall and the concentrations of nutrient elements in the litterfall (KATAGIRI et al., 1978). Studies on the nutrient elements in the litterfall of various forests have been carried out in many parts of Japan. Among them are Yamagata (KAWADA and MARUYAMA, 1986); Shiga (KAWAHARA, 1971); Kyoto (KATAGIRI and TSUTSUMI, 1973); Wakayama (FURUNO, 1986); Yamaguchi (UEDA and TSUTSUMI, 1980); and Kyushu (KATAGIRI et al., 1978). However, data on the nutrient elements in the litterfall of forests in Hokkaido, the northernmost main island of Japan, have not yet been obtained. The object of this paper is to quantify the contents and seasonal changes of such nutrient elements as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) returned to forest floor through the litterfall of the deciduous broad-leaved forests and the evergreen coniferous forests in the northern part of Hokkaido.

2. Study area, materials and methods

This study was carried out in the Moshiri district, at the Uryu Experiment Forest of Hokkaido University by establishing four study plots, P1, P2, P3 and P4. It is situated approximately at E 142°1′-20′, N44°3′-29′, and has an elevation range of about 175-900m above sea level. General climatic conditions and stand structure of the study plots have been reported previously (HARDIWINOTO et al., 1991). P1 was classified as a *Quercus mongolica* var. *grosseserrata* forest, P2 as a *Betula platyphylla* var. *japonica* forest, P3 as an *Abies sachalinensis* forest, and P4 as a *Picea glehnii* forest.

Litterfall in the deciduous broad-leaved forests (P1 and P2) and the evergreen coniferous forests (P3 and P4) which was collected from June, 1988 to May, 1989; and separated into leaves, branches, barks, seeds and other materials (HARDIWINOTO et al., 1991), was used as samples for chemical analyses. Leaf litter of the dominant species in the study sites was analysed for the leaf fall which occurred in July (summer), October (autumn), and November-May (winter). Since the other material litter was largely composed of insect feces, bud scales and cones, these three fractions were analysed for estimating the contents of nutrient elements in this litter.

The sorted litter samples were oven-dried, ground in a mill to pass the mesh screen. The samples were analysed chemically for the concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). The concentration of nitrogen was determined by an automatic micro-Kjeldal method, while that of phosphorus by molybdenum yellow colorimetric method. Contents of potassium were analysed by a flame-photometric method, and those of calcium and magnesium by atomic absorption spectrophotometry.

3. Results

3.1 Concentrations of nutrient elements

Concentrations of nutrient elements in each fraction of *Q. mongolica* var. *grosseserrata* litterfall are shown in Table 1 . Among the fractions, seed and insect feces had the high concentrations of N, P and K, while the high concentration of Ca occurred in leaf and bark litter, and those of Mg in leaf, seed and insect feces litter. In the litterfall of *B. platyphylla* var. *japonica*, leaf, seed and bud scale fraction had the high rates of N, P, as well as K concentrations, while those of Ca and Mg were in leaf fraction (Table 2).

Tables 3 and 4 show the concentrations of nutrient elements in each fraction of evergreen coniferous species litter. The high rate of N, P, K and Mg concentrations in *A. sachalinensis* litterfall was found in the seed litter, and that of Ca in the leaf litter. The

Table 1. Concentrations of nutrient elements (%) in the litterfall of *Q. mongolica* var. *grosseserrata*

	Litterfall fractions				
	Leaf	Branch	Bark	Seed	Ins F
N	0.77	0.47	1.10	1.24	1.86
P	0.013	0.014	0.037	0.118	0.070
K	0.14	0.09	0.13	0.87	0.71
Ca	1.19	0.63	1.45	0.44	0.78
Mg	0.08	0.03	0.05	0.08	0.09

Note: Ins F=Insect feces.

Table 2. Concentrations of nutrient elements (%) in the litterfall of *B. platyphylla* var. *japonica*

	Litterfall fractions				
	Leaf	Branch	Bark	Seed	Bd S
N	1.27	0.55	0.70	1.84	1.59
P	0.075	0.025	0.054	0.229	0.090
K	0.24	0.08	0.11	0.25	0.16
Ca	1.05	0.42	0.12	0.39	0.41
Mg	0.21	0.04	0.06	0.11	0.10

Note: Bd S=Bud scales.

Table 3. Concentrations of nutrient elements (%) in the litterfall of *A. sachalinensis*

	Litterfall fractions				
	Leaf	Branch	Bark	Seed	Cone
N	0.73	0.63	1.37	1.70	0.49
P	0.045	0.028	0.099	0.183	0.034
K	0.13	0.07	0.22	0.24	0.21
Ca	1.09	0.38	0.49	0.06	0.09
Mg	0.05	0.04	0.08	0.09	0.07

Table 4. Concentrations of nutrient elements (%) in the litterfall of *P. glehnii*

	Litterfall fractions				
	Leaf	Branch	Bark	Seed	Cone
N	0.63	0.30	0.52	3.15	0.47
P	0.034	0.014	0.029	0.433	0.019
K	0.09	0.03	0.10	0.27	0.21
Ca	0.65	0.23	1.49	0.09	0.04
Mg	0.03	0.02	0.04	0.16	0.04

Table 5. Concentrations of nutrient elements in the autumn leaf litter of broad-leaved species in P1, P2, P3 and P4

	P1	P2	P3	P4
N	0.84	1.27	1.20	1.04
P	0.034	0.067	0.048	0.029
K	0.21	0.16	0.14	0.23
Ca	1.79	1.17	1.00	1.20
Mg	0.12	0.20	0.20	0.13

high concentration of N, P, K and Mg in *P. glehnii* litterfall was also found in seed litter, and that of Ca in bark litter. Contents of nutrients in the autumn leaf litter of broad-leaved species, excluding *Q. mongolica* var. *grosseserrata* in P1, and *B. platyphylla* var. *japonica* in P2, are presented in Table 5.

