Kor. Turfgrass Sci., 9(4), 275~284, 1995

The Energy Flow and Mineral Cycles in a *Zoysia japonica* and a *Miscanthus sinensis* Ecosystem on Mt. Kwanak 4. The Cycles of Phosphorus

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관악산의 잔디와 억새 생태계에 있어서 에너지의 흐름과 무기물의 순환 4. 인의 순환

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ABSTRACT

In this investigation, the accumulation, mineralization and annual cycle of organic P has been studied in grassland ecosystems of a *Z. japonica* grassland and a *M. sinensis* grassland on Mt. Kwanak. The basic models of the accumulation and mineralization for ash components of a grass-litter have been presented as the equations (1), (2), and (3). The equations (7)~(10) for organic P are derived from these basic concepts.

There was a highly significant relationship between organic matter and organic P. The estimates between organic matter and organic P correlated very high significance. The parameter factors k or k' of mineralization of organic P for the *Z. japonica* and *M. sinensis* grasslands were k=0.412 or k'=0.292 and k=0.224 or k'=0.183, respectively.

The time required for a cycle to be completed from organic P to inorganic P of 50, 95 and 99 % are 3.9, 16.7 and 27.8 years in the *Z. japonica* grassland and 4.1, 17.7 and 29.4 years in the *M. sinensis* grassland.

The annual P cycle formulae for mineralization were based on the equations (5), (11) and (12). Annual yields of mineralization for organic P in the steady state grasslands of *Z. japonica* and *M. sinensis* were 0.407 and 0.504g / m^2, respectively.

Key words : *Zoysia japonica, Miscanthus sinensis,* Mt. Kwanak, Phosphorus cycles

INTRODUCTION

Variation of the amount of demand for available P in establishing and maintaining the high production of grasses is considered to constitute a significant difference between the soil characteristics and the vegetal patterns. Soil inorganic P and fertilizer P usually are the most important P sources in grass growth(Oohara et al., 1971).

Since most of the volcanic ash soil in Hokkaido, Japan, is unusually high in active aluminium, soluble P applied in this soil is fixed in an insoluble state. Hence, Oohara et al. (1963 a, 1963 b, 1969) and Drake et al. (1968) have demonstrated that on soils being low in available P and with a great capacity to fix soluble P, the principle of applying large amounts of fertilizer P in precision bands before planting has been highly effective in establishing and providing P to sustain high yields of improved legume-grass forage.

The importance of soil organic P in plant nutrition was demonstrated by a number of investigators (Acquaye, 1963; Eid et al., 1951, 1954; Fried et al., 1960; and Van Diest et al., 1959).

Organic P, however, assumes great importance only in situations where it forms the main reserve in various sources of organic matter for replenishing grass available P. In such environments, the significance of the organic P fraction depends on the rate of mineralizaton of organic matter, since grasses obtain their P mainly in the inorganic form. The mineralization of soil organic P is influenced by all the factors that affect microbial activity and their counts. Of these, temperature, moisture, soil reaction, and supply of energy materials are of special relevalance. In this respect soil organic matter is an important energy source for the soil microbial population. The mineralization of organic P from this source depends, among other things, on the organic P content of the organic matter in relation to the microbial demand. In this investigation, the mineralization, accumulation and annual cycle of litter organic P were studied in two grassland ecosystems on Mt. Kwanak.

MATERIALS AND METHODS

The samples of the grass-litter were collected from the same habitats as in the previous papers (Chang et al. 1995a & b).

Organic P was estimated as the difference between the inorganic P extracted from comparable ignited (at 550℃) and unignited soil samples (Sanuder and Williams, 1955; Oohara et. al., 1971). Available P was extracted by shaking each 3.57g sample in a shaker, for one minute, with 25mℓ of 0.03 N NH_4F. The extracted P was determined by the molybdenum blue, stannous chloride method of Yuen and Pollard(1955). The pH was determined in a 1:25 (for A_1 and H samples) and 1:5 (for F or L samples), soil: water suspension, by the use of a glass electrode assembly.

ANALYSIS MODELS FOR MINERALIZATION

Since a grass-litter(L) consists of organic matter (Lo) and ash (La), the basic concepts of Oohara et al.(1970 a, b & c) are defined as follows:

$$\begin{aligned} L &= Lo+La \\ &= (Lpc+ Lfc+Lbc+Lnf)+La \\ &= (Lpc+Lfc+ Ls+LG+LH)+La \end{aligned}$$

where Lpc, Lfc, Lbc, Ls, LG and LH are crude protein, crude fat, crude fiber, N-free extant, cellulose, lignin and other carbohydrates of a grass-litter respectively.

