계화 간척지구 강우 유출수의 비점오염원 유출특성에 관한 연구

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Characteristics of Nonpoint Source Pollution from a Reclaimed Rice Paddy Field

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요약 : 본 연구에서는 계화간척농지로부터 발생 되는 비점원 오염물질 유출현황을 조사하였다. 간척 논면적은 2,988ha로 크게 1,181ha와 1,817ha 크기의 두개의 소유역으로 구성되어 있다. 두개의 소유역에 대해 각각 3번의 강우사상에 대해 조사가 이루어졌으며 강우량은 각각 66.0, 23.5, 23mm이었다. 간척농지에서 오염물질 유출특성은 일반 내륙의 논에서와 다른 양상을 나타내었다. 일반적으로 우리나라 논에서는 발생되는 비점오염부하는 큰 반면에 연구대상 간척농지에서 발생되는 TSS, TN, TP의 비점오염 유출수준은 일반 임야지역 수준으로 나타났다. 다른 유역과 다르게 질소의 경우 용존성 유기질소가 주종을 이루고 있으며 인의 경우에는 용존성 인이 주종을 이루고 있었다.

핵심용어 : 농지, 비점오염, 질소, 인

Abstract : This research addressed nonpoint source (NPS) pollution characteristics in a reclaimed rice paddy field. The paddy has an area of around 2,998 ha and is divided as two sub-watersheds, whose areas are 1,181 ha and 1,817 ha, respectively. Monitoring of hydrologic runoff and NPS pollution was undertaken during three-month period from June to August, 2008. Totally, three sampling trips were made when rainfall depth were 66.0 mm, 23.5 mm, and 23.0 mm, respectively. Generally pollution load increased with the heavier cultivation activity in Korea. Exported pollutants from the rice paddy, including TSS, TN and TP, have same levels as forest discharge. Organic nitrogen is main pattern but it mainly exists in the forms of dissolved organic nitrogen (DON). For phosphorus, dissolved inorganic phosphorus (DIP) takes the main part although part of them is associated with fine particles. This is different compared with other watersheds, where particles-associated phosphorus is the main form.

Keywords : Nitrogen, Nonpoint source pollution, Phosphorus, Rice paddy, Runoff

1. Introduction

To investigate NPS pollution and their effects on water quality in Korea, a series of programs and projects have been carried out for many years (KME, 2006). They cover most types of agricultural activities. However, NPS pollution involved in the reclaimed rice paddy and its influence were less known. Many people have thought that water quality problem in the estuary dike dam is a result of the intensive and large-scale operation of rice paddy, mainly due to the NPS pollution caused by rainfall runoff.

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However, quite a few researches indicate that the paddy field have an capability to function in removing nitrogen and phosphorus nutrients. Generally, paddy field had relatively high concentrations of nitrogen and phosphorus in the irrigation water as well as adequate retention time, both of which facilitate purification processes (Zulu et al., 1996; Feng et. al, 2004). In addition, another research demonstrate that purification function was related to the hydraulic retention time. Critical retention time that determines pollutant sink or pollutant source was approximately 4 days for total phosphorus (TP) and chemical oxygen demand (COD) loads and 7 days for total nitrogen (TN) load (Takeda and Fukushima, 2006). Kim et al. (2006) investigated nutrient runoff from a Korean rice paddy watershed during multiple storm events in the growing season and found that nitrogen runoff from paddy field watersheds depends on fertilization rate, while phosphorus runoff is controlled by pond conditions.

The most important feature of rice cultivation is water logging. This leads to anaerobic conditions in paddy soil. Nitrogen tends to be conserved more in paddy soils than in other soils. Because in anaerobic conditions, nitrification is hard to occurs. Meanwhile, NH4-N is retained as a cation on negatively charged soil mineral and organic particles, the leaching of NH4-N from paddy fields is not significant. In the process of anaerobiosis in paddy soils, iron phosphate tends to be reduced, with a release of phosphorus in available forms (Kyuma, 1995). The reduction of paddy soils under submerged conditions is accompanied by an elevation of soil pH. The rise in pH enhances the solubility of iron phosphate and aluminum phosphate, by a factor of 10 times per unit rise in pH. This is a typical mechanism to raise the availability of phosphorus in paddy soils (Kyuma, 1995).

