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Effect of surface state of paddy fields on pollutant load outflow during a non-irrigation period

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ABSTRACT

The purposes of this study are to clarify the effect of the state of the surface of paddy fields on outflow loading during a rainy event in a non-irrigation period and to propose an effective management method to reduce outflow of pollutant loading. We chose four types of paddy fields according to the state of the surface in order to investigate the difference in runoff. Water samples were collected from surface and culvert outflow in each paddy field during two rain events. From surveys of these two events, an L-Q model was developed. Then, we evaluated the pollutant loading during a non-irrigation period (2004.09.01–2005.04.30, 242 days) using the model. Cumulative loadings of SS, T-N, PN, T-P and PP were compared with unit loading in an irrigation period. As a result, unit loading in a non-irrigation period is about 25–51% and 24–89% of the irrigation period unit loading for T-N (45.7 kg/ha) and T-P (8.72 kg/ha), respectively. This result clearly indicated that runoff loading during a non-irrigation period cannot be ignored. From the discharged loading according to the surface state, many pollutants discharged from a Type C paddy field which spread straws after a harvest during a non-irrigation period.

Keywords: Non-point sources pollution; Non-irrigation period; Paddy field; pollutant load; Paddy field management

1. Introduction

Water quality of rivers, lakes and the sea in Japan has deteriorated due to pollutants discharged from the watershed with economic development. As is known, a lake is a lentic habitat and has a long residual time. If a lake is once polluted, it takes a long time to recover. The Japanese government made a Lake Law to control the water pollution problem in 1984. Lake water quality has not been improved over more than 30 years which have passed. The rate of conformity to water environmental quality standards of public water bodies in 2005 are 87.2% in rivers and 76.0% in sea waters while that of lakes is 53.4%. In 2005 the Central Environmental Council of the Japanese government announced the "ideal way about environmental preservation systems of lakes". It examined the reason why water quality of lakes had not been improved, while they controlled point pollution sources. There is not enough previous work to characterize and estimate non-point pollution sources. Plans which were made under these situations could not improve the water problem of lakes. Therefore, the Japanese government amended the Lake Law in 2005.

The agricultural area in Japan is 14% while the forest area is 67%. However, runoff loading from the agricultural area is larger than that of the forest. As over 50% of the agricultural area in Japan is that of paddy fields, accuracy of unit loading from paddy fields affects the

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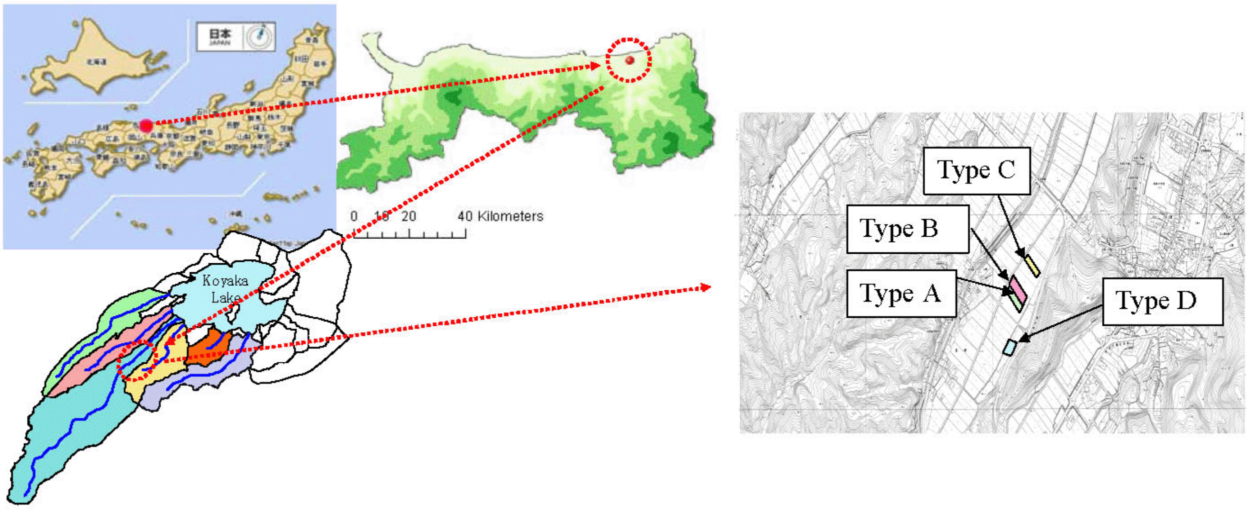

