Kor. Turfgrass Sci., 9(2), 119~129, 1995

Decomposition Models of the Organic Matters in Cultural Media and the Litters in Forest

Lee, Woong-Sang and Nam-Kee Chang*

Department of Biology, Myungji University

* *Department of Biology, College of Education, Seoul National University*

배양액에서의 유기물분해와 식물군락에서의 낙엽분해에 관한 모델

李 雄 相 · 張 楠 基*

명지대학교 이과대학 생물학과, *서울대학교 사범대학 생물교육과

ABSTRACT

Decomposition rates of glucose, starch, spinach leaves and litters in forests are calculated by equation $\frac{dC}{dt}=-kC(C_0-\ln C)$, $\frac{dC}{dt}=-kC^2$, and Olson's negative exponential decay model. $\frac{dC}{dt}=-kC(C_0-\ln C)$ showed a very close fit to decomposition of the organic matters in cultural media by purified microorganisms and $\frac{dC}{dt}=-kC^2$ to decomposition of the litters in forests.

Key words: Organic matters, Cultural media, Glucose, Starch, Leaves, Litters.

INTRODUCTION

Organic materials added to the ecological system will be decomposed. The net rate of change is expressed by the rate of income minus that of loss. Many available data were reported on the rate of decomposition for plant materials in terrestrial habitats and in aquatic ecosystems(Melin, 1930; Daubenmire, 1953; Chang and Yoshita, 1973; Hodkinson, 1975). On the basis of analytic data, Olson(1963) has constructed a mathematical model that describe the phenomenon of decomposition and accumulation of the litters.

However, Minderman(1968) has indicated that this relationship may be fit for individual litter constituents such as cellulose, but may be not suitable for whole litters. So he suggested $W_t = W_o e^{-\frac{P}{100}t}$ as a decay model, in which only $\frac{P}{100}$ is subtituted for k. Both of them are exponential function derived from radioactive decay model. Many authors, however, calculated the rate of decomposition by Olson's negative exponential decay model(Hodkinson, 1975; Brinson, 1977; Chang, *et al.*, 1987).

Organic materials are decomposed by microorganisms. Therefore the faster they grow, the faster organic matters are decomposed. Many authors reported decomposition of litters in relation to microflora and the soil fauna(Bocock, 1934; Frankland, 1969; Witkamp, 1966). As microorganisms grow sigmoidally, decomposition curve will have sigmoidal quality.

On the basis of this idea this paper suggest two decay models. The results are compared to an estimate obtained independentely by the experiments which measured decomposition of plant materials in cultural media and forest litters.

MATERIALS AND METHODS

1. Decomposition of glucose and starch

Saccharomyces cerevisiae and *Bacillus subtilis* were precultured in Erlenmyer flasks containing Hayduck's medium and usual mineral medium respectively. They were then inoculated into cultural media containing glucose and starch. The fermentors (New Brunswick Scientific Model M-1000) were controlled at 30±1°C for 10 days with aeration.

The measurements of the cell number and contents of glucose and starch were made at any given time intervals during the incubation. Glucose was determined by the Benedict's method. Starch was precipitated by iodine and recovered as starch, which was hydrolyzed with acid and determined as glucose(Pucher, 1948).

2. Decomposition of spinach leaves

2 grams of fresh spinach leaves were weighed and placed in 50ml beakers. Each samples was inoculated with 20ml of soil suspension and incubated at 30±1°C for 20days. 3 samples were collected daily and filtrated with 50ml distilled water. They were dried at 60°C for 48hrs, cooled in a desicator, and weighed. Samples were prepared for determinations of potassium, sodium, and calcium contents by grinding with a mortar and pestle. K, Na, and Ca were determined by flamephotometer.

3. Collection and analysis of litters

The litters in forests were collected in litter layer L, fermentation layer F, humus layer H, and A_1 layer with $0.25m^2$ traps. Samples were air-dried and then dry-ashed in a muffle furnace at 450°C for 4hrs. The ash was heated on a sand bath with 6 N HCl and used to determine K, Na, and Ca contents with flamephotometer.

