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Fate of Fertilizer Nitrogen Applied in an Area with High Precipitation in Southern Kyushu

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Abstract

Contamination of shallow groundwater by nitrogen, which has been of great concern recently in Southern Kyusyu, a region with high precipitation, is mainly considered to be brought about by the return of a large amount of livestock waste to arable land. As s result, the fate of excess nitrogen applied to arable land is now being monitored to solve this problem. The results obtained in this study were as follows: 1) The amount of eluviated N ranged from 4 to 28 kg/10 a for the year examined, with a negative correlation between precipitation and crop yields. 2) Eluviation of N in regions with high precipitation was mainly dependent on precipitation factors and involvement of soil factors was limited to low precipitation years. 3) When the amount of applied slurry barnyard manure increased, the rate of N lost (due to volatilization and denitrification) increased. The N concentrations in the soil solutions collected from the plots where a large amount of slurry barnyard manure had been applied decreased with time. In addition, a high concentration of nitrous oxide remained in the subsoils. It was suggested that microbial decontamination of excess N occurred in soil.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: eluviation, nitrate nitrogen, nitrifying activity, nitrous oxide, slurry barnyard manure

Introduction

In Southern Kyushu, the steady increase of nitrate nitrogen concentration in shallow groundwater is becoming a very serious problem, mainly due to the large amount of N liberated from livestock waste as a result of the increase in animal husbandry activities in this region which have been promoted since the 1960s. The sustainability of agriculture from the viewpoint of environmental conservation depends on whether the N-recycling processes which are effectively operating in existing land use systems can incorporate the large influx of N contained in the imported food and feed

*1 Present address: Department of Natural Resources, NIAES (Tsukuba, Ibaraki, 305 Japan) grains. The current situation suggests that the equilibrium of the N cycle has been disrupted in Southern Kyushu in relation to the agro-ecological systems.

In this paper, the current situation and issues of N cycling relating to cattle waste in Southern Kyushu (Kagoshima, Miyazaki) will be reviewed and the fate of N will be described based on experiments that are currently being carried out.

Agriculture in Southern Kyushu and livestock waste

The amount of nitrogen which originates from discharged livestock waste (dairy cattle, beef cattle, horses, pigs, egg-laying chickens, broilers) in Southern Kyushu reaches 6,400 t presently. Fig. 1 shows the yearly changes in the amount of chemical fertilizer N and livestock waste N applied per 10 a of the total planted area. The amount of chemical fertilizers applied is decreasing after both sources of N nearly reached equal amounts in 1975. Assuming that the currently discharged livestock waste is evenly applied to the total planted area, the amount of N would be 25 kg N/10 a (country average is 7 kg), which is equivalent to about 3.6 times the amount of chemical fertilizer N brought into Southern Kyushu.

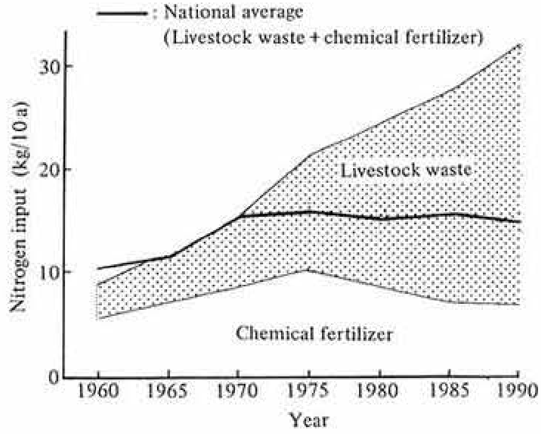

Fig. 1. Yearly changes in nitrogen input in livestock waste and chemical fertilizer in Southern Kyushu

The nitrogen input refers to the rate of nitrogen weight to the total planted area of crops, assuming that all nitrogen is distributed evenly. We calculated the nitrogen weight in livestock waste based on the number of dairy cattle, beef cattle, horses, pigs, egg-laying chickens and broilers, and that in chemical fertilizer based on the amount shipped from factories in this region.

