INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 13, Issue 2, April-June 2022: 679-694 www.ijcs.uaic.ro

ASSESSING THE EFFECTIVENESS OF HYDROMULCHING AS A RAPID SOIL EROSION CONTROL MEASURE: A STUDY IN LANGAT SUB BASIN, PENINSULAR MALAYSIA

Mohammad Zahirul HAQUE[1, 2*], Mohammad Imam Hasan REZA[2*], Sahibin Abd RAHIM[3], Khairul Nizam Abdul MAULUD[4]

[1]Bangladesh Forest Department, Ban Bhaban, Agargaon, Dhaka 1207, Bangladesh
[2]Centre for Environment and Sustainability, Presidency Education, Chittagong 4203, Bangladesh
[3] School of Environmental & Natural Resource Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[4] Department of Civil & Structural Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Abstract

Malaysia like many Southeast Asian countries is experiencing a large-scale soil erosion problem. The catchment area along with the Universiti Kebangsaan Malaysia (UKM) located in the Langat River basin in Peninsular Malaysia releases a substantial amount of sediment. Hill slopes are of sedimentary rock, susceptible to erosion from surface runoff. Establishing permanent vegetation cover is known to be an effective measure to control severe erosion. The objective of this study is to estimate the performance of hydro-mulching as a rapid control measure for soil erosion. Rainfall was measured using the digitized HBO data logger. We measured TSS concentration and discharge rates of the barren and three natural vegetation covered plots from the water samples collected during rainfall events. TSS concentration and discharge rates were measured in hydro-mulched plots. All plots were demarcated by natural fragmentation and hand prepared thin drains on top, right, and left of the slopes, wherever was necessary. The plots were digitized using ArcGIS 9.3 which measured their area slope and elevation. Validation was done through extensive field visits and reviewing existing studies. Our study shows that the performance of experimental vegetation- Resam, Vetiver, and Elephant creeper has effectiveness in controlling erosion. It may suggest that hydro-mulching is an effective measure of controlling the rapid soil erosion on the steep slope.

***Keywords**: Sediment yield; Steep slope; Barren hill forest; Soil erosion in tropics; Runoff water*

Introduction

Malaysia like many Southeast Asian countries is experiencing a large-scale soil erosion problem [1]. Sediment yield in the upper Langat catchment (Universiti Kebangsaan Malaysia, UKM catchment) under the Langat River basin in Peninsular Malaysia shows 28.78 tons/ha/year of sediment yield. The rate of erosion in this catchment is significantly high. Moreover, most of the hillslopes are of sedimentary rock, susceptible to erosion from surface runoff [2, 3]. The UKM practices regular trimming of grass on the slope at ground level, especially in the roadside bottom slopes. This practice regularly exposes the bare soil and causes erosion. Further, the construction of roads and buildings in the hilly site and at the steep

* Corresponding author: zahirfd@yahoo.co.uk (MZH); rezamih@gmail.com (MIHR)

slopes also accelerate soil erosion. Generally, soil loss rates from construction sites can be 10 to 20 times more than that of agricultural lands [4, 5]. The areas where topsoil is disturbed or cleared of vegetation are particularly subject to erosion. These areas often present a challenge in re-establishing vegetation to protect the soil to improve soil quality and fertility [6 - 8]. In addition, heavy machinery and constant traffic compact the soil creating a “hard pan” that decreases infiltration and increases runoff and prevents plant establishment and growth [9, 10].

There are numerous measures practiced for erosion control. Seeding of grass and planting of trees, shrubs, and ground covers provide long-term stabilization of soil. Grass may also be planted for temporary stabilization [11]. Whilst mulching is a temporary ground covering that protects the soil from rainfall impacts, increases infiltration, conserves moisture around trees. Beside shrubs, seeding prevents compaction and cracking of soil, and aids the growth of seeding and plants by holding the seeds, fertilizers, and topsoil in place until growth occurs [12 – 14]. Mattings are made of natural or synthetic materials, which is used to temporarily or permanently stabilize the soil. Mattings reduce erosion from rainfall impact, hold soil in place, absorb and hold moisture near the soil surface [15, 16]. Among other physical stabilizations- Temporary Waterway Crossing [17], Construction Road Stabilization, Diversion of Runoff, Sediment Trapping/Filtering, Flow Velocity Reduction, and such others are effective [18]. The American “National Pollution Discharge Elimination System” urges best management practices (BMPs) for temporary and permanent vegetation establishment and storm water pollution prevention plans [19].

As it is reported, one of the best ways to reduce runoff and control erosion is to establish permanent vegetation as quickly as possible [20 – 22]. Densely grassed areas are nearly equal to undisturbed forests in preventing soil loss [9] and therefore grasses are often specified for erosion control on such critically bared sites [23]. The foliage of dense vegetative covers can intercept between five and 40 percent of total precipitation, never allowing it to touch the soil surface, thus reducing runoff and potential soil loss [9, 24]. Hydro-seed and/or mulching are considered standard practices for applying on construction sites and highly disturbed soils where vegetation establishment is required to prevent accelerated erosion or to stabilize slopes [25]. Therefore, in this study, we consider of measuring the sediment yield from the selected barren and hydromulch applied plot and the naturally grown Resam, Vetiver and Creeper covered plots within the similar physical features in the upper Langat catchment (UKM catchment). The main objective of this study was to estimate the performance of hydromulching as a rapid control measure for the soil erosion.

Methodology

Study area

The study was conducted in four plots in the upper Langat catchment (UKM catchment) area. Among those, one was a barren and afterward hydromulch applied plot and the other three were covered by naturally established Resam (*Dicranopteris decumbens*), Vetiver (*Chrysopogon zizanioides)* and Creeper (*Argyrela nervosa*). Hydromulch was applied on the barren plot of 4340.32m^2. The geological aspect of the area is weathered sedimentary rock. The soil texture ranges from coarse to fine sandy clayunder the soil series of‘Muchong-Seremban’. Sampling points for collecting sediments were fixed at two points on two flow paths at the base of the slope. The other three sides of the plot were separated by the small drains (width 15cm and depth 30cm) to avoid runoff water from outside the plot (2°55´17.029´´N latitudeand 101°46´33.996´´Elongitude).The runoff flows from the plot through narrow and temporary water channels are shown in figure 1a.

The Resam (Figure 1b), Vetiver (Figure 1c), and Creeper (Fig. 1d) covered plots were selected on the basis of the availability of rill and inter-rill aspects and flow paths. Their area and the coordinates were recorded 347.56m^2 and 2.9220737N 101.7795714E; 482.43m^2 and

2.9272641N 101.780304E and 479.28 m^2 and 2.9221944N 101.780304E respectively. The soil series fell under Muchong-Seremban and the soil type was Sandy clay loam for these three plots. The plots were also separated by the drains at their 3 sides to avoid the outside runoff.The physical and climatic features of these four plots are shown in the Table 1 and Table 2.

