

# Nitrogen budget of cattle manure compost incorporated into paddy field.

Mizuhiko Nishida

National Agricultural Research Center for Tohoku Region, National Agriculture and Food Research Organization, Daisen, Akita, Japan, mizuhiko@affrc.go.jp

## Abstract

To estimate the nitrogen (N) budget of cattle manure compost with sawdust (CMC) in a paddy field in the cool climate region of Japan, well-composted  $^{15}\text{N}$ -labeled CMC was applied to a microplot field experiment. Throughout the experimental period of three crop seasons, N from CMC was taken up by rice plants without a marked decline. The percentages of N taken up derived from CMC to applied N as CMC (NUE) were 2–3% for each year. The N from CMC was taken up by rice plants over the entire growth period was 1–2, 2 and 2–3% as NUE at the panicle initiation, heading and maturity stages, respectively. A significant positive linear correlation was found between the cumulative compost N uptake and the number of days transformed to standard temperature (25°C) over the entire experimental period, including the fallow season. The NUE was identical at CMC application rates ranging from 1 to 4 kg/m<sup>2</sup>. Using  $^{15}\text{N}$ -labeled CMC, the results showed that well-composted CMC was a stable N source for rice plants for at least 3 years, regardless of the CMC application rate (ranging from 1 to 4 kg/m<sup>2</sup>) in the cool climate region of Japan. The distribution of CMC N was 7% in the rice plants accumulated over 3 years, 66–69% in the soil and 24–27% was unrecovered at the end of the third crop season.

## Key Words

$^{15}\text{N}$ , paddy field, cattle manure compost, nitrogen use efficiency, rice.

## Introduction

The demand for agricultural produce, including rice, grown using organic materials as a nutrient source is increasing with recognition of the importance of resource recycling farming systems. At the same time, in intensive livestock-farming areas, a great amount of nitrogen (N) is excreted through livestock waste (Ikumo 2003). Estimation of the N balance indicates that surplus excreta N is loaded in some of these areas (Kohyama *et al.* 2003), which necessitates the effective use of livestock waste in areas other than the intensive livestock-farming areas. Thus, the effective use of organic materials, livestock manure compost in particular, in rice farming is anticipated. For the effective use of livestock manure compost in a sustainable recycling system, information about the fate of livestock manure compost N in the paddy field is indispensable. To precisely evaluate the fate of N in organic materials, the use of  $^{15}\text{N}$ -labeled organic materials is a relevant approach (Hood *et al.* 1999; Muñoz *et al.* 2003; Takahashi *et al.* 2000). The objective of this study was to directly evaluate the N budget of cattle manure compost over 3 years, by applying  $^{15}\text{N}$ -labeled compost to a paddy field in the cool climate region of Japan.

## Methods and materials

### Field experiment

The microplot experiment inside a paddy field was conducted from 2000 to 2002 at the National Agricultural Research Center for Tohoku Region (NARCT), Daisen, Akita, Japan (N39°29', E140°30', altitude 30 m). The soil is a fine-textured gray lowland soil (Typic Fluvaquents by Soil Taxonomy) and soil in the plow layer contained 2.35 g/kg total N on a dry-weight basis. A polyvinyl chloride frame (17 cm × 30 cm, height 20 cm) wrapped at the bottom with unwoven cloth was installed into the plow layer (approximately 15 cm depth) inside the paddy field on 22 May 2000. Fresh soil previously collected from the plow layer (6.27 kg dry weight) was passed through a 1-cm sieve and was well mixed with  $^{15}\text{N}$ -labeled cattle manure compost that contained sawdust (CMC). Compound fertilizer was also mixed with the soil. The mixture of soil, CMC and fertilizer was put into the flame on 22 May 2000. The application rates of CMC were 1, 2 and 4 kg/m<sup>2</sup> on a fresh-weight basis, and the rate of compound fertilizer was 8 g/m<sup>2</sup> (as N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O). The  $^{15}\text{N}$ -labeled CMC was made from feces collected from a cow fed with  $^{15}\text{N}$ -labeled corn (*Zea mays* L.). Before composting, sawdust was added to the cattle feces at a rate of approximately 30% to make suitable moisture conditions (Yamamuro 2000). Three replications were set up for the 1 and 4 kg m<sup>-2</sup> CMC treatments. For the 2 kg m<sup>-2</sup> treatment, 21 replicates were initially set up because 18 of 21 replicates were to be eliminated at on-season sampling times. Puddling was carried out on 23 May. On 25 May, 35-day-old rice plant seedlings

(*Oryza sativa* L., cv. Akitakomachi), three seedlings per microplot, were transplanted at the center of each microplot. To the field outside the microplots, only compound fertilizer was applied at a rate of 8 g/m<sup>2</sup> (as N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O), and rice plants were planted at a spacing of 17 cm × 30 cm, the same planting density as the microplot. Plant top samples in the 2kg/m<sup>2</sup> CMC treatment were collected at the panicle initiation stage (10 July) and at the heading stage (3 August) with three replications, respectively. Plant top and soil samples of all treatments were collected at maturity stage (13 September). Plant roots were left in the soil. After sample collection at the maturity stage, the microplots (soil and root in the frame) remained in the ground, up to approximately 15 cm depth, until the next crop season. In 2001 and 2002, only compound fertilizer was applied to the soil of the microplots before crop season; and then similar procedures were carried out.

