Nutrient Losses from a Paddy Field

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The study was carried out to investigate the nutrient losses at a paddy field located at the southwest of central Korea from May 1, 1997 to April 30, 1998. The studying area was 10 ha. The amounts of nutrients loaded by runoff water were measured as follows. The total-N was 1,031 and 61 kg 10 ha^{-1} during the irrigation and non-irrigation periods, respectively. The total amount of N from both periods was 1,092 kg 10 ha^{-1} yr^{-1}. The total-P was 23 and 2 kg 10 ha^{-1} during the irrigation and non-irrigation periods, respectively. The total amount of P from both periods was 25 kg 10 ha^{-1} yr^{-1}. For percolationloss, the losses of total-N, ammonia-N, nitrate-N, and total-P were 167, 30, 122, and 3 kg 10 ha^{-1}, respectively. The respective loss ratios of N and P by runoff water were 55.2 and 11.9%, while the loss ratios of N and P by percolationwere 8.4 and 1.4%.

Key words: *agricultural non-point sources, nitrogen, phosphorus, rainfall-runoff, water pollution.*

Throughout the world, non-point sources continue to be recognized as the major source of pollution. Nitrogen and phosphorus exist in a variety of forms in water and are often associated not only with each other but also with the suspended mineral particles. In addition to carrying nutrients, suspended particles carry many other pollutants and cause turbidity, which is undesirable for drinking water. A nitrogen balance developed for the upper region of Austria demonstrated that nitrogen input to surface waters was significantly greater from non-point sources than from point sources.[1] Nutrient monitoring by Kronvang *et al.*[2] in 270 Danish streams showed that 94 and 52% of the nitrogen and phosphorus loadings were caused by non-point source pollution, primary from agricultural activities. By estimating point and non-point source pollutant loads into Lake Biwa, the largest lake in Japan, Kawara *et al.*[3] showed that rice paddy fields contributed the largest amount of the pollutant load into the lake. Since the land area in Korea is small and the arable land occupies only 24% of the total area, the promotion of agricultural productivity is urgent. The application rate of chemical fertilizer, which is the major pollution factor of agricultural non-point sources, has been increasing every year. As the control of nutrient export from point sources has become more rigorous, research has shifted to the movement of nutrients into streams from non-point sources. To prevent the pollution from agricultural watersheds, it is necessary to find out the source of the pollution. The present study was carried out for one year (from May 1, 1997 to April 30, 1998) to investigate the nutrient losses at a broad paddy field located at the southwest of central Korea, which is 10 ha in size.

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Materials and Methods

Experimental paddy field. The experimental field, broad paddy field that had not been influenced by livestock farming, farmstead, and other industrial complex, located in Maryung-myun, Chinan-gun, Chonbuk, Korea, was arranged in May 1995. The soil of the experimental field was in Jisan series (SiL; fine loamy, mixed mesic family of Fluventic Haplaguepts), and the area was 100,000 m^2 (200 × 500 m) (Fig. 1). The chemical properties of paddy soil are shown in Table 1.

The irrigation period was from May to September, and the non-irrigation period was from October to April of the next year. The experimental field was plowed from May 10 to May 20, 1997. Rice was transplanted by machine on the experimental field from May 20 to May 30, 1997 and harvested from September 20 to September 30, 1997. The paddy field was kept under non-plowing condition during the non-irrigation period. The first plowing was performed in the field from March 20 to March 30, 1998.

Basal fertilizer (12 kg N 10a^{-1} and 2.1 kg P_2O_5 10a^{-1}) was applied from May 10 to May 20, 1997, tillering fertilizer (4.8 kg N 10a^{-1}) from June 10 to June 20, 1997, and panicle fertilizer (3.0 kg N 10a^{-1}) from July 20 to July 30, 1997. The amount of chemical fertilizer applied in 1997 to the study fields was 1,980 kg N 10 ha^{-1} and 210 kg P_2O_5 10 ha^{-1} in 1997, the amount was estimated after personal interviews with farmers.

