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Quantitative Estimates of the Budgets of Nitrogen Applied as Fertilizer, Urine and Feces in a Soil-Grass System

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Abstract
Efficiency and budget of fertilizer and animal nitrogen (N) in a soil-grass system were subjected to analyses with a 15N-tracer method. The utilization efficiency of fertilizer N by orchardgrass was high in spring, while it was low in autumn, depending on seasonal variation in the ability of N uptake by grass and the behavior of soil inorganic N. Annual recovery of labelled N in the orchardgrass sward receiving 250 kg N · ha^{-1} · yr^{-1} was 78-90%, although it was lower in the older sward than in the newly established one. The recovery rates varied among the herbage, the other parts of the plants and soils: i.e. 37-50% in the herbage, 14-18% in the stubbles, litters and roots, and 23-24% in the soil layer up to 50 cm depth. Unrecovered N was 10-22%. The experiment using 15N fertilizer showed that more than half of the N absorbed by grass was derived from soil N. This indicates the importance of N supplying capacity of soil for maintaining grassland productivity. Immobilized fertilizer N in soil contributes to soil fertility through remineralization. The N budget during the 5-year period showed that 76 kg · ha^{-1} of non-labelled N accumulated in the surface soil layer up to 20 cm depth, and 480 kg · ha^{-1} of non-labelled N was removed by cut herbage. This indicates that 556 kg · ha^{-1} of non-labelled N was supplied from outside of the system including the soil below 20 cm. Urine N was readily available, but 40-59% of N was lost from the patches receiving 81-88 N · m^{-2} of urine. Fecal N was less available, and 48-57% of N was incorporated into soli in unavailable forms. Losses of urine N and accumulation of feces N in soil may reduce the efficiency of N returned to pasture through excretion by ruminants.

Discipline: Soils, fertilizers, and plant nutrition/Grassland
Additional key words: animal feces, grassland, N efficiency, orchardgrass

Introduction

While the shortage of nitrogen (N) supply hampers grassland productivity, an excess supply of N often creates environmental problems. Therefore, a quantitative evaluation on N budget in grassland ecosystems is required to adequately manage the N flow for maintaining grassland productivity and environmental quality. This paper attempts to review the results obtained from the studies on quantitative analyses of the N flow in a soil-grass system with a field ^{15}N-tracer method.

The experiments were conducted in a field of orchardgrass (*Dactylis glomerata* L.) sward at the National Grassland Research Institute, located in the central part of Japan. The soil is nonvolcanic alluvial soil (Brown Lowland soil) containing volcanic ash in the surface horizon[6]. The annual precipitation is 1,630 mm, 80% of which falls during the period of April to October. Mean annual air temperature is 12°C.

Utilization efficiency of fertilizer N

N fertilizer is a major input in grass sward. The

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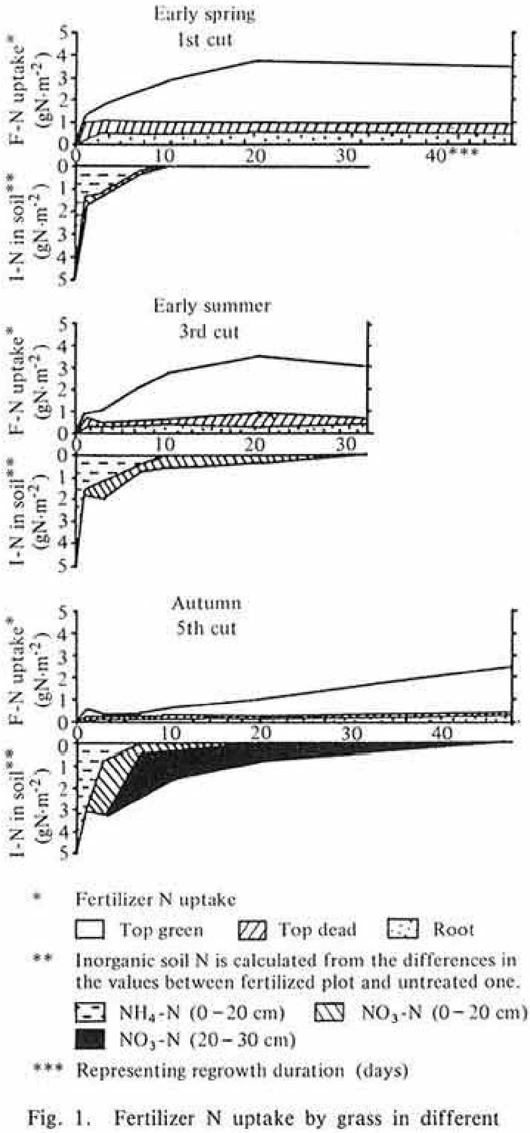

