Nitrogen Dynamics in a Paddy Field Fertilized with
Mineral and Organic Nitrogen Sources

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Abstract: A field study was conducted to investigate dry matter and nitrogen (N) accumulation in rice during the growing season and N availability and dynamics in a paddy field treated with different manures and fertilizers. Cow manure (CM), poultry manure (PM), urea fertilizer (UF), a mixed application of rice straw and urea (SU) and a slow-release compound fertilizer (M-coat) were used as the nitrogen sources. A study was also conducted on field-incubated litterbags using the same applications. Inorganic N (NH_4-N and NO_3-N) in soil was higher for UF and M-coat at the start of the growing season, indicating that N from those applications released rapidly and then decreased afterwards. Mid-season increase in inorganic N was observed for the manure applications except SU. Dry matter and N accumulation were the highest for M-coat. PM gave the highest soil inorganic N, plant N and dry matter accumulation among the organic matter applications. Therefore, PM can be a suitable fertilizer for rice production with environmental sustainability. SU showed the N immobilization in both field and litterbag studies due to its high organic C. Low dry matter, N accumulation and apparent N recovery were observed in CM and sole application of which may not provide the optimal rice production. Results from the litterbag study indicated that N dynamics in the paddy field were greatly affected by soil water movement.

Key words: Cow manure · N dynamics · Paddy soil · Poultry manure · Rice straw · Slow-release fertilizer

INTRODUCTION

Nitrogen (N) is a crucial nutrient for rice growth and its deficiency is a major constraint to stable rice production worldwide. In Asia, where more than 90% of the world's rice is produced, about 60% of the N fertilizer consumed is used on rice [1]. Suzuki [2] reported that rice yield was increased with increasing uptake of N until reaching a peak. Soil N supply plays a dominant role in the N nutrition of wetland rice as one-half to two-thirds of the total N taken up by rice crops even in N-fertilized paddy fields comes from the soil N pool [3]. However, soil fertility has progressively declined due to plant nutrient depletion and soil physical, chemical and biological processes. Therefore, soil fertility and its capacity to supply nutrients require long-term maintenance by replenishment through external inputs.

Today, the use of organic manure in conjunction with or as an alternative to mineral fertilizer is receiving considerable attention. The excessive application of chemical fertilizers has made it imperative that a portion of inorganic fertilizer be substituted by recycling organic waste. Organic manure has been proven to enhance efficiency and reduce the need for chemical fertilizers. Partial N substitution through the use of organic manure demonstrated significant superiority in yield over that

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produced by farmers' conventional practice [4]. The mineralization of organic N or ammonium production is a key process for the N nutrition of wetland rice because N mineralization stops at ammonium production and nitrification is at a low rate in submerged soils [5].

The application of animal manure, which contains both mineral and organic N, is useful for maintaining and improving soil fertility and rice production [6]. Hence, it is important to understand the fate of N in the organic materials applied to paddy fields. The estimation of N availability and plant N recovery for many crops has been investigated by researchers using ^{15}N-labeled preparations. However, a referable N recovery percentage and availability in paddy soil by applying the respective organic matter has yet to be clarified.

Rice straw, which is agricultural waste from paddy fields, is produced in massive amounts in rice-growing areas. Burning of rice straw and stubble is practiced around the world, mainly to reduce biomass waste. Campbell [7] reported that this practice wasted 65-120 kg N ha^{-1} and generated environmental pollution in addition to other chemical reactions that degrade the nutrient availability of soil. In Japan, about 60% of the total production of rice straw is directly incorporated into paddy fields [2]. However, extensive application of undecomposed rice straw may lead to such problems as soil N immobilization and methane gas emission. Research on suitable application in paddy fields and optimum management procedures such as composting and additional N application is still very limited and cannot be used as a reference by ordinary farmers.

Current fertilizer recommendations in Asia typically consist of blanket recommendations with fixed rates and timings for large rice-growing areas. However, considerable progress has been made in recent years in developing field and season-specific nutrient management approaches [8-10]. The increase in yield per unit of applied fertilizer N was decreased with increasing N fertilizer. Recently, farmers profit maximization with proper management practices to improve indigenous soil N supply, reduce amount of applied fertilizer without yield loss and use of organic manures in conjunction with mineral fertilizer is in consideration [10-12].

In order to estimate the appropriate rate of manure application, information on crop nutrient requirements, soil nutrient supply and manure nutrient supply is necessary. However, determining the amount of available N in manure is not a straightforward process. Although inorganic N is immediately available for plant uptake, organic N must first be mineralized. Therefore, seasonal variation of inorganic and total N dynamics in soil according to the application of different manures and fertilizers must be clarified.

