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ARTICLE

Effect of surface cover on the reduction of runoff and agricultural NPS pollution from upland fields

Min Hwan Shin · Chul Hee Won · Jeong Ryeol Jang · Yong Hun Choi · Yong Chul Shin · Kyoung Jae Lim · Joong Dae Choi

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Abstract In this study, two types of simulations were performed. First, indoor rainfall simulation revealed that runoff ratio (0–63.3 %) decreased dramatically with surface cover, compared with no surface cover condition (55–85.3 %), and sediment load and concentration also decreased. With additions of PAM, sawdust, and rice hull to rice straw mat, the runoff ratio decreased to 52.8, 36.6, and 53.2 %, compared with only rice straw mat condition (runoff ratio of 63.3 %). When gypsum was added, no runoff was observed in case of rainfall intensity of 30 mm/h. Under 60 mm/h rainfall condition, 50 % or more runoff reduction was observed. These could be explained in that surface cover reduces detachment of soil particles and keeps infiltration rate by reducing surface sealing with detached soil particle which could happen under non-surface cover condition. Second, when rice straw mat was applied to soybean field, no runoff was observed until rainfall intensity of 5.8 mm/h or greater, while runoff was observed with rainfall intensity of 1.5 mm/h at no surface covered soybean field. In addition, 89.7–99.4 % of pollutant reductions were observed with rice straw mat at the soybean field. When rice straw mat with additions of wood shaves was applied to Chinese cabbage and radish fields, 4.3–75.8 % of runoff reductions and 28–80.8 % of pollutant reductions were observed. In case of Chinese cabbage, 122.1 % yield increase was observed and 153.4 % yield increase in case of radish.

Keywords Surface cover · Runoff · Water quality · NPS pollution · Upland

M. H. Shin · C. H. Won · Y. H. Choi · K. J. Lim · J. D. Choi (✉)
Department of Regional Infrastructures Engineering, Kangwon National University, Chuncheon, Korea
e-mail: jdchoi@kangwon.ac.kr

M. H. Shin
e-mail: uv2000wind@nate.com

C. H. Won
e-mail: chwon@kangwon.ac.kr

Y. H. Choi
e-mail: tlemjin@nate.com

K. J. Lim
e-mail: kjlim@kangwon.ac.kr

J. R. Jang
Rural Research Institute, Korea Rural Community Corporation, Ansan, Korea
e-mail: wgjang@ekr.or.kr

Y. C. Shin
Department of Biological and Agricultural Engineering, Texas A&M University, 2177 TAMU, 201 Scoates Hall, College Station, TX 77843, USA
e-mail: ycshin@tamu.edu

Introduction

Pollutants flowing into streams could be classified as either point source or non-point source pollutant. In recent years, significant amounts of point source pollutants have been controlled with sewer system and waste water treatment facilities. However, non-point source pollutants from agricultural areas have been still causing various negative impacts on receiving water bodies. This is because of most of pollutants from agricultural areas are generated during monsoon period or intensive storm events. According to the study by Shin et al. (2011a), rainfall events of 50–100 mm are comprising of 23.8 % of yearly average precipitation of 1,307 mm at study area, Chuncheon, Korea and these intensive rainfall events or more severe ones (over 100 mm storm events) are causing most non-point source pollutants at agricultural areas. Especially pollutants from steep-sloping agricultural fields are increasing these days to maximize crop production without appropriate management practices to keep water quality. Thus, site-specific best management practices for agricultural areas should be applied to reduce agricultural non-point source pollutants. It has been known that precipitation, rainfall intensity, soil properties, crop, tillage, surface cover, runoff ratio, and slope are major factors affecting soil erosion from agricultural fields (Choi et al. 2000; Wischmeier and Smith 1978).

Fundamental studies to describe the relationship between rainfall, infiltration, and runoff through rainfall simulation in laboratories were conducted by many researchers (Wilson et al. 2004; Grace et al. 1998). Field experimental tests through different tillage treatments including reduced tillage and no-till practices also were carried out by many researchers (Meyer et al. 1999; Dabney et al. 2004; Ghidey and Alberts 1997; Gale et al. 1993; Mamo et al. 2006). Soil surface protection by either crop residue cover or no-till practice was proven to be one of the best management practices (BMPs) by the studies and practical applications. It is because the pores in the soil surface are protected from clogging by small soil and organic particles produced by raindrop impact and sheet flow and therefore, infiltration is not seriously reduced or rather increased in no-till field in general. Raindrop impacts on bare and disturbed soil areas can produce soil erosion up to 225 ton/ha (USDT 1995) and the eroded particles are the main source of the clogging.