The overall objective of the study is to investigate a status of NPS pollution discharge during storm flow condition from a large cultivated rice paddy field which was reclaimed from coastal sea. And then its characteristics will be compared with other land use types.

2. Materials and methods

2.1 Site description in the reclaimed rice paddy field

The watershed examined in this study is Gaehwa area which was reclaimed from shallow coastal sea. It is located in North Jeolla Province of the southwestern part of Korea. The construction of this reclamation project started in 1964 as a part of first five-year developing strategy and completed in 1978. It has a goal of producing 100,000 tons of grain per year. The total area involved in project covered around 3,976 ha which include rice paddy of 2,740 ha and other area (reservoir and channel) of 1,246 ha.

The watershed totally consists of rice paddy and includes small residential area (less than 1%). Originally the lake was not constructed to supply irrigational water but temporally store the return flow from paddy before discharging it to the coastal sea, and control the flooding of the paddy area during rainy season.

2.2 Monitoring methods

As shown in Fig. 1, the paddy field can be largely divided into two sub-watersheds. Return flow and rainfall runoff from sub-watershed #1 enters into the southern part of the lake and those from sub-watershed #2 are discharged into the northern part.

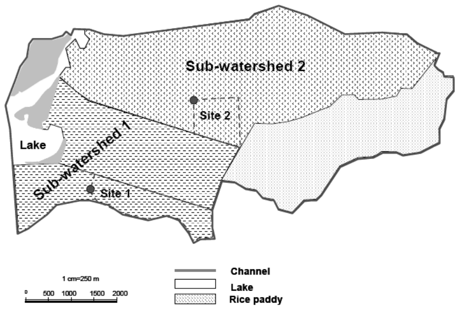

Fig. 1. Sub-watersheds and selected sites for NPS monitoring

At the each sub-watershed, we selected five candidate sites for hydrologic station and NPS monitoring. Based on easiness of flow monitoring, sampling, and accessibility, two sites were finally determined and they are located in two main drainage channels of the reclaimed rice paddy (Fig. 1). The watershed areas of Site #1 and Site #2 are 192 ha and 197 ha, respectively. The watershed is almost flat (mean watershed slope is less than 0.5 %).

The Ultrasonic Doppler instruments (Model 6526, Product from Australia) were installed at the monitoring site to obtain flow velocity, flow depth and water temperature. Ten minutes interval step was set to record these hydrologic data. According to the relationship between cross-sectional area and depth, the instant flow rate was calculated. The flow meter was tested with manually measured and metered data which were collected during storm flow conditions to look at the reliability of instrument.

The flow meters were operated starting from June 25 to September 30 in 2008, and we obtained three months flow data including the dry days and all the rainfall events during the period of monitoring. Hydrologic runoff and NPS monitoring were undertaken during three-month period between June and August, 2008. Totally, three sampling trips for NPS were made (Table 1). On the day of sampling, base-flow samples were taken before the rainfall. And continuously water samples were taken based on flow rate. Finally 15 samples reflecting increase and decrease of the hydrograph were selected for laboratory analysis.

Table 1. Information of sampling rainfall events

Site	Date	ADD* (days)	Rainfall depth (mm)	Duration (hrs)	Rainfall intensity (mm/hr)
Site #1	2008.6.28	6	66.0	18	3.67
	2008.7.25	1	23.0	4	5.75
	2008.8.18	1	23.5	5	4.70
Site #2	2008.6.28	6	66.0	18	3.67
	2008.7.25	1	23.0	4	5.75
	2008.8.18	1	23.5	5	4.70

* ADD : antecedent dry days

The measurement of all water quality parameters was performed in accordance with standard methods (APHA et al., 1995). Total 90 samples (3 rainfall events and 15 samples per events) from two watersheds were collected and analyzed. The specific parameters include pH, EC, Turbidity, TSS, CODcr, BOD and nutrients constituents. In order to determine the particles-related components of the nutrients, dissolved-TN and dissolved TP were also measured.

