Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol 2, No.5, 2012
www.iiste.org

Effect of Vegetation Cover on Sediment Yield: An Empirical Study through Plots Experiment

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Abstract

Rill and gully erosion is a critical environmental problem in India, where vegetal cover plays vital role in the runoff and soil loss reduction and stabilization of disturbed systems. Here, the impact of vegetal cover on runoff and soil erosion in lateritic environment was assessed through experimental observation on five plots (<*5 m^2 area*), containing varied vegetal cover at successive time period. Runoff and rate of soil loss were measured in each plot under seven natural rain storm conditions and compared them. The observed data showed bare plots experienced larger sediment yield than they are with vegetal cover. The simulation results corroborated significant relationship between the soil detachment and explanatory variables, e.g. runoff volume and vegetal cover ($R^2 = 0.95; P<0.001$). A very significant relationship was found between vegetal cover and sediment concentration (*Adjusted* $R^2 = 0.91, P<0.001$). This plot-scale study has the advantage of allowing for detailed process monitoring at micro scale, providing a basic description of the most relevant aspect of vegetal cover on sediment yield.

Keywords: Rill-gully erosion; lateritic environment; sediment yield; vegetation cover

1. Introduction

Rill-gully erosion plays a crucial role in soil erosion process; inflicts multiple and serious damages in managed ecosystems such as crops, pastures, or forests as well as in natural ecosystems (Zuazo et al. 2006; Zuazo and Pleguezuelo 2008). In India, approximately 3.97 million hectare area is affected by rills and gullies. In West Bengal, about 14% of the area is affected by water erosion, of which Puruliya is affected to the extent of 328 thousand ha, followed by West Medinipur (218 thousand ha), Bankura (199 thousand ha), Koch Bihar (174 thousand ha) and Jalpaiguri (132 thousand ha) (Pandey et al. 2011).

Runoff and soil loss by water erosion can be successfully controlled by protecting the soil with a soil surface cover which may aid to reduce runoff and soil loss under different environmental conditions (Poesen and Lavee 1991; Gyssels et al. 2005; Smets et al. 2007). In general, there are differences in soil properties between vegetation patches and open areas that may exert an important influence on soil and water fluxes. It is widely accepted that vegetation strongly reduces soil erosion rates via intercepting raindrops, enhancing infiltration, transpiring soil water and trapping some of the eroded sediment (Styczen and Morgan 1995; Bochet et al. 2000; Rey et al. 2007). These differences commonly result in lower runoff and sediment yields, and higher soil moisture contents in vegetation patches than in open areas (Bhark and Small 2003; Bochet et al. 2006). Vegetation patterns with high patch density can be expected to involve important obstructions to the surface flow and therefore increased opportunities for re-infiltration.

Plot-scale experimental studies are designed to understand interrelationship between the process involving hydrological, ecological and geomorphological factors (Wainwright et al. 2000). Plot-scale studies have the advantage of allowing for detailed process monitoring at large scale, providing a basic description of the most relevant aspects (Michaelides et al. 2009). This study is also useful in providing experimental data involving rainfall, surface runoff and soil erosion. Some researchers have highlighted the role of experimental studies at different scales, in light of the need to increase levels of complexity and connectivity in the study of processes (Bergkamp 1998; Cammeraat 2002).

To understand the effectiveness of vegetation in protecting the soil surface against erosion is not only scientific and environmental interest, but can be of great practical value in land management and agriculture in semi-arid lateritic environments. In the present study, we specially focused on the impact of vegetal cover in reducing runoff and soil loss and to analyze the interrelationship between vegetal cover, surface runoff and sediment concentration on lateritic land.

