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The Removal Rate of the Constituents of the Litters in the Aquatic Plant Ecosystems
Ⅰ. *Phragmites longivalvis* Grasslands in a Delta of the Nakdong River

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수생식물 생태계에 있어서 낙엽의 구성성분의 유실률
Ⅰ. 낙동강 삼각주지역의 갈대 초지

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ABSTRACT

An investigation was performed to reveal the removal rates of organic constituents of the litters in a *Phragmithes longivalvis* grassland in a Delta of the Nakdong River.

The removal rates of the inorganic and organic materials are determined by the mathematical models. The removal rates and time required to decay up to a percentage of each organic constituent were calculated using these new models. The removal rates of cold water soluble fractions, other carbohydrates, hot water soluble fractions, cellulose, crude fat, lignin and crude protein were 2.67, 1.39, 1.25, 1.02, 0.92, 0.49 and 0.47, respectively. The periods required to reach half time to the steady state of the removal 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.

Key words : *Phragmites longivalris*, Removal rate, Organic constituents

INTRODUCTION

The removal rates of the litter productions and losses afford a reliable index to evaluate the water purification. There are a few reports about the addition and decomposition of the pollutants in water. According to Chang and Kim(1993), the self purification model of organic matter in the river water was reported as the bases of the decay models of the organic materials.

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 and the high content of hot water soluble materials. Broadfoot and Pierre(1936) 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(1954), on the other hand, found no consistent correlation with any chemical property of the litter when species were compared. Viro(1956) reported that weak correlation with the base content of the litter. Kim and Chang(1975) working with the oak and pine forests found that factors affecting the decomposition rates of the litter are humus, organic carbon, moisture content, calcium, phosphorus, and nitrogen and 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), Chang and Yoshida(1973), and Chang et al. (1987) reported that there were differences among the decay velocities 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 the *Phragmites longivalvis* grassland in a Delta of the Nakdong River have been made to compare with the removal rates among the organic constituents.

MATERLIALS AND METHODS

1. Study area

The study area in which the samples were collected was shown in Fig. 1. The study area is located 13 km 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 summer and cold dry winter and adequate rainfall ranging 1,300 mm to 1,400 mm annually. About 59%

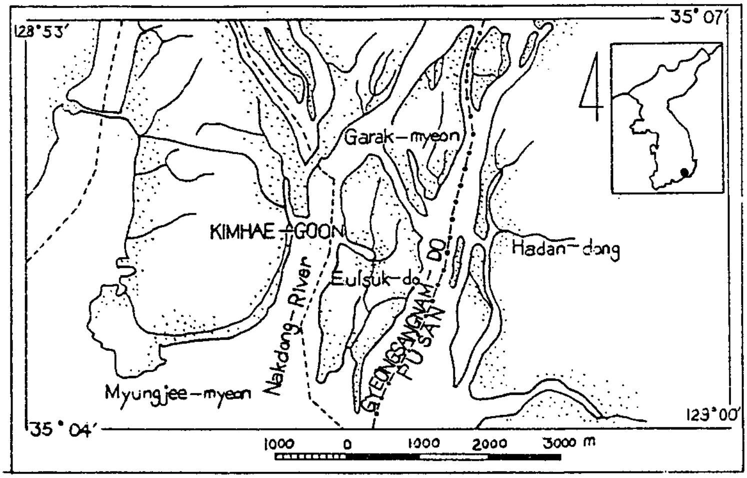

Fig. 1. Map showing the location of the study area.