2.3 Comparison with other agricultural watersheds

The data for comparison comes from NPS pollution monitoring projects carried out mostly by the Institute of Environment Research, Hanseo University, Korea. It has been working on many different NPS programs in last decades which covered various types of land use and rainfall events. These data sources are available in this research.

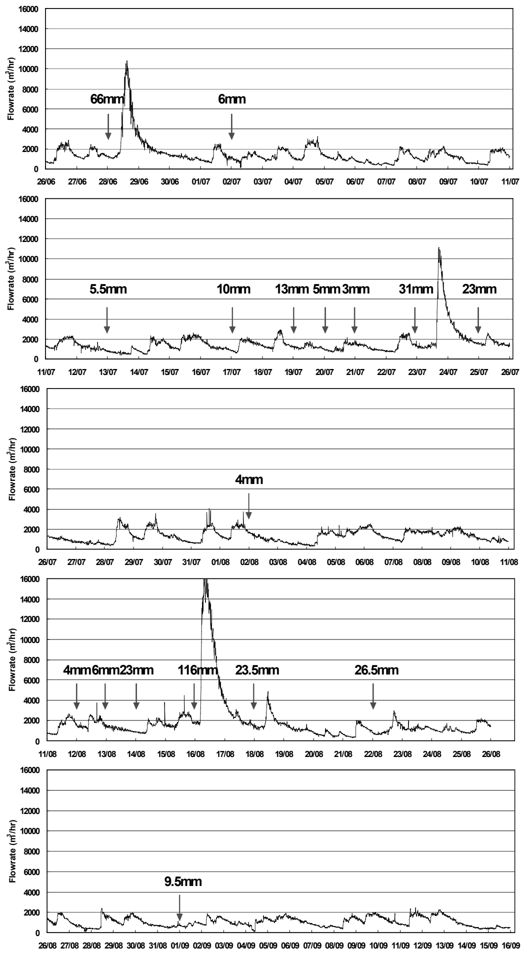

Fig. 2. The observed flow rate during the investigation period

3. Results and discussion

3.1 Hydrology characteristics

The flow rates measured continuously during the investigation period are presented (Fig. 2).

The rainfall events during this period were indicated in the Fig. 2. It can be observed that there is a relatively higher base flow even in the dry period. Sometimes, even the return flow of irrigational water causes peak flows during dry days. High base flow is due to return flow of irrigational water supplied by the reservoir located in the upper part of Gaehwa area, and partly caused by ground water supply from rice paddy.

Actually, the average base flow from Site 1 during dry days is around 34,200 m^3/day. According to monitored flow rate data, small rainfall events(less than 14mm)do not give a storm runoff because of high infiltration rate through sandy soil layer of the reclaimed rice paddy. At the same time, the discharged runoff generally increases with the rainfall depth during the investigation period (Fig. 3), which is in accordance with other research

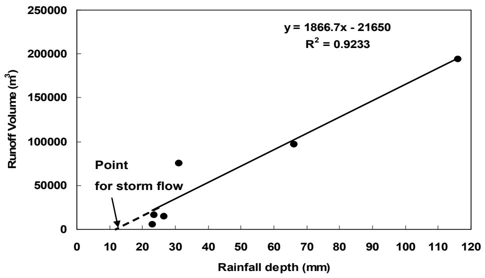

Fig. 3. Relationship between rainfall depth and storm flow runoff

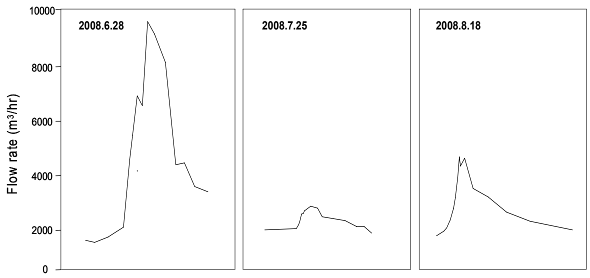

Fig. 4. Hydrograph in the reclaimed rice paddy (Site 1)