However, BMPs and technologies to control soil erosion and sediment discharges in the alpine regions, with steep slope and intensive rainfall events compared with conventional agricultural field, have not been investigated well both theoretically and experimentally in Korea. Agricultural practices and land uses in the alpine regions in Korea are quite intensive. Cereal crops are not preferred but vegetable crops such as potato, radish, and Chinese cabbage are mostly cultivated as primary income to the farmers at that area. Soil surface is completely disturbed by conventional and intensive tillage and exposed without any cover material until the crop canopy develops. And in fact, rainfall season begins before the crops develop full canopy and serious soil erosion and sediment discharges occur during the season. It is very important to protect the soil surface from rain drop impacts and keep the infiltration rate as high as possible by covering the surface with protective materials such as crop residues or straw mat (Jordan et al. 2010; Pote et al. 2004). Because vegetable crops do not leave residues, the soil surface needs to be covered with imported material from other agricultural areas such as rice straw. Transporting, handling, and spreading of the straw over wide fields are very difficult if it is not woven. Woven straw mat could be a good material to protect the soil surface and maintain infiltration if it is timely used and properly managed. It also is important to persuade government people and farmers to support and adopt rice straw mat in their farming practices to dramatically cut down muddy runoff from their sandy soil fields. However, effect of rice straw mats and other residue covers on runoff from alpine sandy soil fields has been investigated by several researchers. According to the study by Shin et al. (2011b), a series of rainfall simulation with a stationary rainfall simulator system developed by Virginia Tech was conducted on a 28 % steep-sloped runoff plots. Four rainfall simulations were conducted with rainfall intensity of 31.1, 36.9, 40.6, and 44.4 mm/h at 5 × 30 m plots. In runoff plot simulation, runoff ratios of 57–76 % were observed with rice straw mat with additions of PAM, sawdust, and rice hull. Reduction in runoff ratio resulted in less sediment load (reductions of 85.9–100 %). However, no field application studies have been performed in Korea to evaluate effects of various surface cover.

Therefore, the objective of the study was to investigate the effect of rice straw mat, rice straw mat with PAM, sawdust, wood shaves, rice hull, and gypsum addition on surface runoff and sediment discharge in field scale experiments. The results could be used as the basis for the development of BMPs and policies that could help reduce muddy runoff and improve water quality at the watershed.

Materials and methods

Two types of experiments, indoor rainfall simulation from 2006 to 2010 and field application experiments, were performed to evaluate effects on reductions of runoff and pollutant loads of various surface covers.

Indoor rainfall simulation

A series of indoor rainfall simulations was performed by using rectangular soil boxes and the ladder type rainfall simulators developed by USDA Soil Laboratory at Purdue University, USA. The size of a soil box was 1.00 × 1.00 × 0.65 m and two gutters at the top and at the bottom of the box were placed to collect surface and subsurface runoff (Fig. 1). Soil texture was sandy originated from weathered granite. The soil is widely distributed throughout the upper stream watershed of the Han River in Korea. Six experimental treatments were control (bare soil), loosely woven rice straw mat (straw mat), straw mat with polyacrylamide (PAM) and rice hull, straw mat with PAM and sawdust, straw mat with PAM–rice hull–soil amendment (gypsum), and straw mat with PAM–sawdust–gypsum. The plot was covered with straw mat, PAM, rice hull,

