The Decomposition rates of the Organic constituents of the Litter in *Phragmites longivalvis* grassland in a Delta of the Nakdong River

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ABSTRACT

Samples from the L, F, H, and A_1 horizons of *Phragmites longivalvis* grassland were collected in a delta of the Nakdong River, and various chemical analyses have been made to compare the decomposition rates of the organic constituents of the litter.

The decomposition rates and periods required to decay up to a certain percentage of each organic constituent were calculated using the theoretical models of Olson (1963) and those of Oohara et al. (1971c). The decomposition rates of cold-water-soluble fractions, other carbohydrates, hot-water-soluble fractions, cellulose, crude fat, lignin, and crude protein were 2.6743, 1.3926, 1.0175, 0.9233, 0.4929, and 0.4691, respectively. The periods required to reach half time to the asymptotic levels of decomposition and accumulation for cold-water-soluble fractions, other carbohydrates, hot-water-soluble fractions, cellulose, crude fat, lignin, and crude protein of the litter were 0.26, 0.50, 0.55, 0.68, 0.75, 1.41, and 1.48 years, respectively.

INTRODUCTION

The ratio of production and decomposition of the litter affords a reliable index to evaluate the soil conditions (Kim and Chang 1975). There are many reports about production and decomposition of the litter. According to Jenny et al. (1949), the annual production of organic matter in the form of leaves and twigs is much higher in the tropical than in the temperate forests, but the rate of breakdown of the litter is in inverse relation. Olson (1963) reported that many ecosystems continue to show a positive net community production for centuries perhaps long after changes in numbers and biomass of some species are reduced to minor fluctuations around a climax composition. Kucera (1959) working with leaves of deciduous angiosperm trees found a positive correlation between the rapidity of decay and the high ash content (with two of the six species showing reversed relations) and the high content of hot-water-soluble materials. Broadfoot and Pierre (1939) found the rates of decomposition to be somewhat correlated with the water-soluble organic fraction, N, and excess of basic elements. Melin (1930) and Mikola (1964), on the other hand, found no consistent correlation with any chemical property of the litter when species were compared, and Viro(1956) found but weak correlation with the base content of the litter. Kim et al. (1966) working with the oak and pine forest stand found that factors affecting the decomposition rates of the litter are humus, organic carbon, moisture content, calcium, phosphorus, and nitrogen. Kim and Chang(1975) reported that the amount of mineral nutrients returned annually to soil is higher in the oak forest than in the pine forest. Oohara et al. (1971c) reported that there were differences among the decay velocity of the organic constituents and each decay rate of the organic constituents had highly significant differences among species.

In this present study, various chemical analyses for the organic constituents of the litter of *Phragmites longivalvis* grassland have been made to compare with the decay rates among the organic constituents.

MATERIALS AND METHODS

1. Study Area

The study area in which the samples were collected was shown in Fig. 1. The study area is located 13km southeast of Kimhae, Gyeongsangnam-do, in a delta of the Nakdong River (E128°57′, N35°06′).

The climate of the study area has a typical continental one with hot wet summers and cold dry winters and adequate rainfall ranging 1,300mm to 1,400mm annually. About 59% of the rainfall has been recorded during summer, from June to September (Fig. 2).

The *Phragmites longivalvis* grassland was selected as a sample plot because of its semi-natural condition in the area. The grassland dominated by *P. longivalvis* was widespread in the study area (Fig. 3).

