沖縄本島北部における天然生常緑広葉樹林の A_0 層の有機物及び養分集積量について

Characteristics of Nutrient Accumulation in Forest Floor under Evergreen Broadleaved Forests in Okinawa Island

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

Key words : evergreen broadleaved forest; forest floor; organic carbon; nutrient accumulation; soil type
キーワード：常緑広葉樹林，A_0層，有機炭素，養分集積量，土壌型

Abstract

The accumulations of organic matter and nutrients in forest floor under natural evergreen broadleaved forests were studied at 22 sites in experimental field, University of the Ryukyus at Yona, Okinawa. The organic matter and total carbon accumulation in forest floor amounted 12.0 Mg(D.W.)·ha^{-1} and 6.1 Mg·ha^{-1}, respectively. The inventory of the other nutrient elements were, N 84.1～258.5 kg·ha^{-1}, P 1.7～10.4 kg·ha^{-1}, K 9.0～37.0 kg·ha^{-1}, Ca 60.0～230.3 kg·ha^{-1}, Mg 15.0～29.7 kg·ha^{-1}, Na 1.9～15.9 kg·ha^{-1}, S 8.7～20.1 kg·ha^{-1}, Al 17.8～132.5 kg·ha^{-1}, Fe 5.3～77.0 kg·ha^{-1}, and Mn 2.0～16.9 kg·ha^{-1}, respectively. The amounts of other microelements such as Cu, Zn, Mo, Co and B accumulating in forest floor were very rather low. The nutrient accumulation in forest floor was, generally, significantly related to the forest floor mass, particularly for C, Mg, S and Ca ($P < 0.001$, t-test), and for N ($P < 0.01$), and for P, K, Zn, Na and Al ($P < 0.05$). Within 15 nutrient elements, Al and Fe were primarily accumulated in the F.H. layer, N, Mg and Mn were, however, mainly accumulated in the foliage litter. The patterns of organic matter and nutrient accumulations in the forest floor evidently differed with soil types.

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*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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Introduction

Sustainable forest management mainly depends on the maintenance and, ideally, improvement of the capacity of forest soil to supply nutrients to growing trees. Soil fertility is, however, coupled to soil organic matter and to forest floor (Gholz and Fisher, 1982 ; Meyer *et al.*, 1994). The forest floor is undoubtedly the most distinctive feature of a forest soil (Pritchett and Fisher, 1987). And the forest floor does not only physically insulate surfaces from extremes in temperature and moisture, offer mechanic protection from raindrop impact and erosional forces, and improve water infiltration rate (wooldridge, 1970), but also provides a source of food and habitat for many microflora and fauna which activity is essential to the maintenance of nutrient cycles, particularly those of nitrogen, phosphorus, and sulfur (Pritchett and Fisher, 1987). Therefore, it is very important to study the property of forest floor. This study presents the nutrient accumulation pattern of forest floor under evergreen broadleaved forests in Okinawa Island.

Material and Methods

The study was carried out in the university forest, Faculty of Agriculture, University of the Ryukyus at Yona, located in the northern part of Okinawa Island, Japan (Fig. 1). The study site and the stand structures of 22 sampling stands, in which there were 6 stands growing on dry yellow soil and the other 16 stands growing on weakly dried yellow soil, were descripted by Xu *et al.* (1997).