Seasonal changes of nutrient concentrations in the leaf litter of the dominant species in the study sites are presented in Table 6. Seasonal changes of N and P concentrations among the species were similar to each other, with high concentrations in summer, lowest in autumn, and increasing again during winter. The high concentrations of K also occurred in summer, decreased greatly in autumn, and except of *Q. mongolica* var. *grosseserrata*, they increased during winter. On the other hand, concentrations of Ca were low in summer, reached the high concentrations in autumn, and decreasing during winter. In the leaf litter of deciduous broad-leaved species, Mg concentrations were high in

Table 6. Seasonal changes of nutrient concentrations in the leaf litter (%)

	Species	Time of leaf fall		
		July (sumeer)	October (autumn)	Nov.-May (winter)
N	Qm	2.06	0.73	1.19
	Bp	2.32	1.08	1.94
	As	1.29	0.57	1.11
	Pg	0.84	0.53	0.75
P	Qm	0.100	0.010	0.037
	Bp	0.156	0.061	0.126
	As	0.091	0.029	0.085
	Pg	0.053	0.026	0.044
K	Qm	0.75	0.12	0.08
	Bp	0.89	0.13	0.19
	As	0.37	0.08	0.23
	Pg	0.23	0.06	0.09
Ca	Qm	0.53	1.22	0.84
	Bp	0.67	1.12	0.46
	As	0.63	1.19	0.86
	Pg	0.48	0.74	0.55
Mg	Qm	0.10	0.08	0.05
	Bp	0.24	0.20	0.09
	As	0.06	0.05	0.06
	Pg	0.04	0.03	0.03

Note:
Qm=*Q. mongolica* var. *grosseserrata*, Bp=*B. platyphylla* var. *japonica*, As=*A. sachalinensis*, Pg=*P. glehnii*.

Table 7. Concentrations of nutrient elements (%) in the green leaves and leaf litter

Species	Leaves	Nutrient concentrations (%)				
		N	P	K	Ca	Mg
Qm	Gr L	1.29	0.094	0.78	0.64	0.10
	L Lt	0.73	0.010	0.12	1.22	0.08
Bp	Gr L	1.72	0.107	0.79	0.70	0.15
	L Lt	1.08	0.061	0.13	1.12	0.20
As	Gr L	1.25	0.093	0.44	1.11	0.06
	L Lt	0.57	0.029	0.08	1.19	0.05
Pg	Gr L	0.82	0.061	0.40	0.56	0.04
	L Lt	0.53	0.026	0.06	0.74	0.03

Note:
Qm, Bp, As, Pg=see Table 6.
Gr L=Green leaves which were taken from their parent trees at the end of July, 1988, L Lt=Leaf litter in October, 1988.

summer, and gradually decreased during autumn and winter, while those in the leaf litter of coniferous species showed rather constant rates during summer, autumn and winter.

In Table 7, concentrations of nutrient elements in the leaf litter and growing leaves of the .four dominant species are presented. The concentrations of N, P and K were obviously lower, while those of Ca were higher in the leaf litter than in the growing leaves. As for Mg, there was not such an obvious difference between the leaf litter and the growing leaves, especially in the coniferous species.

3.2 Amounts and seasonal changes of nutrient element input

In Table 8, total amount of N in the litterfall of P1 is shown. It was 27.3kg/ha·yr, with leaves of *Q. mongolica* var. *grosseserrata* as the major contributor (49.1%), followed by other material litter (23.5%), branch (8.1%), leaves of broad-leaved species (7.7%), bark (5.8%), leaves of coniferous species (4.9%), and seed (0.7%). Total P amounted to 0.8kg/ha·yr (Table 9) with other material litter contributing 35.7%, leaves of *Q. mongolica* var.

Table 8. Amounts of nitrogen in the litterfall from June. 1988 to May, 1989 in Pl ($\times$ 10^{-1}kg N/ha·yr)

	Leaves								
	Qm	Bl	Cl	Br	Bark	Seeds	Oth	Total	[%]
June	1.26	0.06	0.05	0.90	0.14	0.00	17.93	20.34	7.4
July	5.83	0.56	0.04	0.58	0.11	0.00	33.42	40.54	14.8
August	2.04	0.20	0.08	0.55	0.78	0.58	2.92	7.15	2.6
September	2.12	0.80	0.07	0.85	0.35	0.53	1.56	6.28	2.3
October	120.14	19.47	9.44	15.05	2.29	0.80	3.74	170.93	62.5
Nov.-May	2.88	0.06	3.59	4.19	12.17	0.12	5.04	28.05	10.3
Total	134.27	21.15	13.27	22.12	15.84	2.03	64.61	273.29	100.0
[%]	49.1	7.7	4.9	8.1	5.8	0.7	23.6	100.0	

Note:
Qm = *Q. mongolica* var. *grosseserrata*, Bl = Broad-leaved species excluding Qm, Cl = Coniferous species, Br = Branches, Oth = Other materials (insect bodies & feces, cones, bud scales, flowers and unidentified materials).

Table 9. Amounts of phosphorus in the litterfall from June, 1988 to May, 1989 in Pl ($\times$ 10^{-1}kg P/ha·yr)

	Leaves								
	Qm	Bl	Cl	Br	Bark	Seeds	Oth	Total	[%]
June	0.061	0.002	0.004	0.027	0.005	0.000	0.866	0.965	11.9
July	0.283	0.023	0.003	0.017	0.004	0.000	1.304	1.634	20.1
August	0.099	0.008	0.005	0.017	0.026	0.055	0.139	0.349	4.3
September	0.029	0.032	0.003	0.025	0.012	0.051	0.086	0.238	2.9
October	1.646	0.788	0.480	0.448	0.077	0.082	0.218	3.739	46.0
Nov.-May	0.090	0.002	0.275	0.125	0.409	0.013	0.286	1.200	14.8
Total	2.208	0.855	0.770	0.659	0.533	0.201	2.899	8.125	100.0
[%]	27.2	10.5	9.5	8.1	6.6	2.5	35.7	100.0	

Note: See Table 8.