2. Methods

The samples of litter and soil were collected from *P. longivalvis* grassland. The litter

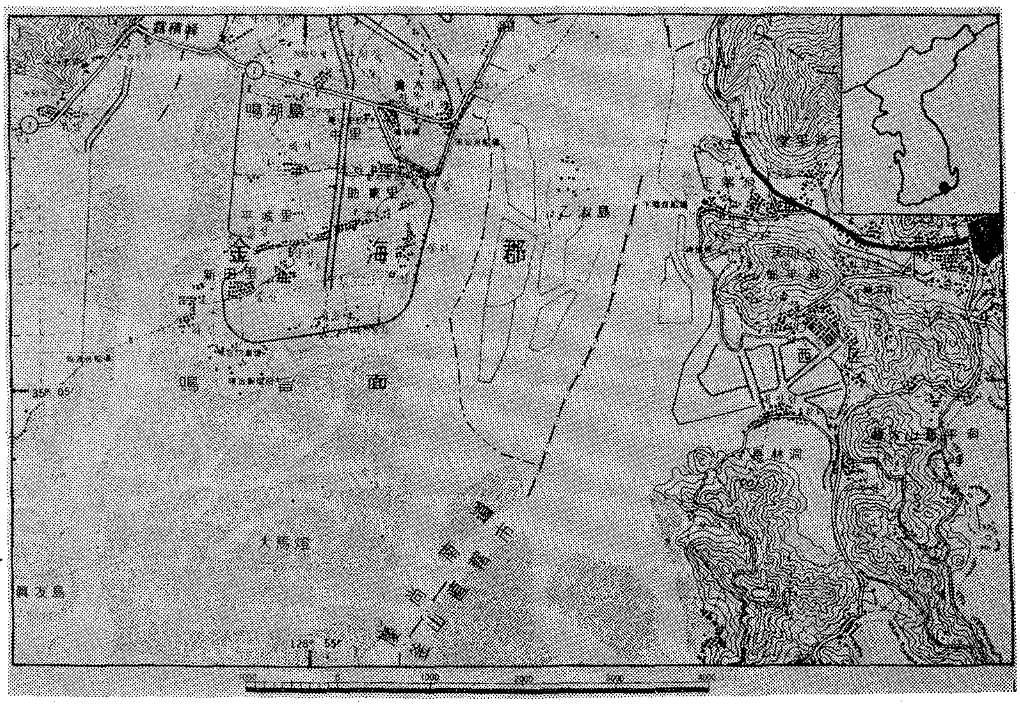

Fig. 1. Map showing the location of the study area.

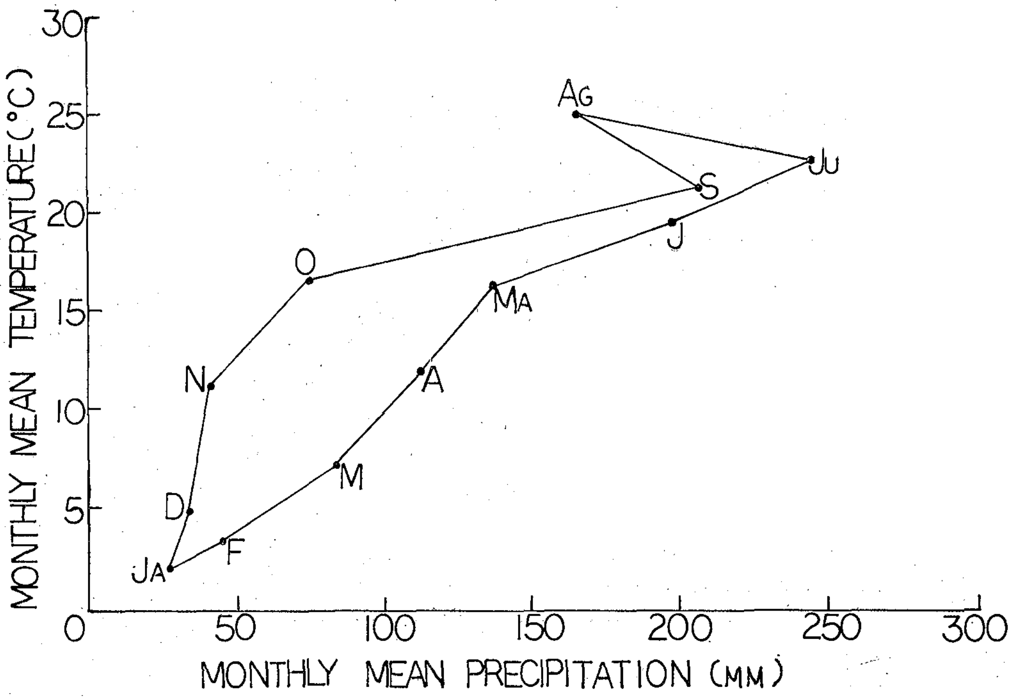

Fig. 2. Hythergraph for the study area, a delta of the Nakdong River.