DECOMPOSITION MODELS

1. Rate of decomposition in cultural media

The decay of an organic matter can be recognized as a bioreaction of an organic matter with microorganisms. This reaction is applied to the growth of the microorganism population. It had been found that the fitting equation to the growth curve, which is sigmoid, is logistic. The decomposition rate of organic matter at an instant in time (t) expressed as follows

$$\frac{dC}{dt} = -kC\,(C_o - \ln C) \cdots\cdots (1)$$

where k, C and C_o are the decay coefficient, concentration of organic matter at time (t) and initial concentration of organic matter, respectively.

Divide both sides of (1) by C $(C_o - \ln C)$ and we have

$$\frac{1}{C(C_o - \ln C)}\,\frac{dC}{dt} = -k \cdots\cdots (2)$$

Integrate both sides of (2) to obtain

$$\ln|\ln C - C_o| = kt + A \cdots\cdots (3)$$

where A is the constant of integration.

Thh graph of (3) is the linear function of t. Thus k can be obtained by the slope of this curve.

Exponentiate both sides of (3) to obtain

$$C_o - \ln C = e^A\, e^{kt}$$

If we let $e^A = a$, then we may write

$$\ln C = C_o - ae^{kt}$$

Then exponentiate

$$C = e^{C_o - ae^{kt}} = e^{C_o}\, e^{-ae^{kt}} \cdots\cdots (4)$$

The constant a is determined by the initial value $C = C_o$ at the time $t = 0$, as follows

$$C_o = e^{C_o - a} = e^{C_o}\, e^{-a}$$

Now take logarithms,

$$\ln C_o = C_o - a$$

$$\text{or } a = C_o - \ln C_o \quad \cdots\cdots (5)$$

In order to sketch the graph of the solution (4) the derivatives of each side of (1) was calculated using the product formular for differentiation on the right hand side ;

$$\frac{d^2C}{dt^2} = -k\,C\left(-\frac{1}{C}\,\frac{dC}{dt}\right) - k\frac{dC}{dt}\,(C_o - \ln C)$$

$$= -k\frac{dC}{dt}(C_o - \ln C - 1)$$

In this expression for the second derivative the factor k is positive and $\frac{dC}{dt}$ is negative so that the graph is concave upward if $C_o - \ln C - 1 > 0$, and concave downward if $C_o - \ln C - 1 < 0$, There is an inflection point at $C = e^{C_o} - 1$ or $t = \frac{-\ln a}{k}$.

The graph is sketched in Fig. 1.

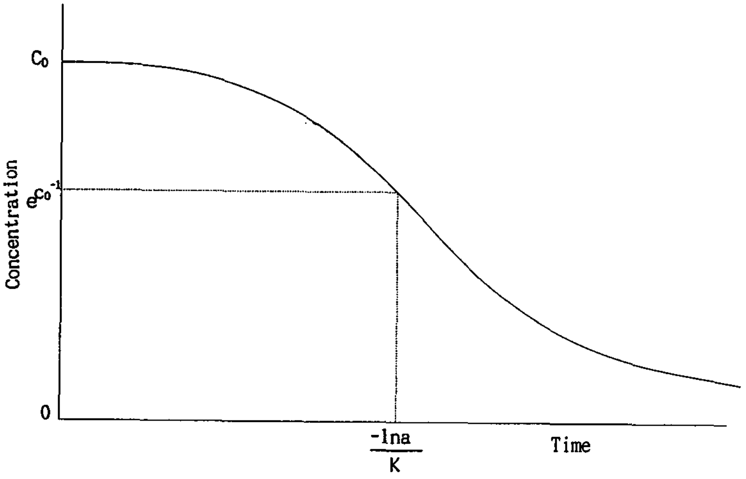

Fig. 1. The graph of $C = e^{co}\, e^{-aekt}$ which is the solution of equation (1).

From eq. (4) the time required for decomposition of the organic material, half time, can be calculated as follows

$$\frac{Co}{2} = e^{Co}\, e^{-aekt}$$

$$e^{kt} = 1 + \frac{\ln 2}{a}$$

$$t_{\frac{1}{2}} = \frac{\ln\left(1 + \frac{\ln 2}{a}\right)}{k} \quad \cdots\cdots (6)$$

2. Rate of decomposition in ecosystem

Since a litter consists of organic matter (L_o)and inorganic matter (L_a), litter content can be expressed as follows (Oohara et al., 1971; Chang and Yoshida, 1973).

$$\begin{aligned} L &= L_o + L_a \\ &= (L_{pc} + L_{fc} + L_s + L_g + L_h) + L_a \end{aligned}$$

where L_{pc}, L_{fc}, L_s, L_g, L_h are crude protein, crude fat, cellulose, lignin and other carbohydrates of a litter, respectively.