The results of a survey conducted on cattle waste utilization in one community within the Kirishima area (3 cities, 7 towns and villages: arable land area 29,840 ha), where organic matter is often recycled within the cultivated land under management, are introduced here. The Kirishima area is a major producing area for dairy and beef cattle in Miyazaki Prefecture and 75 and 62% of all cattle in the prefecture are concentrated in this area. Thus, the cattle density is 4.9 head/ha and about 55% of the total planted area is covered with forage crops and grasses. In this area, the types of cattle waste returned to the cultivated land vary depending on the size of the farms. For farmers owning more than 2 ha of cultivated land, the waste is being returned mainly as slurry barnyard manure, and for farmers with less than 2 ha, it is being returned as farmyard manure[4]. The average production of slurry barnyard manure including water for washing barns was 21.3 m^3/head/year according to this survey. Therefore the amount for possible application to this area based on the number of feeding cattle and cultivated land area is 11.8 t/10 a, assuming that the slurry barnyard manure is thoroughly reutilized. As this figure is within the range of the recommended standard for slurry barnyard manure application (12 t/10 a/year), it should not be a cause of water pollution. However, practically, the storage capacity of slurry barnyard manure in each farm household is so low that frequent applications occur on fallow land, forest land, etc.

Downward movement of nitrogen and precipitation

Recently, it has been observed that each year the nitrate-N concentrations tended to exceed the value of water quality standard, 10 mg/l (city water), based on studies of shallow well-water. In a survey of well-water (8 – 15 m deep) in an area close to a volcanic upland, it was shown that the concentration of nitrate N exceeded 10 mg/l in 38% of the total wells in the area where the corresponding values were below the water standard for nitrate N in 1979[1].

In Southern Kyushu, one of the areas with the highest precipitation in Japan, since severe eluviation of nutrients is common, the yields of summer crops vary depending mainly on the precipitation (Fig. 2). Based on experiments using lysimeters, the amount of eluviated N was nearly proportional to the amount of percolated water.

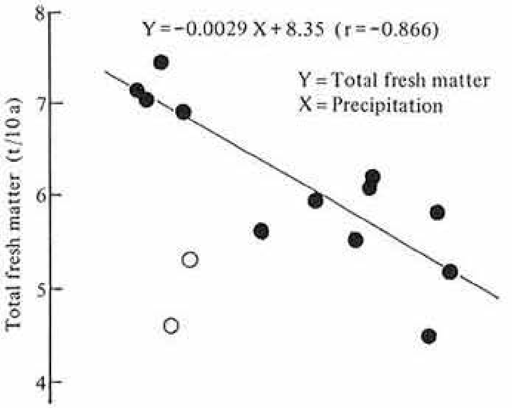

Fig. 2. Relationship between corn yield (cv. Kokei No.10) and precipitation during the vegetative stage
Data from Miyazaki Agricultural Experiment Station, Miyakonojo Branch (presently Upland Crops and Horticulture Branch).
○ : Year with occurrence of insect damage.

In lysimeter experiments (filled in the upper 50 cm zone with coarse-textured volcanic ash soil, Kuroboku and in the sub-layer (50 cm) with pumice, Bora) in Southern Kyushu (Miyakonojo) with an average precipitation of about 2,400 mm, the amount of eluviated N in a year under a soiling sorghum – Italian ryegrass cropping system with fertilizer applied at the recommended standard level ranged from 4 to 28 kg/10 a, most of it resulting from eluviation for summer crops (soiling sorghum cropping season)[3].

Fig. 3 shows the relationship between the amount of eluviated N in the growing season of soiling sorghum (May – August) and total precipitation. The eluviation curve indicates the results obtained under experimental conditions following the recommended standard of fertilizer application at Miyakonojo, including the application of 3 t/10 a farmyard manure (25 kg/10 a of chemical fertilizer N + 27 kg/10 a of N from farmyard manure). The severity of eluviation in Southern Kyushu can be easily recognized by comparing the average amount of