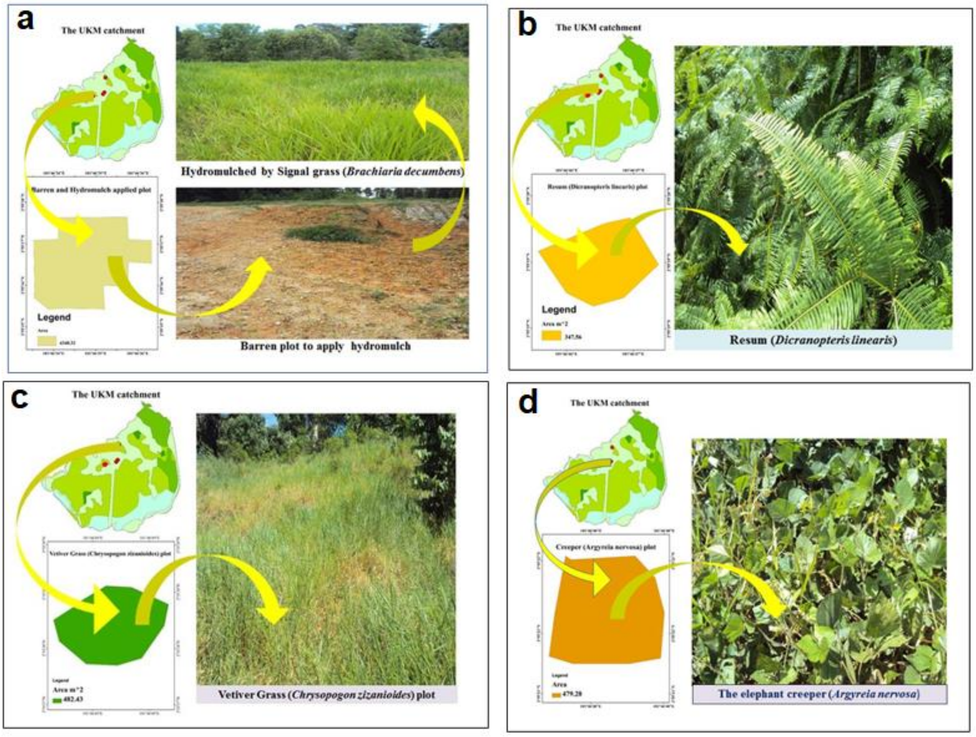

Fig. 1. a) Location map of barren plot; b) Location map of Resam covered plot; c) Location map of Vetiver grass plot;d) Location map of Creeper covered plot

Table 1. Physical features of four experimental plots

Catchment parameters		Value				
		Barren plot		Resam plot	Vetiver plot	Creeper plot
Elevation (m)	: Top	45.47		103.85	73.14	103.85
	: Bottom	33.76		73.14	57.90	73.14
Catchment length (m)		87.25		22.13	25.38	22.33
Mean slope %		21.87		16.08	10.57	30.88
Mean width of flow path (m)		1.60	1.0*	0.90	0.60	0.52
Mean depth of flow path (m)		0.15	0.27*	0.38	0.19	0.21
Mean velocity during sampling (m/sec)		5.62	1.90*	2.07	1.99	1.91

(*After hydromulch application)

Table2. Climatic features of four experimental plots

Climatic feature	Value			
	Barren plot	Resam plot	Vetiver plot	Creeper plot
Total rainfall (mm) in 2015	2880	2880	2880	2880
No of rain-days in 2015	172	172	172	172
Runoff (mm) under vegetation	-	145	145	145
Runoff (mm) on barren land	1478	-	-	-
Runoff number under vegetation	-	38	38	38
Runoff number on barren land	87	-	-	-

Methods

Rainfall was measured using the digitized HBO data logger located at the Faculty of Engineering and Built Environment's new building in Universiti Kebangsaan Malaysia (02° 55′ 21.48″N latitude and 101° 46′ 15.48″E longitude). This rain gauge station was installed to provide rainfall for the UKM catchment. During rainfall events, water samples were collected for measuring Total Suspended Solids (TSS) concentration and discharge rates were measured from the barren and three natural vegetation covered plots. After the samplings were conducted for the barren plot, signal grass was seeded there by hydromulching during the dry period. The growth performance of signal grass was monitored on a weekly and monthly basis and after 2.5 months when signal grass was matured, again sediment sample and discharge rate were measured at the previous barren plot's sampling stations. Three naturally grown Resam, Vetiver and Creeper plots were demarcated by natural fragmentation and hand prepared thin drains on top, right and left of the slopes wherever was necessary for the plot for easy measurement of the area, flow path and catchment length and to collect sediment samples. All the measurements were replicated for the three times in three separate rain events.

A Geographical Positioning System (GPS) was used to record the coordinates of the plots. The plots were digitized using ArcGIS 9.3 which measured the area slope and elevation. The discharge was calculated by the velocity-area method as the product of velocity and cross-sectional area of the flow path at the base of the slope. In the study, three measurements were conducted to accurately characterize the velocity of the water moving down the stream.

Hydromulching

*Hydromulch Machine (Spraying Equipment):*The equipment consists of a water tank of 600 liters of water containing capacity with a diesel engine; an agitator and a high-pressure pump with sufficient power to reach the slope surface. The mechanical power drive agitator is used for its capability of keeping all ingredients in suspension at all times. All pump passages and pipelines are capable of providing clearance to solids of a maximum diameter of 15mm. Two different types of nozzles (long-range and close-range) were supplied so that the mixture could be properly sprayed over distances varying from 5 to 60 meters. The nozzles are connected to the nozzle pipe or to the eventual extension hoses by quick release couplings (Fig. 1).

Fig. 1. Hydromulch machine

Preparation of Hydromulch

In order to apply seed and fertilizer rapidly, it is customary to spray aqueous slurries of seed, fertilizer and other nutrients on the soil to be reclaimed [26]. The materials for hydromulch are selected with the following components.

Signal grass (*Brachiariade cumbens*): Signal grass is selected for its permanent pastures. It can cover the barren ground for erosion control on hillsides. It can also be applied in upland areas of the basin [27]. The species possess high productivity under intensive management and persist in low fertility and acid soils. The seeds are very light and weigh in at an average of 280, 000 seeds per kg [27].

Paper mulch: Fairly small particle sizes, spread to form a mat on the soil. A small amount of newspaper stock is selected for cellulose fibers because it appears to function as a binder or adhesive for the paper mat provided they are finely chopped [28]. The preparation of paper mulch is described as 3kg of old newspapers were soaked overnight with 30L of alkaline water (pH normally 7.4 and above) and b) The paper was blended using a household blending machine with a small amount of water, sieved, and put it in the oven for a few days until it dried completely. The remaining water was not used further. After drying, the paper mulch was ready to be used for hydromulching.

