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ARTICLE

Reduction of runoff and soil loss over steep slopes by using vetiver hedgerow systems

S. Donjadee · T. Tingsanchali

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Abstract Vetiver hedgerow system has potential for reducing runoff and soil loss especially on steep slope areas, but the dynamics of these reductions are not fully understood. This research was conducted to determine reduction in runoff and soil loss by vetiver hedgerow system. Vetiver hedgerow systems with three vertical intervals of hedgerow were tested on three land slopes and compared with the case without hedgerow for six simulated rainfall amounts. The vetiver hedgerows reduce runoff volume and soil loss by 31–69 and 62–86 %, respectively compared to the case without vetiver hedgerow. Runoff volume increases with rainfall amount, and hence increases soil loss. Therefore soil loss increases with land slope, runoff volume, rainfall amount, and vertical hedge interval. Two final equations for estimating soil loss are presented in this study. The first equation contains parameters of runoff volume, land slope, and vertical hedge interval, while the second equation contains rainfall amount instead of runoff volume. The correlation coefficients between estimated soil losses and the experimental data in this study and in the literatures were found to be 0.94 and 0.90 for the first and second equations, respectively.

S. Donjadee
Department of Irrigation Engineering, Faculty of Engineering at Kamphaengsaen, Kasetsart University, Nakhon Pathom, Thailand
e-mail: fengscd@ku.ac.th

T. Tingsanchali (✉)
Program of Civil and Environmental Engineering, Faculty of Science and Technology, Nakhon Pathom Rajabhat University, Nakhon Pathom, Thailand
e-mail: tawatch_t@hotmail.com

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Introduction

Soil erosion can be severe in steep agricultural land areas in high rainfall regions, and it affects crop productivity and income of farmers. Moreover, soil erosion is the most important environmental concern in developing countries (Ananda and Herath 2003; Stocking 1995), especially in Southeast Asia (Valentin et al. 2008). Rainfall amount and intensity are increasing (Nearing et al. 2005) due to rapid changes in land use practices (Valentin et al. 2008), resulting in increasing soil erosion. This is mainly caused by splashing of rain, surface runoff scouring (Morgan 1995), and unsuitable land management. Use of structural techniques to prevent soil loss has been successful in developed countries, but this is not practiced in developing countries (Grimshaw and Helfer 1995) due to inability of farmers to bear the cost of soil conservation. Only cheaper and sustainable methods are acceptable to farmers.

In recent years, use of vetiver hedge barriers has proven successful in conserving natural resources in over 120 countries (Truong and Loch 2004). The vetiver hedgerow is a vegetative barrier of grass which is placed preferably along the contour, perpendicular to the direction of flow in the field to trap sediment, reduce runoff velocity, and increase infiltration (Babalola et al. 2007). It is a simple technology employing live plants for soil and water conservation, and is also an environmentally friendly technique (Greenfield 2008). Furthermore, it has been widely accepted by farmers as a suitable method with cost effectiveness, efficiency and more sustainability for conservation of soil than structural methods (National Research Council 1993).

Two vetiver grasses are used to conserve soil and water, namely Chrysopogon *zizanioides* (*V. zizanioides*) and Chrysopogon *nemoralis* (*V. nemoralis*) in Southeast Asia (Chomchalow 2000). These are native grass species of South and Southeast Asia (Chomchalow 2000; Dalton et al. 1996). The vetiver grass can quickly form a dense barrier when planted correctly (Greenfield 2008). It is tall and its root system grows rapidly and deeply (Dalton et al. 1996; Wong 2003). Vetiver grass can thrive in arid and humid conditions (Grimshaw and Helfer 1995). It resists variety of climatic conditions, such as temperatures from −10 to 50 °C and wide range of soil from pH 3.0–10.5 (Dalton et al. 1996). Vetiver grass can trap sediment due to high density of its hedge (Rodriguez 1997). Besides, it can retard flow of backwater and increase time for water to soak into the soil (Babalola et al. 2007; Hussein et al. 2007; Okon and Babalola 2005).

