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Nitrogen Leaching from Paddy Field under Different Fertilization Rates

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ABSTRACT

Nitrogen leached from a paddy field could adversely affect subsurface water and groundwater quality. A field plot experiment was carried out to determine the effects of five fertilizer application rates on N vertical leaching from 30 and 60 cm soil layers. Results showed that during the paddy growth, NH_4^+ -N was the main form of nitrogen with a high environment risk. The range of NH_4^+ -N /TN varied from 0.27 to 0.89 with NH_4^+ -N concentration peak appearing within 2-4 days after three fertilizer application rates; the highest NH_4^+ -N concentrations were about 38.38 mg L^{-1} for the 360 kg ha^{-1} or N_4 treatment. Significant differences were observed in the two layers between the other four fertilizer application rates. Nitrate concentrations at 30 cm depth soil leachate were higher than at 60 cm depth; however, the peak of about 9.21 mg L^{-1} for the 30 cm depth soil leachate appeared 1-2 days later than the NH_4^+ -N and the concentrations for the 60 cm soil layer leachate which were less than 3 mg L^{-1}. Nitrogen loss from different nitrogen treatments varied from 2.82 to 5.07 % of the urea-based fertilizer applied. The cumulative effect of nitrate leaching on the quality of the shallow ground water should be of concern.

Keywords: Ammonium nitrogen, nitrate nitrogen, nitrate leaching, ammonium leaching, urea fertilization rate

INTRODUCTION

Paddy is an important cereal crop in 111 countries, which is cultivated on 150.7 million hectares of land in almost all Asian countries, most of the countries of the West and North Africa, some countries in Central and East Africa, most of the South and Central American countries, Australia and four states in the United States. Most of the field experiments conducted in rice growing countries indicate that the application of nitrogen either through organic or green manure or chemical fertilizers plays a dominant role in increasing rice yield. The amount of nitrogen used per unit area for rice is greatest in developed countries (FAI 1997). Excessive use of readily available conventional chemical fertilizers for agricultural land is the main source of ground water contamination (Thomsen *et al.* 1993). Nitrogen fertilizers are commonly used in rice cultivation to increase yields. Urea and ammonium sulfate account for 80-90% of the total nitrogen fertilizer required

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in rice cultivation (FAO 1997). The rapid increase in N-fertilizer applications in recent years is the main reason for increased nitrate content in groundwater (Diercks 1983). Contamination of ground water with nitrate leaching is commonly associated with high application rates of N fertilizer (Strebel *et al.* 1989). Nitrogen leaching is caused by an increase in nitrate concentration of surface water in upland cultivation systems. Nitrate-nitrogen (NO_3^- -N) is soluble and moves readily with soil water becoming a potential source of ground water pollution. The most important factors that determine the amount of NO_3^- -N leaching to ground water are soil type, amount of precipitation or irrigation, crop type and the amount of nitrogen (N) fertilizer applied in excess of the amount of N uptake by the crop. The amount of NO_3^- -N leached to the ground water increases with N fertilizer application rates (Schepers *et al*. 1991). Nitrate produced in the surface layer of flooded soil moves easily by diffusion and percolation into the underlying reduced layer. Ammonium nitrogen is less subjected to leaching from the soil compared to nitrate because of its adsorption in the cation exchange complex. However, losses of ammonium nitrogen through leaching occur in coarse-textured soil with a low exchange capacity. The extent of loss can vary from 30-50% (Mangnicent and Broadbent 1977). Nitrogen losses through leaching vary across a field due to differences in soil physical properties and N status of soil. The volume of NO_3^- leached from soil may be decreased by site-specific application of N fertilizer. However, to precisely vary N fertilizer application requires knowledge on variability of the parameters that control N availability (Delcourt *et al.* 1996; Earl *et al*. 1996). Not much research has been conducted to examine nitrogen leaching from paddy fields under different fertilization levels. The objective of this study was to investigate nitrogen-leaching loss potential in a paddy field under different urea fertilization rates.

MATERIALS AND METHODS

Experimental Site

The field experiment was carried out in Shuang Qiao farm of Zhejiang University in the northern part of Zhejiang Province (120°40'E, 30° 50'N) which is located in the South-east coastal area of China. This region has the typical characteristics of a coastal area that practices terraced agriculture. A monthly rainfall of 40 mm was measured during the study period. The soil comprises 29.5 % sand, 50.5 % silt and 20.2 % clay with 0.06 - 0.08 % total N, 0.05 - 0.06 % total P, 1.2 - 1.4 % organic matter, 7.6 - 7.8 pH and a permeability of 180 m hr^{-1}. The soil was a coastal saline soil with medium fertility and paddy was cultivated as a crop. The mean air temperature during the experimental period was 28.1 ^{0}C and the average maximum temperature was 34 ^{0}C.