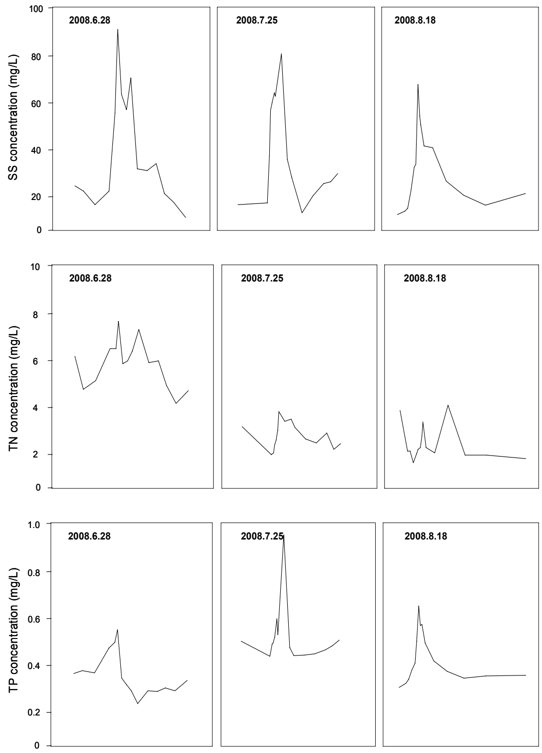

Fig. 5. Pollutograph in the reclaimed rice paddy (Site 1)

(Takeda and Fukushima, 2006). The first sampling case has higher peak flow than other two cases due to higher rainfall depth of 66 mm, compared with 22.0 mm, and 23.5 mm in other two times (Fig. 4).

3.2 Pollutograph and pollutants patterns

In individual watershed, the storm flow hydrograph will be determined by many factors, such watershed types and soil characteristics as well. Accordingly, pollutants carried by storm flow will perform specific characteristics in different watersheds (Yi et al, 2008).

SS, COD, and TP show concentration peaks along with the process of storm flow (Fig. 5). However, the concentration change of TN is not obvious like others. In the first time, TN concentration is greatly higher than other two times, probably due to antecedent activity of fertilization and then washout by the storm flow. This result is same as the result presented by Kim et al. (2006).

Fig. 6 and Fig. 7 give the relationships between flow rate, SS and other pollutants. Obviously there are no linear relationships among them except that TP shows significant relationship with TSS. Generally, TP used to be associated with SS resulted from soil erosion under storm flow conditions.

The following factors would affect soil erosion; (1) slope, (2) rainfall factors, and (3) vegetation surface. The soil erosion from the paddy is not heavy due to its smaller slope, denser vegetation cover and pond system.