Compost: Compost fertilizer was applied in hydromulching to enable the seeds to rapidly grow on the disturbed slopes [29]. The ratio of N: P: K mixture in compost for this experiment is 10:8:10.

Tackifier: The hydromulch mixture includes a binder agent or adhesive such as a naturally occurring gum-latex which assists in holding the mulch composition in place after the application [30]. In this experiment, Tapioca starch is used instead of natural latex at double the quantity.

Water: The spraying hydromulch is prepared by mixing with water to form a suspension. The hydromulch spraying equipment has a tank sufficient in size to hold 600 lit of water. In operation, the tank is filled with water added with a proportion of hydromulch to form a slurry or suspension which is sprayed on the land for the soil to be reclaimed [31].

The composition ratio

For this study, a tray of 30x40x10 cm i.e., 12, 000 cm^3 revealed the best for 12 liters of hydromulching mixture. The mixture requires 20g of paper mulch + 50g of compost + 20g of Signal grass seed + 30g of Tackifier.

Assuming the hydromulching is to cover about 0.5 cm depth of bare soil, then the amount of hydromulch for the same will be 12 liters or 12000 cc of mulch and this amount will cover an area of 2.4m^2 (12, 000 cc/0.5cm). Or, 1.0m^2 can be covered with the mixture of 12/2.4 = 5 liters. The catchment area is estimated at 0.028km^2 = 0.028 x 1, 000, 000 = 28, 000m^2. One tank of hydromulch machine contains 600 liters so it covers 120m. Therefore, 28, 000m^2 of the area requires 280 tanks of the mixture.

Requirement of paper mulch

20g mulch is required for 12 liters, therefore 20/12g of mulch is needed for 1 liter. For 280 tanks of 600 liters each need 280 x 600 x 20/12 = 280, 000g = 280kg. Similarly, for seed, the amount will be 280kg. For compost, it will be 2.5 times of the seed that is 2.5 x 280 = 700kg, andTackifier will be 1.5 times of seed that is 1.5 x 280 = 420kg.

It is observed that instead of 0.5cm of hydromulch depth, 0.2cm can be considered. Therefore, the quantity for all the materials reduces by 2.5 times. The finally applicable materials are stated in Table 3.

Table 3. Composition of hydromulch materials

Area (km^2)	Materials	Quantity (kg)	Remarks
0.028	Seeds	112	
	Compost	280	
	Paper mulch	112	
	Tackifier	168	Tapioca is used

Application in the field

After the materials were mixed into the tank, the machine was pulled to the site by a lorry. Two field men assisted to apply the hydro mulch. The mixture of the slurry was prepared before application. Ingredients were mixed with water to form homogeneous slurry and kept agitated until finally applied to the slope surface. Water used was free from toxic chemicals and other substances harmful to plant life. The pH value of the water sustained from 6.0 to < 8.0. All mixtures were used within 1 hour from the time they were mixed.

The ground cover measurement

The ground cover was measured in 1m x 1m plots where the sunlight penetrated area was sorted by demarcation on the ground and this area was deducted from the plot size to get the ground cover percentage.

Results and Discussions

The four sampling stations in the UKM catchment were selected in order to measure and compare sediment yield from i) barren slope and ii) after hydromulch application. Besides, sediment from the plots under Resam, Vetiver and Creeper were also measured. All the measurements were taken during rainfall events. During the study period, 7 rainfall events were recorded with the highest rainfall of 90mm on 16 June 2015 while the lowest rainfall recorded 43mm on May 03 2015 (Table 4). Total 183 Nos. of runoff occurred against 2880mm of rainfall for the year 2015. The number of runoff depths under vegetation, grassland and on barren land was recorded 38, 58, and 87 Nos. respectively.

Table 4. Hydrological conditions on the date of water sampling at four experimental plots

Date	Stations/Plots	Rainfall (mm)	Runoff depth (mm)
12-6-2015	Barren plot	66	43
13-6-2015	Barren plot	85	61
16-6-2015	Barren plot	90	66
1-11- 2015	Hydromulch applied	59	3
16-11-2015	Hydromulch applied	58	2
16- 11- 2015	Hydromulch applied	58	2
23-4-2015	Resam	75	8
3-5-2015	Resam	43	1
27-5-2015	Resam	45	1
23-4-2015	Vetiver	75	8
3-5-2015	Vetiver	43	1
27-5-2015	Vetiver	45	1
23-4-15	Creeper	75	8
3-5-2015	Creeper	43	1
27-5-2015	Creeper	45	1

The water sampling for TSS concentration from the flow path of barren plot was conducted during rainfall events on 12 June, 13 June and 16 June of 2015, 4 field workers assisted conducting the sampling each day. The minimum and maximum amount of rainfall, runoff and discharge rate during the sampling was 66 and 90mm; 49 and 66mm and 1.49m^3/sec and 1.85m^3/sec on the above days respectively. The minimum and maximum of TSS/L and Sediment/m^2 were recorded 11.05g/L and 11.3g/L and 482.77g/m^2 and 733.04g/m^2 which show the severe sediment yield (Table 5).

Research finding revealed that change in land use from forested to other human activities lead to higher sediment yield particularly during unstable condition [32]. The water samplings for TSS concentration from the hill slope flow path of hydro mulch applied plot (previous barren plot) were conducted on 01 Nov and 16 Nov of 2015 (Table 4).

The ranges of rainfall, runoff and discharge rate during sampling were 58 mm to 59mm, 2mm to 3mm and 0.82 to 0.89m^3/sec respectively. The mean and standard deviations were 58.47± 0.64 mm, 2.20± 0.20mm and 0.86 ± 0.04m^3/sec respectively. At the same time the minimum and maximum of TSS/L and Sediment/m^2 was recorded 82.00 and 89.00mg/L and 0.22and 0.27g/m^2 respectively. The mean and standard deviations of TSS/L and Sediment/m^2 were obtained 85.33±3.51mg/L and 0.24±0.03g/m^2 respectively (Table 5).

