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Characteristics as Fertilizer of Feces of Aigamo Ducks for Rice Plant (*Oryza sativa* L.)

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Abstract : To clarify the characteristics of aigamo duck feces as fertilizer, we analyzed the inorganic components of aigamo duck feces, and examined the correlation of the amount of ammonium nitrogen in soil with the growth and yield of rice, when aigamo duck feces were applied. One gram of air-dried feces contained 26.6mg of total nitrogen. The amount of total nitrogen excreted in feces increased in the period from late June to early July, and remained at the range of about 0.5 g per day after early July. When aigamo duck feces were applied without basal fertilizer, ammonium nitrogen in the soil increased during the late growth stage of rice, but the yield and protein content of brown rice were not. This suggests that the amount of nitrogen supplied from the feces of aigamo ducks is a minor part of nitrogen taken up by rice. It is probably difficult to obtain a sufficient yield of brown rice in the aigamo duck farming system, without nutritional nitrogen supply.

Key words : Aigamo duck farming system, Aigamo feces, Ammonium nitrogen, Protein content of brown rice, Rice (*Oryza sativa* L.).

Aigamo duck farming system is one of organic agriculture systems that is carried out by about 10,000 rice farmers in Japan (Asano et al., 1999a). In this system, aigamo ducks (crossbreed of wild and domestic ducks) are letting in a paddy field during the growth of rice plants and aigamo ducks eat the weeds in the paddy field. Consequently, the weeds would be removed, even without herbicides (Asano et al., 1999a; Manda et al., 1993a). One of the beneficial elements of the aigamo duck farming system for rice is the supply of feces from aigamo ducks. The stimulation of growth of rice and the increase of yield are expected when duck feces are supplied, as the feces contain various inorganic nutrients, including nitrogen, required for the growth of rice. However, in the aigamo duck farming system, the midseason drainage of rice paddy is not carried out during the free-ranging of ducks. Therefore, the time when the nitrogen from soil and feces exerts a fertilizing effect is thought to be quite different from that in the conventional method of rice farming (Tashima et al., 2003b). In fact, it has been shown that in the rice paddy fields where aigamo duck farming system is applied, the nitrogen content of soil sharply rises during the culture season of rice and rapidly decreases after the harvest, as compared with the rice paddies with chemical fertilizers applied (Egashira et al., 2000; Tashima et al., 2003b). The difference of the time of fertilizing effect of nitrogen not only affects the growth of rice but also eventually influences the yield components. Thus, for the increase of yield and the improvement of quality of rice, it is very important to clarify the time when nitrogen exerts the fertilizing effect in various farming systems. We consider that, in aigamo duck farming system, the amount of nitrogen supplied from aigamo duck feces affects yield and quality of the rice. However, no reports indicated the amount of nitrogen supplied from feces of aigamo ducks in different growth stages of rice. Therefore, to clarify the characteristics of aigamo duck feces as fertilizer, we analyzed the inorganic components of aigamo duck feces, and examined the correlation of the ammonium-nitrogen content of soil with the growth and yield of rice, when aigamo duck feces were applied.

Materials and Methods

1. Amounts of mineral nutrients in aigamo duck feces and time-courses of the amounts of feces and total nitrogen excreted by aigamo ducks

Three aigamo ducks (F1 of Khaki Campbell and Mallard, 10 weeks of age) were kept in a cage for the collection of feces starting on June 25. The feed given to the ducks was Kumiai Formula Feed "Yuri Mush 17" (Kanakei Industries, Inc.). The ration given was 100 - 130 g per individual bird per day. In addition, 150 - 200 g of fresh weeds (*Oenanthe javanica* DC., *Hydrodictyon reticulatum* LAGERT., *Monochoria vaginalis* PRESL var. *plantaginea, Ludwigia prostrata* ROXB. and *Cyperus difformis* L.) collected in the non-cropping rice field were given. The feces were collected every day from June 27 to August 21. The feces collected were air-dried and the dry weights of the feces excreted each

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Table 1. Amount (g of air-dried weight) of aigamo duck feces applied to aigamo plot (experiment 2).

Year	6/11	6/18	6/25	7/2	7/9	7/16	7/23	7/30	8/6	Total
2001	−*	0.50	0.70	1.60	2.28	2.40	2.60	2.64	3.00	15.72
2002	0.50	0.70	1.60	2.28	2.40	2.60	2.64	2.80	3.00	18.52

* ; No application.

day were measured.

