沖縄本島北部における天然生常緑広葉樹林のリターフォール及びそれによる養分還元量について

Litterfall and the Nutrient Returns in Evergreen Broadleaved Forests in Northern Okinawa Island

Xiaoniu XU*, Tsutomu ENOKI***, Yoshihiro TOKASHIKI** and
Eiji HIRATA***

Key word : evergreen broadleaved forest; litter fall; nutrient return; seasonal variation; stand growth
キーワード：常緑広葉樹林，リターフォール，養分還元量，季節変化，林分生長量

Abstract

Litter fall and the nutrient returns in a forest were studied. The results obtained from five plots in natural evergreen broadleaved forests at Northern Okinawa Island in the period May 3, 1996 to May 1, 1998. Annual rates of total litter fall ranged from 7328 to 12700 kg ha^{-1} a^{-1} in the first year, and from 5577 to 8073 kg ha^{-1} a^{-1} in the second year, with great variation between the two years being related to the effects of the stronger typhoon No. 12 from August 11 to 12, 1996. And the foliage litter fall contributed the greatest amount, about 63.7 % averagely ranging from 54.6 to 78.8 % of the total litter mass, and peaked in March and August, respectively. The results from this investigation indicated that the annual mean litter fall rate was positively correlated with stem volumes, mean D.B.H. and mean height of the stand, however, was negatively correlated with the stand density and neither related to the stand basal area. The annual amounts of nutrient returned by litter fall in the sampling stands were, N from 61.3 to 128.2 kg ha^{-1} a^{-1}, P from 2.8 to 6.0 kg ha^{-1} a^{-1}, K from 20.8 to 44.5 kg ha^{-1} a^{-1}, Ca from 40.0 to 117.9 kg ha^{-1} a^{-1}, Mg from 13.3 to 28.3 kg ha^{-1} a^{-1}, S from 7.0 to 14.6 kg ha^{-1} a^{-1}, Na from 8.4 to 17.2 kg ha^{-1} a^{-1}, Al from 8.6 to 16.6 kg ha^{-1} a^{-1}, Fe from 0.6 to 1.4 kg ha^{-1} a^{-1}, and Mn from 2.6 to 5.4 kg ha^{-1} a^{-1}, respectively. However, the annual nutrient returns for microelements such as Cu, Zn, Mo, Co and B were very

*Graduate student, Course of Environmental Sciences and Technology, Graduate School of Agriculture, University of the Ryukyus
**Department of Environmental Sciences and Technology, Faculty of Agriculture, University of the Ryukyus
***Experimental Forest, Faculty of Agriculture, University of the Ryukyus
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little. Within the annual cycle, monthly nutrient fall was the most in August and the least in January, and the former was 12～31 times more than the latter. Spring and summer (from March to August) was most important, accounting for over 70 % of the nutrients.

Introduction

Organic matter production and its decomposition are two essential processes in the ecosystem which bring out an equilibrium between the input and output of materials. These two processes, the building up of organic matter and decomposition, occur simultaneously in the forest ecosystem. Litter serves an important role in operating these ecological functions since a major part of the organic matter synthesized during photosynthesis is returned continually to the upper layer of soil in the form of litter. Thus, the quantity and quality of litter are major pathway in the transfer of nutrients to forest soils (Johansson, 1995). Seasonal variation in litter production and litter nutrient concentration affect plant nutrient status and within stand nutrient cycling (Sharma and Paude, 1989; Prescott *et al.*, 1992). In the present investigation an attempt has been made to ascertain (1) the litter fall from trees by main species throughout an annual cycle and (2) the quantitative transfer of nutrients to soil by the various plant parts of various species in order to clear up the characteristics of nutrient cycle in the natural evergreen broadleaved forest ecosystem.

Study Site and Climate

The investigation was carried out in the experimental field, University of the Ryukyus at Yona, northern Okinawa Island. The latitude and longitude of the site are 26° 45′ 30″ N and 128° 05 ′ E, respectively. The climatic conditions in the period of study are showed in Table 1. The study area is covered with evergreen broadleaved forests. A general description

Table 1 Climatic condition at Yona

Climatic factor		1995	1996	1997	1968-1990
	Annual mean	22.3	22.4	22.0	21.6
Air temperature (℃)	Monthly mean maximum	34.6	34.9	33.6	32.1
	Monthly mean minimum	7.3	7.2	7.8	10.8
Annual precipatation (mm)		2243	2197	2120	2653
Wind velocity (ms^{-1})	Annual mean	1.7	1.7	1.7	-
	Maximum	19.7	31.7	37.1	-

* Measured at Yona university forest, University of the Ryukyus.

of the forest was given by Hirata (1994).

Methods

1. The growth of the sampling stands

Five plots of 20×20 m were set up in the forests in the beginning of May, 1996. All trees D.B.H. more than 3.0 cm were numbered, and species were identified. Tree height was also measured. The standing crop data at the beginning of the study are demonstrated in Table 2. The tree numbers, height, and species of the understory were also investigated by one subplot of 5×5 m in the centre over each of plots.

Table 2 General description of the sampling stands studied

Plot No.	P-1	P-2	P-3	P-4	P-5
Altitude (m)	310	310	290	290	295
Direction/Inclination(degree)	S40E/26	N50E/30	N30E/23	N60W/27	N40W/27
soil type	Yc	Yc	Yc	Yc	Yc
Mean D.B.H. (cm)	8.8	8.4	8.8	11.4	9.5
Mean height (m)	6.3	6.0	6.6	7.1	6.4
Stand density (No. ha^{-1})	5175	6050	6250	3850	5550
Stand volume (m^3 ha^{-1})	309.3	265.8	274.7	322.6	310.8
Stand basal area (m^2 ha^{-1})	55.3	55.0	56.0	59.8	62.0
Stand age (yr)	60	60	60	60	60
Vegetation					
Numbers of species	32	34	36	33	34
Main species					

P-1: *Castanopsis sieboldii; Distylium racemusum; Meliosma squamulosa; Eurya japonica; Elaeocarpus japonicus; Schima wallichii ssp. liukiuensis; Quercus miyagii; Rapanea neriifolia; Persea thunbergii; Ilex goshiensis.*