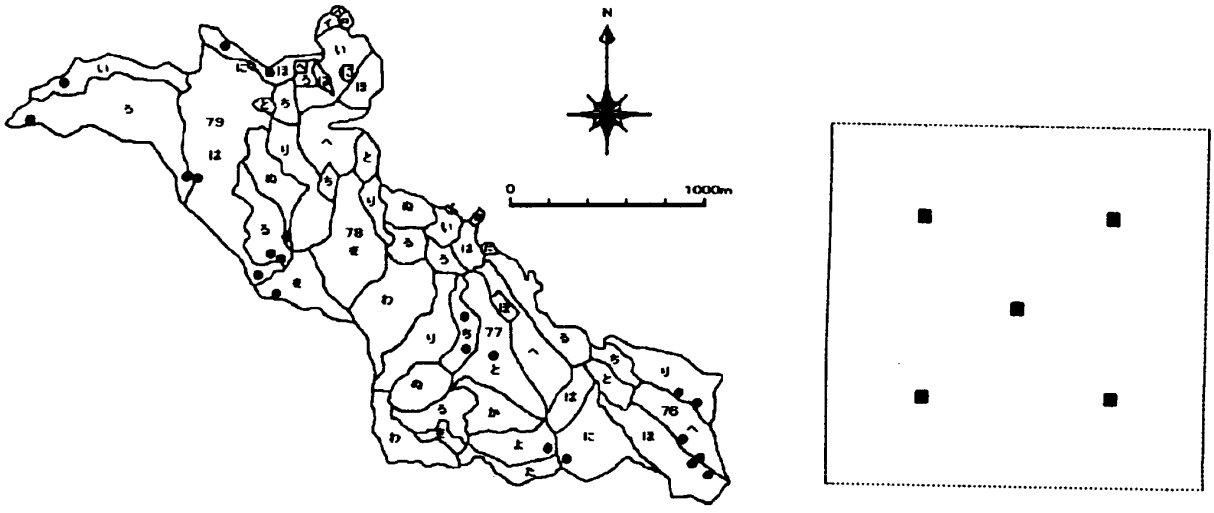

Fig. 1 Location of the sampling plots and position of litter collection

The forest floor mass was estimated by means of 5 quadrates of 1×1 m regularly distributed within each plot (Xu *et al.*, 1997). All materials such as foliage, branch and wood litter and F.H. layer in each quadrate were collected, respectively, and their fresh weights were measured in the field. Samples of various components within each plot were returned to laboratory, oven-dried at 70℃ for one week, weighed and then, milled for chemical analysis,

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

Results

1. Nutrient concentrations

The mean nutrient concentrations in various components in forest floor under the natural evergreen broadleaved forests are showed in Table 1. Within the components, contents of total organic carbon were high in foliage, branch and wood litter, and was relatively low in F.H. layer. The concentrations of various nutrient elements were higher in foliage litter and F.H. layer, and relatively lower in branch and wood litter except for Ca. Also, foliage litter had high concentrations for Ca, Mg, Na and Mn, but had low concentrations for P, K, Al and Fe in comparison with F.H. layer.

Table 1 The mean nutrient concentrations of various components in forest floor under evergreen broadleaved forests (C, N, P, K, Ca, Mg : %; Na, S, Al, Mn, Fe: $mg \cdot g^{-1}$; Cu, Zn, Mo, Co, B : $mg \cdot kg^{-1}$)

Soil type	Component	C	N	C/N	P	K	Ca	Mg	Na	S	Al	Mn	Fe	Cu	Zn	Mo	Co	B
Y_B	Leaf litter	54.5	1.25	43.3	0.030	0.172	0.978	0.249	0.616	1.225	2.963	0.642	0.851	10.6	24.2	14.4	0.9	24.3
	Branch litter	58.0	0.74	78.6	0.017	0.088	1.124	0.145	0.412	0.784	0.760	0.209	0.330	11.7	21.0	5.1	0.7	17.4
	Wood litter	55.1	0.50	114.3	0.011	0.070	0.709	0.125	0.582	0.615	0.938	0.122	0.336	5.2	10.1	2.3	0.5	28.2
	F.H. layer	41.2	1.63	26.2	0.038	0.221	0.531	0.148	0.346	1.419	13.101	0.441	6.195	5.4	21.4	7.7	2.6	5.6
	Mean	51.6	1.13	57.4	0.026	0.152	0.841	0.180	0.494	1.089	4.977	0.413	2.134	8.5	20.4	8.7	1.3	18.3
Y_C	Leaf litter	53.5	1.34	42.0	0.052	0.218	1.058	0.253	0.789	1.294	3.072	0.753	0.997	19.7	19.9	16.2	8.2	21.9
	Branch litter	51.0	0.74	72.7	0.045	0.127	1.152	0.160	0.643	0.960	0.730	0.304	0.266	23.0	20.9	16.2	8.2	14.9
	Wood litter	45.0	0.42	101.7	0.025	0.082	0.958	0.101	0.524	0.646	1.078	0.191	0.454	11.3	13.9	12.6	6.5	14.8
	F.H. layer	42.8	1.36	32.3	0.061	0.273	0.755	0.195	0.721	1.472	13.759	0.604	6.787	20.8	25.7	24.4	9.5	19.5
	Mean	48.7	1.00	60.6	0.046	0.178	0.990	0.185	0.681	1.107	4.376	0.493	1.945	18.6	19.9	17.1	8.1	18.2

