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Research Article

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Pollutant Runoff Reduction Efficiency of Surface Cover, Vegetative Filter Strip and Vegetated Ridge for Korean Upland Fields: A Review

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Abstract

BACKGROUND: In this review paper, the effects of surface cover (SCV), vegetative filter strip (VFS), and vegetated ridge (VRD) on the pollutant runoff from steep-sloping uplands were analyzed to compare the pollutant reduction efficiency in runoff (PRE_{runoff}) of the practices and to investigate how slope and rainfall parameters affect the PRE_{runoff}.

METHODS AND RESULTS: The PRE_{runoff} of SCV, VFS, and VRD for pollutants including suspended solids and biological oxygen demand was compared by analysis of variance. The effect of slope and rainfall parameters on the PRE_{runoff} was explored by either mean comparison or regression analysis. It was found that the PRE_{runoff} differs with the practices due to different pollutant reduction mechanisms of the practices. Though the PRE_{runoff} was likely to be affected by site condition such as slope and rainfall (amount and intensity), more comprehensive understanding was not possible due to the limited data set.

CONCLUSION: The PRE_{runoff} of SCV, VFS, and VRD differed due to the distinctive mechanisms of pollutant removal of the practices. It is necessary to accumulate experimental data across a variety of gradient of slope and rainfall for comprehensive understanding of the effects of the practices on pollutant runoff from steep-sloping uplands.

Key words: Best management practices, Land slope, Rainfall, Soil erosion, Upland fields

Introduction

Intensification of agriculture that relies heavily on high inputs of mineral and organic fertilizers certainly contributed to increases in agricultural productivity (Gilland, 2002). However, high-input intensive agriculture caused water pollution via non-point source pathways such as surface run-off that brought worldwide concerns on the negative impacts of modern agriculture (Withers and Lord, 2002). To reduce the impact of agricultural activities on water pollution, developed

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countries have shifted the agricultural paradigm from high-input intensive agriculture to low-input sustainable agriculture (Parris, 2011). Due to such efforts, fertilizer consumption in OECD countries has been reduced which led to decline in the nutrient surplus by 17% during the last decade (Parris, 2011). However, the relative contribution of agricultural sector to water pollution is reported to be still high, ranging from 30 to 80% for NO_3^- and from 20 to 70% for phosphorus (P) in surface water body (Parris, 2011) with curtailment of pollutants load from point sources (Skinner *et al.*, 1997). Such high contribution of agricultural sector to water pollution highlights the necessity of further efforts to reduce agricultural water pollution. For this reason, in developed countries including USA (Whitney *et al.*, 2012), UK (Kay *et al.*, 2009, 2012), and other OECD countries (OECD report, 2010, DOI: https://doi.org/0.1787/89264086845), agricultural policies such as regulatory instruments, payments, taxes, and nutrient trading market are helpful in reducing agricultural non-point source pollution. In South Korea, the Ministry of Agriculture, Food and Rural Affairs (MAFRA) has also launched a payment program that financially supports farmers' activities to reduce agricultural non-point source pollution (MAFRA report 11-1543000-001840-01, 2017).

In South Korea, upland fields are critical sources of non-point source pollution due to steep-sloping topography as well as seasonal precipitation pattern; *i.e.*, 95% of cropping fields is located at landscape with slope >2% and two-third of annual precipitation (about 1,300 mm) occur during the short-term monsoon period in the summer (Hur *et al.*, 2005). For those reasons, the mean annual soil loss of Korean uplands is estimated to be 37.7 Mg/ha, which is more than 3-folds of the OECD standard of soil erosion (11 Mg/ha) (Jung *et al.*, 2005). Soil erosion not only degrades soil productivity by losing fertile surface soil (den Biggelaar *et al.*, 2004) but also causes water pollution through inflow of nutrient-enriched runoff water into surface water body surrounding the fields (Shi and Schulin, 2018).