The decomposition rate of a litter at an instant in time (t) is

$$\begin{aligned} \frac{dL}{dt} &= \frac{dL_o}{dt} + \frac{dL_a}{dt} \\ &= \left(\frac{\partial pc}{\partial t} + \frac{\partial fc}{\partial t} + \frac{\partial s}{\partial t} + \frac{\partial g}{\partial t} + \frac{\partial h}{\partial t}\right) + \frac{\partial La}{dt} \end{aligned}$$

The inorganic matters of litter is composed of P, K, Ca, Mg, Fe, etc. Therefore, the decomposition rate ($\frac{da}{dt}$) holds the following relationship.

$$\frac{da}{dt} = \frac{\partial P}{\partial t} + \frac{\partial K}{\partial t} + \frac{\partial Ca}{\partial t} + \frac{\partial Mg}{\partial t} + \frac{\partial Fe}{\partial t}$$

Nitrogen content and the content of lignin, waxy substances, and water soluble substances may greatly affect the rapidity of decomposition (Waksman, 1928). Other author, too, pointed out the stimulating or retarding action of certain substances upon the rapidity of decomposition of organic plant materials ; for example, pentosan and lignin, etheral oil, calcium and silica. But the most carbohydrates, proteins, and fats are illustrated by same model. Inorganic matters are also illustrated by same equation. $\frac{dL}{dt}$, therefore, can be expressed by eq. (1).

As $C_o - \ln C$ of eq. (1) can be substituted by C in forests (Fig. 2), eq. (1) can be writed as follows ;

$$\frac{dc}{dt} = -kC^2 \cdots\cdots (7)$$

So for the model of steady income, Litter (L) instantaneous rate of change is as follows ;

$$\frac{dc}{dt} = L - kC^2 \cdots\cdots (8)$$

If and when accumulation reaches a steady state level, Css, the rate of change in eq. (8) is zero, so income=loss

$$L = kC_{ss}^2 \quad \cdots\cdots (9)$$

For this case, the rate parameter k, decay coefficient can be estimated from (9)

$$K = \frac{L}{C_{ss}^2}$$

The special case in which $L=0$ approximates this experimental design.

Equation (7) expresses this losses as a fraction of the residue C currently remaining. A very useful form of the solution to eq. (7) is

$$\frac{C}{C_0} = \frac{1}{1+kC_0t} \quad \cdots\cdots (10)$$

where C_0 is the initial concentration of litter.

For the case in which litter is almost steadily falling, at a rate L, eq. (8) can be rewritten as follows

$$\frac{dC}{\frac{L}{k} - C^2} = -kdt \quad \cdots\cdots (11)$$

For an initial condition with no forest floor, $C=0$, at $t=0$, and the constant of integration is $-\ln(\frac{L}{k})$.

The solution of eq. (11) is

$$C^2 = \frac{L}{k}(1-e^{-kt})$$

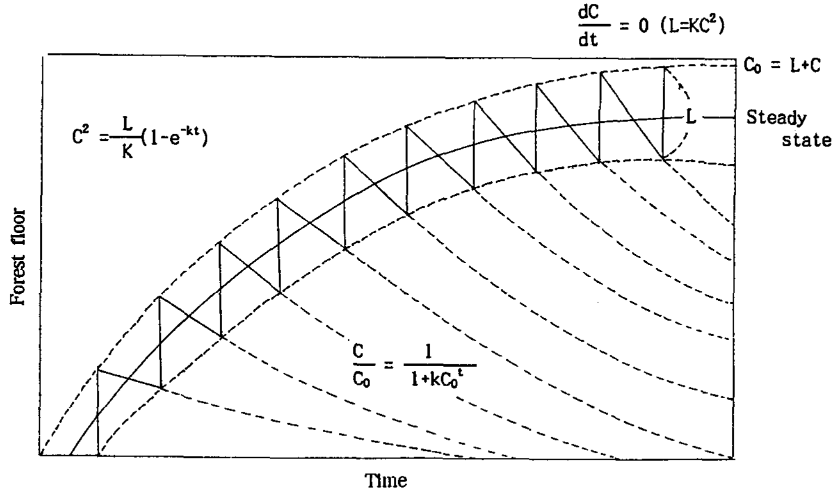

Fig. 2. Decomposition and accumulation curves for idealized deciduous forest.

