

EFFECT OF FERTILIZER TYPES ON NITROGEN SURFACE RUNOFF LOSSES FROM PLATEAU PADDY FIELDS

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Abstract

Agricultural non-point source pollution is the main cause of water quality deterioration in Erhai Lake, where 97% of total nitrogen (N) input is from non-point source. This study investigated the effect of applying different types of fertilizers (no fertilizer, conventional chemical fertilizer, combinations of organic and inorganic fertilizers, and a slow-release fertilizer) in paddy fields on N losses in surface runoff water. Applying the slow-release fertilizer resulted in the highest ($p < 0.05$) rice grain yield while the treatment receiving no fertilizer had the least grain yield. When compared to the conventional fertilizer treatment (CK), application of slow-release fertilizer reduced the concentrations of total nitrogen, ammonium nitrogen, and nitrate nitrogen in the surface runoff by 45, 66, and 55% ($p < 0.05$), respectively. The treatment used slow-release fertilizer also reduced the surface runoff losses of total nitrogen, ammonium nitrogen, and nitrate nitrogen by 47, 67 and 54%, respectively.

Introduction

Application of chemical fertilizers, especially nitrogen (N), has significantly increased crop yields. However, in order to maintain high crop yields, farmers often resort to excessive use of chemical fertilizers. The excess N is not used efficiently by plants but it can result in losses through various pathways (Wang *et al.* 2001, Peng *et al.* 2006). These nitrogen losses cause surface water, groundwater, and air pollution (Liu and Diamond 2005, 2008, Ju *et al.* 2009). Rice is one of the most important cereal crops in the monsoon area of Asia (Kyuma 2004), with China being the world's leading producer. In 2009, China planted rice on some 29.88×10^6 ha and produced a total of 196.68×10^6 tons, accounting for 18.88% of the world's total rice planting area and 28.70% of total rice production. In the Erhai Watershed the amount of chemical fertilizer input was 8,769 t in 1995, 11,633 t in 2000, 16087 t in 2002, and 22,350 t in 2005 (Yang *et al.* 2007). The excessive use of fertilizers boosted crop yields but also resulted in the deterioration of water quality in the Erhai Lake. Nitrogen from non-point source is the main source of pollutant to Erhai, which makes up to 97% of the total amount of N input to the lake (Tang *et al.* 2012). The core area of the watershed is the Dali Cangshan-Erhai National Nature Reserve, which is the national scenic landscape and tourist area. Therefore, the local government cares greatly about the regional environmental quality. From 2000 to 2010, extensive regulations on point-source pollution control were put in place, causing a relative increase in agricultural non-point source pollution to the lake. In addition, agriculture and tourism are important sources of revenue in Erhai watershed. Annual agricultural output from this region amounts to 1.36 billion RMB, which is second to industrial output. The total arable land area is 25947 ha, of which 16667 ha are used for planting rice annually.

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In recent years, a great deal of research on improving nitrogen utilization was carried out in China, especially in the Taihu Lake region (Li *et al.* 2010, Xu *et al.* 2012, Lu *et al.* 2012). Application of slow/controlled-release fertilizer is considered to be an important method that can potentially improve nitrogen use efficiency (NUE) by reducing leaching, surface runoff loss and ammonia volatilization. However, the majority of the studies have been focused on the effect of chemical fertilizer on the yield and quality, and rice NUE in Erhai watershed, but little or no effort has been diverted to how fertilizer use impact surface water quality. Therefore, the objectives of this study were to determine the ratio of N losses from surface runoff water in plateau paddy field under different fertilizer types, and to finding a better effect to control N surface runoff.

Material and Methods

This study was conducted in 2009 at Fengming village, Fengyi Township, near Dali (E 100°7'50", N 25°49'47"), which is located in the Erhai Watershed. The study region is a typical subtropical monsoon climate at a high altitude (1980 meters above sea level) with adequate illumination, and distinct wet and dry seasons. The site has an annual mean temperature of 15.1°C and annual mean rainfall of 1048 mm, and 85 - 96% of the rainfall occurs between May and October (Wang and Huang 2006). The precipitation during the experimental period is shown in Fig. 1. The annual sunshine duration ranges from 2250 to 2480 hrs and mean annual relative