P-2: *Castanopsis sieboldii; Distylium racemusum; Rapanea neriifolia; Meliosma squamulosa; Daphniphyllum glaucescens ssp. teijsmannii; Eurya japonica; Ternstroemia japonica; Ilex liukiuensis; Elaeocarpus japonicus; Persea thunbergii; Schima wallichii ssp. liukiuensis.*

P-3: *Castanopsis sieboldii; Distylium racemusum; Schima wallichii ssp. liukiuensis; Daphniphyllum glaucescens ssp. teijsmannii; Rapanea neriifolia; Meliosma squamulosa; Ternstroemia japonica; Symplocos prunifolia.*

P-4: *Castanopsis sieboldii; Distylium racemusum; Schima wallichii ssp. liukiuensis; Ilex liukiuensis; Rapanea neriifolia; Eurya japonica; Cinnamomum doederleinii; Cleyera japonica; Daphniphyllum glaucescens ssp. teijsmannii; Elaeocarpus japonicus.*

P-5: *Castanopsis sieboldii; Distylium racemusum; Schima wallichii ssp. liukiuensis; Rapanea neriifolia; Ternstroemia japonica; Ilex goshiensis, Eurya japonica; Cleyera japonica; Cinnamomum doederleinii.*

2. Litter fall measurement

Litter fall was measured using five litter traps placed regularly in each plot beginning in May 3, 1996 (Fig. 1). These traps had a circular opening of 1.2 m^2. The traps consisted of a sheet of nylon muslin attached to a plastic hoop by means of a drawstring. The hoop was positioned 1.2 m above the soil surface with plastic stakes firmly driven into the ground to hold the traps. The mesh of the muslin is about 1 mm square. Contents of the traps were collected at monthly intervals. The materials collected were brought to the laboratory and sorted into categories such as foliage, small branches (the diameter at base is equal to or below 1.0 cm), medium branches (the diameter at base is over 1.0 cm and below 5.0 cm), sexual organs and miscellaneous. In addition, foliage litter was separated again by species such as *C. sieboldii, S. wallichii ssp. liukiuensis, Q. miyagii* and the others. The sorted material was oven dried to a constant weight at 70℃, weighed and then

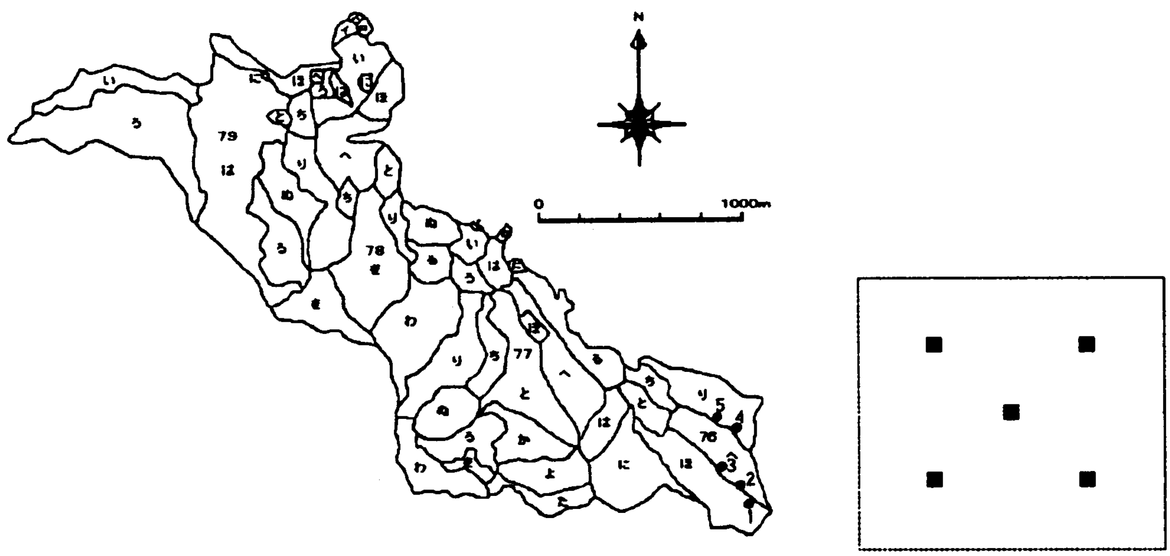

Fig. 1 Location of the studying site and position of the litter traps fixed

milled for chemical analysis, respectively.

3. Chemical analysis

All components from the litter in the study were analyzed for C, N, P, K, Ca, Mg, Na, S, Al, Fe, Mn, Cu, Zn, Mo, B and Co. The contents of total carbon and nitrogen were determined by dry combustion with a C-N Corder (Yanaco, MT-500). The subsamples were wet digested with HNO_3-$HClO_4$ reagent, and the digests analyzed for the contents of P, K, Ca, Mg, Na, S, Al, Fe, Mn, Cu, Zn, Mo, B and Co by Inductively Coupled Plasma Spectrometer (Shimadzu, ICPS-2000).

Results and Discussion

1. Total litter fall

The mean annual total litter fall mass in the sampling stands during the period May 3, 1996 to May 1, 1998, was 8850 kg (D.W.) · ha^{-1} in plot 1, 7116 kg (D.W.) · ha^{-1} in plot 2, 7538 kg (D.W.) · ha^{-1} in plot 3, 9238 kg (D.W.) · ha^{-1} in plot 4, 7307 kg (D.W.) · ha^{-1} in plot 5 (Table 3). This is beyond the range of litter fall reported for subtropical evergreen broadleaved forests (Bray and Gorham, 1964), and high compared with the mean value for evergreen broadleaved forests in Japan (Saito, 1982; Tsutsumi, 1989). Several comparable data in Okinawa to this study are, 9.75 Mg ha^{-1} a^{-1} in *Macaranga fanarius* stand (Abe, 1977), 7.7 ~ 10.8 Mg ha^{-1} a^{-1} in the mangrove stands (Hardwinoto *et al.*, 1989), 10.5 Mg ha^{-1} a^{-1} in the *Rhaphiolepis indica* stand and 5.88 Mg ha^{-1} a^{-1} in *Castanopsis sieboldii* stand (Tokuyama *et al.*, 1996).