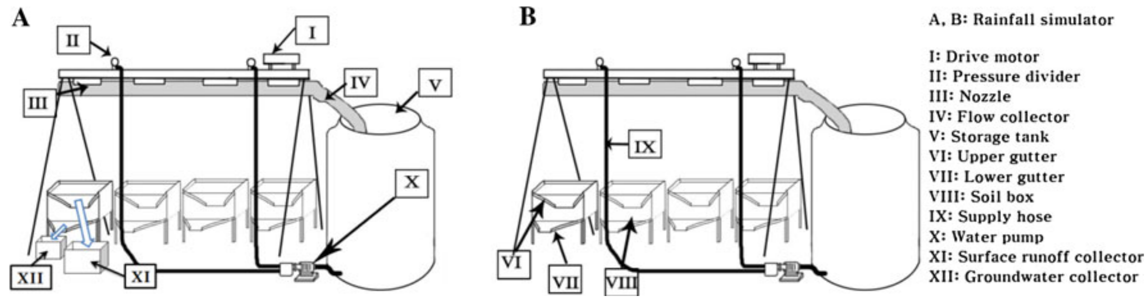

Fig. 1 Sketch of the indoor rainfall simulation

sawdust, and gypsum with density of 3000 kg/ha, 10 kg/ha, 1500 kg/ha, 2000 kg/ha, and 1 Mg/ha, respectively. The different methods were treated on the surface of the soil box, rainfall simulation was conducted, and both surface and subsurface runoff were collected and analyzed with respect to flow volume and sediment. Rainfall intensities were 30 and 60 mm/h and 60-min continuous simulation was conducted for each simulation. Each treatment was replicated three to four times depending on the experimental condition.

Field application of straw mat

Two field applications were tested to evaluate the effect of rice straw mat cover on runoff quantity and water quality. The first application was conducted to a soybean field of 1,297 m^2 and 3 % slope (Fig. 2). Major soil texture of the field was loamy sand. In this study, soybeans were planted at the experiment plot because soybean is one of major crops in Korea (KOSIS 2010). Runoff quantity and quality were measured without rice straw cover under natural rainfall conditions during 2008 and 2009 (Won et al. 2011). On the third year (2010), the field was covered with straw mat with the density of 300 g/m^2 (equivalent to 3,000 kg/ha) and runoff quantity and quality were measured. The same agricultural managements were applied to the field based on conventional farming practices performed at local areas. The second application was performed to radish and Chinese cabbage plots because these two vegetables are primary ingredients of Kimchi and are cultivated intensively at alpine areas. In this study, the effects on runoff ratio, pollutant loads, and crop production of different cropping were evaluated. Six runoff plots are of 5 m × 22 m in size and 3 % in slope (Fig. 3). Runoff plots treated with control, wood shaves, and rice straw mat. Cultivation practices followed the local practices. And runoff quantity and quality under natural rainfall were measured at the edge of each plot where a flume and an automatic water gauge were placed. Water samples were taken during rainfall-runoff events and the samples were

Fig. 2 Scene of the soybean field

analyzed according to the relevant Korean national standard methods with respect to selected water quality indices.

Results and discussion

Effect of straw mat in indoor simulation

Table 1 shows the effect of straw mat [300 g/m^2 (3,000 kg/ha), 600 g/m^2 (6,000 kg/ha), 1 kg/m^2 (10,000 kg/ha)] on runoff ratio based on the data collected and analyzed using indoor rainfall simulation experiments. Runoff ratio of covered plots was significantly less than that of control plots. Runoff ratio of control plots ranged between 55.0 and 85.3 %. However, runoff coefficients of covered plots were between 0.0 and 63.3 %. Especially, the runoff ratios of covered plots under 10 % slope and 30 mm/h simulation were close to zero. Analysis of rainfall-runoff monitoring data at agricultural fields at Chuncheon, Korea revealed that runoff was observed with average rainfall intensity of 4.6 mm/h (maximum rainfall intensity of 21.1 mm/h) according to the Han River Environment Research Center (2011) and Korea Meteorological Administration (2011). Considering that the occurrence of rainfall intensity of 30 mm/h or greater throughout the year at Chuncheon and other areas in Korea is low, it is easily inferred that if a sandy field is covered with straw mat, runoff, and associated NPS pollution discharges could be significantly