The air-dried feces of aigamo ducks were pulverized to make the particle size less than 2 mm and the pulverized samples were analyzed for inorganic components. Items of analysis were total nitrogen, total phosphate, total potassium, total magnesium, total calcium, ammonium nitrogen, available phosphate, water-soluble potassium, water-soluble magnesium and water-soluble calcium. To obtain the amount of total nitrogen, we decomposed the feces with perchloric acid and the content of nitrogen in the decomposed liquid was determined by the semi-micro Kjeldahl method. Total phosphate was determined by the vanadomolybdate yellow method. Total potassium, total magnesium and total calcium were determined by the atomic absorption method.

To determine the amount of ammonium nitrogen, ammonia-containing liquid samples from the feces by the Bremner method and measured the ammonia by the semi-micro Kjeldahl method. Samples for available phosphate were prepared by extraction using the Brey P2 test method and the amount of available phosphate was determined by the molybdenum blue method. Samples for water-soluble potassium, water-soluble magnesium and water-soluble calcium were obtained as follows. Fifty mL of distilled water was added to 10 g of air-dried feces, shaken for 1 hr and filtered through a filter paper (No.2). The amounts of potassium, magnesium and calcium in the filtrate were determined by the atomic absorption method (Model Z-8200, Hitachi High-Technologies Co.).

2. Effects of applying aigamo duck feces on the growth and yield of rice plant (Model cultivation experiment)

Square holes of 1 m × 1 m with a depth of 60 cm, sides and bottom covered with polyvinyl sheet, were constructed as model rice paddies in the Experimental Field of the College of Bioresource Science, Nihon University (Fujisawa City, Kanagawa Prefecture). Rice plants were cultivated in the paddies with aigamo duck feces applied in 2001 and 2002. The soil used in this experiment was the soil (Andsol) in the Experimental Field. The variety of rice used was Koshihikari in both years. As the basal fertilizer, 20 g of ammonium sulfate was applied to all plots in 2001. In 2002, 47 g of ammonium sulfate, 53 g of calcium superphosphate and 12 g of potassium chloride were applied to the basal-nitrogen plots and the same amount of calcium superphosphate and potassium chloride were applied in the no basal-nitrogen plots. Rice seedlings were transplanted as follows. In 2001, two 5-leaf-stage seedlings per hill were transplanted on June 4. In 2002, three 2.5-leaf-stage seedlings were transplanted on May 22. The planting density was 20 cm × 15 cm, 20 hills in each plot. In 2001, the test plots consisted of the control plots with no topdressing, the aigamo plots with aigamo duck feces applied every week between June 18 and August 6, and the ammonium-sulfate plots with a topdressing of 14.3 g of ammonium sulfate on July 23. The source of water supply to the paddy field was rainfall, and only when the water level of paddy field became less than 2cm, was tap water applied. All plots were prepared in quadruplicate. In 2002, in both the basal-nitrogen plots which had the basal fertilizer of ammonium sulfate and the no basal-nitrogen plots which had no basal fertilizer, the following three types of plots were prepared: the control plots with no topdressing, the aigamo plots with aigamo duck feces applied every week from June 11 to August 6, and the ammonium-sulfate plots with a topdressing of 14.3 g of ammonium sulfate on July 23. All the plots were prepared in quintuplet. Table 1 shows the amounts of aigamo duck feces applied in the aigamo plots in experiment 2.

The SPAD values (chlorophyll content measured with an SPAD-502 chlorophyll meter (KONICA MINOLTA Co.), and the number of tillers were surveyed every week. The survey period in 2001 was from June 18 to August 20. The SPAD values were measured at the central part of the longest leaf blade in a hill. In 2002, the survey period for the number of tillers was from June 11 to August 27, and that for the SPAD values was from June 11 to September 17. Six hills were used for the survey in both years.

Rice was harvested on October 4 in 2001 and on September 21 in 2002. The number of panicles per m^2, the number of grains per panicle, the percentage of ripened grains and the weight of 1000 grains of brown rice were measured. The yield of brown rice per m^2 was calculated from these values. Six hills were used for the survey in each type of different plots. After the survey of the yield, the protein content of brown rice was measured with a CN Corder (Model MT-700H, Yanaco Analytical Instruments Co.).

