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Comparison of the Pine Litter Decompositon and Microbial Population Change at Youngwal with Those at Sinlim

Chang, Nam-Kee and Yong-Woo Leem
(Dept. of Biology, College of Education, Seoul National University)

寧越과 新林에 있어서 소나무落葉의 分解와 Microbial Population의 消長 比較

張 楠 基 · 林 溶 雨
(서울大學校 師範大學 生物敎育科)

ABSTRACT

The decomposition of litters of *Pinus densiflora* and the growth of microbial populations in a calcareous region, Youngwal were compared with those in a noncalcareous region, Sinlim. The decay rate of litter in *Pinus densiflora* in Youngwal was 0.128 and that in Sinlim was 0.096. The differences in the populations of soil bacteria and total microorganisms between the two regions were significant at the 5% level, but that of fungi and actinomycetes was not at that level. The differences in the content of calcium and pH value of soil between the two regions were significant at the 1% level. The excessive content of calcium became to increase pH value, in turn the high pH decreased the content of available phosphorus in soil. The vertical distribution of the content of available phosphorus was consistent with that of the populations of fungi and actinomycetes in Youngwal.

INTRODUCTION

In the ecosystem, the solar energy is transformed to chemical energy by photosynthesis of green plant. Through the food web the energy is transmitted to consumers and decomposers. Meanwhile the organic matters return to the inorganic matters such as CO_2. NH_3 and H_2O by decomposers and the latter is used by producers when the photosynthesis is carried out.

In the forest that has been reached steady-state of the litter production, the organic matters, which are mainly from fallen leaves and twigs, return to the inorganic matters, when the fallen leaves are decomposed by the soil organisms. The decomposition rate of litters is dependent on the kinds of trees and the environmental conditions, because the growth of soil microbial populations, which are responsible for the decomposition of litters, is influenced by the organic matters, mineral nutrients and climate (Daubenmire, 1953, 1963, Jenny *et al.*, 1959, Kim *et al.*, 1965, 1967a, b). Kim, *et al.* (1966) reported that the content of calcium had important effects on the decomposition of the organic matters because of its high correlation with decay rate and microbial populations. Kim and Chang (1967a) reported that the soil organic matters was mainly decomposed by fungi among the soil microorganisms and the size of fungi populations correlated with moisture content, organic carbon, total nitrogen, available phosphorus, and exchangeable calcium.

In this paper, the relationships among the decomposition of pine litters, the soil microorganisms, and the environmental conditions were comparatively investigated in a calcareous region and a noncalcareous region.

METHODS AND MATERIALS

Survey of study areas This study, was carried out both at Youngwal, Kwangwon-do and Sinlim, Kwangwon-do. Because of similar latitude and the locations of central inland, both regions have nearly similar continental climate (Figs. 1 and 2). Table 1 shows annual mean temperature, annual mean precipitation, latitude, longitude and altitude of both study areas.

Youngwal is a typical calcareous region in south Korea, so the top soil of that region has been derived from lime stone. The sampling stand is *Pinus densiflora* forest near the Jangreung (an Imperial Mausoleum) and the production of litters in that forest is supposed to be reached steady-state.

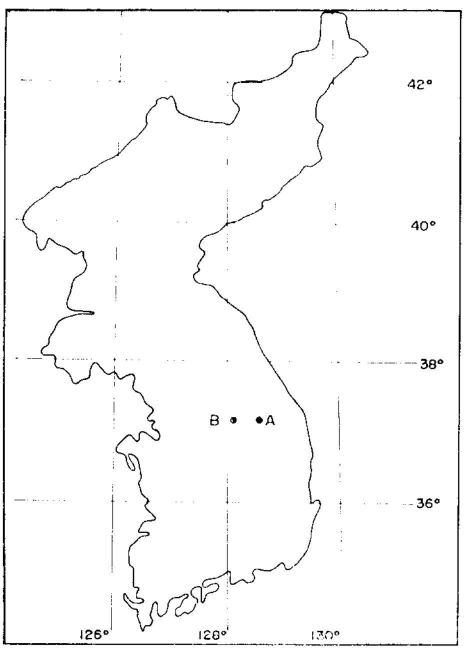

Fig. 1. Geographical map of studied areas, Youngwal (A) and Sinlim (B).

Sinlim is located at the south-east of Wonju, the foot of Mt. Chiak. The sampling stand is *Pinus densiflora* forest which is composed of 40~50 aged trees and is also supposed to be reached steady-state.