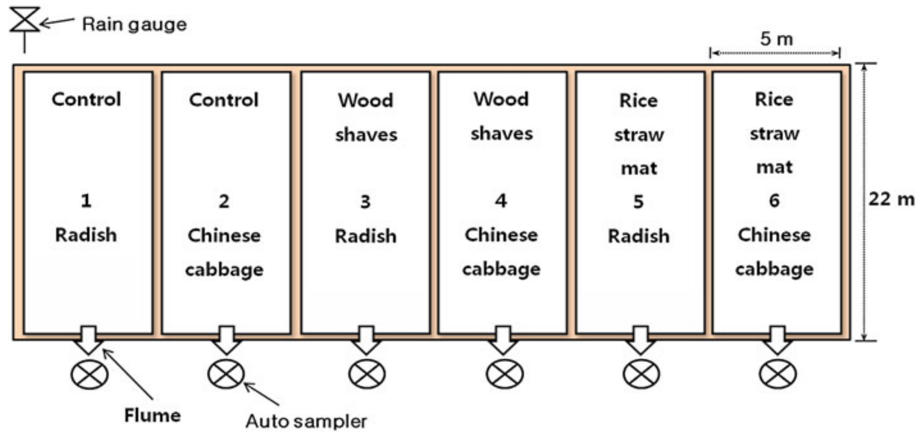

Fig. 3 Sketch of the radish and Chinese cabbage plot field

Table 1 Effect of rice straw mat on runoff ratio with respect to rainfall intensity and slope (Unit: %)

Rainfall intensity (mm/h)	Slope (%)	Rice straw mat cover			
		0 (control) (kg/ha)	3,000 (kg/ha)	6,000 (kg/ha)	10,000 (kg/ha)
30	10	55.0	0.8	0.0	0.0
	20	70.4	12.5	0.0	0.0
60	10	66.1	41.7	5.9	1.3
	20	85.3	63.3	34.0	16.6

Table 2 Effect of rice straw mat cover on sediment discharge with respect to rainfall intensity and slope (Unit: %)

Rainfall intensity (mm/h)	Slope (%)	Rice straw mat cover			
		0 (control) (kg/ha)	3,000 (kg/ha)	6,000 (kg/ha)	10,000 (kg/ha)
30	10	10.32	0.00	0.00	0.00
	20	53.19	2.27	0.00	0.00
60	10	32.57	16.79	2.88	0.00
	20	261.14	89.54	14.84	0.00

reduced. As the rainfall intensity and slope increased to 60 mm/h and 20 %, respectively, the runoff ratio of covered plots also increased but were significantly lower than those of control plots. It is believed that even under extreme rainfall condition of 60 mm/h or greater, straw mat cover may contribute to reduce runoff and NPs pollution from agricultural fields.

Table 2 shows the effect of straw mat on sediment discharge collected and analyzed under indoor rainfall simulation experiments. Sediment discharges of covered plots were significantly less than those of control plots. The straw mat cover protected the soil surface from rain drop impact and reduced soil erosion. In addition, with straw mat cover at the field, development of rills and ephemeral

Table 3 Effect of rice straw mat cover on SS with respect to rainfall intensity and slope (Unit: mg/L)

Rainfall intensity (mm/h)	Slope (%)	Rice straw mat cover			
		0 (control) (kg/ha)	3,000 (kg/ha)	6,000 (kg/ha)	10,000 (kg/ha)
30	10	1,450	160	0	0
	20	2,860	1,000	0	0
60	10	2,050	700	710	500
	20	2,930	1,470	610	570

gullies could be prevented, which could result in fair amount of soil erosion reduction than expected.

Table 3 shows the effect of straw mat on suspended solid (SS) concentration collected and analyzed under indoor rainfall simulation experiments. It was observed that SS concentrations of covered plots were significantly lower than those of control plots. And it also was true that once runoff occurred, SS concentration was relatively high because small soil particles are not easily deposited nor filtered in the plots. Therefore, it is recommended that in order to reduce muddy runoff from agricultural fields, the utmost priority must be given to cover the soil surface with all sort of farm residues or biodegradable material and reduce runoff during rainfall events.

Effects of straw mat, sawdust and rice hull, PAM and gypsum in indoor simulation

It was shown that rice straw mat cover could significantly reduce runoff and agricultural NPS pollution discharges from upland fields. However, the use of straw mat more than 300 g/m^2 is not easy because one layer of straw mat is equivalent to 3,000 kg/ha and the use of two or more layers on a field is practically difficult. It is known that the use of PAM can contribute to reduce runoff and NPS pollution loads. According to the study by Lentz and Bjorneberg

Table 4 Effect of rice straw mat with PAM and rice hull/sawdust on runoff ratio with respect to rainfall intensity and slope (Unit: %)

Rainfall intensity (mm/h)	Slope (%)	Rice straw mat cover			
		Control	RSM + PAM	RSM + PAM + sawdust	RSM + PAM + rice hull
30	10	77.1	6.2	3.3	1.0
	20	85.4	14.3	7.8	1.7
60	10	80.1	53.2	30.5	44.6
	20	87.4	52.8	36.6	53.2

