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Effect of Tillage Management of Paddy Field on Runoff and Nutrient Losses during Non-Cropping Season

Yoon, Kwang Sik* · Choi, Jin Kyu · Im Sang Jun*****

**Department of Bio-Systems and Agricultural Engineering (Inst. of Ag. Sci. and Tech.), Chonnam National University, Kwangju 500-757 Korea*

***Department of Agricultural Engineering, (Inst. of Ag. Sci. and Tech.) Chonbuk National University, Chonju 561-756 Korea*

****Biological Systems Engineering Department, Virginia Tech, Blacksburg, VA, 24061, USA*

Abstract □ Runoff, sediments and nutrient losses were studied under different patterns of paddy field management: (1) fall and spring plowing (Plowing); (2) fall plowing for half of plot and spring plowing (Semi-plowing); (3) no-till for fall and spring plowing (Un-plowing) during the non-cropping period in the southern Korea for two years. The runoff amount and initial abstract were significantly affected by plowing practices. Un-plowing plot showed the highest runoff amount among treatments. The concentrations of sediment from Plowing plot were much higher than those from Un-plowing plot, especially after fall plowing. Sediment losses from Plowing plot were 25% more than those from Un-plowing plot. There was significant difference in nutrient losses via runoff water and sediment according to plowing practice. Two-year average of losses of N from paddy field during non-cropping period were 9.42 kg ha^{-1}, 8.17 kg ha^{-1}, and 7.76 kg ha^{-1} for Un-plowing, Semi-plowing, and Plowing plot, respectively, while losses of P were 0.64 kg ha^{-1}, 0.58 kg ha^{-1}, and 0.58 kg ha^{-1} for each tillage system. Losses of total-N, ammonia-N, nitrate-N, Total-P from Un-plowing plot was larger than those from Plowing and Semi-plowing plots during study period.

Keywords □ Tillage, Water quality, Rice paddy field, Management

I. Introduction

In Korea, paddy field occupies more than 60 % of the total agricultural lands. The nutrient balance in paddy field affects the water environment. It is well accepted that pollutant outflows from paddy fields are much less than those from upland fields (Kim and Cho, 1995). Furthermore, some paddies are able to remove of pollutants such as nitrogen and phosphorus (Kunimatsu, 1983; Tabuchi and Takamura, 1985). It is because paddy fields can provide favorable conditions for nitrification and denitrification as the soil has both aerobic upper layer and anaerobic lower layer under flooded conditions. However, several studies have revealed that rice paddy fields contributed large amount of the pollutant loads to the lake (Davenport et al., 1996; Brady, 1996; Shell, 1996). However, studies on runoff loading of nutrients from paddy fields have been focused on the paddy rice cultivation period. (Kim and Cho, 1995; Shin and Kwun, 1990 ; Lee et al., 1990 ; Takeda et *al.*, 1997 ; Kunimatsu, 1983).

Tillage practices increase soil fertility by enhancing decomposition of organic matters and mineral weathering during the non-cropping period (Yoo et. al., 1997). If runoff by rainfall is not carefully managed after tillage in paddy field, the field can be source of agricultural non-point pollution. Especially, when high rainfall runoff occurs immediately after plowing, significant losses of soluble and sediment-bound nutrients might occur. According to a number of researches related plowing practice of arable lands (Chescheir et. al., 1991; Seta et. al., 1993; Sharpley et. al., 1985), less plowing is desirable to keep nutrients in soil.

The objective of this study was to compare the effects of three different paddy field management {fall and spring plowing (Plowing), fall plowing for half of plot and spring plowing (Semi-plowing), no-till for fall and spring plowing (Un-plowing)} on surface runoff, sediments and nutrient losses under natural rainfall conditions during the non-cropping period in the southern Korea.

II. Procedures

1. Experimental paddy field management

The experimental field locates in Maryeong-myeon, Jinan-gun, Jeonbuk, Korea. The experimental field was divided into three 5,000 m^2 (100 m $\times$50 m) plots which represent treatment of three different paddy field management {fall and spring plowing (Plowing), fall plowing for half of plot and spring plowing (Semi-plowing), no-till for fall and spring plowing (Un-plowing)}. The paddy soil was Jisan soil series (SiL; fine loamy, mixed mesic family of Fluventic Haplaquepts). Non-cropping period of paddy field is between October and April of the next year. Field monitoring was carried out during non-cropping period of two years (from October 1, 1997 to April 30, 1998 and from October 1, 1998 to April 30, 1999).