#### Sample analysis

Total N of the soil and plant samples were determined by Kjeldahl method. The <sup>15</sup>N abundance of these samples was measured using Automated Nitrogen and Carbon Analyzer-Solid and Liquid (ANCA-SL; PDZ Europe, Cheshire, UK). Total N and <sup>15</sup>N abundance of the compost were measured following the same procedure. Water extractable NH<sub>4</sub>-N and NO<sub>3</sub>-N of the compost were measured with an Aquatec 5400 Analyzer (Foss Tecator, Hilleroed, Denmark) after extraction by distilled water in a ratio of compost (fresh weight [FW]) : distilled water of 1:10 for 1 h. Total carbon (C) of the compost was measured with a Vario MAX CN (Elementar Analysensysteme, Hanau, Germany). The biological oxygen consumption of the compost was measured for 50 g of the compost (FW) for 30 min at 35°C using a Compotester (Fujihira Industry, Tokyo, Japan).

#### Calculation of the number of days transformed to standard temperature (25°C)

Using daily mean air temperatures during the experimental period, including the fallow season, the number of days transformed to a standard temperature of 25°C (DTS) was calculated using the following equation, which was obtained from Arrhenius' law (Sugihara *et al.* 1986).

$$DTS = \exp(Ea \times (T_a - T_s) / (R \times T_a \times T_s)) \quad (1)$$

T<sub>a</sub> is the daily mean air temperature (K), T<sub>s</sub> is the standard temperature (298 K), R is a gas constant (1.987 cal/deg/mol) and Ea is the apparent activation energy (cal/mol). As an Ea value, 13,800 kcal/mol was used, which was obtained by an incubation experiment of CMC under submerged conditions (Sakai and Yamamoto 1999). The relationship between DTS and N uptake derived from <sup>15</sup>N-labeled CMC (Ndfc) in the 2 kg/m<sup>2</sup> CMC treatment was examined using a single regression analysis (SAS Institute 2002).

## Results

### Maturity of the CMC

The compost contained a small amount of inorganic N and was almost odorless. Biological oxygen consumption was as low as 1 µg/g/min (Table 1). In cases where the biological oxygen consumption of compost is less than 3 µg/g/min, the compost can be considered to be in a stable phase with high maturity (Furuya *et al.* 2003). Therefore, the CMC used in this study can be regarded as highly matured CMC.

**Table 1. Chemical properties and biological oxygen consumption of <sup>15</sup>N-labeled cattle manure compost.**

N (g/kg)	<sup>15</sup> N (atom%)	C (g/kg)	C/N ratio	NH <sub>4</sub> -N (g/kg)	NO <sub>3</sub> -N (g/kg)	Moisture (g/g)	Biological oxygen consumption (µg/g/min)
3.95	2.54	93.0	24	0.15	0.02	0.73	1

Fresh weight basis

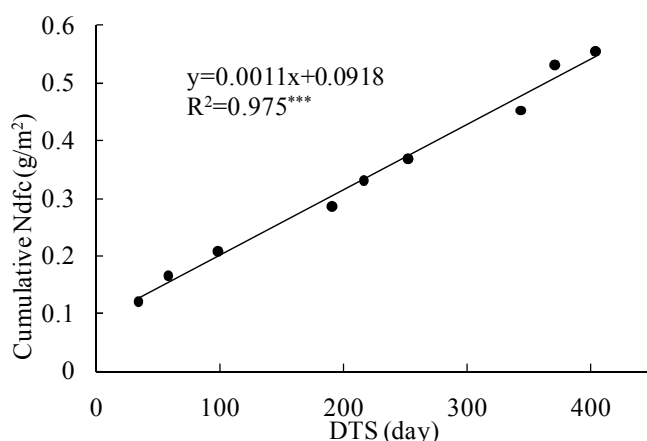
### Nitrogen use efficiency of CMC for rice plants