*: weighted arithmetic mean

Soil types have some impacts on the nutrient concentrations of forest floor materials. On dry yellow soil (granular and nutty structure type, Y_B), the mean concentrations of N, Al, Fe and Zn were higher, thereas the other nutrient elements were lower than those on weakly dried yellow soil (Y_C).

2. Nutrient accumulation

The mean accumulation of respective elements in forest floor are showed in Table 2. The organic carbon accumulation amounted, averagely, 6.1 $Mg \cdot ha^{-1}$ ranging from 4.2 to 8.8 $Mg \cdot ha^{-1}$, and those of the other nutrient elements were, 125.5 $kg \cdot ha^{-1}$ from 84.1 to 258.5 $kg \cdot ha^{-1}$ for N, 4.9 $kg \cdot ha^{-1}$ from 1.7 to 10.4 $kg \cdot ha^{-1}$ for P, 20.8 $kg \cdot ha^{-1}$ from 9.0 to 37.0 $kg \cdot ha^{-1}$ for K, 116.0 $kg \cdot ha^{-1}$ from 60.0 to 230.3 $kg \cdot ha^{-1}$ for Ca, 22.5 $kg \cdot ha^{-1}$ from 15.0 to 29.7 $kg \cdot ha^{-1}$ for Mg, 7.7 $kg \cdot ha^{-1}$ from 1.9 to 15.9 $kg \cdot ha^{-1}$ for Na, 13.4 $kg \cdot ha^{-1}$ from 8.7 to 20.1 $kg \cdot ha^{-1}$ for S, 53.5 $kg \cdot ha^{-1}$ from 17.8 to 132.5 $kg \cdot ha^{-1}$ for Al, 5.7 $kg \cdot ha^{-1}$ from 2.0 to 16.9 $kg \cdot ha^{-1}$ for Mn, and 23.3 $kg \cdot ha^{-1}$ from 5.3 to 77.0 $kg \cdot ha^{-1}$ for Fe.

The amounts of the other microelements accumulating in forest floor under evergreen broadleaved forests, were very low, 247.3 g · ha^{-1} for Zn, 227.7 g · ha^{-1} for B, 188.6 g · ha^{-1} for Cu, 178.2 g · ha^{-1} for Mo, and 74.1 g · ha^{-1} for Co.

Table 2 The mean accumulations of nutrients in forest floor under evergreen broadleaved foerests

