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# Rice Uptake and Recovery of Nitrogen with Different Methods of Applying $^{15}\text{N}$ -Labeled Chicken Manure and Ammonium Sulfate

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**Abstract** : The effects of different methods of fertilization on rice uptake and recovery of nitrogen were studied using  $^{15}\text{N}$ -labelled chicken manure (CM) and ammonium sulfate (AS). The results showed that the application method of totally basal dressing of organic and inorganic fertilizers can increase the N uptake by rice from the fertilizers. The N uptake from CM was obviously higher than that from AS. The N partitioning to rice grain was also higher than other application methods. The effect on increasing yield was obviously higher than the method of application of chemical fertilizers only. This method had such benefits as increasing N use efficiency, increasing N residue in soil and reducing N loss. High rice yield can be obtained while the soil fertility can be maintained with this method. So it is an effective and practical method of fertilization technique thus can be recommended to rice growers.

**Key words** : Ammonium sulfate, Chicken manure, Method of fertilizer application,  $^{15}\text{N}$  -labeled, Nitrogen recovery, Rice.

The N use efficiency of chemical N fertilizer in China is low due to heavy loss (Li et al., 1998). Studies aiming to increase the use efficiency of N are mainly focused on the following aspects: (1) breeding crop varieties with high N use efficiency (Shi et al., 2002), (2) improving the formulation of N fertilizers such as manufacturing of slow-release fertilizers (Huang and Dal, 2002), (3) supplementing nitrification inhibitor (Huang et al., 2002) or using urease inhibitor (Chen and Lu, 1997), and (4) ameliorating of application methods, such as the split application (Kawashima, 1984), deep placement of N fertilizer (Bautista et al., 1999) and flooding the rice field after top-dressed fertilization (Chen et al., 1987). Some report that totally basal dressing to the cultivated layer could significantly increase the N use efficiency and thus increase rice yield (Imori, 1993; Shuai and Yang, 1998). In order to improve the N use efficiency, split application of fertilization is recommended to farmers; especially the fertilization during heading stage is emphasized. However, split application is labor-intensive and often costly. With the development of fertilizer manufacturing technology, special attention is paid again to the technique of totally basal dressing to the whole plough layer, which means that all fertilizers are applied as basal dressing before rice seedling transplanting. The fertilizers can be mixed with soil during the process of land preparation thus distribute evenly in the whole plough layer. This technique could realize high rice yield with less inputs of labor and lower costs, therefore it may be popularized easily. The resources of organic fertilizers

in China are abundant. Total N in farmyard manures amounts up to 8.7 million tons per year, but its recovery rate in the organic wastes is low (Shen, 2002).

It has been proved that application of organic fertilizers could lead to higher and stable yield (Liao et al., 1998; Gao et al., 2002), improvement of crop product quality (Liu, 2002) and amelioration of soil fertility (Chen and Yong, 1995; Zhou et al., 2002). In order to further explore better fertilization method, the effects of totally basal dressing of organic and inorganic fertilizers on the rice yield, N uptake and N transformation in soil are studied in this paper. The objective is to improve the nutrient managements of rice cultivation.

## Materials and Methods

### 1. Materials and experimental design

The hydric paddy soil, which is developed from the Quaternary red clay, is used in the pot-culture experiment. Major physical and chemical characteristics was as follows: pH 6.20, organic matter 38.36 g kg<sup>-1</sup>, total N 1.78 g kg<sup>-1</sup>, alkali-hydrolysable N 145.63 mg kg<sup>-1</sup>, Olsen-P 8.00 mg kg<sup>-1</sup> and exchangeable K 54.73 mg kg<sup>-1</sup>. The rice variety is Zhongyou 402, a hybrid early rice combination with middle growth duration.

Five treatments were included: T1, zero nitrogen fertilizer; T2, totally basal dressing of  $^{15}\text{N}$ -ammonium sulfate; T3, split application of  $^{15}\text{N}$ -ammonium sulfate [1/2 basal dressing+1/2 top dressing (1/4 at tillering+1/4 at heading)]; T4, combined application of chicken manure (CM) and ammonium

Table 1. The dry matter and N accumulation in rice (g pot<sup>-1</sup>).