Some researchers have studied the effectiveness of vetiver hedgerows for reducing runoff and soil loss. Chaowen et al. (2007) found that *V. zizanioides* reduced runoff volume by 55–82 % and soil loss by 67–98 % on a 20 % land slope. Likewise, Rao et al. (1996) found that vetiver hedgerows reduced runoff volume by 56–67 % and decreased soil loss by 70–77 % on a 2.5 % land slope. Owino and Ralph (2002) assessed that vetiver hedgerows reduced runoff volume by only 12 % and soil loss by 48 % on 8 % land slope. Some scholars (Anusontpornperm et al. 1996; Babalola et al. 2007; Baowen et al. 1996; Inthapan et al. 1996; Jagannathan et al. 2003; Keerati-Kasikorn 1996; Rodriguez 1997; Sudhishri et al. 2008; Welle et al. 2006) also have evaluated percentage runoff volume and soil loss reductions by comparing the same plots with and without vetiver hedgerows. They found that vetiver hedgerows could reduce soil loss by 7–74 % of that occurs in similar plots without vetiver hedgerow system. Also, vetiver hedgerow can detain runoff by 35–94 % which occurs in similar plots without vetiver hedgerow system.

These reports show that vetiver hedgerows have good potential for reducing runoff and soil loss. However, the percentage reductions in runoff volume and soil loss are different. This is due to several parameters that can affect the sediment-trapping efficiency and runoff reduction of vetiver hedgerows (Rodriguez 1997). Thus, the dynamics of percentage reductions in runoff volume and soil loss were evaluated in this study. Moreover, most researchers have evaluated soil loss under vetiver hedgerows with land slopes less than 30 %. This experimental study considers larger land slopes between 30 and 50 %.

A few studies have developed equations for predicting soil loss under vetiver hedgerows system such as Sudhishri et al. (2008) and Welle et al. (2006). They analyzed soil loss based on the influence of runoff volume. It was necessary to add other factors to improve the accuracy and predictive ability function of the equation. Thus, experimental data from this study and from other previous studies were analyzed to develop soil loss equations for vetiver hedgerow system.

Therefore, the objectives of this study are: (i) to estimate percentage reduction in runoff volume and soil loss under vetiver hedgerow systems, (ii) to develop equations for estimating soil loss under vetiver hedgerow systems and (iii) to evaluate accuracy of the developed equations with the experimental data in this study and other previous research works.

Materials and methods

Field experiments were conducted at Kasetsart University, Kamphaengsaen Campus, Nakon Pathom province, Thailand. Three experimental plots were used; they were 2 m in width, 3 m in vertical height, 10.44, 8.08, and 6.71 m in length. Their land slopes were 30, 40, and 50 %, respectively. These slopes are characterized as steep slopes in the Soil Map of the World (Young 1997). The studied plots were demarcated by concrete bunds of about 30 cm, except at the downstream end. The experimental plots were designed with the same vetiver hedgerow systems. Each slope had four plots in which one was a control plot (bare soil without vetiver hedgerow) and the other three were vetiver plots (bare soil with vetiver hedgerows) having different vertical hedge intervals (*VI*) of (i) 0.75 m, (ii) 1.50 m, and (iii) 3.0 m, respectively. Before setting up the experiments, vetiver hedgerows (*V. nemoralis*) were grown for one year in planting ground areas each of 0.3 m wide and 2.0 m long with three replicates (number of stems and stem size were measured after testing). These vetiver hedgerows were moved from the planting areas and grown on the experimental plot across its slope. The hedgerows were left for one month before start testing to insure that the vetiver grass would reform in the soil before testing.