Soil type	Component	Organic matter	C	N	P	K	Ca	Mg	Na	S	Al	Mn	Fe	Cu	Zn	Mo	Co	B
Y_C	Leaf litter	3.8	2.1	51.3	2.0	8.4	40.6	9.7	3.0	5.0	11.8	2.9	3.8	75.7	76.3	62.0	31.5	84.1
	Branch litter	2.4	1.2	17.8	1.1	3.0	27.6	3.8	1.5	2.3	1.8	0.7	0.6	55.2	50.2	38.8	19.8	35.7
	Wood litter	2.7	1.3	11.8	0.9	2.8	28.3	3.2	1.7	1.9	3.1	0.5	1.3	37.7	43.8	42.0	22.5	46.9
	F.H. layer	2.3	1.0	30.8	1.4	6.2	17.1	4.4	1.6	3.3	31.1	1.4	15.3	46.9	58.2	55.0	21.6	44.1
	Total	11.2	5.6	111.7	5.3	20.4	113.6	21.1	7.9	12.5	47.7	5.5	21.1	215.5	228.5	197.9	95.3	210.8
Y_B	Leaf litter	5.6	3.1	70.4	1.7	9.7	55.1	14.1	3.5	6.9	16.7	3.6	4.8	59.9	136.2	81.0	4.9	136.9
	Branch litter	3.3	1.9	24.0	0.5	2.8	35.8	4.8	1.6	2.4	2.7	0.7	1.2	27.2	66.0	12.9	2.1	67.0
	Wood litter	1.7	0.9	8.5	0.2	1.2	12.2	2.2	1.0	1.1	1.6	0.2	0.6	9.0	17.4	4.0	0.9	48.6
	F.H. layer	3.6	1.5	59.3	1.4	8.1	19.3	5.4	1.3	5.2	47.7	1.6	22.6	20.8	77.9	28.0	9.6	20.4
	Total	14.2	7.4	162.3	3.8	21.8	122.5	26.4	7.3	15.6	68.7	6.1	29.2	116.9	297.5	125.9	17.5	272.9

① organic matter & C: Mg · ha^{-1}; ② Cu, Zn, Mo. Co & B: g · ha^{-1}; ③ the others: kg · ha^{-1}

Nutrient accumulation in forest floor under subtropical evergreen broadleaved forest by weight was in order N > Ca > Al > Fe > Mg > K > S > Na > Mn > P >> Zn > B > Cu > Mo > Co on Y_B, and was in order Ca > N > Al > Mg > Fe > K > S > Na > Mn > P >> Zn > Cu > B > Mo > Co on Y_C. Al and Fe were primarily accumulated in F.H. layer, and contributed 66.0 % and 73.8 % of the total amount respectively, the other nutrient elements, particularly for N, Mg and Mn were, however, mainly accumulated in foliage litter and contributed 45.0, 48.2 and 54.3 % of the total amount, respectively.

Discussion

Forest floor under subtropical evergreen broadleaved forests was poorly developed (Xu *et al.*, 1997) and forest floor mass was closely related to soil types. The mean total carbon accumulation in forest floor on dry yellow soil (Y_B) amounted 7.4 Mg · ha^{-1}, 32.1% greater than that on weakly dried yellow soil (Y_C), on which amounted 5.6 Mg · ha^{-1}. Within 15 nutrient elements measured, the accumulations of N, Mg, Al, S and Zn in forest floor on Y_B were significantly higher than those on Y_C ($P < 0.05$ t-test), and those of P, K, Ca, Na, Fe, Mn, B, Cu and Mo had not great differences between Y_B and Y_C. The accumulation of Co in forest floor on Y_B was, however, apparently lower than that on Y_C ($P < 0.05$; Fig. 2).

The pattern of nutrient accumulation in forest floor on Y_B has some differences from Y_C. The total accumulation of nutrients on Y_B was, averagely, 464.5 kg · ha^{-1}, in which foliage, branches, wood litter and F.H. layer contributed 40.2 %, 16.6 %, 6.2 % and 37.0 %, respectively. On Y_C, the total amount was 367.7 kg · ha^{-1}, and foliage, branches, wood litter and F.H. layer contributed 37.7 %, 16.5 %, 15.1 % and 30.7 %, respectively. These two nutrient accumulation patterns in forest floor under subtropical evergreen broadleaved forests are very different from those under tropical rain forests and temperate birch stands. In the tropical rain forests at Pasoh, Malaysia, the nutrient accumulation in wood litter covered 82.4 % of the total in forest floor materials (average value from 7 plots, Yoda and Kira, 1982), and in the temperate birch stands in Russia, the nutrients in forest floor material was mainly