Several best management practices (BMPs) has been tested and proposed to reduce soil and nutrient runoff from steep-slopping upland fields in South Korea which include surface cover (SCV) (Shin *et al.*, 2016), vegetative filter strip (VFS) (Seo and Choi, 2013), and vegetated ridge (VRD) (Kim and Kim, 2015). In South Korea, the beneficial effects of SCV, VFS, and VRD on reducing surface runoff and nutrient loss from steep-sloping upland fields have been proven for various soil types, slope levels, and crop species (Seo and Choi, 2013; Kim and Kim, 2015; Shin *et al.*, 2016). However, no information on the differences in the pollutant reduction efficiency of these three BMPs is available even though the pollutant removal mechanisms of SCV, VFS, VRD differ and thus the pollutants removal efficiency may differ depending on the pollutant. In addition, as the efficiency of the BMPs in reducing pollutant load from upland fields are likely to vary with site conditions such as slope and rainfall characteristics, it is necessary to investigate how the reduction efficiency varies with site conditions. Such information may be useful in establishing a goal for pollutant load reduction in the upland fields where the MAFRA's program is implemented.

In this paper, 1) we reviewed studies on the effects of SCV, VFS, and VRD on soil loss and pollutants loads from steep-sloping upland fields of South Korea to compare pollutant reduction efficiency in runoff (PRE_{runoff}) of the three BMPs, 2) when data are available, the effects of site conditions such as slope and rainfall characteristics on the PRE_{runoff} was investigated, and 3) further research direction was suggested to obtain information that might be necessary to support the MAFRA's program.

Materials and Methods

Data Collection

As the pattern of pollutant load from upland fields via runoff is likely to be affected by soil, crop, topography, and seasonal distribution of rainfall (Prosdocimi *et al.*, 2016), we considered studies that were conducted in South Korea to provide information that is more relevant to Korean agricultural environment and thus can support the MAFRA's program. Among various BMPs adoptable to steep-sloping uplands fields, we focused on SCV (Shin *et al.*, 2011a, 2011b, 2012, 2013, 2016; Won *et al.*, 2011, 2013, 2014) (Table 1), VFS (Choi and Jang, 2014; Lee *et al.*, 2015) (Table 2), and VRD (Kim *et al.*, 2012; Kim and Kim, 2015) (Table 3) as these three BMPs have been relatively well studied. Though a few modeling studies were also available, we did not include these studies.

Table 1. Summary of studies on the pollutants reduction efficiency in runoff by surface cover

Study	Experimental conditions					Treatments applied^b	Reduction efficiency (%)					
	Slope (%)	Soil texture^a	Crop	Rainfall amount (mm)	Rainfall intensity (mm/hr)		SS	TN	TP	BOD_5	COD	DOC
Shin *et al.* (2011a)	3	LS	Radish	NA	NA	RS mat	80.8	56.6	56.1	64.3	66.7	80.2
Shin *et al.* (2011b)	28	LS	NA	31.1	31.1	RS mat (+RH, SD, PAM)	99.4~99.7	NA	NA	NA	NA	NA
				36.9	36.9	RS mat (+RH, SD, PAM)	81.2~97.5	NA	NA	NA	NA	NA
				40.6	40.6	RS mat (+RH, SD, PAM)	78.0~94.6	NA	NA	NA	NA	NA
				44.4	44.4	RS mat (+RH, SD, PAM)	69.0~90.0	NA	NA	NA	NA	NA
Won *et al.* (2011)	10	LS	NA	30	30	RS mat (+RH, SD, PAM)	82.3~89.2	NA	NA	NA	NA	NA
				60	60	RS mat (+RH, SD, PAM)	77.6~84.6	NA	NA	NA	NA	NA
	20	LS	NA	30	30	RS mat (+RH, SD, PAM)	87.0~91.3	NA	NA	NA	NA	NA
				60	60	RS mat (+RH, SD, PAM)	74.5~79.2	NA	NA	NA	NA	NA
Shin *et al.* (2012)	3	SL	Radish	NA	NA	RS	52.0	28.5	35.2	NA	NA	NA
						RS mat	79.8	68.3	53.3	NA	NA	NA
Shin *et al.* (2013)	10, 20	LS	Soybean	57.5~279.0	5.8~7.5	RS mat	99.4	94.2	89.7	97.9	99.2	92.5
		L	Cabbage Radish	28.8~359.2	NA	RS mat	80.8	56.6	56.1	64.3	66.7	80.2
Won *et al.* (2013)	28	L	Lettuce	72	5.1	RS mat (+G, PAM)	95.1~99.3	50.2~91.4	66.7~91.7	58.1~90.3	63.3~91.7	NA
				207.5	2.5	RS mat (+G, PAM)	70.7~100	41.1~100	36.8~100	58.8~100	47.6~100	NA
				218	7.0	RS mat (+G, PAM)	90.2~99.5	13.1~80.9	70.4~92.6	58.8~100	47.6~100	NA
Won *et al.* (2014)	10.8	SL	Cabbage	18.0~99.5	1.7~6.1	RS mat (+G, PAM)	71.8~98.1	13.5˜49.9	13.8˜87.1	NA	NA	NA
Shin *et al.* (2016)	2	NA	Soybean	30.4~130.0	1.4~9.3	RS mat	50.0	55.7	54.5	53.9	49.8	38.7
	5.9	NA	Soybean	30.4~130.0	1.4~9.3	RS mat	91.6	80.5	96.7	79.2	87.3	86.5