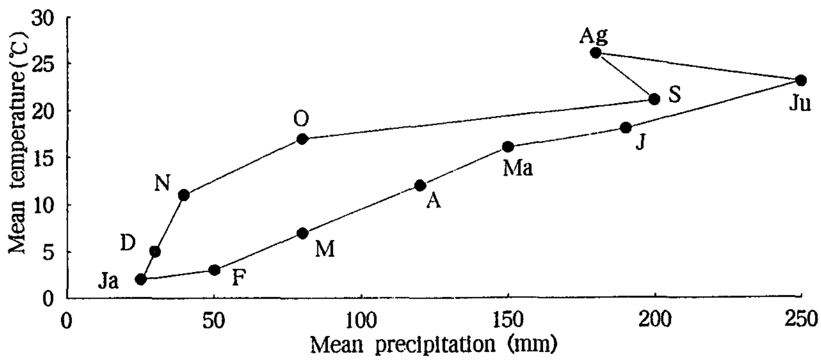

Fig. 2. Hythergraph for the study area, a delta of the Nakdong River.

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. longivavis* was widespread in all the study area.

2. Methods

The samples of the litters and soils were collected in the *P. longivavis* grassland. The litters were collected from the L, F, H and A1 horizons on August 29, 1994. The soil samples were collected from 9 depths in each 5 cm interval down to 45 cm. To obtain the litter and soil samples, a block of soil measuring 50 cm × 50 cm 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), and Oohara et al. (1971c). Chemical analyses of lignin and cellulose were determined by the methods of Crapton and Maynard(1938), and Oohara et al. (1971c). Total nitrogen content was determined by the micro-Kjeldahl method. The pH was determined in a 1 : 2.5 for soil samples and a 1 : 10 for litter samples: sample : water suspension, by use of a glass electrode assembly. Either 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.

THEORETICAL MODEL

In the river water, the loss of the litters of the aquatic plants depend on the removal rates of soluble and insoluble fractions, that is, the water removal velocity. Since the removal rates of the river water can not be determined exactly during one year, the balance of annual production and accumulation of the litters in the aquatic ecosystems is investigated by an unit time of one year basis.

In the removal of litters, let O be the amount of organic matter contained in the liter per square meter on the river bed surface and the annual income of litter organic matter be A, then according to Chang and Yoshida(1973),

$$\frac{dO}{dt} = A - rO \quad \cdots\cdots (1)$$

In the equation (1), r is the removal constant.

For the case in which the annual litter production is almost steadily falling at a annual rate A, the equation (1) can be rewritten as follows;

$$\frac{dO}{\frac{A}{r} - O} = -rdt$$

Then the above equation is integrated as following;

$$\ln\left(\frac{A}{r} - O\right) = -rt + \text{constant} \quad \cdots\cdots (2)$$

In an initial condition with no river bet, O=0 at t=0, and the constant in the equation(2) is -ln(A/r). The antilog of the equation (2) gives the solution as follows;

$$O = \frac{A}{r}[1-\exp(-rt)] \quad \cdots\cdots (3)$$

According to Chang and Yoshida(1973), the net accumulation model for the organic constituents of the the litters is given by

$$O_i = \frac{A_i}{r_i}[1 - \exp(-r_i t)] \quad \cdots\cdots (4)$$

where i is the kinds of organic matters such as crude protein, crude fat, lignin, other carbohydrates of the annual litter. The removal and accumulation models of cold and hot soluble fractions are also developed by the same concepts.

If the special case in which there is no annual litter fallen, A=0, 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;

$$\frac{dO}{dt} = -rO \quad \cdots\cdots (5)$$

or $\frac{dO}{O} = -rdt$

Let the initial amount of organic matter at t=0 be Oo, and the amount remaining after a certain period of time t be O, the equation (5) can be rearranged as following in estimating the removal content.

$$\ln\left(\frac{O}{Oo}\right) = -rt$$

Antilogarithms of both sides of the above equation give the fraction remaining as a negative exponential fraction.

$$\frac{O}{Oo} = \exp(-rt)$$

$$\text{or} \quad O = Oo \exp(-rt) \quad \cdots\cdots (6)$$

The time which is required for the organic matter O to decrease up to half (50%) of Oo can be calculated from the equation (6) as follows;

$$\frac{Oo}{2} = Oo \exp(-rt)$$

$$\frac{1}{2} = \exp(-rt)$$

and thus

$$t_{50\%} = \frac{\ln 2}{r} = \frac{2.303 \log 2}{r} = \frac{0.693}{r} \quad \cdots\cdots (7)$$