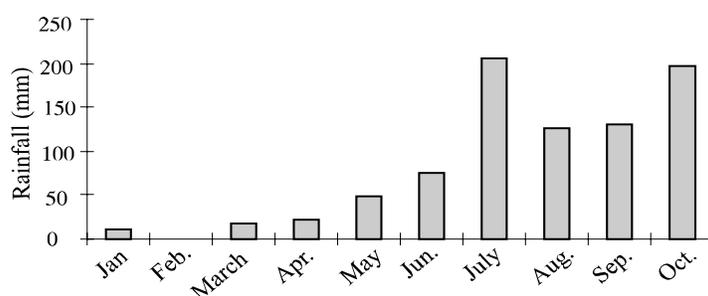


Fig. 1. Precipitation during the experimental period.

humidity is 66%. The soil was a loam soil with a pH of 7.0. The concentrations of total nitrogen (TN), nitrate nitrogen (NO₃-N), ammonium nitrogen (NH₄-N), total phosphorus, available phosphorus, total potassium, and available potassium in the soil were 18.6, 4.45, 3.5, 0.66, 57.2, 4.0, and 56.0 mg/kg, respectively.

Six treatments (no fertilizer (T1), conventional chemical fertilizer (T2, means nitrogen supplied only by chemical fertilizer), organic fertilizer (T3), 80% organic fertilizer + 20% chemical fertilizer (T4, means 80% nitrogen supplied by organic fertilizer, and 20% nitrogen supplied by chemical fertilizer), 50% organic fertilizer + 50% chemical fertilizer (T5, means 50% nitrogen supplied by organic fertilizer, other supplied by chemical fertilizer), and slow-release fertilizer (T6) were applied (Table 1). With the exception of T1, the total amount of N applied in the rest of the five treatments was the same. All the organic and chemical fertilizer were applied on 26th May and mixed in 0 - 20 cm soil layer evenly. Experiment was laid out in completely randomized design and replicated twice. There were a total of 18 experimental plots (4 m × 6 m) and 18 adjacent surface runoff collection pools (3 m × 1 m × 0.5 m). Treatment plots were separated by cement walls 50 cm above ground and 30 cm below ground to prevent water exchanges between plots. A 2 meter wide buffer zone was placed around the experimental area.

Table1. Composition of fertilizer treatments used in the study.

Treatments	Organic fertilizer ¹ (kg/ha)				Chemical fertilizer (kg/ha)				Total (kg/ha)				
	Amount	Pure			Urea	CS ²	SRF ³	Pure					
		N	P ₂ O ₅	K ₂ O				N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O
T1										0	0	0	
T2					375	375		173	60	173	60	0	
T3	7188	173	165	410						173	165	410	
T4	5750	138	132	328	75			35		173	132	328	
T5	3594	86	83	205	188			86		173	83	205	
T6							719	173	43	72	173	43	72

¹Organic fertilizer (N: P₂O₅: K₂O = 2.4: 2.3: 5.7), ²CS: Calcium superphosphate; ³SRF: Slow-release fertilizer (N: P₂O₅: K₂O = 24: 6: 10).

The rice plant was transplanted on 26th May and harvested on 25th October. The rice grain yield from each treatment was obtained at harvest after the grains were air-dried. The surface runoff water was sampled every 15 - 20 days during the dry period of the season and every 7-10 days during the wet period of the growing season. The total volume of runoff in each pool was measured when sampling surface runoff. And then, the surface runoff was drained off after sampling and measuring. The concentrations of TN, NO₃-N, and NH₄-N were determined after each sampling time. Total nitrogen was determined by using potassium persulfate oxidation UV spectrophotometer method. Ammonium-N was determined by using Nessler's Reagent Colorimetric method, and NO₃⁻N was determined by using phenol disulfonic acid method (Lu 2000). The amount of surface runoff loss of TN, NO₃-N, and NH₄-N was calculated according to the following formula:

$$Total\ loss\ of\ TN = \sum_n Q_i \times C(TN)$$

where, Q_i is the surface runoff volume after n-th sampling and C is the concentration of TN. The NO₃-N and NH₄-N loss in surface runoff was calculated similarly. And average runoff N concentration in paddy season calculated with total loss N and total runoff volume.

All quantitative estimates were analyzed and the values were expressed as mean ± standard error. Concentrations of TN, NO₃-N, and NH₄-N were statistically analyzed separately for each sampling, using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test (DMRT), using the SAS 9.0 statistical package. Statistical significance was defined at a p-value of 0.05 (SAS/STAT User's Guide 1989).