2. Materials and Methods

2.1 Experimental site

An experimental plot-scale studies was carried out at Vidyasagar University Campus (22°25′ 48.8 ″ N and 87°17′ 55.1 ″E), in Paschim Medinipur, West Bengal, India (Figure 1). To conduct the study, five closed experimental erosion plots (2 x 2.5 m) were developed on a lateritic upland area (inclination ≈ 12%), and each experimental plot was 2.5 m in length and 2.0 m in width, and 0.1meter in depth. Each experimental plot consisted of a synthetic nylon enclosure, drawer collector, and sediment and runoff tank. Experiment was carried out at different gradient slope (9° - 14°). The surface conditions as well as the slope for each experimental plot are different (Table 1). Soils are micro-aggraded sandy loam and the soil organic matter content ranges from 3.6 to 8.1%. Climatic factors such as rainfall and temperature regulate water availability and biological processes in the region. The climate of the region is semi-arid (mean annual temperature ≈ 28.4°C), and with a high inter-annual variability of rainfall (mean annual rainfall ≈ 1850mm). The vegetation cover is arranged in vegetated patches of one or several grass species. The grass used in the experimental plots are *Andropogon aciculate* (Poaceae), *Eragrostis cynosuroides* (Poaceae), *Panicum maxima* (Poaceae), and *Saccharum munja* (Poaceae); the leaves of which are 10-15 cm higher and grow very well.

2.2 Measurement of vegetation and soil properties

Before experiments, the grasses were transplanted onto the experimental plots and the coverage degree is calculated by the grass area occupied the surface area during experiment. The percentage of soil covered by grass species was recorded at the beginning of monitoring period. The whole area has been divided into 5 cm^2 grid cell. This percentage was determined by counting the number of grid intersections which intercepted vegetation (Zuazo et al. 2006, 2008).

At the same time, three soil samples were taken from each plot using a cylindrical corer (Metal rings: 25 cm long and 5cm diameter). The soil samples were stored at 5ºC temperature and analyzed within 15 days after collection. One of the two soil cores was used to determine bulk density (grams per cubic centimeter) at a depth of 0 - 20 cm by oven drying at 105ºC for 48 h. The collected soil samples were dried and 100g from each sample were mechanically sieved in the laboratory to sort the sediment into different grain size groups. The average and standard deviation of results after analysis in laboratory were recorded in table 1.

2.3. Measurements of rainfall, runoff rate and soil erosion

In the present study, rainfall in natural condition has been considered to carry out the experiment. Self recording rain gauge is used for measuring the rainfall. In the experimental plots, rainfall is commonly represented in millimeter per 24 hour period.

Runoff rate is directly measured by collecting overland flow samples at the lower end of the experimental plot during a certain time period through a container. Soil loss rates are determined by collecting, oven-drying and weighting sediment loaded runoff samples. Soil surface covered area was calculated to estimate soil and water conservation in the experimental plot (Poesen and Lavee 1991). Runoff and soil detachment under varied vegetation cover is compared with those in bare condition to get the value of relative runoff and relative soil detachment.

2.4 Statistical analysis

We explored the relationships between the explanatory variables and the independent variable by computing Pearson's correlation coefficient. Student t-test was used to measure the significance. Because of correlations and interactions between explanatory variables, correlation co-efficient may reveal only part of the relationship between vegetation cover and explanatory variables. Therefore, we also applied linear and multivariate regression analysis, to see how a variable varies in combination with the other variables. Furthermore it gives us an indication of the percentage of variability in vegetation cover explained by the chosen explanatory variables. Results were considered to be significant if $P<0.05$.

3. Results and Discussion

As the global environment alters plot scale studies may provide information about runoff mechanisms, soil erosion and vegetation dynamics process that result from these changes. The potential for retaining resources, especially water, within the system is crucial to ecosystem functioning in semiarid and lateritic upland area.

3.1 Rainfall, runoff and sediment concentration

On the experimental plot area, the natural rainfall was recorded through rain gauge and considered to determine its role on runoff and sediment yield. The total amount of rainfall during the experiment is given in figure 2. During the two months study period, highest rainfall amount was recorded (60 mm) in 6th -14th August, 2011. At the experimental plot, runoff events were relatively frequent. Both runoff and sediments produced by individual rainfall events showed a highly skewed distribution e.g., 0.84 and 0.45 respectively. On an event basis, plot runoff was positively correlated with the rainfall amount ($r = 0.51, P<0.003$). However, total runoff and sediment concentration varied greatly between the experimental plots (Table 2), ranging from 202.55 liter to 1473.72 liter (581.68 ± 63.88), and from 0.072 kg to 0.85 kg (0.36 ± 0.04), respectively. No any significant relationship was found between the total runoff and sediment concentration ($r = 0.27, p<0.020$) on the experimental plot, and it may be due to the effect of vegetation coverage on plots. However, earlier studies have shown that vegetation pattern also plays an important role in functioning of semiarid ecosystems (Bautista et al. 2007; Kéfi et al. 2007).