This curve is the mirror image of the curve for decay.

Accumulation curve for idealized deciduous forest, with sudden annual litter fall and steady litter fall, are illustrated by Fig. 2a and 2b, respectively.

So C_0 of eq. (10) can be expressed by C+L. Then express the quotient $\frac{C_0 - C}{C}$;

$$\frac{C_0 - C}{C} = k\, C_0\, t$$

Thus $\frac{C_0 - C}{C}$ is a linear function of t and kC_0 is the slope of this equation.

The half time can be calculated as follows :

$$\frac{1}{2} = \frac{1}{1 + kC_0 t}$$

$$t_{\frac{1}{2}} = \frac{1}{kC_0} = \frac{1}{k + (L + C)} \qquad \cdots\cdots (12)$$

RESULTS AND DISCUSSIONS

Glucose and starch were decomposed sigmoidally (Fig. 3 and Fig. 4).

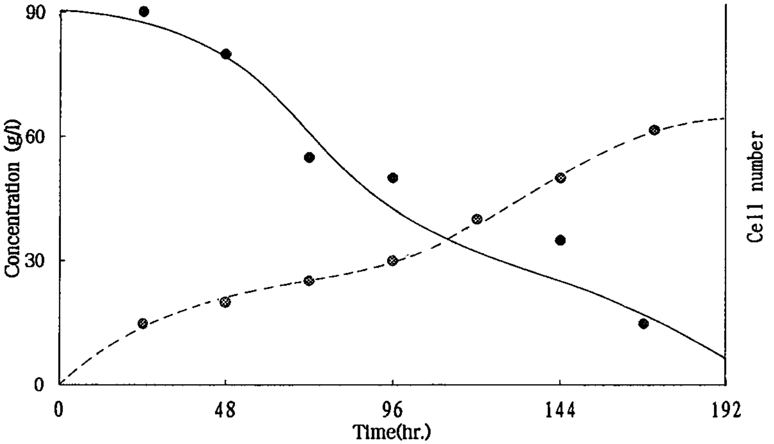

Fig. 3. The decomposition of glucose (•) and growth of population (∘).

Table 1. Decay parameters for glucose and starch

	k					Half time (hrs.)					
	eq.(1)	eq. (7)		Olson's Model		ex.	(1)	(7)		Olson	
Glucose	0.0048	0.015	0.278	0.002	0.013	88	96	128	19	347	53
Starch	0.0062	0.013	0.028	0.004	0.033	83	85	77	4	173	21

Fig. 3 well showed that the decay curve is the mirror image of the growth curve of microorganism population. The decay coefficient (k) and half time calculated by eq. (1), eq. (7), and Olsons negative exponential decay model are given in Table (1)

The half times of glucose and starch in these experiment are 88 and 83 hrs. respectively (Fig. 3, Fig. 4).

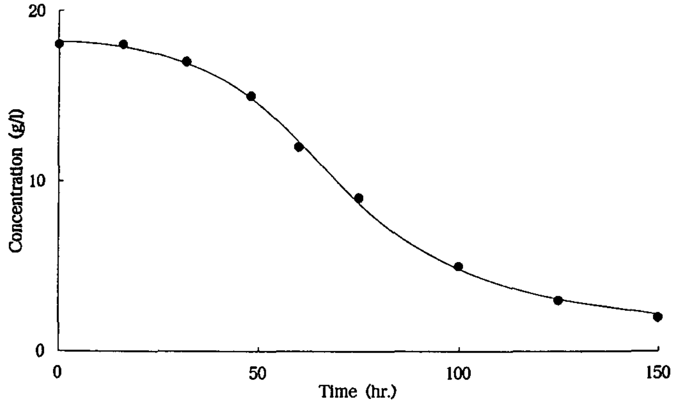

Fig. 4. The decomposition of starch.

In this experiment starch might be more rapidly decomposed because the amount was determined by iodine. The values calculated by theoretical equation (1) are 96 and 85 hrs. which showed a very close fit to experimental data. (Table 1)

But those of equation (7) within 136 hrs. are 128 and 76 hrs. respectively. (Table 1)

Therefore, there are lots of errors between experimental values and theoretical ones.