Table 5. Statistical summary of Sediment yield and its related parameter of barren and vegetation covered plot

Station		Drainage area (m^2)	Slope %	RF (mm)	Runoff depth (mm)	Discharge rate (m^3/sec)	Discharg e time (sec)	Total sediment discharge (kg)	TSS mg/L	Sediment g /m^2
Barren plot	Range	4340.32	21.87-21.87	66-90	43-66	1.49-1.85	128.32-180.43	2095.4-3185.65	11050-11300	482.77-733.04
	Mean ± SD		21.87± 0	80.97± 12.66	57.07±1 1.81	1.63± 0.19	154.59± 26.06	2763.96± 584.97	11150± 132.29	636.81± 134.76
Hydro mulched plot	Range	4340.32	21.87-21.87	58-59	2 -3	0.82-0.89	13.24-16.15	0.96-1.18	82.00-89.00	0.22 -0.27
	Mean ± SD		21.87± 0	58.47± 0.64	2.20± 0.20	0.86± 0.04	14.34± 1.58	1.05±0.12	85.33±3.51	0.24±0.03
Resam plot	Range	347.56	16.08-16.08	43-75	1-8	0.43-0.88	0.22-3.50	0.02-0.40	132-142	0.07 -1.14
	Mean ± SD		16.08±0	54.83± 18.18	3.21± 4, 48	0.30± 0.24	1.38± .68	0.15±0.21	136.67± 5.03	0.44±0.61
Vetiver plot	Range	482.43	10.57-10.57	43-75	1-8	0.21-0.26	1.06-19.56	0.03-0.54	128-146	0.06-0.60
	Mean ± SD		10.57±0	54.83± 18.18	3.21± 4, 48	0.23± 0.03	7.39± 10.58	0.21±0.29	136.00± 9.17	0.43±0.60
Creeper plot	Range	479.28	30.88-30.88	43-75	1-8	0.19-0.25	1.24-19.13	0.03-0.53	132.0-140.0	0.07-1.10
	Mean ± SD		30.88±0	54.83± 18.18	3.21± 4, 48	0.22± 0.03	7.27± 10.27	0.20±0.28	136.67±4.16	0.43±0.59

The periodical growth of Signal grass

The periodical growth of Signal grass was observed after 7 days of hydromulching. Nos. of seeding, growth in height, biomass in g/m^2 and ground cover in percentage were measured. Along with such measurements, hydrological aspects such as rainfall, runoff, rain-runoff ratio and total sediment discharge from the plot were also recorded. The average seedlings after 7 days, 30 days, 60 days, and 75 days were 106 Nos., 128 Nos., 134 Nos., and 145 Nos. respectively. Average growth with respect to these seedlings was 1.0, 51, 74 and72cm while the biomass recorded as0.03, 28.17, 39.64 and 41.23g respectively. At the same periodical interval, mean rainfall was recorded 22, 52, 59 and 28mm and the runoff was 7, 12, 3 and 1mm respectively. The discharge rate was recorded 0.513, 0.35, 0.27 and 0.2m^3/sec while the TSS concentration/L were11.4, 8.7, 0.09 and 0.08g/L respectively (Table 6).

Table 6. Periodical change of Signal grass

Signal grass	Periodical change			
	7 days	**30 days**	**60 days**	**75 days**
No seedlings in 1 /m^2	106	128	134	145
Height (cm)	1	51	74	72
Biomass (g/ m^2)	0.03	28.17	39.64	41.23
Ground cover %	5	20	80	96.7
Flow Rate (m^3/sec)	0.513	0.35	0.27	0.2
TSS (g/L)	11.4	8.7	0.09	0.08
Rain (mm)	22.5	52.7	59.2	28.1
Runoff(mm)	7.11	12.44	3.04	0.1
Runoff - Rainfall ratio	0.32	0.23	0.05	0.004
Total sediment discharged (kg)	351.8	469.7	1.15	0.04

Correlation matrix among the Signal grass parameters shows that height has strong and highly significant correlation with biomass (r = 0.99, P 0<0.01) however, seedling number is moderately strong and significantly correlated with biomass and height (P<0.01, r = 0.73 and

0.70 respectively). On the other hand, discharge and TSS concentration have negative moderate strong but significant correlation with the number of seedling ($P < 0.01$, $r = -0.78$ and -0.65 respectively) but discharge and TSS have strong significantly negative correlation with growth ($P < 0.01$, $r = -0.95$ and -0.90 respectively) and biomass ($P < 0.01$, $r = -0.96$ and -0.89 respectively). Discharge and TSS were highly significant and show the strong correlation ($P < 0.01$, $r = 0.91$). Ground cover shows moderate strong and significant correlation with number of seedling ($P < 0.01$, $r = 0.64$) and same valued strong significant correlation with growth and biomass ($P < 0.01$, $r = 0.86$). Ground cover also shows highly strong and negative significant correlation with discharge and TSS ($P < 0.01$, $r = -0.91$ and -0.99 respectively). P value < 0.01 was analyzed by ANOVA single factor (Table 7).

Table 7. Correlation matrix among the Signal grass parameters

	No seedlings	**Growth**	**Biomass**	**Ground cover**	**Discharge rate**	**TSS**
No seedlings	1					
Growth	0.70	1				
Biomass	0.73	**0.99**	1			
Ground cover	0.64	**0.86**	**0.86**	1		
Discharge rate	-0.78	**-0.95**	**-0.96**	**-0.91**	1	
TSS	-0.65	**-0.90**	**-0.89**	**-0.99**	**0.91**	1

Performance of other Vegetation Covered Plots to Control Erosion

To analyze the performance of Resam (*Dicranopteris decumbens*), Vetiver (*Chrysopogon zizanioides)* and Creeper (*Argyrela nervosa*) on Surface Runoff and Sediment yield, the sediment sampling from the flow path of Resam, Vetiver and creeper covered plots were conducted on 23-4-2015, 3-5-2015 and 27-5-2015 (Table 4).

Resam

For Resam, the ranges of seedling number, growth, biomass and Ground cover during sampling were recorded 40 to 72 Nos.; 0.80 to 1.21m; 38.0 to 82.0g; and 60 to 80% respectively and the averages with standard deviations of these parameters were 56.75±10.08 Nos.; 1.07±0.15m; 57.53± 15.28g and 69.75 ± 5.90 % respectively (Fig. 2).

The ranges of rainfall, runoff and discharge rate during sampling were 43-75mm, 1-8mm and 0.43-0.88m^3/sec respectively. The mean and standard deviations were 54.83 ± 18.18mm; 3.21± 4.48mm and 0.30± 0.24m^3/sec respectively.At the same time, the minimum and maximum of TSS concentration/L and Sediment yield/m^2 were recorded 132 - 142mg/L and 0.07 -1.14g/m^2 respectively. The mean and standard deviations of TSS concentration/L and Sediment yield/m^2 were obtained 136.67± 5.03 mg/L and 0.44±0.61 g/m^2 respectively (Table 5).

Vetiver

The ranges of seedling number, growth, biomass and ground cover during sampling were 55 to 90 Nos.; 0.90 to 1.12m; 38.10 to 67.00g; and 80 to 90% respectively and the averages with standard deviations of these variables were 69.78 ± 12.99 Nos.; 1.00± 0.08m; 53.60±9.62g and 86.78±3.60 % respectively (Fig. 2).