Table 3 The annual litter fall mass (kg (D.W.) ha^{-1})

Component		Foliage litter fall				Branch and bark fall	Sexual organ falll	Miscellaneous	Total
		C. seiboldii	*S. wallichii*	Others	Total				
P-1	I	2916	140	2540	5596	3474	57	500	9627
	%	30.3	1.5	26.4	58.1	36.1	0.6	5.2	100
	II	3039	202	1869	5110	2360	47	556	8073
	%	37.6	2.5	23.2	63.3	29.2	0.6	6.9	100
	Mean	2977	171	2205	5353	2917	52	528	8850
	%	33.6	1.9	24.9	60.5	33.0	0.6	6.0	100
P-2	I	2264	353	2093	4710	2070	52	496	7328
	%	30.9	4.8	28.6	64.3	28.3	0.7	6.8	100
	II	2169	323	1906	4398	1774	130	603	6905
	%	31.4	4.7	27.6	63.7	25.7	1.9	8.7	100
	Mean	2216	338	2000	4554	1922	91	549	7116
	%	31.1	4.7	28.1	64.0	27.0	1.3	7.7	100
P-3	I	1718	723	2876	5317	3109	195	364	8985
	%	19.1	8.0	32.0	59.2	34.6	2.2	4.1	100
	II	1827	784	2192	4803	672	143	473	6091
	%	30.0	12.9	36.0	78.8	11.0	2.4	7.8	100
	Mean	1773	753	2534	5060	1891	169	418	7538
	%	23.5	10.0	33.6	67.1	25.1	2.2	5.6	100
P-4	I	3015	929	2991	6935	4957	197	611	12700
	%	23.7	7.3	23.6	54.6	39.0	1.6	4.8	100
	II	2222	624	1608	4454	505	219	599	5777
	%	38.5	10.8	27.8	77.1	8.7	3.8	10.4	100
	Mean	2618	777	2299	5694	2731	208	605	9238
	%	28.3	8.4	24.9	61.6	29.6	2.3	6.5	100
P-5	I	2578	470	2561	5609	2806	80	543	9038
	%	28.5	5.2	28.3	62.1	31.0	0.9	6.0	100
	II	1893	104	1952	3949	1026	28	574	5577
	%	33.9	1.9	35.0	70.8	18.4	0.5	10.3	100
	Mean	2235	287	2257	4779	1915	54	559	7307
	%	30.6	3.9	30.9	65.4	26.2	0.7	7.6	100

Note: I - the period May 3, 1996 to May 3, 1997; II - the period May 3, 1997 to May 1, 1998.

A breakdown of total litter fall by plant tissues showed that foliage litter fall contributed the greatest amount, about 63.7 % ranging from 54.6 % to 78.8 % of the total litter mass averagely. The branch and bark litter was 28.2 % from 26.2 % to 33.0 %, sexual organs and miscellaneous fraction accounted for 1.4 % and 6.7 %, respectively. The miscellaneous fraction mainly consisted of fragment of leaf tissues and insect feces.

There was marked variation in the rate of litter fall from year to year. The total litter fall along with the foliage litter fall were very high in the first year because there came the stronger typhoon No. 12 (the maximum wind velocity reached 50 m · s^{-1} from August 11 to 12, 1996) which caused a lot of green leaves and living branches and twigs to be fallen. And this could be the most important reason for large decrease in litter fall mass in the second year, particularly in plot 4 and 5, in which the amounts of litter fall in the first year were 2.2 times and 1.6 times the amounts in the second year, respectively. Saito (1981) showed that there was a wide range in the rate of litter fall from year to year, and that the maximum rate was 2.6 times the minimum rate in the stand.

2. Seasonal variations in litter fall

The fall rate of total litter increased abruptly in March forming a peak, then decreased and increased again forming the other peak in August because of the effects of the typhoon, after that decreased rapidly to the minimum value in January (Fig. 2-A).

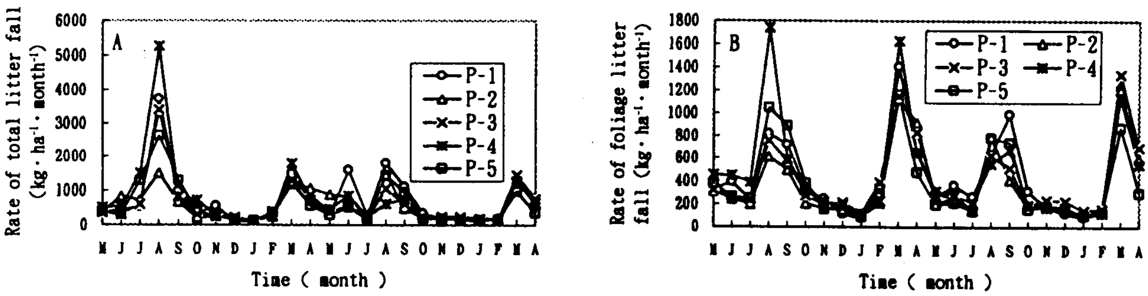

Fig. 2 Seasonal variations in total litter fall and foliage litter fall

The fall rates of foliage litter in the sampling stands also reached two peaks, one of which was in March, and the other was in August or September (Fig. 2-B). Moreover, the patterns of foliage litter fall from the main species such as *C. sieboldii* (Fig. 3-A), *S.wallichii ssp. liukiuensis* (Fig. 3-B), *Q. miyagii* (Fig. 3-C) and the other species (Fig. 3-D) showed the same to the total foliage litter fall. The amounts of foliage litter fall in March were the greatest in all sampling stands, and contributed 25.1 % of the annual foliage litter fall in the first year and 23.8 % in the second year in plot 1, 23.8 % and 23.7 % in plot 2, 21.6 % and 26.3 % in plot 3, 23.5 % and 22.1 % in plot 4, 20.8 % and 17.2 % in plot 5, respectively.