Sampling methods Quadrat (0.25m × 0.25m) was put on forest floor three times a stand, then litter samples were collected from L, F, H and A_1 horizon seperately, insulated in vinyl bag and transported to laboratory on July 27, 1985.

The fresh weight of samples was measured. After homogenization, 3 grams of samples for the culture of soil microbial populations were weighed, insulated and stored at the below 0°C. The remaining samples were air-dried in an oven at 105°C for 24 hours, then air-dried samples were ground in a mill, sieved (diameter: 2mm) and stored in the soil jar at the room temperature.

Counting of microbial populations The number of colonies of soil bacteria, actinomycetes and fungi, that were responsible for the decomposition of the organic matter in the forest soil, was counted by the serial dilution plate methods.

Soil bacteria: One gram of the litters was diluted with distilled water by 10,000 times. The number of colonies, which were cultured in the nutrient agar and broth media (pH 7.0) at 28°C for 3 days, was counted through the Darkfield Quebec colony counter.

Fungi: One gram of the ground litters was diluted with distilled water by 10,000 times. The number of colonies, which were cultured in the Sabouraud agar supplemented with aureomycin media (pH 5.6) at 28°C for 5 days, was counted through the Darkfield Quebec colony counter. (Cappuccino *et al.*, 1983)

Actinomycetes: One gram of the ground litters was diluted with distilled water by 10,000 times. The number of colonies, which were cultured in the glycerol yeast extract agar supplemented with aureomycin media (pH 7.0) at 28°C for 5 days, was counted through the Darkfield Quebec colony counter. (Cappuccino *et al.*, 1983)

Chemical analysis (a) Dry weight and water content of the litters were measured after drying at 105°C for 48 hours. (b) The pH was measured through the Beckman pH meter. (c) The content of the organic matters was measured in terms of loss on ignition, after the samples were ashed at 500~550°C for 5 hours in the furnace. The content of the organic carbon was calculated from that of the organic matters divided by 1.732. (Champman, 1976) (d) In the case of the total analysis, the samples were absolutely ashed by the acid digestion method in which hydrochloric acid was used as a solvent and the suitable aliquotes of the ash solution were taken for analysis. (e) In the case of the exchangeable analysis, the extractants were varied according to the properties of soil. Ammonium acetate (NH_4OAc, pH=9.0) was used in the samples from calcareous region and ammonium acetate (NH_4OAc, pH=7.0) was used in the samples from noncalcareous region. (f) Total nitrogen was determined by the micro-Kjeldahl method. (g) Phosphorus was determined by the standard molybdate method using spectrophotometer. (h) Calcium, potassium and sodium were determined by the flame emission method using flamephotometer.

Determination of decay rate, k Many authors have used Olson's negative exponential model for the determination of decay rate. According to Olson(1963), the decomposition of the organic carbon in litters a unit time can be expressed as equation(1).

$$dc/dt = L - kC \qquad (1)$$

In the above equation, C is the amount of the organic carbon in litters, L is the annual production of the organic carbon in litters and k is a loss constant or a decay rate. If the forest reaches steady-state, then the rate of change equals 0 due to the same amount of the accumulation as decomposition of the organic carbon. When C_{ss} is the amount of the organic carbon accumulated in the steady-state forest floor, equation (1) becomes;

$$dc/dt = L - kC_{ss} = 0 \qquad (2)$$

Dacay rate can be calculated from equation (2).

$$k=L/C_{ss} \quad (3)$$

Meanwhile if there is no inflow of fallen leaves on the forest floor, then $L=0$. Therefore equation (1) becomes

$$dc/dt=-kC \quad (4)$$

When C_0 is the initial amount of the organic carbon at $t=0$, differential equation (4) has a solution like equation (5).

$$C=C_0e^{-kt} \quad (5)$$

By using equation (5), the time periods which are required for the initial carbon C_0 to decrease up to half (50%), that is half time, 95% and 99% can be calculated.

The time periods are

$$t_{(0.5)}=0.693/k \quad (6)$$

$$t_{(0.95)}=3/k \quad (7)$$

$$t_{(0.99)}=5/k \quad (8)$$

RESULTS AND DISCUSSION

Differences in the environmental conditions

Temperature and precipitation Many authors reported that temperature and precipitation had great effects on the growth of microbial populations and decay rate (Kim, et al, 1972, Chang et al, 1968, Lee, 1981, Witkamp, 1966). According to Lee (1981), both temperature and precipitation had effects on the decomposition of litters, but at high elevation precipitation had more effects than temperature.