The ranges of rainfall, runoff and discharge rate during sampling were 43-75mm, 1-8mm and 0.43-0.88m^3/sec respectively. The mean and standard deviations were 54.83±18.18mm; 3.21± 4.48 and 0.30±0.24m^3/sec respectively. At the same time, the minimum and maximum of TSS concentration/L and Sediment yield/m^2 were recorded 128-146 and 0.06-0.60g/m^2 respectively. The mean and standard deviations of TSS concentration/L and sediment yield/m^2 were obtained 136.00± 9.17mg/L and 0.43±0.60g/m^2 respectively (Table 5).

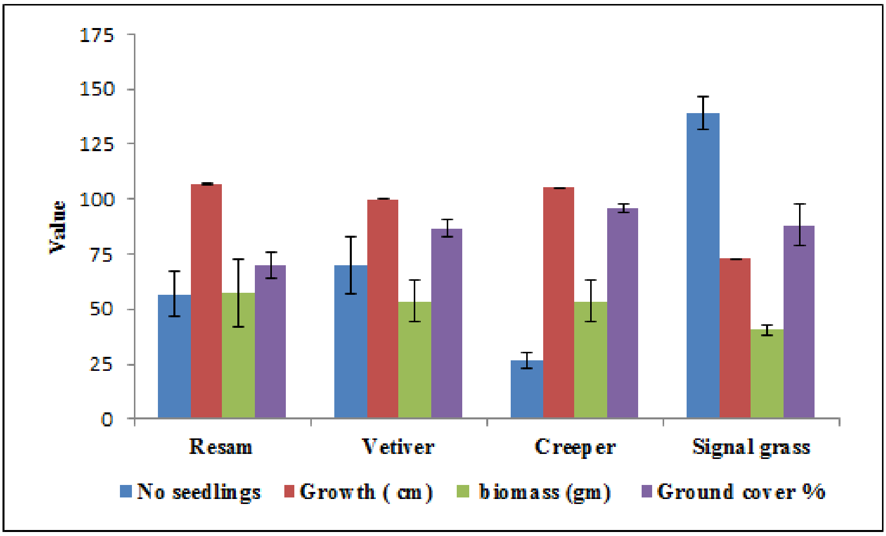

Fig. 2. Graphical Performances of Resam, Vetiver and Creeper (Area 1 x 1m)

Creeper

The ranges of seedling number, growth, biomass and ground cover during sampling were 20 to32 Nos.; 0.90 to 1.25m; 38.10 to 67.00g; and 93 to 98% respectively and the averages with standard deviations of these variables were 26.44±3.61Nos. 1.05±0.12m; 53.60±9.62g and 96.00±1.94% respectively (Figure 2).

The ranges of rainfall, runoff and discharge rate during sampling were 43-75mm, 1-8mm and 0.43-0.88m^3/sec respectively. The mean and standard deviations were 54.83±18.18mm; 3.21± 4.48mm and 0.30± 0.24m^3/sec respectively. At the same time the minimum and maximum of TSS concentration/L and Sediment yield/m^2 were recorded 132.0-140.0mg/L and 0.07-1.10g/m^{2}respectively. The mean and standard deviations of TSS/L and Sediment yield/m^2 were obtained136.67±4.16mg/L and 0.43±0.59g/m^2 respectively (Table 5).

The effect of hydro-mulching in erosion controlling

In context with the slopes, the result shows that when slope is 21.87%, the mean discharge and sediment yield for signal grass are 0.86m^3/sec and 1.58g/m^2 respectively; when slope is 16.08% the mean discharge and sediment yield for Resam plot are 0.70m^3/sec and 2.53g/m^2 respectively; when slope is 10.57% the mean discharge and sediment yield for Vetiver grass are 0.23m^3/sec and 2.51g/m^2 respectively and when slope is 30.88% the mean discharge and sediment yield for Creeper are 0.22m^3/sec and 2.53g/m^2 respectively (Fig. 3).

The study reveals that the increase in rainfall contributes 66% (R^2= 0.66) for the runoff increase (Fig. 4) i.e. 34% other factors such as vegetation cover, soil type, duration and intensity of rainfall, slope and elevation could affect runoff with respect to rainfall.

The runoff is highly strong and significantly correlated (r = 0.99, P <0.01) with sediment yield and bears 99 % responsibility for sediment yield. Trendline equation shows that sediment yield (kg) = 50.521* runoff (mm) -148.69 (Fig. 5). Again, discharge rate and sediment yield is also strong and highly significantly correlated (r = 0.85) but appeared 74% (R^2 =0.74) responsible for changes in sediment yield and 26% might be other factors such as catchment slope, vegetation cover, weathering area of sedimentary rocks, rainfall intensity (Fig. 6). These results have a similarity with the work of Mingguo and co-researchers [33].