Table 10. Amounts of potassium in the litterfall from June, 1988 to May, 1989 in Pl (× 10^{-1}kg K/ha·yr)

	Leaves								
	Qm	Bl	Cl	Br	Bark	Seeds	Oth	Total	(%)
June	0.46	0.01	0.01	0.17	0.02	0.00	4.01	4.68	8.3
July	2.12	0.14	0.01	0.11	0.01	0.00	12.07	14.46	25.7
August	0.74	0.05	0.02	0.11	0.09	0.41	0.70	2.12	3.8
September	0.35	0.20	0.01	0.16	0.04	0.33	0.22	1.31	2.3
October	19.75	4.87	1.32	2.88	0.27	0.31	0.52	29.92	53.2
Nov.-May	0.19	0.01	0.74	0.80	1.44	0.04	0.54	3.76	6.7
Total	23.61	5.28	2.11	4.23	1.87	1.09	18.06	56.25	100.0
(%)	42.0	9.4	3.8	7.5	3.3	1.9	32.1	100.0	

Note: see Table 8.

Table 11. Amounts of calcium in the litterfall from June, 1988 to May, 1989 in Pl (× 10^{-1}kg Ca/ha·yr)

	Leaves								
	Qm	Bl	Cl	Br	Bark	Seeds	Oth	Total	(%)
June	0.32	0.13	0.03	1.20	0.19	0.00	5.89	7.76	2.2
July	1.50	1.20	0.02	0.77	0.15	0.00	13.62	17.26	4.9
August	0.52	0.43	0.04	0.74	1.03	0.21	0.99	3.96	1.1
September	3.54	1.70	0.14	1.13	0.46	0.17	0.42	7.56	2.2
October	200.78	41.49	19.71	20.18	3.02	0.15	0.93	286.26	81.6
Nov.-May	2.03	0.13	2.78	5.61	16.04	0.02	1.29	27.90	8.0
Total	208.69	45.08	22.72	29.63	20.89	0.55	23.14	350.70	100.0
(%)	59.5	12.9	6.5	8.4	6.0	0.2	6.6	100.0	

Note: see Tale 8.

Table 12. Amounts of magnesium in the litterfall from June, 1988 to May, 1989 in Pl (× 10^{-1}kg Mg/ha·yr)

	Leaves								
	Qm	Bl	Cl	Br	Bark	Seeds	Oth	Total	(%)
June	0.06	0.01	0.00	0.06	0.01	0.00	1.02	1.16	4.9
July	0.28	0.08	0.00	0.04	0.01	0.00	1.65	2.06	8.7
August	0.10	0.03	0.00	0.04	0.04	0.04	0.16	0.41	1.7
September	0.23	0.11	0.01	0.05	0.02	0.03	0.10	0.55	2.3
October	13.17	2.78	0.83	0.96	0.10	0.04	0.27	18.15	76.2
Nov.-May	0.12	0.01	0.19	0.27	0.55	0.01	0.33	1.48	6.2
Total	13.96	3.02	1.03	1.42	0.73	0.12	3.53	23.81	100.0
(%)	58.6	12.7	4.3	6.0	3.1	0.5	14.8	100.0	

Note: see Table 8.

grosseserrta 27.2%, leaves of broad-leaved species 10.5%, leaf of coniferous species 9.5%, branch 8.1%, bark 6.6% and seed 2.5%. Total amount of K in the litterfall of P1 was 5.6kg/ha·yr (Table 10), while that of Ca was 35.1kg/ha·yr (Table 11), and Mg was 2.4kg/ha·yr (Table 12). Although with different rates, seasonal changes of nutrient element input to the forest floor were similar in each element, with their first peak in July and a remarkable peak in October.

The total amount of N in the litterfall of P2 was 30.9kg/ha·yr (Table 13), while that of P was 1.8kg/ha·yr (Table 14), K was 5.6kg/ha·yr (Table 15), Ca was 23.7kg/ha·yr (Table 16), and Mg was 4.3kg/ha·yr (Table 17). Since leaf litter of *B. platyphylla* var. *japonica* was the major contributor to total litter, it has also highest proportion in the total amount of nutrients. This amounted to 70.4% for N, 72.5% for P, 74.9% for K, 76.3% for Ca, and 82.7% for Mg. The input of nutrient elements fluctuated seasonally, with the first peak in June and an outstanding peak in October.

Table 13. Amounts of nitrogen in the litterfall from June, 1988 to May, 1989 in P2 ($\times 10^{-1}$kg N/ha·yr)

	Leaves								
	Bp	Bl	Cl	Br	Bark	Seeds	Oth	Total	(%)
June	29.84	0.09	0.09	0.69	0.20	0.00	8.76	39.67	12.8
July	11.09	0.15	0.04	0.40	0.05	0.02	9.14	20.89	6.8
August	18.77	0.47	0.03	0.39	0.14	0.09	2.84	22.73	7.3
September	23.77	1.17	0.03	1.55	0.04	0.47	2.84	29.87	9.7
October	133.54	12.95	4.14	14.73	0.35	1.59	8.45	175.75	56.8
Nov.-May	0.87	0.04	3.22	6.81	0.74	0.14	8.65	20.47	6.6
Total	217.88	14.87	7.55	24.57	1.52	2.31	40.68	309.38	100.0
(%)	70.4	4.8	2.4	7.9	0.5	0.7	13.1	100.0	

Note:
Bp=*B. platyphylla* var. *japonica*, Bl=Broad-leaved species excluding Bp, Cl=Coniferous species, Br=Branches, Oth=Other materials (insect bodies & feces, cones, bud scales, flowers and unidentified materials).