Results and Discussion

The slow release fertilizer treatment had the highest grain while no fertilizer had the lowest yield (Fig. 2). Rice grain yield had the following order: slow-release fertilizer > conventional chemical fertilizer > 50% organic fertilizer + 50% chemical fertilizer > 80% organic fertilizer + 20% chemical fertilizer > 100% organic fertilizer > no fertilizer ($p < 0.05$). The difference in cumulative runoff volume (drainage) between treatments was relatively small with a range of 88 - 93 l/m² ($p > 0.05$).

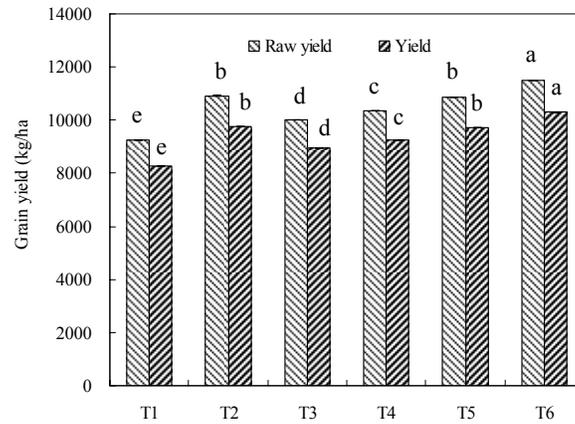


Fig. 2. Rice grain yields of different fertilizer treatments.

The average N concentrations of each form ($\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, TN) in the surface runoff from different fertilizing treatments (the average concentration calculated with the total N loss and total runoff water volume of each pool in total paddy season) are presented in Fig. 3. The TN concentration in the runoff decreased in the following order: conventional chemical fertilizer (T2) > 80% organic fertilizer + 20% chemical fertilizer (T4) > 50% organic fertilizer + 50% chemical fertilizer (T5) > 100% organic fertilizer (T3) > slow-release fertilizer (T6) > no fertilizer (T1). Compared to T4, T5, T3, T6, and T1 treatments, the TN concentration in the runoff from T2 was 50, 63, 81, 83, and 138% higher, respectively. This level of TN concentration of T2 (1.8 mg/l) exceeded the limit recommended in the “Quality Standard for Surface Water Resources (SL63-94)”. However, the other five fertilizer treatments did not exceed this upper limit.

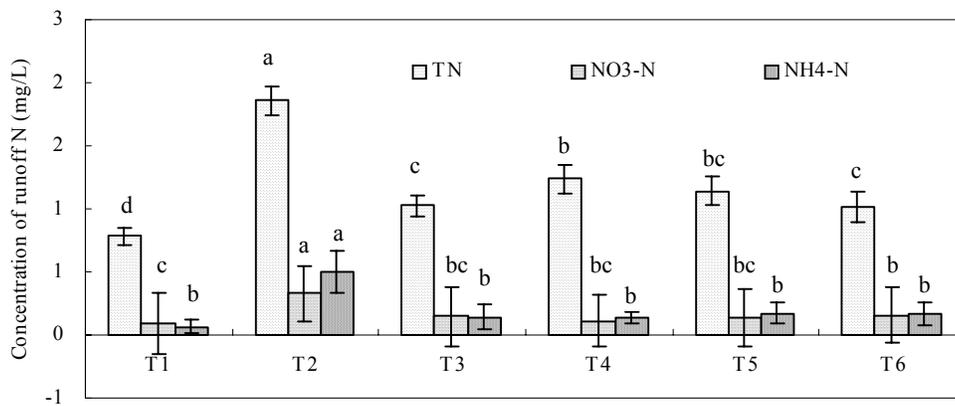


Fig. 3. Average N concentrations from different treatments in total paddy season.

The $\text{NO}_3\text{-N}$ concentration in the runoff from each treatment decreased in the following order: $\text{T2} > \text{T6} > \text{T3} > \text{T5} > \text{T4} > \text{T1}$. In comparison to T6, T3, T5, T4, and T1 treatments, the $\text{NO}_3\text{-N}$ concentration in the surface runoff from T2 was higher ($p < 0.05$) by 113, 124, 147, 196 and 255%, respectively, and there was no significant difference in $\text{NO}_3\text{-N}$ concentrations in the surface runoff from the other five treatments.