When the O decreases to 95% or 99% of Oo, the value of t is as following, respectively;

$$t_{95\%} = \frac{3}{r} \quad \cdots\cdots (8)$$

$$t_{99\%} = \frac{5}{r} \quad \cdots\cdots (9)$$

According to Oohara et al.(1971) and Chang and Yoshida(1973), since the litter is analysed into the crude protein, crude fat, cellulose, lignin, and other carbohydrates, the net removal rates of the litter per unit time are given by

$$\frac{dO}{dt} = \frac{\partial Pc}{\partial t} + \frac{\partial Fc}{\partial t} + \frac{\partial Ce}{\partial t} + \frac{\partial Li}{\partial t} + \frac{\partial Oc}{\partial t} \quad \cdots\cdots (10)$$

where O, Pc, Fc, Ce, Li and Oc are the contents of organic matter, crude protein, crude fat, cellulose, lignin and other carbohydrates, respectively, and t is time in year. The equation (10) can be rearranged as

$$\frac{dO}{dt} = - r_1Pc - r_2Fc - r_3Ce - r_4Li - r_5Oc$$

$$\text{or } rO = r_1Pc + r_2Fc + r_3Ce + r_4Li + r_5Oc \quad \cdots\cdots (11)$$

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

$$O = Pco\exp(-r_1t) + Fco\exp(-r_2t) + Ceo\exp(-r_3t) + Lio\exp(-r_4t) + Oco(-r_5t) \quad \cdots\cdots (12)$$

where Pco, Fco, Ceo, Lio and Oco are the initial levels of each constituent.

RESULTS

1. The contents of the organic constituents of the litter on the river bed

Table 1 presents the chemical analyses for the organic constituents of the litter samples of *P. longivavis* community in a delta of the Nakdong river. As shown in Table 1, the high percentage of the cellulose, other carbohydrates and lignin were detected. However, a little amount of ether soluble fractions of 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 horizons under F horizon.

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 A1 horizon. The water table of the study area was 55 cm. The range of total nitrogen content of the soil was 0.15% to 0.25%. The range of soil pH was 5.70 to 6.65.

Table 1. Average levels of chemical constituents of the litter in *P. longivalvis* grassland in a delta of the Nakdong River

Horizon	Cold H_2O sol. (%)	Hot H_2O sol. (%)	Crude protein (%)	Ether sol. (%)	Cellulose (%)	Lignin (%)	Other carbohydrates (%)	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	1.04	5.86	1.16	34.57	21.76	16.70	80.05	19.95	5.88
H	1.23	5.65	4.02	0.45	11.61	18.25	8.23	42.55	57.45	6.46
Al	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.

Table 2. The production and accumulation of important organic constituents of the litter in *P. longivalvis* grassland in a delta of the Nakdong River

Hori-non	Cold H_2O sol. (g/m^2)	Hot H_2O sol. (g/m^2)	Cellu-lose (g/m^2)	Lignin (g/m^2)	Other carbohy-drates (g/m^2)	Organic mater (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
Al	8.247	29.073	60.453	77.436	50.459	210.712

2. The estimations of the removal constants for each organic constituents

Table 2 presents the production and accumulation of important organic constituents of the litters of *P. longivalvis* in a delta of the Nakdong River. As shown in Table 2, the production of cellulose was very high.

To compare with the removal rates of the organic constituents, the estimations of the removal rates, r_1, r_2, r_3, r_4, r_5, r_6, and r_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 *P. longivalvis*. These data were indicated in Fig. 3 and Table 2.

As shown in Fig. 3, the estimation of the removal constant for cold water soluble fractions was 2.67, for other carbohydrates 1.39, for hot water soluble fractions 1.25, for cellulose 1.02, for crude fat 0.92, for lignin 0.49, and for crude protein 0.47, respectively. Generally speaking the removal rates for the organic constituents, that of cold water soluble fraction 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.