Half times of glucose and starch calculated by Olson's model (Table 1) are also far different from experimental ones. These have shown that the extent of decomposition of carbohydrates depends on the nature of the microorganisms.

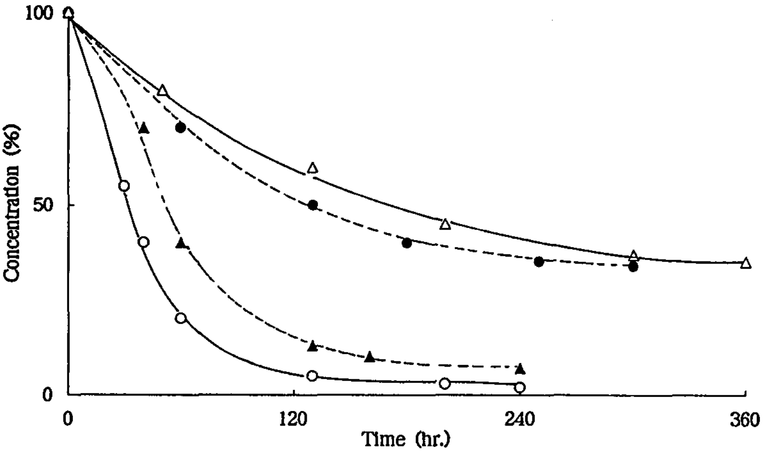

Fig. 5. The loss of dry weight (△), Ca (•), Na (▲), and K (○) in spinach leaves.

Waksman and *et al.*(1928) reported the decomposition rate of carbohydrates depends not only on the nature of the microorganisms, but also on the nature and amount of available nitrogen.

As glucose and starch were decomposed under controlled condition in this experiment, decay rates of those are mirror image of the growth curve of microorganisms population.

The loss of dryweight, Ca, Na and K in spinach leaves are given in Fig. 5.

The half time of K and Na calculated by experimental data are 47 and 65, which showed a very close fit to values calculated by eq. (1) (Table 2).

Table 2. Decay coefficients and half times for spinach leaves

	k			Half time (hrs.)			
	eq.(1)	eq. (7)	Olson's Model	ex.	(1)	(7)	Olson
K	0.015	0.063	0.034	43	36	17	22
Na	0.007	0.002 0.023	0.14	65	75	480 43	48
Ca	0.005 0.001	0.007	0.007 0.003	115	98 527	151	103 278
D-Wt	0.004 0.001	0.008	0.006 0.003	132	126 527	125	116 231

But in the case of Ca loss and dry weight loss those are more similar to values calculated by eq. (7). As K, Na, and Ca are accumulated in litters decomposed and in soils, they seem to be decomposed much more slowly in nature. But samples were filtered with distilled water, large amounts of soluble K, Na, and Ca are leached. Brinson (1977) reported rates of loss were significantly different between sites. The curves of cellulose loss in an alluvial swamp forest and levee were mirror image of the sigmoid, but in a river was exponential. However the values calculated by Olson's model are quite different from experimental data (Table 2). Total weight, K, Na, and Ca contents of litter and humus in forests are given in Table 3.

The decay parameters of litter in forests in Kwangnung are compared with values

Table 3. Total dry weight of litter and their contents of K, Na, Ca in forests in Kwangnung

Forest	Layer	D.W. (g/m)	Ash (%)	Ca /Ash	Ca /DW	Ca (g/m)	Na /Ash	Na /DW	Na (g/m)	K /Ash	K /DW	K (g/m)
Pine	L	501.8	5.4	29.0	1.6	8.0	30.0	1.6	8.0	4.5	0.2	1.00
	F	752.5	28.7	45.5	13.1	98.6	56.0	16.1	121.2	15.0	4.3	32.36
	H	751.3	70.2	70.2	14.4	108.2	36.5	25.6	192.3	25.0	17.6	132.22
	A_1	1585.5	90.1	9.5	8.6	136.4	40.5	36.5	578.7	28.0	25.2	401.1
Carpinus	L	489.2	8.9	69.0	6.1	29.8	39.5	3.5	17.1	8.0	0.7	3.42
	F	628.7	17.8	77.0	13.7	86.1	47.5	8.5	53.4	13.0	2.3	14.46
	H	1030.3	54.7	11.0	6.0	61.8	29.0	15.9	163.8	22.5	12.3	126.72
	A_1	137.6	48.0	14.0	6.7	9.2	65.5	31.4	43.2	42.3	20.3	27.94