Table 14. Amounts of phosphorus in the litterfall from June, 1988 to May, 1989 in P2 ($\times 10^{-1}$kg P/ha·yr)

	Leaves								
	Bp	Bl	Cl	Br	Bark	Seeds	Oth	Total	(%)
June	2.006	0.005	0.006	0.032	0.016	0.000	0.496	2.561	14.3
July	0.746	0.008	0.003	0.018	0.004	0.002	0.370	1.151	6.4
August	1.262	0.025	0.002	0.018	0.011	0.011	0.152	1.481	8.3
September	1.343	0.062	0.001	0.070	0.003	0.058	0.157	1.694	9.5
October	7.543	0.683	0.211	0.670	0.027	0.185	0.484	9.803	54.8
Nov.-May	0.057	0.002	0.247	0.310	0.057	0.016	0.495	1.184	6.6
Total	12.957	0.785	0.470	1.118	0.118	0.272	2.154	17.874	100.0
(%)	72.5	4.4	2.6	6.3	0.7	1.5	12.1	100.0	

Note: see Table 13.

Table 15. Amounts of potassium in the litterfall from June, 1988 to May, 1989 in P2 ($\times$ 10^{-1}kg K/ha·yr)

	Leaves								
	Bp	Bl	Cl	Br	Bark	Seeds	Oth	Total	[%]
June	11.45	0.01	0.03	0.10	0.03	0.00	0.88	12.50	22.3
July	4.25	0.02	0.01	0.06	0.01	0.00	3.11	7.46	13.3
August	7.20	0.06	0.01	0.06	0.02	0.01	0.42	7.78	13.9
September	2.86	0.15	0.00	0.22	0.01	0.06	0.34	3.64	6.5
October	16.07	1.63	0.58	2.14	0.06	0.22	1.00	21.70	38.8
NOv.-May	0.09	0.00	0.67	0.99	0.12	0.02	1.01	2.90	5.2
Total	41.92	1.87	1.30	3.57	0.25	0.31	6.76	55.98	100.0
[%]	74.9	3.3	2.3	6.4	0.4	0.6	12.1	100.0	

Note: see Table 13.

Table 16. Amounts of calcium in the litterfall from June, 1988 to May, 1989 in P2 ($\times$ 10^{-1}kg Ca/ha·yr)

	Leaves								
	Bp	Bl	Cl	Br	Bark	Seeds	Oth	Total	[%]
June	8.62	0.08	0.04	0.53	0.03	0.00	2.26	11.56	4.9
July	3.20	0.14	0.02	0.30	0.01	0.00	3.62	7.29	3.1
August	5.42	0.43	0.01	0.29	0.02	0.02	0.81	7.00	3.0
September	24.65	1.08	0.06	1.18	0.01	0.09	0.77	27.84	11.8
October	138.49	11.93	8.65	11.25	0.06	0.19	2.15	172.72	73.0
Nov.-May	0.21	0.04	2.49	5.20	0.13	0.01	2.20	10.28	4.3
Total	180.59	13.70	11.27	18.75	0.26	0.31	11.81	236.69	100.0
[%]	76.3	5.8	4.8	7.9	0.1	0.1	5.0	100.0	

Note: see Table 13.

Table 17. Amounts of magnesium in the litterfall from June, 1988 to May, 1989 in P2 ($\times$ 10^{-1}kg Mg/ha·yr)

	Leaves								
	Bp	Bl	Cl	Br	Bark	Seeds	Oth	Total	[%]
June	3.09	0.01	0.00	0.05	0.02	0.00	0.55	3.72	8.7
July	1.15	0.02	0.00	0.03	0.00	0.00	0.46	1.66	3.9
August	1.94	0.07	0.00	0.03	0.01	0.01	0.17	2.23	5.2
September	4.40	0.18	0.00	0.11	0.00	0.02	0.18	4.89	11.4
October	24.73	2.04	0.36	1.07	0.03	0.09	0.57	28.89	67.6
Nov.-May	0.04	0.01	0.17	0.50	0.06	0.00	0.58	1.36	3.2
Total	35.35	2.33	0.53	1.79	0.12	0.12	2.51	42.75	100.0
[%]	82.7	5.5	1.2	4.2	0.3	0.3	5.9	100.0	

Note: see Table 13.

In the litterfall of P3, total N amounted to 28.4kg/ha·yr (Table 18), of this, 46.7% was from leaf litter of *A. sachalinensis*, 24.0% from leaf litter of broad-leaved species, 11.3% from other material litter, 8.4% from branch, 5.4% from leaf litter of *P. glehnii*, 2.6% from bark and 1.5% from seed. Total amount of P in the litterfall of P3 was 1.6kg/ha·yr (Table 19), and that of K was 4.3kg/ha·yr (Table 20), Ca was 29.8kg/ha·yr (Table 21), and Mg was 2.6kg/ha·yr (Table 22). Leaf litter of *A. sachalinensis* was the highest contributor to the total amount of nutrient elements; 52.4% of P, 53.8% of K, and 67.1% of Ca were obtained from this litter. As for Mg, the largest contributor was leaf litter of broad-leaved species, with a percentage of 43.2%, while the leaf litter of *A. sachalinensis* contributed 36.7%. The return of nutrients to the forest floor of P3 fluctuated seasonally being very low during June, July, August and September, and with a great peak appearing in October.