An artificial rainfall system was setup beside the experimental plot. In order to get the best results rainfall needed to be simulated. This required several criteria to make it similar to natural rainfall including drop size distribution, drop impact velocity (terminal velocity), vertical angle of impact, storm patterns, duration, and a uniform rainfall application over the entire test treatment. This rainfall simulator has a similar design concept as the single-nozzle simulator described by Meyer and Harmon (1979). The nozzles used on this simulator are 1/4HH-14WSQ Full Jet manufactured by Spraying System Co® in Wheaton, Illinois, USA. The simulator consists of an array of spraying nozzles that can produce raindrops with a median drop size of 0.5–4.3 mm in diameter. The flow to each nozzle was controlled by a compression stop valve

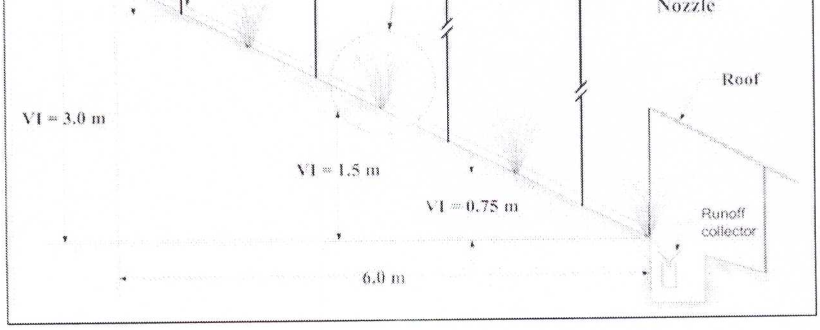
Nozzle
Roof
VI = 3.0 m
VI = 1.5 m
VI = 0.75 m
Runoff
collector
6.0 m

Table 1 Soil characteristics

Soil characteristics	Size			Bulk density (%)	Organic matter (%)
	Sand (%)	Silt (%)	Clay (%)		
Value	57.1	33.6	9.3	1.12–1.24	1.09–1.17

stems/m^2 with a standard deviation of 70.2 stems/m^2 and an average stem diameter of 11.8 mm with a standard deviation of 0.46 mm.

Results and discussion

Runoff

Runoff measured from the experiments with three land slopes (30, 40, and 50 %), three vertical hedge intervals (0.75, 1.5, and 3.0 m), and six rainfall amounts (52.5, 90.0, 127.5, 165.0, 202.5, 240.0 mm) are plotted and shown in Fig. 2. Runoff volume increases with rainfall amount for both control plots (bare soil plots) and vetiver plots. The values of runoff volume per testing area (depth of runoff) range from 12.1 to 144.6 mm for control plots and from 6.6 to 98.2 mm for vetiver plots. The runoff coefficients are 0.23–0.60 for control plots and 0.12–0.41 for vetiver plots. It is found that smaller *VI* reduces runoff volume more than larger *VI*. However, the runoff volume only slightly increases with increasing *VI*s. Runoff volume is found to decrease with increasing slope of the control plot.

This is because when the slope of control plot steepens, a more permeable soil layer is formed and therefore the final infiltration rate increases with land slope. This reduces the runoff volume accordingly. The same is true for other rainfall amounts. The results agree with those reported by Agassi et al. (1990); Assouline and Ben-Hur (2006); Warrington et al. (1989).

However, land slope did not affect runoff volume in the vetiver plots. This was also found by Rodriguez (1997) in the vetiver plots on 15 and 26 % land slopes under simulated field conditions in Venezuela, at the elevation of 1800 m above mean sea level.

Percentage reduction in runoff volume by vetiver hedgerows

The percentage reduction in runoff volume by vetiver hedgerows is shown in Table 2. In this study it was found that the vetiver hedgerow (*V. nemoralis*) reduces runoff volume compared with the control plots by 31–69 %. This is because of a combination of several processes. First, some rainfall is absorbed by the vetiver canopy. Second, the vetiver hedgerow reduces the flow velocity of runoff due to a relatively high roughness against the flow. This was also reported by Welle et al. (2006). Third, vetiver hedgerows act as a small permeable water barrier which stores water and increases infiltration rate; hence, the runoff volume is decreased.