Fig. 3. The *Phragmites longivalvis* grassland in a delta of the Nakdong River.

samples were collected from the L, F, H, and A_1 horizons, respectively, on August 29, 1976. The soil samples were collected from nine depths in each 5cm interval down to 45cm. To obtain the litter and soil samples, a block of soil measuring 50cm×50cm was cut out using a spade and a pruning scissors, and each horizon was separated using same tools.

Cold- and hot-water-soluble fractions were determined by the methods used by Daubenmire and Prusso (1963). Chemical estimates of lignin and cellulose were determined by the methods of Crampton and Maynard (1938). Total nitrogen content was determined by the micro-kjeldahl method. The pH was determined in a 1 : 2.5(for soil sammples) and a 1 : 10(for litter samples), sample: water suspension, by use of a glass electrode assembly. Ether-soluble fractions or crude fat were extracted with ethyl-ether for 8 hours, with other analyses following procedures recommended by the Association of Official Analytical Chemists (1970).

THEORETICAL ASSUMPTION

In the decay of litter, let C be the amount of organic matter contained in the litter per square meter of the grassland surface and the annual income of organic matter be L, then according to Olson (1963),

$$\frac{dC}{dt}=L-kC \tag{1}$$

In the above equation, k is a constant loss rate.

If the special case in which there is no litter fallen, $L=O$, the organic matter accumulated on top of the soil would be gradually decreased by the lapse of time. So the equation(1) can be rewritten as following:

$$\frac{dC}{dt}=-kC \tag{2}$$

or

$$\frac{dC}{C}=-kdt \tag{3}$$

Let the initial amount of organic matter at $t=0$ be Co, and the amount remaining after a certain period of time t be C, the equation (3) can be rearranged as following in estimating the loss content.

$$\ln\left(\frac{C}{Co}\right)=-kt \tag{4}$$

Antilogarithms of both sides of the equation (4) give the fraction remaining as a negative exponential fraction.

$$\frac{C}{Co}=e^{-kt} \tag{5}$$

or

$$C=Coe^{-kt} \tag{6}$$

The time which is required for the organic matter C to decrease up to half (50%) of Co can be calculated from the equation (6) as following:

$$\frac{Co}{2}=Co\ e^{-kt}$$

$$\frac{1}{2}=e^{-kt}$$

and thus

$$t_{1/2}=\frac{\ln 2}{k}=\frac{2.303\ \log 2}{k}=\frac{0.693}{k}$$

When the C decreases to 95% or 99% of Co, the value of t is as following respectively:

$$t_{1/20}=\frac{3}{k}$$

$$t_{1/100}=\frac{5}{k}$$

According to Oohara et al. (1971c), since the litter is analysed into the crude protein, crude fat, cellulose, lignin, and other carbohydrates, the net decomposition rate of the litter per unit time is given by

$$\frac{dC}{dt}=\frac{\partial Pc}{\partial t}+\frac{\partial Fc}{\partial t}+\frac{\partial S}{\partial t}+\frac{\partial G}{\partial t}+\frac{\partial H}{\partial t} \tag{7}$$

where C, Pc, Fc, S, G, and H are the value of organic matter, crude protein, crude fat, cellulose, lignin, and other carbohydrates respectively, and t is time in year. The equation (7) can be rearranged as