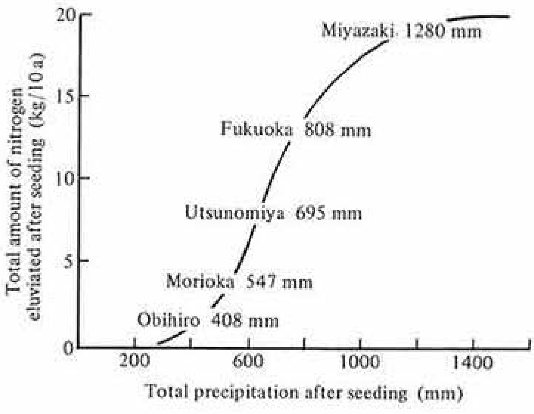

Fig. 3. Effect of precipitation on nitrogen eluviation
The amount of eluviated N was measured in the growing season of soiling sorghum (May – August) with lysimeters.
Chemical fertilizer N: 25 kgN/10 a,
Farmyard manure N: 27 kgN/10 a.

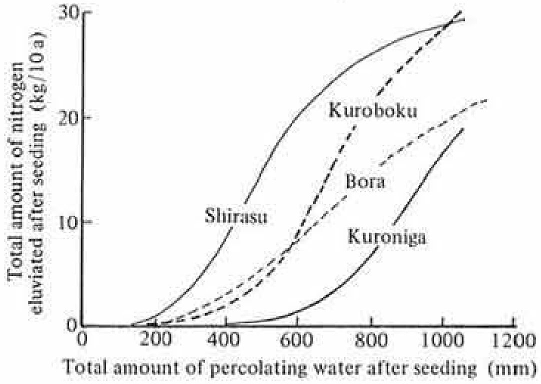

Fig. 4. Difference in nitrogen eluviation curve among 4 soils in growing season of soiling sorghum
Kuroboku: Volcanic ash soil, coarse-textured,
Bora: Volcanic porous gravel,
Kuroniga: Buried volcanic ash soil, fine-textured,
Shirasu: Sandy.

precipitation observed at different locations during the same period plotted on a line. The rise of the slope of the N eluviation curve varied with soil factors affecting water retention in soil, such as soil texture (clay, sand and gravel content) and humus content, though the difference among soils was less pronounced with the increase of precipitation (Fig. 4). In other words, in Southern Kyushu where the precipitation is high, the intensity of the factors affecting N eluviation is in the following order: precipitation factor $\gg$ soil factor.

Decontamination of excess nitrogen by soils

Fate of N when a large amount of slurry barnyard manure is returned to the land, which is a major problem for Southern Kyushu, is described here. Inorganic N in slurry barnyard manure accounts for 50–60% of total N, and thus, the probability of N eluviation is very high in the case of slurry barnyard manure compared with farmyard manure. In field experiments, it is impossible to analyze the precise amount of eluviated N, though a rough estimation can be made if N concentrations in downward percolating water are monitored all the year round.

Fig. 5 shows a comprehensive N balance over 5 years in a forage crop field with a large amount of slurry barnyard manure applied every cropping year. The amount of N of the slurry barnyard manure applied (60 t/10 a/year over 5 years) was 1,239 kg/10 a and the amount of N lost by corn and Italian ryegrass cultivation during the period reached 247 kg/10 a in total. In an approximate calculation about the N balance in a plow layer (0–15 cm), 59% of N was found to be missing. The amount of total inorganic N in the soil layer from 0 to 390 cm, was 80 kg/10 a. Here, the amount of inorganic N in each soil layer was cumulatively determined based on the measurement of the amount of inorganic N and the bulk density (air-dry soil) of the samples collected from each layer (15 cm thick). The results indicated that since a large amount of inorganic N was distributed in the lower layers, N moved downward. However the total amount was only about 9% of that of the missing N–I in the plow layer.

Assuming that the amount of percolated water in a year is 1,000 mm, the amount of eluviated N for 5 years in each soil layer was calculated based on the average N concentration of the soil solutions (n = 26) collected in the lower part of each soil layer (August 1987–March 1990). The results showed that the amount of N eluviated below the 4 m soil layer was 129 kg/10 a or 10.4% of the amount of applied fertilizer N. In addition, a decreasing trend in the ratios of missing N–II was recognized in the lower layers.