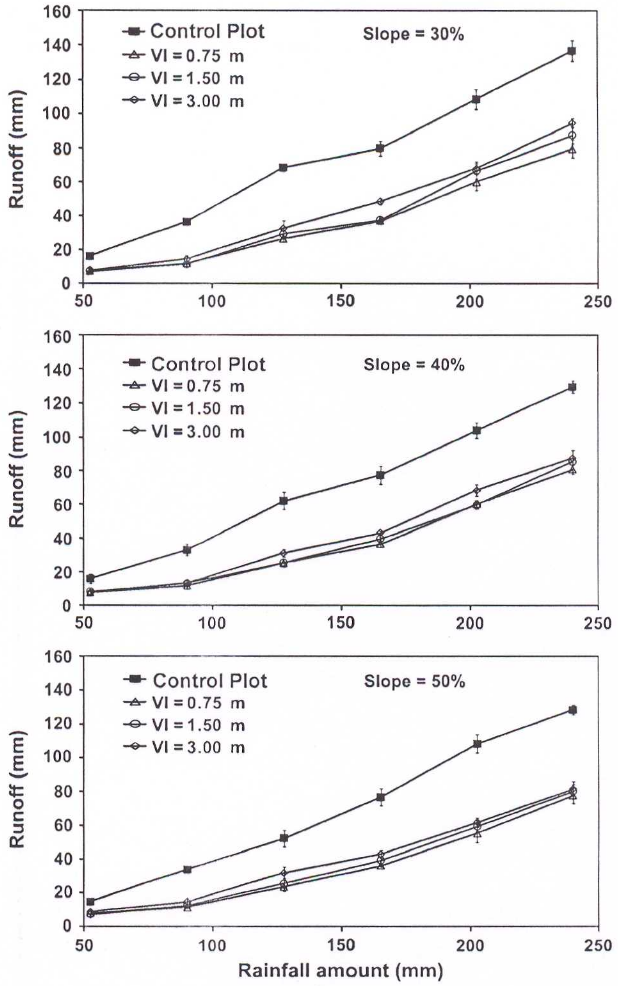

Fig. 2 Runoff volume versus rainfall amount (*bars* represent one standard deviation)

The percentage reductions in runoff volume in this study are similar to the results of Keerati-Kasikorn (1996), who found that one-year-old *V. zizanioides* reduced runoff volume by about 57 % on a 6 % land slope, and 100-day-old hedge reduced runoff volume by 73 % on a 3 % land slope. Their work was tested on loamy sand soil at Roi Et, Thailand. Likewise, Rao et al. (1996) found that vetiver hedgerows reduced runoff volume 56–67 % when tested at Rajendranagar, Hyderabad, India on a 2.5 % land slope. In addition, Welle et al. (2006) found that vetiver hedgerows reduced runoff volume by 62–63 % on a 9 % land slope in Jijiga area of the northern part of Somali region of Ethiopia. Also, Sudhishri et al.(2008) found that vetiver

Table 2 Experimental results on reduction of runoff volume and soil loss due to vetiver hedgerow system

Country	Land slope (%)	Width of vetiver hedge (m)	Vertical hedge interval (m)	Percent reduction		Source
				Runoff (%)	Soil loss (%)	
China	20.0	0.5	1.21	55–82	67–98	Chaowen et al. (2007)
	8.7–10.5	–	–	7–28	54–84	Baowen et al. (1996)
Ethiopia	9.0	1.0	1.98	62–63	56–62	Welle et al. (2006)
India	2.5	–	1.00	56–67	70–77	Rao et al. (1996)
	2.5	–	0.25	21–26	48–51	Jagannathan et al. (2003)
	2.5	–	0.37	16–24	44–48	Jagannathan et al. (2003)
	11.0	0.3	1.10	68–70	70–72	Sudhishri et al.(2008)
Kenya	8.0	–	–	12	48	Owino et al. (2006)
Nigeria	7.0	0.5	0.70	53–74	68–75	Babalola et al. (2007)
Venezuela	15.0	0.5	0.74	–	93	Rodriguez (1997)
	26.0	0.5	1.26	–	86	Rodriguez (1997)
Thailand	6.0	–	–	57	–	Keerati-Kasikorn (1996)
	3.0	–	–	73	–	Keerati-Kasikorn (1996)
	3.0	–	–	–	49	Anusontpornperm et al. (1996)
	4.0	–	–	–	53	Anusontpornperm et al. (1996)
	3.2	–	0.50	–	88	Inthapan et al. (1996)
	3.2	–	1.00	–	89	Inthapan et al. (1996)
	3.2	–	1.50	–	94	Inthapan et al. (1996)
	5.0	–	0.50	–	52	Inthapan et al. (1996)
	5.0	–	1.00	–	52	Inthapan et al. (1996)
	5.0	–	1.50	–	48	Inthapan et al. (1996)
	20.0	–	1.00	–	40	Inthapan et al. (1996)
	20.0	–	2.00	–	35	Inthapan et al. (1996)
	20.0	–	3.00	–	40	Inthapan et al. (1996)
	30.0	0.3	0.75	42–68	75–81	This study
	30.0	0.3	1.50	36–69	71–77	This study
	30.0	0.3	3.00	31–60	62–76	This study
	40.0	0.3	0.75	38–65	80–84	This study
	40.0	0.3	1.50	34–60	73–85	This study
	40.0	0.3	3.00	32–59	69–79	This study
	50.0	0.3	0.75	40–67	83–86	This study
	50.0	0.3	1.50	38–63	75–85	This study
	50.0	0.3	3.00	37–58	72–80	This study

