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The Energy Flow and Mineral Cycles in a *Zoysia japonica* and a *Miscanthus sinensis* Ecosystem on Mt. Kwanak 3. The Cycles of Nitrogen

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관악산의 잔디와 억새 생태계에 있어서 에너지의 흐름과 무기물의 순환 3. 질소의 순환

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ABSTRACT

This investigation is carried out to clarify the cycles of nitrogen in the grassland ecosystems of *Zoysia japonica* and a *Miscanthus sinensis* on Mt. Kwanak.

The basic differential equation for the rate of change of nitrogen storage is illustrated by build-up and turnover of organic nitrogen, particularly in the ecosystems.

The turnover velocity fractions of nitrogen for the *Z. japonica* and *M. sinensis* grasslands were k=0.181 and k=0.166, respectively.

The times required to reach 50, 95 and 99 percent of the steady state levels and turnover values of nitrogen on the grassland floors were 3.85, 16.67 and 27.78 years in the *Z. japonica* grassland and 4.08, 17.65 and 29.41 years in the *M. sinensis* grassland.

The amount of annual cycles of nitrogen are 560.2 g/m^2 in the *Z. japonica* grassland and 654.1 g/m^2 in the *M. sinensis* grassland.

Key words : *Zoysia japonica, Miscanthus sinensis*, Mt. Kwanak, Nitrogen cycle.

INTRODUCTION

The synthesis of organic matter depends on the photosynthesis of the producers in an ecosystem. All the organic matter in a *Zoysia japoonica* and a *Miscanthus sinensis* grassland ecosystem is decayed by the consumers and decomposers. The amount of production of litters in grasslands is closely related to the level of available N, when soil humidity is sufficient. Natural nitrogen input into soils and output from soils of *Z. japonica* and *M. sinensis* grasslands are not clearly defined.

The changes in an environment shift the N contents toward a new steady state of the litter production and decay. Ultimately, annual climate homogeneity of the ecosystem will result in a continuing balance between the nitrogen losses and gains in the grassland ecosystems.

Numerous investigators(Jenny, 1941; Walker, 1956; Barthorn and Kirkham, 1960; Jenkinson, 1963; and Jansson, 1963, 1968; Oohara et al., 1971) have used the mathematical model to describe changes in the soil nitrogen as a function of time. Since in the grasslands of the steady state the net velocity of change in the annual addition of nitrogen into soil is equal to the rate of the annual mineralization, this investigation has been performed to elucidate the accumulation and turnover of organic nitrogen on the grassland floor.

MATERIALS AND METHODS

The area and litter samples studied in this investigation were the same with those in the previous papers(Chang et al., 1995a,b). The samples were taken from the boxes, air-dried, and weighed. The litter production was calculated on a dry weight basis. Total organic nitrogen was determined by the micro-Kjeldahl method.

1. Mathematical models

The basic concepts of the decay of the litter also apply to turnover of organic nitrogen (Oohara et al., 1970a; 1971). Therefore, the net velocity of change in the amount of nitrogen in a grassland ecosystem is equal to the rate of addition minus the rate of decomposition. For the model of the annual steady addition of nitrogen to an unit area of soils sampled in the depth, d, the fundamental equation is

$$\frac{dN}{dt} = A - kN \qquad (1)$$

where t is time, N is the amount of nitrogen per unit area in soils sampled in the depth d, A is the annual addition of nitrogen to an unit area of soils sampled in the depth and k is the constant of N decomposed per year.

