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Decrease of Nitrate and Restoration of Mineral Balance in Forage Field Soil and Corn Plant in Dairy Farms

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Abstract

Excess nitrogen corresponding to about 2-3 times the amount required for forage plant growth had been applied continuously for many years in dairy farms at Shisui machi, Kumamoto Prefecture in Kyusyu because of the limited area of crop fields. Field experiments with reduced application of animal waster (RAAW) which contained only half the amount of requirements for corn plant growth were conducted to decrease nitrate nitrogen (NN) accumulation and restore the mineral balance in corn plants and crop field soil in 6 dairy farms. (1) The NN concentration in the corn stem decreased to less than 5 g/kg (dry matter basis) and no whole plant shoots with a NN concentration above 2 g/kg were observed after the reduction of animal waste application for 1 year. (2) The content of exchangeable potassium (EK) in the dairy farm soil decreased from 60 to 27 mg/100g after RAAW for 2 years. (3) Average dry yield of corn plants in the 4th year was 16% lower in the case of RAAW than in the case of excess utilization of animal composts, but the difference was not significant. The concentration of K was lower in RAAW, which resulted in the decrease of the K/ (Ca+Mg) equivalent ratio from 1.78 to 1.15 in the corn plants. These data suggest that RAAW can improve the feed quality by reducing the NN content and restoring the mineral balance in plant.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: environmental conservation, K/ (Ca+Mg) equivalent ratio, nitrate nitrogen, potassium, sustainable agriculture

Introduction

Recycling of animal wastes in agrosystems is very important for sustainable agriculture and environmental conservation[3]. Animal wastes contain most of the plant nutrients such as nitrogen, phosphorus and potassium (K). For example, nitrogen occurs in both ammonia and organic forms, while the latter one may be transformed into ammonia through the mineralization process in soil, which may be further transformed into nitrate through the nitrification process in soil under aerobic conditions. Nitrate can be readily taken up by plants. However, if an excessive amount of animal wastes is applied into fields, the residue part of the nutrients which could not be absorbed by plants tends to accumulate in the soil, resulting in the pollution of the surrounded environment including surface water, groundwater and air through drainage, leaching, and denitrification processes.

In fact, excessive amounts of animal wastes have being applied onto many dairy farms for many years in Japan due to the limited area of forage crop fields[2]. It is generally recognized that nitrate nitrogen (NN) from animal wastes is leaching into the groundwater and sometimes causes nitrate pollution of drinking water in some regions. Moreover, as the excessive amount of nitrate taken up by plant roots can not be metabolized into organic forms, nitrate tends to accumulate together with K in the stems of the forage. And if such kind of forage is fed to dairy cattle, nitrate will be converted into nitrite in the rumen. Nitrite can react directly with hemoglobin in livestock animals to produce methemoglobin, which impairs the ability of red blood cells to transport oxygen and damages livestock's health[11].

Therefore it is essential to decrease the application volume of animal wastes onto forage fields. In this report the restoration of the nitrate and mineral balance in dairy farm soils and forage plants which had not been thoroughly investigated in Japan hitherto will be confirmed.

Materials and methods

Six dairy farmers operating 16 forage fields were surveyed in this study. The dairy farms were located in Shisui machi, Kumamoto Prefecture in Kyushu. On the average, one farmer operates 6 ha of arable land and

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Table 1. Average supply and absorption of nitrogen (N) and potassium (K) in 6 dairy farms

Supply and absorption of N and K (kg/ha)	N	K
Before 1994		
Animal wastes	1,190*	727*
Chemical fertilizer	54	15
Absorption by forage		
Corn	247	365
Italian ryegrass	128	119
Total	415	507
After 1994		
Reduced application of animal wastes (RAAW)	139*	81*
Chemical fertilizer	54	15

Density of milking cows is 11.2 head/ha.
*Each average value was estimated based on statistical data of animal wastes[8].

owns 67 milking cows. Usually forage corn is grown for summer cropping followed by Italian ryegrass for winter cropping every year, and sometimes corn is grown 2 times annually in summer and autumn. In 1994, we collected data about the application rate of animal wastes from these 6 farms, while soil and corn samples were taken from 10 fields belonging to 2 representative farmers. From late 1994, a composting facility was built in the dairy farm and part of the wastes was converted to organic fertilizer to be used in other farms, so as to reduce the load volume of animal wastes in some forage fields. Therefore, from late 1994, we recommended that the farmers reduce the application rate of animal wastes in part of their fields. The outline of the reduction of application of animal wastes (RAAW) is shown in Table 1. About half the amount of nitrogen requirement for corn growth was applied to decrease NN accumulation in the corn plant and to restore the soil mineral balance. The soil pH (0–30 cm in depth) ranged from 6.01 to 6.85 at the time of corn harvest in 1994. We suggested that the volume of application of ground dolomitic limestone should decrease because a rate of 1 to 2 t/ha had been used every year until 1994. Three farmers reduced the application time every other year and the other 3 farmers discontinued the application in the following year. Soil pH did not change and remained stable after these treatments. In 1995 and 1996, 4 fields from 1 representative farmer were continuously monitored, and in 1997, soil and corn samples at the harvesting stage in all the 16 forage fields were collected to determine the effect of this practice on soil properties and corn growth.