For branch and bark fall there is a main peak in August and a small peak in June (Fig. 4-A). The peak fall of branches in August was caused by the typhoon. The mean amounts of branch and bark fall from five sampling stands in this period were, 2671 kg (D.W.) · ha^{-1} in 1996 and 1057 kg (D.W.) · ha^{-1} in 1997 in plot 1, 662 and 552 kg (D.W.) · ha^{-1} in plot 2, 2430 and 344 kg (D.W.) · ha^{-1} in plot 3, 3168 and 22 kg (D.W.) · ha^{-1} in plot 4, and 1341 and 557 kg (D.W.) · ha^{-1} in plot 5, respectively.

The fall rates of sexual organs also show annual cycles, but have irregular seasonal

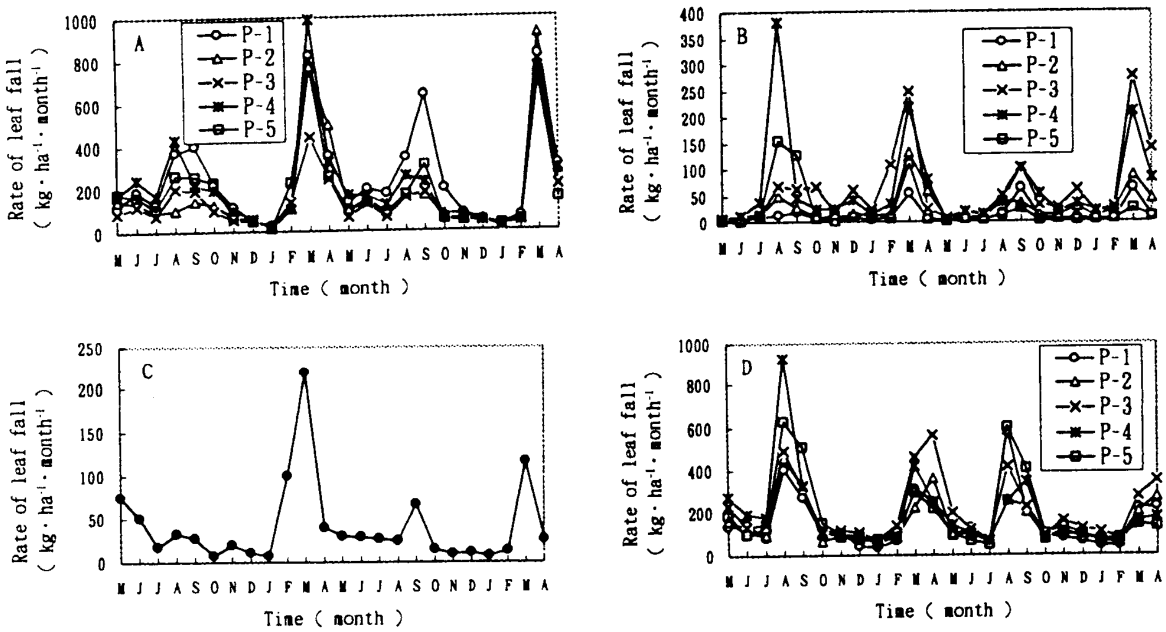

Fig. 3 Seasonal variations in the fall rates of foliage from different species
A : *C. sieboldii*, B : *S. wallichii ssp. liukiuensis*,
C : *Q. miyagii* (appeared only in plot 1) D : the others

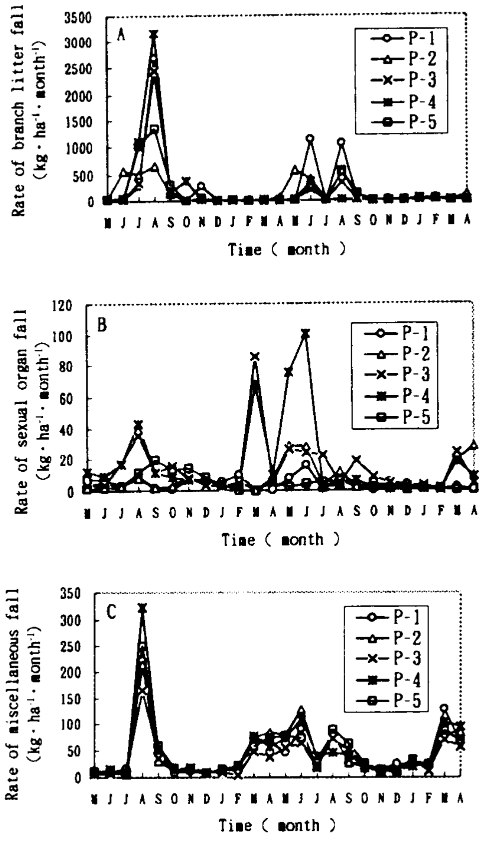

Fig. 4 Seasonal variations in the fall rates of branches and barks (A), sexual organs (B) and miscellaneous materials (C)

trends throughout the year (Fig. 4-B). In plot 3 and 4, the fall rates of sexual organs were greater than that in the other plots because of the differences in species composition. And in these two plots, there were many more sexual organs fallen from *S. wallichii ssp. liukiuensis* than that in the other plots.

The fall rates of miscellaneous were higher in August, and less from October to February (Fig. 4-C). The amount of miscellaneous litter was the most in August, 1996 during the studying period because a stronger typhoon came then.

3. Relationship between litter fall and stand structure

There were large differences between the sampling stands for the amounts of litter fall per year (Table 3). These differences might be related to the stand structure. Fig. 5 shows the relationships between the growth factors of stands and the mean rates of annual litter fall in the studying period. It indicated that the rates of annual total litter fall along with the foliage litter fall was closely correlated with mean D.B.H., mean height, stand density, and stem volume of the stand, but could not be related to stand basal area. Gresham (1982) is one of the few studies to have established a relationship between basal area and litter fall which was independent of age. Miller (1986) produced a regression for leaf fall on volume growth covering a range of species, and Tsutsumi *et al.* (1983) reported that the rate of annual litter fall was associated with the stem volume increment in *Chamaecyparis obtusa* stands and with the mean height of the stand in natural deciduous broadleaved forest. On the other hand, however, many studies, for example, those of Radwan *et al.* (1984), Stohlgrem (1988) and Miller *et al.* (1996) found no relationship with site index, stand age, basal area or bole volume. These results demonstrate that many fac-