1) The storage by continuous addition of nitrogen

To calculate the yield of nitrogen, the equation (1) can be rewritten as integrating and transposing, where N_0 is the initial amount of nitrogen in the soil.

$$N = \frac{A}{k} + \left(N_0 - \frac{A}{k}\right) e^{-kt} \qquad (2)$$

2) The turnover with no annual addition of nitrogen

For the special case of A=0, the equation (1) can be rearranged to express the turnover as fraction of the residue N currently remaining.

$$\frac{dN}{dt} = -kN \quad \cdots\cdots (3)$$

The integrated equation (3) is

$$\frac{N}{N_o} = e^{-kt} \quad \cdots\cdots (4)$$

and then

$$N = N_0 e^{-kt} \quad \cdots\cdots (5)$$

It permits the calculation of the time required to transform 50, 95 and 99% of an initial level. That is, these are expressed as $t_{1/2}=0.693/k$ in the case of $t_{1/2}$, as $t_{1/20}=3/k$ in the case of $t_{1/20}$ and as $t_{1/100}=5/k$ in the case of $t_{1/100}$.

3) The evaluation of the constant k

The radio-nitrogen tracer (N^{13} or N^{15}) and dating techniques have been used to show that various fractions or constants of the soil nitrogen mineralized in various velocities. However, there are no long-lived radioactive isotopes of nitrogen.

When the accumulation of nitrogen reaches a steady state condition, Nss, in a grassland ecosystem, the rate of annual addition A is the same with the rate of turnover.

$$A = k\,Nss \quad \cdots\cdots (6)$$

In this case, the fraction k can be estimated by

$$k = \frac{A}{Nss} \quad \cdots\cdots (7)$$

Where A and k can be estimated independently upon N, then their ratio might used to predict the steady state level in a grassland ecosystem which has not yet come to a balance of addition and turnover.

$$Nss = \frac{A}{k} \quad \cdots\cdots (8)$$

RESULTS

Thes site selected for this study were the grasslands of *Z. japonica* and *M. sinensis* on Mt. Kwanak. The production and turnover of nitrogen on the grassland floors were estimated in these areas.

1. The production of nitrogen in grassland ecosystems

Fig. 1 shows a wide range in nitrogen production, plotted along the vertical axis in terms of grams of nitrogen per square meter per year. Annual nitrogen productions of the *Z. japonica* and *M. sinensis* grasslands were average 5.38g and 8.32g N/m^2, respectively. As compared with a *Reynoutria sachalinensis* and a *Sasa purpurascens* grassland in Obihiro, Hokkaido, Japan, those data are high, while those grasslands show low yields (1.00~4.00g N/m^2).

As shown in the total nitrogen percent of the litter of the *Z. japonica* and *M. sinensis* grassland on Mt. Kwanak(Table 1), the scattering points of evaluating in Fig. 1 indicate that the production and accumulation of total nitrogen are not closely related. In fact, the diagram demonstrates an inverse relation as a whole. Under the assumption that grassland floors in the study sites may approximate a steady state, one method of estimating the fraction k can be made from the ratio of the vertical and horizontal coordinates of each point in Fig. 1

2. Estimating turnover fraction k

The estimates of fraction k for nitrogen turnover are collected in Fig. 1 and Table 2. It was determined by Fig. 1 from the data of Table 1. These values show k=0.181 in the

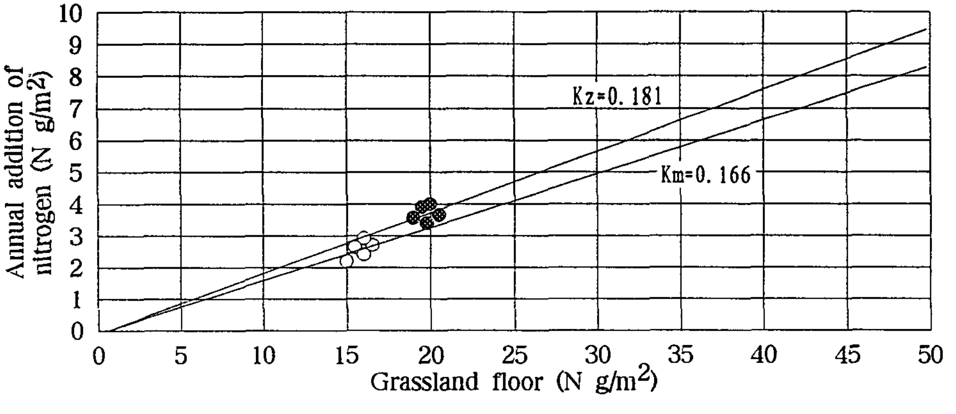

Fig. 1. Estimates of turnover fraction k for nitrogen in a grassland of *Zoysia japonica* and *Miscanthus sinensis* from the ratio of annual N-addition, A, to the approximately steady state accumulation of the grassland floor, Nss.