RSM rice straw mat

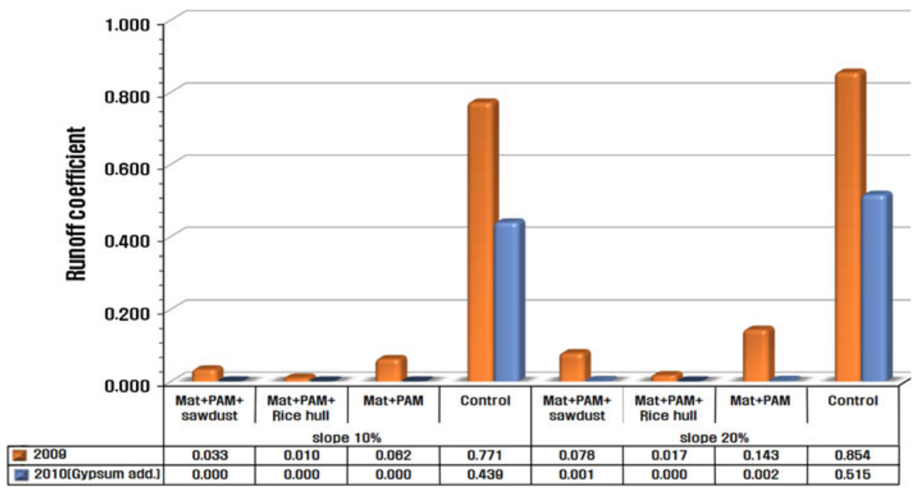

Fig. 4 Comparison of runoff ratio with respect to different surface cover with or without gypsum treatment under rainfall intensity of 30 mm/h

(2003), approximately 64 % of sediment could be reduced with wheat straw and 100 % of sediment reduction would be expected with addition of PAM. However, continuous and extensive use of PAM may degrade the physical properties of soil seriously (Flanagan et al. 1997). Therefore, it was necessary to compromise the use of straw mat and PAM, and improve the efficiency of mat and PAM in the reduction of runoff and NPS pollution loads. Table 4 shows the effect of rice straw mat with PAM and rice hull/sawdust on runoff ratio with respect to rainfall intensity and slope.

Tables 1 and 4 show the runoff ratio under the same rainfall intensity and slope conditions. However, runoff ratio varied depending on soil moisture condition, time interval between rainfall simulations. Tables 1 and 4 show effects on runoff ratio of various surface cover conditions. Tables 1 and 4 showed that addition of PAM and sawdust or rice hull to rice straw mat could contribute significant amount of runoff reduction, which could cause less soil erosion in the field. Addition of PAM and sawdust or rice hull to rice straw mat show greater runoff reduction from the test plots under rainfall intensity of 30 mm/h. However, the addition of PAM and sawdust or rice hull could effectively reduce runoff in case rainfall was 60 mm/h and slope was 20 % because the runoff ratio reduced from 87.4 to 52.8, 36.6, and 53.2 %, respectively, depending on various additions as shown in Table 4. It was expected that if the one layer of straw mat is combined well with PAM and rice hull or sawdust and applied to upland fields, its effect on runoff reduction could be similar to the effect of 6,000 kg/ha straw mat application. Further literature review (Lee et al. 2010) revealed that the use of gypsum together with PAM could increase the efficiency in the reduction of runoff and soil erosion. And additional indoor rainfall simulations were performed to measure the effect of gypsum on the reduction of runoff and sediment when used together with straw mat, PAM, rice hull, and sawdust. Figures 4 and 5 show the effect of gypsum on runoff ratio reduction. As shown in the figures, the effect of gypsum on runoff reduction was prominent. Under the condition of 30 mm/h rainfall simulation, runoff from the covered 10 and 20 % plots with the gypsum addition of 1 ton/ha did not practically occur. Runoff ratio reduced to 43.1 and 39.7 % when compared to control plots under 10 and 20 % slope plots, respectively. It means that if the gypsum is applied to the soil surface and the soil is covered by the straw mat with PAM and rice hull or sawdust, almost no runoff is expected and thus, no NPS pollution also is expected during rainfall event of less than 30 mm/h. However, as rainfall intensity increased to 60 mm/h, runoff ratio of the experimental plots increased regardless of gypsum application. Under the condition of 60 mm/h rainfall simulation, runoff ratio of the covered plots treated by gypsum decreased to 51.5 and 53.3 % for the 10 %