Table 18. Amounts of nitrogen in the litterfall from June, 1988 to May, 1989 in P3 ($\times$ 10^{-1}kg N/ha·yr)

	Leaves								
	As	Pg	Bl	Br	Bark	Seeds	Oth	Total	(%)
June	1.42	0.19	0.30	0.25	0.07	0.00	2.13	4.36	·1.5
July	1.10	0.10	0.83	0.16	0.22	0.00	3.44	5.85	2.1
August	2.62	0.32	1.21	0.18	0.29	0.00	2.90	7.52	2.7
September	1.57	0.46	1.30	0.16	0.56	0.34	1.59	5.98	2.1
October	73.33	6.45	60.76	6.23	1.32	2.44	9.14	159.67	56.3
Nov.-May	52.46	7.88	3.77	16.88	4.93	1.36	12.87	100.15	35.3
Total	132.50	15.40	68.17	23.86	7.39	4.14	32.07	283.53	100.0
(%)	46.7	5.4	24.0	8.4	2.6	1.5	11.3	100.0	

Note:
As=*A. sachalinensis*, Pg=*P. glehnii*, Bl=Broad-leaved species, Br=Branches, Oth=Other materials (cones, bud scales, flowers, insect feces & bodies, and unidentified materials).

Table 19. Amounts of phosphorus in the litterfall from June, 1988 to May, 1989 in P3 ($\times$ 10^{-1}kg P/ha·yr)

	Leaves								
	As	Pg	Bl	Br	Bark	Seeds	Oth	Total	(%)
June	0.100	0.012	0.012	0.011	0.005	0.000	0.121	0.261	1.7
July	0.077	0.006	0.033	0.007	0.016	0.000	0.158	0.297	1.9
August	0.185	0.020	0.048	0.008	0.021	0.000	0.163	0.445	2.8
September	0.080	0.022	0.052	0.007	0.041	0.037	0.092	0.331	2.1
October	3.731	0.316	2.430	0.277	0.095	0.273	0.547	7.669	49.0
Nov.-May	4.017	0.462	0.151	0.750	0.356	0.147	0.755	6.638	42.4
Total	8.190	0.838	2.726	1.060	0.534	0.457	1.836	15.641	100.0
(%)	52.4	5.4	17.4	6.8	3.4	2.9	11.7	100.0	

Note: see Table 18.

Table 20. Amounts of potassium in the litterfall from June, 1988 to May, 1989 in P3 ($\times 10^{-1}$kg K/ha·yr)

	Leaves								
	As	Pg	Bl	Br	Bark	Seeds	Oth	Total	〔%〕
June	0.41	0.05	0.04	0.03	0.01	0.00	0.25	0.79	1.9
July	0.31	0.03	0.10	0.02	0.04	0.00	0.90	1.40	3.3
August	0.75	0.09	0.14	0.02	0.05	0.00	0.32	1.37	3.2
September	0.22	0.05	0.15	0.02	0.09	0.05	0.22	0.80	1.9
October	10.29	0.73	7.09	0.69	0.21	0.33	1.68	21.02	49.5
Nov.-May	10.87	0.95	0.44	1.88	0.79	0.18	1.97	17.08	40.2
Total	22.85	1.90	7.96	2.66	1.19	0.56	5.34	42.46	100.0
〔%〕	53.8	4.5	18.7	6.3	2.8	1.3	12.6	100.0	

Note: see Table 18.

Table 21. Amounts of calcium in the litterfall from June, 1988 to May, 1989 in P3 ($\times 10^{-1}$kg Ca/ha·yr)

	Leaves								
	As	Pg	Bl	Br	Bark	Seeds	Oth	Total	〔%〕
June	0.69	0.11	0.25	0.15	0.02	0.00	0.55	1.77	0.6
July	0.54	0.06	0.69	0.10	0.08	0.00	1.20	2.67	0.9
August	1.28	0.18	1.01	0.11	0.10	0.00	0.76	3.44	1.2
September	3.28	0.64	1.08	0.10	0.20	0.01	0.40	5.71	1.9
October	153.09	9.01	50.63	3.76	0.47	0.09	2.19	219.24	73.7
Nov.-May	40.64	5.78	3.14	10.18	1.76	0.05	3.17	64.72	21.8
Total	199.52	15.78	56.80	14.40	2.63	0.15	8.27	297.55	100.0
〔%〕	67.1	5.3	19.1	4.8	0.9	0.1	2.8	100.0	

Note: see Table 18.

Table 22. Amounts of magnesium in the litterfall from June, 1988 to May, 1989 in P3 ($\times 10^{-1}$kg Mg/ha·yr)

	Leaves								
	As	Pg	Bl	Br	Bark	Seeds	Oth	Total	〔%〕
June	0.07	0.01	0.05	0.02	0.00	0.00	0.14	0.29	1.1
July	0.05	0.00	0.14	0.01	0.01	0.00	0.19	0.40	1.5
August	0.12	0.02	0.20	0.01	0.02	0.00	0.18	0.55	2.1
September	0.14	0.03	0.22	0.01	0.03	0.02	0.12	0.57	2.2
October	6.43	0.37	10.13	0.40	0.08	0.13	0.76	18.30	69.6
Nov.-May	2.84	0.32	0.63	1.07	0.29	0.07	0.97	6.19	23.5
Total	9.65	0.75	11.37	1.52	0.43	0.22	2.36	26.30	100.0
〔%〕	36.7	2.9	43.2	5.8	1.6	0.8	9.0	100.0	

Note: see Table 18.