The decay rate of a grass-litter at an instant in time (t) is

$$\begin{aligned} \frac{dL}{dt} &= \frac{dc}{dt} + \frac{dt}{da} \\ &=(\frac{\partial Pc}{\partial t} + \frac{\partial Fc}{\partial t} + \frac{\partial Bc}{\partial t} + \frac{\partial Ng}{\partial t}) + \frac{da}{dt} \\ &=(\frac{\partial Pc}{\partial t} + \frac{\partial Fc}{\partial t} + \frac{\partial S}{\partial t} + \frac{\partial G}{\partial t} + \frac{\partial H}{\partial t}) + \frac{da}{dt} \end{aligned}$$

where $\frac{dc}{dt}$ is the same rate as set forth in the previous papers (Oohara et al., 1970 a, b & c) and $\frac{da}{dt}$ is the rate of change of mineralization for the grass ash. The ash of a grass-litter is analyzed into various mineral oxides such as P, K, Ca, Mg, Na, Fe, Mn, Cu, Co, Zn, Mo etc. Therefore, the decay rate of ash $\frac{da}{dt}$ holds the following relationship.

$$\frac{da}{dt} = \frac{\partial P}{\partial t} + \frac{\partial K}{\partial t} + \frac{\partial Ca}{\partial t} + \frac{\partial Mg}{dt} + \frac{\partial Na}{\partial t} + \cdots \quad (1)$$

The models of the accumulation and decomposition on the grassland floor are expressed by the same principles as in the previous papers(Oohara et al., 1970 a, b, c & d). However, since the litter ash in samples of F, H, and A_1 horizons can not be analyzed, each mineral nutrient must be considered separately. Thus each mineral nutrient of organic form and inorganic form are determined by chemical methods and then the respective mineralization is analyzed by the following theoretical models. The mineralizatoion for the litter under a grassland ecosystem of a steady state condition is derived from the basic concept of decomposition (Oohara et al., 1970 a).

$$\frac{dM}{dt} = -kM \quad \cdots (2)$$

where M is the weight of mineral nutrient per unit area in soil sampled at depth d, and k is the constant of mineral nutrient mineralized per year. The integrated equation(2) is

$$M = M_0 e^{-kt} \quad \cdots\cdots (3)$$

where M_0 is the weight of mineral nutrient in the soil initially. In the case of a steady state grassland, the characteristics of the soils for a regular annual cycle of mineral nutrients are shown.

The yield of mineralization or annual cycle M_Y of ash constituents at an instant in time is defined as the equation for the annual peak values Fm minus the annual accumulative values Ma.

$$M_Y = Fm - Ma \quad \cdots\cdots (4)$$

The equation (4) is calculated at

$$M_Y = Lm\left(\frac{1-e^{-k't}}{K'} - \frac{1-e^{-kt}}{K}\right) \quad \cdots\cdots (5)$$

where k' is the constant for the theoretical limiting values of the annual peak values.

When the time t limits ∞, $e^{-k't}$ and e^{-kt} approach zero and thus is

$$M_Y = Lm\left(\frac{1}{k'} - \frac{1}{k}\right)$$

Therefore, in steady state grassland the annual cycle of mineral nutrient is

$$M_Y = Lm \quad \cdots\cdots (6)$$

where Lm is the mineral production due to the annual litter addition.

RESULTS AND DISCUSSION

1. Characteristics of the surface soils

Organic P content in surface soils of the *Z. japonica* and *M. sinensis* grasslands varied from 78 to 522 ppm and from 66 to 458 ppm, respectively. The other soil characteristics are shown in Table 1.

There was a highly significant relationship($r=0.742$, $n=8$ & $p=0.018$) between organic matter and organic P(Kaila, 1963; Acquaye, 1963; Sharma et al., 1963; Oohara et al., 1971). These results show that organic matter and organic P varied together in the soils (Table 1).

