Annual Runoff Loading of Nitrogen and Phosphorus from a Paddy Field

Kang-Wan Han*, **Jae-Young Cho and Jin-Kyu Choi**[1]

Agricultural Science Technology Research Center, Chonbuk National University, and
[1]Department of Agricultural Engineering, Chonbuk National University, Chonju 561-756, Korea

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The present study examined annual runoff loading of nitrogen and phosphorus in the paddy field from 1 May, 1997 to 30 April, 1998. In the investigated area, the amount of rainfall was 1,095.6 mm and 414.6 mm during cropping season and non-cropping season. The annual rainfall was 1,510.2 mm. The total amount of runoff water was 1,043.2 mm and 281.0mm during cropping season and non-cropping season, and the added total amount of runoff water during two seasons was 1,324.2 mm. The runoff loading of nutrients caused by runoff water was measured as follows. The total-N was 149.23 and 8.67 kg ha^{-1} (total amount=157.90 kg^{-1}ha^{-1}yr^{-1}), the ammonia-N 102.98 and 4.44 kg ha^{-1} (107.42 kg^{-1}ha^{-1}yr^{-1}), the nitrate-N 28.45 and 1.23 kg ha^{-1} (29.68 kg^{-1}ha^{-1}yr^{-1}), the total-P 4.16 and 0.38 kg ha^{-1} (4.54 kg^{-1}ha^{-1}yr^{-1}) during cropping and non-cropping season respectively. When the loss ratio was calculated based on amounts of chemical fertilizer, about 68.6% of nitrogen and 16.7% of phosphorus was lost by runoff from applied fertilizer amount.

Key words : *agricultural non-point source, paddy field, nutrient, runoff, sediment*

Water has been managed mainly at point source for streams and lakes in Korea. However, the water quality of streams and lakes has not been improved significantly even though the water treating equipment at point source has been increased. This may be because the environmental capacity on agricultural non-point source among several non-point sources such as pesticides, fertilizers and agricultural drainage which can give impact on water environment has not been evaluated properly.[1,2] Chung reported on 1996 that chemical fertilizer, pesticide and livestock were the main factors that polluted and caused eutrophication in streams or lakes.[3] Since the national land area is small and the farming land occupies only 24% of total land area in Korea, the promotion of agricultural productivity is urgent. In this process, the application rate of chemical fertilizer, which is the major pollution factor at agricultural non-point sources, has been increasing every year. In 1995, the applied chemical fertilizer was 444 kg ha^{-1}yr^{-1} which was four times as much as the world average amount (99 kg ha^{-1}yr^{-1}). In Korea, paddy fields occupy over 60% of total farming lands. The nutrient balance at paddy fields controls the nutrient supply and demand for rice plant and gives impact on water environment. Therefore quantitative evaluation concerning this is required.

The current study examined annual runoff loading and runoff characteristics of nitrogen and phosphorus. For the study area, the paddy fields of 5,000m^2 in Maryung-myun, Chinan-gun, Chonbuk, Korea were selected. For twelve months from May 1, 1997 to April 30, 1998, the outflowed amounts of runoff water and runoff sediments and annual concentration change of nitrogen and phosphorus were measured after which the annual runoff loading was calculated based on the above measurements.

*Corresponding author
Phone: 82-652-270-2547; Fax: 82-652-270-2550
E-mail: riverhan@moak.chonbuk.ac.kr

Materials and Methods

Experimental field and measurements. For the experimental field, the arranged field for farmland since May 1995, where overflow was little and meteorological data collection was easy, was selected. It is located in Maryung-myun, Chinan-gun, Chonbuk, Korea. This rice cultivation area had been protected from livestock farming, farmstead and industrial complex. The area was 5,000m^2 (100×50 m). The soil of experimental field was in Jisan series (Silt loam, SiL; fine loamy, mixed mesic family of Fluventic Haplaguepts). The physico-chemical properties of the soil are shown in Table 1.