$$\frac{dC}{dt}=-k_1Pc-k_2Fc-k_3S-k_4G-k_5H \tag{8}$$

or

$$kC=k_1Pc+k_2Fc+k_3S+k_4G+k_5H \tag{9}$$

It follows from the equation (6) that the decay model for the important organic constituents of the litter is given by

$$C=Pcoe^{-k_1t}+Fcoe^{-k_2t}+Soe^{-k_3t}+Goe^{-k_4t}+Hoe^{-k_5t} \tag{10}$$

or

$$Coe^{-kt}=Pcoe^{-k_1t}+Fcoe^{-k_2t}+Soe^{-k_3t}+Goe^{-k_4t}+Hoe^{-k_5t} \tag{11}$$

where Co, Pco, Fco, So, Go, and Ho are the initial levels of each constituent.

For the case in which litter is almost steadily falling at a rate L, the equation (1) can be rewritten like equation (3). after dividing all terms by k:

$$\frac{dC}{L/k-C}=-kdt \tag{12}$$

This has an integral form as following:

$$\ln(L/k-C)=-kt-\text{constant} \tag{13}$$

For an initial condition with no grassland floor, $C=0$ at $t=0$, and the constant in equation (13) is $-\ln$ (L/k). The antilog of equation (13) gives the solution as following:

$$C=L/k(1-e^{-kt}) \tag{14}$$

Hence the net accumulation model for the organic constituents of the litter is given by

$$C=Lpc/k_1\ (1-e^{-k_1t})+Lfc/k_2(1-e^{-k_2t})+Ls/k_3(1-e^{-k_3t})+$$
$$Lg/k_4(1-e^{-k_4t})+Lh/k_5(1-e^{-k_5t}) \tag{15}$$

or

$$L/k(1-e^{-kt})=Lpc/k_1(1-e^{-k_1t})+Lfc/k_2(1-e^{-k_2t})+$$
$$Ls/k_3(1-e^{-k_3t})+Lg/k_4(1-e^{-k_4t})+Lh/k_5(1-e^{-k_5t}) \tag{16}$$

where L, Lpc, Lfc, Ls, Lg, and Lh are the estimations of organic matter, crude protein, crude fat, cellulose, lignin, and other carbohydrates of the annual litter. The decay and accumulation models of cold- and hot-water-soluble fractions are also developed by the same concepts.

RESULTS

1. The levels of the organic constituents of the litter

Table I presents the chemical analyses for the organic constituents of the litter samples in *P. longivalvis* grassland. As shown in Table I, the high percentage of the cellulose, other carbohydrates, and lignin were detected. However, a little amount of ether-soluble fractions or crude fat was included.

From inspection of the vertical distribution of the organic constituents, it could be said that cold-water-soluble fractions, crude fat, cellulose, and other carbohydrates decreased rapidly at H and A_1 under F horizon.

Table I. Average levels of chemical constituents of the litter in *P. longivalvis* grassland in a delta of the Nakdong River

Horizons	Cold H_2O sol. (%)	Hot H_2O sol. (%)	Crude protein (%)	Ether sol. (%)	Cellulose (%)	Lignin (%)	Other carbo-hydrates (%)	Organic Matter (%)	Ash and Soil (%)	pH*
L	8.95	13.99	4.05	1.24	40.45	16.64	31.17	93.55	6.45	5.70
F	2.42	7.04	5.86	1.16	34.57	21.76	16.70	80.05	19.95	5.88
H	1.23	5.65	4.01	0.45	11.61	18.25	8.23	42.55	57.45	6.46
A_1	1.18	4.16	2.93	0.27	8.65	11.08	7.22	30.15	69.85	6.65

* Medians instead of arithmetic averages are given for all pH values of the logarithmic nature of this factor.

On the other hand, the percentage of crude protein and lignin per organic matter content were increased in F and H horizons as compared with L horizon. The pH values seem to increase from L to A_1 horizon. The water table of the study area was 55cm. The range of total nitrogen content of the soil were 0.15% to 0.25%. The range of soil pH were 5.70 to 6.65.

