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The Rain Drop Impact on the Water Discharge and Sediment Transport under the Full-Scale Test

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***Abstract*—The magnitude of soil erosion by water remains high in the tropical regions. The construction activities further worsen this process which leads to the undesirable effects. The newly constructed highway embankments usually remain bare and are considered to be the prime agent of soil loss. The soil surface with an appropriate cover helps restricting the soil detachment for which many agronomic soil conservation practices have been used. This paper integrates that why a simple grass cover has been recommended to cope with this inevitable issue. It further assimilates the results obtained from a full scale test conducted in the Perak State Malaysia under the simulated rainfall condition of 40 mm/hour (average rainfall event) for which the rainfall data was obtained from the Meteorological department Perak State, Malaysia from the year (2005-2011). The volume rate of water flow and sediment transport was observed at different time intervals for three plots i.e. (Plot-I) the fully grass covered surface, (Plot-II) the bare soil surface, and (Plot-III) 50% of the grass covered surface with an area of 2 meters by 6 meters having a slope angle of 30°. The results obtained showed maximum water discharge and soil loss for (Plot-II) the bare soil surface, which was found to be 5.78 x 10^{-5} m^3 sec^{-1} and 500.9 g m^{-2} respectively.**

***Index Terms*—Bare soil, Grass cover, Soil detachment, Volume rate of water flow**

I. Introduction

ENGINEERING practice requires knowledge on rainfall and runoff response for developing the humid tropical regions [1]. Soil erosion is an inevitable process which cannot be neglected [2]. It is such an issue for which it is appropriate to say "think globally, act locally" as it leads to the problems which are responsible for both on-site and off-site affects [3]. Erosion is one of the vital environmental issues which spoils the nutrient-rich top soil and increases the concentration of pollutants in the water bodies for which the treatment of the diffused pollutants at its source is considered effective [4].

Figure 1 illustrates that slope degradation is mainly caused by surficial erosion and mass movement. However, this paper concerns with the surficial erosion which is responsible for the detachment and transport of the individual particles for which grasses are suggested to be one of the most effective measures that can help mitigating this process [5].

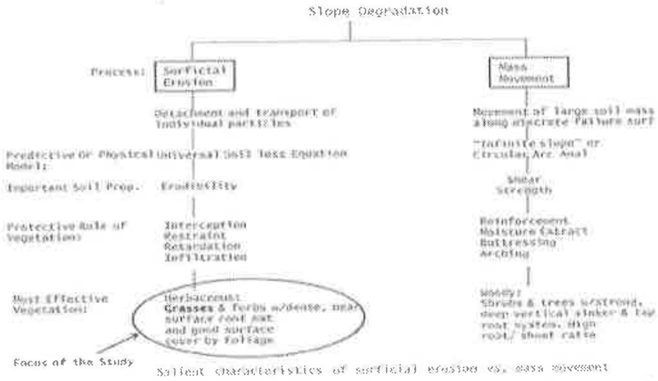

Figure 1. Salient Characteristics of Surficial Erosion vs. Mass Movement [5]

Planting grass as a land cover on the slopes for restricting soil loss is suggested to be an inadequate selection [6]. On the other side, land cover has been favored against erosion as it influences the flow velocity of runoff which is correlated with the detachment of soil particles [7]. A diminution in sediment production was observed by 31% in the catchment area caused by gully erosion in Chinese loess plateau, when a farmland was decreased by 46% and the forestland and grassland were increased by 42% [8] which shows that the increment in the grass cover gives prominent resistance against soil loss [9]. Herbaceous vegetation has been recommended as more effective than woody vegetation in controlling surficial erosion [5] as the high roughness of grass allows water to infiltrate [4]. It germinates quickly and provides complete cover with a dense root network which strengthen and ties the soil particles [10]. It further softens the raindrop impact on the soil surface which conserve soil [11]. Its implication is therefore suggested to be much more reliable conservation measure as it is the best natural protector of soil than the artificial methods [12].