Results

1) Nitrate accumulation and mineral imbalance in soil and forage before 1994

Before the sowing of corn in the spring, chemical fertilizer had been applied to each field at the rates of 39 kg N, 54 kg P_2O_5 and 18 kg K_2O/ha. However most of the nutrients required for corn growth were derived from animal wastes. Table 1 shows the average input and output value of nitrogen and K estimated based on statistical

Table 2. Mineral content in soil and corn shoot at harvesting stage in 1994

Farm		Soil (0 – 30 cm depth)					Corn		
				Exchangeable (mg/100g)			Dry matter yield (t/ha)	NN[b] (% dry matter basis)	
		PH	W.S.N[a]	K	Mg	Ca		Stem	Shoot
A	Mean	6.63	3.6	52	42	534	2.06	0.418	0.165
	Max	6.85	4.8	53	46	578	2.45	0.621	0.260
	Min	6.41	2.4	32	32	496	1.88	0.245	0.098
B	Mean	6.14	2.8	69	39	427	1.64	0.386	0.145
	Max	6.23	2.5	116	60	537	1.86	0.546	0.219
	Min	6.01	3.1	61	28	290	1.31	0.283	0.131
S.D[c]		6.0 – 6.5	–	12 – 23	24	400			

a): Hot water-extracted nitrogen. b): Nitrate nitrogen. c): Standard value of soil diagnosis.

data[7,8] from 6 dairy farms. In this Table we also listed the volume of chemical fertilizer and animal wastes utilized for corn production after RAAW treatment. As the dairy cattle density was very high, the farmers had to apply all the animal wastes in winter. Obviously, the amount of nitrogen applied in animal wastes was about 2–3 times higher than that removed by corn and Italian ryegrass. Table 2 gives the mineral content in the soil and corn plant at the harvesting stage in 1994. The amounts of EK and magnesium (Mg) were very high in the soil, and hot water-soluble nitrogen[10] was still present in the soil at high concentrations even at the harvesting stage. A value as high as 0.2% nitrate nitrogen (NN) on a dry matter basis was detected in corn even at the yellow ripe stage. Therefore, it was demonstrated that an excessive amount of nutrients from animal wastes accumulated in the dairy farm every year and a larger amount of nitrate also accumulated in corn before 1994.

2) Effect of RAAW on forage NN content

Reduced application of animal wastes decreased the NN content in the corn stems (Fig. 1). In Field 1, the NN content of the corn stems decreased significantly from 1994 to 1997. Especially, the value decreased by 50% in 1995 just after 1 year's practice. In Field 3, since animal wastes had been heavily applied for many years, the NN content remained high, but also decreased in 1997. Fields 2 and 4 showed different patterns, because these 2 fields were located far away from dairy cattle, and the animal waste load volume varied. In 1996, the nitrate nitrogen content of corn stems increased sharply in Field 4 due to the large increase of animal waste load volume. It is likely that nitrate accumulation in the corn stems depended on the animal waste load volume and might have decreased within 2 or 3 years if the load volume could have been controlled.

3) Exchangeable K (EK) in soil

Fig. 2 shows the content of exchangeable K (EK) in soil. The EK content in all the fields was relatively higher at the beginning of the practice, but after 3 years, the EK content significantly decreased except in Field 4, which suggested that the EK content in soil could also decrease within 2 or 3 years.

4) Effect of reduced application of animal wastes for 3 years

Fig. 3 shows the effect of RAAW in the 16 farm fields in 1997. In 10 fields RAAW was implemented compared with 6 fields with continued heavy application of animal wastes. Although the corn dry yield relatively decreased due to the decrease of animal waste application, the nitrogen content, K content and K/(calcium(Ca)+Mg) equivalent ratio in the corn plant as well as the contents of hot water-soluble nitrogen and exchangeable K in soil decreased, while the contents of exchangeable Mg and Ca increased in soil.