2. The estimations of the decay constants for each organic constituent

Table II presents the production and accumulation of important organic constituents of the litter. As shown in Table II, very high production of cellulose was shown (Table II).

To compare with the decomposition of the organic constituents, the estimations of decomposition rate factors, k_1, k_2, k_3, k_4, k_5, k_6, and k_7 for crude protein, crude fat, cellulose, lignin, other carbohydrates, cold- and hot-water-soluble fractions were calculated from the ratio of the annual production to the steady state accumulation on the grassland floor of

Table II. The production and accumulation of important organic constituents of the litter in *P. longivalvis* grassland in a delta of the Nakdong River

Horizons	Cold H_2O sol. (g/m^2)	Hot H_2O sol (g/m^2)	Cellulose (g/m^2)	Lignin (g/m^2)	Other carbohydrates (g/m^2)	Organic matter (g/m^2)
L	97.627	152.603	441.228	181.509	340.002	1020.442
F	21.972	63.918	313.871	197.566	151.624	726.798
H	6.286	28.875	59.334	93.268	42.060	217.454
A_1	8.247	29.073	60.453	77.436	50.459	210.712

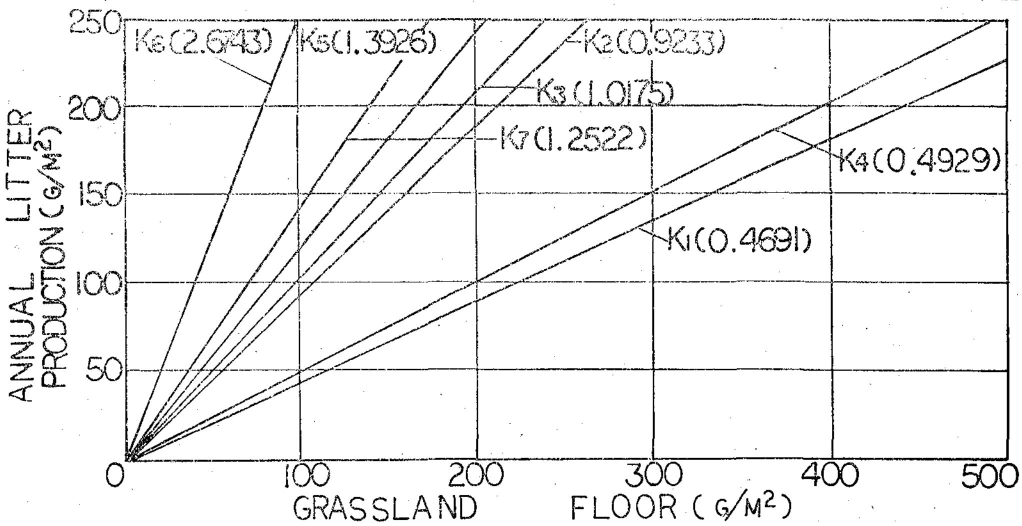

Fig. 4. Estimates of decomposition rate factor k for crude protein (k_1), fat (k_2), cellulose (k_3) lignin (k_4), other carbohydrates (k_5), cold- and hot-water-soluble fractions (k_6 and k_7) of the litter in the *P. longivalvis* grassland in a delta of the Nakdong River.

P. longivalvis. These data were indicated in Fig. 4 and Table V.

As shown in Fig. 4, the estimations of decay constant for cold-water-soluble fractions was 2.6743, for other carbohydrates 1.3926, for hot-water-soluble fractions 1.2522, for cellulose 1.0175, for crude fat 0.9233, for lignin 0.4929, and for crude protein 0.4691, respectively. Generally speaking the decomposition rates for the organic constituents, that of cold-water-soluble fractions was highest, those of other carbohydrates, hot-water-soluble fractions, cellulose, and crude fat were higher than those of lignin and crude protein, while that of crude protein was lower than that of lignin.