Table 1. The values of total nitrogen percent and contents of nitrogen (grams per square meter) for each soil horizon of two grassland ecosystems on Mt. Kwanak

Grasslands	Horizon	Soil air dry weight (g/m^2)	Total nitrogen (%)	Total nitrogen (g/m^2)
	L	780.6± 61.67	0.69±0.0256	5.38±0.581
Zoysia	F	292.5± 2.58	1.53±0.1340	4.48±0.314
japonica	H	553.9± 60.43	0.26±0.0289	1.44±0.107
	A_1	8344.9±599.14	0.22±0.0254	18.36±1.530
	L	1224.9± 66.13	0.68±0.0401	8.32±0.482
Miscanthus	F	2890.3±133.12	0.90±0.0755	26.01±1.972
sinensis	H	6111.3±316.74	0.19±0.0095	11.61±0.397
	A_1	4282.2±306.66	0.10±0.0115	4.28±0.301

grasslands of *Z. japonica* and k=0.166 in the *M. sinensis* grassland. The fraction k corresponds not only to the wide variation between nitrogen contents and annual productions of the litter but between nitrogen contents of the soil profiles and nitrogen levels of the annual litter (Table 1).

3. Accumulation of nitrogen on the grassland floor

The significant differences of nitrogen accumulation among the grasslands of *Z. japonica* and *M. sinensis* are expressed in Table 1.

The amount of the total storage of nitrogen in the *Z. japonica* grasslands was average 29.66g $/m^2$ and the *M. sinensis* grassland has an average value of 50.22 g $/m^2$.

The curves for accumulation and turnover of nitrogen in each grassland ecosystem are shown in Fig. 2. As the fraction k increases or decreases, the steady state level $Nss=A/k$ decreases or increases accordingly. Since N is $N_0(=0)$ at $t=0$, the models expressed by the equation (2) give the *Z. japonica* grassland and the *M. sinensis*.

4. The turnover of nitrogen in grassland ecosystems

Since the fraction k has been determined by the equation (7), the turnover models of nitrogen for the two grasslands of *Z. japonica* and *M. sinensis* can be obtained from the equation (5) for the grassland ecosystems at the Mt. Kwanak

The graphical changes of turnover of nitrogen contained in the litter were expressed in

Table 2. Durations of accumulation and turnover of nitrogen on the grassland floors of *Zoysia japonica* and *Miscanthus sinensis* on Mt. Kwanak

Grasslands	Fraction "k"	1/k	$t_{1/2}$	$t_{1/20}$	$t_{1/100}$
Zoysia japonica	0.181	5.56	3.85	16.67	27.78
Miscanthus sinensis	0.166	5.88	4.08	17.65	29.41