3. Effects of applying aigamo duck feces on the ammonium-nitrogen content of soil in the rice paddy fields (Model experiment)

Effects of applying aigamo duck feces on the amount of ammonium nitrogen in the soil was studied.

Rice paddies were constructed in 2002 in a manner similar to experiment 2, but without no transplanting of rice seedlings. The plots and methods of applying ammonium sulfate or aigamo duck feces were the same as in the second year (2002) of experiment 2. The soil was sampled once every month, on the day of 27th from May to September. The soil and the liquid in the Falcon tube were transferred into a 300 mL Erlenmeyer flask. Then 100 mL of 2.1 M potassium chloride solution was added and the mixture was stirred for 1 hr. The soil suspension was filtered through a filter paper (No.2). Fifty mL of the extract was distilled using a Kjeldahl automatic still (Model VS-SA-1, Mitamura Riken Co.). The distillate obtained was titrated with 1/200 N sulfuric acid. The amounts of ammonium nitrogen were obtained from the titer values.

Results

1. Amount of mineral nutrients in aigamo duck feces and time-courses of amount of feces and total nitrogen excreted by aigamo ducks

Table 2 shows the amounts of mineral nutrients contained in aigamo duck feces. The most abundant nutrient among the inorganic components analyzed was calcium, being 153.3 mg per g of fece. Nitrogen and potassium contents were 26.6 mg and 18.2 mg per g of feces, respectively. The water-soluble potassium was 13.3 mg, indicating that most of the potassium contained in the feces was water-soluble, but the ammonium nitrogen was 1.1 mg.

Table 2. Mineral nutrient (mg per g air-dried feces) of aigamo duck feces (experiment 1).

Total-N	26.6 ± 1.5
Total-P_2O_5	11.3 ± 0.8
Total-K	18.2 ± 1.2
Total-Mg	4.8 ± 0.4
Total-Ca	153.3 ± 14.3
NH_4-N	1.1 ± 0.1
Available- P_2O_5	5.4 ± 0.2
Water -soluble K	13.3 ± 0.9
Water -soluble Mg	1.1 ± 0.1
Water -soluble Ca	3.4 ± 0.1

Value is mean ± SE.

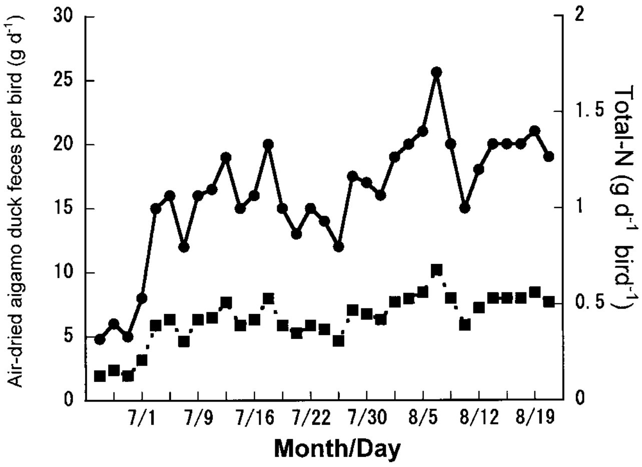

Fig. 1. Time-courses of the amount of feces and total-nitrogen excreted from an aigamo duck (experiment 1). —●— Feces, - -■- - Total-N.

Fig. 1 shows the amounts of feces and total nitrogen excreted by an aigamo duck per day. The amount of excreted feces increased from late June to early July. Thereafter, the amount was relatively stable, remaining in the range of 15 - 20 g per day per bird. As a result, the total amount of feces excreted per bird was 775 g. On the other hand, the amount of total nitrogen excreted in feces increased in the period from late June to early July, and remained at the range of about 0.5 g per day after early July.

2. Effects of applying aigamo duck feces on the growth and yield of rice plant

Number of tillers

In 2001, no difference was observed among the plots up to July 9. The number of tillers in the aigamo plot became slightly larger thereafter. However, there was no statistically meaningful difference in the number of tillers among plots.