Treatment	Rice grain		Rice straw		Rice root		Whole plant	
	DW	N	DW	N	DW	N	DW	N
T1 <sup>1</sup>	25.9	0.378	26.1	0.198	4.9	0.031	56.9	0.607
T2 <sup>2</sup>	52.5	0.864	67.2	0.443	10.9	0.065	130.6	1.372
T3 <sup>3</sup>	55.6	0.902	61.8	0.498	10.7	0.067	128.1	1.467
T4 <sup>4</sup>	57.4	0.920	62.0	0.439	10.1	0.059	129.5	1.418
T5 <sup>5</sup>	54.3	0.869	58.6	0.434	10.0	0.063	122.9	1.366
L.S.D <sup>0.05</sup>	2.9	0.015	3.0	0.091	0.5	0.004	2.9	0.033
L.S.D <sup>0.01</sup>	3.9	0.021	4.1	0.013	0.7	0.007	3.9	0.047

<sup>1</sup>T1: zero nitrogen fertilizer.

<sup>2</sup>T2: totally basal dressing of <sup>15</sup>N-ammonium sulfate.

<sup>3</sup>T3: split application of <sup>15</sup>N-ammonium sulfate [1/2 basal dressing+1/2 top dressing (1/4 at tillering+1/4 at heading)].

<sup>4</sup>T4: combined application of chicken manure (CM) and ammonium sulfate (AS) as totally basal dressing [(a) 1/2 <sup>15</sup>N-CM+1/2 <sup>14</sup>N-AS, and (b) 1/2 <sup>14</sup>N-CM+1/2 <sup>15</sup>N-AS].

<sup>5</sup>T5: combined application of chicken manure and ammonium sulfate as split application [(a) 1/2.

<sup>15</sup>N-CM as basal dressing+1/2 <sup>14</sup>N-AS as top dressing (1/4 at tillering+1/4 at heading), and (b) 1/2.

<sup>14</sup>N-CM as basal dressing+1/2 <sup>15</sup>N-AS as top dressing (1/4 at tillering+1/4 at heading)].

sulfate(AS) as totally basal dressing [(a) 1/2 <sup>15</sup>N-CM+1/2 <sup>14</sup>N-AS, and (b) 1/2 <sup>14</sup>N-CM+1/2 <sup>15</sup>N-AS]; and T5,combined application of chicken manure and ammonium sulfate as split application [(a) 1/2 <sup>15</sup>N-CM as basal dressing+1/2 <sup>14</sup>N-AS as top dressing (1/4 at tillering+1/4 at heading),and (b) 1/2 <sup>14</sup>N-CM as basal dressing+1/2 <sup>15</sup>N-AS as top dressing (1/4 at tillering+1/4 at heading)]. Each treatment or sub-treatment was repeated six times.

Rice was planted in pot, which has an inner diameter of 24 cm and height of 27 cm. Each pot contains 8.5 kg air-dried soil. Three hills were transplanted in each pot, each hill has 2 rice tillering seedlings. The fertilizers included <sup>15</sup>N-labeled AS with abundance of 7.33%, <sup>15</sup>N-labeled CM with abundance of 4.69%, ordinary AS and CM. Each pot was applied with N 1.0g, P<sub>2</sub>O<sub>5</sub> 0.5 g, and K<sub>2</sub>O 1.0 g. The P and K fertilizers, which were calcium magnesium phosphate and potassium chloride respectively, were applied before transplanting. The shortage of P and K in CM was supplemented with calcium magnesium phosphate and potassium chloride respectively. All N fertilizers were applied according to the requirements of experimental treatments. The pots were placed in the open field isolated with wire entanglement. Major growth stages of rice were shown in Table 3. The pots were kept flooding with about 2-3 cm of surface water until the heading stage, then alternate wet and dry irrigation was adopted.