Fig. 6 shows the relation between the amount of applied slurry barnyard manure and the changes in N concentrations in the soil solutions collected from the lower part of the Kuroboku horizon (Andosol). The examination was begun on the 3rd year of the start

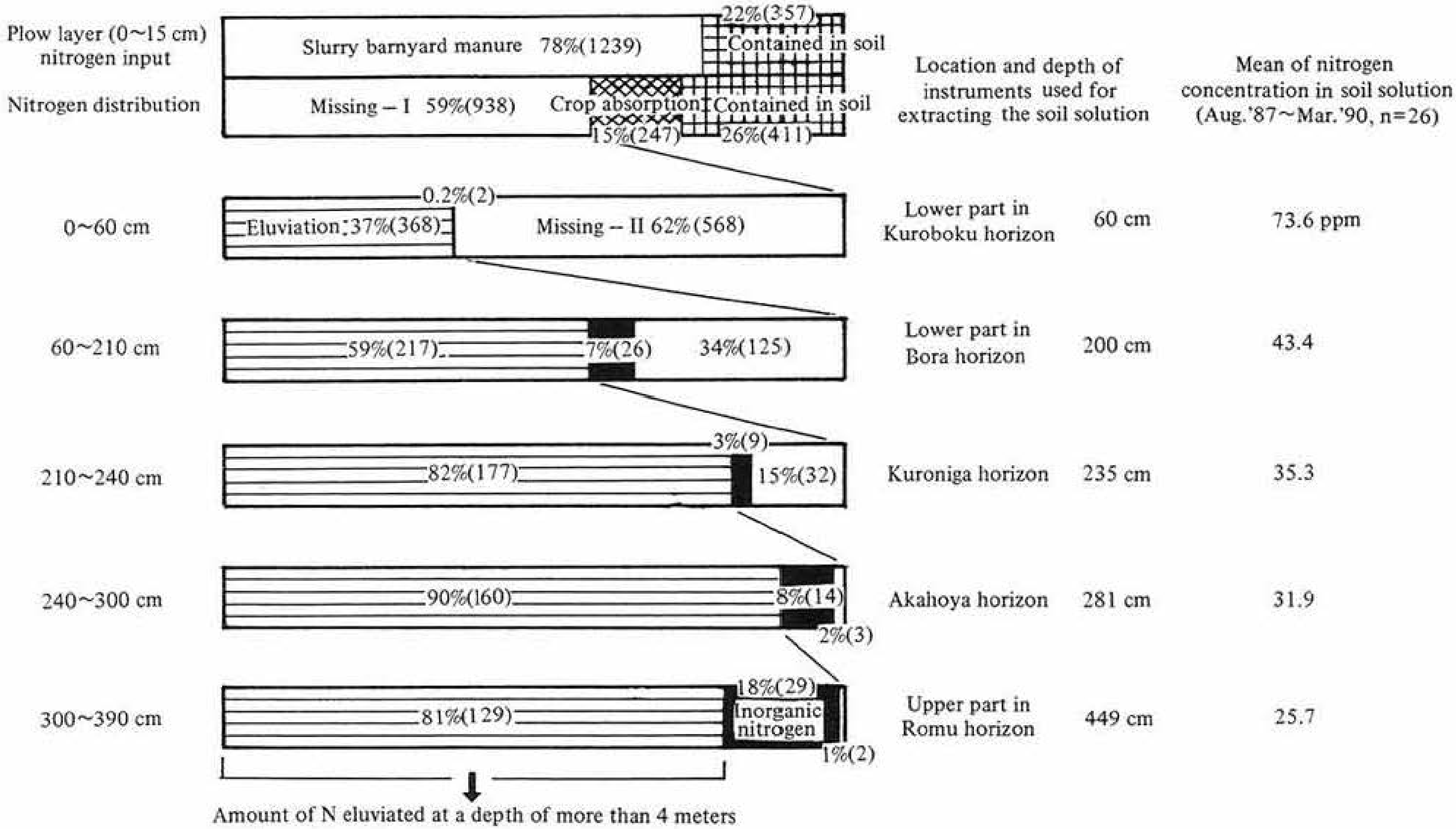

Fig. 5. Nitrogen balance over 5 years in a forage crop field with a large amount of slurry barnyard manure applied every year
Figures in parentheses indicate each amount (kg/10 a).
Amount of nitrogen eluviation: Nitrogen concentration in the soil solution × 5,000 (mm) which corresponds to the amount of percolating water over a 5-year period.