The percentages of Ndfc (N uptake derived from <sup>15</sup>N-labeled CMC) to applied N as CMC (NUE) are listed in Table 2. The N originated from CMC was taken up by the rice plants in the three crop seasons. The NUE values at the maturity stage were 2–3% for each year, and no marked decline in NUE was observed. Hence, N efficiency of the CMC was stable up to the third crop season from CMC application. In the 2 kg/m<sup>2</sup> CMC treatment, N uptake from CMC continued throughout the growth period for the three crop seasons, and was 1–2, 2 and 2–3% as NUE at the panicle initiation, heading and maturity stages, respectively. Thus, using <sup>15</sup>N-labeled CMC, the results showed that CMC with high maturity was a stable N source for rice plants throughout the entire 3-year growth period. The relationship between DTS (number of days transformed to standard temperature at 25°C) and cumulative Ndfc over the 3 years in the 2 kg/m<sup>2</sup> CMC treatment is shown in Figure 1. A significant positive linear correlation was found between the DTS and the cumulative Ndfc, suggesting that mineralization of CMC N and its uptake by rice plants depended on the temperature. The NUE at the maturity stage was almost constant regardless of the application rate of CMC, indicating N efficiency per unit weight of the CMC was similar at application rates ranging from 1 to 4 kg/m<sup>2</sup>.

**Table 2. Nitrogen use efficiency (percentage of Ndfc (N uptake originated from <sup>15</sup>N-labeled CMC) to applied N as CMC.**

Year	CMC application rate	Growth stage		
		Panicle initiation	Heading	Maturity
2000	1 kg/m <sup>2</sup>	-	-	2.6 ± 0.6 a
	2 kg/m <sup>2</sup>	1.5 ± 0.3	2.1 ± 0.4	2.6 ± 0.3 a
	4 kg/m <sup>2</sup>	-	-	2.8 ± 0.0 a
2001	1 kg/m <sup>2</sup>	-	-	1.9 ± 0.1 a
	2 kg/m <sup>2</sup>	1.0 ± 0.1	1.6 ± 0.2	2.0 ± 0.2 a
	4 kg/m <sup>2</sup>	-	-	2.0 ± 0.2 a
2002	1 kg/m <sup>2</sup>	-	-	2.4 ± 0.2 a
	2 kg/m <sup>2</sup>	1.1 ± 0.1	2.1 ± 0.1	2.4 ± 0.2 a
	4 kg/m <sup>2</sup>	-	-	2.5 ± 0.1 a

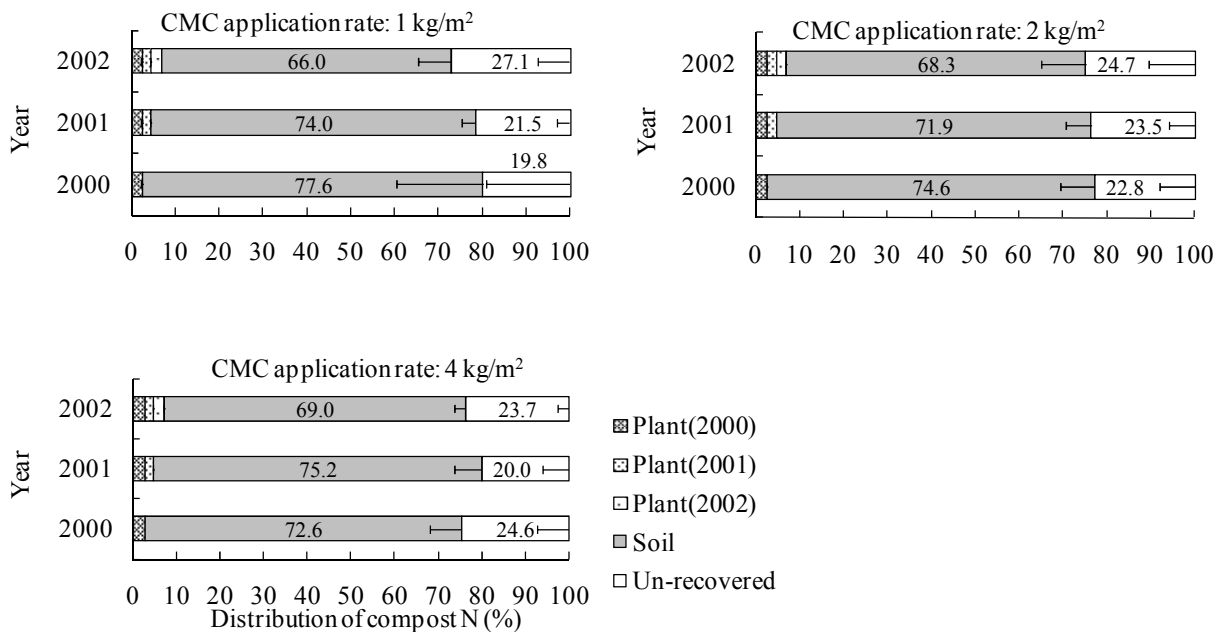
Mean ± SD. Means followed by same letters within a year are not significantly different by Tukey-Kramer's test ( $P < 0.05$ ).