The process preparation of <sup>15</sup>N-labeled Chinese cabbage and CM was as follows. Chinese cabbage is planted in plastic pots (1.4 m<sup>2</sup>) containing sandy soil (with total N 0.5 g kg<sup>-1</sup>) in greenhouse. Sufficient P and K fertilizer was applied before seeding. During the growing stage (21 Nov 2002–30 Jan 2003), 120 g

of <sup>15</sup>N-labeled AS with abundance of 20% was applied four times. Total 6.75 kg of <sup>15</sup>N-labeled Chinese cabbage with abundance of 12.61% was harvested. The cabbage, added with starch (without N) and minor quantity of salt, is fed to chickens for 15 days. Total 4.23 kg of <sup>15</sup>N-labelled CM with abundance of 4.69% is collected, and then stored in a hermetically sealed chamber to rot and ferment. The method of producing <sup>15</sup>N-labeled Chinese cabbage and CM<sup>1</sup> used in this study is similar to that used by Uenosono et al. (2002).

## 2. Analysis and calculation

The NH<sub>4</sub><sup>+</sup>-N contents in the surface water and in the soil layer at the depth of 0–10cm and 10–20cm were determined at scheduled intervals. The water and soil were sampled with pipet and soil auger respectively. After harvesting, the yield components were examined. Samples of grain, straw, root and soil in the ploughed layer were collected for further analysis.

The N contents in CM, rice plant and soil were determined by the improved Kieldahl method (Bremner, 1965). The samples were pre-treated with the method reported by Chen and Cao (1983). The <sup>15</sup>N abundance was determined with MI 1305 mass spectrometer according to the method of Bremner (1965). The percentages of N derived from fertilizer (Ndff), N derived from soil (Ndffs), N use efficiency, N residue in the soil and N loss were calculated with the following equations:

$$\text{Plant Ndff}(\%) = \frac{{}^{15}\text{N atom excess in plant}(\%) }{{}^{15}\text{N atom excess in fertilizer}(\%) } \times 100\%$$

$$\text{Plant Ndff}(\text{g pot}^{-1}) = \text{Ndff}(\%) \text{ in plant} \times \text{total N uptake by plant.}$$

<sup>1</sup> In addition to the Chinese cabbage, starch and salt are fed to chickens. Major reason to choose Chinese cabbage in this study is that it has short growth duration and can be planted easily.

Table 2. Quantity and partitioning of soil N and fertilizer N taken up by rice<sup>1</sup>.

Treatment		Rice grain		Rice straw		Rice root		Whole plant	
		mg pot <sup>-1</sup>	%	mg pot <sup>-1</sup>	%	mg pot <sup>-1</sup>	%	mg pot <sup>-1</sup>	%
T2	AS <sup>2</sup>	384.8	45.9	196.7	45.7	25.5	39.8	607.0	45.6
	Soil	452.9	54.1	233.9	54.3	38.5	60.2	725.3	54.4
T3	AS	422.5	48.1	202.4	44.8	24.9	37.2	679.8	47.6
	Soil	455.5	51.9	249.9	55.3	42.1	62.8	747.5	52.4
T4	AS	192.0	21.5	82.8	19.4	13.7	24.0	288.4	20.9
	CM <sup>3</sup>	308.4	34.4	126.4	30.4	17.4	30.5	452.2	32.8
T5	Soil	394.6	44.1	217.1	50.9	25.9	45.4	637.6	46.3
	AS	225.2	26.7	85.6	20.3	14.5	20.8	325.3	24.5
T5	CM	265.1	31.4	108.0	35.6	17.4	25.0	390.5	29.4
	Soil	353.7	41.9	227.7	54.1	29.1	54.1	610.5	46.0

<sup>1</sup>39.7 mg pot<sup>-1</sup> N in the seedlings had been deducted from the amounts of N uptake.

<sup>2</sup>ammonium sulfate.

<sup>3</sup>chicken manure.

$$\text{N use efficiency (\%)} = \frac{\text{Plant Ndff (g pot}^{-1}\text{)}}{\text{Fertilizer N (g pot}^{-1}\text{) applied}} \times 100\%$$

$$\text{Plant Ndfs (\%)} = (1 - \text{plant Ndff (\%)} ) \times 100\%$$

$$\text{Plant Ndfs (g pot}^{-1}\text{)} = \text{plant Ndfs (\%)} \times \text{total N uptake by plant}$$

$$\text{Residue in soil Ndff (\%)} = \frac{{}^{15}\text{N atom excess in soil (\%)}}{{}^{15}\text{N atom excess in fertilizer (\%)}} \times 100\%$$

$$\text{Residue in soil (g pot}^{-1}\text{)} = \text{Residue in soil Ndff (\%)} \times \text{total N in soil}$$

## Results

### 1. Effects of different fertilization patterns on N accumulation

The rice yield of all treatments with fertilization were higher than that of T1, and the order of the yield was T4>T3>T5>T2>T1 (Table. 1). The results of variance analysis showed that the rice yield of T4 was 5.7% higher than that of T5, and that of T3 was 5.9% higher than that of T2. Both of differences reach to the significant level. The results showed that the totally basal dressing of combined organic and inorganic fertilizers to the whole plough layer and the split application of chemical fertilizers could significantly increase rice yield.