NA, not available.

[a] LS, loamy sand; SL, sandy loam; L, loam.

[b] RS, rice straw; RH, rice hull; SD, saw dust; PAM, polyacrylamide; G, gypsum.

For each study, characteristics of experimental site including slope, soil texture, crop species, and rainfall amount and intensity as well as the $\mathrm{PRE}_{\mathrm{runoff}}$ for each event of each BMP were obtained if they were available. The considered pollutants were suspended solids (SS), total nitrogen (TN), total phosphorus (TP), biological oxygen demand (BOD), chemical oxygen demand (COD), and total dissolved organic carbon (DOC).

Data Analysis

For each BMP (SCV, VFS, and VRD), arithmetical mean of the $\mathrm{PRE}_{\mathrm{runoff}}$ was calculated to investigate overall effects of the BMPs on the reduction in pollutant load across experimental conditions including slope, soil texture, crop species, and rainfall amount. The difference in the $\mathrm{PRE}_{\mathrm{runoff}}$ of the three BMPs was compared with analysis of variance (ANOVA). The effects of slope on the $\mathrm{PRE}_{\mathrm{runoff}}$ was investigated for the three BMPs by comparing the $\mathrm{PRE}_{\mathrm{runoff}}$ with different slopes. The effects of rainfall amount and

Table 2. Summary of studies on the pollutants reduction efficiency in runoff by vegetative filter strip

Study	Experimental conditions					Vegetated grass species	Reduction efficiency (%)					
	Slope (%)	Soil texture[a]	Crop	Rainfall amount (mm)	Rainfall intensity (mm/hr)		SS	TN	TP	BOD_5	COD	DOC
Choi and Jang (2014)	5	LS	Soybean	38.1	NA	Turf grass	96.9~99.2	21.5~73.8	78.2~96.6	17.6~53.8	79.6	24.4~41.5
				70.7	NA		94.7~99.7	11.8~29.3	33.7~73.6	-96.8~100	70.1~83.0	-34.3~22.4
				76.8	NA		92.3	72.7	86.3	6.5	68.1	40.0
				97.4	NA		84.7	71.4	75.7	7.3	66.7	97.2
				122.3	NA		82.5~97.9	0.0~83.7	0.0~66.0	-65.8~91.3	3.3~60.8	-30.2~5.8
				184.8	NA		76.6	91.1	87.8	5.2	62.0	38.1
	5	LS	Soybean	38.1	NA	Kentucky blue grass	98.4~99.2	71.8	96.1~96.5	25.2~56.6	79.6	24.4~47.2
				70.7	NA		98.4~100	45.4~50.0	70.7~81.7	-34.1~4.3	85.5~88.3	17.9~28.8
				76.8	NA		77.8	61.9	79.1	21.0	52.3	22.2
				97.4	NA		83.2	70.8	82.8	24.1	67.0	52.5
				122.3	NA		96.9~99.9	84.0~90.8	83.8~84.6	-45.0~12.8	54.8~71.7	-42.4~21.5
				184.8	NA		90.7	87.9	84.5	25.0	77.3	28.3
Lee *et al.* (2015)	8	L	Soybean	65.6	NA	Turf grass	35.9	82.1~84.2	7.9~40.5	NA	NA	NA
				78.4	NA		-195~58.2	56.5~75.5	-37.9~58.6	NA	NA	NA
				103.6	NA		26.0~39.4	31.6~51.6	-64.7~64.7	NA	NA	NA

NA, not available.