Soil Erosion relates to the impact of rain drop which is the most significant factor as it loosens, erodes and removes the soil particles from their place of origin. This affects the soil geometry and undermines the soil arrangement, resulting in its failure. It allows the detached particles to flow with the surface runoff which then reaches the rivers and the process of deposition occurs which deteriorate the water quality and

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affects the marine life. It is therefore suggested to tackle the phenomenon at its point of occurrence. The primary objectives of the study were to observe the behavior of Plot-I, Plot-II, and Plot-III against soil erosion and water discharge under the average rainfall event obtained for the Perak State, Malaysia. Several literatures were reviewed to justify grass efficiency against soil loss. Based on the following reasons the grass cover was recommended.

A. The Grass Structure

Figure 2 shows the description of a simple grass structure which clarifies that why its use has been recommended by the previous studies. The *Gramineae* family of plants for which the common name is "Grass" is one of the largest families on earth having more than 9000 known species. The grass structure is very simple having fibrous roots at the base which grasp into the soil, collect nutrients and protect the plant. The culms which are also called grass stems originate from the crown. The culms are stiff in many of the grass species except at the joints (nodes).The leaves raise from the culms with the alternate directions. The first leave originate from right, the second one from the left and so on. The upper part of the leaf is called blade and the lower part is called sheath. The connection between the blade and sheath is surrounded by a ligule which is in the form of thin membrane. Through photosynthesis grass collects the energy from the sun and the green color of grass is due to the presence of photosynthesizing chlorophyll in the leaf. The rhizomes are the stems that grow below the grass and the stolons are the stems that crop along the ground [13].

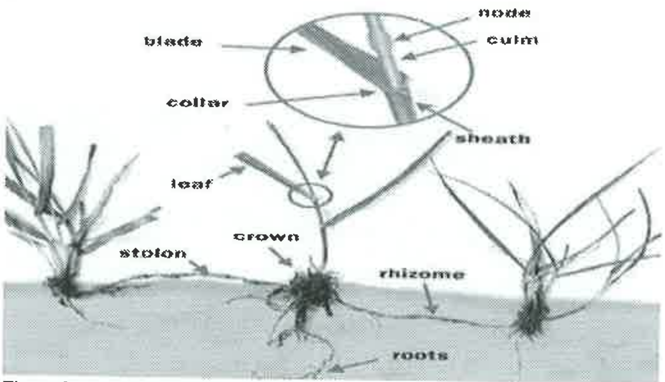

Figure 2. A Simple Grass Structure [13]

B. The Influence of Roots

The integral part of the plant which is also called the root zone is mostly disregarded. The major function of the root includes absorption, anchorage, and hormone synthesis. Absorption of nutrients and water from soil is the primary purpose of the roots which helps growing shoot zone. Roots firmly fix the plant and make it stable which restricts it from being blown away and washed away. Roots are considered to be the principal source of gibberellins and cytokinins which are considered as a necessary medium for the development of shoot zone [14].

C. The Planting Opportunities at Different Slope Angles

The increment in the slope angle increases the chances of soil loss. However, based on the slope inclination Figure 3 shows different planting opportunity mitigating and controlling soil loss. Grass cover has been suggested for almost all the inclined planes whereas planting of trees is recommended only for the slopes which are less than 35°, similarly shrubs are proposed for the inclined planes of 45°, and for the slope inclination of 55° erosion control mats have been preferred [15].

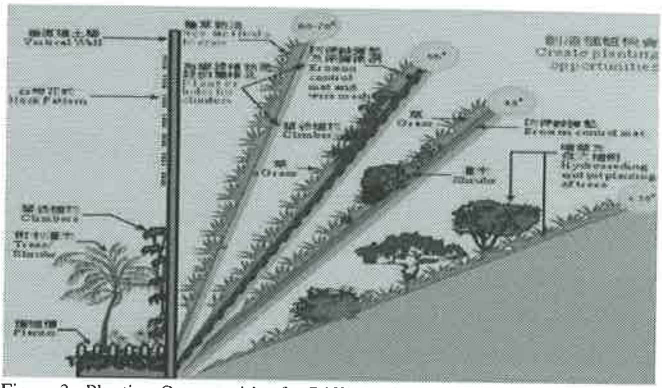

Figure 3. Planting Opportunities for Different Slope Angles [15]