Rainfall and flow measurements. In the experimental field, a set of rain gauge, flow meter, flume, infiltrometer, evaporometer, and ceramic porous cup were established. The analogue rain gauge was set beside the irrigation canal of the experimental field for daily recording. The flow of irrigation water was measured with the flow meter set at the head of

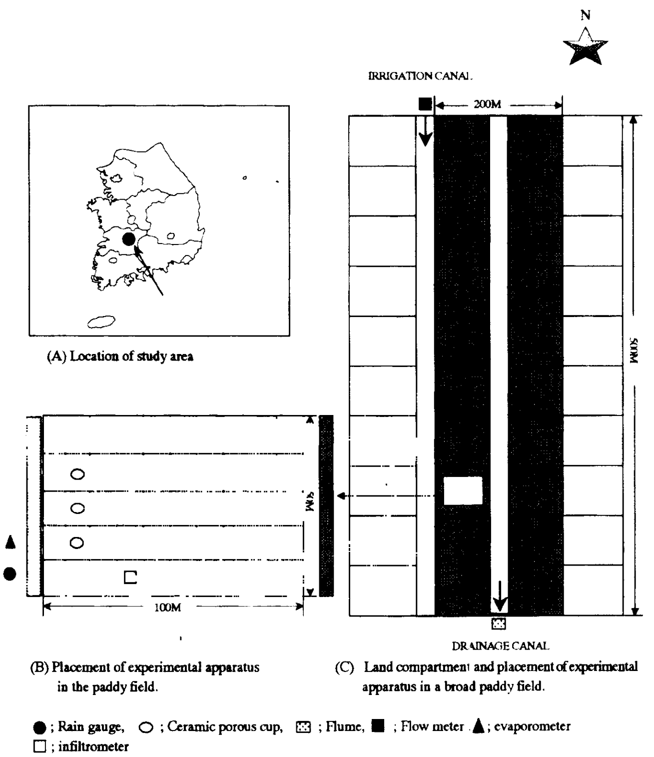

Fig. 1. Sketch of study area.

Table 1. Physical and chemical properties of the experimental paddy soil.

Chemical properties		Particle size fraction (%)	
Organic matter (g 100 g^{-1})	2.32	Sandy	25.0
pH (1:5)	5.89	Silt	56.9
Total-N (mg kg^{-1})	889.3	Clay	18.1
Total-P (mg kg^{-1})	284.2		
CEC (cmol^{+} kg^{-1})	9.6		
Exchangeable cations (cmol^{+} kg^{-1})			
Ca	3.2		
Mg	2.1		
Na	0.1		
K	0.6		

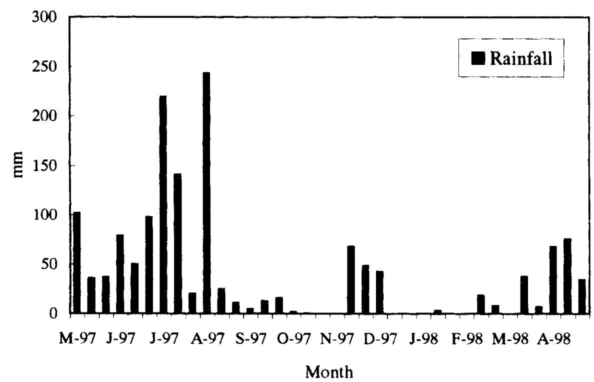

Fig. 2. Status of precipitation.

the irrigation canal. The flow of each irrigation activity was measured and compared by bucketing. The flume was set at the outlet of the experimental field to measure the runoff water in the paddy field. Empty ceramic porous cups were buried at four sites at a depth of 90 cm to measure the movement of nutrients underground. All measurements were carried out from May 1, 1997 to April 30, 1998.

Samplings and sample analyses. Samples of rainfall and irrigation water were taken for each event, and those of runoff water were taken periodically before, during, and after the peak runoff for each event. Percolationwater was sampled at two-week intervals. Bottles containing sample composites were placed in insulated chests and crushed ice was added to fill the chests. All samples were refrigerated at 0 to 4°C soon after collection until analyses. Runoff water samples were shaken to obtain homogeneous aliquots for total-N and total-P analyses. Ammonia-N and nitrate-N were determined in aliquots which were centrifuged and filtered through 0.45 μm Millipore filters. Chemical analyses for total-N, nitrate-N, and ammonia-N were conducted using standard methods as described in the FWPCA manual.[4)] Total-P determinations were made using the isobutanol extraction method described by Golterman and Clym.[5)]