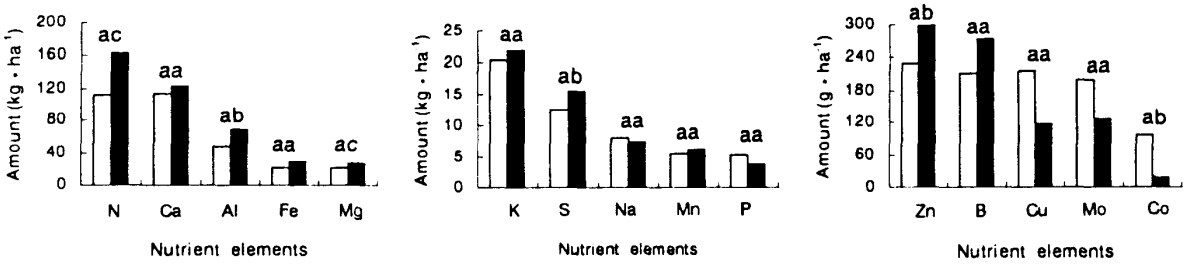

Fig. 2 The relationships between nutrient accumulations and soil types

□ Y_C ■ Y_B

ab and ac : significant at the $P<0.05$, and 0.01 levels of probability, respectively ; aa : nonsignificant t-test.