The $\text{NH}_4\text{-N}$ concentration in the surface runoff from each treatment decreased in the following order: $\text{T2} > \text{T5} > \text{T6} > \text{T3} > \text{T4} > \text{T1}$. The $\text{NH}_4\text{-N}$ concentration in the surface runoff from T2 was 118, 199, 253, 265 and 642% higher ($p < 0.05$) than T5, T6, T3, T4 and T1, respectively. There was no significant difference in $\text{NH}_4\text{-N}$ concentrations in the runoff from the other five treatments.

The TN concentrations in the surface runoff from different fertilizing treatments in each sampling are presented in Fig. 4. The TN concentration in the surface runoff from each treatment was the highest during the June 24th sampling because of the plots were manually drained 30 days after the rice was transplanted as a common management practice, which led to massive loss of applied N. The TN concentrations in the runoff in July and October were relatively low, which might be due to dilution from heavy precipitation. For example, TN concentration in runoff from conventional fertilization measured in May, August and September varied between 3.1 to 4.8 mg/L, while it decreased to 0.8 and 0.6 mg/L in July and October, respectively.

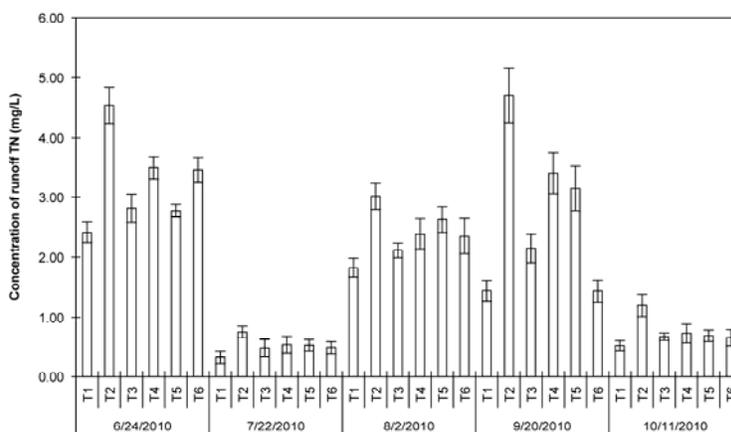


Fig. 4. TN concentrations in the runoff from different treatments in each sampling.

The temporal changes in $\text{NO}_3\text{-N}$ concentration in surface runoff from different fertilizer treatments are presented in Fig. 5. As the season progressed, the $\text{NO}_3\text{-N}$ concentration in runoff started to increase but later declined in the following order: $\text{T2} > \text{T6}$, combined application of organic and chemical fertilizer $> \text{T1}$. Most of the N in the fertilizers was in amide or organic form. In these forms, nitrogen needs to be hydrolyzed and mineralized to $\text{NH}_4\text{-N}$, and the $\text{NH}_4\text{-N}$ is then transformed to $\text{NO}_3\text{-N}$ in the presence of oxygen or under high oxidation reduction potential (ORP). The increase in $\text{NO}_3\text{-N}$ concentration across the different fertilizing treatments is the result of the fertilizer N being transformed into $\text{NO}_3\text{-N}$ in the soil.

The temporal changes of $\text{NH}_4\text{-N}$ concentration in surface runoff from different fertilizer treatments are presented in Fig. 6. The $\text{NH}_4\text{-N}$ concentration initially increased but later decreased in the growing season. The average concentrations were in the following order among all treatments: $\text{T2} > \text{T6}$, combined application of organic and chemical fertilizer $> \text{T1}$. This could be because amide or organic nitrogen in fertilizers took a while to be transformed into ammonium

nitrogen or that some of the $\text{NH}_4\text{-N}$ produced during the earlier period had been absorbed or fixed in the soil. The large amount of $\text{NH}_4\text{-N}$ in the surface runoff observed early in the experimental period was probably due to the heavy precipitation.