There was also a significant positive correlation($r=0.737$, $n=8$ & $p=0.018$) between or-

Table 1. Mineralized phosphorus and some characteristics of the soil samples used

Grasslands	Horizon	pH	Organic phosphorus (%)	Available phosphorus (ppm)	Organic matter (%)
	L	5.02	0.522±0.0159	143.2± 7.91	71.77±2.53
Zoysia	F	5.43	0.476±0.0151	56.8± 2.65	35.93±1.93
japonica	H	6.00	0.355±0.0083	24.2± 2.74	16.52±2.11
	A_1	5.74	0.078±0.0079	13.7± 2.09	12.96±1.52
	L	4.89	0.412±0.0362	79.4±11.78	53.42±1.68
Miscanthus	F	4.57	0.458±0.0336	42.9± 6.44	45.46±1.78
sinensis	H	5.70	0.105±0.0117	22.0± 1.76	8.04±1.34
	A_1	5.50	0.066±0.0138	17.1± 2.40	4.45±1.03

ganic P and available P. This suggests that available P is increased by the mineralization of organic P and utilized by the grass, while the soluble erosion by rain water decreases the content of available P in surface soils.

2. Phosphorus mobilization

The estimates for available P correlated very highly significant(r=0.787, n=8 & p=0.010) with the organic matter. This means a possitive proportionality in organic matter and organic P content of the decaying organic matter.

The very low estimates of available P content for the A_1 horizon as compared with L, F and H indicate that there was a luxurious absorption of available P by plants and microorganisms where available P levels were high.

3. The production of organic phosphorus

As show in Table 2 and Fig.1, organic P production is high amounting to 0.407 g/m² in the *Z. japonica* grassland and 0.504 g/m² in the *M. sinensis* grassland. The scattering in any one portion of Fig. 1 indicates that the production and storage of organic phosphorus are not closely related. In fact, the diagram as a whole demonstrates an inverse relation. Low storage of P in the highly productive grasslands contrasts with high levels of organic P accumulation in the relatively unproductive grasslands. A major reason for this inverse relation clearly involves rates at which dead organic matter is broken down or incorporated into the mineral soil by microorganisms.

4. Phosphorus mineralization

As shown in Table 3 the estimates of k or k' ranges and durations of accumulation or mineralization of organic P for the grass-litter were determined in the two grassland ecosystems used. The *Z. japonica* grasslands have values scattered around the line for k=0.412 and k'=0.292, while *M. sinensis* grasslands range down toward the line for k=0.224 and k'=0.183. This suggests that, of the two grasslands the mineralization of organic

Table 2. The estimates of the production and accumulation of organic phosphorus for the surface soils under the two grassland ecosystems on Mt. Kwanak

Grasslands	Horizon	Air dry weight(g/m²)	Water content(%)	Organic phosphorus(g/m²)
	L	780.55± 61.67	23.00±1.32	0.407±0.0157
Zoysia	F	292.51± 2.58	58.50±3.94	0.139±0.0078
japonica	H	553.87± 60.43	36.40±2.89	0.197±0.0085
	A_1	8344.87±599.14	12.96±2.87	0.651±0.0231
	L	1224.91± 66.13	59.73±3.58	0.504±0.0396
Miscanthus	F	2890.33±133.12	59.58±4.77	1.324±0.0795
sinensis	H	6111.25±316.74	25.08±1.10	0.643±0.0533
	A_1	4282.22±306.66	18.20±1.33	0.284±0.0214

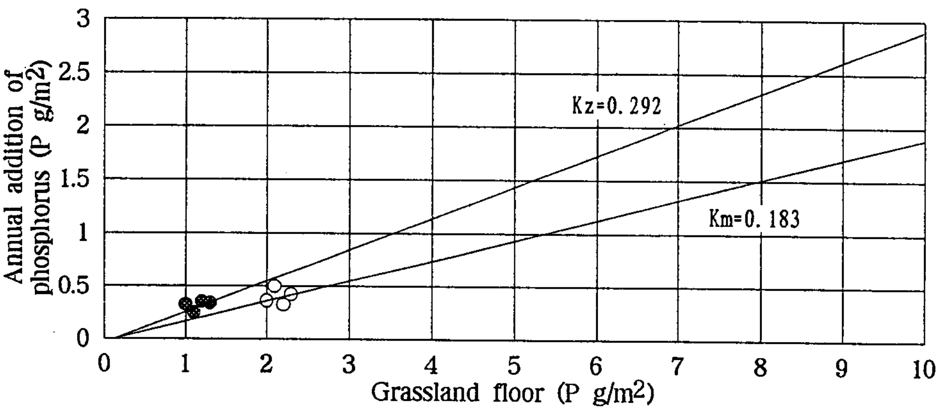

Fig. 1. Estimates of mineralization rate factor k for in *Zoysia japonica* and *Miscanthus sinensis* grasslands, from the ratio of annual addition of P to a steady state accumulation of the grassland floor.