Table 23 shows the total amount of N in the litterfall of P4. It was 28.3kg/ha·yr, obtained from leaf litter of *P. glehnii* (38.3%), leaves of broad-leaved species (20.5%), other material litter (18.3%), *A. sachalinensis* leaves (10.4%), bark (6.5%), branches (4.3%) and seed litter (1.7%). Total P in the litterfall of P4 amounted to 1.4kg/ha·yr (Table 24), while that of K was 4.0kg/ha·yr (Table 25), Ca 29.8kg/ha·yr (Table 26) and Mg 2.1kg/ha·yr (Table 27). In these total amounts of P, K and Ca, leaves of *P. glehnii* was the major distributor with contribution of 41.2% for P, 37.2% for K and 37.6% for Ca. As the concentration of Mg in broad-leaved species leaf litter was much higher than that in coniferous species, the contribution of broad-leaved species leaf litter (35.3%) to total Mg was higher than that of *P. glehnii* (26.0%). The seasonal changes in the amounts of nutrient returned to the forest floor of P4 were similar to those of P3.

The amounts of nutrient elements in the litterfall of the present study and several forest types in Japan are shown in Table 28. Ranges of nutrient amounts in the litterfall

Table 23. Amounts of nitrogen in the litterfall from June, 1988 to May, 1989 in P4 ($\times 10^{-1}$kg N/ha·yr)

	Leaves								
	Pg	As	Bl	Br	Bark	Seeds	Oth	Total	(%)
June	4.56	0.67	0.89	0.17	0.23	0.00	1.83	8.35	3.0
July	3.81	0.40	0.51	0.12	0.18	0.00	2.99	8.01	2.8
August	6.22	1.29	0.56	0.23	0.75	0.02	1.41	10.48	3.7
September	5.40	0.29	0.76	0.16	0.69	0.29	0.88	8.47	3.0
October	47.75	16.47	54.12	3.08	2.99	2.20	4.72	131.33	46.5
Nov.-May	40.43	10.23	1.07	8.29	13.55	2.27	39.98	115.82	41.0
Total	108.17	29.35	57.91	12.05	18.39	4.78	51.81	282,.46	100.0
(%)	38.3	10.4	20.5	4.3	6.5	1.7	18.3	100.0	

Note:
Pg=*P. glehnii*, As=*A. sachalinensis*, Bl=Broad-leaved species, Br=Branches, Oth=Other materials (cones, bud scales, flowers, insect feces & bodies, and unidentified materials).

Table 24. Amounts of phosphorus in the litterfall from June, 1988 to May, 1989 in P4 ($\times 10^{-1}$kg P/ha·yr)

	Leaves								
	Pg	As	Bl	Br	Bark	Seeds	Oth	Total	(%)
June	0.288	0.047	0.025	0.008	0.013	0.000	0.102	0.483	3.4
July	0.240	0.028	0.014	0.006	0.010	0.000	0.138	0.436	3.0
August	0.392	0.091	0.016	0.011	0.042	0.002	0.075	0.629	4.4
September	0.265	0.015	0.021	0.008	0.038	0.031	0.046	0.424	3.0
October	2.343	0.838	1.509	0.144	0.167	0.261	0.245	5.507	38.5
Nov.-May	2.372	0.784	0.030	0.387	0.756	0.296	2.216	6.841	47.8
Total	5,900	1.803	1.615	0.564	1.026	0.590	2.822	14.320	100.0
(%)	41.2	12.6	11.3	3.9	7.2	4.1	19.7	100.0	

Note: see Table 23.

of the DBF obtained in this study were 27.3-30.9kg/ha·yr for N, 0.8-1.8kg/ha·yr for P, 5.60 -5.63kg/ha·yr for K, 23.7-35.1kg/ha·yr for Ca and 2.4-4.3kg/ha·yr for Mg; and those of the ECF were 28.3-28.4kg/ha·yr for N, 1.4-1.6kg/ha·yr for P, 4.0-4.3kg/ha·yr for K, 29.76 -29.81kg/ha·yr for Ca and 2.1-2.6kg/ha·yr for Mg. The amounts of nutrient elements in two DBF of this study were lower than those obtained in a *Fagus crenata* forest in Yamagata, and much lower compared with those obtained in mixed deciduous broad-leaved forests in Kyoto. In the ECF, the amounts were also lower in comparison with data obtained in coniferous forests in Shiga and Shikoku.

4. Discussion

Litterfall supplied to the forest floor is composed of various fractions with different concentrations of nutrient elements (TSUTSUMI, 1977). In the litterfall of *Q. mongolica* var. *grosseserrata*, a high concentration of N, P and K was found in seed and insect feces fraction. Among fractions in the litterfall of *B. platyphylla* var. *japonica*, *A. sachalinesis* and *P. glehnii*, seed fraction had the high concentrations of N, P and K, and in the branch fraction, concentrations of the three elements were low. The low concentrations of N, P and K were also found in branch litter of evergreen broad-leaved forests in Kyushu (KATAGIRI and TSUTSUMI, 1978), and *Chamaecyparis obtusa* stands (TSUTSUMI et al., 1983).

The high concentration of Ca was found in bark litter of *Q. mongolica* var. *grosseserrata*, leaf litter of *B. platyphylla* var. *japonica*, *A. sachalinensis* and *P. glehnii*, while that of Mg was in insect feces litter of *Q. mongolica* var. *grosseserrata* forest, leaf litter of *B. platyphylla* var. *japonica*, seed litter of *A. sachalinensis* and bark litter of *P. glehnii*. Except in bark litter of *B. platyphylla* var. *japonica*, the concentrations of Ca and Mg were generally higher in bark litter than those in branch litter.

TSUTSUMI (1977) reported that the concentration of nutrient elements in leaf litter of evergreen coniferous forests was lower than that in leaf litter of deciduous broad-leaved forests. Except for the very low concentration of P in the leaf litter of *Q. mongolica* var. *grosseserrata*, generally the concentrations of nutrient elements in leaf litter of coniferous tree species were also lower than those for deciduous broad-leaved species.