The record of tillage practice and agricultural managements are summarized in Table 1. All plots were applied by rice straw after the harvest on September 29, 1997. In the Plowing plot, fall plowing was conducted on October 5, 1997 and the spring plowing was conducted on April 25, 1998. In the Semi-plowing plot, a half of plot was plowed on October 5, 1997 (fall plowing) and the rest of plot was plowed on March 20, 1998 (1^{st} spring plowing). The second spring plowing was done on April 25, 1998. Rice straw was applied on the Un-plowing plot after the harvest on September 29, 1997 and paddy field was kept under no-till conditions. The next spring, the first and second spring plowing were conducted on March 20 and April 25, 1998.

The experimental field was plowed before transplanting on May 11, 1998 and maintained

Table 1 The record of agricultural management on experimental paddy fields

Treatment date	Agricultural management		Remark
Year 1 (1997-1998)	Sep 29, 1997	harvest	
Plowing	Oct 5, 1997	fall plowing	whole plot
	Apr 25, 1998	spring plowing	whole plot
Semi-plowing	Oct 5, 1997	fall plowing	half of plot
	Mar 20, 1998	1st spring plowing	rest half of plot
	Apr 25, 1998	2nd spring plowing	whole plot
Un-plowing	Mar 20, 1998	1st spring plowing	whole plot
	Apr 25, 1998	2nd spring plowing	whole plot
Year 2 (1998-1999)	May 11, 1998	basal fertilization	95 kg N ha^{-1}, 30 kg P_2O_5 ha^{-1}
	May 26, 1998	Rice transplanting	
	Jun 13, 1998	tillering fertilization	50 kg N ha^{-1}
	Jul 24, 1998	panicle fertilization	30 kg N ha^{-1}
	Oct 3, 1998	harvest	
Plowing	Oct 9, 1998	fall plowing	whole plot
	Apr 29, 1999	spring plowing	whole plot
Semi-plowing	Oct 9, 1998	fall plowing	half of plot
	Mar 26, 1999	1st spring plowing	rest half of plot
	Apr 29, 1999	2nd spring plowing	whole plot
Un-plowing	Mar 26, 1999	1st spring plowing	whole plot
	Apr 29, 1999	2nd spring plowing	whole plot

under flooding condition. Rice was transplanted (transplanting distance, 15 × 30 cm, three seedlings) by machine in the experimental field on May 26, 1998 and harvested on October 9. Same pattern of paddy field management was conducted for next non-cropping period. Fall plowing was conducted on October 9, 1998 and the first and second spring plowing was conducted on March 26 and April 29, 1999, respectively.

The application rate of chemical fertilizer during the present study was as follows: In the first year, basal fertilizer (107 kg N ha^{-1} and 36 kg P_2O_5 ha^{-1}) was applied on May 10, 1997. The field was amended with tillering fertilizer (50 kg N ha^{-1}) on June 10, 1997 and with panicle fertilizer (30 kg N ha^{-1}) on July 20, 1997. And then it was applied with silicate fertilizer (500 kg ha^{-1}) on March 18, 1998. In the second year, basal fertilizer (95 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1}) was applied on May 11, 1998. The field was amended with tillering fertilizer (50 kg N ha^{-1}) on June 13, 1998 and with panicle fertilizer (30 kg N ha^{-1}) on July 24, 1998.

2. Rainfall and flow measurements

A set of rain gauge, water level gauges, and weir were installed at the experimental field (Fig. 1). A rain gauge was placed beside the irrigation canal of the experimental field for measurement of daily rainfall. The rectangular weir with a width of 30 cm was installed at the bottom of paddy field to measure surface runoff. A water-level gauge was also placed to measure the

Fig. 1 Equipment installed at the experimental plot

flow depth in paddy field. All measurements conducted from October 1, 1997 to April 30, 1998 and from October 1, 1998 to April 30, 1999.

3. Samplings and sample analyses

The samples of rainfall were taken for each event. Samples of runoff water were taken before, during, and after peak runoff for each event. The soil samples of paddy field were taken at two-week intervals. All samples taken for chemical analyses were stored in a refrigerator soon after collection until analyses at 0 to 4 ℃. The total P content of surface soil and sediments was determined by digestion with perchloric acid (O' Connor and Syers, 1975). Available P was determined by the Bray-1 procedure (Bray and Kurtz, 1945). Total N was determined by a semimicro-kjeldahl procedure and nitrate-N by 2M KCl extraction and microdiffusion (Bremner, 1965). Total-N, ammonia-N, and nitrate-N in runoff water were measured by automated procedures described in FWPCA methods for chemical analysis of water and wastes (USDI, 1971). Suspended sediment concentration of runoff water was determined in duplicate as the difference in weights of 500 mL aliquots of unfiltered and filtered samples after evaporation to dryness. Total P was determined similarly on samples following a complete perchloric acid digestion of unfiltered samples. Soluble P concentration was determined colorimetrically on filtered samples (0.45?m, millex-ha, Millipore) by the method of Murphy and Riley (1962).