The experimental field was plowed on May 13, 1997. Rice was transplanted by machine on the experimental field on May 26, 1997 and harvested on September 29 in the same year. The paddy field covered with rice straw was left under non-plowing condition for non-cropping season. The first plowing was made onto the field on April 25, 1998 and the second plowing followed after on May 20 in the same year. The application rate of chemical fertilizer during the present study was as follows. Onto the study field, basal fertilizer (10.72 kg N 10a^{-1} and 2.72

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

Chemical properties		Particle size fraction (%)	
Organic matter (%)	2.15	Sandy	29.5
pH (1:5)	5.81	Silt	55.3
Total-N (mg kg^{-1})	856.47	Clay	15.2
Total-P (mg kg^{-1})	246.34		
CEC (cmol kg^{-1})	10.54		
Exchangeable cations (cmol kg^{-1})			
Ca	4.35		
Mg	3.02		
Na	0.15		
K	0.45		

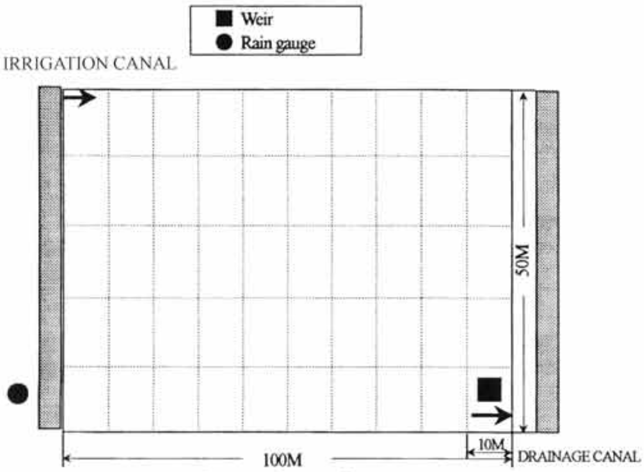

Fig. 1. Placement of experimental apparatus.

kg P $10a^{-1}$) and whole layer application were added on May 22, 1997. The field was applied with tillering fertilizer (7.36 kg N $10a^{-1}$) on June 13 and with panicle fertilizer (3.68 kg N $10a^{-1}$) on July 28. It was then treated with silicate fertilizer (200 kg $10a^{-1}$) on March 18, 1998. The applied amount of chemical fertilizer into the current study was twice as much as the recommended fertilizer amount for rice cultivation in Korea. In the experimental field, one set of rain gauge and another set of magnetic water level gauge and weir were established (Fig. 1). The analogue-magnetic rain gauge was set beside the irrigation canal of the study field. The gauge measured the amount of rainfall from May 1, 1997 to April 30, 1998. The weir was set at the outlet of the experimental field to measure runoff water in each compartment of paddy field. The rectangular weir with diameter of 30 cm was established below the paddy bottom to make overflow easy. The weir to which the stilling well of diameter of 40 cm and the magnetic water level gauge were attached measured the water level during the study period.

Sampling and sample analyses. Runoff water was sampled into polyethylene containers from the weir at the experimental field outlet at two-hour intervals. The sampled water was preserved under 4°C . To get runoff sediments, a rubber hose was connected to the weir outlet and a plastic bottle (200 *l*) into which runoff water flowed. Sediments were collected from fixed runoff water for three days, dried at room temperature and sieved with a 2 mm sieve. Chemical analyses of runoff water samples were conducted by standard methods as described by Hormer and Parker.[4] Micro-Kjeldahl distillation apparatus and Nesslers reagent determined total-N and ammonium forms. Nitrate-N was analyzed by ion chromatography (SYKAM, S3111 conductivity detector, S1121 solvent delivery system, Germany) after filtered with 0.45 μm milipore filter. Total-P determinations were made using the isobutanol extraction method described by Golterman and Clymo.[5] Runoff sediment samples were conducted by methods of soil analysis described by Jackson.[6] Total-N and ammonia-N were determined by micro-Kjeldahl procedures. Vanado-molybdate and Bray No. 2 methods described above determined total-P and ortho-P determinations.

Results and Discussion

Rainfall and runoff status. The results of rainfall and rainfall characteristics at 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 181% of average year. The length of rainy season (28 days), which was from June 20 to July 18, was almost the same to that (29 days) of average year. The amount of rainfall in June, July and August, when the input and output amount of water from the paddy field was the greatest, was 887.1 mm and rainfall day was counted to be 40 days. The amount of rainfall (36.1 mm) in September and October was 60% of that of average year. The rainfall amount (162.8 mm) in November and December was 150% of that of average year. From January to March in 1998, the rainfall amount was 75 mm. In April, the amount of rainfall was 178.2 mm which was 160% of that of average year and rainfall day was counted to be 7 days. The rainfall amount within the investigated area was 1,095.6 mm during cropping season while it was 414.6 mm during non-cropping season. The annual amount of rainfall was 1,510.2 mm