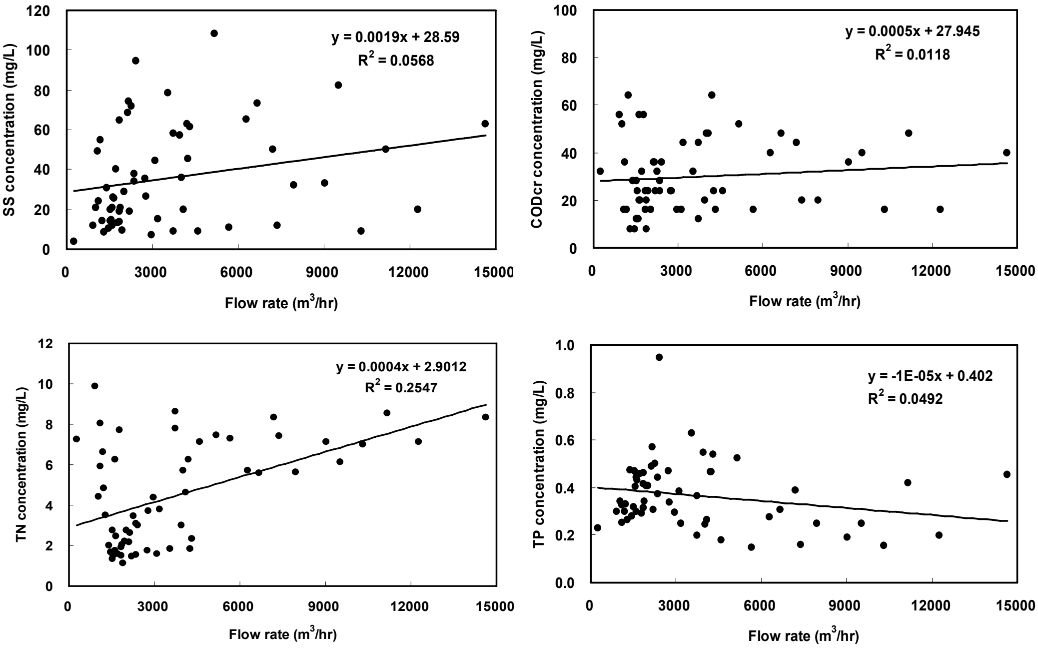

Fig. 6. Relationships between pollution constituents and flow rate

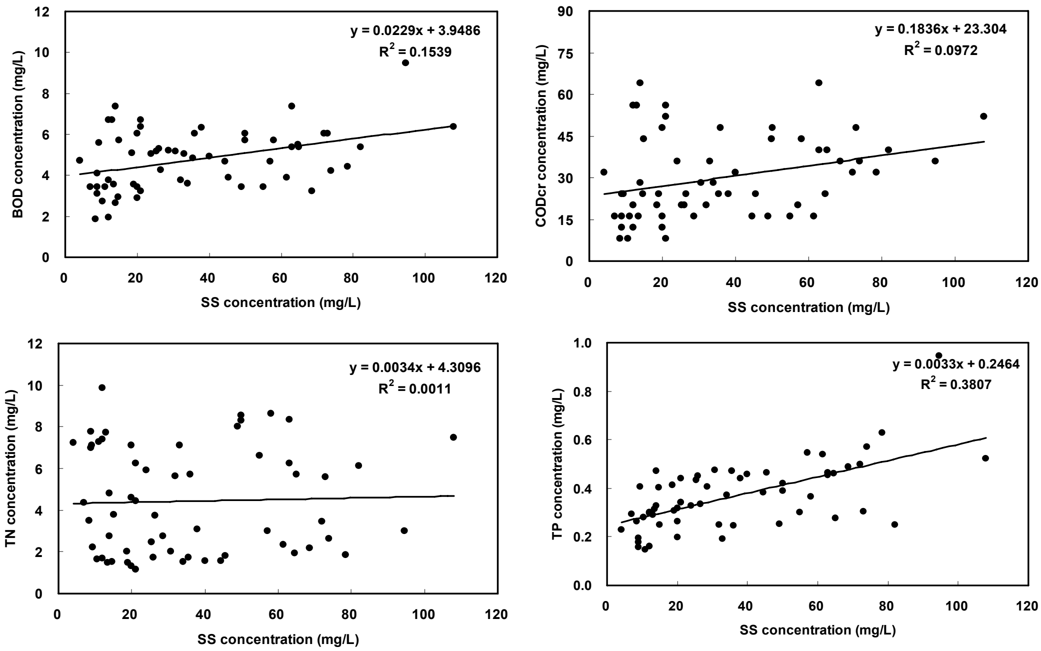

Fig. 7. The relationship between SS and the other pollutants

These conditions are not favorable for soil erosion and transport if compared with other watersheds. For example, in croplands, it generally present linear regression relationships