Experimental Procedure

Fifteen individual plots separated by ridges were established in a grid. Each plot was 4 m × 5 m in size and infiltration-proof nylon was inserted into the soil to 60

cm depth at the three edges of the plots to isolate lateral movement of soil water. There were separate hydrants in front of each plot for irrigation with one PVC pipe lying in the buffer zone for drainage. The surface water was maintained at about 7 cm depth. Excess rainwater automatically drained through a PVC pipe into a tipping bucket sample collection apparatus when the depth of the surface water rose above 10 cm *(Fig. 1)*. In the centre of each plot, two soil *in situ* solution samplers were inserted at 30 and 60 cm soil depths to collect leachates from the upper soil *(Fig. 2)*. Rice seedlings were transplanted on the same day when basal fertilizer was applied. The 'one season' rice variety, Jia-9312, was used because one season rice (one summer rice crop in rotation with one winter crop species each year) has become popular in Zhejiang province.

Fig. 1: View of the experimental plots

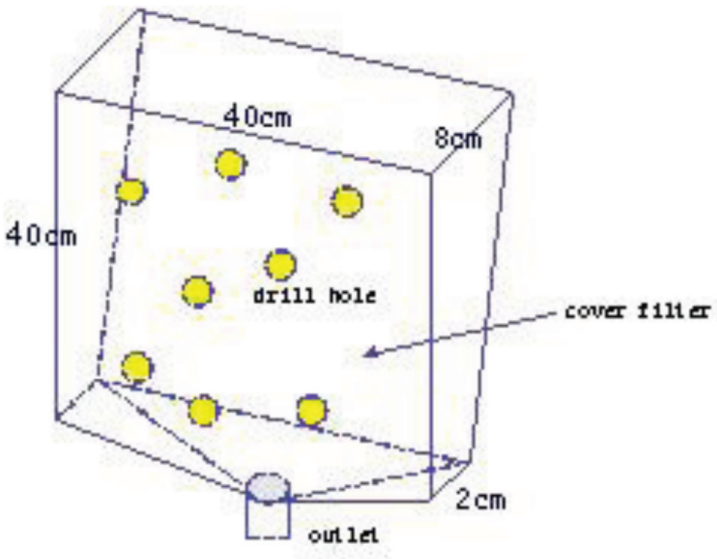

Fig. 2: Nitrogen leaching in situ sampler

Treatment

Table 1 shows the nitrogen fertilizer application rate in the experimental plots. The rate of 180 kg N ha^{-1} as urea was the typical N application rate (TNAR) in the region. There were five treatments: (1) N_0, no N application (control); (2) N_1, 90 kg N ha^{-1} as urea (50 % of the TNAR in the region); (3) N_2, 180 kg N ha^{-1} (the TNAR); (4) N_3, 270 kg N ha^{-1} (150% of the TNAR); and (5) N_4, 360 kg N ha^{-1} (double the TNAR). The N fertilizer rates given above were applied in the following schedule: 60 % as basal fertilizer (applied on 7th July) and 40 % as additional top dressing (20% + 20%, two additional fertilizer applications on 16th July and 2nd August) to the field plots.

TABLE 1
Different nitrogen fertilizer application rates

Nitrogen treatment	Urea (kg ha^{-1})	Nitrogen (kg ha^{-1})
N_0	0	0
N_1	196	90
N_2	392	180
N_3	588	270
N_4	784	360

Sampling and Analysis

Figure 1 shows the schematics of the in-situ sampler to measure nitrogen leaching. There were three layers at 8 cm depth inside the samplers, with pebble layer in the lowest position, granular sand in the middle and quartz sand layer in the upper. Besides, one piece of 40 x 40 cm fibre cloth was fixed on the surface of the sampler to prevent large-sized soil particles entering the sampler. The samplers were inserted into 30 and 60 cm soil depths, six months before rice seed planting. The bottom of the sampler had space to store the nitrogen leachate.