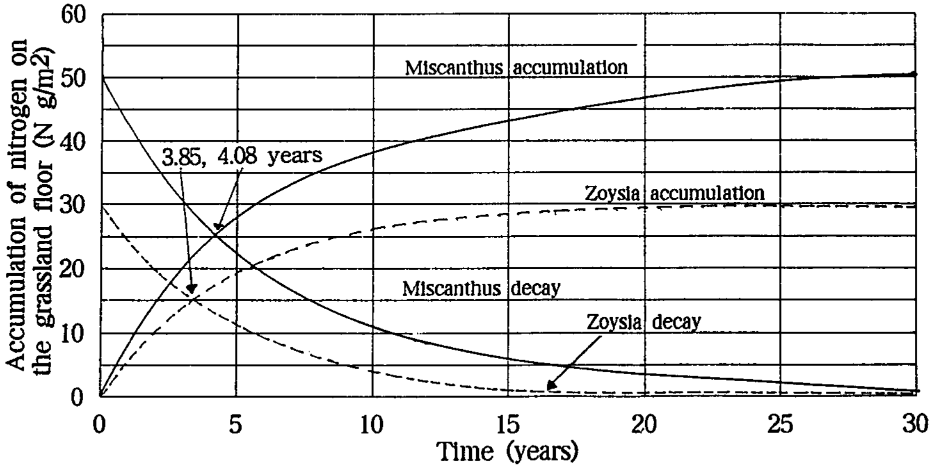

Fig. 2. The exponential equation for nitrogen in the grassland ecosystem of *Zoysia japonica* and *Miscanthus sinensis* on Mt. Kwanak.

Table 3. Parameters for exponential accumulation of nitrogen in the grassland ecosystems with steady state addition A

Grasslands	k	A = 1	A = 2	A = 3	A = 4	A = 5	A = 6	A = 7	A = 8	A = 9
Zoysia japonica	0.181	5.56	1.11	16.67	22.22	27.78	33.33	38.89	44.44	50.00
Miscanthus sinensis	0.166	5.88	11.76	17.65	23.53	29.41	35.29	41.18	47.06	52.94

Fig. 2. This curve is the mirror image of the curve for accumulation of nitrogen on the grassland floor(Fig. 2).

5. Annual turnover cycle of nitrogen in grassland ecosystems

The convenient virtue of the exponential model is that the time required to reach 50, 95 and 99 percent of accumulated nitrogen on the grassland floors are 3.85, 16.67 and 27.78 years in the *Z. japonica* grassland and 4.08, 17.65 and 29.41 years in the *M. sinensis* grassland, respectively.

These periods are estimated by the solution of the equation (5) substituting the values of fraction k. These data are shown in Table 2. Because a small fraction of any one year's production is spent in turnover during early stages of grassland floor accumulation, the storage of nitrogen must continue until the total production becomes so large, the product kN gradually approaches the income A and approximates the balance in the equation (7).

In this case, because the velocity of change in the equation (1) is 0, so the input is equal to the output. The amounts of annual cycles of nitrogen in the grassland ecosystems of *Z. japonica* and *M. sinensis* are 5.38 and 8.32 g /m^2, respectively.

The levels of accumulation on the grassland floor are also obtainable from the equation

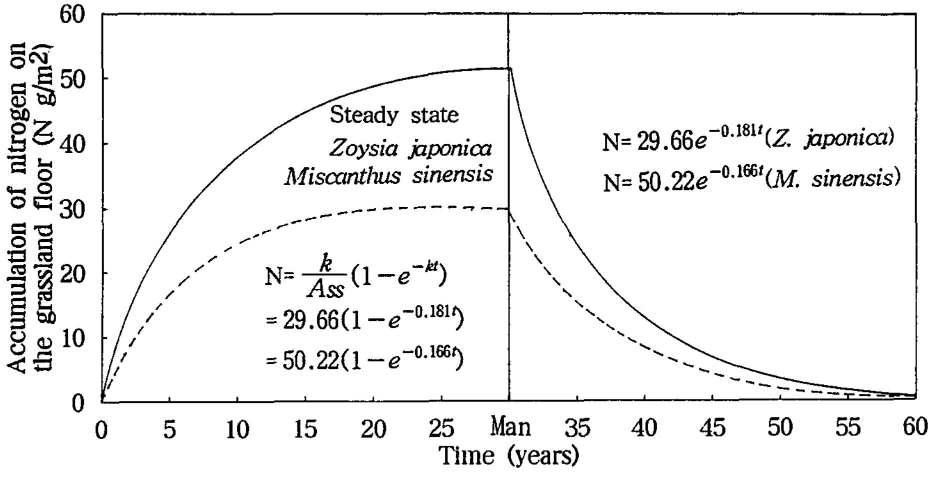

Fig. 3. The predictable illustration of natural build up of soil nitrogen and its subsequent modification by men.