Results and Discussion

Rainfall status. The results of rainfall and rainfall characteristics of the investigated area from May 1, 1997 to April 30, 1998 were as follows (Fig. 2). The amount of rainfall in May was 175 mm which was equivalent to 181% of that of a normal year (1996). The duration of the rainy season (28 days), which occurred from June 20 to July 18, was almost the same as that (29 days) of a normal year. The flooding period was 887 mm with 40 rainy days. The amount of rainfall (36 mm) in September and October was 60% and November and December was 150% of that of a normal year. From January to March of 1998, the rainfall amount was 75 mm. In April, the amount of rainfall was 178 mm which was 160% of that in a normal year (1997) and there were 7 rainy days. The rainfall amount within the investigated area was 1,095 mm during the irrigation period while 415 mm during the non-irrigation period. The amount of runoff water was 1,043 mm during the irrigation period while 281 mm during the non-irrigation period.

Water balance. The water balance in the paddy field was determined using the following equation:

$$W_t = W_{t-1} + I_t + P_t (R_t + E_t + F_t)$$

where
W_t = flooding depth, I_t = amount of irrigation water,
P_t = amount of rainfall,
R_t = amount of runoff water,
E_t = amount of evapotranspiration,
F_t = amount of percolation water, and t = days.

The amount of rainfall, irrigation water, runoff water,

Table 2. Water balance in the experimental paddy field from May 1, 1997 to April 30, 1998.

Period (Year. Month. Day)	Rainfall	Irrigation water	Runoff water (m^3)	Evapotranspiration	Infiltration water
1997.05.01~05.10	10190	5144	10034	1400	2730
05.11~05.20	3590	23308	16908	3430	3900
05.21~05.30	3700	21089	16433	3270	4290
06.01~06.10	7920	22943	12472	2960	3900
06.11~06.20	4990	16500	13505	2500	3900
06.21~06.31	9800	18347	20453	2120	3900
07.01~07.10	21940	19875	32463	2630	2700
07.11~07.20	14090	18446	24911	2350	3600
07.21~07.30	2040	41655	25732	3850	2520
08.01~08.10	24330	45052	53526	5630	3000
08.11~08.20	2500	27631	19386	4860	2800
08.21~08.31	1100	35539	25905	5270	3190
09.01~09.10	490	26471	15998	5590	4400
09.11~09.20	1290	16683	10614	2690	2550
09.21~09.31	1590	0	916	540	0
10.01~10.10	190	0	0	0	190
10.11~10.20	50	0	0	0	50
10.21~10.30	0	0	0	0	0
11.01~11.10	0	0	0	0	0
11.11~11.20	6820	0	3453	0	1760
11.21~11.31	4870	0	2435	0	1550
12.01~12.10	4110	0	1989	0	1340
12.11~12.20	150	0	0	0	150
12.21~12.30	0	0	0	0	0
1998.01.01~01.10	0	0	0	0	0
01.11~01.20	330	0	0	0	330
01.21~01.31	0	0	0	0	0
02.01~02.10	0	0	0	0	0
02.11~02.20	190	0	0	0	190
02.21~02.31	2200	0	1000	0	940
03.01~03.10	270	0	0	0	270
03.11~03.20	300	0	0	0	300
03.21~03.28	4160	0	1400	533	1690
04.01~04.10	6810	0	4220	576	1670
04.11~04.20	7570	0	4190	620	1678
04.21~04.31	3450	0	890	750	1300

evapotranspiration and percolation water were 151,030 m^3, 338,684 m^3, 318,924 m^3, 51,569 m^3, and 60,788 m^3, respectively (Table 2). The uncounted amount in inflow water was 510 m^3 when water balance was calculated during the study period.

The relationships between precipitation and runoff loading from the paddy field. When the relationship of precipitation and runoff loading of nutrients for the paddy field were compared with respect to the irrigation period due to few rainfall-runoff events during the non-irrigation period, no relationship was observed between the runoff water and precipitation (Fig. 3 and 4). These results were affected by the precipitation intensity, hydrological condition in the paddy field, cropping and land conditions during the irrigation period.