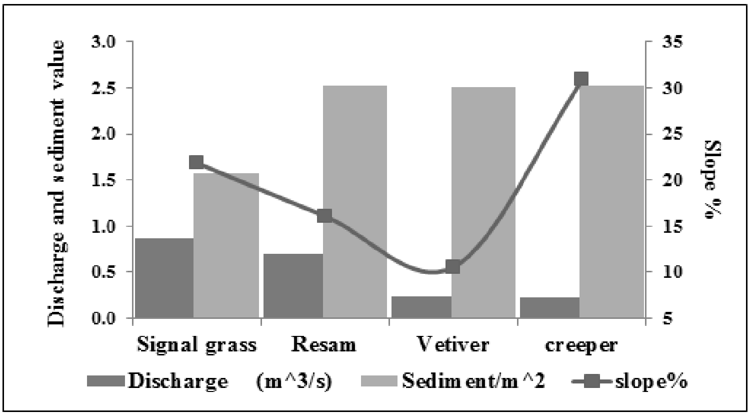

Fig. 3. Sediment yield and discharge rate with slope

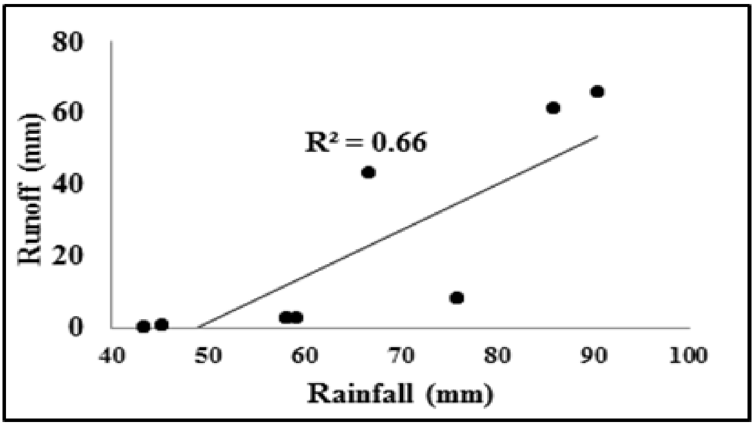

Fig. 4. Runoff-rainfall relations

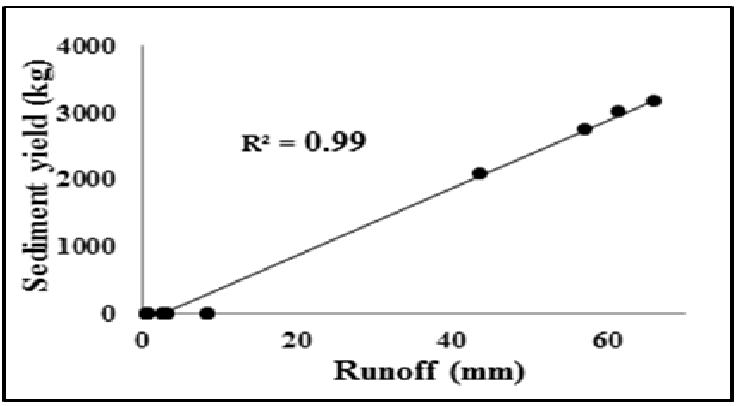

Fig. 5. Runoff-Sediment yield relation

The result revealed that the sediment discharge from the barren plot (636g/m^2) and hydromulch applied plot (0.24g/m^2) makes a significant difference in sediment change (133:1). This indicates that the establishment of Signal grass by hydromulch application can play a vital role to minimize soil erosion [33]. The ratio of discharge rate and sediment yield/m of barren

(1:390), Signal grass (1:0.28), Resam (1:1.47), Vetiver (1:1.95) and Creeper (1: 1.95) indicate that Signal grass with more discharge rate, yields the minimum sediment per unit area than for other vegetation covered plots (Fig. 6). The biomass volume and ground cover percentage for Signal grass, Resam, Vetiver and creeper are similar to each other respectively but the seedling number varies for Signal grass and Creeper due to age of the plants where a greater number of Signal grass (average 132 Nos.) and the minimum number of Creeper (average 26 Nos.) were observed in 1.0m^2 plot.

Log transformed rainfall (mm) and TSS/L variable shows that increase of TSS depends approximately 50% on rainfall. The other factor can be predicted as vegetation and soil texture (Fig. 7). It was reported that the regression model fitted to non-coarse particle concentration across all surfaces was proportional to rainfall depth. Rose to a negative power and peak 6-min rainfall intensity rose to a positive power, where the proportionality constant varies by surface type [34].

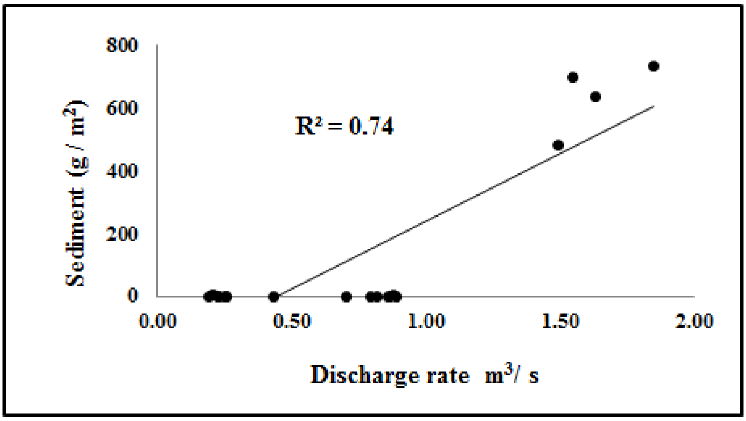

Fig. 6. Discharge rate- Sediment yield relation

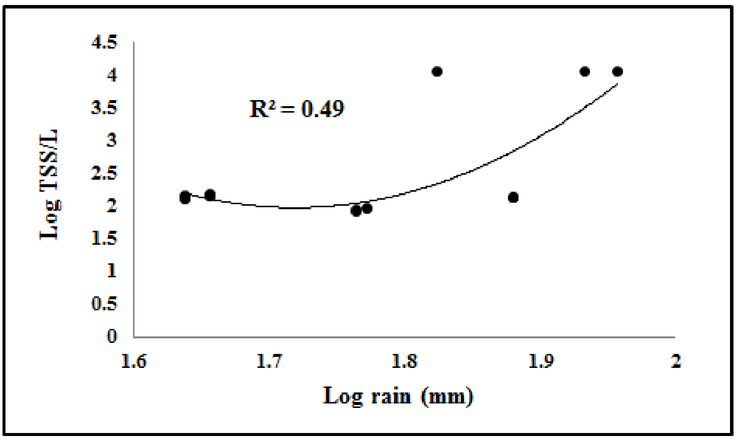

Fig. 7. Rainfall -TSS relation

This study exposes that the value of ground cover is nearly close to each other (60% - 98%) In such similar dense vegetation ground cover log-transformed data shows that they have negative and weakly significant correlation ($r = -0.7$, $P < 0.01$). The regression value denotes that ground cover has a 49% contribution to reducing discharge (Fig. 8). A similar finding states that the presence of the stable density of forest canopy of the Bangi Forest Reserve plays an important role in minimizing surface erosion which is expected as one of the major contributorsto sediment yield in rivers. The successive layers of the canopy act as a filter through the interception process [35] and reduce the impact from splash erosion by raindrops [36].

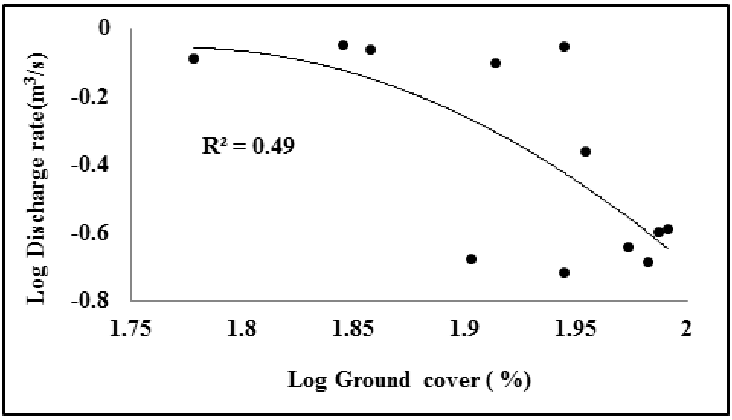

Fig. 8. Ground cover – discharge rate relation

For barren land, runoff contributed 99% for increasing or decreasing sediment yield. During the study sediment yield from the barren plot of 4340.32m^2 is calculated 2763.96kg for the mean runoff of 80.97mm. In the year 2015 barren land runoff was calculated at 1478.77mm. It is predicted from the Trendline that for the whole year 2015 the sediment from the barren plot would be 74.0 tons or 16.84 kg·m^{-2} (Fig. 9).