(6) without collection of samples and without the data of analysis of total organic nitrogen. Those of various cases were provided in Table 3.

DISCUSSION

The velocity fraction k measures partly the balance of the effectiveness of producer and decomposer organisms such as green plants, bacteria, fungi and certain animals in synthesizing and breaking down organic materials. Some of this breakdown of the litter which is accumulated on the top of the mineral soil involves leaching and physical transport of materials into the mineral soils does providing income of nitrogen for soil organic matter. Decomposition of the litter on the grassland floor presumably represents N-mineralization from the ecosystem due to respiration of the decomposing organisms. This must be considered in the nitrogen budget of the ecosystem as a whole.

The discussion of this model is essentially given by Jenkinson(1963). He (Jenkinson, 1964 a, b) added labeled C^{14} grass tops and roots to soil and found, even after 4 years, that the decomposition rate of the added plant carbon was still four times that of the native or humus carbon, and that growing grass depressed the decomposition. Paul et al.(1964) measured an apparent mean residence time (mrt) of 99±60 years for the 0 to 15cm soil depth and 1130±70 years for the 15 to 25 cm depth. Canpbell et al. (1967) showed that various mrt values can be obtained when the organic matter of a soil is fractionated. But we must remember that the C^{14}-dating values only represent an average value for all the carbon of the soil, and that the value does not describe the flex of organic material through a given soil.

Under the steady state conditions, the organic matter and nitrogen do not accumulate indefinitely but reach a plateau where the annual mineralizaion balances with the annual addition. The fraction k for nitrogen turnover from such a steady state of the grassland was determined by the equation (7) and the half life was calculated by the equation (5). The half lives for the turnover and accumulation of nitrogen were 3.85 years in the *Z. japonica* grassland and 4.08 years in the *M. sinensis* grassland. (Table 2).

Jansson (1963, 1968) used another approach to study the turnover of nitrogen in soils, He applied labeled fertilizer nitrogen and then measured its recovery over a long interval of time by cropping the soils to oats. The relationship is the analogy with the equation (4). Jansson (1968) assumes that the average annual rate of labeled nitrogen for the years 1962 through 1967 gave approximations of the velocity constant k and using this value of k calculated the half life for fertilizer nitrogen. The half lives ranged from 27 to 53 years depending on the treatment given to the soil.

However, because there are no long-lived radioactive isotopes of nitrogen, a tough question is involved to determine radioactivity of the nitrogen isotope used in this case,

Those investigators did not study the annual cycles of nitrogen in the grassland ecosystems and did not express systematically the theoretical models of turnover and storage like the equations (1), (3) and (6). These objections do not invalidate the basic ideas of the models or the conclusions drawn by those investigators.

Considering the total development of an ecosystem of a pasture, and a grassland storage of nitrogen on the grassland floor will continue only the turn-over like in Fig. 3. So as to maintain and to harvest the annual production of grasses for the steady state levels, managers of a pasture and a grassland must supply the same amount with the annual cycle levels of nitrogen in the form of N-fertilizer.

적 요

본 연구는 관악산의 잔디 및 억새의 초지군락에서 질소의 순환을 규명하고자 한 것이다. 이러한 유기질소의 생성 및 분해는 질소 축적량의 변화속도에 대한 미분방정식으로 설명될 수 있다. 잔디와 억새의 질소량에 대한 분해상수는 각각 k=0.181과 k=0.166으로 나타났다.

축적된 질소가 50%, 95%. 99%로 분해되는데 필요한 시간은 잔디와 억새초지에서 각각 3.85년, 16.67년과 27.78년 및 4.08년, 17.65년과 29.14년이었다. 질소의 연생산량은 잔디가 우점종인 초지에서는 560.2g /m² 이었고 억새가 우점종인 초지에서는 654.1g /m²이었다.

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