[a] LS, loamy sand; L, loam.

Table 3. Summary of studies on the pollutants reduction efficiency in runoff by vegetated ridge

Study	Experimental conditions					Reduction efficiency (%)					
	Slope (%)	Soil texture[a]	Crop	Rainfall amount (mm)	Rainfall intensity (mm/hr)	SS	TN	TP	BOD_5	COD	DOC
Kim *et al.* (2012)	3	SCL	Radish	101	NA	-67.0	82.9	-114.1	-19.7	-57.2	-55.1
			Cabbage	110	NA	75.7	86.7	55.3	83.4	54.7	59.7
				345	NA	54.8	76.9	53.3	50.8	38.4	27.0
Kim and Kim (2015)	3	SCL	Soybean	27.6	2.8	62.2	59.5	68.4	52.1	52.8	48.6
				91.6	3.7	68.2	-224.5	28.6	34.9	36.5	-16.9
	6	L		65.6	3.1	-50.6	65.1	50.0	23.6	17.6	21.3
				130	10.0	80.9	67.9	93.6	57.0	61.3	57.8
	8	L		65.6	3.1	-26.3~61.3	-4.5~62.5	-2.5~46.7	25.3~44.0	11.2~43.2	36.3~50.6
				130	32.6	64.6~77.3	52.0~52.5	93.4~93.9	40.5~45.7	49.4~51.4	49.9~51.8

NA, not available.

[a] SCL, silt clay loam; L, loam.

intensity on the $\text{PRE}_{\text{runoff}}$ was investigated by regression analysis for only SCV which had enough data set for regression analysis. For the analysis of the effects of slope and rainfall on the $\text{PRE}_{\text{runoff}}$, SS was considered as a representative water quality parameter due to a large size of data set. All the statistical analysis was conducted using IBM SPSS Statistics 23 (IMP Corp. Armonk, NY, USA) α value of 0.05 was chosen to indicate statistical significance.

Results and Discussion

Pollutant Reduction Efficiency in Runoff by BMPs

Though several studies that investigated the effects of SCV, VFS, and VRD on reduction of pollutant runoff from Korean uplands are available (Tables 1–3), there was no study that compared the $\text{PRE}_{\text{runoff}}$ of the three BMPs. Overall, SCV and VFS had a greater $\text{PRE}_{\text{runoff}}$ than VRD for SS ($P<0.001$), TP ($P=0.050$), and COD ($P=0.007$); *e.g.*, the $\text{PRE}_{\text{runoff}}$ for SS was 84.4±