Ⅲ. Results and Discussion

1. Rainfall and surface runoff

Characteristics of rainfall and surface runoff during non-cropping period in the study area were not much different between year 1997 and 1998. Total rainfall amounts of study period of 1997 and 1998 were 368 mm and 323 mm, respectively. Total 22 surface runoff events occurred during study period.

The measured runoff of the Un-plowing, Semi-plowing, and Plowing plot was 259.5 mm, 203.3 mm, and 177.4 mm for the non-cropping period of 1st year (1997 to 1998), respectively. For the non-cropping period of 2nd year (1998 to 1999), observed runoff of each plot was 189.6 mm, 169.3 mm, and 162.7 mm, respectively (Table 2). Un-plowing plot showed the highest runoff for the both years. It was considered that fall plowing, which developed depression and macro-pore, might increase surface storage and permeability of paddy field, eventually reduced runoff amount.

The initial abstraction, which is the rainfall, lost before runoff generation was also determined by comparing rainfall record and runoff hydrograph. For the non-cropping period of 1st

Table 2 Observed rainfall, runoff, and initial abstraction of each event from the experimental paddy field during a non-cropping season

Event No.	Date	Rainfall (mm)	Runoff amount (mm)			Initial abstraction (mm)			Previous rainfall (mm)	Days of drought
			U[a]	S[b]	P[c]	U[a]	S[b]	P[c]		
1-01	13-Nov-97	56.7	44.0	32.7	22.7	11.0	18.4	29.0	2.4	43
1-02	18-Nov-97	11.5	6.6	1.0	1.0	3.0	6.9	8.0	56.7	2
1-03	26-Nov-97	18.8	12.5	5.6	3.6	4.2	11.4	11.6	16.9	3
1-04	30-Nov-97	24.5	19.0	13.2	12.0	3.4	6.9	9.1	18.8	3
1-05	08-Dec-97	41.1	29.1	19.6	11.0	8.9	19.0	26.4	24.5	7
1-06	21-Feb-98	16.5	2.6	3.8	1.0	11.2	11.2	17.3	47.8	71
1-07	21-Mar-98	34.5	22.0	15.0	15.0	10.3	15.4	17.0	27.7	23
1-08	03-Apr-98	40.5	34.7	32.2	31.9	4.3	4.9	5.9	41.6	10
1-09	07-Apr-98	20.0	13.0	13.0	13.0	4.3	5.0	5.2	40.5	3
1-10	14-Apr-98	57.3	47.0	42.7	40.2	4.7	5.5	3.6	27.6	5
1-11	25-Apr-98	34.5	29.0	24.5	26.0	3.0	7.4	6.0	65.7	8
		355.9*	259.5*	203.3*	177.4*	6.1**	10.2**	12.6**		
2-01	13-Oct-98	43.0	31.2	25.0	19.0	10.5	17.0	22.4	43.2	15
2-02	31-Oct-98	11.2	2.5	2.0	2.2	5.0	7.0	6.0	45.5	16
2-03	05-Nov-98	16.9	7.2	6.0	6.0	3.7	5.0	5.9	11.2	4
2-04	11-Nov-98	18.8	11.0	9.5	9.0	6.0	6.9	8.3	16.9	4
2-05	16-Nov-98	61.4	44.1	42.5	41.5	15.0	20.0	23.0	18.8	4
2-06	25-Nov-99	12.0	5.6	5.0	5.0	3.8	5.9	4.7	61.4	6
2-07	15-Mar-99	43.0	23.2	19.8	20.0	19.2	22.8	23.0	36.4	103
2-08	02-Apr-99	11.2	2.5	2.0	2.0	7.0	7.2	10.5	43.0	17
2-09	07-Apr-99	16.9	7.2	6.0	6.0	6.2	7.8	10.5	11.2	4
2-10	13-Apr-99	18.8	11.0	11.0	11.0	12.0	12.0	14.5	16.9	4
2-11	18-Apr-99	61.4	44.1	40.5	41.0	14.3	13.9	16.9	18.8	4
		314.6*	189.6*	169.3*	162.7*	9.3**	11.2**	13.2**		