The N accumulation in rice plant increases with the increase of grain yield. The order of the amounts of N accumulation in rice grain also was T4 T3 T5 T2 T1. The differences between T5 and T4, between T3 and T2 reach extreme significant levels. However, the N accumulation in rice plant ranks in order as T3>T4>T2>T5>T1, which did not correspond with the order in rice yields. This showed that total N accumulation in rice plant was related to rice yield to some extent, but N accumulation in rice grain was closely related to rice yield. The ratios of N content in rice grain to that in rice straw follow the order of T4 (2.10)>T5(2.00)>T2(1.95)>T1(1.91)>T3(1.81). This showed that combined application of organic and inorganic fertilizers, especially when they are applied as totally basal dressing to the whole plough layer

could promote the partitioning of N to rice grain, thus is advantageous to increase grain yield. This result was similar to the report of Wu and Ni (1990). The correlated coefficients between the N accumulation and dry matter of grain, straw, root and the whole plant were 0.9987\*\*, 0.9583\*, 0.9909\*\*, 0.9923\*\* (n=5) respectively. This means that both economic yield and biomass were closely correlated with N supply from soil and fertilizers. This finding was in agreement with the report by Liu et al. (2002).

### 2. N uptake by rice from soil and fertilizer and its partitioning in different organs

When the inputs of N source were the same, the methods of fertilization had influence on the total quantity of N uptake from soil and fertilizers, but had almost no influence on the ratio of the N from the soil to N from the fertilizer. When chemical fertilizers are applied, 45.6–47.6% of the total N uptake came from the fertilizers while 52.4–54.4% from the soil. When both organic manure and chemical fertilizers were applied together, 53.7–53.9% of the total N uptake came from fertilizers while 46.1–46.3% come from the soil (Table 2). The amounts of fertilizer N absorbed by rice of the treatments with combined application of organic manure and inorganic fertilizers were obviously higher than that of the treatments with only chemical fertilizers applied, and the organic N taken up by rice was obviously higher than chemical fertilizer N. This result could be attributed to the stimulating effect of chemical fertilizer N to organic manure as well as the easy N loss of chemical fertilizers. As to the partitioning rates of soil N and fertilizer N in the different parts of rice plant, all the fertilization treatments had almost the same tendency. The soil N content in the different parts was in the order of root > straw > grain, while the fertilizer N content was in the reverse order. This result is slightly different from these of other studies (Liu et al., 2002).

Table 3.  $\text{NH}_4^+$ -N amounts in soil in different fertilization treatments.

Treatment	Depth (cm)	Panicle initial stage (28 May)			Booting stage (16 June)			Heading stage (2 July)			Maturing stage (24 July)		
		mg kg <sup>-1</sup>	Ndff% <sup>1</sup>	Ndfs% <sup>2</sup>	mg kg <sup>-1</sup>	Ndff%	Ndfs%	mg kg <sup>-1</sup>	Ndff%	Ndfs%	mg kg <sup>-1</sup>	Ndff% <sup>4</sup>	Ndfs% <sup>4</sup>
T1	0-10	18.26	-	-	110.24	-	-	98.28	-	-	23.94	-	-
	10-20	20.96	-	-	116.43	-	-	119.70	-	-	23.14	-	-
T2	0-10	102.63	50.25	49.75	152.49	1.93	98.07	134.56	0.60	99.40	27.13	2.64	97.36
	10-20	128.65	51.82	48.18	160.01	3.72	96.28	140.28	0.78	99.22	22.61		
T3	0-10	90.61	42.77	57.23	150.14	1.26	98.74	130.20	0.79	99.21	25.54	2.00	98.00
	10-20	89.31	42.05	57.95	154.13	1.94	98.06	125.44	1.02	98.98	25.54		
T4	0-10	82.69	35.59	64.41	149.37	2.91	97.09	133.70	1.31	98.69	20.08	2.99	97.01
	10-20	93.43	36.81	63.19	160.09	7.69	92.31	141.61	1.29	98.71	26.33		
T5	0-10	80.00	34.95	65.05	150.79	2.02	97.98	141.62	0.80	99.20	28.20	2.59	97.41
	10-20	76.96	32.48	67.52	152.66	2.87	97.13	140.70	1.06	98.94	27.27		