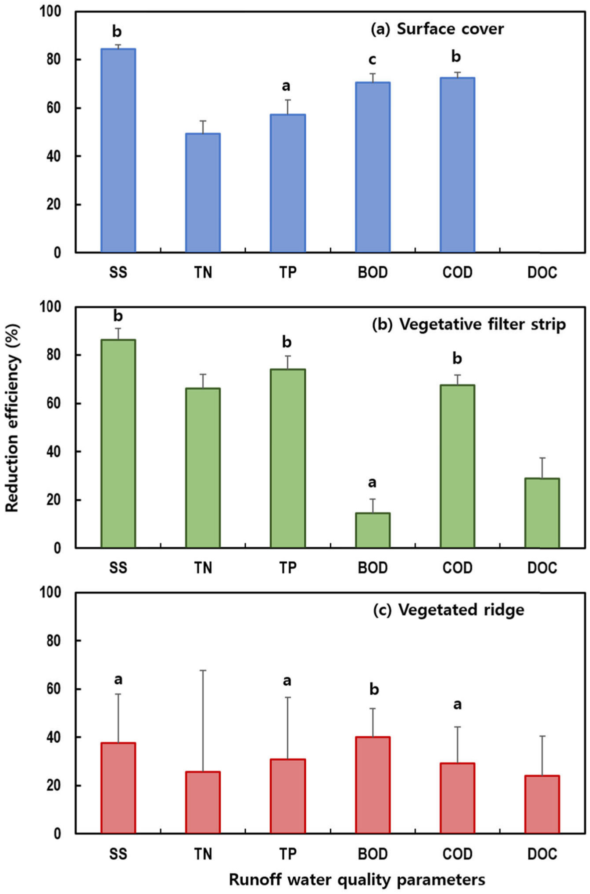

Fig. 1. Pollutants reduction efficiency in runoff by (a) surface cover (n=19), (b) vegetative filter strip (n=15), and (c) vegetated ridge (n=9). Values are the means of the data presented in Tables 1–3, and vertical bars are the standard errors of the mean. For surface cover, DOC data were not available. ANOVA for comparison of the effects of surface cover, vegetative filter strip, and vegetated ridge on the pollutants reduction efficiency in runoff are provided in Table 4, and different lowercase letters indicate significant difference between surface cover, vegetative filter strip, and vegetated ridge at α =0.05.

Table 4. Analysis of variance (ANOVA) for comparison of the effects of surface cover, vegetative filter strip, and vegetated ridge on the pollutants reduction efficiency in runoff

Pollutants	*F*	Degree of freedom[a]	*P*[b]
SS	10.9	2	**<0.001**
TN	1.3	2	0.290
TP	3.3	2	**0.050**
BOD	9.6	2	**0.001**
COD	6.3	2	**0.007**
DOC	0.08	1	0.774

[a] Surface cover effects on DOC was not available.

[b] Bolds indicate statistically significant difference among surface cover, vegetative filter strip, and vegetated ridge.

1.8% for SCV, 86.4±4.7% for VFS, and 37.6±20.4% for VRD (Fig. 1). For TN, there was no difference (*P*=0.290) between SCV, VFS, and VRD, and for BOD (*P*=0.001), VFS had lower $\mathrm{PRE}_{\mathrm{runoff}}$ than VRD (Fig. 1). Therefore, our review suggests that SCV, VFS, and VRD could reduce pollutant runoff substantially, but the $\mathrm{PRE}_{\mathrm{runoff}}$ differs with the BMPs probably due to differences in the reduction mechanisms of the three practices.

Surface cover can reduce surface runoff by up to 96% via protecting soil aggregates against raindrop impact and by decreasing overland flow velocity due to increased surface roughness (Prosdocimi *et al.*, 2016). Reduction of soil loss and/or erosion rate by SCV or surface mulching has been extensively studied and the $\mathrm{PRE}_{\mathrm{runoff}}$ varies with the mulching materials and application rate (Prosdocimi *et al.*, 2016). For example, it has been reported that wood mulching is more effective than straw mulching (Robichaud *et al.*, 2013) and maize residue is better than soybean and sorghum residues (Gilley *et al.*, 1986a, 1986b). Regarding mulching application rate, it has been suggested that a surface mulching cover of 60% area is the minimum threshold for a significant reduction of soil loss (Pannkuk and Robichaud, 2003; Cerdà and Doerr, 2008). However, in this review, it was not straightforward to discuss the potential effects of SCV materials and application rate on the $\mathrm{PRE}_{\mathrm{runoff}}$ for Korean uplands due to the lack of relevant data.

Vegetative filter strip is often established in the downside area of upland fields to remove sediment and pollutants from surface runoff through filtration, sedimentation, and infiltration (Lobo and Bonilla, 2017). It has been shown that VFS could remove up to 99% of SS (Osborne and Kovacic, 1993), 90% of TP and 80% of TN from runoff (Chaubey *et al.*, 1994). Considering the physical mechanisms of pollutant removal by VFS, however, dissolved pollutants may not be removed as efficiently as particulate pollutants by VFS (Lobo and Bonilla, 2017). Therefore, in this review, a lower $\mathrm{PRE}_{\mathrm{runoff}}$ for BOD and DOC than other pollutants (Fig. 1) should be ascribed to the physical removal mechanisms of VFS that has limitation in removing dissolved pollutants. In addition, supply of organic C from root exudates might further contribute to the lower $\mathrm{PRE}_{\mathrm{runoff}}$ for BOD of VFS than that of VRD (Zhai *et al.*, 2013).