[a]Un-plowing, [b]Semi-plowing, [c]Plowing, *total, **average.

year, initial abstraction of the Un-plowing, Semi-plowing, and Plowing plots ranged 3.0 to 11.2 mm (average = 6.1 mm), 4.9 to 19.0 mm (average = 10.2 mm), and 3.6 to 29.0 mm (average = 12.6 mm), respectively. For the non-cropping period of 2nd year, the ranges of initial abstraction were 3.7 to 19.2 mm (average = 9.3 mm), 3.9 to 22.8 mm (average = 11.2 mm), and 4.7 to 23.0 mm (average = 13.2 mm) for Un-plowing, Semi- plowing, and Plowing plot, respectively. The runoff and initial abstraction were significantly affected by plowing practices ($P < 0.01$).

2. Changes in the concentrations of nutrients in runoff water

The concentration changes of nitrogen and phosphorous sources in runoff water were discussed and shown in the Fig. 2- Fig. 5. Field management methods did not much affect the concentration of Total-N and Total-P in runoff during non-cropping period of 1st year. Decomposition of applied paddy straw attributed to increased concentration initially, but the concentrations decreased gradually due to losses by several runoff events during March and April. However, the concentrations of ammonia-N and

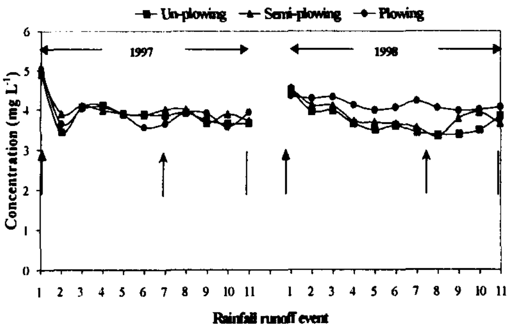

Fig. 2 Concentration changes of Total-N in runoff water from paddy fields.(↑ fall plowing; ↑ 1st spring plowing; | 2nd spring plowing)

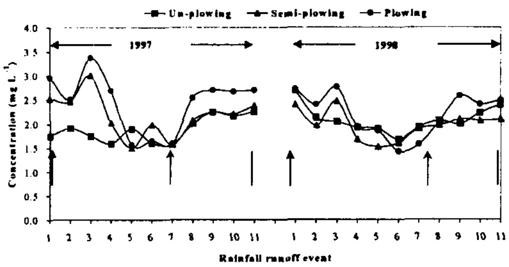

Fig. 3 Concentration changes of Ammonia-N in runoff water from paddy fields.(↑ fall plowing; ↑ 1st spring plowing; | 2nd spring plowing)

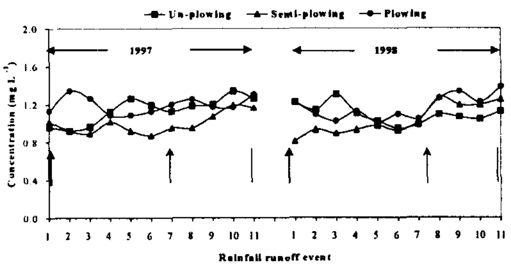

Fig. 4 Concentration changes of Nitrate-N in runoff water from paddy fields.(↑ fall plowing; ↑ 1st spring plowing; | 2nd spring plowing)

nitrate-N were increased by warm ground temperature and active microbial activity during March and April (Fig. 3 - Fig. 4). Ammonia concentrations of Plowing and Semi-plowing plots were higher than those of Un-plowing plot

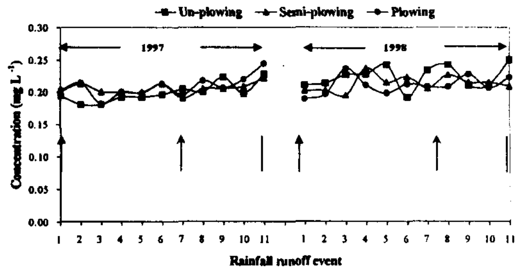

Fig. 5 Concentration changes of Total-P in runoff water from paddy fields.(↑ fall plowing; ↑ 1st spring plowing; | 2nd spring plowing)

after fall tillage. Total-N concentration of Plowing treatment showed the highest concentration among treatments in the study period of 2nd year. Fall plowing effect on ammonia was apparent 1st year. In general, the concentrations of Ortho-P were below detectable level.