* Fertilizer N uptake

Top green / Top dead / Root

** Inorganic soil N is calculated from the differences in the values between fertilized plot and untreated one.

NH_4-N (0–20 cm) / NO_3-N (0–20 cm) / NO_3-N (20–30 cm)

*** Representing regrowth duration (days)

Fig. 1. Fertilizer N uptake by grass in different seasons

Source: Kimura & Kurashima (1985)[3].

sward in Japan that is intensively cut usually receives 200–300 kg $N\cdot ha^{-1}\cdot yr^{-1}$ as a fertilizer. Although the utilization efficiency of fertilizer N by grass has been studied in the USA and some European countries[7], it is unlikely that the same level of efficiency is applicable to Japan, since it generally has more precipitation and warmer temperature.

Fig. 1 shows the process of plant uptake of fertilizer N and the disappearance of inorganic N in soils in three different seasons, under the cultivation of sward plants receiving 250 kg $N\cdot ha^{-1}\cdot yr^{-1}$ with five equal-split applications. There were seasonal variations in the efficiency of fertilizer N. The fertilizer N applied in early spring was rapidly absorbed by grass, while the rate of fertilizer N uptake reduced in the later season, especially in autumn. The rate of fertilizer N uptake during the early stage of regrowth was lower in the second year than in the first year (Table 1). Inorganic soil N disappeared quickly after the fertilizer application in early spring, but remianed longer in the later seasons, especially in autumn. While in early spring, inorganic N was found in the top 5 cm of soil layer in the form of ammonium N, in the warm season most of it was in the form of nitrate, which was leached out to the subsoil layer by rainfalls in autumn (Fig. 2). It was presumed that the seasonal variation of tiller density of grass, the low activity of root system in autumn after the summer depression and the behavior of inorganic N in soils caused the above-mentioned seasonal variation of N uptake by grass, and as a consequence, the efficiency of applied fertilizer N was kept high in spring and low in autumn.

The result of the studies on the annual budget of fertilizer N in the sward plants receiving 250 kg $N\cdot ha^{-1}\cdot yr^{-1}$ at several stages after the establishment showed that the recovery of applied N in herbage was 37–50% with lower contents in the older swards than in the newly established ones (Tables 2 and 3). Dry matter yield, total N uptake and soil N uptake (N uptake excluding fertilizer N) in herbage were also lower in the older swards. More than half of the total N in cut herbage was derived from soil N. This indicates that the N supplying capacity of soil is important in raising grassland productivity. The other parts of plants (stubbles, litters and roots remianed in the following year) contained 14–18% of the applied N. In the whole grass plants including total cut herbage, stubbles, litters and roots, the recovery of the applied N was 66% in the first year sward, while it reduced to 55–58% in the subsequent years. The soil of 0–50 cm depth immobilized 23–24% of the applied N, irrespective of the sward ages. Over 90% of the immobilized N distributed in the surface 20 cm of soil. Total recovery of the fertilizer N was as high as 90% in the first year sward, and 78–81% in the following years with a small variation among the sward ages. Annual loss of the fertilizer N accounted for 10% in the first year, and 19–22% in the subsequent years.

Table 1. Seasonal variation in the recovery and uptake rate of fertilizer N

Season of application	1st-harvest year		2nd-harvest year	
	Uptake rate[a] (N $g \cdot m^{-2} \cdot day^{-1}$)	Recovery[b] (%)	Uptake rate[a] (N $g \cdot m^{-2} \cdot day^{-1}$)	Recovery[b] (%)
Early spring	0.37	74	0.29	70
Early summer	0.33	78	0.27	60
Autumn	0.15	60	0.06	49

a): Mean for the first 10 days after the application of fertilizer.
b): Recovery of applied N in the whole grass (top and root).
Source: Kimura & Kurashima (1985)[3].