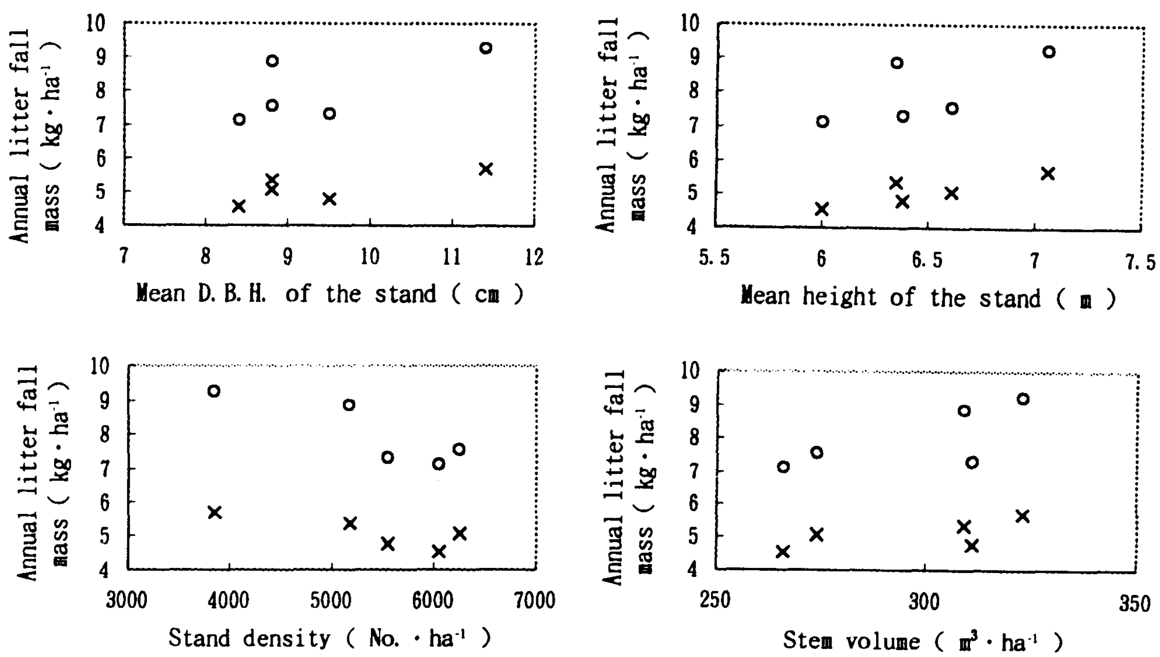

Fig. 5 The relationships between the stand growth and the fall rates of mean annual total litter and foliage litter
○ total litter × foliage litter

tors other than stand structure, such as soil fertility (Miller *et al.*, 1976; Satoo, 1979; Miller *et al.*, 1996), climatic conditions (Saito, 1981), floristic composition (Gosz *et al.*, 1972) and so on, may be responsible for production of litter. Moreover, typhoons are frequent in Summer and Autumn at this area, which may cause rather premature fall of many types of plant parts, and large variations in the pattern of litter fall from year to year are to be expected. Therefore, these findings suggest that more critical studies have to be carried out to make these points clear up.

4. Nutrient fall

Litter fall occurred throughout the year, but there were seasonal peaks for many types of plant tissue. Since the quantity and order of element abundance varied with different

Table 4 The weighted mean annual nutrient concentrations of litter fall in evergreen broadleaved forests