Vegetated ridge is constructed across the slope

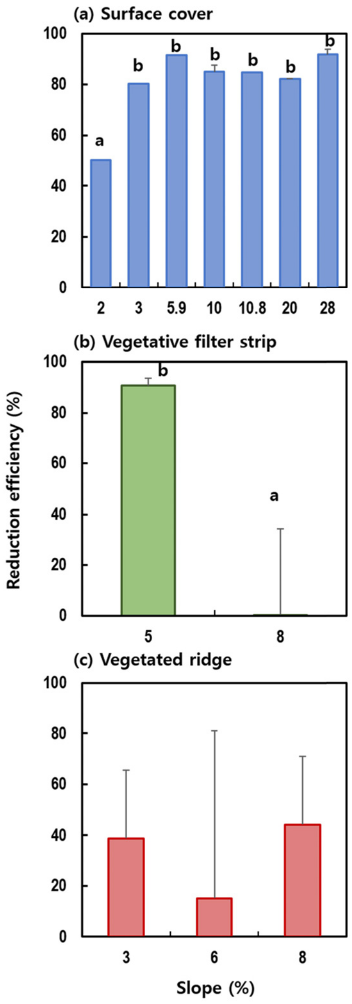

Fig. 2. Changes in the reduction efficiency of suspended solids in runoff by (a) surface cover, (b) vegetative filter strip, and (c) vegetated ridge as affected by slope. Values are the means of the data presented in Tables 1–3, and vertical bars are the standard errors of the mean. Different lower case letters indicate significant difference with slope at α=0.05.

similar to contour ridge systems, which results in rainwater ponding in the furrow area that reduces runoff velocity while increasing infiltration and reducing soil erosion (Liu *et al.*, 2014). Due to the confined capacity of the ridge, however, when the ponded rainwater exceeds the storage capacity, it overflows the ridge and the concentrated rainwater might lead to soil erosion (Flanagan and Livingston, 1995; Hatfield *et al.*, 1998), resulting in a relatively low PRE$_{runoff}$ as observed in this review (Fig. 1).

Effects of Slope and Rainfall Parameters on Pollutants Reduction Efficiency in Runoff

Soil loss and pollutant runoff are highly dependent on slope and rainfall parameter such as rainfall amount and intensity, and soil loss usually increases with increasing slope gradient and rainfall amount and intensity (Römkens *et al.*, 2001; Shen *et al.*, 2016). In this review, the effect of slope on PRE$_{runoff}$ for SS was found to differ among SCV, VFS, and VRD (Fig. 2). For SCV, the PRE$_{runoff}$ was 50% at slope of 2%, and it increased to >80% at slope of 3% and there was no difference in the PRE$_{runoff}$ at slope between 3 and 28%, suggesting that the PRE$_{runoff}$ for SS by SCV is not affected by slope greater than 3%. For VFS, the PRE$_{runoff}$ for SS was >90% at slope of 5%, but it was close to 0% at slope of 8%, and for VRD, the PRE$_{runoff}$ for SS did not differ with slope. Slope gradient has direct impact on soil erodibility and percolation (Li *et al.*, 2010) and is also indirectly related to several factors affecting infiltration rate that include surface soil sealing, soil water storage, and effective rainfall (Fox *et al.*, 1997). Therefore, slope gradient should collaborate with the BMPs on the PRE$_{runoff}$. However, as seen in Tables 2 and 3, only a few studies are available for VFS and VRD, and thus more experimental studies at different slope are required to evaluate the effects of slopes on the PRE$_{runoff}$ of VFS and VRD.

The relationship between either rainfall amount or rainfall intensity and the PRE$_{runoff}$ for SS by SCV was not significant when all the data were included (Fig. 3). However, for events with rainfall amount below <100 mm, the PRE$_{runoff}$ for SS tended to decrease with rainfall amount (Fig. 3a). For rainfall intensity, similar pattern was found for events with rainfall intensity >30 mm/hr (Fig. 3b). These results suggest that at a given site conditions, the PRE$_{runoff}$ for SS of SCV is likely to vary with rainfall parameters. Raindrops impact the physical properties of soil surface by creation of surface seal that further impacts infiltration rate, soil water storage, water suction, and surface roughness (Bradford *et al.*, 1987; Mualem *et al.*, 1993; Fohrer *et al.*, 1999; Assouline, 2004). However, again, due to the limited number of experimental data, it is not straightforward to interpret such relationship between rainfall parameters and the PRE$_{runoff}$ for SS of SCV, strongly highlighting the necessity of accumulation of experimental data that might allow comprehensive understanding of the interactive effects of SCV and rainfall parameters on SS runoff reduction.