<sup>1</sup>Ndff: percentage of N derived from fertilizer.

<sup>2</sup>Ndfs: percentage of N derived from soil.

### 3. Dynamics of $\text{NH}_4^+$ -N in the soil layer and surface water layer

#### (1) $\text{NH}_4^+$ -N content in soil

The  $\text{NH}_4^+$ -N contents in each soil layer of treatments of fertilization were three to six times higher than that of T1 in the initial stage of panicle differentiation (Table 3). The contents of those treatments of chemical fertilizers were higher than that of combined organic and inorganic fertilizers. The content of that of totally basal dressing was higher than that of the split application. This was greatly related to the slow nutrient release rates of organic manure at the initial stage and greater amount of fertilizers in the totally basal dressing. As for the contents of  $\text{NH}_4^+$ -N in each soil layer, those of the top layer were smaller than those of bottom layer of the treatments of T1 and totally basal dressing; while for the treatments of split application, those of the top layer were larger than those of bottom layer. This result was mainly caused by the fact that fertilizers of the totally basal dressing were mixed well with soil and thus distributed evenly in the soil. The rice root systems distributed and absorbed nutrients mainly in the top soil layer. The fertilizers of the top dressing were applied on the top of the soil, so the nutrients could not be totally absorbed by rice. As for the sources of  $\text{NH}_4^+$ -N, the amount of  $\text{NH}_4^+$ -N from the soil and fertilizers in the treatments of chemical fertilizers showed little difference, each shared about 50%. However,  $\text{NH}_4^+$ -N from the fertilizers was about half that from the soil in the combined fertilization of organic and inorganic fertilizers. This showed that relatively more N came from the soil. The reason is that the mineralization rates of organic manures are affected negatively by low temperature.

From the booting stage to the heading stage, the  $\text{NH}_4^+$ -N contents in soil of all fertilization treatments increased obviously. This showed that the soil N supply reaches its climax during this period. As for the  $\text{NH}_4^+$ -N contents in different soil layers of different treatments, those of the top layer were smaller than those of the bottom layer during the booting stage. In the treatments of treatments of totally basal dressing, those of top layer also were smaller than that of bottom layer at the heading stage. However, the  $\text{NH}_4^+$ -N content of the top layer of treatment of top dressing with split application was larger than that of the bottom layer, which is the result of fertilization of top dressing at booting stage. According to the <sup>15</sup>N-labeled tracing results, it could be seen that the proportions of soil  $\text{NH}_4^+$ -N from the fertilizers of treatments of the totally basal dressing were higher than those of top dressing with split applications, while those of the combined application of organic and inorganic fertilizers were higher than those of applying chemical fertilizers only. However, in general, most of the N came from the soil, while the proportion from fertilizer N was relatively low. Only 1.26% to 7.69% at the booting stage and 0.60% to 1.31% at the heading stage came from fertilizer N. This shows that the soil N is the major N supplier to rice during the middle and later growth stages.

During the maturing stage, the  $\text{NH}_4^+$ -N contents in the soil layers of each fertilization treatment decrease significantly. This may be related to the alternate wet and dry soil condition, under which  $\text{NH}_4^+$ -N transformed into  $\text{NO}_3^-$ -N and N was uptaken by rice.

#### (2) Dynamics of $\text{NH}_4^+$ -N in the surface water

$\text{NH}_3$  volatilization is the major N-loss channel in the paddy field. Lowering  $\text{NH}_4^+$ -N concentration in the

Table 4. NH<sub>4</sub><sup>+</sup>-N concentration in the surface water (mg L<sup>-1</sup>).