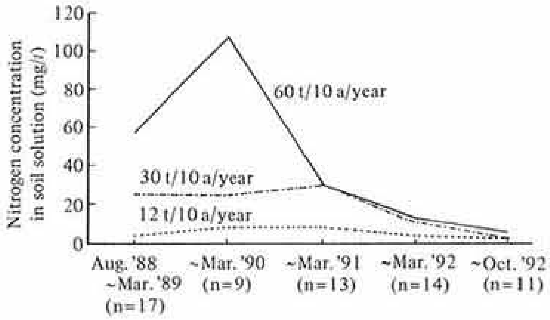

Fig. 6. Relation between the amount of applied slurry barnyard manure and changes in nitrogen concentrations in the soil solutions collected from the lower part in Kuroboku horizon
Extracting depth: 60 – 85 cm.
Nitrogen concentration indicates the mean of each period.

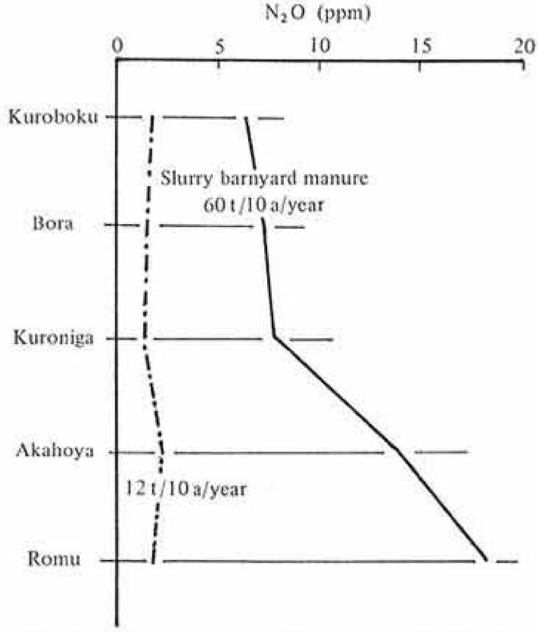

Fig. 7. Concentration of nitrous oxide (N_2O) retained in porous cups buried in the lower part in each soil layer

of consecutive applications of slurry barnyard manure. The N concentrations increased until the 4 to 5th year after the start of applications, and thereafter they decreased in every plot. Particularly, the decrease of the N concentration in the plot with 60 t/10 a slurry barnyard manure application was remarkable with a value of only 1/22 (4.6 mg/*l*) of the maximum concentration. These findings indicate that the ratios of the missing N – II increased in the upper soil layers with time, and became particularly more significant in plots with heavy applications of slurry barnyard manure, as shown in Fig. 5. It is likely that most of the missing N – II was due to volatilization and gaseous release associated with denitrification. Ammonia volatilization immediately after the spread of slurry barnyard manure accounted for 20 – 30% of applied N. Besides volatilization, the disappearance of inorganic N due to immobilization can also occur, in particular when slurry barnyard manure was spread to the crop following Italian ryegrass with a large amount of root residues. The immobilization of N is an effective method for preventing temporarily the downward movement of excess N brought about by the application of a large amount of slurry barnyard manure. However, as already mentioned, waste disposal rather than effective use of organic materials accounts for most of the slurry barnyard manure which is unevenly returned in large amounts. In such a case, methods for removing excess N in addition to conventional N cycling system through denitrification must be developed.

Hayano et al.[2] analyzed in this experimental field the vertical distribution of microorganisms in the soil profiles 45 days after the application of slurry barnyard manure. The analysis showed that the population densities of microorganisms and denitrifying activities in the Kuroboku horizon and the underlying "Bora" horizon of the plot consecutively amended with 60 t/10 a of slurry barnyard manure were higher than those of the plot with consecutive applications of slurry barnyard manure at a standard level (12 t/10 a/year).