Kunimatsu *et al.* (1994) reported that the concentrations of total-N, ammonia-N, and nitrate- N in runoff from paddy field during a non-cropping period were 0.96 to 5.40 mg L^{-1}, 0.01 to 0.12 mg L^{-1}, and 0.02 to 2.90 mg L^{-1}, respectively. The magnitude of concentrations between ammonia-N, and nitrate-N are different from the results of this study. And they found that concentration of total P in runoff water was 0.19 to 1.41 mg L^{-1}, which was higher than the results of this study. Therefore, it was found that nutrient concentrations in runoff would be varied according to paddy filed management, soil, type and amounts of applied chemical fertilizer, and characteristics of climate during non-cropping period.

3. Changes in concentrations of sediment in runoff water

The sediment in runoff of the Plowing plot showed the highest concentration while the

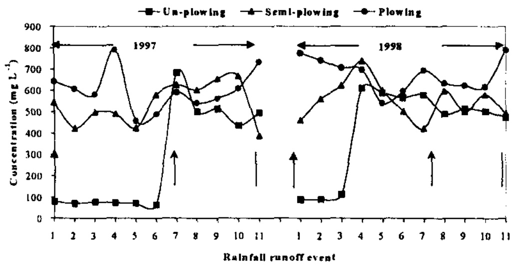

Fig. 6 Concentration changes of sediment in runoff from paddy fields.(↑ fall plowing; ↑ 1st spring plowing; | 2nd spring plowing)

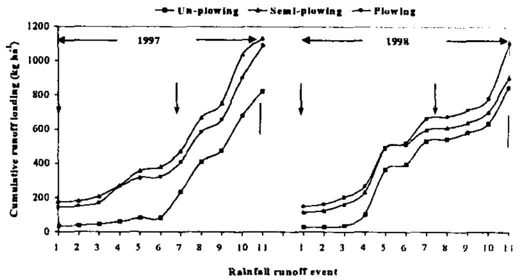

Fig. 7 Cumulative sediment losses from paddy fields according to tillage practices during non-cropping period.(↑ fall plowing; ↑ 1st spring plowing; | 2nd spring plowing)

lowest concentrations were observed in the Un-plowing plot (Fig. 6). In the Un-plowing plot, the concentration was 60 to 100 mg L^{-1} during wintertime but it significantly increased to 500 to 600 mg L^{-1} after March 20, 1998 when the spring plowing was made. In the Semi-plowing plot, the concentration was 400 to 500 mg L^{-1} in early of October when the first plowing was conducted on half area of paddy plot and then increased to 500 to 600 mg L^{-1} from March 20, 1998 when the plowing of the rest of paddy field was made. In the Plowing plot, the concentration had been 650 to 700 mg L^{-1} since early October when the first plowing was made, and then gradually decreased. After the second plowing on April 25th, it increased again. Kunimatsu *et al.* (1994) reported that the concentration of sediment in runoff water was 10 to 20 mg L^{-1} before a plowing and 600 mg L^{-1} after a plowing during non-cropping period in paddy fields.

4. Sediment losses from paddy field according to plowing practices

Sediment losses were computed as the product of runoff volume and the corresponding concentration of composite samples. Two-year average showed that sediment losses from paddy field during non-cropping period were 834 kg ha^{-1}, 1016 kg ha^{-1}, and 1098 kg ha^{-1} for Un-plowing, Semi-plowing, and Plowing plot, respectively (Fig. 7). Plowing plot showed 25 % more sediment losses compared to those of Un-plowing plot. However, there was no significant difference between Semi-plowing and Plowing plot ($P > 0.05$). This result attributed to larger runoff amount from Semi-plowing plot than Plowing plot even though concentrations of sediment from Plowing plot were higher than those from Semi-plowing plot after fall plowing. Another reason for the result is that concentration differences between Plowing plot and Semi-plowing plot was getting reduced after spring plowing. On the other hand, Yoon et al.(2002) reported that soil losses of same paddy plot during cropping period were 1,221~1,274 kg ha^{-1}.

Most of studies on soil erosion in arable lands have been conducted on upland patch slopes in Korea (Kim and Miller, 1995; Jung *et al.* 1995; Kim, 1997). Soil losses from paddy fields have been ignored since paddy fields were managed under flooding conditions and flat slope.

However, the results of this study recommend further intensive studies on soil erosion in non-slope paddy field.