Table 2. Characteristics of NPS pollutants in the storm flow

Site		Concentration of base flow (mg/L)				Average concentration (mg/L)				Peak concentration (mg/L)				Total load (kg)			
		SS	COD	TN	NH3-N	SS	COD	TN	NH3-N	SS	COD	TN	NH3-N	SS	COD	TN	NH3-N
Site 1	First	2.0	36.0	5.9	0.40	40.9	44.3	7.3	0.73	108.0	64.0	9.7	1.20	4310	4042	572	75
	Second	14.0	28.0	2.8	0.80	41.3	26.7	2.4	1.00	9.5	36.0	3.4	1.20	879	704	67	28
	Third	8.5	8.0	3.5	0.50	32.5	18.1	2.0	0.30	78.5	32.0	3.7	0.50	1269	859	88	12
Site 2	First	4.0	32.0	9.4	1.57	28.3	30.4	10.1	1.80	63.0	56	12.8	2.90	3519	3973	1422	244
	Second	4.7	24.0	1.9	0.62	7.1	29.6	1.4	0.53	11.3	52.0	3.2	0.67	236	1033	44	16
	Third	7.5	12.0	1.3	0.30	30.5	19.5	2.1	0.22	80.5	24.0	2.9	0.33	966	733	81	8

Table 3. Characteristics of NPS pollutants in the storm flow (continued)

Site		Concentration of base flow (mg/L)			Average concentration (mg/L)			Peak concentration (mg/L)			Total load (kg)		
		NO3-N	TP	PO4-P	NO3-N	TP	PO4-P	NO3-N	TP	PO4-P	NO3-N	TP	PO4-P
Site 1	First	0.47	0.33	0.03	0.59	0.32	0.04	0.73	0.52	0.07	62.9	27.8	3.5
	Second	0.36	0.47	0.16	0.30	0.50	0.20	0.50	0.90	0.40	8.9	13.5	5.1
	Third	0.06	0.26	0.07	0.10	0.40	0.09	0.20	0.60	0.11	5.5	16.2	4.5
Site 2	First	0.58	0.23	0.02	0.55	0.27	0.02	0.73	0.45	0.048	78.3	37.9	2.8
	Second	0.34	0.24	0.09	0.30	0.23	0.09	0.37	0.27	0.12	9.5	7.4	3.0
	Third	0.09	0.22	0.08	0.12	0.37	0.09	0.39	0.60	0.12	3.04	12.2	3.5

between flow rate and particles-related pollutants (SS, COD and TP).

3.3 Comparison with other agricultural watersheds

The characteristics of NPS pollutants in the storm flow from the reclaimed rice paddy are presented in Table 2 and Table 3. Event mean concentration (EMC) values are calculated in individual rainfall event at each site (Table 4). EMC can be calculated by the following equation.

$$EMC = \sum QiCi/\sum Qi$$

Where Qi is the flow rate at time t (m^3/hr), Ci is the concentration of the pollutant (mg/L), and EMC is flow weighted mean concentration in a storm event (mg/L).

The distribution of the EMC values is shown in Fig. 8. TSS concentration has a range of 25.0 to 41.8 mg/L while CODcr ranges from 18.8 to 39.2 mg/L. TN concentration is relatively lower in the second and third events compared with the

Table 4. EMC values in the two sites

Sties	Sampling trips	SS (mg/L)	COD (mg/L)	BOD (mg/L)	TN (mg/L)	NH3-N (mg/L)	NO3-N (mg/L)	TP (mg/L)	PO4-P (mg/L)
Site 1	First	41.8	39.2	5.4	7.2	0.73	0.61	0.27	0.03
	Second	31.2	25.0	5.1	2.4	1.0	0.31	0.48	0.18
	Third	27.8	18.8	3.7	1.9	0.26	0.12	0.35	0.10
Site 2	First	25.0	28.2	4.5	7.8	1.74	0.56	0.27	0.02
	Second	31.4	25.2	5.0	2.4	0.55	0.31	0.48	0.20
	Third	25.2	19.1	3.4	2.1	0.20	0.08	0.32	0.09

first one, which was due to the antecedent fertilization activity, and subsequent washout within this storm evens as discussed previously.