To avoid disturbing the soil, sampler installation involved digging a trench outside the plot area and then digging sideways to insert the samplers into the plot at depths of 30 and 60 cm. The collection pan was wedged tightly to the top of the horizontal excavation, and excavations were backfilled. Leachate was collected on a daily basis for one week after fertiliser application and at 4-day intervals subsequently.

The leachate that leached into the upper soil was extracted from the 30 and 60 cm layers. Total nitrogen, ammonia nitrogen and nitrate in the leachate water samples were analyzed according to standard Chinese methods (National Environmental Bureau 1996), which were modified from Eisenrich *et al.* (1975). The nitrogen loss of the field surface water was calculated from the field surface water volume and concentration by using arithmetic method.

Data Analysis

SPSS (V.10 for windows), MS Excel and Adobe Photoshop 7.0 programs were used in this paper for data analysis, graph preparation and drawing picture. All data were subjected to analysis of variance for a randomized complete block design with a split plot arrangements of treatments. Test of hypothesis was two way covariance i.e. H_1: $\mu_1 >$ or $< \mu_2$; a high significant difference between the treatments at 0.05 level was found. In order to evaluate the effects of different nitrogen treatments on NH_4^+ -N and NO_3^- -N, analysis of variance (ANOVA) and pairs of mean values were compared by using test of least significant difference (LSD) at the 0.05 levels. Data were tested by analysis of variance and pairs of mean values were compared by using SPSS of least significant difference (LSD) at the 0.05 level. Also, replications differed between treatments and are shown in the legends of tables.

RESULTS AND DISCUSSION

Nitrogen Concentration Variation at 30-and 60-cm Depths of Soil Layer Leaching Water

Figure 3a shows total nitrogen variation at 30 cm depth of soil layer for each fertilizer treatment at 4-days interval for a period of 2 months. The initial increase in TN concentration at 30 cm depth was higher with increasing rate of N fertilizer application and the TN concentration at the highest rate peaked within about 1 week of application. Total nitrogen concentration was higher on 8th July, declining gradually after 22nd July for each treatment and finally reaching a constant value after about 60 days. TN concentration did not differ from N_0 – N_3 treatments. TN concentration was high in N_4 treatment perhaps due to maximum N fertilizer application for that treatment. From 8th July onwards, there was little difference in TN content of the four treatments (N_0 – N_3) with all being very low except for the N_4 treatment. This occurred because rice plants take up more fertilizer from 30 cm depth which is within the root zone of the paddy plant. Fluctuation of total nitrogen concentrations at the 30 cm depth appeared to correspond to changes in nitrification.

Figure 3b shows NH_4^+ -N concentration (mg L^{-1}) at the depth of 30 cm at different rates of urea application from 8th July to 8th September. Urea fertilizer application is a common practice in paddy fields. Preliminary results showed that amount of NH_4^+ -N concentration at the 30 cm depth increased following basal, first (16th July) and the second (10th August) additional application of urea. Of the total urea, 60% was applied as basal fertilizer, 20% in the first application and 20% in the second application. As a result, NH_4^+ -N concentrations were higher on immediate respective application dates. Due to the higher application rate of urea, NH_4^+ - N concentration was higher at N_4 treatments. It indicated that applications of N fertilizer increased field surface N concentrations greatly and these effects were more pronounced with increasing fertilizer application rates. In the control treatment (N_0), NH_4^+ -N concentration remained constant.