Changes in the concentration of nitrogen and phosphorus. The concentration changes of nitrogen and phosphorus in precipitation, irrigation, runoff, and percolation water for the period of May 1, 1997 to April 30, 1998 are shown in the Fig. 5, 6, 7, and 8, respectively. In the case of precipitation, nutrient concentration increased slightly from May to June then leveled off. For irrigation water, the concentration of nitrogen and phosphorus which were high in the early stage of rice transplantation after the application of fertilizer, decreased during the period of mid-June to mid-July due to the high rate of precipitation. In this particular case, similar results have been reported by Lee *et al.*[6] For the case of runoff water, the concentration of

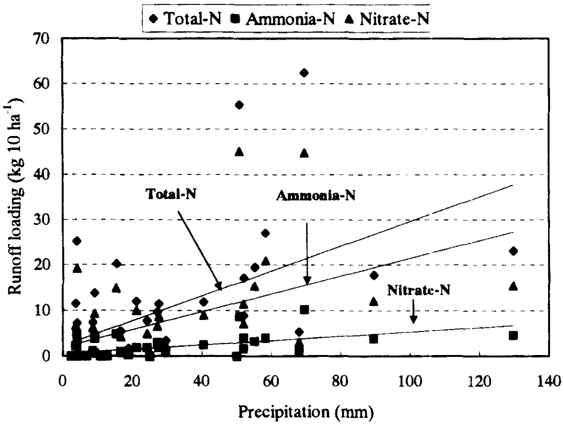

Fig. 3. Relationships between runoff loading of nitrogen sources and precipitation of the paddy field. Total-N: $Y=0.2733X+2.2245(R^2=0.3054)$, ammonia-N : $Y=0.0471X+0.5491$ $(R^2=0.3144)$, nitrate-N : $Y=0.1956X+1.8543$ $(R^2=0.2753)$

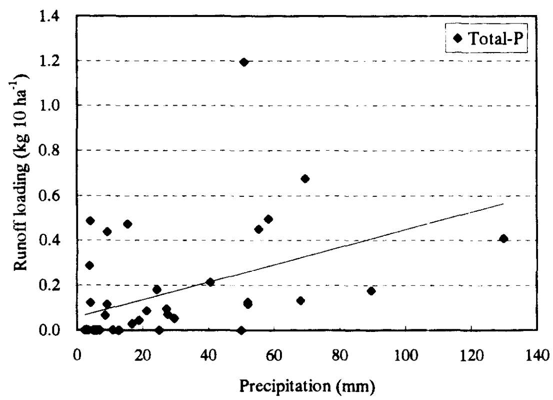

Fig. 4. Relationships between runoff loading of total-P and precipitation of the paddy field. $Y=0.0039X+0.0565(R2=0.2006)$

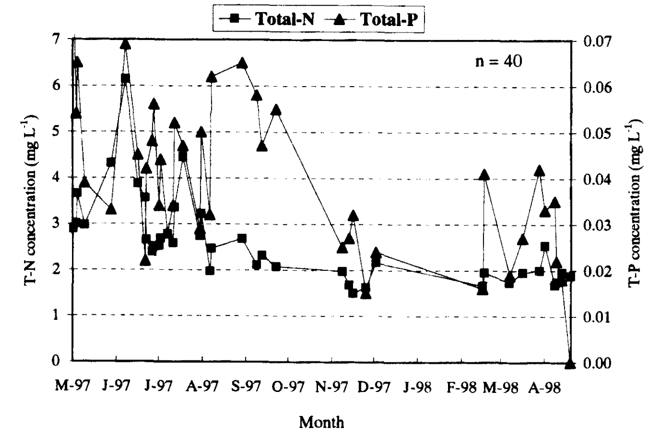

Fig. 5. Changes in the concentration of total-N and total-P in precipitation.

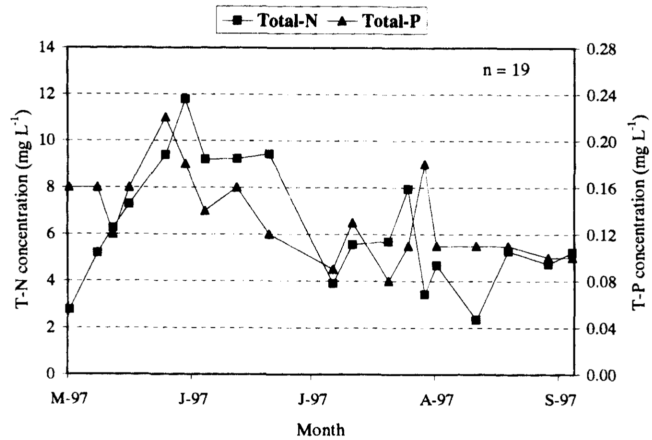

Fig. 6. Changes in the concentration of total-N and total-P in in irrigation water.

nitrogen increased significantly during the application of basal, tillering, and panicle fertilizers and then decreased. The concentration of total-N in runoff water was 10-15 mg L^{-1} during the period of fertilizer application as reported by Kim and Cho.[7] They stated that fertilizer runoff would not exert any impact since the loading concentration of paddy water itself was notably low after July. However, in the present study, the concentrations of nutrients were still high after July, which may be due to the accumulation of fertilizers applied in the paddy field.