In 2002, when ammonium sulfate was not applied

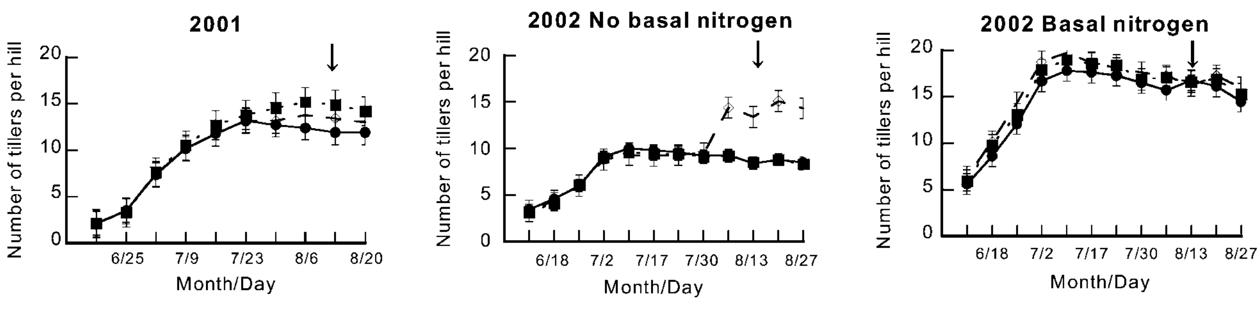

Fig. 2. Effects of aigamo duck feces on the number of tillers of rice plants (experiment 2).
● ; Control, ■ ; Aigamo, ◇ ; Ammonium sulfate.
↓ ; Heading time.

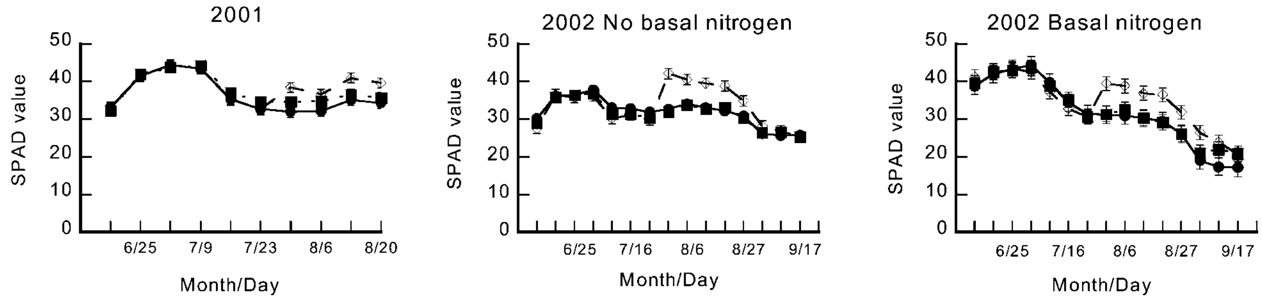

Fig. 3. Effects of aigamo duck feces on the SPAD value of rice plants (experiment 2).
● ; Control, ■ ; Aigamo, ◇ ; Ammonium sulfate.

Table 3. Effects of aigamo duck feces on the yield, yield component and protein content of brown rice (experiment 2).

Year	Plots	Number of panicle (m^{-2})	Number of grains per panicle	Percentage of ripened grains (%)	1000-brown rice-weight (g)	Yield (g per m^2)	Protein content (%)
2001	Basal nitrogen − Control	236a	80.4a	75.3a	19.8a	283a	7.7b
	Basal nitrogen − Aigamo	294a	79.5a	76.5a	19.6a	353a	7.9b
	Basal nitrogen − Ammonium sulfate	266a	85.9a	72.6a	20.8a	345a	8.5a
2002	No basal nitrogen − Control	162b	91.5a	78.7a	20.4a	239b	6.8b
	No basal nitrogen − Aigamo	171b	84.7a	80.0a	20.3a	236b	6.8b
	No basal nitrogen − Ammonium sulfate	311a	66.4b	77.3a	20.2a	321a	7.9a
	Basal nitrogen − Control	273a	78.6a	84.4a	19.4a	358a	6.8b
	Basal nitrogen − Aigamo	289a	81.9a	82.9a	19.5a	379a	6.8b
	Basal nitrogen − Ammonium sulfate	307a	87.8a	78.8a	20.3a	429a	7.8a

Means followed by the same letters are not significantly different at 0.05 level according to Tukey's multiple range test.

as the basal fertilizer, no difference in the number of tillers was observed among the plots up to July 30. However, in the ammonium-sulfate plots, the number of tillers rapidly increased after the topdressing of ammonium sulfate. A statistically significant difference ($P \leqq 0.05$) was observed between the ammonium-sulfate plots and other plots. When ammonium sulfate was applied as the basal fertilizer, no difference was observed among the plots (Fig. 2).