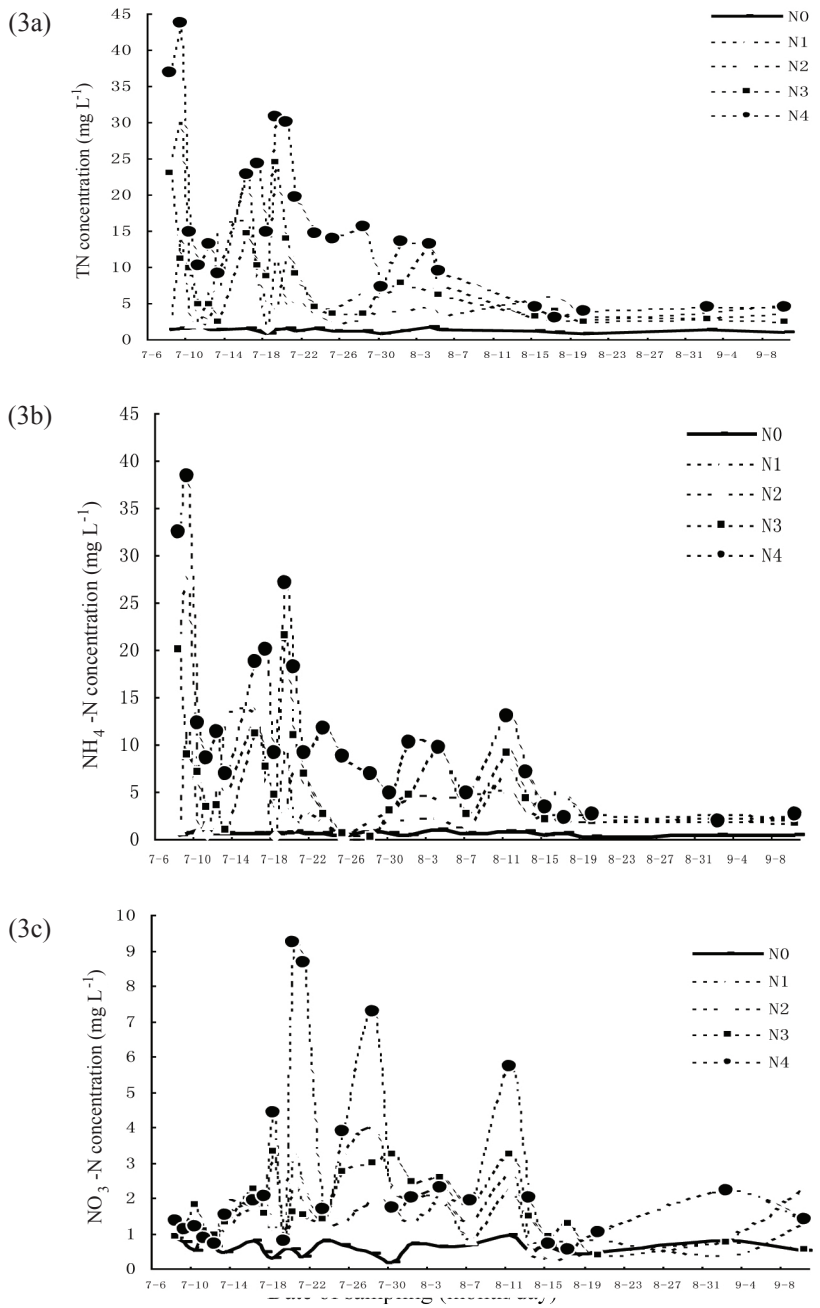

Fig. 3: (a) TN, (b) NH_4^+-N and (c) NO_3-N concentration in leachate at 30cm soil depth on different days after split N applications (mg L^{-1})

Figure 3c shows NO_3^- -N concentration variations for different urea rates at 30 cm depth. Each treatment gave rise to significantly higher NO_3^- -N concentrations at 30 cm depth, 7 days after application and there was no loss of N by drainage following rain during this period. On 20th July, NO_3^- -N concentration increased significantly in N_4 treatment due to application of urea. Otherwise, fluctuation of NO_3^- -N was approximately the same in each treatment except for the N_4 treatment. Also, the increase in NO_3^- -N on 20th July is referred to as nitrification which means that NO_3^- -N concentration depends on rate of N application and water or moisture effect.

Total nitrogen concentration in the leachates at 60 cm soil depth at 4-day intervals is presented in Figure 4a. On 18th July, total nitrogen concentration was higher in each treatment because fertilizer was applied on that day. From 12th July to 3rd August, TN concentrations at N_4 treatment were higher (14 to 45 mg L^{-1}) and then reached a constant as in the case of other treatments. It was found that TN concentration was actually proportionately related to N application rate but the increased N in the surface water derived from N fertilizer was more readily leached down the soil profile. As a result, TN declined much more quickly, finally reaching a constant in each treatment.

The cumulative distribution of nitrogen applications in the paddy field and its effects on NH_4^+ -N concentrations for different treatments at 60 cm depth are shown in Figure 4b. It shows NH_4^+ -N concentrations at 60 cm depth at different intervals. On 18th July for each treatment, the NH_4^+ -N concentrations were higher because sampling commenced earlier, that is, on the second day after fertilizer application and the maximum NH_4^+ -N concentrations following the highest N application occurred very soon after fertilizer application. Gradually, the NH_4^+ -N concentrations decreased. Fluctuations were observed in the control plot, possibly due to lateral movement or seepage of NH_4^+ -N concentrations from the treated plot.