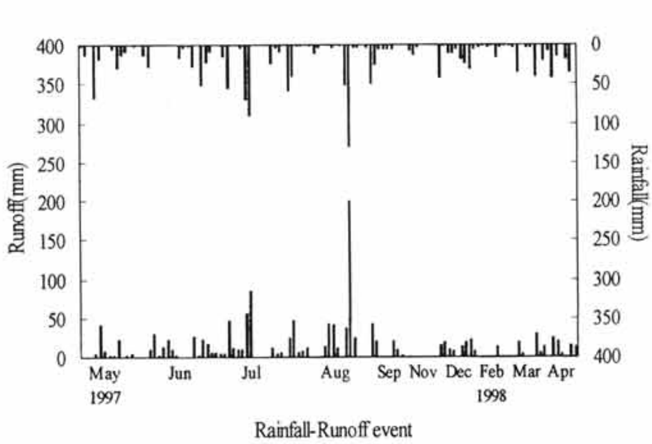

Fig. 2. Events of rainfall-runoff.

which was somewhat greater than the annual amount of rainfall (1,274 mm) in Korea. Twenty-nine runoff events occurred during the study period and the total amount of runoff water was 1,324.2 mm. The amount of runoff water was 1,043.2 mm (79%) during cropping season (from May through September) while it was 281.0 mm (21%) during non-cropping season (from October through April).

Concentration changes of nitrogen, phosphorus and total suspended solids in runoff water and sediments. Within the runoff water, the concentration of total-N was 3.66~20.14 mg l^{-1} (average value=8.44 mg l^{-1}), while that of ammonia-N and nitrate-N was 1.53~14.63 mg l^{-1} (5.22 mg l^{-1}) and 0.42~3.99 mg l^{-1} (1.63 mg l^{-1}), respectively (Fig. 3). The concentration of nitrogen sources increased during the period of fertilizer application such as basal fertilization, tillering fertilization and panicle fertilization, and then showed a tendency of gradual decrease. Kim and Cho[7] and Lee *et al.*[8] reported there would be no influence by fertilizer component runoff since the concentration of total-N was 10~15 mg l^{-1} in the period of fertilizer application and the concentration of paddy water itself was low after July. In the present study, however, the concentration of total-N was still high in non-cropping season. The concentration of total-P was 0.17~0.30 mg l^{-1} (0.21 mg l^{-1}) which increased gradually after basal fertilizer application and decreased gradually after late June. Ortho-P was not detected during the study period. The total suspended solids was 72.50~683.50 mg l^{-1} (200.42 mg l^{-1}). The majority of solids were 100~150 mg l^{-1} in cropping season (Fig. 4). However, the concentration increased rapidly during non-cropping season since the first plowing disturbed the soil layer. Kunimatsu *et al.*[9] reported that the concentration of total suspended solids was 10~20 mg l^{-1} before

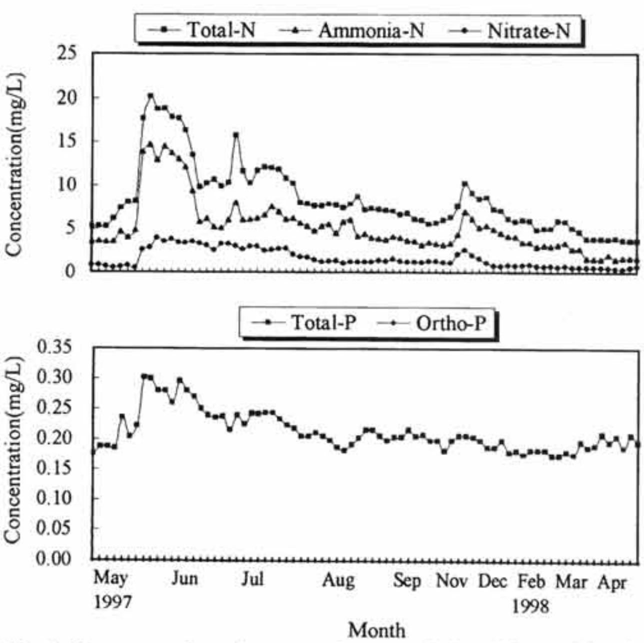

Fig. 3. Concentration changes of suspended solid particles in runoff water.