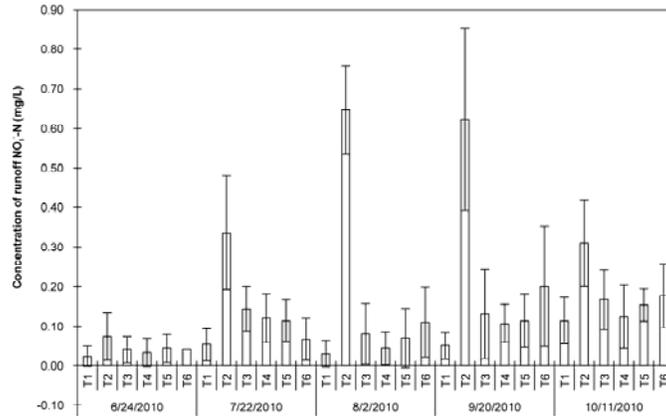


Fig. 5. $\text{NO}_3\text{-N}$ concentrations in the runoff from different treatments in each sampling.

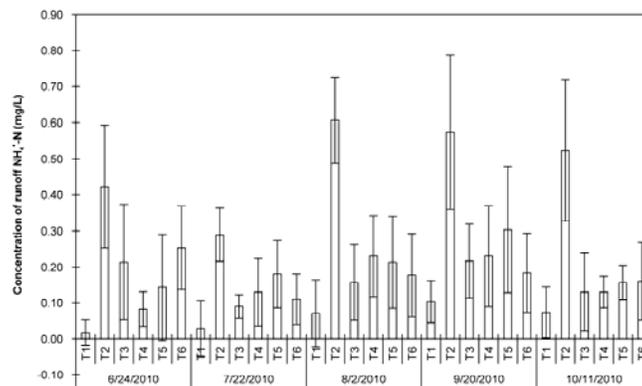


Fig. 6. $\text{NH}_4\text{-N}$ concentrations in the runoff from different treatments in each sampling.

The surface runoff nitrogen losses from the rice field under different fertilizer treatments are presented in Table 2. Decrease in total nitrogen, $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ in the following order: $\text{T2} > \text{T4} > \text{T5} > \text{T3} > \text{T6} > \text{T1}$ indicates that slow-release fertilizer treatment can reduce nitrogen losses by slowing down the release of available N to match plant N uptake. Rainfall intensity had greater influence on N loss in runoff in late growing periods of the rice. For example, the rainfall from Oct. 9 to Oct. 10 was 99.4 mm and the TN loss on Oct. 11 was 1802 mg/plot from T2. The loss of total, nitrate-, and ammonium-nitrogen in runoff accounted for 57 - 69%, 83 - 92%, and 76 - 91% of the total losses of their respective forms, respectively. The loss of available nitrogen (nitrate and ammonium nitrogen) in runoff accounted for 20 - 44% of the total nitrogen losses and the conventional fertilizer treatment contributed the highest proportion. In late June, the losses of TN were caused by artificial drainage, accounting for 22 - 32% of the total nitrogen loss of the entire season. Delaying the application of fertilizers, deep fertilizer application, and controlling the

irrigation drainage process can reduce the loss of nutrients in runoff water, which in turn could help reduce non-point source pollution from paddy fields.

Regression analysis showed that drainage volume was linearly correlated with the total ($r^2 = 0.55$, $p < 0.05$), nitrate ($r^2 = 0.79$, $p < 0.05$), and ammonium ($r^2 = 0.51$) nitrogen losses at each sampling. Cumulative drainage volume showed significant linear correlation with total ($r^2 = 0.82$, $p < 0.05$), nitrate ($r^2 = 0.80$, $p < 0.05$), ammonium ($r^2 = 0.83$, $p < 0.05$) nitrogen losses. Therefore, better management of runoff caused by drainage of paddy fields and intense precipitation is a crucial strategy to minimize nutrient losses from rice fields.

Table 2. N losses under different treatments at each sampling time during paddy season.

	24-June (kg/ha)			22-July (kg/ha)			2-Aug. (kg/ha)			20-Sep. (kg/ha)		
	TN	NN	AN	TN	NN	AN	TN	NN	AN	TN	NN	AN
T1	191.3	1.8	1.3	26.5	4.3	2.4	38	0.6	1.5	107.8	3.8	7.8
T2	397	6.4	37	66.9	30.2	26	69.1	14.8	13.9	431.1	57.1	52.6
T3	234.4	3.3	17.8	40	11.9	7.5	44	1.7	3.3	187.8	11.4	19
T4	283.8	2.7	6.8	47	10.5	11.4	54.8	1	5.3	269.4	8.4	18.2
T5	225.3	3.5	11.6	47.2	10.2	16.1	54.8	1.5	4.4	275.3	9.9	26.5
T6	295.3	3.4	21.6	42.9	5.8	9.6	53.9	2.5	4.1	113.2	15.8	14.5

TN, NN and AN are total nitrogen, $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$, respectively. R is the ratio of $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ to TN in the same treatment.