Fig. 1. Map of the study area.

estimation of total runoff loading from watershed [1]. Paddy fields use large quantities of irrigation water and fertilizer. Pollutant loading from paddy fields has been generally thought to be discharged during the irrigation period. Sonoda estimated unit loading of SS, COD, T-N and T-P during 3 years of irrigation period and 2 years of non-irrigation period [2]. Kunimatsu reported that non-irrigation period runoff which was not noticed in the previous works accounts for 51% of T-N and 68% of T-P of annual loading, respectively [3]. Many researchers have focused on runoff during the irrigation period rather than the non-irrigation period. However, runoff can always occur through surface and subsurface drains during the non-irrigation period because the outlet is always open during that period. The runoff water contains significant amounts of pollutant which has accumulated during the irrigation period. Therefore we should not ignore runoff during the non-irrigation period. Moreover, there are various surface states of paddy fields according to the farmer's management — for example, paddy fields which are left as they are, those in which ditches are made, and those on which straws are spread after harvest. There seem to be differences of runoff loading according to the surface state of paddy field.

The purposes of this study are to clarify effect of the surface state of paddy fields on outflow loading in a non-irrigation period during a rainy event and to propose effective management method to reduce outflow of pollutant loading.

2. Materials and methods

2.1. Study area

The study area is the Rokutanda area which is located around Lake Koyama in the Tottori prefecture, Japan

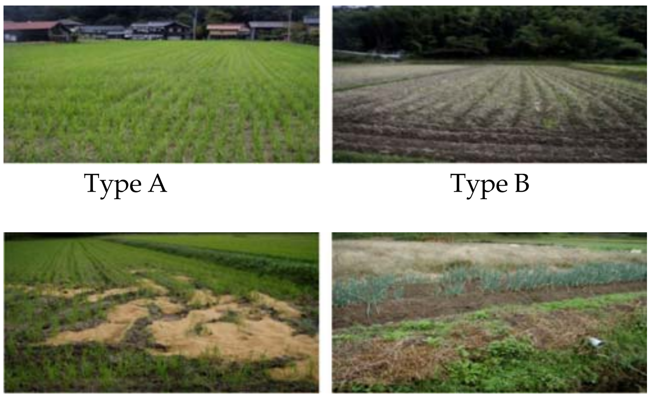

Fig. 2. Pictures of each paddy field. Type A, no activities after harvest. Type B, farmer digs ditches after harvest. Type C, farmer spreads straw after harvest. Type D, upland field.

Table 1
Area and percentage of each type of field

Type	Studied area (m^2)	Percentage (%)
A	2060	49
B	2150	16
C	3600	2
D	777	24

(Fig. 1). We chose three types of paddy fields and upland fields according to the surface state in order to investigate the difference in runoff depending on surface states. Table 1 and Fig. 2 explain the information of each area. Type A accounted for 49% of its catchment, and Type C accounted for just 2%. But Type C is not a rare paddy field in Japan, while it shows low percentage in its catchment.

2.2. Study method

We investigated two rainy events during the non-irrigation periods: November and December, 2007. Water samples were collected from surface and culvert outflow in each paddy field. Total rainfalls in the events were 24 mm and 14 mm, respectively. We analyzed suspended solids (with GF/F), T-N (total nitrogen), DTN (dissolved total nitrogen), ammonia, nitrate, T-P (total phosphate), DTP (dissolved total phosphate), and phosphate by Japan standard analysis methods. On the basis of these results, we made a model to estimate pollutant loading during the non-irrigation period, and we evaluated pollutant loading during the non-irrigation period according to rainfall.