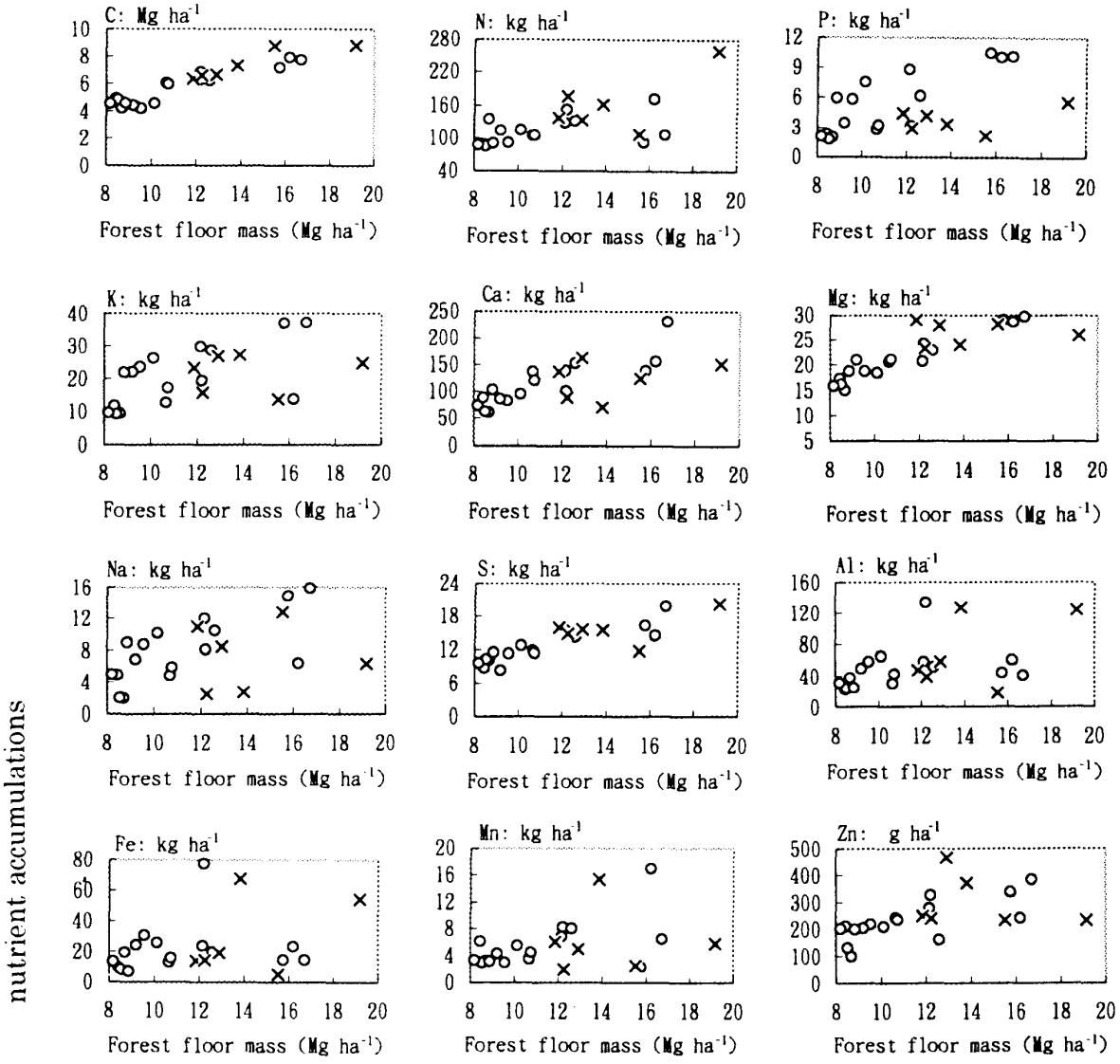

Fig. 3 The relationships between forest floor mass and nutrient accumulations

○ soil type Y_C × soil type Y_B

Table 3 Summary of the regression results of the relationship between nutrient accumulation and forest floor mass

Nutrien elements	Y_B (n=6)		Y_C (n=16)		Total (n=22)	
	r	t	r	t	r	t
C	0.91*	4.39	0.94***	10.31	0.94***	12.30
N	0.66	1.76	0.47	1.99	0.63**	3.60
P	0.40	0.87	0.82**	5.36	0.53*	2.83
K	0.05	0.10	0.64**	3.12	0.51*	2.64
Ca	0.29	0.61	0.86***	6.31	0.71***	4.45
Mg	-0.03	0.06	0.96***	12.83	0.85***	7.15
Na	0.07	0.14	0.70**	3.67	0.45*	2.26
S	0.50	1.15	0.89***	7.30	0.85***	7.12
Al	0.49	1.12	0.31	1.22	0.43*	2.16
Fe	0.45	1.01	0.16	0.61	0.30	1.43
Mn	0.00	0.00	0.56*	2.53	0.38	1.83
Zn	-0.31	0.65	0.73**	4.00	0.51*	2.66

*, **, ***: significant at the $P < 0.05$, 0.01, and 0.001 levels of probability by t-test, respectively.

accumulated in the F.H. layer which covered 94.4 % of the total nutrient accumulation (Remezov and Pogrebnyak, 1969).

Specifically, nutrient accumulation in F.H. layer on Y_B amounted 171.9 kg · ha^{-1}, 52.4 % higher than that on Y_C. And the organic matter and carbon accumulation in F.H. layer on Y_B were 3.6 Mg · ha^{-1} and 1.5 Mg · ha^{-1}, respectively, higher than those on Y_C (2.3 Mg · ha^{-1} and 1.0 Mg · ha^{-1}). This demomstrated that F.H. layer was developed better on Y_B than on Y_C.

Despite the great differences in nutrient concentrations among the various components, the accumulations of most nutrient elements in forest floor are primarily dependent on the forest floor mass. And it is confirmed that the relationships between forest floor mass and nutrient amounts are statistically significant by t-test (Table 3 and Fig. 3). Generally, the accumulations of organic carbon, N, Ca, Mg, S, P, K, Na, Al and Zn were significantly related to the forest floor mass (Fig. 3). However, on Y_B, the organic carbon accumulation is the only one which is significantly related to the forest floor mass. And on Y_C, the accumulations of organic carbon, Ca, Mg, S, P, K, Na, Zn, and Mn were significantly related to the forest floor mass, respectively (Table 3).