5. Nutrients losses from paddy field according to plowing practices

Nutrients losses were computed as the product of runoff volume and the corresponding concentration of composite samples. Figures 8 to 12 show cumulative nutrient losses from paddy field during non-cropping period. Two-year average of losses of N (soluble + sediment-bound) from

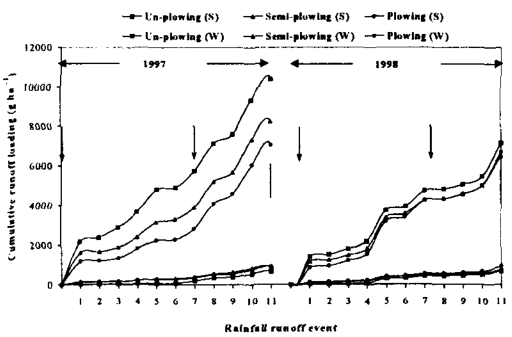

Fig. 8 Cumulative Total-N losses via runoff(W) and sediment (S) from paddy field.(↑ fall plowing; ↑ 1st spring plowing; | 2nd spring plowing)

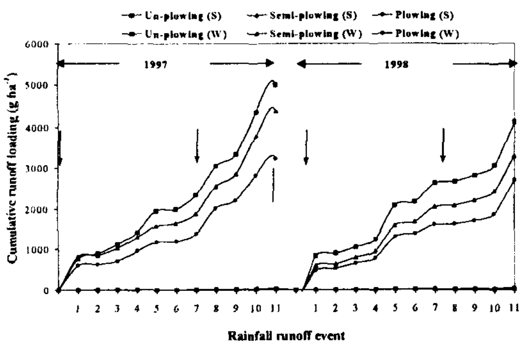

Fig. 9 Cumulative Ammonia-N losses via runoff(W) and sediment (S) from paddy field.(↑ fall plowing; ↑ 1st spring plowing; | 2nd spring plowing)

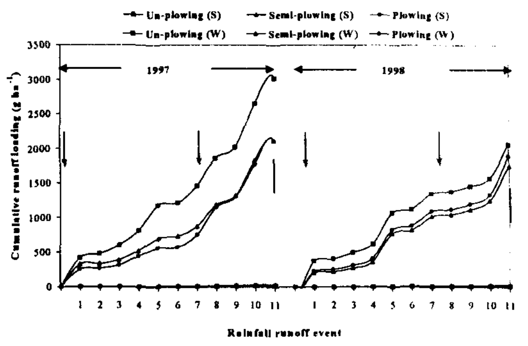

Fig. 10 Cumulative Nitrate-N losses via runoff(W) and sediment (S) from paddy field.(↑ fall plowing; ↑ 1st spring plowing; | 2nd spring plowing)

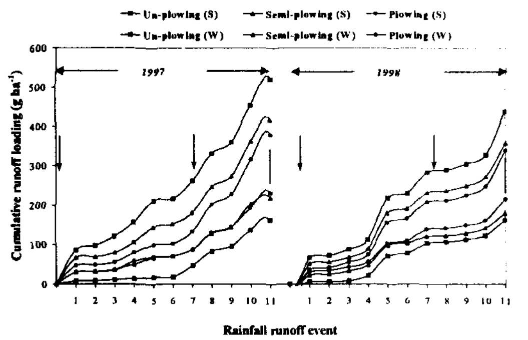

Fig. 11 Cumulative Total-P losses via runoff(W) and sediment (S) from paddy field.(↑ fall plowing; ↑ 1st spring plowing; | 2nd spring plowing)

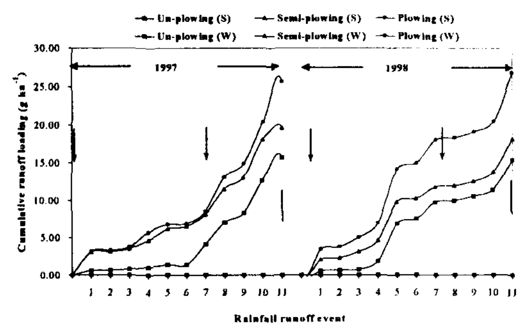

Fig. 12 Cumulative Ortho-P losses by runoff(W) and sediment (S) from paddy field.(↑ fall plowing; ↑ 1st spring plowing; | 2nd spring plowing)

paddy field during non-cropping period were 9.42 kg ha^{-1}, 8.17 kg ha^{-1}, and 7.76 kg ha^{-1} for Un-plowing, Semi-plowing, and Plowing plot, respectively. On the other hand, losses of P (soluble + sediment-bound) from paddy field during non-cropping period were 0.64 kg ha^{-1}, 0.58 kg ha^{-1}, and 0.58 kg ha^{-1} for Un-plowing, Semi-plowing, and Plowing plot, respectively.