The rice (*Oryza sativa* L.) used in this study was the Manawthuka variety, which is very popular among Myanmar farmers for its high yield potential and wide adaptability. However, there is little available research and information related to Manawthuka. Therefore, one of the objectives in this work was to provide useful information to Myanmar farmers, at least on crop response to manure and fertilizer application of Manawthuka.

The food industry has now grown accustomed to using genetically modified and hybrid crops with high chemical fertilizer application in order to supply the world's growing population. Nonetheless, it is necessary to compare the effects of applying organic and inorganic fertilizer on the yield and the chemical and physical properties of soil. This study was carried out to investigate the accumulation of dry matter and N in rice during a growing season and N availability and dynamics in a paddy field treated with different manures and fertilizers.

MATERIALS AND METHODS

Site Description: The field experiment was conducted in 2008 at Kyushu University Farm in Fukuoka Prefecture, Japan (33°37'N, 130°25'E). Temperature and rainfall data for this area is shown in Table 1. The soil (clay loam) is under yearly rice cultivation and its physicochemical properties are shown in Table 2. Nutrient content of the soil was determined by H_2SO_4-salicylic acid-H_2O_2 digestion [13] followed by the indophenol method [14] for total N; ascorbic acid method [15] for total phosphorus (P); and atomic absorption spectrophotometry (Z-5300, Hitachi) for total potassium (K). Total carbon (C) and hydrogen (H) content were determined using a CHN corder analyzer (MT-5, Yanaco). Cation exchangeable capacity (CEC) was determined by the ammonium acetate shaking extraction method [16]. In this area, mineral fertilizer application is generally carried out for yearly rice production using M-coat, an S100H-polymer-coated slow-release compound fertilizer (10-7-7% of N-P_2O_5-K_2O) (JA Kasuya Co., Fukuoka, Japan) at the rate of 730 kg ha^{-1}.

Treatment and Experimental Design: In June 2008, 1.2×5.0-m plots were prepared by inserting plastic frames into the subsoil layer (about 15 cm underground) of a large paddy field. Cow manure (CM), poultry manure (PM), rice straw and urea mix application (SU),

Table 1: Mean temperature and total rainfall in the study site of Kyusyu University Farm, Fukuoka, Japan

Month	Mean temperature (°C)	Total rainfall (mm)	DAT
Jun-Jul	24.8	86.61	1-13
Jul	29.3	14.48	14-23
	30.4	1.02	24-34
Aug	29.3	34.54	35-44
	28.3	299.23	45-54
	25.1	85.09	55-65
Sep	25.8	36.58	66-75
	25.7	25.40	76-85
	23.1	71.37	86-95
Oct	21.1	45.98	96-105
	19.8	0.00	106-115
	18.2	11.18	116-126

DAT = Days after transplantation

Table 2: Selected physicochemical properties of soil and organic materials

	Soil	Cow manure	Poultry manure	Rice straw
N (%)	0.15	1.04	2.76	0.61
P (%)	0.12	0.78	4.80	0.12
K (%)	1.11	3.78	10.14	3.56
H (%)	0.86	4.02	3.32	5.48
C (%)	2.00	31.87	22.92	36.56
C/N ratio	-	31	8	60
pH $_{H2O}$	5.73	-	-	-
Bulk density	1.16	-	-	-
CEC (mol$_c$ kg^{-1})	12.11	-	-	-

urea (UF) and M-coat slow-release fertilizer (M-coat) were used as the nitrogen sources for comparison with no application (Control). For SU, the dual N sources were in the form of rice straw (raw, cut into pieces 3-5 cm) and urea at a total N ratio of 1:1. The selected chemical properties of organic matter (total N, P, K, C and H content) were determined using the methods described above (Table 2). Manure and fertilizer application rate was at two levels: 40 and 80 kg N ha^{-1} as level I and level II, respectively excluding for M-coat. M-coat fertilizer was applied at the rate of 730 kg ha^{-1} (73 kg N ha^{-1}) at basal application. In all plots using urea fertilizer, split application was made three times: as the basal application, at active tillering (40 DAT; days after transplantation) and at panicle initiation (77 DAT). Rice straw was incorporated at 18 days before transplantation followed by irrigation. The other fertilizers and manures (including urea for SU) were applied 3 days before transplantation, followed by hand mixing using a fork hoe.

Randomized complete block design was used with three replications. Rice (*Oryza sativa* L.) variety Manawthuka was used as a test crop. Irrigation was conducted as a common management practice together with the surrounding area. Intermittent drainage was conducted from mid July to the first week of August.