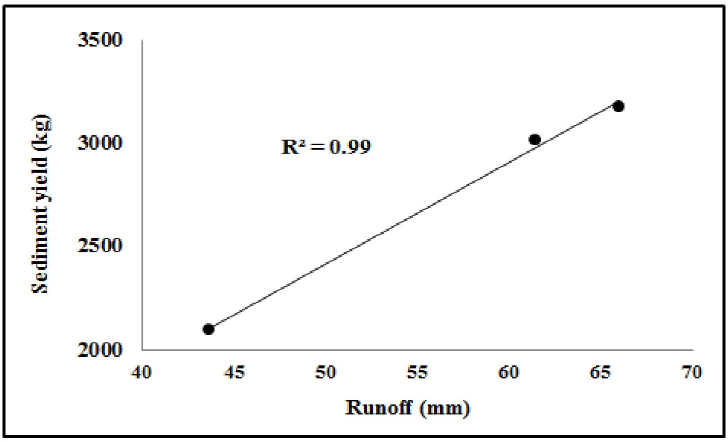

Fig. 9. Runoff- Sediment yield relation in barren plot

After hydromulch application, the sediment yield from the plot of 4340.3 2m^2 is calculated 1.05kg for the mean runoff of 2mm. In the year 2015, the total runoff for the vegetation-covered land was calculated at 145mm. It is predicted from the Trendline that for the year 2015 the sediment from the plot would be 82.25 kg or 18.95g/m^2 (Fig. 10).

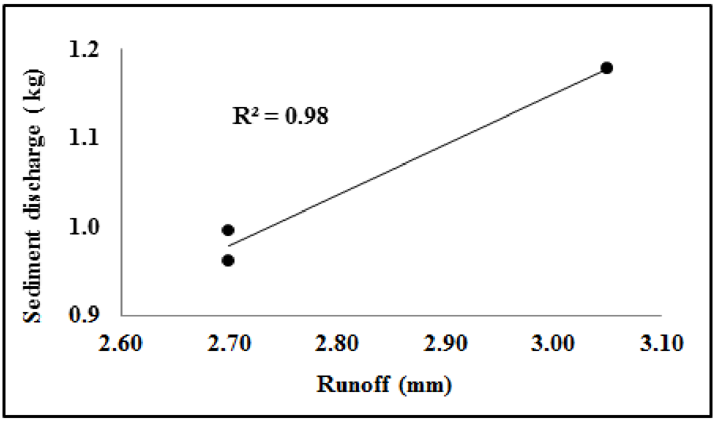

Fig. 10. Runoff- Sediment relation in Hydromulch applied plot

In the year 2015, the total runoff for the vegetation-covered land of UKM catchment was calculated at 145.29 mm. However, during this study, the mean runoff was 3.21mm. During sampling time, sediment yield from Resam (347.56m^2), Vetiver (482.43m^2), and Creeper (479.28m^2) plot were calculated 0.15kg, 0.21kg, and 2.0kg respectively. It is predicted from the Trendline equation that for the year 2015, the sediment from the Resam, Vetiver and Creeper plot would be 6.86kg or 19.73g/m^2; 9.37kg or 19.43g/m^2 and 9.16 kg or 19.10g/m^2 (Fig. 11).

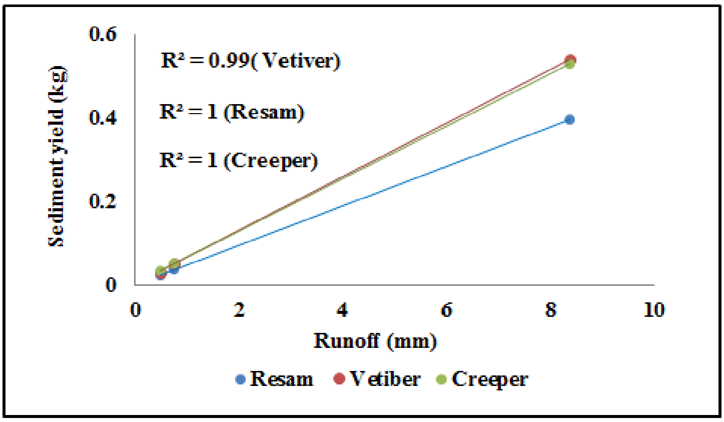

Fig. 11. Runoff- Sediment relation in Resam, Vetiver, and Creeper covered plot

This analysis reveals that hydro mulching with signal grass is the maximum effective controlling measures for soil erosion among the four different vegetation-covered plots.

Conclusion

The study revealed that hydro mulch application can be one of the effective measures to control erosion. The establishment cost for hydro mulch is also considerably very low. This study revealed that hydro mulching is very convenient and it is time and cost-effective. On the other hand, it requires fewer labour than the other practices, therefore, it is suitable for land management too.

Therefore, hydromulching can be considered a rapid method to controlling erosion. After application, no vacancy filling was required and the survival percentage showed 99.39% which was very satisfactory. The performance of hydromulching compared with other selective vegetation can suggest that management strategy for erosion control can be rapid, cost-effective, easy handling, and sustainable. Nevertheless, there are some limitations like the supply of grass seeds, latex, and lorry for transportation for carrying the machine to the site of application.

Acknowledgments

The authors are thankful to the Faculty of Engineering and Built Environment, Earth Observation Centre & Institute for Environment and Development (LESTARI) of Universiti Kebangsaan Malaysia for providing excellent support to carry out various studies.