Figure 4c shows the NO_3^- -N concentrations for the 60 cm soil depth for each treatments with respect to time. The NO_3^- -N concentrations did not differ among treatments; it fluctuated from 8th July to 11th August, declined on 15th August and later reached a constant. This could be due to the fact that NO_3^- -N normally accumulates in soils because of fertilizer addition and this accumulation is further enhanced when crop demand is much less than the rate of NO_3^- -N production. Otherwise, nitrate will directly leach into ground water.

Nitrogen leaching was compared between 30 and 60 cm depths for paddy soil treated with five different urea fertilization rates under natural conditions. The NH_4^+ -N, NO_3^- -N and TN concentration at 30 and 60 cm depths showed a discontinuous pattern with time (Figs. 3 and 4). The NO_3^- -N concentrations were higher at 30 cm compared to 60 cm depth. Possibly, NO_3^- -N remained within the 30 cm depth for absorption by paddy roots and the rest of the NO_3^- -N was leached into the ground water. Maximum variability was observed in the most intensive system, where high values were followed by medium or low values at short intervals of time. The high concentrations may be related to management

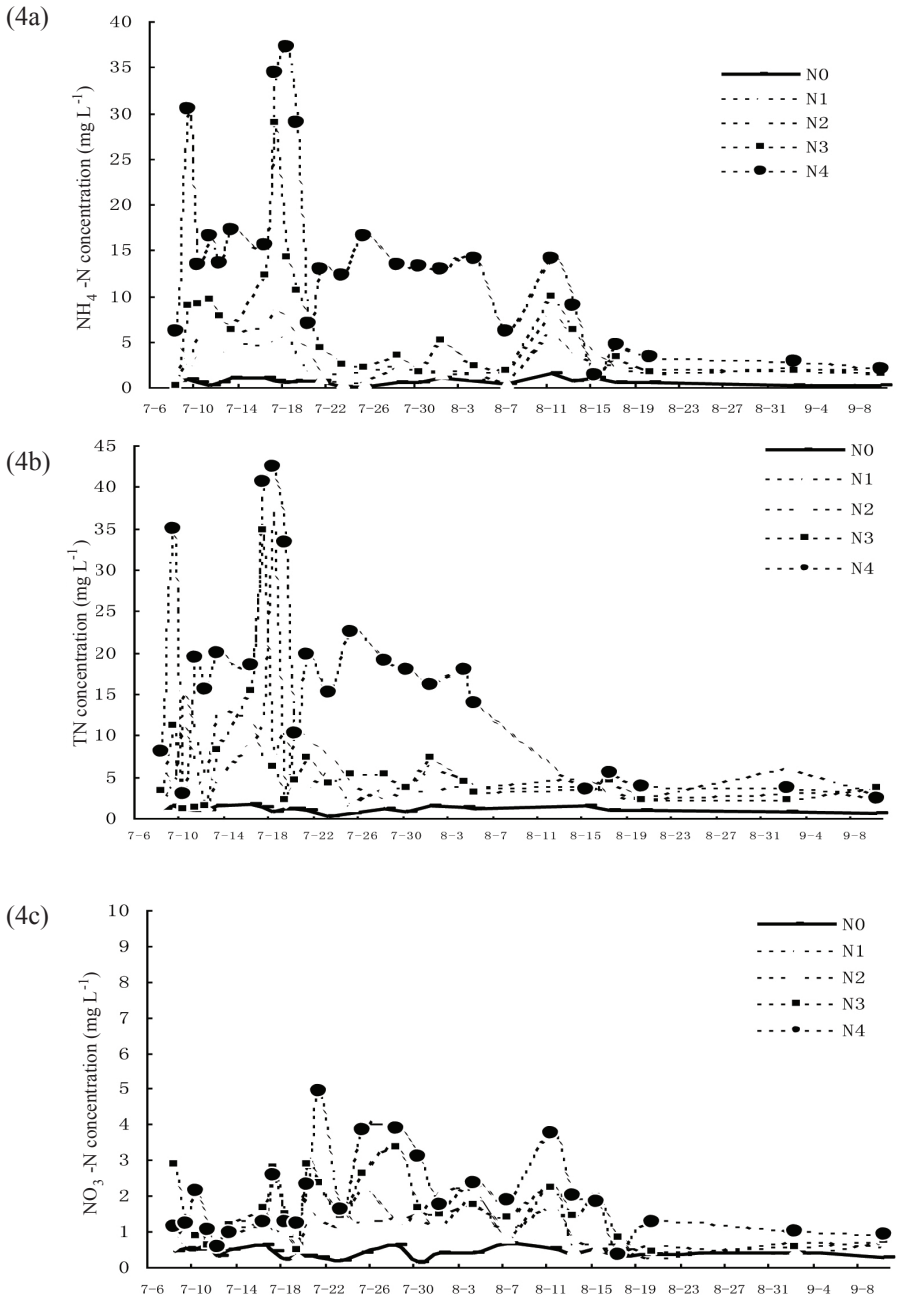

Fig. 4: (a) TN (b) NH_4^+-Nand (c) NO_3^-N conc. in leachate at 60cm soil depth on different days after split N applications (mgL^{-1})