3.2 Vegetation covers versus relative soil detachment and runoff

One of the most important factors in predicting soil detachment is the effect of vegetation cover. Vegetation cover (grass surface) during the first period did not affect measurable runoff or sediment yield prior to onset of monsoon. As the rain stabilized, vegetative cover became more dominant. However, vegetation cover and its functional diversity showed significant correlations with the hydrologic response variables (Table 3). To determine the independent effect of vegetal cover on runoff and relative soil detachment, we used partial correlation analysis, controlling for the effects of the variables correlated with vegetal cover (percent of surface cover). We found a negative independent effect of vegetal cover on relative soil detachment ($r = -0.95, p= <0.002$) and on relative runoff volume ($r = -0.94, p = 0.001$). However, an explanatory analysis of these data derived from experimental plots suggested a very significant linear relationship between soil detachment and explanatory variables (relative runoff volume and vegetal cover) (*Adjusted* $R^2 = 0.95, df = 2, p = <0.001$). Previously, this result is also proved and established by other researchers (Dillaha et al. 1988; Xiong et al. 1996; Zhang and Liang 1996; Van Dijk et al. 1996). Hence, in the hillslope–gully side erosion system, the grass coverage degree must be increased in order to reduce soil loss.

Vegetation cover is considered a good explanatory variable for runoff and sediment yields (Elwel and Stocking 1976; Thornes 1990). The analysis of our result showed a significant interaction between sediment concentration on percent of vegetation cover and surface runoff (*Adjusted* $R^2=0.95, p<0.008$). The regression coefficients and the significance levels are given in table 4. The results also indicate that soil detachment increases with decreasing the percent of vegetal cover and increasing with the surface runoff (Figure 3). As the rainy period continued, vegetation and biological activity interacted with soil, increasing porosity and enhancing soil storage capacity.

3.3. Vegetation covers versus sediment concentration

Another important observation from this study was the sediment concentration in the experimental plot. During the study period, 35 precipitation-runoff-sediment yield events were recorded and their physical properties were evaluated. It was observed that as the rainy period progressed, the vegetation density increased, along with the increase infiltration capacity and soil water storage, and consequently sediment concentration dropped to below 0.072. Thus vegetal cover was negatively correlated to sediment concentration (figure 3), because vegetal cover in the plots most dense at the end of the rainy season. A very significant relationship was found between vegetal cover and sediment concentration (Adjusted $R^2= 0.91$, $p=<0.001$). Initially, the concentration of sediment was very high (Figure 3); it may be due to less the vegetal cover, however, the concentration of sediment decreases by increasing vegetal cover on the surface in the experimental plot. Rogers & Schumm, (1991) demonstrated that sediment yield increases rapidly as vegetative cover decreases from 43% to 15%, but with less than 15% vegetative cover the rate of increase of sediment yield diminishes markedly.

4. Conclusion

Our results present empirical evidence for the relationship between the hydrologic response of lateritic lands and functional diversity of vegetation. The effect of spatial distribution of grass cover on the sediment yield is obvious. The present study suggests that an increasing in vegetation cover has a negative effect on sediment yield. In general, plant's structural attributes are better explanatory variables for runoff and erosion than soil surface attributes. The present study is based on only five plots each monitored for seven storms. A furthers detailed and continued study may yield considerable value of data, that may enable to draw concrete inference.

Acknowledgement

We would like to thanks to Vidyasagar University, Department of Geography for providing laboratory facility to carry out the research work. We are also very much thankful to Nityananda and Rabindra for their assistance during the data collection.