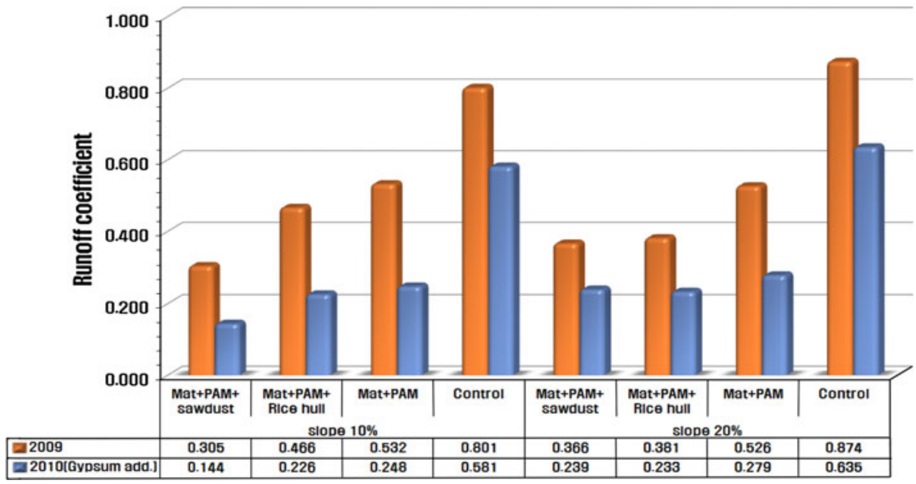

Fig. 5 Comparison of runoff ratio with respect to different surface cover with or without gypsum treatment under rainfall intensity of 60 mm/h

slope and between 34.7 and 47.0 % for the 20 % plots, respectively. Runoff ratio reduced to 17.5 and 27.4 % when compared to control plots under 10 and 20 % slope plots, respectively. The results clearly showed that the use of gypsum could effectively reduce runoff, sediment, and other NPS pollution discharges from upland fields. However, because the experiments were conducted under the tightly controlled laboratory, both runoff plot and field scale application experiments are necessary before the development of BMPs and policies that can be applied to upland fields.

Effect of rice straw mat in soybean field

Effect of rice straw mat cover on runoff was measured for 3 years at a soybean field. Runoff was measured without surface cover for the first 2 years (2008–2009) and then, measured with one layer of straw mat cover for the third year (2010). For the first 2 years, 20 rainfall-runoff events were occurred as shown in Table 5. Range of rainfall that produced runoff was between 40.4 and 239.4 mm. The rainfall lasted between 1 and 2 days. Amount of runoff was between 0.24 and 103.5 m^3 depending on the rainfall and runoff ratio of the 20 rainfall-runoff events ranged from 0.4 to 33.3 %. Runoff of a field is a function of the amount and intensity of a rainfall. From the Table 5, it can be drawn that the field can produce runoff if daily runoff of 40 mm or more or average rainfall intensity of 1.5 mm/h or greater occurs.

In 2010 which is the third year, rainfall-runoff event occurred only three times as shown in Table 6. The number of rainfall events and the amount of rainfall in 2010 were greater than 2008 and 2009. However, only three times of rainfall-runoff was observed, while ten and eight times of rainfall-runoff were observed for year 2008 and 2009 because of surface covers at the field in 2010. It was clear that runoff occurred when rainfall intensity in 2010 was

Table 5 Rainfall-runoff event for the first 2 years at a soybean fields without surface cover