Discussion

Animal wastes are rich in nutrients for increasing crop yield and improving soil fertility. However, the nitrogen content in soil has increased significantly by heavy application of animal wastes for many years since

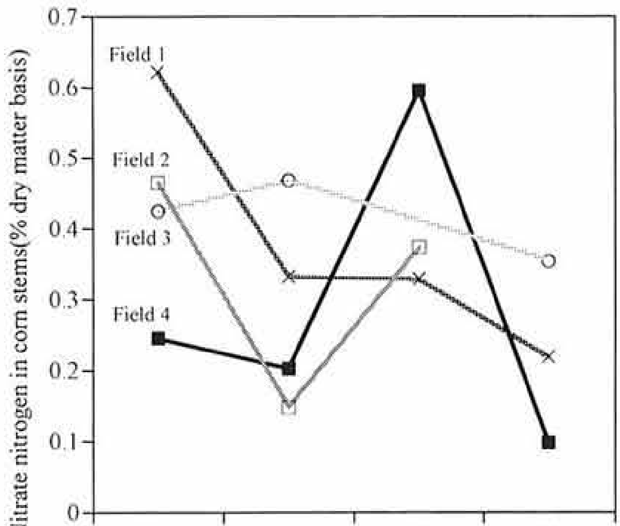

Fig. 1. Time course of nitrate nitrogen content in corn stems under reduced application of animal wastes

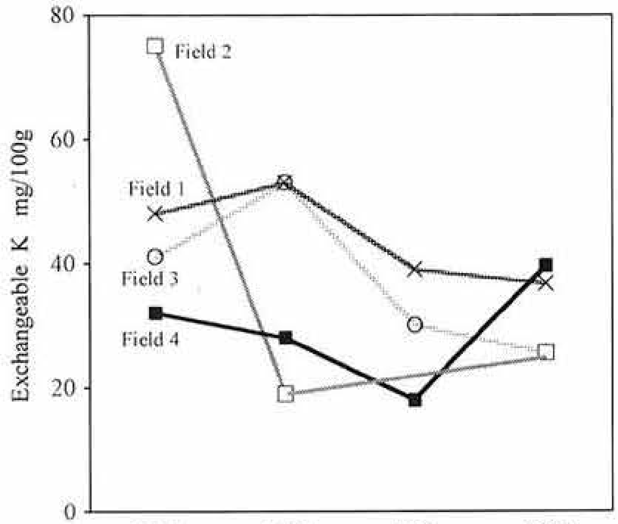

Fig. 2. Time course of exchangeable potassium content in the forage field soil (0–30 cm in depth) under reduced application of animal wastes