3. Results and discussion

3.1. Flow rate

Fig. 3 shows the flow rate variation of surface and culvert outflow during the survey in November and December. We could not collect water samples when outflow was too small. In November, we could obtain only culvert outflow. And we could not obtain surface outflow of a Type B paddy field in December. The average flow rate of surface outflow was 94.36 ml/s, compared to the culvert outflow which was 10.49–13.84 ml/s in a Type A paddy field. Large amounts of outflow were discharged from the surface of the paddy field in the case of where the farmer did nothing after harvest, and the field is covered with weeds and rice stubble. This created a difficult condition for rainfall water to infiltrate into soil. In addition, surface outflow is restrained by weeds and rice stubble. On the other hand, much outflow discharged from the culvert in Type B and C. Cultivating paddy field made a chink, and it created an easy condition for rainfall to infiltrate into soil in Type B.

3.2. SS

Figs. 4–6 show the variation of flow rate and SS concentration of surface and culvert outflow in November and December. Types A, B and C showed a high SS concentration before peak flow in November (Fig. 4), and showed similar pattern between flow rate and SS concentration. Upland fields showed a similar pattern for both flow rate and SS concentration. In December, surface flow rate of Type A was seven times greater than flow rate from culvert flow. However, SS concentration of surface is lower than culvert runoff. From this, we think that rice stubble and weeds are effective to control surface runoff of SS. SS concentration in surface runoff water of Type D is higher than that of culvert discharge. We consider that as the upland field was in cultivated state, SS was easily discharged through surface.

3.3. Nitrogen compounds

Figs. 7–9 show the variation of flow rate and nitrogen concentration of surface and culvert outflow in November and December. From the variation of culvert outflow in November, we could see high T-N concentration before peak flow. TN concentration decreased with increasing of

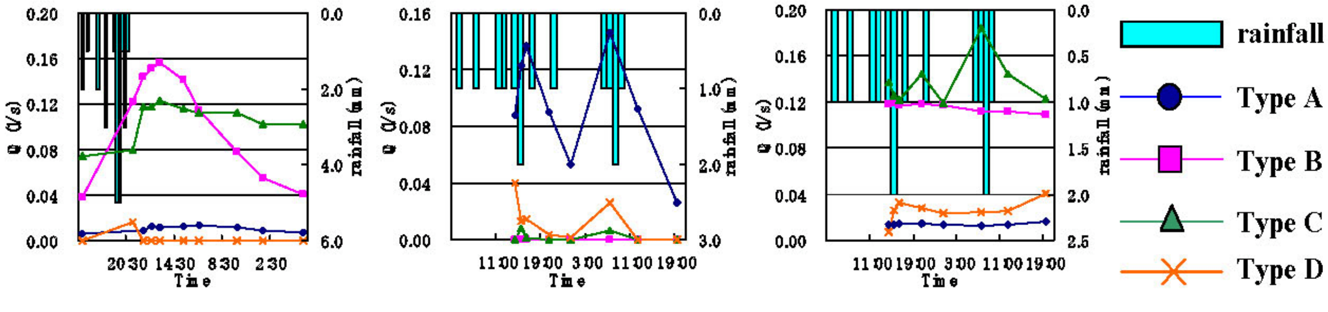

Fig. 3. Variation of flow rate (culvert in November, surface in December, culvert in December).

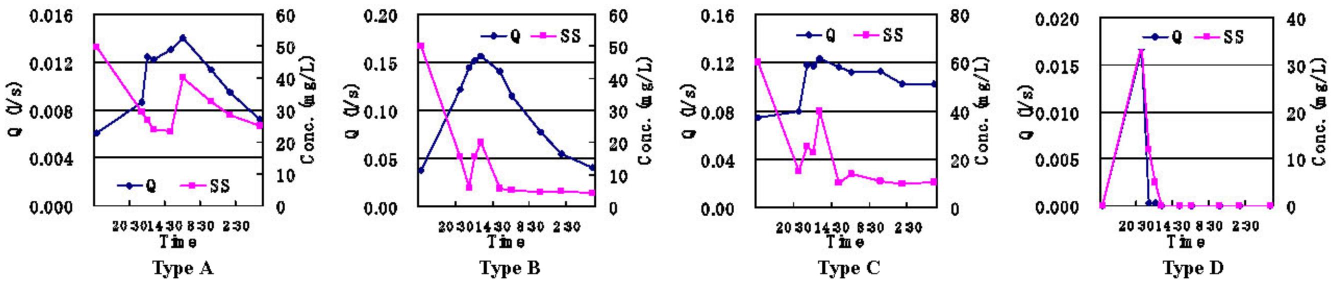

Fig. 4. Variation of Q and SS concentration of culvert outflow in November.