**Figure 1. Relationship between cumulative N uptake originated from <sup>15</sup>N-labeled cattle manure compost (CMC) and number of days transformed at standard temperature (25°C) of the whole experimental period including fallow season in 2 kg/m<sup>2</sup> CMC treatment. Ndfc: N uptake originated from CMC. DTS: number of days transformed at standard temperature (25°C). \*\*\*  $P < 0.001$ .**

#### *Distribution of CMC nitrogen*

The distribution of CMC N was 6.9–7.3% in the rice plants, 66–69% in the soil and 24–27% was unrecovered at the end of the third crop season (Figure 2). The distributions of compost N were similar in all application rates of CMC. The percentage of compost N distributed to the soil did not significantly differ with CMC application rate throughout the experimental period. Greater portion of compost N, approximately 70%, remained in the soil even after the third crop season. This remaining N would continue to be a N source for rice plants. The unrecovered part could represent the loss of the compost N and the N derived from CMC in a substantial part of the rice roots. Nitrogen in the roots was not measured in the present study. However, taking into account the ratios of top to root weight of rice plants, which were around 20, most of the unrecovered part could be ascribed to the loss. The greatest loss was found in the first crop season. Although the tested CMC in this study was highly matured, inherent inorganic N and N in easily decomposable organic matter in the CMC might be lost in the early growth period, before the root system was well developed, in the first crop season. The amount of water percolation in this field was 10 mm/day. Percolation in the field could affect the loss of compost N by leaching. In this study, however, loss through leaching, denitrification and volatilization were not separately evaluated. Hence, the contribution of the loss through leaching to all loss was unclear. A limited number of studies have demonstrated the N distribution of CMC in paddy fields. Among these studies, including the present study, the balances of compost N distribution were different, and a general explanation about N distribution of CMC cannot be made at this time. Further study is needed to clarify relationship among the property of compost, environmental conditions and N budget of the compost.



**Figure 2. Distribution of N originated from <sup>15</sup>N-labeled cattle manure compost (CMC) at the maturity stage. Error bars indicate standard deviation.**

### Conclusion

Using <sup>15</sup>N-labeled CMC, characteristics regarding the N budget of well-composted CMC, which was applied to a paddy field in a cool climate region, appeared to be: (1) N originated from CMC was taken up by rice plants for at least 3 years without marked decline, (2) within a crop season, the N from CMC was taken up over the entire growth period, (3) cumulative N<sub>dfc</sub> linearly increased with DTS for 3 years including the fallow season, (4) at application rates ranging from 1 to 4 kg/m<sup>2</sup>, the NUE of CMC was identical, (5) approximately 70% of compost N remained in the soil even after the third crop season.

### References

- Furuya S, Furukawa C, Itoh M (2003) Relationship between compost temperatures and biological oxygen consumption rates for judging the compost maturity during composting process of animal manures. *Japanese Journal of Soil Science and Plant Nutrition* **74**, 645-648.
- Hood RC, N'Goran K, Aigner M, Hardarson G (1999) A comparison of direct and indirect <sup>15</sup>N isotope techniques for estimating crop N uptake from organic residues. *Plant and Soil* **208**, 250-270.
- Ikumo H (2003) Estimation of potential supply of animal waste compost to replace chemical fertilizer use on Prefectural basis in Japan. *Journal of Agriculture Science* **58**, 469-474.
- Kohyama K, Hojito M, Sasaki H, Miyaji H (2003) Estimation of nitrogen load originating from cattle farming using agricultural statistics mesh data. *Japanese Journal of Soil Science and Plant Nutrition* **74**, 425-433.
- Muñoz GR, Powell JM, Kelling KA (2003) Nitrogen budget and soil N dynamics after multiple application of unlabeled or <sup>15</sup>Nitrogen-enriched dairy manure. *Soil Science Society of America Journal* **67**, 817-825.
- Sakai K, Yamamoto T (1999) Low input paddy rice culture for reducing environmental N input based combined use of coated fertilizer and animal manure with predicted mineralization rate. *Japanese Journal of Soil Science and Plant Nutrition* **70**, 185-189.
- SAS Institute (2002) JMP 5.0.1a. SAS Institute, Cary
- Sugihara S, Konno T, Ishii K (1986) Kinetics of mineralization of organic nitrogen in soil. *Bulletin of the National Institute of Agro-Environmental Sciences* **1**, 127-166
- Takahashi S, Yamamuro S, Ono S (2000) Nitrogen uptake by rice and tomato from nitrogen-15 labeled composted cattle dung. *Japanese Journal of Soil Science and Plant Nutrition* **71**, 246-248
- Yamamuro S (2000) Production of <sup>15</sup>N labelled composts of livestock and agricultural wastes and study on the fate of the <sup>15</sup>N labeled composts in soils. *Radioisotopes* **49**, 323-324.