Concentrations of N,P and K in leaf litter of evergreen broad-leaved species generally tended to be high in winter, spring, and decreased gradually toward the end of the growing season, while that of Ca was low in winter, increasing through the summer months toward autumn (KATAGIRI et al., 1978). UEDA and TSUTSUMI (1979) also reported that the high N concentration in leaf litter of *Chamaecyparis obtusa* in summer decreased gradually to the minimum in autumn when the amount of leaf litter reached the maximum. In this study, seasonal changes of N, P and K concentrations in the leaf litter of the dominant species were similar each other, with high rates occurring in summer, and low rates in autumn. A similar result was reported by LANG and FORMAN (1978) in a mature oak forest. On the other hand, the concentrations of Ca were low in summer, and reached the highest rates in autumn. In the leaf litter of deciduous broad-leaved tree species, the concentrations of Mg were high in summer, decreasing gradually in autumn and winter; while those in the leaf litter of coniferous species showed rather constant rates during summer, autumn and winter.

LIM and COUSENS (1986) reported that the concentrations of N, P, K and Mg in Scots pine needles generally decreased with the needle age toward minimum in dead needles. In a semi-arid savanna in Botswana, N and P were translocated from the deciduous leaves to perennial organs before the leaf abscission (TOLSMA et al., 1987). RAUNEMAA et al. (1983) also reported that the concentrations of P and K in needle litter of Scots pine were much lower than those for the growing needles. In this study, the N, P and K concentrations in the leaf litter of coniferous as well as of deciduous broad-leaved species were obviously lower than those in the growing leaves. The withdrawal of N and P from leaves to branches and stems before the leaf abscission was expected to be used for the growth of the trees during the next growing season (TSUTSUMI, 1987 ; HENDRICKSON 1987).

In the DBF, even though with different rates, amounts of nutrients returned to the forest floor fluctuated seasonally with a similar trend for all nutrients ; namely, the first peak occurred in early summer, June or July, and the fluctuations were marked by an outstanding peak in October. About 50-80% of each nutrient element input of *Q. mongolica* var. *grosseserrata* forest and about 40-70% of that of *B. platyphylla* var. *japonica* forest occurred in this month.

Seasonal trends of nutrient amounts returned to the floor of the ECF were also similar among the nutrients, though with differences in their rates. In the ECFs, the amounts were very low during summer, and marked peaks appeared in October, with about 50-70% of each element in *A. sachalinensis* forest, and 40-60% in *P. glehnii* forest, respectively.

KATAGIRI et al. (1978) pointed out that amounts of nutrient elements supplied to the forest floor fluctuated seasonally, depending on the rates of litterfall and the concentrations of nutrient elements in the litterfall. In this study, since the amounts of nutrients returned to the forest floor fluctuated seasonally in similar trends to the fluctuation of litterfall rates in all investigated forests, it is suggested that the seasonal changes of nutrient input were mainly controlled by the rates of the litterfall.

Although the amount of litterfall in *B. platyphylla* var. *japonica* forest was the lowest among the four forests, it has the highest amounts of N and P returned to its forest floor due to the high concentrations of N and P in the leaf litter of the dominant species. The lowest amount of P input to the floor of *Q. mongolica* var. *grosseserrata* forest, and that of K and Mg to the floor of *P. glehnii* forest was attributable to the lowest concentration of the nutrient elements in leaf litter of the dominant species in the forests. On occasion, the total amounts of nutrients returned to floor of the forests were probably more affected by concentrations of nutrient elements in the litterfall.

Total amounts of nutrient element input to the forest floor through litterfall of the DBF in this study were lower than results obtained in various forests in other regions of Japan, and the amounts indicated a similar trend in the ECF. Though the comparative data were limited, it can be considered that the amounts of nutrients in the litterfall increased gradually from the northern forests to the southern forests.

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References

1) DANIEL, T. W., Helms, J. A. and Baker, F. S. (1980). Principles of Silviculture. McGraw-Hill Inc., New York. 500 pp.

2) FURUNO, T. (1986). Investigation on the productivity of Japanese fir (*Abies firma*) and hemlock (*Tsuga sieboldi*) stands in Kyoto Uuiv. Forest in Wakayama (VIII) Litterfall and its fluctuation in the mixed fir and hemlock stand over thirteen years. Bull. Kyoto. Univ. For. 58: 35-50 (in Japanese with English resume).

3) HARDIWINOTO, S., YAJIMA,T. and IGARASHI, T. (1991). Stand structure and litter production of deciduous broad-leaved forests and evergreen coniferous forests in northern Hokkaido. Res. Bull. Exp. For. Hokkaido Univ. 48 (1): 115-155.

4) HENDRICKSON, O. (1987). Winter branch nutrients in northern conifers and harwoods. For. Sci. 33 (4): 1068-1074.

5) KATAGIRI, S. and TSUTSUMI, T. (1973). The relation between site condition and circulation of nutrients in forest ecosystem (I) Litterfall and nutrient contents. J. Jap. For. Soc. 55: 83-90.

6) KATAGIRI, S., MATSUTANI, Y. and TSUTSUMI, T. (1978). Mineral cycling. In: Biological production in a warm temperate evergreen oak forest of Japan, JIBP Synthesis 18: 276-285, eds. Kira, T., Ono, Y. and HosoKawa, T. Univ. of Tokyo Press, Japan.

7) KAWADA, H. and MARUYAMA, K. (1986). Effects of seed bearing of a natural beech (*Fagus crenata* BLUME) forest on amount of litterfall and its nutrients. Jap. J. Ecol. 36: 3-10 (in Japanese with English synopsis).