Table 4. Decay parameters of total dry weight, K, Na, Ca in forests

Forest	L	C_0	Olson's const.	Half time by eq (7), yrs.	Half time by Olson, yrs.
Pine	0.162	1.162	0.162	5.321	4.278
	0.272	1.272	0.272	2.890	2.548
	0.002	1.002	0.002	499.0	346.5
	0.020	1.020	0.020	9.02	34.65
Carpinus	0.009	1.009	0.009	110.1	77.00
	0.066	1.066	0.066	14.21	10.50
	0.023	1.023	0.023	42.50	30.13
	0.190	1.190	0.190	4.423	3.65

The decay parameters of litter in forests in Kwangnung are compared with values calculated by eq. (7) and Olson's model. (Table 4). Values calculated by eq. (7) are very similar to those calculated by Olson's model but slightly greater because of the latent phase in the decomposition curve. Eq. (7), therefore, showes a more close fit to decomposition of litters than Olson's model.

The demerits of eq. (7) compared with Olson's model are that the contents of organic matter are expressed in concentration or ratio to humus contents and the initial value (C_0) is remained in solution of eq. (7). But it is thought that more close values from new mathematical equations could be obtained. It can also represent the decomposition curve by microorganisms more correctly because it is deduced from growth curve.

적 요

미생물에 의한 분해를 이용하여 분해에 관한 모델식을 유도하였다. 실험데이타를 이 모델식과 Olson의 모델식으로 풀어 실험결과와 비교하였다. 그결과 순수분리한 미생물에 의한 분해는 모델식 $\frac{dC}{dt}=-kC(C_0-\ln C)$가 실험치와 가장 근사하며 토양미생물에 의한 식물군락에서의 분해는 $\frac{dC}{dt}=-kC^2$이 가장 적합한 모델식이었다.

REFERENCES

1. Bocock, K.L. 1964. Changes in the amounts of dry matter, nitrogen carbon and energy in decomposing woodland leaf litter in relation to the activities of the soil fauna. J. Ecology, 52, 273~284.
2. Brinson, M.M. 1977. Decomposition and nutrient exchange of litter in an alluvial swamp forest. Ecology, 58, 601~609.
3. Chang, N. K., and S. Yoshida. 1973. Studies on the gross metabolism in a *Sasa paniculata* type grassland. Ⅲ The decay sytem of the litter. J. Japan Grassl. Sci. 19(4) : 341~357.

4. Chang, N. K., S. K. Lee, B. S. Lee and H. B. Kim. 1987. The litter accumulation, decay and turnover models and their Ualìdation. Korean J. Ecol. 10(3) : 139~149.
5. Daubenmire, R. 1953. Nutrient content of leaf litter of trees in the Northern Rocky Mountains. Ecology, 34, 786~793.
6. Frankland, J.C. 1966. Fungal decomposition of brocken petioles. J. Ecology, 57, 25~36.
7. Hodkinson, I.D. 1975. Dry weight loss and chemical changes in vascular plant litter of terrestrial origin, occurring in a beaver pond ecosystem. J. Ecology, 63, 131~142.
8. Kim, C.M. 1966. The decomposition rate of litters affecting the amount of mineral nutrients of forest soil in Korea. Seoul University Journal, 17, 83~92.
9. Melin, E. 1930. Biological decomposition of some types of litter from North American forests. Ecology, 11, 72~101.
10. Minderman, G. 1968. Addition, decomposition and accumulation of organic matter in forests. J. Ecology, 56, 355~362.
11. Olson, J.S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. Ecology, 44, 322~331.
12. Oohara, H., Yoshida, N., and Chang, N.K. 1971. Balance of producers and decomposers in a grassland ecosystem in Obihiro. : J. Japan Grassl. Sci., 17, 19~27.
13. Pucher, G.W., Leaverworth, C.S., and Vickery, H.B. 1948. Determination of starch in plant tissues. Anal. Chem., 20, 850~852.
14. Waksman, S.A., and Tenney, F.G. 1927. The decomposition of natural organic materials and their decomposition in the Soil : Soil Sci., 24, 275~283 : 317~333.
15. Witkamp, M. 1966. Decomposition of leaf litter in relation to environment, microflora, and microbial respiration. Ecology 47, 194~201.