	Component	N	P	K	Ca	Mg	Na	S	Al	Mn	Fe	Cu	Zn	Mo	Co	B
Plot-1	Leaves															
	Leaves (1)	1.22	0.056	0.440	0.681	0.257	1.564	1.169	1.393	0.442	0.109	7.2	9.5	1.5	1.0	170.0
	Leaves (2)	1.19	0.067	0.590	0.737	0.224	2.335	1.335	1.521	0.696	0.131	10.9	11.6	4.4	2.8	106.5
	Leaves (3)	1.13	0.057	0.390	0.727	0.174	1.180	1.157	0.601	0.558	0.121	8.9	9.5	1.4	1.0	54.9
	Leaves (4)	1.34	0.060	0.526	0.797	0.260	1.783	1.458	2.411	0.488	0.096	4.7	8.8	2.5	1.5	159.8
	Branches	0.60	0.021	0.119	1.339	0.196	0.844	0.963	0.605	0.327	0.094	3.7	28.0	0.5	0.3	43.6
	Sexual organs	1.30	0.052	0.644	0.577	0.167	1.228	1.194	0.825	0.243	0.054	1.5	11.3	3.2	0.3	91.0
	Miscellaneous	1.35	0.088	0.383	0.886	0.236	1.099	1.459	1.350	0.458	0.239	7.2	16.6	2.1	1.3	57.7
Plot-2	Leaves															
	Leaves (1)	1.13	0.061	0.414	0.722	0.257	1.641	1.135	1.379	0.428	0.124	9.5	11.5	1.7	1.2	133.6
	Leaves (2)	1.18	0.074	0.604	0.750	0.228	2.245	1.349	1.552	0.793	0.140	12.0	11.4	4.8	3.1	78.5
	Leaves (4)	1.17	0.049	0.479	0.710	0.243	1.659	1.301	2.041	0.420	0.092	13.8	7.1	3.8	2.5	141.1
	Branches	0.70	0.030	0.181	1.383	0.214	0.911	1.150	0.997	0.333	0.185	4.5	27.5	0.7	0.3	151.8
	Sexual organs	1.30	0.053	0.683	0.558	0.184	1.360	1.210	0.793	0.244	0.049	1.9	12.6	1.8	0.3	101.0
	Miscellaneous	1.31	0.089	0.380	0.893	0.236	1.079	1.463	1.366	0.458	0.249	7.2	16.6	2.5	1.6	52.6
Plot-3	Leaves															
	Leaves (1)	1.21	0.056	0.417	0.689	0.257	1.578	1.149	1.397	0.393	0.108	6.6	8.8	2.1	1.4	144.8
	Leaves (2)	1.19	0.058	0.537	0.759	0.235	2.347	1.351	1.528	0.636	0.119	10.5	9.3	5.9	3.8	83.3
	Leaves (4)	1.18	0.054	0.492	0.726	0.241	1.707	1.300	2.127	0.419	0.106	5.6	8.1	3.5	2.3	133.9
	Branches	0.61	0.020	0.107	1.374	0.197	0.843	0.963	0.629	0.342	0.097	3.5	27.8	0.2	0.2	59.7
	Sexual organs	1.80	0.116	0.675	0.566	0.208	1.448	1.430	2.119	0.299	0.134	10.6	12.0	0.5	0.1	99.5
	Miscellaneous	1.32	0.082	0.359	0.880	0.239	1.079	1.405	1.314	0.455	0.241	6.5	16.4	2.8	1.8	65.2
Plot-4	Leaves															
	Leaves (1)	1.20	0.058	0.395	0.659	0.259	1.682	1.221	1.453	0.451	0.120	8.3	8.8	1.3	0.8	124.3
	Leaves (2)	1.32	0.069	0.712	0.668	0.200	1.778	1.220	1.279	0.966	0.110	7.1	6.6	3.2	2.0	58.4
	Leaves (4)	1.24	0.057	0.507	0.686	0.233	1.759	1.302	2.116	0.448	0.082	4.4	7.6	2.7	1.7	113.7
	Branches	0.63	0.025	0.149	1.300	0.199	0.873	0.960	0.699	0.307	0.093	2.9	26.2	0.1	0.1	82.0
	Sexual organs	1.50	0.105	0.677	0.546	0.198	1.324	1.347	1.853	0.274	0.120	8.9	10.8	0.6	0.1	98.5
	Miscellaneous	1.38	0.083	0.336	0.956	0.240	1.071	1.451	1.446	0.425	0.254	5.8	15.7	1.9	1.2	51.9
Plot-5	Leaves															
	Leaves (1)	1.13	0.054	0.364	0.688	0.255	1.546	1.209	1.417	0.488	0.114	7.9	9.4	1.5	1.0	150.5
	Leaves (2)	1.31	0.068	0.720	0.624	0.193	1.945	1.233	1.223	0.877	0.104	6.4	5.8	2.9	1.9	104.8
	Leaves (4)	1.20	0.052	0.499	0.728	0.243	1.856	1.365	2.087	0.492	0.075	4.3	8.0	3.3	2.1	163.3
	Branches	0.65	0.022	0.131	1.424	0.207	0.948	1.037	0.827	0.330	0.098	3.3	28.3	0.2	0.1	118.6
	Sexual organs	1.39	0.057	0.729	0.503	0.211	1.487	1.162	0.761	0.223	0.040	1.6	9.7	1.4	0.2	199.7
	Miscellaneou	1.38	0.079	0.325	0.962	0.240	1.092	1.456	1.473	0.427	0.252	5.7	15.6	2.5	1.6	63.2

Note: ① from N to Mg: %; ② from Na to Fe: $mg \cdot g^{-1}$; ③from Cu to B: $mg \cdot kg^{-1}$; ④ dry weight basis. Leaves (1), (2), (3) & (4) stand for leaves of *C. sieboldii*, *S. wallichii ssp. liukiuensis*, *Q. miyagii* and the other species, respectively.

species and tissues, the nutrient content of litter also varied throughout the year. As already reported, N and P concentrations were usually high in Spring and decreased gradually to the minimum in Autumn, when the amount of leaf fall reached the maximum (Katagiri and Tsutsumi, 1973; Tsutsumi *et al.*, 1983). In the case of subtropical evergreen broadleaved forests in Okinawa, N concentrations of foliage litter was high from August to January, and low from February to May. P and K concentrations were different, and high from September to October, low from January to March. Ca and Mg concentrations were high in spring months and low from July to November. The weighted annual mean nutrient concentrations of litter fall was estimated for each element, and the result is given in Table 4. Moreover, there were differences in concentrations within litter components. In general, the tissues such as medium branches and barks had lower concentrations of nutrients, especially N, P and K. Leaf, flower and miscellaneous materials had higher concentrations of nutrients. Also, there existed differences in nutrient concentrations among the sampling plots and among the foliage litter from different species (Table 4). This may be

Table 5-1 The annual amounts of nutrient return from litter fall under evergreen broadleaved forests