Forest floor characteristics under evergreen broadleaved forests in this study compares with the other stands (Table 4). The mean forest floor mass (12.0 Mg · ha^{-1}) and Mg accumulation (22.5 kg · ha^{-1}) were the lowest. However, N accumulation was 125.5 kg · ha^{-1}, higher than evergreen broadleaved forest at Kumamoto (113.5 kgg · ha^{-1}; Kawahara, 1971) and lower than the other stands (Katagiri and Tsutsumi, 1978; Remezov and Pogrebnyak, 1969; Yoda and Kira, 1982). P and Ca accumulations were 4.9 kg · ha^{-1} and 116.0 kg · ha^{-1}, respectively, higher than tropical rain forest (4.5 kg · ha^{-1} and 71.1 kg · ha^{-1}) at Pasoh, Malaysia (Yoda and Kira, 1982), lower than the other stands. K accumulation was 20.8 kg · ha^{-1}, lower than the deciduous broadleaved stand at Kyoto (36.8 kg · ha^{-1}, Katagiri and Tsutsumi, 1978) and higher than the other stands. Therefore, the nutrient accumulation in forest floor under subtropical evergreen broadleaved forests was, generally, neither rich nor

poor. However, the accumulation of P on Y_B was rather low. This maybe become one of the factors limiting tree growth.

Table 4 The weights and properties of forest floor layer under some forest types

Forest type	Forest floor mass	Organic carbon	Nutrient elements ($kg \cdot ha^{-1}$)				
	($Mg \cdot ha^{-1}$)	($Mg \cdot ha^{-1}$)	N	P	K	Ca	Mg
Evergreen broadleaved forest, Okinawa Y_B	14.2	7.4	162.3	3.8	21.8	122.5	26.4
Y_C	11.2	5.6	111.7	5.3	20.4	113.6	21.1
Mean	12.0	6.1	125.5	4.9	20.8	116.0	22.5
Birch stand-old growth, Russia[1)]	18.1	-	245.0	23.6	19.8	224.4	52.5
Deciduous broadleaved forest, Kyoto[2)]	15.5	7.6	260.0	12.0	36.8	151.2	25.7
Evergreen broadleaved forest, Kumamoto[3)]	12.6	-	113.5	5.3	10.5	172.8	25.8
Tropical rain forest at Pasoh, Malaysia[4)]	49.4	24.5	237.3	4.5	4.9	71.1	23.9

1. Remezov & Pogrebnyak, 1969; 2. Katagiri & Tsutsumi, 1978; 3. Kawahara, 1971; 4. Yoda & Kira, 1982.

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沖縄本島北部における天然生常緑広葉樹林の A_0 層の有機物及び養分集積量について

徐　小牛*・渡嘉敷義浩**・榎木　勉***・平田永二***

要　旨

沖縄本島北部の天然生常緑広葉樹林における地表（A_0層）に集積する有機物および養分について、22 プロットでリターを採取（1996年 7 月～ 8 月）して測定した結果、およそ次のことが明らかとなった。

1．A_0層の有機物集積量は、12 Mg ha^{-1}で、その内、有機炭素が 6 Mg ha^{-1}を占めた。

2．A_0層中の養分集積量は，全窒素が 84.1 ～ 258.5 kg ha^{-1}, リンが 1.7～10.4 kg ha^{-1}, カリウムが 9.0 ～ 37.0 kg ha^{-1}, カルシウムが 60.0 ～ 230.3 kg ha^{-1}, マグネシウムが 15.0 ～ 29.7 kg ha^{-1}, ナトリウムが 1.9 ～ 15.9 kg ha^{-1}, いおうが 8.78 ～ 20.1 kg ha^{-1}, アルミニウムが17.8～132.5 kg ha^{-1}, 鉄が 5.3 ～ 77.0 kg ha^{-1}, マンガンが 2.0 ～ 16.9 kg ha^{-1}で、微量元素の銅、亜鉛、ほう素、モリブデン、コバルトは極めて少ないことがわかった。

3．各元素の集積量と有機物集積量の関係について検討した結果、炭素、窒素、リン、カリウム、カルシウム、マグネシウム、いおう、ナトリウム、アルミニウムおよび亜鉛の10元素に 0.51～0.94 のかなり高い相関（ $P < 0.05$, t-test ）が認められた。

4．土壌型は、有機物集積量及び養分集積量への影響が大きく、弱乾性黄色土（Y_C）よりも、乾性黄色土（Y_B）の方が多くなることが明らかとなった。

＊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