3. A comparison among the organic constituents of the litter

Oohara et al. (1971 a,b) induced the basic concepts for the decay and accumulation models of each organic constituent, and the total models of the organic constituents were given by the equation (10), (11), (15), and (16). These theoretical models were shown in Tables III and IV.

As shown in Tables III and IV, the negative exponential equations for the idealized decomposition of organic constituents of the litter were expressed in the weight loss proportional to the amount remaining at any one time. Gradually rising exponential increments for accumulation under the conditions of steady income and loss were also compared with step-wise increase for additions and losses of the litter in the idealized grassland ecosystem (Oohara et al. 1971 a). The accumulation curves are the mirror images of the curves for decay, shown in Fig. 5, for the various cases of k_1, k_2, k_3, k_4, k_5, k_6, and k_7 in yearly units.

Table III. The decay and accumulation models of organic constituents of the litter in *P. longivalvis* grassland in a delta of the Nakdong River

Orgımic constituents	Decay models	Accumulation models
Crude protein	$Pc=Pcoe^{-0.4691t}$	$PcA=Lpc/0.4691(1-e^{-0.4691t})$
Crude fat	$Fc=Fcoe^{-0.9233t}$	$FcA=Lfc/0.9233(1-e^{-0.9233t})$
Cellulose	$S=Soe^{-1.0175t}$	$SA=Ls/1.0175(1-e^{-1.0175})$
Lignin	$G=Goe^{-0.4929}$	$GA=Lg/0.4929(1-e^{-0.4929t})$
Other carbo.	$H=Hoe^{-1.3926t}$	$HA=Lh/1.3926(1-e^{-1.3926t})$
Cold H_2O sol.	$Wc=Wcoe^{-2.6743t}$	$WcA=Lwc/2.6743(1-e^{-2.6743t})$
Hot H_2O sol.	$Wh=Whoe^{-1.2522t}$	$WhA=Lwh/1.2522(1-e^{-1.2522t})$

Table IV. Total models of decay and accumulation of the litter in *P. longivalvis* grassland in a delta of the Nakdong River

	Total Models
Decay	$C=Pcoe^{-0.4691t}+Fcoe^{-0.9233t}+Soe^{-1.0175t}+Goe^{-0.4929t}+Hoe^{-1.3926t}$
Storage	$CA=Lpc/0.491(1-e^{-0.4691t})+Lfc/0.9233(1-e^{-0.9233t})+Ls/1.0175(1-e^{-1.0175t})$ $+Lg/0.4929(1-e^{-0.4929t})+Lh/1.3926(1-e^{-1.3926t})$

A convenient virtue of those exponential models (Tables III and IV) is that the time required to reach half time to the asymptotic level is the same as that required for decomposition of half of the accumulated organic matters (Oohara et al. 1971 a). Furthermore, it permits the calculation of the time required to decay or accmulate a certain percentage of the litter such as 95% or 99%.

Those periods for 50%, 95%, and 99% were selected respectively in Table V to compare the decomposition and accumulation among the organic constituents of the litter. Table V indicates that the time required to reach a steady state or the zero level for crude protein, crude fat, cellulose, lignin, other carbohydrates, cold-water-soluble fractions of the litter varies to each organic constituent.