Annual mean temperature of Youngwal (1973~1984) was 10.0°C and that of Sinlim was 10.3°C. Annual mean precipitation of Youngwal was 1163.0mm and that of Sinlim was 1226.8mm (Table 1). Differences in temperature and precipitation between the two regions were not significant at the 5% level (Table 4).

Mineral nutrients Table 2 and Table 3 show the results of chemical analysis. Table 4 shows the results of statistical analysis. Because the data was not normal distribution, Wilcoxon's rank-sum test was used instead of general Student's t-test to test the differences between the two statistical populations. Wilcoxon's rank-sum test isakind of nonparametric inference, whose merit is that there is no rigid assumption about the statistical population, and has higher efficiency than t-test when the statistical population is thicker-tailed distribution than nomal distribution.

Table 1. Longitude, latitude, altitude, annual mean temperature and annual mean precipitation at two *Pinus densiflora* forests studied

Locality	Youngwal	Sinlim
Longitude	128°04′E	128°27′E
Latitude	37°14′N	37°12′N
Altitude(m)	300—400	300—400
Annual mean tem. (°C)	10.0	10.3
Annual mean preci. (mm)	1,163.0	1,226.8

The differences in water content, organic matter, total nitrogen, available phosphorus and exchangeable potassium were not significant at the 5% level. The difference

Table 2. Water content, dry weight, organic matter and organic carbon in litter samples

Locality	Horizon	Water content (%)	Dry wt. (g/m^2)	Organic matter (%)	Organic matter (g/m^2)	Organic carbon (g/m^2)
Youngwal	L	5.67±0.667	864.8±276.8	95.79	828.4± 277.9	478.3±160.5
	F	9.67±4.94	3,281.7±691.96	78.51	2,576.6±1,019.4	1,487.7±588.56
	H	3.72±0.453	3,721.9±818.13	34.72	1,292.3± 339.42	746.1±196.0
	A_1	1.29±0.558	3,891.8±735.52	66.95	2,605.6±1,249.0	1,504 ±721.17
Simlim	L	4.67±0.333	377.1± 64.48	93.53	352.7± 47.56	203.6± 27.46
	F	5.50±0.500	2,023.6±175.52	96.48	1,952.4± 191.67	1,127.2±110.68
	H	1.50±0.289	3,804.2±982.56	33.74	1,283.4± 303.87	741.0±175.4
	A_1	2.39±0.125	3,206.5±553.19	14.08	451.6± 110.0	260.7± 63.54

in exchangeable sodium was significant merely at the 5% level and the differences in exchangeable calcium and pH were significant at the 1% level, But though the difference in exchangeable sodium was statistically significant, the real dfference is very slight (0.0003%). The difference in exchangeable calcium was prominent and the content of exchangeable calcium in Youngwal was higher than that in Sinlim by about two times at minimum and about ten times at maximum. The rock facies in Youngwal, that is called Youngwal group geolgically, is correlated with a great lime stone group, but unclassified in age. The rock facies in much part of Sinlim is also Youngwal group, however, that is rounded by granitic gneiss of Gyeonggi gneiss complex. The rock facies in Keumok-dong, Sinlim-myon, the sampling stand in this study, belongs to not Youngwal group but Gyeonggi gneiss complex (The geological map, 1974, The Korean Institute of Energy and Resources).

Thus the difference in the content of exchaneable calcium between the two regions was thought to be out to the difference in the geology. With the content of exchangeable calcium, pH in Youngwal was much higher than that in Sinlim. The reason that the pH

Table 3. The content of total N, available P, exchangeable K, Ca, Na in litter samples

Locality	Horizon	Total N (%)	Exchangeable ions				pH
			P(%)	K(%)	Ca(%)	Na(%)	
Youngwal	L	0.341	0.017	0.041	0.431	0.001	4.4
	F	0.444	0.010	0.033	0.797	0.001	5.9
	H	0.241	0.004	0.024	0.693	0.001	6.8
	A_1	0.209	0.002	0.020	0.714	0.001	7.1
Sinlim	L	0.452	0.015	0.050	0.037	0.001	4.1
	F	0.657	0.017	0.050	0.465	0.001	4.0
	H	0.215	0.004	0.016	0.323	0.000	4.4
	A_1	0.071	0.001	0.013	0.172	0.000	4.6

Table 4. Statistical analysis: Wilcoxon's rank-sum test about the differences in various factors between the two regions