Table 2. continued from the right hand side.

	11-Oct. (kg/ha)			Total losses (kg/ha)			R
	TN	NN	AN	TN	NN	AN	
T1	325	70.8	45.8	688.6	81.4	58.8	20.4
T2	750.8	195	329.3	1714.8	303.6	458.7	44.5
T3	418.8	104.2	81.3	925.1	132.5	128.8	28.2
T4	454.2	77.1	81.3	1109.2	99.7	122.9	20.1
T5	429.2	95.8	97.9	1031.8	120.9	156.7	26.9
T6	408.3	110.4	100	913.6	138	149.8	31.5

Chemical and organic fertilizers play an important role in improving soil fertility and increasing rice yields (Shen *et al.* 2004, Rasool *et al.* 2007), especially when the initial soil fertility is low (Li *et al.* 2010). Chemical fertilizers generally stimulate growth better than organic fertilizers (Fan *et al.* 2005) due to high availability of nutrients. The findings from this study are consistent with other studies in those aspects (Fig. 1). Other short-term experiments have also indicated that when the proportion of organic fertilizer in mixtures of organic and inorganic fertilizers exceeded a certain level, crop yields could be reduced (Ou *et al.* 2009). However, long-term studies showed that organic fertilizers were as effective as inorganic fertilizers in increasing crop yields (Dawe *et al.* 2003). The nutrient release rate of slow-release fertilizers is controlled and can result in prolonged nutrient supply. Results from this study showed that application of

slow-release fertilizers resulted in higher yields compared to conventional chemical fertilizer or mixtures of chemical and organic fertilizers (Xie *et al.* 2006). This is because slow-release fertilizers can promote tillers (Suresh *et al.* 1999), reduce ammonia volatilization, nitrification, denitrification and nitrate leaching (Zheng *et al.* 2004) so that crop yields are increased.

A large amount of N is lost through volatilization, runoff and leaching in a rice production system (Zhu and Chen 2002). Long-term studies showed that nitrogen losses due to ammonia volatilization accounted for 10 - 60% of total nitrogen applied (Liang *et al.* 2007). Loss of nitrogen through runoff and leaching were also identified as main causes of soil nitrogen reductions. The amount of runoff from rice fields varies greatly from country to country and is also influenced by management strategies. In their study, Yoon *et al.* (2006), reported that 59.7 kg/ha N was lost in 1.6 m of runoff water, accounting for 47.8% of the total applied nitrogen. Cho and Han (2002) reported runoff of 1027 mm and nitrogen loss in the runoff of 113.7 kg/ha, accounting for 61.8% of the total applied nitrogen. Jang *et al.* (2012) found runoff to be only 229.5 mm with nitrogen loss of 8.5 kg/ha, accounting for 15.5% of the nitrogen applied. In our study, 0.9 - 1.7 kg/ha N was lost in 88 - 92 mm runoff water, accounting for only 0.5 - 1.0% of the total applied nitrogen. These findings are in agreement with those of Hitomi *et al.* (2010), who recorded runoff at 144.4 mm and nitrogen loss in runoff of 0.8 - 2.0 kg/ha, accounting for 1.25 - 3.13% of the total applied nitrogen. Slow-release fertilizer treatment was found to be more effective than the other five fertilizer treatments in reducing runoff losses of total, nitrate, and ammonium nitrogen (Figs 2, 3, 4 and 5). This finding is supported by other studies (Friedman and Mualem 1994, Delgado and Mosier 1996, Shoji *et al.* 2001, Javier *et al.* 2007, Pereira *et al.* 2009).

Results of this experiment indicate that drainage volume was significantly correlated with total, nitrate, and ammonium nitrogen losses. Loss of nitrogen through runoff can be reduced by efficient irrigation technologies such as irrigation by non-continuous flooding, combined with efficient fertilizer application (Peng *et al.* 2011), dry-wet alternate irrigation (Peng and Bouman 2007), and the intensification of rice production systems (Uphoff *et al.* 2011). In addition, appropriately increasing the overflow height also has significant effect on controlling nutrient loss (Jang *et al.* 2010, Yoon *et al.* 2006).

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