Treatment	Date			
	13 May	24 May	14 June	30 June
T1	1.39	0.60	2.64	3.20
T2	26.80	10.39	3.71	3.47
T3	14.20	41.16	4.52	3.38
T4	20.71	2.08	2.54	6.31
T5	3.47	19.29	2.85	5.37
L.S.D <sup>0.05</sup>	2.60	3.76	1.29	0.83
L.S.D <sup>0.01</sup>	3.53	5.09	1.75	1.13

Table 5. Fates of fertilizer N.

Treatment	Uptake by rice		Residue in soil		Recovery		Gaseous loss	
	mg pot <sup>-1</sup>	%	mg pot <sup>-1</sup>	%	mg pot <sup>-1</sup>	%	mg pot <sup>-1</sup>	%
T2	607.0	60.7	145.6	14.6	752.6	75.3	247.4	24.8
T3	679.8	68.0	130.4	13.0	810.2	81.0	189.8	19.0
T4	740.6	74.1	214.0	21.4	954.6	95.5	45.4	4.5
T5	715.8	71.6	200.8	20.1	916.6	91.7	83.4	8.3
L.S.D <sup>0.05</sup>	80.7		37.7		118.4		46.1	
L.S.D <sup>0.01</sup>	117.4		54.8		172.2		67.1	

surface water is one of the critical methods to reduce gaseous loss of ammonia in the paddy field. It could be found from Table 4 that at the initial tillering stage (13 May, before top dressing), the NH<sub>4</sub><sup>+</sup>-N concentration in the surface water of T2 was highest (26.80 mg L<sup>-1</sup>). Those of T4, T3, T5 and T1 decreased in this order, i.e., that of totally basal dressing was higher than that of fertilization with split application, that of fertilization of chemical fertilizers were higher than that of the corresponding combined application of organic and inorganic fertilizers. And the differences reached significant level. The reason might be that more fertilizers were applied at the early stage for totally basal dressing, and the nutrient releasing rate of organic manures was relatively low. While at the initial stage of panicle differentiation (24 May), the NH<sub>4</sub><sup>+</sup>-N concentrations in the surface water of the totally basal dressing treatments decreased sharply, but that of the fertilization with split application increased greatly. The differences were significant also. This might be the result of uptake of nutrients by rice and the top dressing fertilization. At the booting stage (14 June), the NH<sub>4</sub><sup>+</sup>-N concentration in the surface water was also lower in the two treatments of combined application of organic and inorganic fertilizers (T4 and T5); while that of the totally basal dressing was lower than that of the top dressing by split application, but the differences were not significant. At the heading stage (30 June), the NH<sub>4</sub><sup>+</sup>-N concentration in the surface water of all the treatments showed little changes, but that of the two treatments of combined application of organic and inorganic fertilizers (T4 and T5) increased obviously. This might be due to the

fact that mineralization of organic manures still exists at the later stage. All in all, at all stages but heading, the NH<sub>4</sub><sup>+</sup>-N concentrations in the surface water of the two fertilization treatments of combined application of organic and inorganic fertilizers (treatments) were lower than that of the corresponding treatment of chemical fertilizers (treatments). The results showed that the combined application of organic and inorganic fertilizers could reduce gaseous loss of N thus increase the N use efficiency.

#### 4. The fate of fertilizer N

After N fertilizer is applied into the soil, the N mainly goes to the plant, resides in the soil, and goes to air through NH<sub>3</sub> volatilization and denitrification. The amounts of N assimilation by the plant and residue in the soil were determined by <sup>15</sup>N-labeled tracing technique. The gaseous N loss was calculated by subtraction method.

It can be seen from Table 5 that the order of the rates of N uptake by the rice plant from the fertilizers was T4>T5>T3>T2, and the differences between T4 and T2, and between T5 and T2 reach extreme significant and significant levels respectively. Viewing the quantity of N uptake by the rice plant from the fertilizer of T4 and T5, the N uptake from CM was 1.6 and 1.2 times that from AS respectively (Table 2). This showed that the combined application of organic and inorganic fertilizers could improve N use efficiency and CM played a better role. The N resided in the soil of the combined application of organic and inorganic fertilizers was about one and a half times that of the chemical fertilization. The difference also reached

to significant level. The N recovery of T4 and T5 was also remarkably higher than that of T2 and T3. The order of the fertilizer N loss was  $T2 > T3 > T5 > T4$ . The N loss of the combined application was remarkably lower than that of the chemical fertilization; this was just contrary to the N assimilation by the rice plant and N residue in the soil. Therefore, the combined application of organic and inorganic fertilizers was advantageous to the reduction of N loss and advantageous to increase the N use efficiency.