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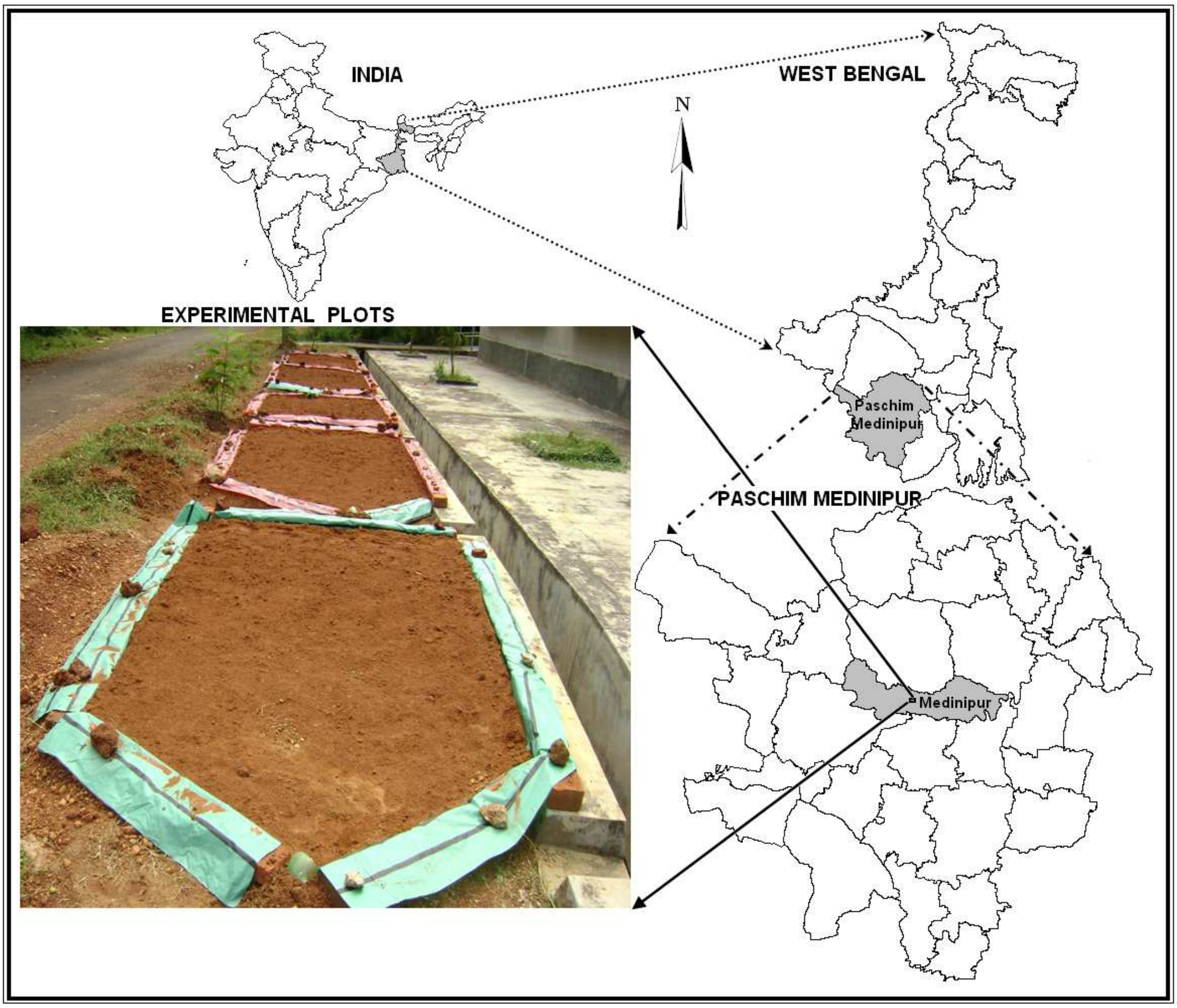