Inorganic N (NH$_4$-N and NO$_3$-N) and Microbial Biomass C and N in Soil: For the estimation of inorganic N (NH$_4$-N and NO$_3$-N), soil samples (0-10 cm depth) were collected at 14, 28, 42, 63, 84 and 112 DAT. Soil extraction was immediately performed by shaking with 2 M KCl and the extracts were stored in a cold room prior to analysis. Inorganic N in the extract was determined using the Conway microdiffusion method and device mentioned in Shimada [17]. The extract was reacted with 12% MgO during 24 h incubation at 30°C. The released NH$_4$-N was received with 0.5 M H$_2$SO$_4$ in a separate chamber of the device. At the same time, NO$_3$-N in the extract was reduced by the addition of Devarda's alloy and was reacted with 12% MgO in the second set followed by 48 h incubation. Therefore, the diffused N in the second set was for both NH$_4$-N and NO$_3$-N in the extract. After incubation, diffused NH$_4$-N was measured by the indophenol method [14]. N content in the first set represented NH$_4$-N and the difference between the second and the first set represented NO$_3$-N.

At 112 DAT sampling, microbial biomass C (C-mic) and N (N-mic) were determined using the direct chloroform fumigation extraction method referred to in Witt *et al.* [18]. Ethanol-free chloroform was used for fumigation. One portion of soil sample was extracted immediately by shaking with 0.5 M K$_2$SO$_4$ (unfumigated sample). The steps mentioned above were conducted in the laboratory within 2-3 h after sampling. Fumigated samples were incubated for 24 h in the dark at 30°C. After removal of chloroform gas for 30 min, shaking extraction was conducted using 0.5 M K$_2$SO$_4$. In the extract, the extractable C was determined using the procedure described in Witt *et al.* [18], while the extractable N was determined by H$_2$SO$_4$-H$_2$O$_2$ digestion [13] followed by the indophenol method [14]. C-mic and N-mic represented the difference in extractable fractions between fumigated and unfumigated soil; no correction factor was used.

Dry Matter Weight, Plant N Accumulation and Apparent N Recovery: Mid-season plant sampling was carried out four times, once at 42, 63, 84 and 112 DAT at active tillering, booting, flowering and grain filling stages, respectively and once at harvesting (126 DAT). Aboveground portions (cut 2-3 cm from the ground) of three contiguous hills in the selected row of a replicated plot were sampled, oven-dried and measured for dry matter and plant N accumulation. N in the plant was determined by H$_2$O$_2$-H$_2$SO$_4$ digestion [13] followed by the indophenol method [14].

The apparent recovery method is used to compare rice nutrient uptake in the treatments and the control [19]. It is assumed that each soil provides the same amount of nutrient elements and any additional whole-plant uptake above each control is a result of the treatment. Apparent N recovery (ANR) is calculated using the following equation:

ANR (%) = (Treatment N uptake-Control N uptake) / Total N applied × 100

In the above equation, the uptake represents the aboveground whole-plant N accumulation.

Field-incubated Litterbags: The litterbag experiment was conducted on the respective treatment plots as part of the field experiment. At one week after rice transplantation, 50 g air-dry soil was treated with CM, PM, SU and UF at the rate of 80 kg N ha^{-1} and was used to fill 11.0×10.5-cm polyester polypropylene bags one day prior to burial. The bags were closed with a nylon string and randomly buried (5-cm depth) in a horizontal position 15 cm to the side of a row of rice. Three bags from each plot were sampled at 14, 42, 70 and 119 days after burial (DAB). Sampled bags were placed into individual plastic bags, brought to the laboratory and extracted immediately with 2 M KCl. The extract solutions were stored in a cold room until analysis. Inorganic N (NH$_4$-N and NO$_3$-N) in the extract was determined using the Conway microdiffusion method as mentioned above. At each sampling, total N in the litterbag was determined by H$_2$SO$_4$-salicylic acid-H$_2$O$_2$ digestion [13] followed by the indophenol method [14] after air-drying the soil sample.

Statistical Analysis: Analysis of variance (ANOVA) to test the statistical significance and Tukey-Kramer HSD (honestly significant difference) test to calculate the least significant difference (LSD) at the 5% probability level were conducted using a statistical software program (JMP IN, Version 5.0.1a, SAS Institute Inc., Cary, NC, USA).