	Rank-sum of Youngwal	Rank-sum of Sinlim	Z
Temperature(°C)	143	157	−0.404
Precipitation(mm)	147	153	−0.173
Water content(%)	161	139	0.637
Organic matter(%)	160	140	0.577
Total N(%)	149.5	150.5	−0.029
Available P(%)	163.5	136.5	0.783
Exchangeable K(%)	158	142	0.462
Exchangeable Ca(%)	212	88	3.580**
Exchangeable Na(%)	186.5	113.5	2.108*
pH	209.5	90.5	3.443**
Decay rate, k	13	8	1.091
Bacteria($\times 10^4$/g·dry)	186	114	2.079*
Fungi($\times 10^4$/g·dry)	148.5	151.5	−0.087
Actinomycetes($\times 10^4$/g·dry)	159.5	140.5	0.552
Total microorganisms($\times 10^4$/g·dry)	194	106	2.540*

* significant at the 5% level, ** significant at the 1% level

Table 5. The number of bacteria, fungi, actinomycetes and total microorganisms in Youngwal and Sinlim

Locality	Horizon	Bacteria ($\times 10^4$/g·dry)	Fungi ($\times 10^4$/g·dry)	Actinomycetes ($\times 10^4$/g·dry)	Total ($\times 10^4$/g·dry)
Youngwal	L	182± 58.0	14±6.7	39±16	235± 41.2
	F	393± 19.2	6±2	5± 3	404± 19.2
	H	197± 15.5	3±1	4± 2	204± 13.0
	A_1	174± 20.8	1±0.6	0±0.3	175± 20.7
Sinlim	L	69± 15	0±0.3	1± 0.3	70± 16
	F	288±127	5±2	6± 0.3	300±128
	H	141± 45.3	5±1	4± 0.7	151± 44.8
	A_1	142± 17.2	2±0.4	2± 0.7	152± 19.1

Table 6. Parameter and times in year for decomposition of organic matter

Locality	Youngwal	Sinlim
Forest	***Pinus densiflora***	***Pinus densiflora***
k	0.128	0.096
Decay parameter(1/k)	7.813	10.417
Half time(0.693/k)	5.414	7.219
95% time(3/k)	23.439	31.251
99% time(5/k)	39.065	52.085

Table 7. The decay and accumulation model

Locality	Decay model	Accumulation model
Youngwal	$C=3,738.2e^{-0.128t}$	$C=3,738.2(1-e^{-0.128t})$
Sinlim	$C=2,128.9e^{-0.096t}$	$C=2,128.9(1-e^{-0.096t})$

in Youngwal was much higher than any other region was the higher content of basic calcium.

Decay rate and microbial populations

Table 5 shows the microbial popualtions, Table 6 shows decay rate and Table 7 shows decay model. Because the number of colonies of bacteria, actinomycetes, fungi and the total number of microbial colonies in Youngwal were generally greater than those in Sinlim except H, A_1 horizons for actinomycetes and F, A_1 horizons for fungi, the whole activities of the microorganisms in Youngwal was thought to be greater than that in Sinlim. But according to Wilcoxon's rank-sum test (Table 4), the differences in the populations of bacteria and total microorganisms were slightly significant at the 5% level, and those of fungi and actinomycetes were not significant at the 5% level.

Decay rate of ***Pinus densiflora*** forest in Youngwal was 0.128, that was lower value than the mean decay rate of ***Pinus densiflora*** forest in South Korea, 0.161, according to Park (1986). As decay rate of ***Pinus densiflora*** forest in Sinlim was 0.096, Youngwal had slightly higher decay rate, however, the difference in decay rate was not significant at the 5% level (Table 4).

Kim and Chang (1967a, b) reported that there was positive correlation with microbial populations and decay rate, and that though bacteria and fungi had the same responsible for decomposition, fungi was more responsible than bacteria.

But in this study, the simple correlation coefficients between microbial populations and decay rate were not significant at the 5% level. The reason that correlation coefficients were not significant was due to the decrease of degree of freedom. That was occured during statistical procedures. Because the microbial populations were measured in terms of horizons ($n=12$) and decay rates were calculated in terms of plots ($n=3$), the microbial populations were summed a plot to execute the correlation analysis with decay rates. If decay rates had been measured in terms of horizons like the microbial populations, then the same results as the Kim and Chang (1967a, b) would have been expected.

And because the difference in the populations of fungi, which were more responsible for decomposition, was not significant and that of bacteria, which were less responsible for decomposition, was slightly significant ($p=0.0376$, two-tailed probability) between the two regions. the difference in decay rate was thought to be not significant statistically (Table 4).