D. Grass Efficiency against Runoff and Soil Loss

Surface runoff is inversely proportional to grass cover percentage. Increment of the grass cover decreases the surface runoff as it hindrances the flow velocity which decelerate the flow speed and reduces its impact on the soil surface. The surface runoff observed from the grass cover at 0-10%, 20-30%, 40-50%, 60-70%, and greater than 80% was found to be approximately 42 liters, 39 liters, 36 liters, 15 liters, and 06 liters respectively at the time interval of 35 min as shown in Figure 4 [9].

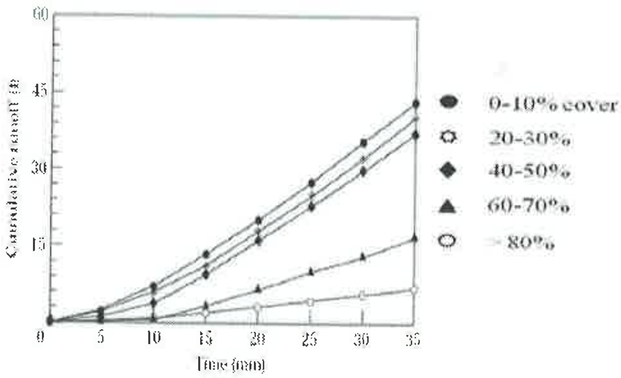

Figure 4. The Influence of Grass Cover on Runoff [9]

Table I states the soil loss values which were obtained at different rainfall intensities for three plots, Plot A (grass covered plot), Plot B (mulch covered plot), and Plot C (bare surface). The maximum soil loss was observed from Plot C for all the rainfall events. However, the difference between the soil loss from grass covered and mulch covered surface under the middle rain, heavy rain, rainstorm, and heavy storm were 0.0017, 0.0013, 0.0013, and 0.0015 kg mm^{-1} ha^{-1}. Except for

TABLE I
EROSION OBSERVED AT DIFFERENT RAINFALL INTERVALS FOR THREE DIFFERENT PLOTS

Rainfall Pattern	Date	Rainfall Intensity (mm h^{-1})	Sediment Yield		
			A (kg mm^{-1} ha^{-1})	B (kg mm^{-1} ha^{-1})	C (kg mm^{-1} ha^{-1})
middle rain	10thDec, 2003	0.8830	0.0137	0.0120	0.3299
heavy rain	17thApril,2004	1.3826	0.0025	0.0038	0.0440
rainstorm	21stFeb, 2004	2.5592	0.0038	0.0051	1.0998
heavy storm	17th July, 2002	5.1455	0.0042	0.0057	6.2789

the middle rainfall event, the grass cover was found effective in controlling the soil loss for heavy rain, rainstorm, and heavy storm events [16].

(Source: LI Xin-Hu, 2010)

A study reveals that 90% of erosion reduction was observed by establishing 60% of the grass cover when compared with the bare surfaces [17] as it matures and spread quickly with a good dense surface coverage that prevent soil loss. However, shrubs are more expansive to plant and their germination period is long and considered difficult to establish [5]. Table II shows the average runoff and soil loss rate for the grass and shrub cover. Grass cover showed adequate results when compared with the shrub cover at the rainfall intensity of 45 mm/hr. Whereas, for the rainfall intensity of 87 mm/hr and 127 mm/hr shrub cover showed prominent results both for the average runoff and average soil loss rates [18].