RESULTS

Inorganic N (NH$_4$-N and NO$_3$-N) and Microbial Biomass C and N in Soil: A large variation in inorganic N (NH$_4$-N and NO$_3$-N) was observed throughout the growing season, especially in the NH$_4$-N fraction (Figure 1). NO$_3$-N in soil was relatively low compared to NH$_4$-N for all treatments; however, that for SU-II, UF-I, M-coat and control was higher in the sampling at 63 and 84 DAT. An increase in NO$_3$-N was also observed for CM-I, CM-II, PM-II and SU-I at 63 DAT. Generally, NH$_4$-N was higher

Table 3: Microbial biomass C and N in soil sampling at 112 DAT

	C-mic	N-mic	
	μg g^{-1} soil		C-mic/ N-mic
CM-I	188 ± 20[a]	22 ± 1.3	8
CM-II	231 ± 16	23 ± 0.8	10
PM-I	244 ± 9	25 ± 1.2	10
PM-II	240 ± 18	29 ± 2.6	8
SU-I	234 ± 14	18 ± 4.8	13
SU-II	312 ± 48	18 ± 4.9	17
UF-I	254 ± 12	24 ± 1.1	11
UF-II	240 ± 7	20 ± 3.4	12
M-coat	244 ± 28	20 ± 1.6	12
Control	221 ± 10	26 ± 3.0	9

[a]mean ± standard error, C-mic: microbial biomass C, N-mic: microbial biomass N

at the start of the growing season (14 DAT) and differed largely among the treatments. A higher level of application gave higher soil NH$_4$-N for CM, PM and UF treatments. In contrast, both NH$_4$-N and NO$_3$-N were higher throughout the growing season for SU-I compared to SU-II in which rice straw and urea application was double the amount used for SU-I. As a visual observation for SU, yellowing of rice seedlings was observed up to 4 weeks after transplantation. For organic matter application treatments excluding SU-II, a mid-season increase in inorganic N was observed.

Microbial biomass C (C-mic) was highest for SU-II among the treatments (41% higher than the control), while it was the lowest for CM-I (15% lower than the control) (Table 3). Microbial biomass N (N-mic) was higher for PM and CM applications compared to other treatments, while it was the lowest for SU treatments. High chemical fertilization application such as UF-II and M-coat produced lower microbial biomass N compared to the control and manure treatments (Table 3).

Dry Matter Accumulation: Dry matter weight of rice was increased gradually for all treatments during the growing season and rapid growth was observed after the active tillering stage (between 63 and 84 DAT). Dry matter accumulation was higher for all organic matter and fertilizer applications compared to the Control. For CM and PM, higher levels gave higher dry matter weight in sampling at harvest (126 DAT). Dry matter was 18% higher for CM-II than for CM-I; and 10% higher for PM-II than for PM-I (Figure 2). However, the dry matter obtained for CM-I was almost the same as that for the Control. Dry matter weight for SU was low compared to PM, UF and M-coat, although urea was applied at half the total amount of N for SU (Figure 2). The highest dry matter was obtained
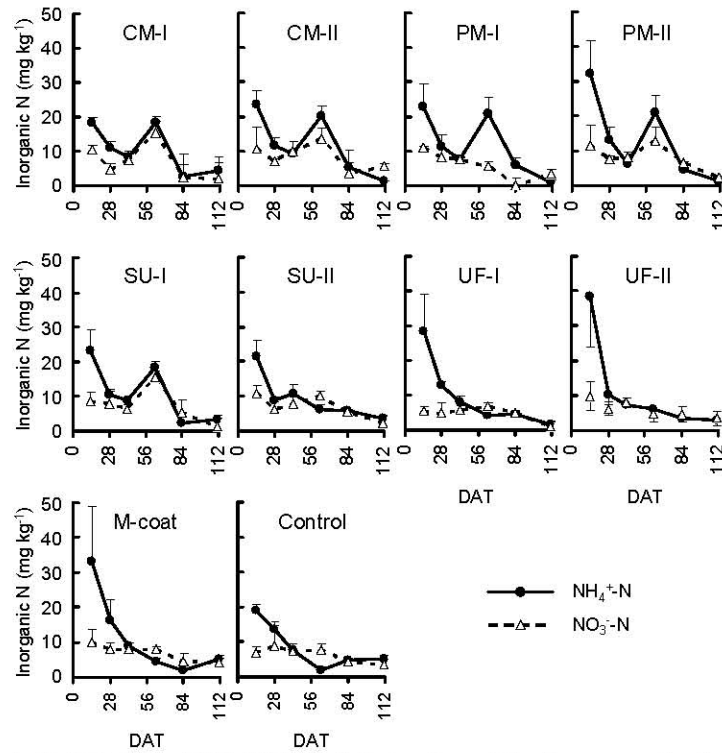
Fig. 1: Changes of inorganic N (NH₄-N and NO₃-N) in soil during the cultivation season by the application of different N sources. The error bars represent the standard error of the means (*n* = 3). DAT = Days after transplantation
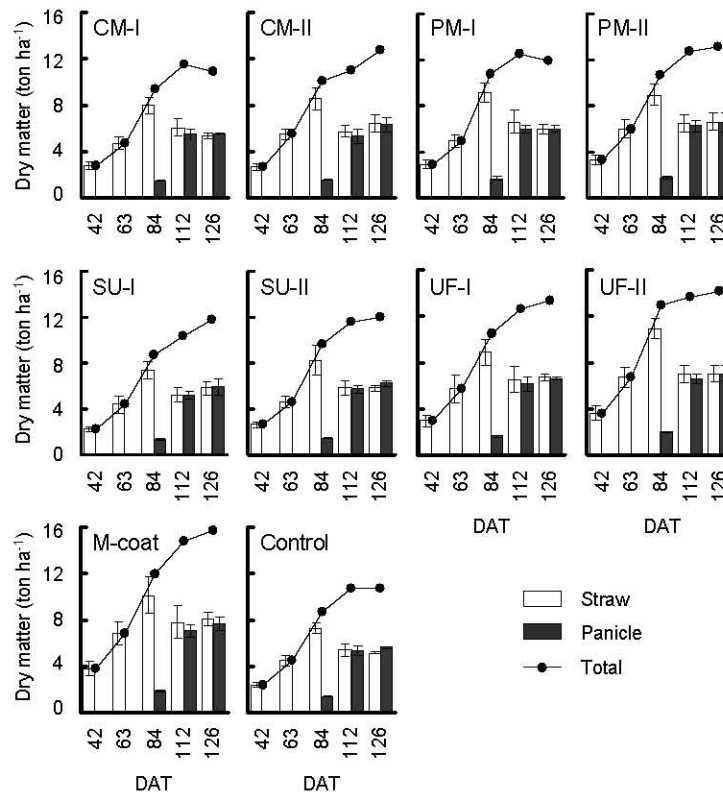