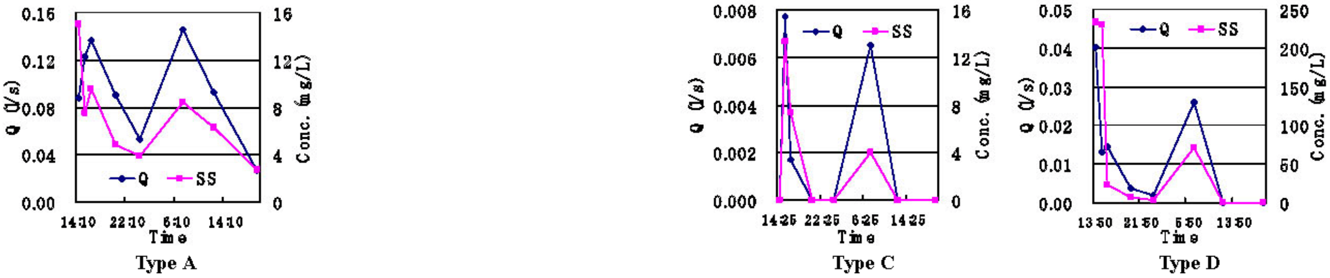

Fig. 5. Variation of Q and SS concentration of surface outflow in December.

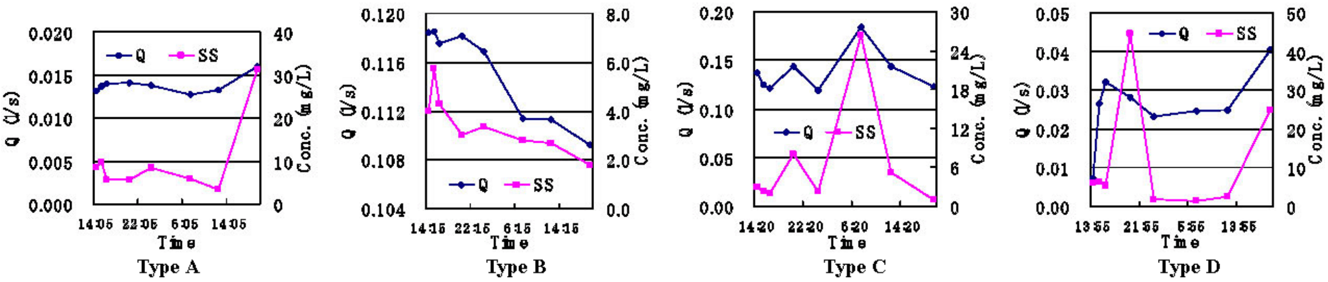

Fig. 6. Variation of Q and SS concentration of culvert outflow in December.

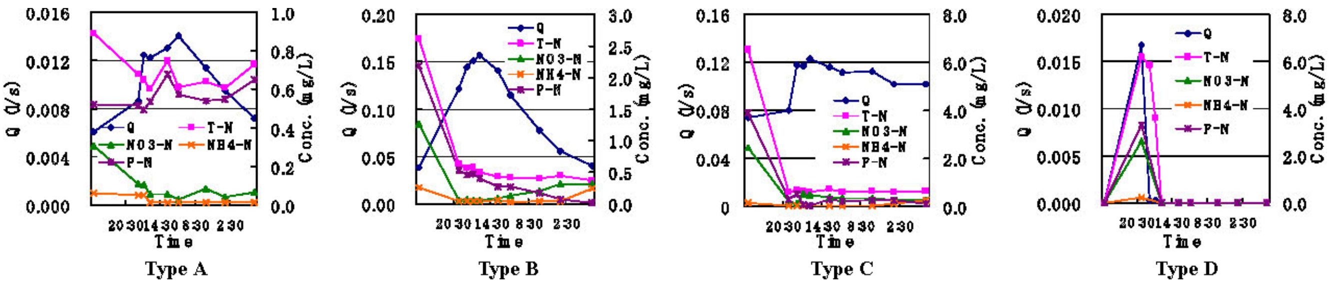

Fig. 7. Variation of Q and nitrogen concentration of culvert outflow in November.