hedgerows reduced runoff volume by 68–70 % on an 11 % land slope in Orissa, India.

However, the percentage reductions in runoff volume in this study are slightly less than the works by Chaowen et al. (2007), who found that *V. zizanioides* reduced runoff volume by 55–82 % on a 20 % land slope in China, and Babalola et al. (2007) who observed that vetiver hedgerows reduce runoff volume by 53–74 % on a 7 % land slope in the sub-humid region of Southern Nigeria.

On the other hand, the result of this study is much higher than the result of Owino et al. (2006), who stated that vetiver hedgerow reduced runoff volume by only 12 % on an 8 % land slope in Kenya. Jagannathan et al. (2003) reported that *V. zizanioides* reduced mean annual runoff volume by 16–26 % on a 2.5 % land slope in Tamil Nadu, India. Likewise, Baowen et al. (1996) studied the effects of water conservation of *V. zizanioides* in 50 months on 8.7–10.5 % land slopes in Guangdong province, located in southeast China. They found that *V. zizanioides* reduced runoff volume by about 7–28 %.

Many researchers have studied the effectiveness of vetiver hedgerows for conserving runoff volume as mentioned earlier. The percentage reduction in runoff volume varies from one case to another case depending on many factors such as width of the vetiver hedge, vertical hedge row interval, land slope, runoff volume, and soil characteristics, etc. In this study, the effects of three parameters namely: runoff volume, land slope, and vertical hedge

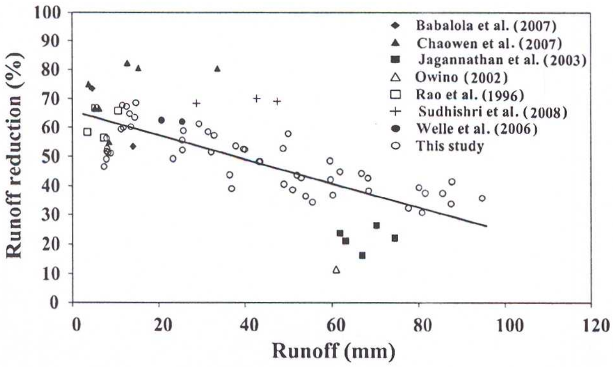

Fig. 3 Relationship of runoff volume and its percentage reduction

interval are considered. It is found that the effects of land slope and vertical hedge interval are not significant on percentage reduction in runoff volume. The runoff volume has a significant effect on the percentage reduction in runoff volume as shown in Fig. 3.

Figure 3 shows that the percentage reduction in runoff volume by vetiver hedgerow decreases when runoff volume increases.

Soil loss

To investigate the effects of rainfall amount, *VI* and land slope; soil loss versus rainfall amount for three slope gradients and three different *VI*s are plotted as shown in Fig. 4. It is found that soil loss increases with increasing rainfall amount for both control plots and vetiver plots. Soil losses range from 0.88 to 71.91 t ha^{-1} on the control plots and 0.13–17.37 t ha^{-1} on the vetiver plots. The smaller *VI* reduces soil loss more than the larger *VI*. The soil loss increases with land slope for both control plots and vetiver plots.