References

[1] A. Malmer, H. Grip, *Soil Disturbance and Loss of Infiltrability Caused by Mechanized and Manual Extraction of Tropical Rainforest in Sabah, Malaysia,* **Forest Ecology and Management, 38**(1-2), 1990, pp.1-12.
[2] O. Igwe, *The geotechnical characteristics of landslides on the sedimentary and metamorphic terrains of South-East Nigeria, West Africa.* **Geoenvironmental Disasters, 2**(1), 2015, pp. 1-14.
[3] T.J.Dunai, G.G. López, J. Juez-Larré, *Oligocene–Miocene Age of Aridity in the Atacama Desert Revealed by Exposure Dating of Erosion-Sensitive Landforms*, **Geology, 33**(4), 2005, pp. 321-324.
[4] M.M. Kaufman, *Erosion Control at Construction Sites: The Science–Policy Gap*, **Environmental Management, 26**(1), 2000, pp.89-97.
[5] M.G. Wolman, A.P. Schick, *Effects of Construction on Fluvial Sediment, Urban and Suburban Areas of MaryLand,* **Water Resources Research, 3**(Second Quarter), 1967, pp. 451-464.
[6] K.C.Puntenney-Desmond, K.D. Bladon, U. Silins, *Runoff and sediment production from harvesting hillslopes and the riparian area during high intensity rainfall events*, **Journal of Hydrology, 582**, 2020, pp. 124452.
[7] E. Bochet, P. García-Fayos, *Factors Controlling Vegetation Establishment and Water Erosion on Motorway Slopes in Valencia, Spain*, **Restoration Ecology, 12**(2), 2004, pp.166-174.
[8] C.Kosmas, S.Gerontidis, M. Marathianou, *The Effect of Land Use Change on Soils and Vegetation over Various Lithological Formations on Lesvos (Greece),* **Catena, 40**(1), 2000, pp. 51-68.
[9] N.C. Brady, R.R. Weil, **The Nature and Properties of Soils,** Prentice-Hall Inc., New Jersey, USA, 1996.
[10] M. Rab, *Soil Physical and Hydrological Properties Following Logging and Slash Burning in the Eucalyptus Regnans Forest of Southeastern Australia*, **Forest Ecology and Management, 84**(1), 1996, pp. 159-176.
[11] J.Albaladejo Montoro, J.Alvarez Rogel, J.Querejeta, E. Diaz, V. Castillo, *Three Hydro-Seeding Revegetation Techniques for Soil Erosion Control on Anthropic Steep Slopes*, **Land Degradation & Development, 11**(4), 2000, pp. 315-325.
[12] M.D.Ricks, W.T.Wilson, W.C.Zech, X. Fang, W.N. Donald, *Evaluation of hydromulches as an erosion control measure using laboratory-scale experiments*, **Water, 12**, 2020, pp. 515.
[13] S.Bautista, J. Bellot, V.R. Vallejo, *Mulching Treatment for Postfire Soil Conservation in a Semiarid Ecosystem*, **Arid Land Research and Management, 10**(3), 1996, pp.235-242.

[14] N.L. Hartwig, H.U. Ammon, *Cover Crops and Living Mulches*, **Weed Science, 50**(6), 2002, pp. 688-699.
[15] L.Faucette, L.Risse, M.Nearing, J. Gaskin, L. West, *Runoff, Erosion, and Nutrient Losses from Compost and Mulch Blankets under Simulated Rainfall*, **Journal of Soil and Water conservation, 59**(4), 2004, pp. 154-160.
[16] G.A.Romanek, R.E.Moon, M.L. Marienfield, S.S. Guram, **Erosion Control Mat**, Google Patents, 1993.
[17] J. Grace, *Forest Road Sideslopes and Soil Conservation Techniques*, **Journal of Soil and Water conservation, 55**(1), 2000, pp. 96-101.
[18] T.K. Hui, *Best Management Practices on Soil Erosion and Sediment Control in the Construction Industry*, **Bultin Ingenieur**, 2010.
[19] P. Dorn, J. Rodgers, *Variability Associated with Identification of Toxics in National Pollutant Discharge Elimination System (Npdes) Effluent Toxicity Tests*, **Environmental Toxicology and Chemistry, 8**(10), 1989, pp.893-902.
[20] N.S.Ahmad, F.B. Safiah, Y.M. Yusoff, G. Didams, *A systematic review of soil erosion control practices on the agricultural land in Asia*, **International Soil and Water Conservation Research, 8**(2), 2020, pp.103-115.
[21] V.H.D. Zuazo, C.R.R. Plegueezuelo, *Soil-erosion and runoff prevention by plant covers. A review*, **Agronomy for Sustainable Development, 28**, 2008, pp. 65-86.
[22] C.Robinson, M. Ghaffarzadeh, R. Cruse, *Vegetative Filter Strip Effects on Sediment Concentration in Cropland Runoff*, **Journal of Soil and Water conservation**, **51**(3), 1996, pp. 227-230.
[23] J.M. Ditomaso, *Invasive Weeds in Rangelands: Species, Impacts, and Management*, **Weed Science, 48**(2), 2000, pp. 255-265.
[24] E.J. Veneklaas, R. Van Ek, *Rainfall Interception in Two Tropical Montane Rain Forests, Colombia*, **Hydrological Processes, 4**(4), 1990, pp. 311-326.
[25] S.A. Hayes, R. Mclaughlin, D. Osmond, *Polyacrylamide Use for Erosion and Turbidity Control on Construction Sites*, **Journal of Soil and Water conservation**, **60**(4), 2005, pp. 193-199.
[26] O.R. Videen, **Method and Device for Coloring Bulk Hydro Mulch Fibers**, Google Patents, 1980.
[27] A.Sotomayor-Ríos, J.Velez-Fortuno, R.Woodbuky, K. Schertz, A. Sierra-Bracero, *Description and Cytology of a Form of Signal Grass (Branchiaria Brizantha Stapf.) and Its Agronomic Behavior Compared to Guinea Grass Panicum Maximum Jack*, **Journal of Agriculture of the University of Puerto Rico, 44**, 1960, pp. 208-220.
[28] G.W. Hamilton Jr, **Pelletized Mulch Composition and Process for Preparing Same**, Google Patents, 1995.
[29] L.Beesley, E. Moreno-Jiménez, J.L. Gomez-Eyles, *Effects of Biochar and Greenwaste Compost Amendments on Mobility, Bioavailability and Toxicity of Inorganic and Organic Contaminants in a Multi-Element Polluted Soil*, **Environmental Pollution, 158**(6), 2010, pp. 2282-2287.
[30] S.F.Vaughn, J.A.Kenar, F.C.Felker, M.A.Berhow, S.C.Cermak, R.L.Evangelista, G.F.Fanta, R.W. Behle, E. Lee, *Evaluation of Alternatives to Guar Gum as Tackifiers for Hydromulch and as Clumping Agents for Biodegradable Cat Litter*, **Industrial Crops and Products, 43**, 2013, pp. 798-801.
[31] W.B. Hansford, **Sprayable Hydromulch**, Google Patents, 1981.
[32] D.E. Walling, *Linking Land Use, Erosion and Sediment Yields in River Basins*, **Hydrobiologia**, 410, 1999, pp. 223-240.
[33] Z.Mingguo, C. Qiangguo, C. Hao, *Effect of Vegetation on Runoff-Sediment Yield Relationship at Different Spatial Scales in Hilly Areas of the Loess Plateau, North China*, **Acta Ecologica Sinica, 27**(9), 2007, pp.3572-3581.

[34] I.M. Brodie, P.K. Dunn, Commonality of Rainfall Variables Influencing Suspended Solids Concentrations in Storm Runoff from Three Different Urban Impervious Surfaces. **Journal of Hydrology, 387**(3), 2010, pp. 202-211.
[35] M.E. Toriman, M.N. Shukor, *An Analysis of Rainfall Interception on the Selection Experimental Plot of Pangkor Hill Reserved Forest*, **Journal of Wildlife and Parks, 22**(2), 2007, pp. 169-178.
[36] P. Pinet, M. Souriau, *Continental Erosion and Large-Scale Relief*, **Tectonics, 7**(3), 1988, pp. 563-582.

Received: August 02, 2021
Accepted: April 20, 2022