Nutrient losses from paddy field during non-cropping period have been ignored since rainfall amount is less than one fifth of cropping period in Korea. However, this study revealed that significant amount of nutrient were lost during non-cropping period from paddy field. Kunimatsu et al. (1994) reported that 14.41kg ha^{-1} of total-N and 3.37kg ha^{-1} of total-P were lost from paddy field during non-cropping period in Japan. Takeda et al. (1991) found that 23.76 kg ha^{-1} of Total-N and 1.22 kg ha^{-1} Total-P were lost from paddy field during non-cropping period in other area of Japan.

Losses of Total-N, ammonia-N, nitrate-N, Total-P from Un-plowing plot were larger than Plowing and Semi-plowing plots during study period. Even though concentrations of nutrient constituents were higher from Plowing plot than those of Un-plowing plot, larger runoff amount from Un-plowing plot account for the observed results.

When the losses of nutrients from paddy field during non-cropping period were separated into soluble and sediment-bound, the majority of N sources that flowed into streams were contributed by soluble form. Regardless of fall plowing methods, N losses from paddy field as sediment-bound form was less than 10 % of N lost. For the case of total P, about 68 to 75 % of P was lost by runoff water and the rest of them were lost by sediment according to tillage practices.

Paddy field is blocked by levee to maintain flooding conditions. The height of outlet for drainage is managed lower than that of levee. Therefore, levee and outlet of paddy field are comparable to reservoir dike and spillway. The amount of runoff is influenced by the volume available between the water surface and the sill of the outlet just before the storm event as well as soil permeability and water management practices employed during storm. Usually, farmers lower drainage outlet up to ground level to achieve full drainage for machine operation at the time of harvest and do not care about outlet control until next year spring. The study results showed that about 40 to 60 % of nutrients losses of non-cropping period were occurred during March and April. To maintain soil moisture and minimize sediment and nutrient losses from paddy field during non-cropping period, drainage outlet control even non-cropping period is desirable.

IV. Summary and Conclusions

Three tillage systems of paddy field were studied for the non-cropping period to determine their effects on runoff, sediments and plant nutrient losses under natural rainfall conditions in the southern Korea for two years. Three tillage systems were (1) fall and spring plowing (Plowing); (2) fall plowing for half of plot and spring plowing (Semi-plowing); (3) no-till for fall and spring plowing (Un-plowing) during the non-cropping period.

Un-plowing plot showed the highest runoff potential among treatments. The concentrations of sediment from Plowing plot were much higher than those from Un-plowing plot, especially after fall plowing. Two-year average showed that sediment losses from paddy field during non-cropping period were 834 kg ha^{-1}, 1016 kg ha^{-1}, and 1098 kg ha^{-1} for Un-plowing, Semi-plowing, and Plowing plot, respectively. Sediment losses from Plowing plot were 25% more than those from Un-plowing plot.

There was some difference in nutrient losses via runoff water and sediment according to plowing practices. Two-year average of losses of N from paddy field during non-cropping period were 9.42 kg ha^{-1}, 8.17 kg ha^{-1}, and 7.76 kg ha^{-1} for Un-plowing, Semi-plowing, and Plowing plot, respectively, while losses of P were 0.64 kg ha^{-1}, 0.58 kg ha^{-1}, and 0.58 kg ha^{-1} for each tillage system. Losses of total-N, ammonia-N, nitrate-N, Total-P from Un-plowing plot was larger than Plowing and Semi-plowing plot during study period. Even though concentrations of nutrient constituents were higher from Plowing and Semi-plowing plots than those of Un-plowing plot, larger runoff amount from Un-plowing plot account for the observed results. Sediment and total-P losses from Semi-plowing plot were close to those of Plowing plot. Less than 10% of N lost from paddy field during non-cropping period was attributed to sediment in runoff while about 25-38% of P lost was sediment-bound form according to tillage systems. No-till practice during fall (Un-plowing plot) effectively reduced sediment losses but generated more runoff and subsequent more nutrient losses than plowed conditions. Nutrient losses from paddy during non-cropping period have been ignored in many previous studies, but this study revealed that significant amount of nutrient were lost during non-cropping period from paddy field.