Plot No.	Period	Component	Amount	N	P	K	Ca	Mg	Na	S	Al	Mn	Fe	Cu	Zn	Mo	Co	B
		Leaves	5596	70.04	3.24	26.18	40.69	13.88	9.05	7.12	9.30	2.67	0.60	37.0	52.1	10.5	6.7	852.8
		Branches	3474	20.85	0.73	4.12	46.52	6.80	2.93	3.34	2.10	1.14	0.33	13.0	97.4	1.6	1.2	151.5
	I	Sexual organs	57	0.74	0.03	0.37	0.33	0.10	0.07	0.07	0.05	0.01	0.003	0.1	0.6	0.2	0.01	5.2
		Miscellaneous	500	6.77	0.44	1.92	4.43	1.18	0.55	0.73	0.67	0.23	0.12	3.6	8.3	1.0	0.7	28.9
Plot-1		Total	9627	98.40	4.44	32.58	91.97	21.96	12.60	11.26	12.13	4.05	1.04	53.6	158.4	13.3	8.6	1038.4
		Leaves	5110	63.77	2.96	23.87	36.80	12.79	8.33	6.43	8.37	2.42	0.55	34.4	47.9	9.5	6.1	797.4
		Branches	2360	14.16	0.49	2.80	31.60	4.62	1.99	2.27	1.43	0.77	0.22	8.8	66.2	1.1	0.8	102.9
	II	Sexual organs	47	0.61	0.02	0.30	0.27	0.08	0.06	0.06	0.04	0.01	0.003	0.1	0.5	0.1	0.01	4.3
		Miscellaneous	556	7.53	0.49	2.13	4.93	1.31	0.61	0.81	0.75	0.25	0.13	4.0	9.2	1.2	0.7	32.1
		Total	8073	86.09	3.97	29.11	73.61	18.80	10 99	9.57	10.59	3.46	0.90	47.3	123.8	11.9	7.7	936.8
		Leaves	4710	54.06	2.66	21.53	33.87	11.69	7.98	5.77	7.94	2.13	0.52	54.6	44.8	13.4	0.9	625.4
		Branches	2072	14.50	0.62	3.75	28.65	4.43	1.89	2.38	2.07	0.69	0.38	9.4	57.0	1.5	0.7	314.6
	I	Sexual organs	52	0.67	0.03	0.35	0.29	0.10	0.07	0.06	0.04	0.01	0.003	0.1	0.7	0.1	0.01	5.2
		Miscellaneous	496	6.51	0.44	1.88	4.43	1.17	0.54	0.73	0.68	0.23	0.12	3.6	8.2	1.2	0.8	26.1
Plot-2		Total	7330	75.74	3.75	27.52	67.24	17.39	10.47	8.94	10.73	3.06	1.03	67.7	110.7	16.2	10.5	971.3
		Leaves	4398	50.46	2.49	20.06	31.63	10.93	7.45	5.38	7.38	1.98	0.49	50.8	42.0	12.4	8.3	584.0
		Branches	1774	12.42	0.53	3.21	24.52	3.79	1.62	2.04	1.77	0.59	0.33	8.1	48.8	1.3	0.6	269.3
	II	Sexual organs	130	1.69	0.07	0.89	0.73	0.24	0.18	0.16	0.10	0.03	0.01	0.2	1.6	0.2	0.03	13.1
		Miscellaneous	603	7.90	0.54	2.29	5.38	1.42	0.65	0.88	0.82	0.28	0.15	4.3	10.0	1.5	1.0	31.7
		Total	6905	72.47	3.62	26.45	62.27	16.38	9.89	8.46	10.08	2.88	0.97	63.4	102.5	15.4	9.9	898.1
		Leaves	5316	63.31	2.93	25.20	38.20	13.04	9.32	6.69	9.62	2.34	0.58	35.2	45.2	18.0	11.8	697.0
		Branches	3109	18.96	0.63	3.34	42.73	6.12	2.62	3.00	1.96	1.06	0.30	11.0	86.3	0.7	0.5	185.5
	I	Sexual organs	195	3.52	0.23	1.32	1.10	0.41	0.28	0.28	0.41	0.06	0.03	2.1	2.3	0.1	0.01	19.4
		Miscellaneous	364	4.79	0.30	1.31	3.20	0.87	0.39	0.51	0.48	0.17	0.09	2.4	6.0	1.0	0.6	23.7
Plot-3		Total	8985	90.58	4.09	31.16	85.23	20.44	12.61	10.48	12.47	3.63	0.99	50.6	139.8	19.7	12.9	922.7
		Leaves	4803	57.29	2.66	22.61	34.45	11.82	8.46	6.01	8.41	2.14	0.52	32.7	41.2	16.1	10.6	623.3
		Branches	672	4.10	0.14	0.72	9.24	1.32	0.57	0.65	0.42	0.23	0.07	2.4	18.7	0.1	0.1	40.1
	II	Sexual organs	143	2.58	0.17	0.97	0.81	0.30	0.21	0.21	0.30	0.04	0.02	1.5	1.7	0.1	0.01	14.3
		Miscellaneous	473	6.23	0.39	1.70	4.16	1.13	0.51	0.66	0.62	0.22	0.11	3.1	7.7	1.3	0.8	30.8
		Total	6091	70.20	3.35	26.00	48.66	14.57	9.75	7.53	9.76	2.62	0.72	39.7	69.3	17.6	11.5	708.5

Note: ① litter fall mass: $kg \cdot ha^{-1}$, dry weight; ② from N to Fe: $kg \cdot ha^{-1}$; ③ from Cu to B: $g \cdot ha^{-1}$.
I — period May 3, 1996 to May 3, 1997; II — period May 3, 1997 to May 1, 1998.

Table 5-2 The annual amounts of nutrient return from litter fall under evergreen broadleaved forests

Plot No.	Period	Component	Amount	N	P	K	Ca	Mg	Na	S	Al	Mn	Fe	Cu	Zn	Mo	Co	B
		Leaves	6935	85.41	4.10	33.70	46.58	16.63	11.98	8.71	11.90	3.60	0.71	44.9	55.4	15.0	9.6	769.0
		Branches	4957	31.35	1.22	7.40	64.46	9.85	4.33	4.76	3.46	1.52	0.46	14.4	130.0	0.4	0.3	406.3
	I	Sexual organs	197	2.96	0.21	1.33	1.08	0.39	0.26	0.27	0.37	0.05	0.02	1.7	2.1	0.1	0.02	19.4
		Miscellaneous	611	8.44	0.51	2.05	5.84	1.47	0.65	0.89	0.88	0.26	0.16	3.5	9.6	1.2	0.8	31.7
Plot-4		Total	12700	128.16	6.03	44.49	117.95	28.34	17.23	14.62	16.61	5.44	1.35	64.5	197.1	16.7	10.6	1226.5
		Leaves	4454	54.74	2.64	21.38	29.83	10.75	7.67	5.57	7.43	2.33	0.47	30.0	35.9	9.3	5.9	495.4
		Branches	505	3.19	0.12	0.75	6.56	1.00	0.44	0.48	0.35	0.16	0.05	1.5	13.2	0.0	0.03	41.4
	II	Sexual organs	220	3.30	0.23	1.49	1.20	0.44	0.29	0.30	0.41	0.06	0.03	1.9	2.4	0.1	0.02	21.6
		Miscellaneous	599	8.27	0.50	2.01	5.72	1.44	0.64	0.87	0.87	0.25	0.15	3.5	9.4	1.2	0.7	31.1
		Total	5777	69.50	3.49	25.63	43.32	13.62	9.05	7.22	9.05	2.80	0.69	36.9	60.9	10.6	6.7	589.5
		Leaves	5609	66.19	3.03	25.54	39.30	13.72	9.65	7.19	9.57	2.93	0.53	34.5	47.6	13.7	8.8	855.3
		Branches	2805	18.20	0.62	3.68	39.95	5.80	2.66	2.91	2.32	0.92	0.27	9.3	79.4	0.4	0.3	332.8
	I	Sexual organs	80	1.12	0.05	0.58	0.40	0.17	0.12	0.09	0.06	0.02	0.003	0.1	0.8	0.1	0.02	16.0
		Miscellaneous	543	7.49	0.43	1.77	5.23	1.31	0.59	0.79	0.80	0.23	0.14	3.1	8.5	1.4	0.9	34.4
Plot-5		Total	9037	92.99	4.13	31.57	84.88	20.99	13.02	10.98	12.75	4.11	0.95	47.0	136.2	15.7	10.0	1238.5
		Leaves	3948	46.31	2.10	17.37	27.87	9.78	6.75	5.08	6.88	1.98	0.37	24.1	34.1	9.6	6.1	614.4
		Branches	1026	6.65	0.23	1.35	14.61	2.12	0.97	1.06	0.85	0.34	0.10	3.4	29.0	0.2	0.1	121.7
	II	Sexual organs	28	0.39	0.02	0.21	0.14	0.06	0.04	0.03	0.02	0.01	0.001	0.0	0.3	0.0	0.01	5.6
		Miscellaneous	574	7.91	0.46	1.87	5.52	1.38	0.63	0.84	0.85	0.25	0.14	3.3	8.9	1.5	0.9	36.3
		Total	5577	61.27	2.80	20.79	48.15	13.34	8.39	7.01	8.60	2.57	0.62	30.8	72.3	11.3	7.2	778.0