No.	Date	Rainfall (mm)	Intensity (mm/h)	Runoff (m^3)	Runoff coeff. (%)
1	2008.06.18	84.6	5.2	5.4	4.9
2	2008.07.02–03	45.6	1.6	4.1	6.9
3	2008.07.12–13	64.2	2.8	1.5	1.8
4	2008.07.19–21	131.4	2.7	11.1	6.5
5	2008.07.24–25	239.4	6.5	103.5	33.3
6	2008.07.30	40.4	11.5	6.8	12.9
7	2008.08.02–03	69.2	3.3	15.2	16.9
8	2008.08.18	56.6	4.6	6.9	9.4
9	2008.08.22–23	86	3.0	6.3	5.6
10	2008.09.01–02	59.8	2.1	0.3	0.4
11	2009.05.02	51.2	2.9	0.24	0.4
12	2009.06.02–03	56.6	2.8	4.39	6.0
13	2009.06.09–10	43.0	2.2	1.10	2.0
14	2009.07.09	202.0	11.3	46.07	17.6
15	2009.07.11–12	133.4	5.9	40.01	23.1
16	2009.07.14	204.4	9.4	59.10	22.3
17	2009.07.17–18	42.8	1.5	6.70	12.1
18	2009.07.25	50.2	9.1	3.81	5.9
19	2009.08.11–12	196.6	7.1	51.86	20.3
20	2009.08.26–27	59.4	2.6	1.02	1.3

much greater than that in 2008 and 2009. When the soil was not covered, runoff occurred if average rainfall intensity was 1.5 mm/h or greater but when the soil was covered, runoff could occur if the intensity was 5.8 mm/h or greater. It meant that straw mat cover could effectively reduce runoff from upland fields and thus, reduce soil erosion and other NPS pollution loads. Table 7 shows the selected NPS pollution loads and reduction rate between conventional (2008–2009) and straw mat covered (2010) soybean cultivations. The pollution load reduction rate of straw covered field compared to conventional field was

Table 6 Rainfall-runoff event for the third year at a soybean fields with straw met surface cover

Date	Rainfall (mm)	Intensity (mm/h)	Runoff (m^3)	Runoff coeff. (%)
2010.05.09	57.5	5.8	3.06	4.1
2010.08.23–24	105.5	7.5	16.36	12.0
2010.09.09–11	279.0	7.0	121.59	33.8

Table 7 Average NPS pollution loads (kg/ha) and reduction rate (%) between conventional and straw mat covered soybean cultivations

Treatment	SS	COD_{Cr}	COD_{Mn}	BOD	TN	TP
Conventional (2008–2009)	1219.4	39.4	14.4	11.6	3.6	3.2
Straw mat cover (2010)	7.8	3.0	1.1	0.6	0.2	0.3
Reduction rate (%)	99.4	92.5	92.2	94.9	94.2	89.7

between 89.7 and 99.4 %. It is very natural that if the soil is covered, both runoff and pollutant concentration are reduced and thus, leading to the dramatic reduction of pollution loads. It is also understandable that straw mat covered cultivation take much more labors and material cost for farmers than conventional cultivation. But it is also clearly understood that if the NPS pollution loads must be reduced for water quality conservation, one of the best BMPs is surface cover.

Effect of straw mat in Chinese cabbage and radish plots

Three rainfall-runoff events were occurred and monitored during the radish and cabbage cultivation from September to early November, 2010. Table 8 shows runoff ratios of the three rainfall-runoff events. Runoff ratios varied widely depending on the size of rainfall. The more the rainfall occurred, the greater the runoff ratios observed. Runoff ratios of the cabbage and radish plots were greater than those of soybean field because of soil texture. Soil texture of the soybean field was loamy sand while the cabbage and radish plots were loam with gravel. Because infiltration of loam (13.208 mm/h) is much lower than that of loamy sand

Table 9 NPS pollution loads and reduction rates of the radish plot

Surface cover	BOD	SS	COD_{Mn}	DOC	TN	TP
Measured NPS pollution loads (g/110 m^2)						
Control	39.7	1054.1	45.9	18.8	20.1	23.2
Wood shaves	25.1	620.8	26.3	5.5	14.5	15.3
Straw mat	14.2	202.1	15.3	3.7	8.7	10.2
Reduction rate (%) with respect to control						
Wood shaves	36.8	41.1	42.7	71.0	28.0	34.0
Straw mat	64.3	80.8	66.7	80.2	56.6	56.1

(61.214 mm/h), runoff ratios of the cabbage and radish plots are greater than those of soybean field. Reduction of runoff ratios of straw mat covered plots compared to control ones was between 4.3–30.3 and 33.8–75.8 % for the cabbage plots and between 5.5–30.6 and 34.8–75.0 % for the radish plots, respectively. Runoff reduction in straw mat covered plots was greater when rainfall was smaller.