Fig. 2: Dry matter accumulation of rice during the cultivation season by the application of different N sources. The error bars represent the standard error of the means (*n* = 3)
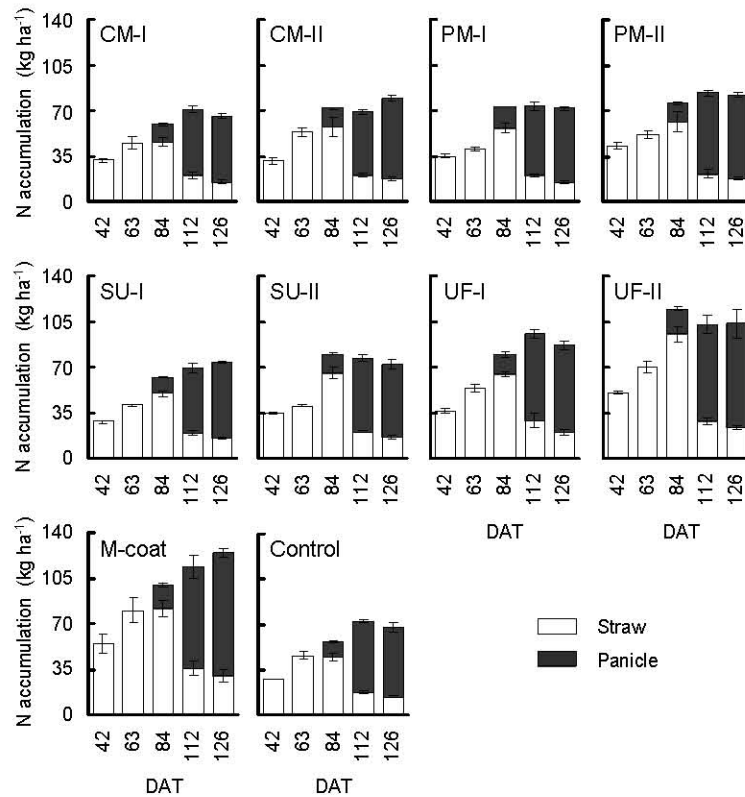
Fig. 3: Nitrogen accumulation in mid-season sampling of rice plant affected by the application of different N sources. The error bars represent the standard error of the means ($n = 3$)

Table 4: Total plant N accumulation, N input-out balance (NB) and apparent N recovery (ANR) of rice applied with different N sources

	Total plant accumulation	NB	ANR
	kg N ha^{-1}		%
CM-I	65 d[a]	-25 b	-5 c
CM-II	79 cd	1 a	15 c
PM-I	72 cd	-32 bc	10 c
PM-II	82 cd	-2 a	18 c
SU-I	74 cd	-34 bcd	16 c
SU-II	72 cd	8 a	5 c
UF-I	87 bc	-47 cd	49 b
UF-II	104 b	-24 b	45 b
M-coat	124 a	-51 d	78 a
Control	67 d	-	-

[a]Means in the same column followed by the same letter do not differ significantly according to the Tukey-Kramer HSD test ($P < 0.05$).

for UF-II and M-coat, while the lowest was for the control. Applied N was lower for M-coat (73 kg N ha^{-1}); however, dry matter weight was 11% higher than for UF-II.