Fig. 8 shows comparison result with other agricultural watersheds in terms of EMC values (Fig. 8). The paddy has low TSS concentration, which is located on the same level as that in a forest area. It would be explained mainly from three facts. Firstly, the paddy can act as a pond system for sediments settling. Secondly, rice paddies are covered well with vegetation, which can prevent the loss of soils. Thirdly, the slope of paddy is rather flat, which is not favorable for transport of soil particles. TP has the same trends since it is generally associated with suspended solids and transported with particles as discussed before.

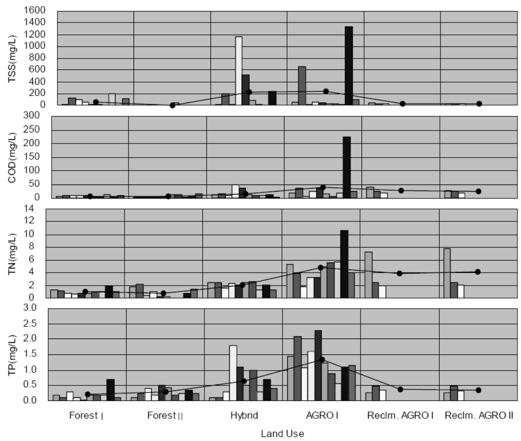

Fig. 8. EMC comparison between different land uses

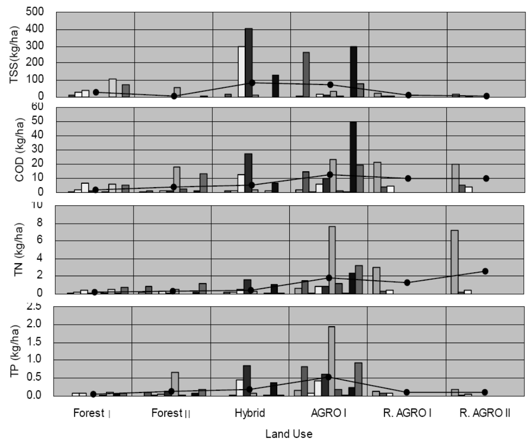

Fig. 9. Unit load comparison between land use types

(Forest I: 285 ha, cultivation area occupies 2.5%; forest II: 338.4 ha, cultivation area occupies 0.5%; Hybrid area: 496 ha, cultivation area occupies 14.8%; Agricultural area: 2737 ha, cultivation area occupies 35.9%; data from Kim, 2006)

Actually, there are many researches presenting that rice paddy has a pollution purification function. Takeda et al. (2006) made an investigation on the water quality and hydrology for 8 years in a paddy watershed using a circular irrigation system. The results showed that rice paddy performedpurification for TP and COD. And Kim et al. (2006) also found that ponding on rice paddy played very important role in reducing soil-erosion-related phosphorus export.

The unit load comparison of different pollution constituents during individual rain events are shown in Fig. 9, which also support the above discussion. Note that the exported loads of SS, TN and TP are on the same level as that in forest watershed.

3.4 Characteristics of nutrients export

In rice paddy, more than 90 percent of nitrogen exists with a form of total Kjeldahl nitrogen (TKN). In rice paddy field, most of nitrogen exists in soil organic forms. Microbial decomposition of the organic matter gradually releases NH4-N. The anaerobic conditions of a rice paddy soils make it hard to loss through nitrification activities. Most of NH4-N is retained as captions on negatively charged soil mineral and organic particles, which is readily until the rice roots take it up. Because of its hardness to transport of particles-related nitrogen (Fig. 7), it released from paddy soils within the forms of dissolved organic nitrogen (DON, data not shown).