Table 9 shows NPS pollution loads and reduction rates of the radish plots of two monitored rainfall events (2010.09.09–12 and 10.02–03). By covering the surface with straw mat, SS showed the greatest reduction of 80.8 %. For TP, the lowest reduction of 56.1 % was observed when compared to those of control plots. The reduction rates of the radish plots were much less than those of soybean field because the runoff reduction was small.

Table 10 shows the productivity of the plots. Yield of both radish and cabbage of the straw mat covered plots increased by 153.4 and 122.1 %, respectively, compared to that of control plots. It was thought that by covering the soil surface, the ridges were not eroded and thus, availability of soil moisture and nutrients to the crops was sufficient enough for crops to grow better. Ridges of control plots were eroded badly by raindrop impacts at the beginning of seeding and transplanting period, and supply of moisture and nutrients to crops was not as good as that of covered plots. It is true that the use of straw mat on farming practices asks additional costs and labors that are not necessary in conventional farming. However, the use of straw mat may produce greater yield and need less management works such as weeding by inhibiting weed growth than conventional farming. It is believed that the greater

Table 8 Rainfall and runoff ratio of the experimental plots

Date	Rainfall (mm)	Chinese cabbage			Radish		
		Control	Wood shaves	Rice straw mat	Control	Wood shaves	Rice straw mat
2010.09.09–12	359.2	0.74	0.61	0.48	0.72	0.60	0.48
2010.09.21	49.0	0.57	0.54	0.37	0.56	0.54	0.37
2010.10.02–03	28.8	0.11	0.08	0.03	0.10	0.07	0.03

Table 10 Productivity of the plots

Surface cover	Chinese cabbage			Radish		
	Unit wt. (g)	Yield (kg/10a)	Yield index (%)	Unit wt. (g)	Yield (kg/10a)	Yield index (%)
Control	1,713	5,561	100.0	793.3	3158.9	100.0
Wood shaves	2,077	6,451	116.0	1166.0	4643.0	147.0
Straw mat	2,216	6,789	122.1	1217.1	4846.2	153.4

yields and less management cost may compensate the additional costs. And if the government is willing to support farmers by providing the material cost (rice straw mat) as an incentive, farmers may be willing to adopt the BMP of surface cover and help to improve water quality of receiving waters and eventually freshwater reservoirs.

Conclusions

This study was conducted to evaluate effects of rice straw mat and with other additions on runoff ratio and pollutant load reduction. In this study, two types of experiments were conducted; first, indoor rainfall simulation was done with rice straw mat and with additions of PAM, sawdust, rice hull, and gypsum for analysis reductions in runoff ratio, sediment concentration and loads; and, runoff plot simulation was done with rice straw mat and with additions of PAM, sawdust/rice hull for runoff ratio, and sediment reduction analysis; second, rice straw mat with other substances was applied to the fields to evaluate runoff ratio, pollutant load reductions, and crop yields.

(1) Indoor rainfall simulation revealed that runoff ratio (0–63.3 %) decreased dramatically with surface cover, compared with no surface cover condition (runoff ratio of 55–85.3 %) and sediment load and concentration also decreased. With additions of PAM, sawdust, and rice hull to rice straw mat, the runoff ratio decreased to 52.8, 36.6, and 53.2 % from only rice straw mat condition (runoff ratio of 63.3 %). When gypsum was added, no runoff was observed in case of rainfall intensity of 30 mm/h. Under 60 mm/h rainfall condition, 50 % or more runoff reduction could be expected. These could be explained in that surface cover reduce detachment of soil particles and keep infiltration rate by reducing surface sealing with detached soil particle under non-surface cover condition.

(2) When rice straw mat was applied to soybean field, no runoff was observed until rainfall intensity of 5.8 mm/h or greater, while runoff was observed with rainfall intensity of 1.5 mm/h at no surface covered soybean field. In addition, 89.7–99.4 % of pollutant reductions were observed with rice straw mat at the soybean field.

(3) When rice straw mat with additions of wood shaves was applied to Chinese cabbage and radish fields, 4.3–75.8 % of runoff reductions and 28–80.8 % of pollutant reductions were observed. In case of Chinese cabbage, 122.1 % of yield increase was observed and 153.4 % of yield increase in case of radish.

As shown in field experiment, rice straw mat could play important role in reducing pollutant loads and increasing economic benefit for the farmers. Also, various positive effects of rice straw mat on soil carbon sequestration could be expected although long-term monitoring should be implemented.

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