practices such as nitrogen application followed by significant rainfall or they occurred after high rainfall in a period without significant uptake by the paddy plant and in the absence of fertilizer application in the period preceding the rainfall. The nitrogen uptake by paddy fertilized with liquid manure, did not prevent nitrogen leaching and pollution of the environment. Cultural practices played a vital role in nitrogen leaching. Due to mechanized cultivation, a hard pan did not exist to facilitate leaching. Other researchers also have a similar opinion. The presence of a plough sole, which has a very low hydraulic conductivity, is vital in controlling the leaching rate (Wopereis *et al*. 1992; 1994; Bouman et al. 1994; Chen *et al*. 2002). Puddling, harrowing and leveling the soil under water-saturated conditions create the plow sole, which is also called 'the hard pan'. In general, the plough sole layer with a low hydraulic conductivity was about ten centimeters thick and almost 20 to 30 cm underneath the surface soil. However, this layer can also be destroyed by agro-behaviours such as tractor plowing and inversely increases the nitrogen leaching potential into shallow groundwater. Chen *et al*. (2002) also found that breakage of the plough sole layer increased soil water infiltration rate by a factor of 3.7.

Effects of Different Nitrogen Rates on Nitrogen Transformation

Table 2 shows that the value of NH_4^+ -N concentration at 30 cm depth at the N_4 level varied from 4.48 to 38.3 mg L^{-1}, which equals 1-5 times of the N_0-N_3 levels. The NH_4^+ -N concentration at 2 to 6 days after basal N application at 30 cm depth at N_4 level was significantly different from the other four levels, because the soil was flooded and the NH_4^+ -N concentrations were directly affected by N levels. The NH_4^+ -N concentrations between N_2 and N_1 treatments were significantly different. At 2 to 6 days after basal N application, the NH_4^+ -N concentrations for N_2 and N_1 was from 1.43, 2.69 mg L^{-1} to 9.75, 11.51 mg L^{-1}, respectively. NH_4^+ -N concentrations did not differ ($P > 0.05$) between N_0 and N_1 treatments. However,

TABLE 2
Concentrations of NH_4^+-N in leachate at 30 cm soil depth on different days after split N applications (mg L^{-1})

Nitrogen treatment	Days after basal FA			Days after second FA				Days after third FA		
	3	7	3	7	14	21	3	7	14	30
N_0	0.91c	0.57c	0.59e	0.76d	0.30c	0.69e	0.65d	0.50c	0.26b	0.39a
N_1	1.43c	2.69c	4.55d	1.53cd	2.33b	4.19d	2.47c	2.09b	1.85a	2.11a
N_2	11.51b	9.76b	6.35c	2.81c	1.58c	5.94c	3.78b	2.22b	2.13a	1.96a
N_3	13.14b	10.46b	7.68b	9.71b	2.23b	9.30b	4.26b	4.78a	1.78a	1.63a
N_4	38.38a*	13.43a	10.03a	28.13a	4.48a	11.98a	6.97a	2.13b	2.51a	2.65a

*Within columns, means followed by the same letter are not significantly different by Least Significant Difference (LSD) at the 0.05 level

N_2 and N_3 treatments differed after basal N application with the mean concentration being similar in both treatments. The NH_4^+ -N concentration varied greatly in the five treatments rates within two days after the first additional N application (second N application). After a peak, NH_4^+ -N concentration in the two soil layers in the following days were all below the 10 mg L^{-1}. There were significant differences between N_0-N_3 levels; the NH_4^+ concentrations for N_4 treatment was significantly higher than that of the other 4 rates. The NO_3^- -N concentrations at 30 cm depth did not significantly differ between the 5 N rates within 2 days after the two N fertilizer applications (Table 3). However, an increase in NH_4^+-N enhanced the microbial growth and transformation of NH_4^+ -N to NO_3^- -N. The NO_3^- -N concentration 4 days after fertilizer application was highest for N_4 treatment.