During the irrigation period, the changes in nitrogen and phosphorus concentrations in the percolation water passing through the buried ceramic porous cups (90 cm in depth) in the experimental field were also observed. The concentrations were highest during the early period of transplantation due to the high concentration of nutrients in paddy water.

Nutrient losses in a broad paddy field. Many approaches for reducing the amount of pollutants are called for, including improvement of soil property and fertilizer application, and removal of pollutants in wetlands and riparian forests among others. However, accurate pollutant outflows from various types of non-point sources have not yet been elucidated due to the fact that the extent of non-point source pollutants related to uncontrollable climatic events and irrigation conditions may differ greatly from place to place and year to year. Therefore, intensive long-term studies on various sites of non-point sources are needed. The nutrient balance in the paddy field could be divided into input, inner, and output systems. Factors such as fertilizer application rate, rice straw, rainfall, irrigation water, and sediments belonged to the input system, biological nitrogen fixation and amounts of soil residues belongs to the inner system, and ammonia volatilization, nitrogen loss by denitrification, percolation loss, removed of rice grains, runoff water, and sediments to the output system. To calculate the input/output of nutrients, the amounts of rainfall, irrigation water, runoff water, and percolation water were measured, and they were then multiplied by the concentration for each event. The content of sediments corresponded to the amount of the total suspended solids in irrigation and runoff water.

Input system. During the study period, the input

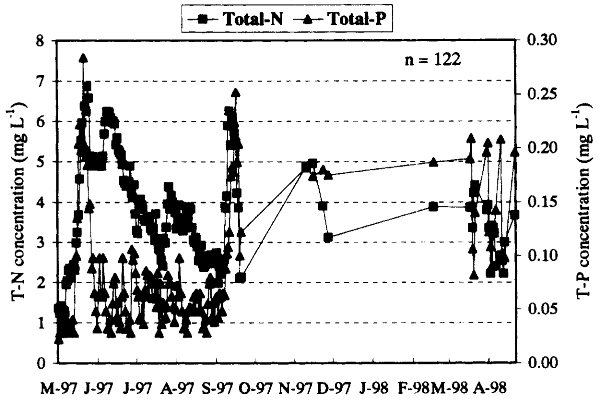

Fig. 7. Changes in the concentration of total-N and total-P in runoff water.

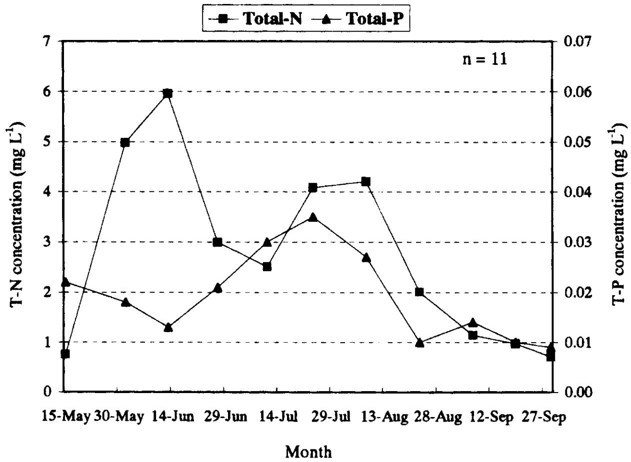

Fig. 8. Changes in the concentration of total-N and total-P in infiltration water.

amounts of nitrogen and phosphorus to the experimental paddy field were 1,980 kg N 10 ha^{-1} and 210 kg P 10 ha^{-1} through chemical fertilizer application. The input amounts by rainfall were total-N 325 and 103 kg 10 ha^{-1}, ammonia-N 187 and 54 kg 10 ha^{-1}, nitrate-N 107 and 32 kg 10 ha^{-1}, and total-P 5 and 1 kg 10 ha^{-1} during the irrigation and non-irrigation period, respectively. From irrigation water, the input amount was 212, 53, 145, and 5 kg 10 ha^{-1} for total-N, ammonia-N, nitrate-N, and total-P, respectively.