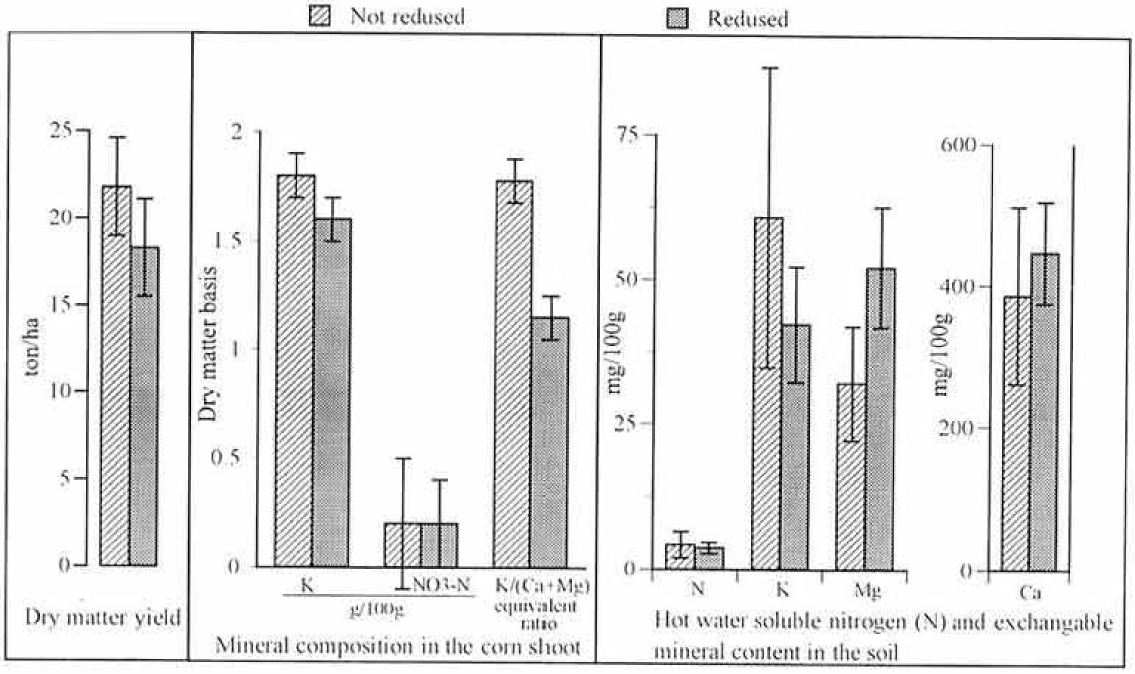

Fig. 3. Effect of reduced application of animal wastes on dry matter yield and mineral composition of the corn shoot and mineral balance in soil

Results are means ± SE. n=6 (Not reduced), n=10 (Reduced).

large-scale animal production was introduced in Japan[5]. Nitrogen enrichment in forage fields has caused problems in animal health[11], and resulted in groundwater pollution by nitrate. Besides nitrogen enrichment, K also accumulated in such fields. Owing to the antagonistic effect of K, absorption of Ca and Mg by crops was retarded, resulting in the increase of the K/(Ca+Mg) equivalent ratio[9]. It was reported that if the K/(Ca+Mg) ratio in forage crops increases to a large extent, there will be a higher risk of grass tetany[4]. Also, a high K level induces metabolic alkalosis in prepartum dairy cows, which reduces the ability of the cows to maintain Ca homeostasis[1]. Therefore, not only for the farmers but also for the people living in such rural areas better management of animal wastes should be implemented[6].

In the dairy farms, the nitrogen volume applied as animal wastes was estimated to amount to about 2 times that of the corn requirement before 1994 (Table 1). Even at the harvesting stage, a higher amount of hot water-soluble nitrogen was still present in the crop field soil (Table 2). The average EK content in the fields tested also increased to about 3 times that of the standard soil diagnosis value in volcanic soil.

From late 1994, the mean amount of nitrogen applied as animal wastes decreased to half of that required by corn approximately. However, the amount removed by corn still exceeded 200 kg/ha (Table 1), indicating that the organic nitrogen from the wastes which had accumulated in the soil for many years had undergone nitrification, and that the amount of nitrate was adequate for corn growth. Furthermore it is important to decrease nitrate accumulation in the corn stems (Fig. 1). Obviously, after several years of continuous RAAW, the amount of N and K nutrients in soil may become insufficient for plant growth. That is to say, soil nutrient diagnosis tests should be carried out every few years to determine the suitable application volume of animal wastes, should the nutrients be unable to meet the requirement for crop growth.

In the present investigation, we observed that exchangeable K had accumulated in soil in 1994, the content being 2–7 times higher than the standard value of soil diagnosis (Table 2). Ito et al. (1982) reported that the movement of K down the soil profile was fairly large in the case of humus-rich volcanic ash soil[4]. It is possible that the EK may move out from the soils investigated by leaching in the rainy season. Furthermore, owing to the large biomass of corn and higher requirement of K, as much as 365 kg/ha K was removed during the cultivation of corn in summer (Table 1). These factors led to the decrease of the content of exchangeable K after the amount of animal waste application was reduced (Fig. 2).

As shown in Fig. 3, the mean value of corn yield after reduced application of animal wastes for 3 years exceeded 18 t/ha. The volume was about 4 t/ha less than that in the case of heavy application and no significant difference was observed. Moreover, the reduction of application of animal wastes led to the decrease of the nitrogen content and the restoration of the mineral balance in both forage field soil and corn plant as shown in Table 2 and Fig. 3. The K/(Ca+Mg) equivalent ratio is an important parameter to evaluate the mineral balance in plant. The decrease of this ratio was caused by the decrease of the EK value in soil. We also observed an increase of the contents of exchangeable Ca and Mg in soil with RAAW, for unknown reasons. The decrease of the K content in the plant should enable livestock to obtain more Ca and Mg, which are essential to maintain Ca homeostasis[1] and to avoid the risk of grass tetany. It was considered that the restoration of the mineral balance in these field soils may require a long period of time. The present study shows that the restoration of the mineral balance in plant and soil was very rapid within 2 or 3 years of reduced application of animal wastes in the dairy farmer fields.

The farm size of the dairy farmers surveyed here is representative of that in Japan. Many of these farmers have been burdened by the large volume of animal wastes required for application in their fields. With the production of compost fertilizer, the application volume could be reduced, and nitrate accumulation and the mineral balance in forage could be improved simultaneously within 2 or 3 years.

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