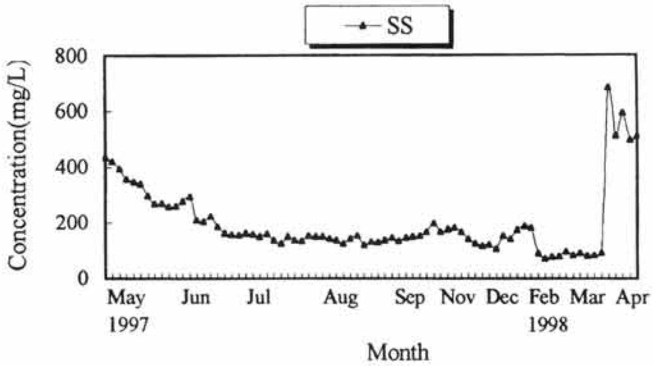

Fig. 4. Concentration changes of suspended solid particles in runoff water.

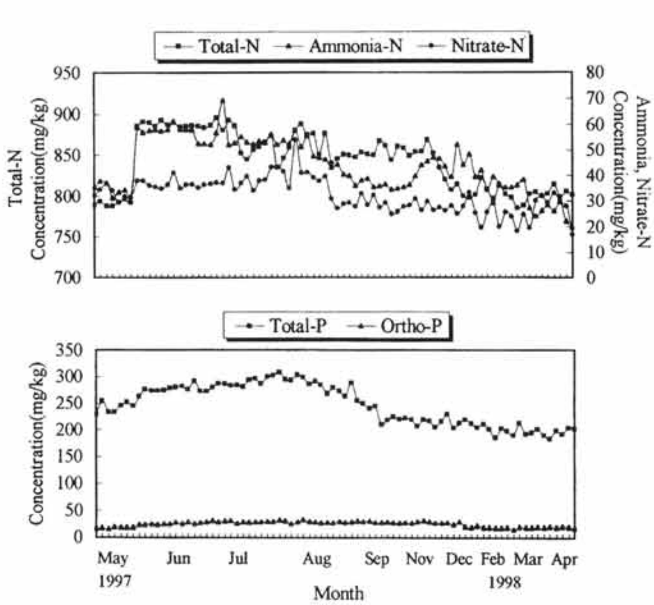

Fig. 5. Concentration changes of nitrogen and phosphorus of suspended soil particles in runoff water.

plowing and more than 600 mg l^{-1} after plowing in paddy fields. The present study showed a similar trend to it.

The total-N in suspended soil particles of runoff water was 785.4 mg kg^{-1} before basal fertilizer application and 891.0 mg kg^{-1} after basal fertilizer application (Fig. 5). However, it decreased gradually because of increased amount by runoff and rice plant absorption. The total-P was 182.60~308.22 mg kg^{-1} (246.72 mg kg^{-1}). It increased a bit after basal fertilizer application and decreased gradually after the end of July.

Annual Runoff Loading of Nitrogen and Phosphorus from Runoff Water and Sediments. Annual loading for each parameter was estimated from the mean concentration in all samples taken during the year multiplied by total annual discharge. Variations in concentrations with discharge were automatically taken into account because the samples used to calculate the mean were taken at flow proportional intervals. The runoff loading of nutrients caused by runoff water was measured as follows (Fig. 6). The total-N was 149.23 and 8.67 kg ha^{-1} (Total amount=157.90 kg ha^{-1} yr^{-1}), the ammonia-N 102.98 and 4.44 ha^{-1} yr^{-1} (107.42

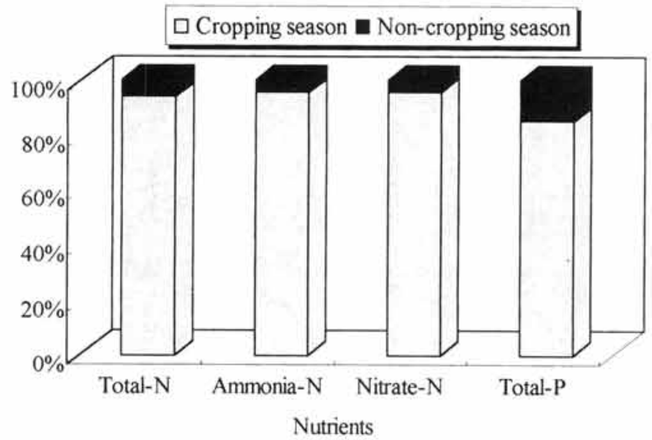

Fig. 6. Comparison of runoff loading of nitrogen and phosphorus during cropping season and non-cropping season.