Output system. The runoff loading of nutrients caused by runoff water was measured as follows. The amount of total-N was 1,031 kg 10 ha^{-1} during the irrigation period and 61 kg 10 ha^{-1} during the non-irrigation period (total = 1,092 kg 10 ha^{-1} yr^{-1}). The amount of ammonia-N was 280 kg 10 ha^{-1} during the irrigation period and 12 kg 10 ha^{-1} during the non-irrigation period (total = 292 kg 10 ha^{-1} yr^{-1}). The amount of nitrate-N was 700 kg 10 ha^{-1} during the irrigation period and 43 kg 10 ha^{-1} during the non-irrigation period (total = 743 kg 10 ha^{-1} yr^{-1}). The amount of total-P was 23 kg 10 ha^{-1} during the irrigation period and 2 kg 10 ha^{-1} during the non-irrigation period (total = 25 kg 10 ha^{-1} yr^{-1}).

The runoff loading was the highest in June due to the high concentrations of chemical components affected by the applied fertilizers. Kim and Cho[7] investigated the nutrient losses from runoff water during the rice cultivation period and reported that the nitrogen and phosphorus losses were 15 and 0.59 kg ha^{-1}, respectively. Takeda *et al.*[8] measured the nutrient losses in a paddy field (11.6 ha) around Biwa watershed and reported that the total-N and total-P losses were 45.7 and 8.72 kg ha^{-1}, respectively. The runoff loadings of nitrogen and phosphorus in the present study were significantly higher than those reported by other authors (Takeda *et al.*, 1991; Kim and Cho, 1995). In most studies the runoff loading was calculated only during the irrigation period and the results were from watersheds and not from paddy fields. It appears that different conditions such as the method of fertilizer application, amount of applied fertilizer, fertilizer application time, irrigation water, and amounts and components of rainfall resulted in the differences in runoff loading. When the runoff loading was calculated based on the amount of applied chemical fertilizer as the loss ratio, the loss of nitrogen and phosphorus by runoff amounted to a total 55.2 and 11.9% of the application amounts, respectively.

The losses of nutrients by percolation were measured as follows. The losses of total-N, ammonia-N, nitrate-N, and total-P were 167, 30, 122, and 3 kg 10 ha^{-1}, respectively. The amount was the highest in May and June, presumably because the concentration of nutrients in paddy water increased after basal fertilizer application in May. According to Kunimatsu[9], the percolation losses of nutrient in paddy fields were 11.3-32.3 kg ha^{-1} yr^{-1} for total-N and 0.19-1.38 kg ha^{-1} yr^{-1} for total-P. Shin and Kwon[10] reported that the percolation losses were 7.54 kg ha^{-1} for total-N and 2.06 kg ha^{-1} for total-P in paddy fields. The percolation losses of total-N in the present study were twices higher that those reported by Shin and Kwon[10] but were similar to those reported by Kunimatsu.[9] The losses of total-P in the current study were much lower than those reported by Shin and Kwon[10] but were similar to those reported by Kunimatsu.[9] When the loss ratio of nutrients by percolation was calculated based on the amount of chemical fertilizer applied in paddy fields, nitrogen and phosphorus accounts for 8.4 and 1.4% of the application amounts, respectively.

In Japan, it is well accepted that pollutant outflows of non-point sources from paddy fields are much less than those from upland fields. Furthermore, some paddies are able to remove of pollutants such as nitrogen and phosphorus (Kunimatsu, 1983; Tabuchi and Takamura, 1985). Probably because they can provide favorable conditions for nitrification and denitrification as the soil is separated into aerobic upper layer and anaerobic lower layer under flooded conditions. However, several studies have evaluated that rice paddy fields contributed the largest amount of the pollutant loads to the lake (Davenport et al., 1996; Brady, 1996; Shell, 1996).

From the monitoring results, it is very difficult to separate the specific share of point source from the non-point source pollution. The most important parameters are precipitation/runoff ratio and conditions such as land cover, amount of fertilizers, and erosion danger, in the particular areas of the watershed. Further studies are needed to quantify the effects of land use and treatments at a watershed scale. To solve water pollution problem caused by agricultural non-point sources, farmers need to consider the fertilizer application time, types of chemical fertilizer, and application method, in order to minimize the loss of nutrients to streams and to maximize the absorption by crops.

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