Table 2. Dry matter yield and N-uptake of cut herbage in the swards of different ages

Dry matter and N source		Age of sward (year)			
		1st	2nd	3rd	10th
Dry matter	($g \cdot m^{-2}$)	1544[a]	1229[b]	1175[b]	922[c]
Total N	($g \cdot m^{-2}$)	28.9[a]	25.7[b]	24.0[b]	19.3[c]
Fertilizer N	($g \cdot m^{-2}$)	12.4[a]	11.1[b]	10.2[c]	9.2[c]
Soil N	($g \cdot m^{-2}$)	16.5[a]	14.6[a]	13.8[a]	10.1[b]
F-N/T-N	(%)	42.9	43.2	42.5	47.7

The values are means of triplet for each age of sward.
Significant differences ($P<0.05$) was found between figures with different alphabetical letters.
Source: Kimura & Kurashima (1985)[4].

Table 3. Annual budget of fertilizer N in the swards of different ages

Distribution of fert. N	Recovery of fertilizer N							
	1st year		2nd year		3rd year		10th year	
	($g \cdot m^{-2}$)	(%)	($g \cdot m^{-2}$)	(%)	($g \cdot m^{-2}$)	(%)	($g \cdot m^{-2}$)	(%)
Whole grass[a]	16.40	65.6	14.41	57.6	13.94	55.8	13.74	55.0
Herbage	12.41	49.6	11.01	44.0	10.15	40.6	9.16	36.6
Stubble	2.28	9.1	1.98	7.9	2.22	8.9	2.00	8.0
Litter	0.21	0.8	0.21	0.8	0.23	0.9	0.76	3.0
Root	1.50	6.0	1.21	4.8	1.34	5.4	1.82	7.3
Soil	6.03	24.1	5.75	23.0	6.07	24.3	5.71	22.8
Total recovery[b]	22.43	89.7	20.16	80.6	20.01	80.0	19.45	77.8
Unrecovery	2.57	10.3	4.84	19.4	4.99	20.0	5.55	22.2

a): Sum of herbage, stubble, litter and root.
b): Sum of the whole grass and soil.
Source: Kimura & Kurashima (1985)[4].

Soil N supply and turnover of fertilizer N

Fig. 3 shows sources of the N absorbed by herbage during the five-year period after the establishment of sward. The N was applied as a ^{15}N-labelled fertilizer at a rate of 250 kg $N \cdot ha^{-1} \cdot yr^{-1}$. The N absorbed by the grass was devided into two components: fertilizer N absorbed within the same year, and soil N. The soil N was divided into the following three sub-sources: non-labelled N absorbed under no N fertilization, non-labelled N additionally absorbed under N fertilization, and turnover N labelled which was derived from soil-immobilized N of fertilizer applied in the previous years. The non-labelled N absorbed by the grass in the plot without N fertilization reduced remarkably in the first two years, and gradually in the subsequent years. On