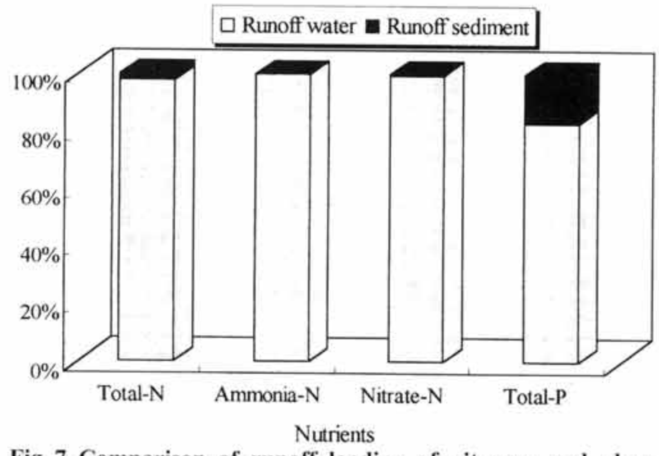

Fig. 7. Comparison of runoff loading of nitrogen and phosphorus by runoff water and runoff sediment.

kg ha^{-1} yr^{-1}), the nitrate-N 28.45 and 1.23 ha^{-1} yr^{-1} (29.68 kg ha^{-1} yr^{-1}), the total-P was 4.16 and 0.38 ha^{-1} yr^{-1} (4.54 kg ha^{-1} yr^{-1}) during cropping and non-cropping season respectively. The runoff loading was the highest in June maybe because of the high chemical component concentration effected by applied fertilizer. When the loss ratio was calculated based on amounts of chemical fertilizer, 68.6% of nitrogen and 16.7% of phosphorus was lost by runoff from applied fertilizer amount. Kim and Cho[7] reported that the loss amount of nitrogen and phosphorus was 15 kg ha^{-1} and 0.59 kg ha^{-1}, respectively, when they measured the nutrient loss caused by agricultural drainage during rice cultivation period. Kunimatsu[9] stated that 14.3 kg ha^{-1} yr^{-1} of total-N and 0.482 kg ha^{-1} yr^{-1} of total-P was lost by surface runoff from paddy fields. When the results of the current and other studies were compared, the runoff loading of nitrogen and phosphorus was fairly high. The majority of studies calculated the runoff loading only in cropping season and reported the results from watersheds not from a compartment of paddy fields. It seems as if different conditions such as method of fertilizer application, amount of applied fertilizer, fertilizer application time, irrigation water and amounts and components of rainfall among different studies made the difference of runoff loading.

When the total suspended solids in runoff water were converted into the amount of suspended soil particles, the runoff sediments were 1,615.7 kg ha^{-1} in cropping season and 2,173.4 kg ha^{-1} in non-cropping season. The amount of two seasons summed into 3,789.1 kg ha^{-1} yr^{-1}. The runoff loading of nutrients was measured as follows. The total-N was 1.74 and 1.46 kg ha^{-1} (total amount=3.20 kg ha^{-1} yr^{-1}), the ammonia-N 0.10 and 0.06 kg ha^{-1} (0.16 kg ha^{-1} yr^{-1}), the nitrate-N 0.07 and 0.05 kg ha^{-1} (0.12 kg ha^{-1} yr^{-1}), the total-P 49 and 0.43 kg ha^{-1} (0.92 kg ha^{-1} yr^{-1}) during cropping and non-cropping season respectively.

When the runoff loading of nutrients was compared by runoff water and sediments, the majority of nitrogen sources were flowed into streams by runoff water. The runoff loading of nitrogen sources by runoff sediments was little in its amount. About 80% of total-P by runoff water and the rest 20% by runoff sediments were flowed into streams (Fig. 7). The phosphorus compounds, which were flowed into streams by runoff sediments and then sedimentation, keep exchanging with water at water body in undelivered condition. And it moves gradually into water layer. This process can cause eutrophication continually and repeatedly in water environment. Therefore a sound program is needed to reduce soil erosion from farmlands.

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