Note: ① litter fall mass: kg · ha^{-1}, dry weight; ② from N to Fe: kg · ha^{-1}; ③ from Cu to B: g · ha^{-1}.
I — period May 3, 1996 to May 3, 1997; II — period May 3, 1997 to May 1, 1998.

correlated with soil properties (Tsutsumi *et al.*, 1983) and the eco-physiological characteristics of species.

The amounts of nutrients returned to the soil through litter fall is given in Table 5. The amount of N contained in the total litter fall of evergreen broadleaved forests in Okinawa ranged from 75.7 to 128.2 kg ha^{-1} a^{-1} (1st year), and from 61.3 to 86.1 kg ha^{-1} a^{-1} (2nd year) in the sampling plots. The inventory of the other nutrient elements were, P from 3.8 to 6.0 kg ha^{-1} a^{-1} (1st year) and from 2.8 to 4.0 (2nd year), K from 27.5 to 44.5 kg ha^{-1} a^{-1} (1st year) and from 20.8 to 29.1 kg ha^{-1} a^{-1} (2nd year), Ca from 67.2 to 118.0 kg ha^{-1} a^{-1} (1st year) and from 43.3 to 73.6 kg ha^{-1} a^{-1} (2nd year), Mg from 20.4 to 28.3 kg ha^{-1} a^{-1} (1st year) and from 13.3 to 18.8 kg ha^{-1} a^{-1} (2nd year), S from 8.9 to 14.6 kg ha^{-1} a^{-1} (1st year) and from 7.0 to 9.6 kg ha^{-1} a^{-1} (2nd year), Na from 10.5 to 17.2 kg ha^{-1} a^{-1} (1st year) and from 8.4 to 11.0 kg ha^{-1} a^{-1} (2nd year), Al from 10.7 to 16.6 kg ha^{-1} a^{-1} (1st year) and from 8.6 to 10.6 kg ha^{-1} a^{-1} (2nd year), Fe from 1.0 to 1.3 kg ha^{-1} a^{-1} (1st year) and from 0.6 to 1.0 kg ha^{-1} a^{-1} (2nd year), Mn from 3.1 to 5.4 kg ha^{-1} a^{-1} (1st year) and 2.6 to 3.5 kg ha^{-1} a^{-1} (2nd year), respectively.

Monthly nutrient fall was the most in August, and the least in January. The amount of nutrients from litter fall in August is 12~31 times more than that in January. The most important season was spring and summer (from March to August), supplying over 70 % of the nutrients annually

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沖縄本島北部における天然生常緑広葉樹林のリターフォール及びそれによる養分還元量について

徐　小牛*・榎木　勉***・渡嘉敷　義浩**・平田　永二***

要　旨

沖縄本島北部の琉球大学農学部附属与那演習林で，天然生常緑広葉樹林のリターフォール量とそれによる養分還元量の季節変化を，1996年５月から1998年２月までの２年間にわたって調べた結果，以下のことが明らかになった。

年間のリターフォール量は，一年目には 7328～12700 kg ha^{-1}，二年目に5577～8073 kg ha^{-1}で，年間の差が大きかった。これは，台風の影響によるものと思われる。リターの内訳をみると，落葉量，落枝量，生殖器官の落下量およびその他の平均割合が，それぞれ63.7%，28.2%，1.4%，6.7%となった。リターフォールの年間量の平均値と林分構造との関係をみると，平均直径，平均樹高，ヘクタール当たり本数及び材積とは比較的高い相関が認められたが，ヘクタール当たり断面積との間には相関がなかった。

リターフォールによる年間養分還元量は，窒素 61.3～128.2 kg ha^{-1}，リン2.8～6.0 kg ha^{-1}，カリウム 20.8～44.5 kg ha^{-1}，カルシウム 40.0～117.9 kgha^{-1}，マグネシウム 13.3～28.3 kg ha^{-1}，いおう 7.0～14.6 kg ha^{-1}，ナトリウム 8.4～17.2 kg ha^{-1}，アルミニウム 8.6～16.6 kg ha^{-1}，マンガン 2.6～5.4 kg ha^{-1}，鉄 0.6～1.4 kg ha^{-1}であった。しかし，微量元素の銅，亜鉛，モリブデン，コバルト及びホウ素の還元量は極めて少なかった。また，養分還元量は８月に最も多く，年間量の19.3%～38.3%を占め，１月には最も少なくて，僅か年間量の 1.2%～2.0%であった。養分還元量は３月から８月までの間に集中し，この６か月間で年間総量の70%以上を占めた。

リターフォールの養分含有率はプロット間に違いがみられたが，これは立地条件の違いのほかに樹種構成の変化とも関係しているものと思われる。

＊琉球大学大学院農学研究科生産環境学専攻
＊＊琉球大学農学部生産環境学科
＊＊＊琉球大学農学部附属演習林