### Discussion

This study showed that rice yield was mainly related to the accumulation of N in rice grain though the total N accumulation in the rice plant was also relevant. The ratio of N accumulation in grain to straw was relatively higher when both organic and inorganic fertilizers were applied, especially when they were applied as totally basal dressing. This showed that the combined application of organic and inorganic fertilizers as totally basal dressing could promote N partitioning to the rice grain and thus increase yield. This was similar to the result reported by Wu and Ni (1990). When fertilizers were applied as totally basal dressing, the N use efficiency of combined application of organic and inorganic fertilizers was higher than that of application of chemical fertilizers only (Xu et al., 2002). The use efficiency of the former method was 36.5%, while that of the latter one was 27%. This study proved that when both organic and inorganic fertilizers were applied, the N use efficiency of totally basal dressing was higher than that of split application. When only chemical fertilizers were applied, the N use efficiency of totally basal dressing was lower than that of split application. So, the use efficiency of totally basal dressing was closely related to the varieties of fertilizers. The N use efficiencies in this study, which range from 60 to 74%, were much higher than that of reported by Xu et al. (2002). This may be caused by the difference of experimental conditions. (Zhang et al., 1997) reported that the contents of available N, P and K in the soil of totally basal dressing were higher than those of traditional fertilization method at early growth stage, while at later stage, no difference existed between the fertilization methods. This study shows that the  $\text{NH}_4^+$ -N content in the soil of totally basal dressing was higher than that of split application at the early growth stage when same sources of N were applied. While at the middle and later stages, almost no difference existed in all the treatments. At the early growth stage, the proportion of  $\text{NH}_4^+$ -N in the soil from the fertilizers in the application of chemical fertilizer was higher than that of the combined fertilization of organic and inorganic fertilizers, while at the middle and later stages, the results were just the reverse. This showed that the combined application of organic and inorganic fertilizers could supply balanced nutrients

and sustain longer. In the combined application of organic and inorganic fertilizers, the  $\text{NH}_4^+$ -N content in the surface water in the paddy field was significantly lower than that in the treatments of only chemical fertilizers. This was advantageous to decrease  $\text{NH}_4^+$ -N loss.

Zhu and Wen (1992) reported that higher N residue in the soil was advantageous to the maintenance and improvement of the stock of soil N, and that the use efficiency of N residue in the soil was generally higher than that of the soil N, which was thus advantageous to the maintenance and improvement of the use efficiency of the soil N. This study showed that the combined application of organic and inorganic fertilizers could not only improve the use efficiency of fertilizer N and reduce N losses, but also could obviously increase the N residue in the soil of fertilizer N. The N residue in the soil in the combined application of organic and inorganic fertilizers as totally basal dressing was one and a half that of the fertilization of only chemical fertilizers, which could thus improve the soil N supply and promote the N recovery. From the aspects of the transformation and utilization of N, the organic manure is actually a certain kind of slow-releasing N fertilizer (Lu, 1998). Combined application of organic and inorganic fertilizers is advantageous to making full use of the on-farm organic manures, which is beneficial to the increase of crop yield and the maintenance of the soil fertility (Li and Zhang, 2000).

Comparing with applying only chemical fertilizers, the method of fertilization of combined application of organic manure and inorganic fertilizers as totally basal dressing is beneficial to the balanced releasing of nutrients and reducing of N loss, thus increasing the N use efficiency. This method can promote the N partitioning to grain thus increase the rice yield. The N residues in the soil is also higher with this fertilization method, therefore increase the N supply of soil and the maintenance of the soil fertility. In addition, this method of fertilization is a labor-saving and cost-saving technique. So, combined application of organic and inorganic fertilizers as totally basal dressing is technically feasible, economic viable and environmental friendly.

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\* In Chinese with English abstract

\*\* In Chinese

\*\*\* In Japanese