Plant N Accumulation and Apparent N Recovery (ANR): Plant N accumulation gradually increased during the growing season and was in line with the dry matter

weight. Generally, plant N accumulation at each growing stage for all applications, except CM-I, was higher compared to that for the control (Figure 3). After the flowering stage, at about 84 DAT, a decrease in N was observed for SU and at the same time, N in panicles was increased for all treatments. Decrease in total plant N accumulation was observed in CM-I, SU-II, UF and control after the flowering period. This phenomenon was severe for UF-II compared to M-coat in which N accumulation was very high in panicles (Figure 3). At harvesting, the highest plant N accumulation was obtained from PM-II in the organic N applications and from M-coat among all treatments (Table 4). A lower plant N accumulation was obtained from SU-II compared to UF-I, although the amount (40 kg N ha^{-1}) and time of urea application were the same in both treatments. At harvesting, the plant N accumulation for M-coat was 85% higher than for the control and 54% for UF-II, 29% for UF-I, 21% for PM-II, 18% for CM-II, 9% for SU-I and 6% for PM-I and SU-II, while it was 3% lower for CM-I (Table 4).

Differences between applied N (input) and total plant N accumulation (output) are shown in Table 4. Generally, negative values of N input-output were observed for most
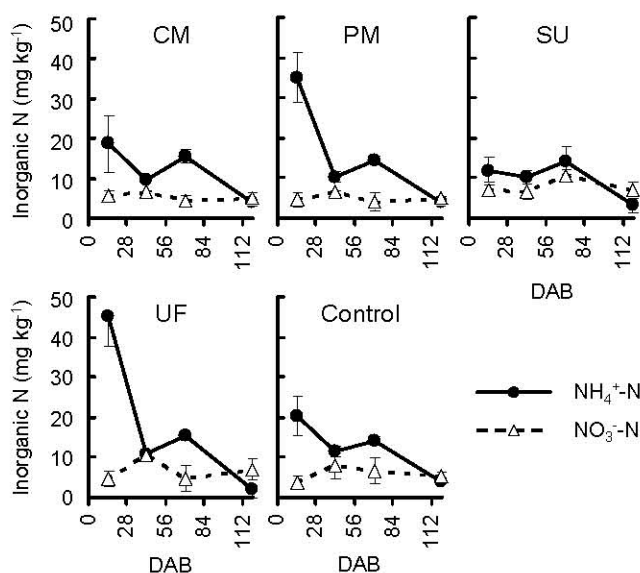
Fig. 4: Changes in inorganic N (NH₄-N and NO₃-N) in the litterbag field incubated samples with different N application. The error bars represent the standard error of the means (*n* = 3). DAB = Days after burial
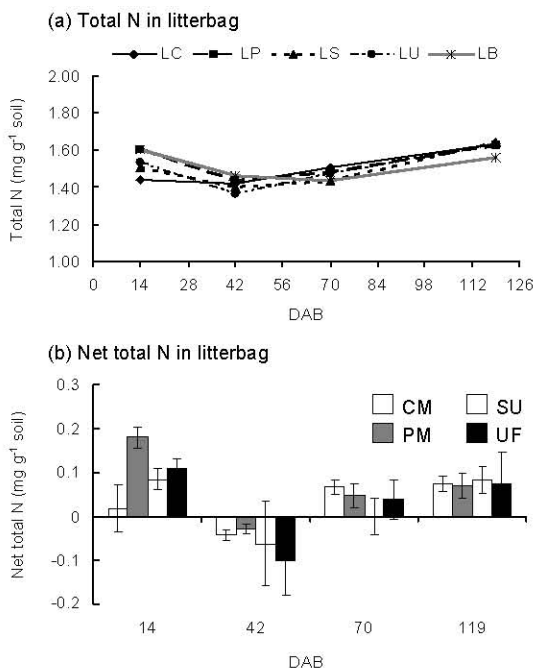

Fig. 5: Effects of different N application on (a) total N in litterbag and (b) net total N in litterbag (subtracted by control total N from the treatment total N) in respective period of samplings. The error bars represent the standard error of the means (*n* = 3). DAB = Days after burial

treatments because the amount of N taken up by the plant was higher than that of the total applied N. Larger negative values of N input-output were observed for mineral N applications. For CM, PM and SU, significantly larger negative values of N input-output were observed at low-level compared to high-level application. ANR for M-coat application (78%) was significantly higher than for the other treatments (Table 4). ANR was significantly lower for UF than M-coat. However, it was higher for UF than for the organic N applications. There was no significant difference among organic N applications and relatively low ANR was observed compared to mineral N applications.