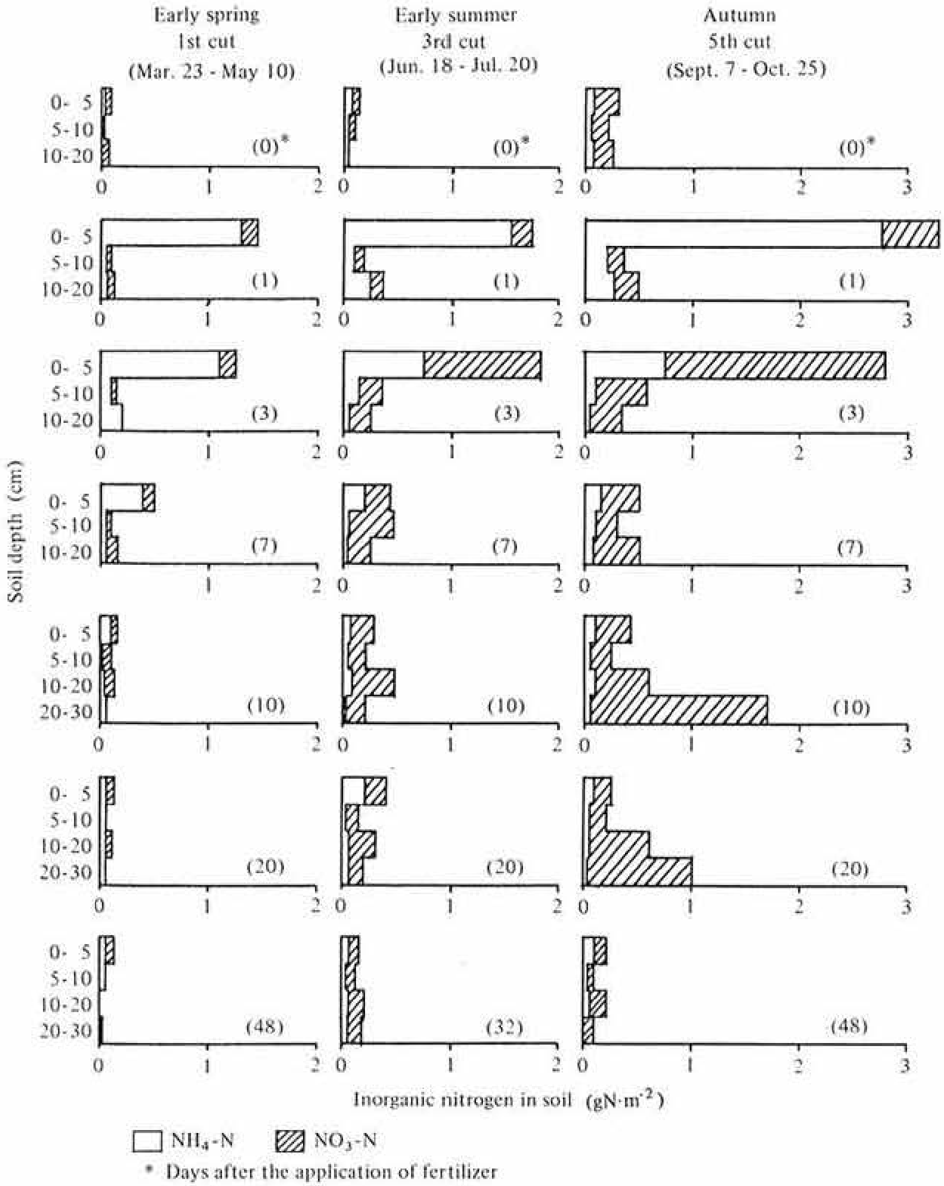

Fig. 2. Distribution of inorganic nitrogen in the soil horizon (2nd-harvest year)
Source: Kimura & Kurashima (1985)[3].

the other hand, the supply of turnover N and additional non-labelled N by N fertilization increased year by year, and exceeded 50% of the total supply of soil N in the fourth and fifth years. These results show that N fertilization to grass sward contributes to maintaining of the N-supplying capacity of soil by turnover of immobilized fertilizer N and by real or apparent priming effects[2].

A comparison between the soil N removed by grass and the remains of fertilizer N in the sward showed that the positive budget at a rate of 63 kg $N \cdot ha^{-1}$ in the established sward was offset by 64 kg $N \cdot ha^{-1}$ of the negative budget at the end of the first year (Table 4). The removal of soil N and the immobilization of fertilizer N were equally balanced in the subsequent years. This indicates that in order to maintain N supplying capacity of soil, at least an equivalent amount of the N which is removed from the soil by cut herbage has to be supplied.

The total N content of surface soil increased year by year. At the end of the fifth year, the N content increased by 20% in surface 10 cm of soil, and by 4% in the next 10 cm of soil layer, as compared with the content at the start of the experiment. It was confirmed that the increase in soil N content was attributed mainly to the accumulation of labelled N, and to a less extent to non-labelled N in the surface soil as well.

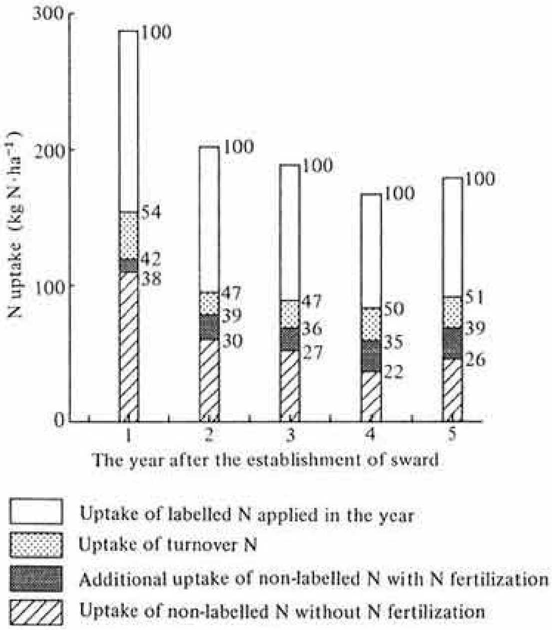

Fig. 3. The source of N absorbed by herbage in 5 years following the sward establishment
Source: Kimura & Kurashima (unpublished).