TABLE II
AVERAGE RUNOFF AND SOIL LOSS RATES FROM GRASS AND SHRUB COVER

Rainfall Intensity (mm/hr)	Average Runoff rate (mm/hr)		Average Soil loss rate (g/min.m^2)	
	Grass	Shrub	Grass	Shrub
45	4.2	9.3	4.2	9.3
87	31.9	25.9	31.9	25.9
127	73.1	58.2	73.1	58.2

(Source: Xiao, P, 2011)

II. METHODOLOGY

A. Site location and Rainfall data

The study was conducted at Universiti Teknologi PETRONAS, Perak Malaysia. Three plots were constructed with the dimension of 2 meters by 6 meters to study the water discharge and sediments transport under the rainfall intensity of 40 mm/hour as shown in Figure 5. The rainfall data for the Perak State was obtained from Meteorological Department Malaysia. The data analyzed for this study was from the year 2005 to 2011. The study was conducted for the slope angle of 30° which represents the road side slopes and embankments that remain bare after the construction and aids to the soil erosion.

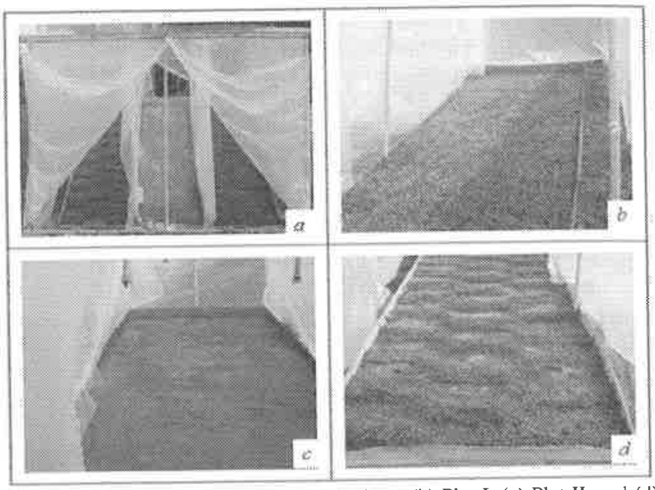

Figure 5. (a) Site Location of the Study Area, (b) Plot-I, (c) Plot-II, and (d) Plot-III

B. Experimental procedure

The study was performed individually on each plot as shown in Figure 6. Once the rainfall simulation was started the flow that generated was collected in the container which was placed at the bottom to calculate the water discharge received after every 15 minutes for a period of two hours. Similarly, the soil samples were collected after every 15 minutes which were then dried in the oven for 24 hours at 105 °C to determine the amount of soil detached by the raindrop impact and surface flow.

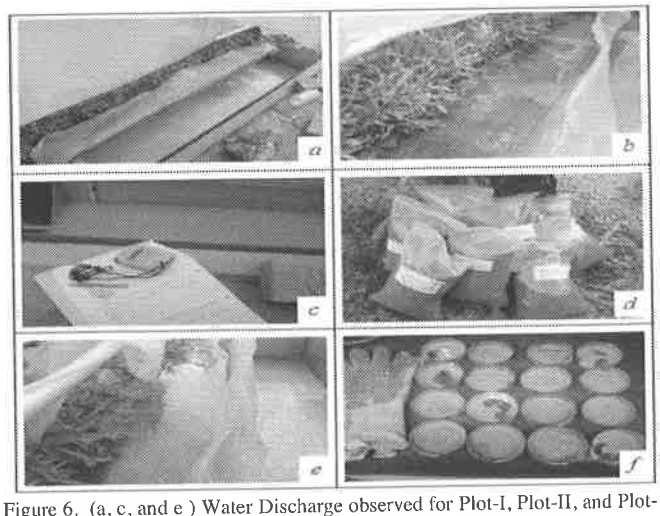

Figure 6. (a, c, and e) Water Discharge observed for Plot-I, Plot-II, and Plot-III, (b, d, and f) Eroded Soil from Plot-I, Plot-II, and Plot-III

III. RESULTS AND DISCUSSIONS

A. Water Discharge

Figure 7 shows the values for the water discharge obtained from Plot-I, Plot-II, and Plot-III under the rainfall intensity of

40 mm/hour at different time intervals of 15 min, 30 min, 45 min, 60 min, 75 min, 90 min, 105 min, and 120min.