Table 3. Parameters for exponential accumulation and mineralization of organic phosphorus in grassland ecosystems with a steady litter fall rate

Grasslands	Constants	k and k'	1/k and 1/k'	Half time (years)	95% time (years)	99% time (years)
Z. japonica	k	0.412	2.43	1.68	7.28	12.14
	k'	0.292	3.45	2.39	10.34	17.24
M. sinensis	k	0.224	4.46	3.09	13.39	22.32
	k'	0.183	5.56	2.48	16.67	27.78

P was more rapid in *Z. japonica* than *M. sinensis*.

From equation (2) and (3), the theoretical curves of mineralization of organic P for the grass-litter in the present grassland ecosystems are shown Fig. 2. These models for a *Z. japonica* grassland and a *M. sinensis* grassland are given by

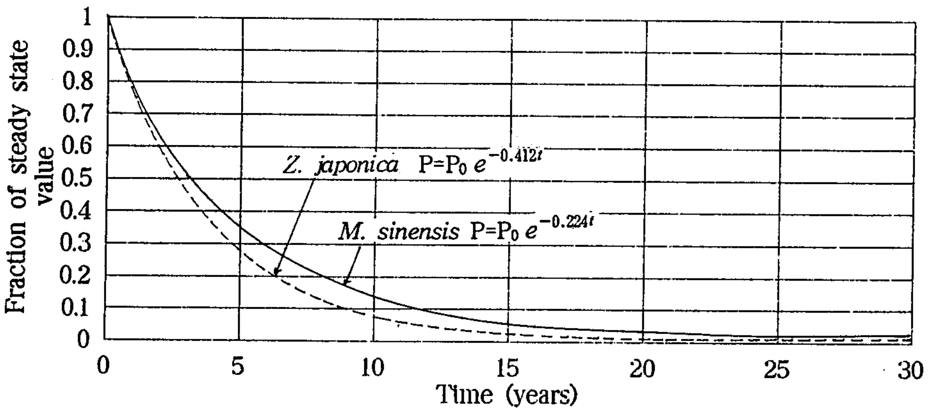

Fig. 2. Exponential curves for mineralization of organic P of grass-litters under the grassland ecosystems of *Zoysia japonica* and *Miscanthus sinensis* on Mt. Kwanak.

$$P=P_0e^{-0.412t} \quad \cdots\cdots (7)$$

and

$$P=P_0e^{-0.224t} \quad \cdots\cdots (8)$$

where P is the organic P content of the remainder for the grass-litter and P_0 is the level of the initial organic P.

Since P is $P_0=0$ at $t=0$, the models of organic P accumulation on the grassland floors are as follows:

In a *M. sinensis* grassland

$$P_A=0.987(1-e^{-0.412t}) \quad \cdots\cdots (9)$$

and in a *Z. japonica* grassland

$$P_A=2.251(1-e^{-0.224t}) \quad \cdots\cdots (10)$$

where P is the accumulation of organic P. Thus mineralization of organic P seems to depend on the phosphorus in the organic form according to the grass species rather than on the C: organic P ratio*(Oohara et al., 1971).

5. Annual cycle of phosphorus

The time required for a cycle to be completed from organic P to inorganic P of 50, 95 and 99% are given by the solution of the exponential models (7)and (8). Table 3 presents these data for the grass litter which are accumulated and decomposed in the two grassland ecosystems respectively.

The important differences among the years for the mineralization of organic P are illustrated by the jagged curves, Figs. 3~4, with peaks and valleys. There is no longer a steady replacement of the P mineralizing between pulses of annual addition by litter fall and the remainder of the steady amount after 1 year of mineralization is less than the amount which had accumulated after either 1 or 2 years of steady addition and mineralization. This deficit below the theoretical level for the steady accumulation is then made up by the second sudden autumn litter fall.

An equation for the annual peak values which occur right after the t-th year's annual addition includes this annual yield of mineralization with accumulation. Therefore, the annual cycle (from the equation 5) is given in the *Z. japonica* grassland by

$$P_Y = 407\left(\frac{1-e^{-0.292t}}{292} - \frac{1-e^{-0.412t}}{412}\right) \quad \cdots\cdots (11)$$

and in the *M. sinensis* grassland by

$$P_Y = 504\left(\frac{1-e^{-0.183t}}{183} - \frac{1-e^{-0.224t}}{224}\right) \quad \cdots\cdots (12)$$

These equations indicate that annual yields of mineralization for organic P in the steady state grasslands of the *Z. japonica* and *M. sinensis* grassland are 0.407 and 0.504 g/m^2, respectively. It is expected that if and when these grasslands are subjected to a complete removal of the accumulated grass litter the same amount as that of the annual yield of mineralized P must be supplied to maintain the steady state conditions of these grasslands.