Percentage reduction in soil loss by vetiver hedgerows

In this study it is found that soil loss is greatly affected by the vetiver hedgerow system. The vetiver hedgerows (*V. nemoralis*) reduce total soil loss by 62–86 % compared with the control plots.

Percentage reductions in soil loss by vetiver hedgerows have been studied by other researchers. Babalola et al. (2007) found that the vetiver hedgerows reduced soil loss by 68–75 % on a 7 % land slope; Chaowen et al. (2007) reported that one-year-old 50 cm vetiver hedgerows reduced soil loss by 67–98 % on a 20 % land slope; Rodriguez (1997) pointed out that a 50 cm width of vetiver hedgerows can reduce soil loss by 93 % on a 15 % land slope and 86 % on a 26 % land slope; Sudhishri et al. (2008) reported that the vetiver hedgerows reduced soil loss by 70–72 % on an 11 % land slope. Other scholars (Anusontpornperm et al. 1996; Baowen et al. 1996; Inthapan et al. 1996; Meyer et al. 1995; Oscar and Rodriguez 2000; Owino and Ralph 2002; Rao et al. 1996; Welle et al. 2006) studied other various conditions, and found that vetiver hedgerows can reduce average soil loss from 35 to 94 % on land slopes of not more than 20 %.

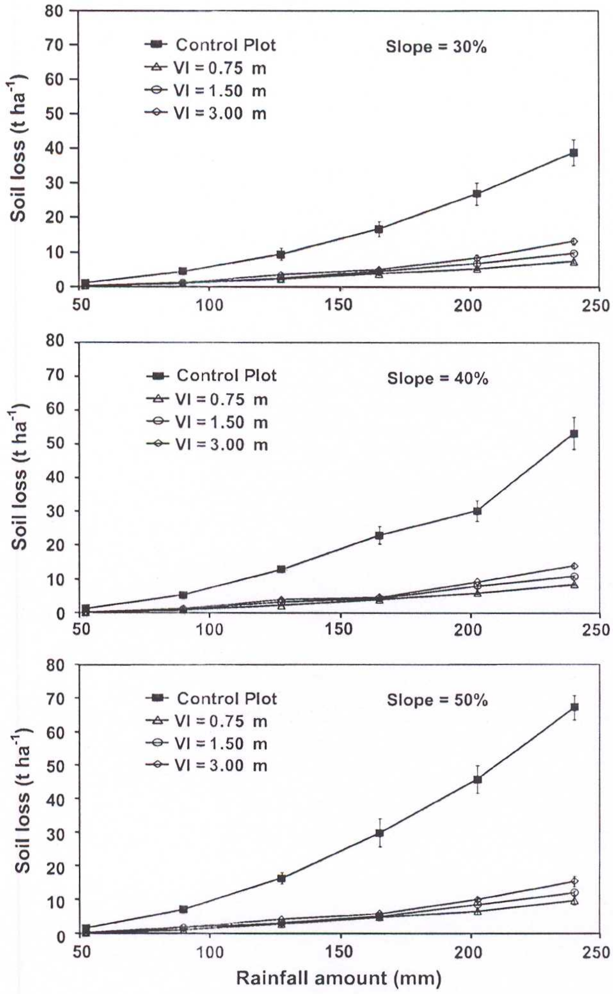

Fig. 4 Soil loss versus rainfall amount

The percentage reduction in soil loss depends on many parameters, for example soil characteristics, vetiver grass characteristics, rainfall characteristics, and runoff characteristics. However, in this study only the effects of vertical hedge row interval, land slope, and runoff volume are considered. It is found that the percentage reduction in soil loss increases with land slope. On the other hand, the percentage reduction in soil loss decreases with increasing runoff volume and vertical hedge interval as shown by Eq. 1.

$$E_f = 43.4\, VI^{-0.065}\, R_o^{-0.023}\, S^{0.188} \quad (1)$$

where E_f is percentage reduction in soil loss, S is land slope in percent, R_o is runoff volume in mm, and VI is the vertical interval between hedgerows in m.