TABLE 3
Concentrations of NO_3^- -N in leachates at 30 cm soil depth on different days after split N applications (mg L^{-1})

Nitrogen treatment	Days after basal FA			Days after second FA			Days after third FA			
	3	7	3	7	14	21	3	7	14	30
N_0	0.92a*	0.46abc	0.28a	0.34d	0.73bc	0.69a	0.49d	0.41c	0.45a	0.87a
N_1	0.93a	1.91b	1.36a	2.54c	3.42b	1.98a	0.52c	0.27c	0.50a	2.23a
N_2	0.94a	1.19c	1.96a	2.69bc	2.90c	1.86a	0.81c	0.77b	0.80a	1.29a
N_3	1.33a	1.32abc	3.29a	1.93bcd	2.97b	2.57a	1.46b	1.27a	0.89a	0.55a
N_4	1.01a	1.52abc	4.41a	9.21a	7.28a	2.30a	2.00a	0.52b	1.02a	1.38a

*Within columns, means followed by the same letter are not significantly different by Least Significant Difference (LSD) at the 0.05 level

Table 4 shows that due to soil adsorption and bacteria transformation, the NH_4^+ -N concentrations at 60 cm depth of 5 N rates did not differ significantly except for the N_4 treatment at which the concentrations varied from 11.96 to 37.22 mg L^{-1} that is 2-7 times of the N_0-N_3 treatments. The NH_4^+ -N concentrations at the 60 cm depth was not affected by a fertilizer application rate of lower than the N_3 rate.

TABLE 4
Concentrations of NH_4^+-N in leachates at 60 cm soil depth on different days after split N applications (mg L^{-1})

Nitrogen treatments	Days after basal FA			Days after second FA			Days after third FA			
	3	7	3	7	14	21	3	7	14	30
N_0	0.65d*	0.36c	0.40e	0.13b	0.38b	0.59b	0.65d	1.50c	0.56a	0.22a
N_1	5.52c	0.83c	5.77d	0.466b	0.83b	3.54b	3.47c	2.31b	1.93a	2.15a
N_2	7.33b	8.31b	10.79c	1.45b	0.26b	1.47b	5.78b	1.97b	1.55a	1.43a
N_3	6.96bc	12.95a	24.24b	2.30b	1.97b	2.31b	6.26b	3.36b	1.60a	1.55a
N_4	11.96a	15.80a	37.22a	4.22a	12.39a	12.89a	8.97a	4.69a	3.26a	2.03a

*Within columns, means followed by the same letter are not significantly different by Least Significant Difference (LSD) at the 0.05 level

Effects of Nitrogen Leaching Concentrations on Water Quality during Paddy Growth

The increase in NH_4^+ -N concentration enhanced nitrobacteria growth, leading to transformation of NH_4^+ -N to NO_3^- which inversely led to a lower degree of NH_4^+ -N concentration and subsequently decreasing the ratio of NH_4^+ -N /TN (Table 5). At 30 cm depth, the ratio varied from 0.89 to 0.32 with 75% above 0.70, and at 60 cm depth, the ratio varied from 0.87- 0.41 with 69% less than 0.70 after first N application. From then on, the ratio varied from 0.7 to 0.85 for both 30 and 60 cm depths. In general, the NH_4^+ -N concentration was the main form in the leachates at the two soil depths.

TABLE 5
Concentrations of NO_3^- -N in leachates at 60 cm soil depth on different days after split N applications (mg L^{-1})

Nitrogen treatments	Days after basal FA		Days after second FA				Days after third FA			
	3	7	3	7	14	21	3	7	14	30
N_0	0.87b*	0.35a	0.67a	0.88a	0.64a	0.22a	0.48c	0.39c	0.38b	0.20a
N_1	0.85b	1.28a	1.05a	2.97a	1.36a	1.87a	0.52c	0.65c	0.27b	0.55a
N_2	0.74b	1.19a	1.30a	3.39a	1.27a	1.85a	0.80b	0.39c	0.63b	0.71a
N_3	0.89b	1.03a	1.42a	2.90a	2.62a	1.75a	1.46b	0.81b	0.43b	0.75a
N_4	1.63a	1.42a	2.59a	1.79a	3.92a	2.34a	2.00a	1.37a	1.24a	0.92a