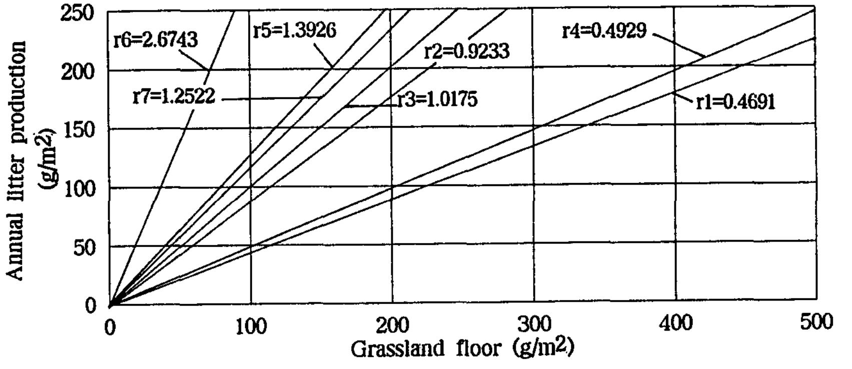

Fig. 3. Estimates of removal factor r for crude protein (r_1), fat (r_2), cellulose (r_3), lignin (r_4), other carbohydrates (r_5), cold- and hot-water-soluble fractions (r_6 and r_7) of the litter in *P. longivalvis* grassland in a delta of the Nakdong River.

3. A comparison among the removal rates of the organic constituents of the litter

Oohara et al.(1971a,b), and Chang and Yoshida(1973) induced the basic concepts for the decay and accumulation models of each organic constituent, and the total models of the organic constituents 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 the steady income and loss were also compared with stepwise increase for additions and losses of the liter in the idealized grassland ecosystem(Oohara et al., 1971a). The accumulation curves are the mirror images of the curves for removal loss, shown in Fig. 4, for the various cases of r_1, r_2, r_3, r_4, r_5, r_6, and r_7 in yearly units.

Table 3. The parameters and periods (years) for remove and accumulation of the organic constituents in a *P. longivalvis* grassland in a delta of the Nakdong River

	r	1/r	$t_{1/2}$	$t_{1/20}$	$t_{1/100}$
Organic matter (r)	0.8835	1.1319	0.7844	3.3957	5.6595
Crude protein (r_1)	0.4691	2.1317	1.4773	6.3951	10.6585
Crude fat (r_2)	0.9233	1.0831	0.7506	3.2493	5.4155
Cellulose (r_3)	1.0175	0.9828	0.6811	2.9484	4.9140
Lignin (r_4)	0.4929	2.0288	1.4060	6.0864	10.1440
Other carbo. (r_5)	1.3926	0.7181	0.4976	2.1543	3.5905
Cold H_2O sol. (r_6)	2.6743	0.3739	0.2591	1.1217	1.8695
Hot H_2O sol. (r_7)	1.2522	0.7986	0.5534	2.3958	3.9930