Figure 1. Location map and Experimental plot

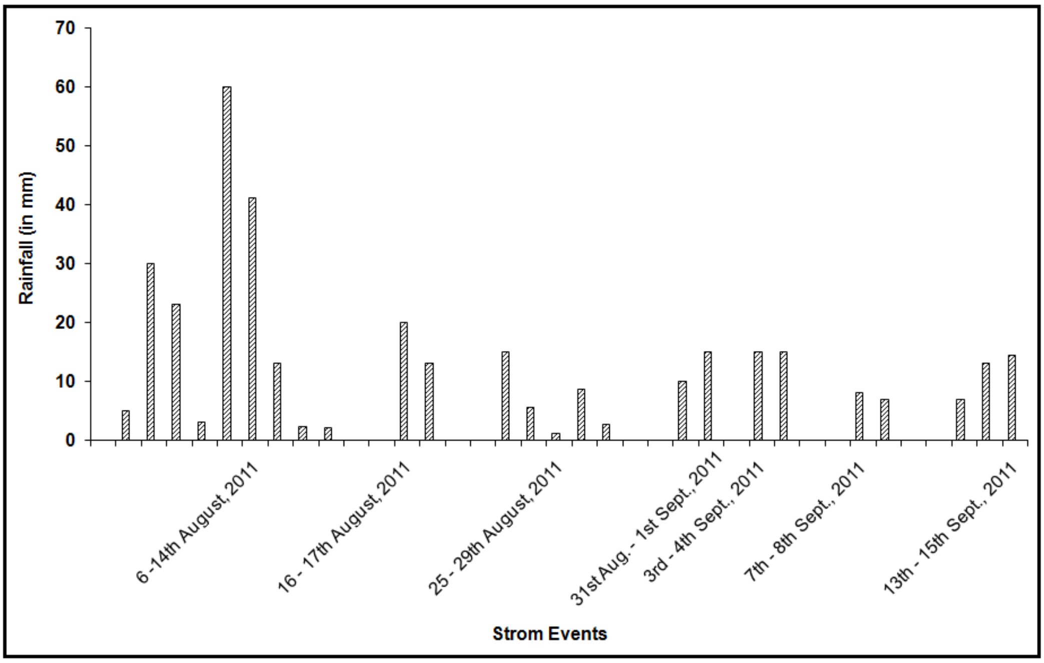

Figure 2. Amount of rainfall during the experiment, collected from the experimental plots using rain gauge.