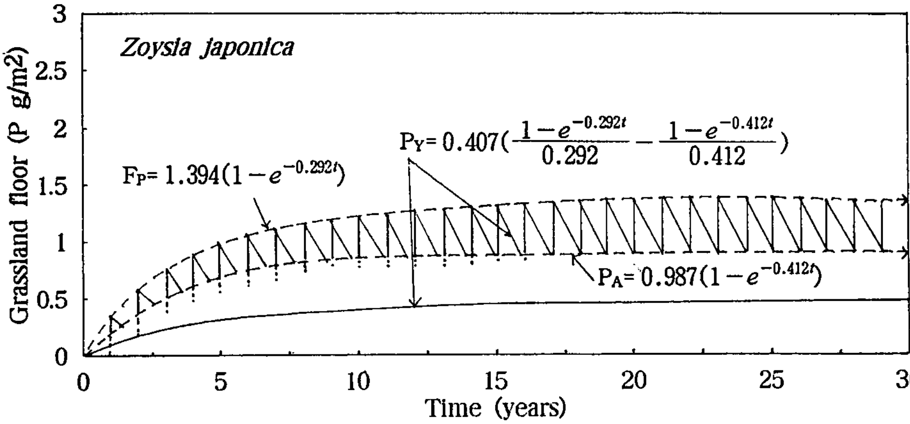

Fig. 3. The annual P cycle for mineralization of grass-litter in a *Z. japonica* grassland on the Mt. Kwanak.

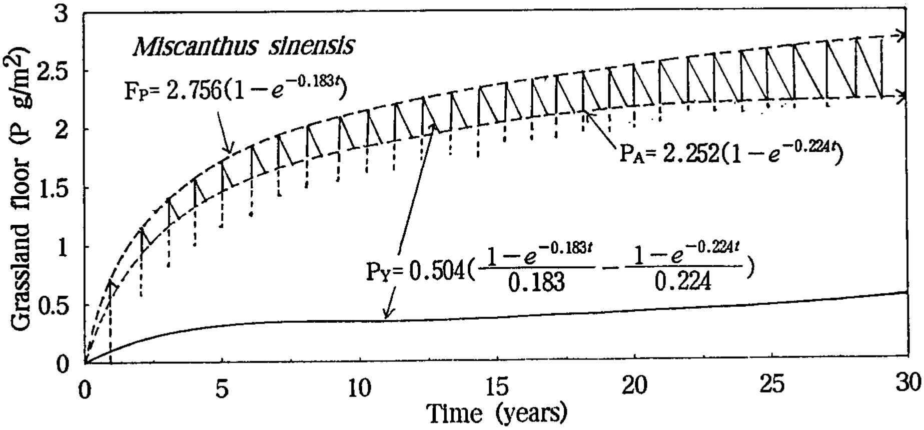

Fig. 4. The annual P cycle for mineralization of grass-litter in a *M. sinensis* grassland on the Mt. Kwanak.

적 요

본 연구는 관악산의 잔디와 억새초지에서 유기인산의 축적과 무기화 및 순환에 대한 것이다. 초지낙엽의 축적과 무기화에 대한 기본적인 식은 식(1), (2), 및 (3)에 나타나 있다. 유기인에 대한 식 (7)~(10)은 이러한 기본적인 개념으로부터 유도한 것이다.

유기물질과 유기인산은 아주 높은 정상관을 보여준다. 유기인산의 무기화 상수 k, k'은 잔디와 억새초지에서 각각 0.412와 0.292 및 0.224와 0.183이었다.

유기인산이 50%, 95%, 99% 무기인산으로 돌아가는데 필요한 시간은 잔디와 억새초지에서 각각 3.9년, 16.7년과 27.8년 및 4.1년, 17.7년과 29.4년이었다.

무기화에 대한 연간 인산순화에 대한 공식은 식(5), (11)와 (12)에 기초한다. 유기인산의 연 생산량은 잔디와 억새초지에서 각각 0.407g/m^2 및 0.504g/m^2 이다.

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