(1) SPAD values

In 2001, there was no significant difference among the plots up to July 16. However, the SPAD value observed in the ammonium-sulfate plots became larger after July 30. A statistically significant difference ($P \leqq 0.05$) was observed between the ammonium-sulfate plots and other plots (the control plots and the aigamo plots).

In 2002, no significant difference was observed among the plots up to July 23, both with and without ammonium sulfate applied as the basal fertilizer. However, in the ammonium-sulfate plots, the SPAD value became higher after the topdressing of ammonium sulfate. The SPAD values in the ammonium-sulfate plots remained at higher values from July 30 to August 27. The differences observed between the ammonium-sulfate plots and other plots during this period were statistically significant ($P \leqq 0.05$) (Fig. 3).

(2) Yield components, yield of brown rice and protein content

In 2001, the numbers of panicles per m^2 were 236 in the control plots, 294 in the aigamo plots and 236 in the ammonium-sulfate plots; the largest in the aigamo plots. However, the differences among plots were not statistically significant. The numbers of grains per panicle were 80.4 in the control plot, 79.5 in the aigamo plots and 85.9 in the ammonium-sulfate plots. Here again, no statistically significant differences were observed. There were no statistically significant differences in the percentage of ripened grains and the weight of 1000 grains of brown rice among the plots. The yields of brown rice per m^2 were the highest in the aigamo plots (353 g), followed by the ammonium-sulfate plots (345 g) and the control plots (282 g). However, the differences in the yield of brown rice were not statistically significant. The protein content of brown rice was the highest in the ammonium-sulfate plots (8.5 %), and was 7.9 % and 7.7 % in the aigamo plots and the control plots, respectively. There was a statistically significant difference ($P \leqq 0.05$) between the ammonium-sulfate plots and other plots.

In 2002, when ammonium sulfate was not applied

Table 4. Effects of aigamo duck feces on NH_4-N content of paddy field soil (experiment 3).

Plots	Mon./Date				
	5/27	6/27	7/27	8/27	9/27
No basal nitrogen − Control	−	−	−	−	0.7 ± 0.1
No basal nitrogen − Aigamo	−	−	−	0.9 ± 0.1	1.4 ± 0.1
No basal nitrogen − Ammonium sulfate	−	−	2.6 ± 0.1	1.4 ± 0.1	2.5 ± 0.4
Basal nitrogen − Control	17.2 ± 0.9	2.5 ± 0.2	3.0 ± 0.3	1.5 ± 0.1	3.0 ± 0.1
Basal nitrogen − Aigamo	19.9 ± 1.2	2.4 ± 0.1	3.1 ± 0.1	1.6 ± 0.2	2.9 ± 0.1
Basal nitrogen − Ammonium sulfate	18.2 ± 1.9	3.2 ± 0.2	8.2 ± 0.3	2.6 ± 0.1	1.8 ± 0.1

Data are shown in mg per 100g fresh soil weight.
− ; Below detection limit.
Value is mean ± SE.

as the basal fertilizer, the numbers of panicles per m^2 were 162 in the control plots which had no topdressing, 171 in the aigamo plots and 311 in the ammonium-sulfate plots. The panicle number in the ammonium-sulfate plots was significantly larger ($P \leqq 0.05$) than other plots. The number of grains per panicle was the highest in the control plots (91.5), followed by the aigamo plots (84.7) and the ammonium-sulfate plots (66.4). The number of grains per panicle in the ammonium-sulfate plots was significantly larger ($P \leqq 0.05$) than that in the other plots. The percentage of ripened grains and the weight of 1000 grains of brown rice showed no statistically significant differences among the plots. The yield of brown rice in the ammonium-sulfate plots (321 g per m^2) was the highest and was significantly ($P \leqq 0.05$) higher than those in the control and the aigamo plots. When ammonium sulfate was applied as the basal fertilizer, there were no statistically significant differences in the yield components and the yields of brown rice among plots.

The protein content of brown rice was the highest in ammonium-sulfate plots both with and without ammonium sulfate applied as the basal fertilizer. The differences in the protein content of brown rice in the ammonium-sulfate plots and other plots (the control and the aigamo plots) were statistically significant both year ($P \leqq 0.05$) (Table 3).