The fact that high concentrations of nitrous oxide were retained in the porous cups buried

Table 1. Vertical distribution of various microorganisms

Plot	Soil horizon	(cm)	Bacteria	Actinomycete bacteria	Ammonium-forming bacteria	Ammonium-oxidizing bacteria	Denitrifying bacteria (gas production)	Denitrifying bacteria (C_2H_2 inhibition)	Nitrate-reducing bacteria (loss of NO_3^-)	Nitrate-reducing bacteria (alkali reaction)
			Log cfu/g	Log cfu/g	Log MPN/g	Log MPN/g	Log MPN/g	Log MPN/g	Log MPN/g	Log MPN/g
	Surface in Kuroboku	(0–10)	8.95	7.28	7.59	6.59	7.59	5.32	7.62	7.62
	Lower part in Kuroboku	(40–50)	6.69	6.48	6.76	4.26	3.36	6.41	3.88	6.41
	Upper part in Bora	(98–108)	5.48	5.83	4.95	1.66	1.97	5.52	1.62	4.54
	Lower part in Bora	(180–185)	4.34	3.60	4.11	1 >	1 >	4.38<	0.51	3.49
60t	Kuroniga	(200–210)	4.11	3.92	4.11	1 >	1 >	4.79<	0.85	3.95
	Akahoya	(227–237)	2.79	3.96	3.04	1 >	1 >	3.94	1 >	3.43
	Romu	(293–303)	3.28	2.18	2.20	1 >	1 >	3.19	1 >	2.97
	Seisou-Shirasu	(560–570)	4.76	3.15	3.56	1 >	3.48	3.30	3.34	4.52
	Seisou-Shirasu	(1210–1220)	1.00	1 >	1 >	1 >	1 >	1 >	1 >	1.23
	Irito-Shirasu	(1890–1900)	0.88	1 >	1.08	1 >	1 >	0.71	1 >	1.95
	Surface in Kuroboku	(0–10)	7.92	7.20	7.54<	5.71	4.58	7.11	5.20	6.49
	Lower part in Kuroboku	(40–50)	6.38	6.45	4.94	1.58	2.30	5.79	2.58	4.58
	Upper part in Bora	(98–108)	4.51	5.30	4.61	1 >	1 >	3.79	1 >	3.41
	Lower part in Bora	(180–185)	4.15	4.0>	3.23	1 >	1 >	2.89	0.56	2.54
12t	Kuroniga	(200–210)	4.49	4.49	3.90	1 >	1 >	4.61	1.45	3.95
	Akahoya	(227–237)	2.49	3.32	3.92	1 >	1 >	3.78	1 >	3.46
	Romu	(293–303)	3.53	2.78	3.00	1 >	1 >	3.68<	1 >	2.64
	Seisou-Shirasu	(560–570)	4.52	3.00	4.48	1 >	5.52<	4.36	5.52<	5.52<
	Seisou-Shirasu	(1210–1220)	1.04	1 >	0.88	1 >	1 >	1.28	1 >	1.73
	Irito-Shirasu	(1890–1900)	1.11	1 >	1 >	1 >	1 >	0.67	1 >	1 >

Source: Hayano, K. & Watanabe, K. (1992)[2].

in each soil layer for the collection of soil-solutions (Fig. 7) also supported the above-mentioned assumption regarding the upper layers. The nitrous oxide concentrations increased with the increase of the amount of applied slurry barnyard manure and the depth of the soil layer. As shown in Table 1, since no significant differences were observed in the layers below the "Kuroniga" horizon between the amount of slurry barnyard manure applied and the population densities of microorganisms, it is likely that nitrous oxide seeped from the upper layers down to the lower layers and accumulated there. While the release of nitrous oxide, one of the greenhouse gases, is a problem in terms of the atmospheric environment, the microbial decontamination of excess N in soil seems to be effective to some extent, since denitrifying bacteria could be detected in the "Shirasu" horizon, which occurs at a soil depth of 20 m.

The tolerance capacity for decontamination of the excess N by soils is currently being examined by observing the changes in N concentrations in the groundwater (19 m deep) just below the plots consecutively amended with large amounts of slurry barnyard manure, though no conclusions have yet been reached. However, since the N concentrations in shallow groundwater in Southern Kyushu are actually increasing, it is considered that this phenomenon is due to the increase of the tolerance capacity for decontamination of soil associated with an excessive increase in the number of cattle over a period of 25 years.

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