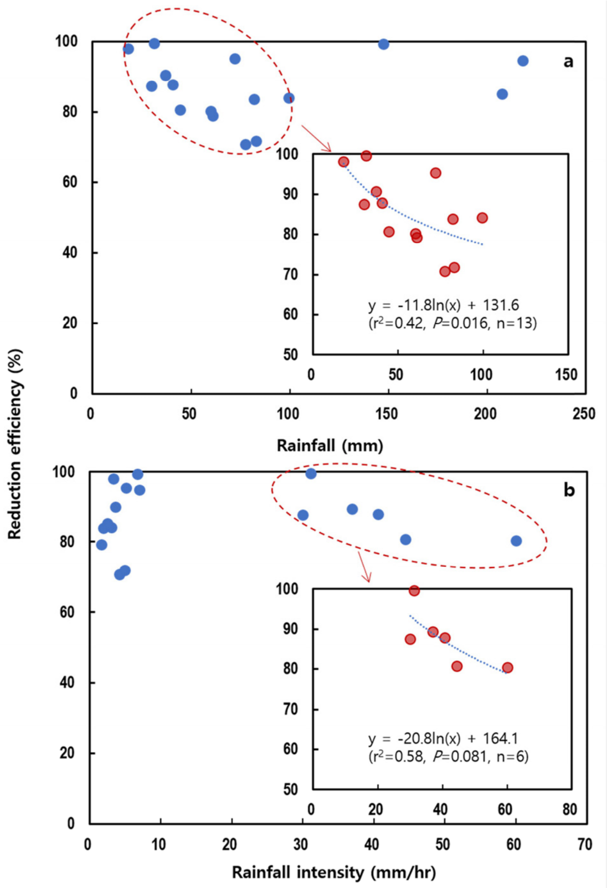

Fig. 3. Changes in the reduction efficiency of suspended solids by surface cover as affected by (a) rainfall amount and (b) rainfall intensity. Figures were not presented for vegetative filter strip and vegetated ridge due to lack of relevant data.

Conclusions

In this review, it was found that SCV, VFS, and VRD could reduce pollutant runoff substantially, even though the $\mathrm{PRE}_{\mathrm{runoff}}$ varies with the BMPs due to different pollutant runoff reduction mechanisms of the BMPs. Among the three BMPs, SCV was proven to be most effective in removing all pollutants studied; whereas VFS that relies on physical filtration of pollutants does not reduce BOD satisfactorily compared with SCV and VRD probably due to low filtration efficiency of dissolved pollutants as well as supply of organic C from root exudates. The VRD has a relatively low $\mathrm{PRE}_{\mathrm{runoff}}$ (except for BOD) compared to SCV and VFS due to confined rainwater ponding capacity of ridge. Slope and rainfall parameters such as rainfall amount and intensity should collaborate with the BMPs in reduction of pollutant runoff; however, limited number of data set did not allow more systematic analysis of the effects of slope and rainfall on the $\mathrm{PRE}_{\mathrm{runoff}}$ of the BMPs. Therefore, it is necessary to accumulate experimental data across a variety of gradient of slope and rainfall for comprehensive understanding of the effects of the three BMPs on the $\mathrm{PRE}_{\mathrm{runoff}}$. As the previous studies have rarely been replicated and thus our current understanding of the effects of BMPs lacks statistical significance, future studies need to be fully replicated (*e.g.*, triplicates) to allow statistical analysis of the effects of BMPs. In addition, to implement the BMPs at a farm scale, information on expense, labor cost, and profit loss associated with the BMPs should also be provided to support a financial payment program of the MAFRA.

Note

The authors declare no conflict of interest.

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