References

1. Brady, D.J., 1996. The watershed protection approach. *Water Science Technology*. 33:17-25.
2. Bray, R.H., Kurtz, L.T., 1945. Determination of total, organic and available forms of phosphorus in soils. *Soil Science* 59: 39-45.
3. Bremner, J.M., 1965. Methods of soil analysis, Part 2. *Agronomy* 9: 1149-1178.
4. Chescheir, G.M., Gilliam, J.M., Skags, R.W., Broadhead, R.G., 1991. Nutrient and sediment removal in forested wetlands receiving pumped agricultural drainage water. *Wetlands* 11: 87-103.
5. Choi, J.K., Koo, J.W., Son, J.G., Yoon, K.S., Cho, J.Y., 2001. Nutrient Balance and Runoff Loading During Cropping period from a Paddy Plot in Maryeong Irrigation District. *Journal of the Korean Society of Agricultural Engineers* 43(5): 153-162. (in Korean)
6. Davenport, T.E., Phillips, N.J., Kirschner, B.A., Kirschner, L.T., 1996. The watershed protection approach. *Water Science Technology* 33: 23-32.
7. Jung, P.K., Lee, K.S., 1995. Annual report of agricultural research, Rural Development Administration, Suwon, Korea.
8. Kim, B.Y., Cho, J.K., 1995. Nutrient effluence by the outflowing water from the paddy field during rice growing season. *Korean Committee Irrigation and Drainage* 2:150-156. (in Korean)
9. Kim, K.H., Miller, W.P., 1995. Soil detachment by single and multiple waterdrops. *Agricultural Chemistry and Biotechnology* 38:151-156.
10. Kim, S.J., 1997. Physically based soil water erosion model. *Journal of the Korean Society of Agricultural Engineers* 39: 82-89. (in Korean)
11. Kunimatsu, T., 1983. Crop land recycling of nutrients and purification function in paddy fields. Research Report of Lake Biwa Research Institution 2:28-35.
12. Kunimatsu, T., Rong, L., Sudo, M., Takeda, I.,

1994. Runoff loadings of materials causing water pollution from a paddy field during a non-planting period. *Trans. JSIDRE* 170:45-54.

13. Lee, C.K., Lee, K.C., Lee, H.J., Rhu, H.I., Lee, M.H., Jun, S.H., Kim, S.S., Kim, S.K., Kim, S.D., 1990. Studies on good agricultural practice in the use of fertilizer and agrochemical. *Report of Korean Environmental Research* 12:293-310. (in Korean)
14. Murphy J and Riley JP, 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta* 27: 31-36.
15. O' Connor, P.W., Syers, J.K., 1975. Comparison of methods for the determination of total phosphorus in waters containing particulate material. *Journal of Environmental Quality* 4: 347-350.
16. Seta, A.K., Blevins, R.L., Frye, W.W., Barfield, W., 1993. Reducing soil erosion and agricultural chemical losses with conservation tillage. *Journal of Environmental Quality* 24:106-111.
17. Sharpley, A.N., Smith, S.J., Berg, W.A., Williams, J.R., 1985. Nutrient runoff losses as predicted by annual and monthly soil sampling. *Journal of Environmental Quality* 14:354-359.
18. Shell, S.E., 1996. The uncertain future of clean water act agricultural pollution exemption after concerned area residents for the environment. *Land Water Review* 31:113-120.
19. Shin, D.S., Kwun, S.K., 1990. Input output of nitrogen and phosphorus in a paddy field. *Korean Journal of Environmental Agriculture* 9:133-141. (in Korean)
20. Tabuchi, T., Takamura, Y., 1985. Nitrogen and phosphorus outflow from catchment area. Tokyo University Press, Tokyo
21. Takeda, I., Fukushima, A., Tanaka, R., 1997. Non-point pollutant reduction in a paddy-field watershed using a circular irrigation system. *Water Research* 31:2685-2692.
22. Takeda, I., Kunimatsu, T., Kobayshi, S., Maruyama, T., 1991. Pollutant balance of a paddy field area and it' s loading in the water system. *Trans. JSIDRE* 153: 63-72.
23. US Department of Interior, 1971. FWPCA methods for chemical analysis of water wastes. National Environmental Research Center, Ohio.
24. Yoo, C.H., Shin, B.W., Jeong, J.H., Han, S.S., Kim, S.J., Han, S.S., 1997. Changes of soil physico-chemical properties under different tillages of paddy soil. *Journal of Korean Society of Soil Science and Fertilizer*. 30:140-145. (in Korean)
25. Yoon, K.S., Cho, J.G., Han, K.H., Choi, J.K., Son, J.G, Cho, J.Y., 2002. Sediment Losses from a Paddy Plot during Cropping Period. *Journal of Korean Society of Rural Planning* 8(1):60-68.