In the paddy field, the average ratio of soluble reactive phosphorus (SRP) to TP is around 30% (Fig. 11), which is rather high compared with that in forest area (Yi et al., 2008). In rice paddy, phosphorus mainly exists in the forms of Fe-P and Al-P but it is not readily soluble. Lee et al. (2004) studied long-term effect of fertilization on the forms and availability of soil phosphorus in rice paddy. It indicated that application of chemical fertilizer together with compost accelerated the decrease in the organic-P and then increase inorganic-P fraction significantly. Accordingly, SRP ratio is relatively higher than that in forest area.

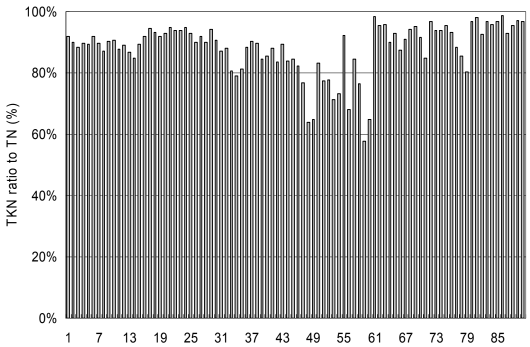

Fig. 10. TKN ratio to TN in the reclaimed area

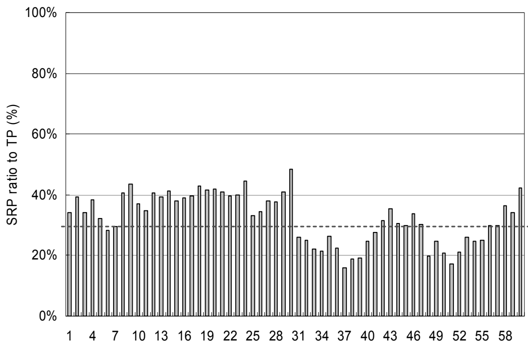

Fig. 11. Percent ratio between SRP and TP in the reclaimed area

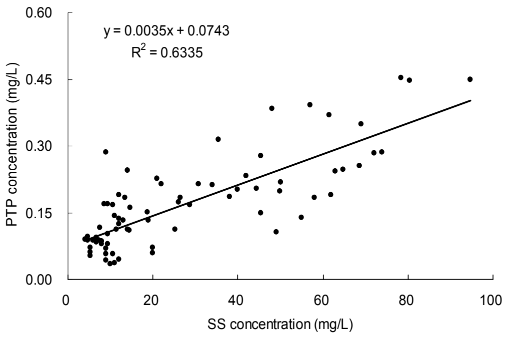

Fig. 12. Relationship between PTP and SS concentration

Further analysis found that average dissolved total phosphorus (DTP) ratio to TP is 53%. Accordingly, around 63% of SRP exists in the water column. Still phosphorus is related to particles, and especially fine particles are abundant with phosphorus. There is significant regression between SS concentration and particle total phosphorus (PTP) concentration (Fig. 12).

4. Conclusions

In the reclaimed rice paddy field, characteristics of NPS pollution were analyzed and compared with other land use types from different aspects. The characteristics of the reclaimed rice paddy field are rather different from other agricultural watersheds. The features of rice paddy is not favorable for transport of soil particles and nutrients as well. Vegetation cover and pond system can act as a potential purification function of pollutants. Effluents of TSS, TN and TP have same levels as forest export. Like other watersheds, organic nitrogen is main patterns of NPS pollution discharge. But it exists in the DON forms. Phosphorus exists mainly in SRP pattern although part of them associated with fine particles. Relatively, particles-related phosphorus is the main forms in other agricultural watersheds.

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