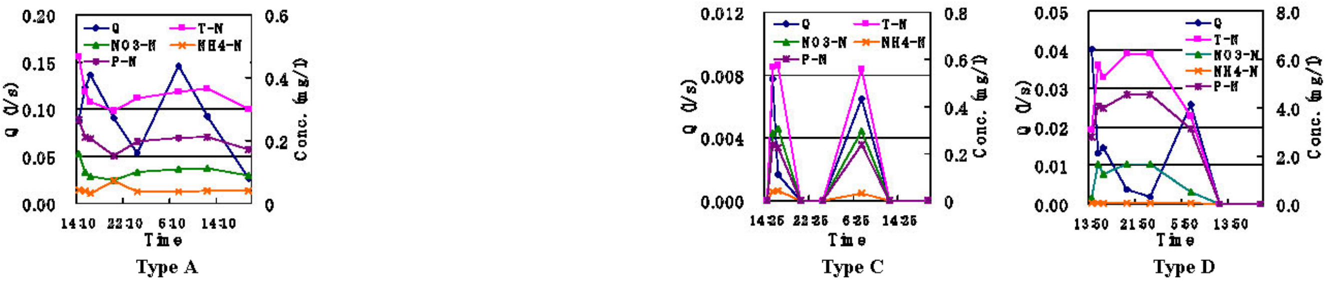

Fig. 8. Variation of Q and nitrogen concentration of surface outflow in December.

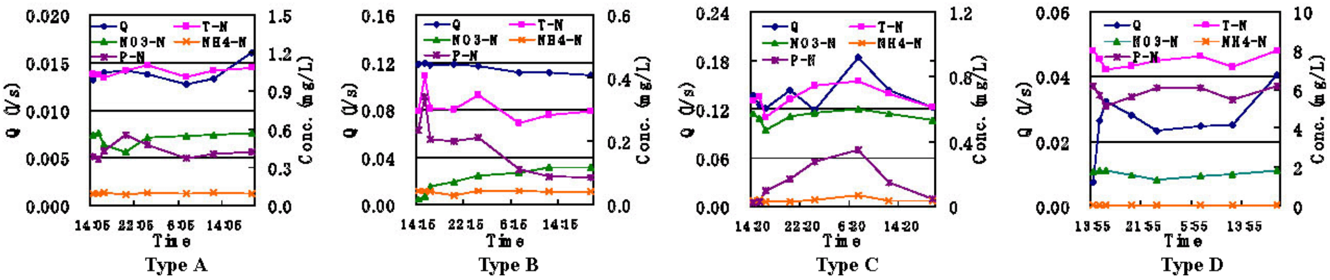

Fig. 9. Variation of Q and nitrogen concentration of culvert outflow in December.

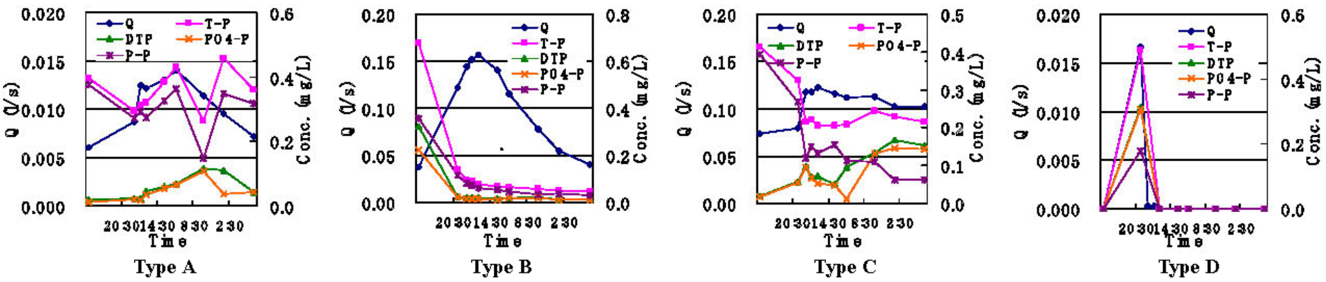

Fig. 10. Variation of Q and phosphorus concentration of culvert outflow in November.