Vertical distribution of microbial populations and mineral nutrients

Table 5 shows the vertical distribution of microbial populations. In Youngwal the populations of soil bacteria were 182×10^4/g. dry at L horizon, increased 393×10^4/g. dry at F horizon and decreased $197\times10_4$/g. dry at H horizon, 174×10^4/g. dry at A_1 horizon gradually. This trend was similar to that in Simlim. In Sinlim the populations of soil bacteria were 69×10^4/g. dry at L horizon, increased 288×10^4/g. dry at F horizon and decreased at H horizon and A_1 horizon gradually. This trend was consistent with the results according to Kim and Chang (1967a, b). Chang and Rim (1968) and Kim, *et al.* (1972). That L horizon was incipient step in microbial contamination and F and F and H horizon was easy to be invaded by microorganisms as the litter was slightly decomposed. was thought to be the reasons of that trend.

There were differences in the vertical distributions of fungi and fungi and actinomycetes between the two regions. In Youngwal the populations of fungi and actionmycetes were the most at L horizon as 14×10^4/g. dry and 39×10^4/g. dry respectively, and decreased in order of F, H and A⁾ horizon. In Sinlim, the pupulations of fungi and actinomycetes were the least at L horison as 0×10^4/g. dry and 1×10^4/g. dry respectively and increased at F, H and A_1 horizon without remarkable bifferences in theses three horizons. But Kim and Chang (1967a, b), Chang and Rim (1968) and Kim, *et al.* (1972) reported that the populations of actinomycetes and fungi were the most at F horizon and decreased in order of H, A_1 like soil bacteria. This trend was consistent with the vertical distributions of actinomycetes and fungi in Sinlim, but there was severe discrepancies ln the vertical distributions of fungi and actinomycetes in Youngwal with that trend.

The total microbial populations were the most at F horizon and decreased in order of H, A_1 horizon in both regions, so the trend was consistent with many author's results. Table. 3 shows the vertical distriibutions of mineral nutrients.
The contents of total nitrogen were the most at F horizon and decreased at lower horizons in both regions.

In Youngwal, the content of available phosphorus was the most at L horizon and decreased radically in order of F, H and A_1 horizon, but in Sinlim the content of available phosphorus was the most at F horizon and decreased at lower horizons. In both regions the contents of exchangeable potassium were the most at L horizon and decreased very gradually at lower horizons. The content of exchangeable calcium in Youngwal was the most at F horizon, decreased a little at H horizon and increased again A_1 horizon. But the content of calcium in Sinlim was the most at F horizon and decreased gradually at lower horizons. The pH in Youngwal was the least at L horizon and increased up to 7.1 at lower horizons, butin Sinlim there was no outstanding changes in pH between horizons.

In Sinlim, the populations of fungi was the most at F horizon, at which the contents of mineral nutrients was the most. Generally the vertical distribution of the microbial populations was consistent with that of the contents of mineral nutrients. But in Youngwal, the vertical distributions of fungi and actinomycetes were consistent with that of the content of available phosphorus, and the vertical distribution of soil bacteria was consistent with that of the contents of the rest mineral nutrients. Therefore the characteristic trend in the vertical distribution of the populations of fungi and actinomycetes in Youngwal was thought to be due to the characteristic environmental conditions, especially the content of available phosphorus.

Influences of calcium

Kim *et al.* (1966) reported that the content of calcium had important effects on the decomposition of the organic matter because of its high correlation with decay rate and microbial populations. Kim and Chang (1967) reached the same conclusion. But Kim and Chang (1967) reported that there was no change in decay rate when some of calcium was added because of the exsisting presence of calcium beyond some content.

The influence of calcium in a calcareous region, Youngwal on the decomposition of litters was thought to be dut to the excessive content of calcium. According to Park, *et al.* (1968), the minimum level of calcium for ***Pinus densiflora*** was 0.1%, then the content of calcium in Youngwal was higher than minimum level by about eight times maximum. It was thought that high content of calcium increased the pH bayoud the pertinent level insted of promoting the decompnsition of the organic matters through effects on the growth of microbial populations.