3. Effects of applying aigamo duck feces on the ammonium-nitrogen content of soil in the rice paddy fields

When ammonium sulfate was not applied as the basal fertilizer, the ammonium-nitrogen content of the soil gradually increased in the aigamo plots. The amount of ammonium nitrogen per 100 g of fresh soil in aigamo plots on September 27 was 0.7 mg larger than that in the control plots. When ammonium sulfate was applied as the basal fertilizer, the ammonium-nitrogen content of the soil increased after the topdressing of the ammonium-sulfate. There was no large difference between the values in the control plots and the aigamo plots on any date of the survey (Table 4).

Discussion

The yield of brown rice is about 500 kg per 10 a in Japan. The yield of 500 kg brown rice requires nitrogen uptake of 12.5 kg by the rice plant (Matsushima, 1995). Taking the nitrogen supply from irrigated water and soil into account, an application of 5.3−8.3 kg of nitrogen is probably required to obtain the yield of 500 kg of brown rice per 10 a (Matsushima, 1995). In aigamo farming system, aigamo ducks are free-ranged for about 2 months (Asano et al., 1999b). From the result of experiment 1, the total amount of feces excreted by an individual aigamo duck during the period of free ranging is estimated to be about 800 g (Fig. 1). Since the total nitrogen in the feces of aigamo ducks was 26.6 mg per g in this study (Table 2), the total amount of nitrogen supplied during free ranging is calculated to be 21.28 g per bird. Though the number of aigamo ducks free-ranging in the aigamo duck farming system varies with the farmer and the acreage of paddy field, the number generally ranges from 10 - 30 birds per 10 a (Asano et al., 2001). This means that the total amount of nitrogen supplied to rice paddy by feces of ducks in the aigamo duck farming system is about 200 - 600 g per 10 a. When the feces of aigamo ducks were applied for the cultivation of rice, the number of tillers and the SPAD value of leaf blade were not different from those in the control plots (Figs. 2 and 3). Furthermore, the yield components and the yield of brown rice were also not different from those in the control plots (Table 3). In our experiment, the yield of brown rice in the aigamo plots was much lower than that of the plots applied ammonium sulfate as topdressing (Table 3). These results suggest the difficulty to obtain a sufficient yield of brown rice in the aigamo duck farming system, when the supply of nitrogen is only from the feces of aigamo ducks. Furthermore, ammonia nitrogen increased in the soil during the late growth stage (August 27, September 27) of rice when aigamo duck feces were applied without basal fertilizer application (Table 4). However, there was no difference in the protein content of brown rice between the aigamo duck plot and the control plot (Table 3). This indicates that the increase of ammonia nitrogen in the soil was not sufficient to increase the protein content of brown rice. However, the yield and the protein content of brown rice were much increased when aigamo ducks were free-ranged in the rice paddy field, as compared with those in the field where ducks were not introduced (Manda et al., 1993b; Asano et al., 1998; Asano et al., 1999b; Goh et al., 2001). This suggests that the free-ranging of aigamo ducks has additional effects to increase the supply of nitrogen for the growth of rice besides the supply of nitrogen from the duck feces. For example, Tashima et al. (2003a) showed that in the aigamo duck farming system the growth of weeds before transplanting was more vigorous than in the farming systems using herbicides and insecticides. In addition, they clarified that the supply of nitrogen from weeds was 4 - 5 times larger than that from the feces of aigamo ducks (Tashima et al., 2003a). In general paddy fields, nitrogen is also supplied from biological N_2 fixation at the soil surface, irrigated water and rainwater, the amount reaching 50 - 70 kg per ha (Toriyama, 1996; Tashima et al., 2003a). The activities of phototrophic N_2-fixing microorganisms are promoted by the organic and inorganic nutrients (Yoo et al., 1990). This is suspected from the promotion of the ativities of phototrophic N_2-fixing microorganisms by the supply of nutrients from aigamo duck feces. The physical mixing of paddy soil by aigamo ducks during free-ranging also increased the nitrogen content of the soil (Egashira et al., 2000; Tashima et al., 2003b). The phenomena described above are considered to contribute to the increased rice yield and protein content of brown rice in the aigamo farming system. Thus, we conclude that the amount of nitrogen supplied from the feces of agamo ducks in the aigamo duck farming system is a minor part of nitrogen taken up by rice.

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