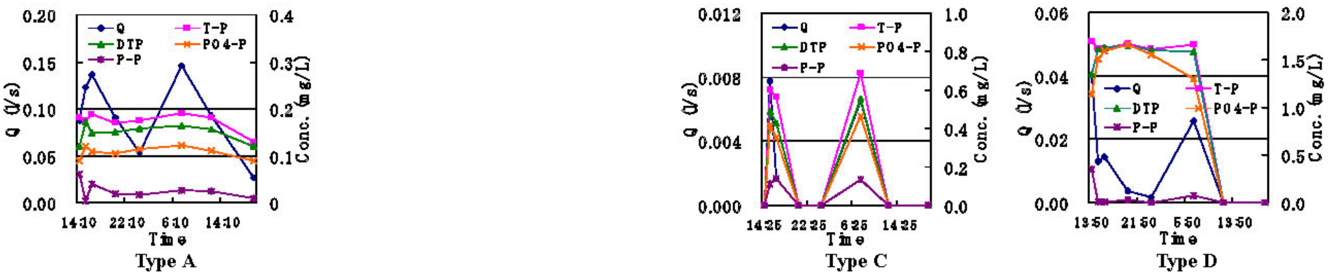

Fig. 11. Variation of Q and phosphorus concentration of surface outflow in December.

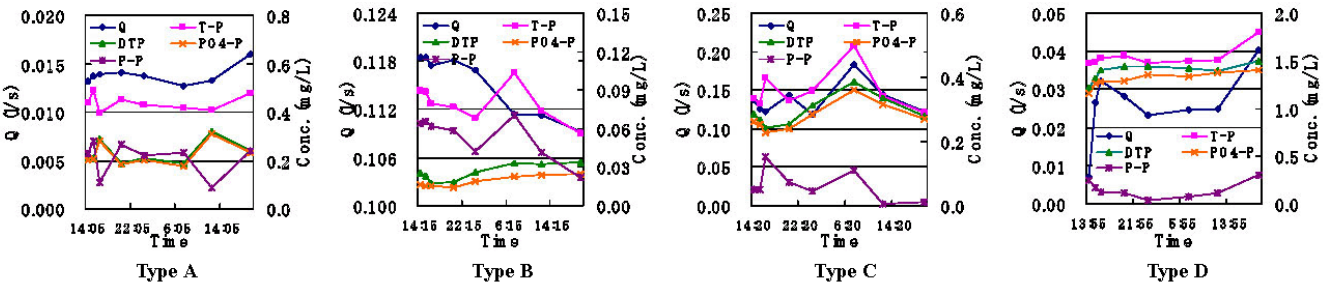

Fig. 12. Variation of Q and phosphorus concentration of culvert outflow in December.

flow rate in Type A, B and C. We consider that TN discharged from culvert was diluted by outflow water. However, Type D (upland field) shows the same variation between flow rate and TN concentration. On the other hand, we did not find a relationship between flow rate and T-N in December.

T-N concentration of Type A was highest of all the paddy fields. T-N and nitrate concentration of Type C was high and PN concentration was low, while surface runoff was low. We think spreading rice straw and rice bran have affected reduction of particulate materials runoff. T-N concentration of Type D (upland field) was higher than the paddy fields. We consider it was affected by use of fertilizer.

3.4. Phosphorus compounds

Figs. 10–12 show the variation of flow rate and phosphorus concentration of surface and culvert outflow in November and December. T-P concentration is high before peak flow, and DTP getting increased in the latter half of the survey. We could also check that PP concentration, which is shown as between T-P and DTP, increases with time. From this we understood that particulate phosphorus is discharged earlier and dissolved phosphorus is discharged later. In culvert outflow during the survey, T-P concentration is highest at Type A and lowest at Type B. Surface T-P concentration of Type C is highest among paddy fields. Both surface and culvert T-P concentration of type D (upland field) is higher than those of paddy fields as in the case of T-N.