The N flow in a soil (0–20 cm)-grass system during the five-year period after the sward establishment was summarized in Fig. 4. The sward received 1,350 kg $N \cdot ha^{-1}$ of fertilizer as labelled N. The whole grass plants including cut herbage, stubbles, litters and roots, removed 720 $kg \cdot ha^{-1}$ of labelled N and 400 $kg \cdot ha^{-1}$ of non-labelled N. Although an amount of 480 $kg \cdot ha^{-1}$ of non-labelled N was lost from the root-soil system, non-labelled N gained 76 $kg \cdot ha^{-1}$ in the surface 20 cm of soil. This indicates that 556 $kg \cdot ha^{-1}$ of non-labelled N was supplied to the surface 20 cm of soil layer from an outer-system including the soil below 20 cm depth.

Impacts of urine and feces excreted by ruminants

In intensively grazed pasture, ruminants excrete 75–95% of N ingested at a rate of about 30–100 g $N \cdot m^{-2}$ in the patches of excretion[1]. The N flow through the excretion of urine and feces is one of the important pathways. An attempt was made to evaluate the N efficiency of urine and feces in grassland receiving 100 kg $N \cdot ha^{-1} \cdot yr^{-1}$ as a fertilizer, by using ^{15}N-labelled excreta. The ^{15}N-labelled urine and feces were prepared by feeding sheep with ^{15}N-labelled orchardgrass cultivated with ^{15}N-fertilizer[5].

The microplot experiment simulating urine or dung patches was conducted by applying urine at a rate of 8–88 g $N \cdot m^{-2}$ or feces at a rate of 0.3 kg as a lump of about 10 cm in the diameter. The feces were

Table 4. Comparison of removal of soil N by herbage with remains of fertilizer N in the sward following its establishment

($kg\ N \cdot ha^{-1}$)

Period[a)]	Removal of soil N by herbage (A)	Remains of fertilizer N in the sward[c)] (B)	Difference (B) − (A)
Establishing[b)]	0	63	63
1st year	155	91	−64
2nd year	95	86	−9
3rd year	87	94	7
Sum	337	334	−3

a): The sward received 100 kg $N \cdot ha^{-1}$ at the establishment in September and 250 kg $N \cdot ha^{-1} \cdot yr^{-1}$ in the subsequent years.
b): The period until the application of fertilizer in the following year.
c): Fertilizer N remained at the end of each period.
Source: Kimura & Kurashima (unpublished).