8) KAWAHARA, T. (1971). The return of nutrient with litterfall in the forest ecosystems (II) The amount of organic matter and nutrients. J. Jap. For. Soc. 53: 231-238 (in Japanese with English summary).

9) LANDSBERG, J. J. (1986). Physiological ecology of forest production. Academic Press, London. 198 pp.

10) LANG, G. E. and FORMAN, T. T. R. (1978). Detrital dynamics in a mature oak forest: Hutcheson Memorial Forest, New Jersey. Ecol. 59 (3): 580-595.

11) LIM, M. T. and COUSENS, J. E. (1986). The internal transfer of nutrients in a Scots pine stand (I) Biomass components, current growth and their nutrient content. Forestry 59 (1): 1-16.

12) MAGGS, J. (1985). Litterfall and retranslocation of nutrients in a refertilized and prescribed burned *Pinus eliotii* plantation. For. Ecol. Manage., 12: 253-268.

13) RAUNEMAA, T., HAUTOJARVI, A., SAMELA, J., ERKINJUNTTI, R., HARI, P. and KELLOMAKI, S. (1983). On seasonal variation in the nutrient cotent of needle litter from Scots pine. Can. J. For. Res. 13: 365-371.

14) TOLSMA, D. J., ERNST, W. H. O., VERWEIJ, R. A. and VOOIJS, R. (1987). Seasonal variation of nutrient concentrations in a semi-arid savanna ecosystem in Bostwana. J. Ecol. 75: 755-770.

15) TSUTSUMI, T. (1977). Storage and cyling of mineral nutrients. In: Primary productivity of Japanese forests, JIBP Synthdsis 16: 140-162, eds. SHIDEI, T. and KIRA, T. Univ. of Tokyo Press, Japan.

16) TSUTSUMI, T. (1987). The nitrogen cycle in a forest. Mem. Coll. Agric. Kyoto Univ. 130: 1-16.

17) TSUTSUMI, T., NISHITANI, Y. and KIRIMURA,Y. (1983). On the effects of soil fertility on the rate and nutrient element concentrations of litterfall. Jap. J. Ecol. 33 : 313-322.

18) TURNER, J., COLE, D. W. and GESSEL, S. P. (1976). Mineral nutrient accumulation and cycling in a stand of red alder (*Alnus rubra*). J. Ecol. 64 : 965-974.

19) UEDA, S. and TSUTSUMI, T. (1979). The amount of nutrient elements of litterfall in *Chamaecyparis obtusa* stands : Influences of fertilization and site condition. Bull. Kyoto. Univ. For. 51 : 84-95 (in Japanense with English resume).

20) UEDA, S. and TSUTSUMI, T. (1980). The amount of nutrient elements contained in litterfall of natural evergreen broad-leaved forest dominated by *Machilus thunbergii* SIEB. et ZUCC. Bull. Kyoto Univ. For. 52 : 32-43 (in Japanese with English resume).

摘　　要

本研究は北海道大学農学部附属雨龍地方演習林で行った。1988年5月に4つの方形調査区，P1，P2，P3，P4を設定した。相対胸高断面積と上木の相対密度によって，P1をミズナラ（*Quercus mongolica* var. *grosseserrata*）優占林分，P2をシラカンバ（*Betula platyphylla* var. *japonica*）優占林分，P3をトドマツ（*Abies sachalinensis*）優占林分，P4をアカエゾマツ（*Picea glehnii*）優占林分とした（HARDIWINOTO et al., 1991）。

リターフォールの養分を明らかにするためそれぞれ優占する4樹種を研究対象とし，1988年6月から1989年5月までに採集したリターフォールを葉，枝，樹皮，タネ，その他に分け，養分分析を行った。分析した養分は窒素，リン，カリウム，カルシウム，マグネシウムであった。

1．リターフォールの養分濃度

リターフォールは様々な材料から成っており，それぞれの材料の養分濃度は異なっていた。4樹種のリターで窒素，リン，カリウム濃度が高い値を示したのは種子であり，落枝の値は低かった。落葉の窒素，リン，カリウム濃度は4樹種とも類似した季節変化を示し，夏の落葉では最も高く，秋には非常に低くなった。これに反して，カルシウム濃度は秋の落葉では高い値が現れた。マグネシウム濃度はミズナラとシラカンバの夏の落葉で高く，秋と冬では低くなった。トドマツとアカエゾマツの落葉の場合にはあまり季節変化が認められなかった。優占4樹種の秋の落葉の窒素，リン，カリウム濃度は緑葉のものより低い値であった。

2．リターフォールの養分量

リターフォール量と養分濃度から求めた林床への養分の供結量の季節変化は，各養分とも同様の傾向を示した。供給養分量の季節変化はリターフォール量に大きく影響され，総養分量は養分濃度に影響された。落葉広葉樹林の総養分量の範囲は，窒素は27.3-30.9 kg/ha·yr，リンは0.8-1.8 kg/ha·yr，カルシウムは5.60-5.63 kg/ha·yr，カルシウムは23.7-35.1 kg/ha·yr，マグネシウムは2.4-4.3 kg/ha·yrであった。常緑針樹林の総養分量の範囲は，窒素は28.3-28.4 kg/ha·yr，リンは1.4-1.6 kg/ha·yr，カリウムは4.0-4.3 kg/ha·yr，カルシウムは29.76

-29.81 kg/ha･yr，マグネシウムは 2.1-2.6 kg/ha･yr であった。落葉広葉樹林の総養分量は山形のブナ林の総養分量より低く，京都の落葉広葉混交林の総養分量よりさらに低い値が得られた。常緑針葉樹林の総養分量も滋賀，四国における針葉樹林の総養分量より低い値が認められた。この結果から一般的に，北方の森林のリターに含まれる総養分量は南方の森林のものより低くなっていることが明らかになった。