*Within columns, means followed by the same letter are not significantly different by Least Significant Difference (LSD) at the 0.05 levels

TABLE 6.
Ratios of NH_4^+-N/TN percolation at 30 cm and 60 cm soil layer depths after 3 urea applications

Nitrogen treatment		Days after basal FA			Days after second FA*				Days after third FA			
		1	3	7	1	3	7	14	1	3	7	30
N_0		0.28	0.59	0.53	0.53	0.51	0.37	0.71	0.52	0.51	0.34	0.42
	60cm	0.55	0.47	0.61	0.54	0.63	0.48	0.70	0.57	0.57	0.56	0.41
N_1	30cm	0.43	0.83	0.79	0.70	0.63	0.61	0.53	0.63	0.75	0.81	0.44
	60cm	0.79	0.61	0.81	0.76	0.27	0.64	0.50	0.67	0.79	0.71	0.72
N_2	30cm	0.86	0.87	0.73	0.69	0.58	0.52	0.49	0.66	0.74	0.78	0.55
	60cm	0.53	0.73	0.69	0.78	0.76	0.75	0.47	0.75	0.79	0.76	0.39
N_3	30cm	0.87	0.80	0.38	0.75	0.74	0.59	0.43	0.67	0.68	0.58	0.68
	60cm	0.65	0.81	0.76	0.83	0.58	0.57	0.46	0.74	0.74	0.73	0.43
N_4	30cm	0.89	0.88	0.74	0.82	0.47	0.79	0.69	0.63	0.71	0.73	0.60
	60cm	0.77	0.87	0.86	0.85	0.66	0.80	0.74	0.72	0.75	0.85	0.86

*FA=fertilizer application

Nitrogen Loss

The percentages of nitrogen losses for different treatments are shown in Table 7. These results clearly show that the highest TN loss was from N_1 treatment (4.57 kg ha^{-1}) and for NH_4^+ -N concentration, the highest loss was from N_4 treatment (11.22 kg ha^{-1}). The loss of nitrogen from the paddy field was higher with fertilizer application than from the field without fertilizer application. The amount of NH_4^+ -N, NO_3^- -N and TN losses increased with each treatments. This clearly indicates

(i) the importance of avoiding excess N fertilizer application in the paddy field during cultivation and (ii) water pollution risks. Results shown in Tables 2-6 indicate that nitrogen leaching occurred in the form of NH_4^+ -N, NO_3^- -N and TN that affected the environment. One of the most important aspects of controlling agricultural pollution is to control total nitrogen interconversion which could arise rapidly among the N species which comprise of NH_4^+ -N, NO_3^- -N and TN in the ecosystem (Shuller 1980).

TABLE 7

Nitrogen loss from paddy field in treatments with different N fertilizer applications

Nitrogen treatments	NH_4-N		NO_3-N		TN	
	Loss (kg ha^{-1})	Percentage (%)	Loss (kg ha^{-1})	Percentage (%)	Loss (kg ha^{-1})	Percentage (%)
N_O	0.57	-	0.38	-	1.04	-
N_1	2.91	3.23	1.25	1.38	4.57	5.07
N_2	4.07	2.26	1.14	0.63	5.73	3.18
N_3	5.21	1.93	1.73	0.64	7.62	2.82
N_4	11.22	3.11	2.20	0.61	14.75	4.10

CONCLUSIONS

Total nitrogen concentration at both the surface layers of soil (0-30 and 30-60 cm) was higher than the NH_4^+ -N and NO_3^- -N concentration with time. Also, NH_4^+ -N increased due to ammonification and NO_3^- -N due to nitrification at both depths of the surface soil. At N_4 (310 kg ha^{-1}) rate NH_4^+ and NO_3^- were higher than the other four N treatments at 30 cm depth. As for the NO_3^- -N concentration at 60 cm depth, it varied from 0 to 3 mg L_{-1} for the other five N treatments, but the NO_3^- -N did not differ. At 60 cm depth, NH_4^+ -N concentrations were higher, compared to the depth at 30 cm. After 60 days of N application, NH_4^+ -N, NO_3^- -N and TN declined. NO_3^- -N concentrations were quite low at both 30 and 60 cm depth. This is mainly attributed to plant uptake of nitrogen at 30 cm depth as N_2O can be emitted into the atmosphere from a shallow depth of soil. This study concludes that the unique conditions of the paddy ecosystem can promote N losses through denitrification and leaching. Further studies are recommended to protect N loss by the use of slow release N fertilizers.

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