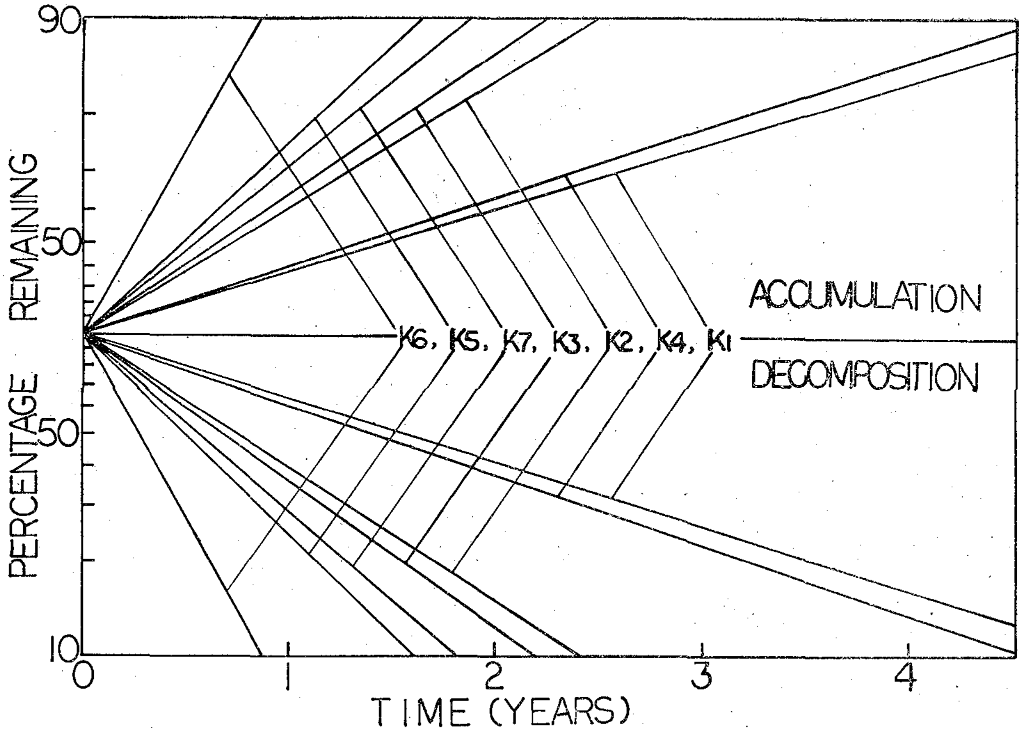

Fig. 5. Exponential models of decomposition and accumulation for crude protein (k_1), crude fat (k_2), cellulose (k_3), lignin (k_4), other carbohydrates (k_5), cold- and hot-water-soluble fractions (k_6 and k_7) of the littler in *P. longivalvis* grassland in a delta of the Nakdong River.

Table V. The parameters and periods (years) for decay and accumulation of the organic constituents in *P. longivalvis* grassland in a delta of the Nakdong River

	K	1/K	$t_{1/20}$	$t_{1/20}$	$t_{1/100}$
Organic matter (k)	0.8835	1.1319	0.7844	3.3957	5.6595
Crude protein (k_1)	0.4691	2.1317	1.4773	6.3951	10.6585
Crude fat (k_2)	0.9233	1.0831	0.7506	3.2493	5.4155
Cellulose (k_3)	1.0175	0.9828	0.6811	2.9484	4.9140
Lignin (k_4)	0.4929	2.0288	1.4060	6.0864	10.1440
Other carbo. (k_5)	1.3926	0.7181	0.4976	2.1543	3.5905
Cold H_2O sol. (k_6)	2.6743	0.3739	0.2591	1.1217	1.8695
Hot H_2O sol. (k_7)	1.2522	0.7986	0.5534	2.3958	3.9930

DISCUSSION

While some fraction of the solar energy fixed by producing plants is relaesed by respiration of these plants and of animals, much of it is stored in dead organic matter on top of the mineral soil until released by decomposing organism which decompose the organic matters (Olson 1963). According to Daubenmire and Prusso (1963), the rate of decay of plant litter would appear to be governed by three factors: (1) the physico-chemical properties of the substrate: (2) the environment under which decay takes place: and (3) the species active the particular substratal and environmental conditions.

Large amounts of organic matters are decomposed by decomposing organism such as fungi, bacteria, and certain animals (Olson 1963). But some of this breakdown of litter, accumulated on top of the mineral soil, involves leaching by snow or rain-water and decomposition by light or heat, while it involves physical transport of materials into the mineral soil (Oohara et al. 1971c).