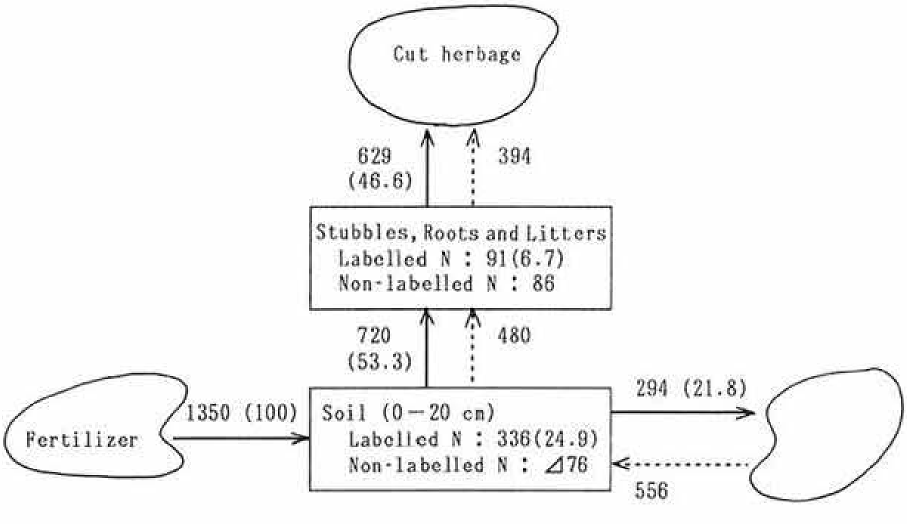

Fig. 4. Summarized budget for 5 years following the sward establishment (g $N \cdot ha^{-1}$)
The sward received 100 kg $N \cdot ha^{-1}$ at the establishment, and 250 kg $N \cdot ha^{-1} \cdot yr^{-1}$ in the following 5 years.
Compartment values are the amount of N presented at the end of experiment.
Delta symbol indicates net change.
Parenthesized values are percentages of applied fertilizer N.
The net N flow is shown as labelled N (—) and non-labelled N (---).
Source: Kimura & Kurashima (unpublished).

Table 5. Annual recovery of urine N and feces N applied at the different seasons

	Urine[a]									Feces	
	Spring			Summer			Autumn			Spring	Summer
	L[c]	M	H	L[c]	M	H	L[c]	M	H		
Herbage	43	44	42	37	39	26	35	35	24	10	12
Remained[b]	5	4	3	7	5	2	9	6	5	7	5
Soil	27	28	15	26	22	13	30	25	14	48	57
Feces	—	—	—	—	—	—	—	—	—	20	0
Unrecovered	25	24	40	30	34	59	26	34	57	15	26

a): Urine is applied at 3 rates (L: 8–9 g $N \cdot m^{-2}$, M: 27–29 g $N \cdot m^{-2}$, H: 81–88 g $N \cdot m^{-2}$).
b): Including stubble, litter and root.
c): Average of the data obtained in 2 years.
Source: Kimura & Kurashima (unpublished).

crushed, mixed and adjusted so that the water content is maintained at 85% in fresh weight before use. The annual recovery of N varied with the rate and the season of application (Table 5).

In the patches received 8–29 g $N \cdot m^{-2}$ of urine, 35–44% and 22–30% of the applied N was recovered in herbage and the top 20 cm of soil, respectively and unrecovered N was 24–35%. In the patches receiving an increased rate of 81–88 g $N \cdot m^{-2}$ of urine, the recovery of the applied N by herbage was 42% in spring, while it remarkably declined to the level of 24–26% in the warm season. The recovery in soil was also reduced to 13–15%. The distribution of immobilized urine N extended to the deeper soil layer with the increase in the rate of N application. Unrecovered urine N accounted for 40% of the N applied in spring and 57–59% of the N applied in the warm season.

Feces applied on the soil surface in summer readily disappeared, but 20% of fecal N applied in spring remained in the residual fecal lump even after a year. Herbage absorbed 10–12% of the applied fecal N in the first year following the application, and only 7% in the subsequent two years. The recovery from soil was 48% and 57% of the N applied in spring and summer, respectively. The unrecovered N accounted for 15–26%.

Although 40–59% of urine N was lost from the patches receiving 81–88g $N \cdot m^{-2}$, a larger amount of urine N might have been lost in intensively grazed pasture, providing that as much as 100 g $N \cdot m^{-2}$ of excreta were supplied. Fecal N is less readily available than urine N, and most of it was incorporated into soil in an unavailable form. Even when the fecal N had been absorbed by grass in dung-patches, most of the grass would not be consumed by grazing ruminants owing to its bad smell and would be returned to soil as litters. As a consequence, the N budget of urine and fecal N under grazing might be somewhat different from the above-mentioned result which is obtained excluding grazing ruminants. Thus, losses of urine N and soil accumulation of feces N may reduce the efficiency of urine and feces in grassland.

Conclusions

This study on the N budget in a soil-grass system showed that during a five-year period, additional 556 $kg \cdot ha^{-1}$ of N other than fertilizer N was supplied to surface soil and grass from outside of the system. Since N input through symbiotic N_2 fixation could not be expected in this system, evaluation of the N supplying capacity of soil should include a subsoil layer.

The above data suggest important roles of the N supplying capacity of soil in maintaining productivity of grasssland, the contribution of fertilizer N to the supply of soil N, and the stable accumulation of fecal N in soil. In improving grassland productivity and related environmental quality, more detailed information on the N flow, including affecting factors and controlling measures, would be required.

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