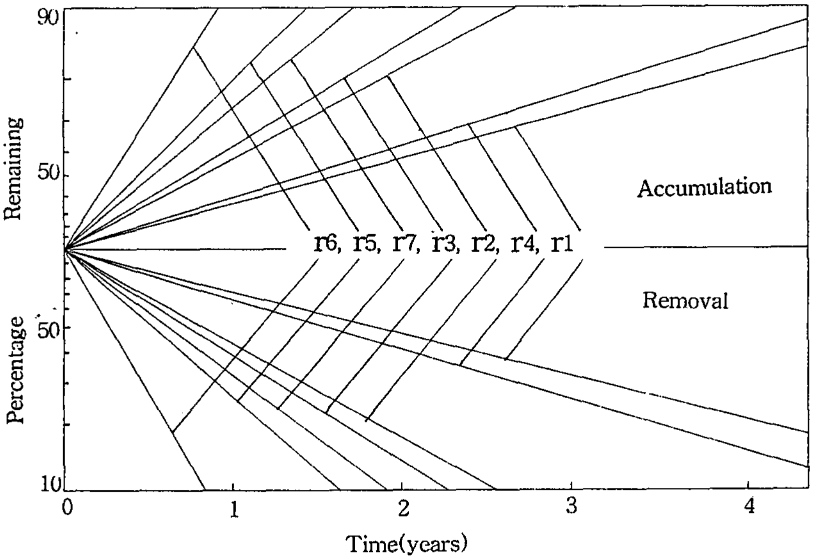

Fig. 4. Estimates of removal rate factor r for crude protein (r_1), crude fat (r_2), celluloe (r_3), lignin (r_4), other carbohydrate (r_5), cold and hot water soluble fractions (r_6) and (r_7) of the litter in a *P. longivalvis* grassland in a delta of the Nakdong River.

A convenient virtue of those exponential models is the time required for the removal loss of half of the accumulated organic matters. Furthermore, it permits the calculation of the time required to remove or accumulate a certain percentage of the litter such as 95% and 99%.

The periods for 50%, 95% and 99% were selected respectively in Table 3 to compare the removal loss and accumulation among the organic constituents of the litter in a aquatic plant ecosystem. Table 3 indicates that the time required to reach a steady state or the zero level for crude protein, crude fat, cellulose, lignin, other carbohydrates, cold and hot water soluble fractions of the litter varied to each organic constituent.

DISCUSSION

While some organic fraction of the solar energy fixed by synthesizing plants is released by respiration of microorganisms, plants and animals, some of it is stored in dead organic and living organic matter on top of the mineral soils until removed by flow water and released by decomposing organism which decompose the organic matters(Olson, 1963; Oohara et al., 1971c; Chang and Yoshida, 1973). According to Daubenmire and Prusso (1963), the rate of decay of plant litters would appear to be governed by three factors: (1) the physicochemical properties of the substrate, (2) the environment under which decay takes place, and (3) the species active under the particular substantial and environmental conditions.

Large amounts of organic matters are decomposed by decaying organism such as fungi, bacteria and certain animals(Olson, 1963). But the decomposition of the litter, accumulated on the top of the mineral soil, involves leaching by snow or rain water and decay 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 crude protein and lignin were decomposed more slowly than any 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(Oohara 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 that the highest decay velocity is affected by leaching seems to reflect the concerted influence of the properties of substrates and microorganisms.

In this study, 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 microorganism as energy sources(Oohara et al., 1971c). Therefore, it 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 microclimate at four latitudes and found that the 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 microorganisms 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, the decay rates increase with increasing temperature, at least through the range of 10~30℃ and over 16 weeks. 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 and removal 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 such as chlorophyll a and b, and carotene were affected by other decomposers except microorganisms such as light rays but the decomposition of fat, wax, resin, etc. of these ether soluble fractions was governed by microorganisms.

The lignin was decomposed more slowly than any other organic constituents except the crude protein. The lignin seems to be resistant to decomposition. The decay velocity of crude protein was slowest of all organic constituents. 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 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 microorganisms.

요 약

낙동강 하구의 갈대 초지에서 낙엽의 각 유기조성분별 유실율을 조사 연구하였다. 그 결과는 다음과 같다.

1. 수중식물이 생산하는 낙엽의 유기물의 유실을 나타내는 수학적 모델을 이론화하고, 각 유기조성분별 유실과 이들이 유실되는 데 소요되는 시간을 측정하였다.
2. 유실상수는 냉수추출이 2.67, 기타탄수화물이 1.39, 열수추출물이 1.25, 섬유소가 1.02, 조지방이 0.92, 목질소가 0.49, 및 조단백질이 0.47로서 각 유기조성분별로 분해상수의 차이가 있었다.
3. 낙동강하구 갈대 초지에 있어서 낙엽의 유실과 축적에 대한 점근선 수준의 절반에 도달하는 데 소요되는 시간은 냉수추출물 0.26년, 기타 탄수화물 0.55년, 섬유소 0.68년, 조지방 0.75년, 목질소 1.41년 및 조단백질 1.48년이었다.

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