Changes in Inorganic N and Total N in Field-incubated Litterbags: Inorganic N (NH₄-N and NO₃-N) in the litterbags differed between samplings throughout the study, showing a large variation in NH₄-N and comparatively lower value for NO₃-N. NH₄-N in the litterbag experiment differed greatly in the first sampling at 14 days after burial (DAB) and it was the largest for UF (Figure 4). Among the organic N treatments, higher inorganic N was observed for PM application, compared to CM and the Control at 14 DAB, while it was the lowest for SU.

Decrease in total N in the litterbags was observed at the second sampling (42 DAB) but it subsequently increased for all treatments (Figure 5 a). Net total N residue in the litterbags was calculated by subtracting the total N for the control from that for the treatments to compare the effects of applications. In all samplings, the net total N was the highest for all treatments and significantly differed among the applications at 14 DAB,

(Figure 5 b). Decrease in net total N was observed at 42 DAB with a negative value for all applications. However, a re-increase was observed for samplings at 70 and 119 DAB. There was no statistical difference between treatments for samplings at 70 and 119 DAB (Figure 5 b).

DISCUSSION

Soil N Dynamics: Soil NH_4-N varied greatly at the start of the growing season due to the application of different N sources in both the field study (Figure 1) and the litterbag experiment (Figure 4). This suggests that most of the readily decomposable organic matter in the manure and a large proportion of the applied mineral fertilizer dissolved in the soil water and produced plant-available N, especially NH_4-N, within a short period. This was most obvious for PM application among the organic N sources. NH_4-N is a significant portion of the total N in poultry manure, which also contains uric acid. Uric acid rapidly metabolizes to NH_4-N in most soils [20]. The released NH_4-N declined drastically in the next soil sampling at 28 DAT, possibly due to plant uptake since higher dry matter and N accumulation was observed in subsequent plant samplings, notably for UF-II (Figure 2 and 3).

Serna and Pomares [21] reported that animal manure, especially PM, contains both a rapidly mineralizable fraction and a slowly mineralizable fraction, determined through mineralization analysis; the latter mineralized within 14 to 112 days under aerobic soil incubation. In our study, the temporary increase in inorganic N (NH_4-N and NO_3-N) for organic matter application was observed and it might be due to decomposition (Figure 1). Organic matter decomposition was increased by the drying process during the cultivation period. In Japan and several other rice-growing countries in Asia, midsummer drainage or intermittent drainage is intentionally conducted for many weeks to promote rice root growth, organic matter decomposition and N mineralization. This practice is also effective for depressing methane emission by supplying oxygen to the soil [2]. Mid-season soil drying followed by irrigation enhanced the increase in inorganic N (both NH_4-N and NO_3-N). An increase in NO_3-N was observed in the samplings at 63 DAT for all organic matter treatments except PM-I, which might be due to nitrification process (Figure 1). Kyuma [22] explained that after a month, or from the start of waterlogging, a thin oxidized layer of the paddy soil is differentiated from the reduced plow layer and NH_4-N is readily transformed to NO_3-N by nitrifying bacteria.

Soil C was the energy source for microorganisms, which in turn promote organic matter decomposition and N availability under favorable conditions such as temperatures above 25°C and high moisture content [2, 18]. However, in our study, no statistical difference was observed in N-mic among the treatments. On the other hand, C-mic was significantly higher for SU-II in which a larger amount of C was applied (Table 3). This indicates that higher organic C application promotes C-mic in paddy soil and enhances soil C sequestration. However, large organic C application did not provide increased NH_4-N due to N immobilization rather than mineralization, which was evident for SU-II in our study.

In the litterbag experiment, an increase in total N was observed at 70 and 119 DAB, which might be due to external effects such as underground water evaporation. During harvest season drainage, the rice field started drying out, leading to upward capillary movement of underground water. Evaporation followed by depositing of dissolved N in the soil surface layer increased the total N content for all treatments. Litterbags were buried in a shallow layer (5 cm below the soil surface) and therefore, the effects of soil water movement on total N content should be considered as a principal factor. No similar reports have been found on such seasonal observation of total N dynamics in paddy soil and further systematic study will be necessary.

Dry Matter and N Accumulation of Rice: Inorganic N dynamics in the soil with M-coat application showed a decreasing trend throughout the rice growing season (Figure 1); however, plant N accumulation and dry matter were the highest throughout the season (Figure 2 and 3). This might be due to the slow-release property of M-coat, which indicates that the plant could absorb the released nutrients slowly and steadily. In our study, one of the goals of using organic manures was to obtain plant-available nutrients by slow release action throughout the growing season. From this point of view, we suggest that the use of PM may provide the highest effectiveness for plant N availability. PM has a higher nutrient content and more rapid mineralization rate compared to other animal manures and the use of PM as soil amendment would provide appreciable quantities of all the important plant nutrients [20, 21]. To secure its superiority, the application may be advanced by splitting or by using pelletized PM; however, further investigation is necessary.