According to Park, *et al.* (1968), the minimum level of pH ***Pinus densiflora*** was 4.1～6.0. In the case of ***Pinus densiflora*** forest in Youngwal, the pH at L horizon was only 4.4 and the pH at F, H and A_1 horizon was 5.9, 6.8 and 7.1 respectively over the range of minimum value. In the case of ***Pinus densiflora*** forest in Sinlim, the pH was 4.1～4.6 within reach of minimum level. According to Chang (1968), the content of available phosphorus was decreased gradually under pH 5.2, increased in the pH range 5.3～6.3 and decreased again over pH 6.4. The pH in Youngwal was in such range that decreased the content of available phosphorus and in fact, the content of available phosphorus in Youngwal was decreased in order of L, F, H and A_1 horizon. And in Youngwal, because the vertical distribution of the content of available phosphorus was consistent with that of the populations of fungi and actinomycetes and the populations of fungi that was the most responsible for decomposition was decreased, the decrease of available phosphorus was thought to have a negative effect on the decomposition of the organic matters indirectly. But further study about the relation between the content of available phosphorus and fungi and actinomycetes was required.

적 요

석회암지대인 영월에서의 소나무의 낙엽분해와 미생물의 소장을 비석회암지대인 신림과 비교 연구하였다. 영월의 소나무림의 낙엽분해상수는 0.128이고 신림의 소나무림의 낙엽분해상수는 0.096이었다. 두 지역에서 bacteria와 총 미생물 수는 유의수준 0.05에서 통계적으로 유의한 차이가 있었으나 Fungi와 actinomycetes의 수에는 유의한 차이가 없었다. 두 지역에서 칼슘의 함량과 pH는 유의수준 0.01에서 차이가 인정되었다. 영월에서의 과다한 칼슘 함량은 토양의 pH를 높이고, 높아진 pH는 유효인산의 함량을 낮춘다고 생각되었다. 영월에서 유효인산량의 수직분포와 fungi, actinomycete의 수직분포에는 일치된 경향이 있었다.

LITERATURE CITED

Cappuccino, I. G. anc N. Sherman. (1983). Microbrology, a laboratory mannual. Addison Wesley Pub. Co., New York. pp. 315~320.

Chang, N. K. (1968). The amounts of the available phosphours in soils of Kwang-nung forest. Korean J. Botany, **11**:18~22.

Chang, N. K. and Y. D. Rim. (1968). Studies on microbial population affecting the decomposition of fir litter, Kor. Jour. Microbio, **6**:93~99.

Chapman, S. B. (1976). Methods in plant ecology, John Wiley and Sons. New York.

Daubenmire, R. (1953). Nutrient content of leaf litter of trees in the northern Rocky Mountains. Ecology, **34**:786~793.

Daubenmire, R. and D.C. Prusso. (1963). Studies of the decomposition rates of tree litter. Ecology, **44**:589~592.

Jenny, H., S.P. Gesel and F.T. Bingham. (1959). Comparative study of decomposition rates of organic matter in temperate and tropical regions. Soil, **10**:419~432.

Kim, C.M. and N.K. Chang. (1965). The decomposition rates of litter affecting the amount of mineral nutrients of forest soil in Korea. Bul. Ecol. Soc. Amer.: Sept., **14**:1965.

Kim, C.M. and N.K. Chang. (1967a). Effect of the soil microorganism, temperature, moisture content and mineral salts on the decay rate of soil organic matter. CollegeEducation Review, **9**: 117~126.

Kim, C.M. and N.K. Chang. (1967b). On the decay rate of soil organic matter and changes of soil microbial population. Korean J. Bot., **10**:21~30.

Kim, C.M., N.K. Chang and W.H. Chung. (1966). Decomposition rate of plant residue and the vertical distribution of mineral nutrients in the woodland soil. J. Graduate School, Coll. Education, S.N.U., **3**:113~125.

Kim, C.M., N.K. Chang and T.K. Woo. (1973). Effect of microflora, temperature and moisture content on CO_2, NH_3 and NO_2 evolution from the floor of oak forest. J. Graduate School, Coll. Education, S.N.U., **10** : 153~164.

Lee, I.S. (1981). A model for litter decompsition of the forest ecosystem in south Korea. Ph. D. Thesis. Ewha Women's University, Seoul. pp. 6~7.

Olson, J.S. (1963). Energy storage and the balance of producers and decomposers in ecological systems. Ecology, **44**:322~331.

Park, N.C. (1986). A study on the production and decomposition of litters of Pinaceae forests in south Korea. M.E. Thesis. Seoul Natl. Univ., Seoul. pp. 8~21.

Park, B.K. (1968). Estimating the minimum levels of soil nutrients for Japanese red pine, Pitch pine, and Korean pine. J.K.R.I.B.L., **1**:23~33.

Witkamp, M. (1966). Decomposition of leaf litter in relation to envionment, microflora, and microbial respiration. Ecology, **47**:194~201.

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