3.5. Estimation of pollutant loading during non-irrigation period

Because outflow is caused by rain during non-irrigation periods, it is very important to understand the relationship between rainfall and flow rate as well as between flow rate and runoff loading. We developed a regression model for the relationship among rainfall, flow rate and loading. Table 2 shows the model equations which give flow rate by rainfall and pollutant load by flow

Table 2
Equation of *Q-R* and *L-Q* of surface (left) and culvert (right) outflow

Surface outflow:

	Q		SS		T-N	
	Q-R	r	L-Q	r	L-Q	r
Type A	$Q=0.010R^{4.13}$	0.929	$L=15.27Q^{0.09}$	0.987	$L=0.442Q^{0.95}$	0.999
Type B	$Q=0$	–	$L=0$	–	$L=0$	–
Type C	$Q=0.004R^{3.59}$	0.981	$L=10.94Q^{0.62}$	0.999	$L=0.566Q^{0.99}$	1.000
Type D	$Q=0.029R^{3.19}$	0.972	$L=725.24Q^{0.52}$	0.965	$L=15.267Q^{1.02}$	0.994
	PN		T-P		PP	
	L-Q	r	L-Q	r	L-Q	r
Type A	$L=0.265Q^{0.95}$	0.999	$L=0.110Q^{1.16}$	0.977	$L=0.029Q^{0.98}$	0.999
Type B	$L=0$	–	$L=0$	–	$L=0$	–
Type C	$L=0.235Q^{1.00}$	1.000	$L=0.603Q^{1.05}$	1.000	$L=0.118Q^{1.07}$	1.000
Type D	$L=3.167Q^{1.02}$	0.997	$L=1.688Q^{0.99}$	1.000	$L=0.755Q^{0.50}$	0.994

Culvert outflow:

	Q		SS		T-N	
	Q-R	r	L-Q	r	L-Q	r
Type A	$Q=0.193R^{1.89}$	0.801	$L=0.46Q^{1.36}$	0.920	$L=1.251Q^{0.89}$	0.989
Type B	$Q=1.158R^{2.03}$	0.831	$L=1.57Q^{1.29}$	0.912	$L=0.189Q^{1.18}$	0.921
Type C	$Q=1.240R^{1.83}$	0.773	$L=0.53Q^{1.61}$	0.946	$L=0.460Q^{1.18}$	0.921
Type D	$Q=1.530R^{1.65}$	0.601	$L=4.12Q^{1.28}$	0.947	$L=7.646Q^{0.98}$	0.998
	PN		T-P		PP	
	L-Q	r	L-Q	r	L-Q	r
Type A	$L=0.339Q^{1.10}$	0.998	$L=0.499Q^{0.93}$	0.995	$L=0.209Q^{1.06}$	0.995
Type B	$L=0.155Q^{1.16}$	0.926	$L=0.064Q^{1.11}$	0.956	$L=0.050Q^{1.09}$	0.959
Type C	$L=0.006Q^{1.80}$	0.907	$L=0.452Q^{0.94}$	0.991	$L=0.036Q^{1.25}$	0.937
Type D	$L=5.624Q^{0.99}$	0.989	$L=1.484Q^{0.97}$	0.954	$L=0.253Q^{0.85}$	0.986

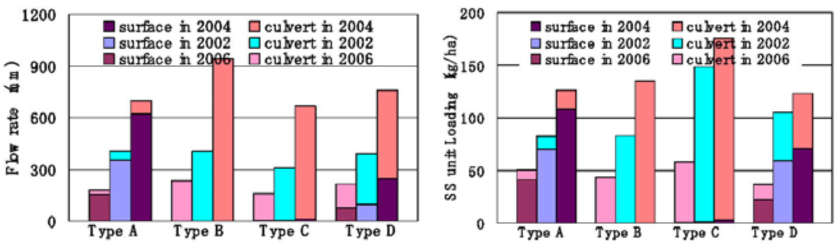

Fig. 13. Estimation *Q* and SS loading during non-irrigation period in each year.