When organic matter was applied to the soil, N mineralization took place. N mineralization is a relatively

slow microbial process that is affected by factors such as amendment composition, soil type, temperature, pH, aeration and moisture [23-26]. Therefore, the lowest accumulation of dry matter (Figure 2) and plant N (Figure 3) for CM (C/N ratio is 31) and SU (C/N ratio is 60) treatment might be due to its composition such as the higher C/N ratio. Suzuki [2] stated that organic materials with a high C/N ratio are likely to compete with crops for N, which can lead to N deficiency in extreme cases.

Savant and DeDatta [27] reported that plant recovery of top dressed nitrogen was always higher because it was applied when the root system was well developed. For UF, an increase in inorganic N in the soil sampling at 63 DAT was not observed (Figure 1); however, rice plants obtained N and increased growth due to urea split application at 40 and 77 DAT (Figure 2 and 3). However, urea split application effects on SU was lower due to N immobilization.

Soil N Balance: Soil fertility and nutrient supply capacity of the soil can be maintained on a long-term basis only by replenishing the nutrients (by addition through external inputs) that were removed by cropping and depleted through soil physical, chemical and biological processes [28]. In agricultural land, plant nutrient removal is one of the highest among all soil nutrient depletion processes. In our study, the value of the N input-output balance (NB) (Table 4) was investigated very simply; however, it does not perform well on a small scale. Farmers must be aware of the input-output balance for N and other nutrients to obtain sustainability for soil fertility and plant production. Generally, plant uptake is governed by external input and soil nutrient availability. High levels of external input enhance plant growth, which in turn increases the highest plant uptake. Large negative values of NB indicate that a large amount of N was taken up by the crop and replenishment via organic or inorganic sources is necessary to retain soil fertility and moreover, to ensure sustainable production for upcoming seasons. Higher NB value was observed for SU-II and it can be assumed that a residual effect from the manure application will be achieved in future seasons. Shiga [29], in a 5-year field study, reported that rice straw compost application enhanced the highest soil residual C and N, which increased the ability of organic materials to supply N and increase soil fertility. Although plant growth was relatively low for organic N applications such as PM-II and CM-II, NB values are preferable for soil fertility sustainability compared to mineral N application.

Apparent N Recovery: Apparent N recovery (ANR) was higher for chemical N application compared to organic N treatments. M-coat gave the highest ANR%, likely due to the slow-release property of the fertilizer. Castellanos and Pratt [30] and Kelling *et al.* [31] reported nitrogen availability as 30% for CM and 70% for PM while Myint *et al.* [32] reported it as 10-25% for CM and 30-50% for PM in the fertile soil of a pot experiment. However, relatively lower ANR for manure application was observed in this study. For CM application, not only ANR but also plant dry matter weight and plant N accumulation were lower compared to the other treatments. Therefore, only CM application might not produce an optimal rice yield. Low recovery of cattle (cow) manure compost N by rice plants was also described in many reports including Uenosono *et al.* [33] and Nishida *et al.* [34]. Cattle manure compost did not increase the dry matter weight or N uptake by rice at the time of the first application and successive applications for more than 3 years were necessary [35-37]. Recently, many researchers including Singh and Gangwar [4]; Khan *et al.* [11; 38] and Antil and Singh [12] indicated that use of organic manures in conjunction with mineral fertilizer is very important for ensuring better soil health and in sustaining crop productivity. Therefore, a mix application of manures (such as CM and PM) with mineral N fertilizer might provide high inorganic N in soil and higher crop production, however, further studies will be necessary.

CONCLUSIONS

We conclude that within-season inorganic N dynamics are governed by the type of applied manure and fertilizer; understanding this may help to manage the fertility of paddy soil for rice production. For all organic material applications, an increase in inorganic N was observed during the growing season; however, further studies will be necessary to manage the amount of released N and the timing to ensure synchronization with the crop requirements. Fertilizer with slow-release properties (M-coat) had the highest efficiency in crop N and dry matter accumulation, which may lead to higher yield and crop production. Organic matter application also had the promising quality of slowly releasing the nutrient as required. This study demonstrated the higher ability of PM, such as the production of larger inorganic N in the soil and higher plant N and dry matter accumulation throughout the growing season. Therefore, it is suggested that a higher level of PM (80 kg N ha^{-1}) should be applied consecutively for obtaining an optimum rice yield with environmental sustainability.

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