In agreement with the results of Oohara et al. (1971c), cold-water-soluble fractions were decomposed faster than any other organic constituents of the litter. And the crude protein and lignin were decomposed more slowly than other organic constituents of the litter. The cold-water-soluble fractions are presumably decomposed by snow or rain but the end products of these fractions are turned out by the microorganism (Ochara et al. 1971c). Nykvist (1963) found that the losses from leaves on land during the 8 weeks in the litter are probably attributable largely to leaching of water-soluble-materials. The fact the highest decay velocity is affected by leaching seems to reflect the concerted influence of the properties of substrates and micro-organisms.

In this experiment, other carbohydrates of the litter decomposed faster than other organic constituents except the cold-water-soluble fractions. Since the other carbohydrates of the litter contain monosaccharides, disaccharides, starch, and so on, these are utilized by the micro-organisms as energy sources (Oohara et al. 1971c). Therefore that is an important factor to determine the rate of initial decomposition.

Mikola (1960) compared the decay rates of two kinds of the litter under natural forest microclimates at four latitudes and found that rate of decay followed mean summer temperature rather closely. According to Oohara et al. (1971c), it is possible that hot-water-soluble fractions of the litter are not only decomposed by the micro-organisms but also melted at a high temperature in summer on the grassland floors and then leached by rain-water into the mineral soil. Mork (1938) has made significant contribution to the effects of temperature alone on the decay of organic matter of forest floors. According to Mork (1938), in the organic matter that is easily nitrified (therefore considered of high quality from a forester's standpoint), the decay rates increases with increasing temperature, at least through the range of 10—30°C and over a 16-week period. Kim and Chang (1967) also reported that the decay rates of soil organic matter were accelerated with the increasing temperature. Therefore, the fact that the decomposition rate of hot-water-soluble fractions is comparatively high can be explained by the high temperature and much rainfall in summer. Oohara et al. (1971b) reported that the decomposition of a part of ether-soluble-fractions or crude fat (chlorophyll a and b, carotene, and so on) were affected by other decomposers except micro-organisms such as light rays but the decomposition of fat, wax, resin, etc. of these ether-soluble-fractions was governed by micro-organisms.

The lignin was decomposed more slowly than any other organic constituents except the crude protein. The lignin seems to be resistant to decomposition.

The decaying velocity of crude protein was slowest of all organic constituents. And it increased in relative amount of organic matters in the F horizon. Oohara et al. (1971b) found that the nitrogenous compound or crude protein involves DNA, RNA, chlorophyll, amino acids, and so on. According to Waksman (1936), the slowest decay velocity of crude protein results from the bonding protein in the cell wall, microbial protein, and the the lignin-protein complex. Therefore, it can only be explained by the fact that these are rendered resistant to further rapid decomposition, and new protein is formed through the synthesizing activities of the micro-organisms.

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洛東江 三角州地域의 갈대초지에 있어서 落葉의 有機組成分別 分解率에 관한 研究

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要　　約

洛東江 河口의 갈대草地에 있어서 落葉의 各 有機組成分別 分解率을 調査 研究한 結果는 다음과 같다.

1. 各 有機組成分別 分解率과 이들이 分解되는데 所要되는 時間은 Olson(1963)및 Oohara 等(1971c)의 理論的 模型을 使用하여 計算하였다.

2. 分解常數는 冷水抽出物 2.6743, 其他炭水化物 1.3926, 熱水抽出物 1.255, 纖維素 1.0175, 粗脂肪 0.9233, 木質素 0.4929, 및 粗蛋白質 0.4691로서 各 有機組成分別로 差異가 있었다.

3. 갈대草地에 있어서 落葉의 分解와 蓄積에 대한 漸近線 水準의 切半에 到達하는데 所要되는 時間은 冷水抽出物 0.26年, 其他炭水化物 0.50年, 熱水抽出物 0.55年 纖維素 0.68年, 粗脂肪 0.75年, 木質素 1.41年, 및 粗蛋白質 1.48年이었다.