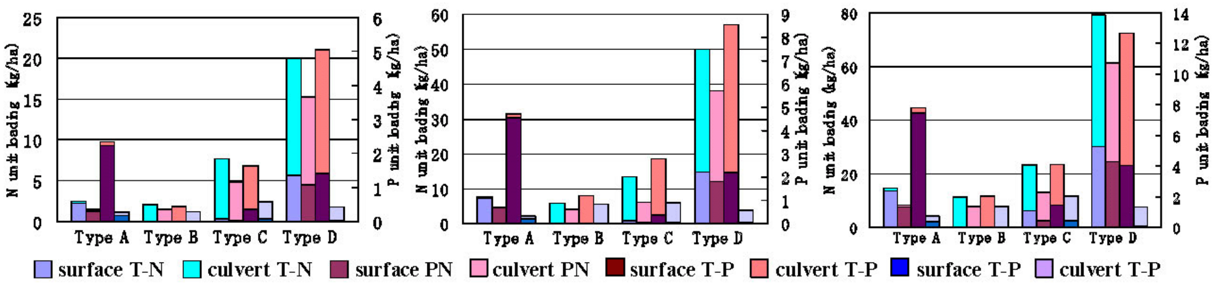

Fig. 14. Estimation N, P loading during the non-irrigation period in 2006 (L), 2002 (C), 2004 (R).

rate. We estimated the flow rate and loading from 1 September 2006 to 30 April 2007, which has less rainfall from 1 September 2002 to 30 April 2003, which has average rainfall, from 1 September 2004 to 30 April 2005, which has more rainfall using the equation. Fig. 13 shows the estimated flow rate and SS during non-irrigation period in each year.

Fig. 14 shows the estimated nitrogen and phosphorus during non-irrigation periods in 2006, 2002 and 2004. From Figs. 13 and 14 we see that runoff loading during the non-irrigation period was strongly affected by rainfall. Takeda et al. [4] surveyed loading of paddy fields during the irrigation period. He showed T-N loading was 45.7 kg/ha and T-P loading was 8.72 kg/ha. From comparing the estimated T-N, T-P loading of paddy fields during non-irrigation periods with these values, it is about 25–51% and 24–29% of the T-N and T-P loading surveyed by Takeda et al., respectively. This means that we cannot ignore runoff loading during non-irrigation periods. Also, PN loading accounted for 10–80% of T-N loading, and PP loading accounted for 10–70% of T-P. T-N and T-P loading of Type D (upland field) is very high compared with paddy fields, while SS is not.

4. Conclusions

From this study, we understood that we cannot ignore runoff loading during non-irrigation periods. We also found that the surface state of paddy fields affected runoff loading. Rice stubble and weed growth in Type A paddy fields created a difficult condition for rainfall to infiltrate into the soil. Therefore, it is hard to runoff nitrogen compounds in soil. Pollutant loading discharged from Type C paddy fields is caused by straw. Hence, we expect that if straw is not spread, pollutant loading will be reduced. We thought that surface runoff can be reduced through constructing a weir near the outlet, and culvert runoff can be reduced by control of the culvert; for example by closing the culvert before the rain and opening it gradually.

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References

[1] T. Kunimatsu, Nitrogen load runoff of watershed. Jap. Environ. Measure. Chem. Anal. Assoc., 21(11) (1994) 51–67 [in Japanese].

[2] K. Sonoda, Y. Tokuta, K. Ohashi, S. Okamoto, Y. Tanaka and R. Kitano, Report of agricultural research results in Chugoku Region, Vol. 1997, 1998, pp. 105–106 [in Japanese].

[3] T. Kunimatsu and K. Muraoka, Model Analysis of River Pollution, Gihodo Syuppan, Tokyo, 1989 [in Japanese].

[4] I. Takeda, T. Kunimatsu, S. Kobayashi and T. Maruyama, Pollutants mass balance and runoff loading of paddy field in water systems. Trans. Jap. Soc. Irrigation Drainage Rural Eng., 153 (1990) 63–72 [in Japanese].