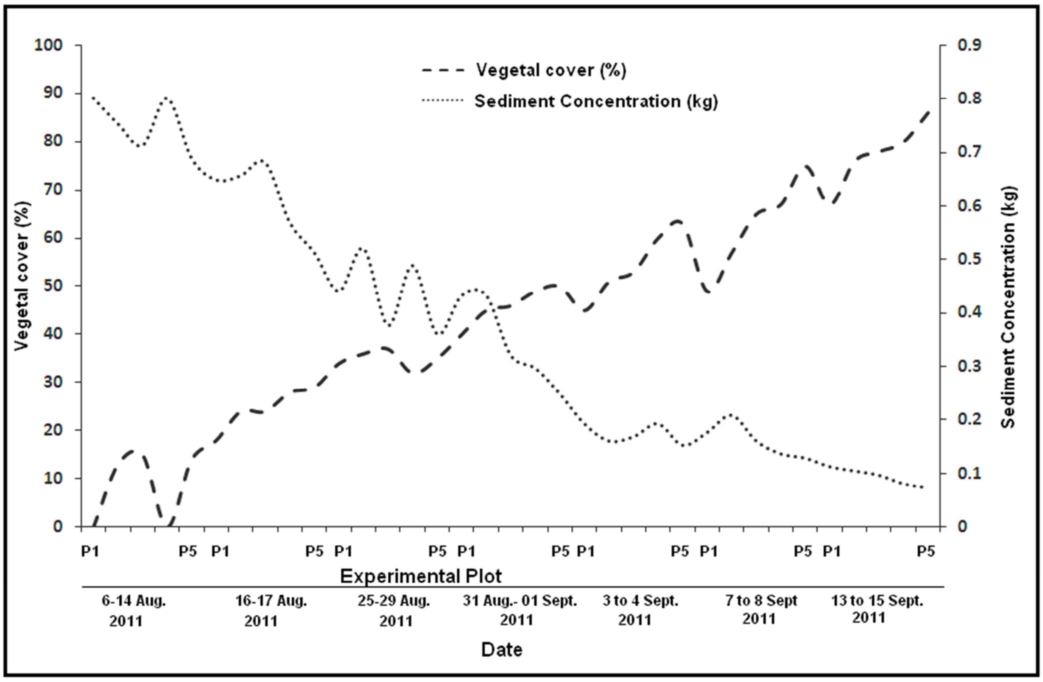

Figure 3. Line graph, showing the relationship between vegetal cover and sediment concentration at different experimental plots during the study period.

Table 1. Particle size distribution of the surface soil (0-20 cm depth) on the experimental plots (P1-P5)

Micro-aggraded Sandy loam soil	Slope gradient in degree	Sand (>0.06 mm) (in %)	Silt loam (0.002-0.06mm) (in %)	Clay (<0.002mm) (in %)	Bulk density (g/cm3)
P1	12	48.33±5.68	33.00±2.64	18.66±6.11	1.16±0.47
P2	13	45.00±3.00	36.33±3.51	18.66±5.77	1.23±0.15
P3	9	46.00±3.46	37.00±2.64	17.00±6.08	1.40±0.40
P4	14	41.33±2.88	32.00±2.64	26.66±0.57	1.43±0.15
P5	10	45.66±0.57	38.66±2.08	15.66±2.51	1.46±0.25

Mean values ± SD

Table 2. vegetation cover, runoff and sediment concentration during the study period

Period	Vegetation cover (%)	Relative soil Detachment	Relative runoff volume
Period1 (6 to 14 August , 2011)	8.4±7.70	0.938±0.06	0.926±0.93
Period2 (16 to 17 August , 2011)	25±3.61	0.766±0.09	0.744±0.06
Period3 (25 to 29 August , 2011)	34.8±1.92	0.546±0.09	0.658±0.12
Period4 (31 August to 01 Sept, 2011)	46±3.94	0.432±0.10	0.462±0.11
Period5 (3 to 4 Sept, 2011)	54.4±7.19	0.216±0.02	0.248±0.04
Period6 (7 to 8 Sept, 2011)	62.6±9.93	0.202±0.04	0.182±0.04
Period7 (13 to 15 Sept, 2011)	77.4±6.91	0.116±0.02	0.15±0.03

Table 3. Relationship between the explanatory variables (runoff and soil detachment) and independent variable (vegetation cover) in the experimental plot during the study period.

Period	Relative soil Detachment	Relative runoff volume	Significance level
Period1 (6 to 14 August , 2011)	-0.91 (-3.91)	-0.89 (0.3.36)	<0.05
Period2 (16 to 17 August , 2011)	-0.81 (-2.41)	-0.76 (-2.05)	<0.05
Period3 (25 to 29 August , 2011)	-0.37 (-0.68)	0.49 (0.99)	>0.05
Period4 (31 August to 01 Sept, 2011)	-0.87 (-3.13)	-0.86 (-2.95)	<0.05
Period5 (3 to 4 Sept, 2011)	-0.38 (-0.71)	-0.95 (-5.23)	<0.05
Period6 (7 to 8 Sept, 2011)	-0.77 (-2.11)	-0.70 (-1.72)	<0.05
Period7 (13 to 15 Sept, 2011)	-0.93 (-4.30)	-0.98 (-7.95)	<0.05

**Correlation (Student t-test)*

Table 4. Multivariate Regression result considering % vegetation coverage as independent and soil detachment and runoff rate.

Variables	Coefficient	Standard error	T-stat	*P-value*
Intercept	0.36 (0.10-0.63)	0.13	2.78	0.008
% vegetation cover	-0.005 (-0.008- -0.001)	0.002	-2.93	0.006
Relative runoff volume (liter)	0.64 (0.38-0.88)	0.12	5.09	<0.000

Adjusted R^2*=0.95, n=35*