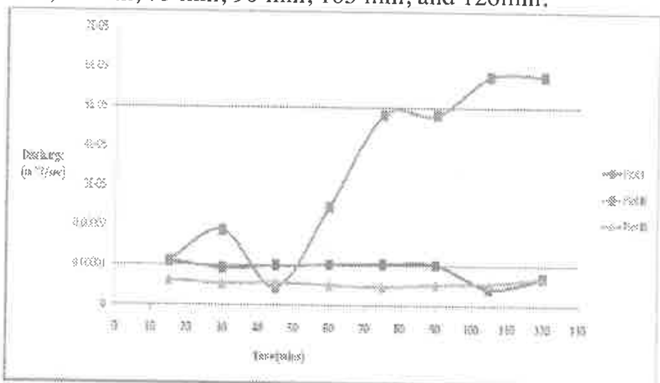

Fig. 7. The Water Discharge observed for Plot-I, Plot-II, and Plot-III under the rainfall intensity of 40 mm/hour

B. Sediments Transport

Figure 8 shows the values for the soil particles which were eroded from Plot-I, Plot-II, and Plot-III under the rainfall intensity of 40 mm/ hour at different time intervals of 15 min, 30 min, 45 min, 60 min, 75 min, 90 min, 105 min, and 120min.

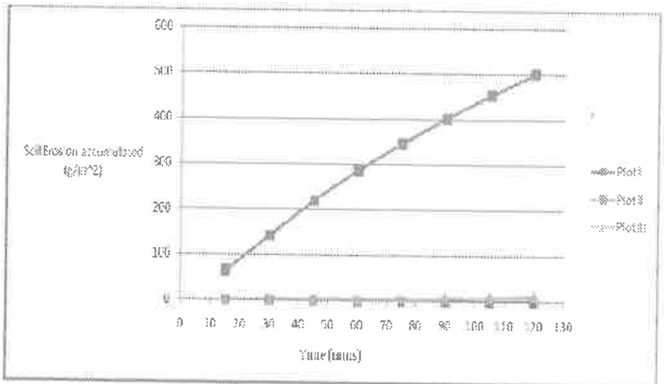

Figure 8. Eroded Soil Particles observed from Plot-I, Plot-II, and Plot-III under the Rainfall event of 40 mm/hour

The maximum values obtained for water discharge under the rainfall event of 40 mm/hour from Plot-I, Plot-II, and Plot-III were 1.10 x 10^{-5} m^3 sec^{-1}, 5.78 x 10^{-5} m^3 sec^{-1}, and 6.87 x 10^{-6} m^3 sec^{-1} respectively at different time intervals. The water discharge was observed to be very low from Plot-III as compared to Plot-I and Plot-II. However, for the water discharge Plot-III showed adequate results which were comparatively lower than the values attained from Plot-I and Plot-II.

The soil loss was negligible from Plot-I under the rainfall event of 40 mm/hour. The maximum value obtained for detached particles under the rainfall event of 40 mm/hour from Plot-II was 500.9 g m^{-2} and for Plot-III, the value was observed to be 11.94 g m^{-2}. The results obtained for the soil loss under the simulated rainfall intensity of 40 mm hr^{-1} shows that the increment in grass cover reduces the detachment of soil particles.

IV. Conclusions

The study limits that the results obtained are suitable for the slope angle which are less than 30° and for the soils whose texture contains the sandy loam. However, to provide immediate protection to the bare road embankments the exposed soil surface must be sheltered. The research revealed that under the rainfall event of 40 mm hr^{-1} there was observed a minimal soil loss from Plot-III whereas the discharge was found to be very low from Plot-III as compared to Plot-I and Plot-II. Therefore, such an implementation should be favored to provide sufficient protection to the soil surface which remains exposed to the raindrop impact.

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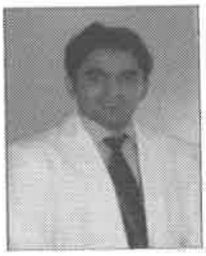

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