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Rice Straw Geotextile As Ground Cover ForSoil Erosion Mitigation

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Abstract

Generally, the study aimed to mitigate soil erosion using rice straw geotextile as ground cover. Specifically, it attempted to: evaluate the effect of RSM and RSN as ground cover in mitigating soil erosion at varying slope gradients and different rainfall intensities, and; determine the relationship of slope gradient versus sediment concentration, sediment yield and quantity of soil loss at different levels of rainfall intensity. Results revealed that RSGT as ground cover greatly affected soil erosion. Under rainfall intensities of 75, 100 and 125 mm/hr, RSM had significantly lower soil loss as compared to RSN, CCN And NGC. However, RSN and CCN were comparable with each other but differ significantly with NGC. Sediment concentration, sediment yield and soil erosion exhibited a nonlinear relationship with slope gradient. At any given level of rainfall intensity, the three indicators increased correspondingly as the slope was increased from 10 to 35^o and then declined when the slope was further increased from 35 to 60^o.

Sediment concentration best fitted ($R^2 = 0.977$) in a quadratic model in the form of a second-degree polynomial equation:

$$SC = 0.551 + 0.626S - 0.008S^2$$

Likewise, observed sediment yield best fitted ($R^2 = 0.954$) a second degree polynomial equation as expressed by a quadratic model:

$$SY = 356.0 + 61.70S – 0.972S^2$$

Moreover, the observed soil erosion was best modeled with R^2 = 97.1% confidence by a second degree polynomial equation. The regression model is quadratic in form and is given by the equation:

$$SE = 68.92 + 11.11S - 0.174S^2.$$

Keywords: rice straw, geotextile, ground cover, soil erosion, mitigation, rainfall simulation

1. Introduction

The Philippines is basically an agricultural country which is very rich in agro-waste resources. One of the most abundant and readily available agro-waste resources in the country is rice straw. Elauria et al. (1999) reported that the country generated a volume of about 18.52 billion kilograms of rice straw annually. Most farmers consider rice straw as nuisance in the field because it does not rot easily, thus causes obstruction during farm operations. Hence, farmers resorted to open field burning as an easy means of disposal. However, burning of rice straws emit green house gases (GHG) and pollutes the atmosphere (Magcale-Macandog, 2007).

Rice straw can be recycled into geotextile like rice straw mat (RSM) and rice straw net (RSN) to enhance its economic potential and environmental importance. Rice straw geotextiles (RSGT) can be utilized as ground cover for slope stabilization and erosion control. Smets (2009) reported that RSGTs are the most effective geotextiles in reducing runoff and soil loss.

Rice straw mat and net are biodegrable, environmentally and eco-friendly material as ground cover for erosion control. When used as ground cover, it will not only stabilize the top soil but also helps in the stablishment of vegetation for surface cover and improves soil physical structure and condition when decomposed into organic matter. Most importantly, the development of this technology will open a new opportunity to small farmers as they can sell their rice straw to augment their income. Farmers can also process their rice straw as form of livelihood project, thus, creating jobs in the rural areas.

Generally, the study aimed to mitigate soil erosion using rice straw geotextile as ground cover. Specifically, it attempted to: (1) evaluate the effect of RSM and RSN as ground cover in mitigating soil erosion and compare it with coco coir net and bare plot at different rainfall intensities and; (2) determine the relationship of slope gradient versus sediment concentration, sediment yield and quantity of soil erosion at different levels of rainfall intensity.

2. Review of Literature

Experimental evidence showed that soil loss can be greatly reduced by good maintenance of surface cover. The use of wire gauze or mosquito netting a short distance above the soil surface was found to reduce erosion to about one hundreth of its value on unprotected bare soil (Hudson, 1981). A ground cover of mulch is very effective in controlling erosion. With straw or crop residue mulches of 5 t/ha, soil losses become small, while at 1 to 2 t/ha can still have substantial effects (Lal, 1976). Barfield et al. (1977) further stressed that dense mulches and grasses can also be used to slow run-off to induce deposition and filter out sediment. On an agricultural plot on a 20 to 25-degree slope, erosion was kept to well below 1 t/ha/yr by cover-based management, including mulching with weeds and crop residues (Lundgren, 1980).

Other technique employed in mitigating soil erosion is the application of bioengineering method with the use of live materials, specifically plant parts like cuttings, roots and stems, which serve as the main structural and mechanical elements in a slope protection system (Schiechtl, 1985). The use of biodegrable geotextile in controlling soil erosion is widely accepted being cheap, environment and eco-friendly.

In a simulation study conducted by Bergado et al. (2008), they found that coco coir geotextile is very effective at 30 and 40-degree slope gradients under rainfall intensity of 125 mm hr^{-1} as it surpassed the 80% threshold level for geotextile effectiveness. Berboso et al. (2008) reported similar result on the effectiveness of coco coir geotextile combined with hydroseeding. They claimed that at rainfall intensity of 120 mm hr^{-1} and slope of 65^{O}, soil erosion was reduced by 97.7%.

3. Method

3.1 Preparation Rice Straw Geotextile

Both the RSM and RSN used in the study were prepared manually. Rice straw mat with thickness of 4.1 mm is a non-woven mat made of individual grid of straw interlaid with each other at random direction. It was was bound using rubber latex as binder (Figure 1a). Likewise, rice straw net is a geotextile made of rice straw. It was first made into twine approximately 3.6 mm in diameter by spinning two or more straws. After which, two twines were spinned together to form a rope. Finally, the straw rope was weaved into net with mesh opening of 20x20 mm (Figure 1b).

The other geotextile used in the study was coco coir net (CCN). It is a commercial geotextile used to compare the performance of RSM and RSN as erosion control material. A sample of CCN with thickness and mesh opening of 10 mm and 20x20 mm, respectively is shown in Figure 1c.

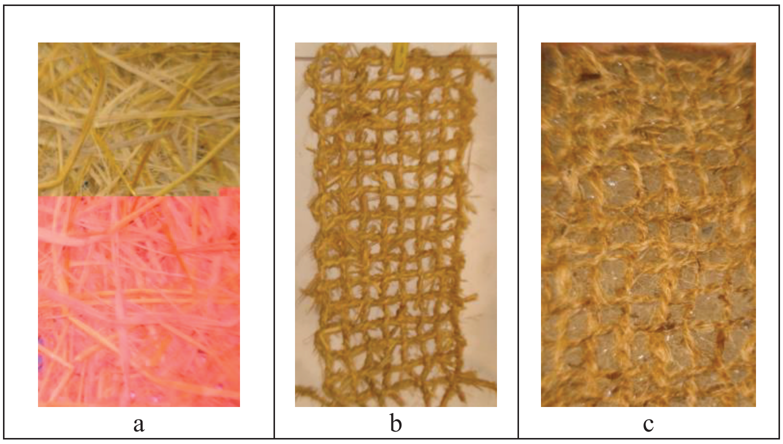
a b c

Figure 1. Different geotextiles used in the study: a) rice straw mat, b) rice straw net and, c) coco coir net

3.2 Evaluation of Rice Straw Geotextile

Evaluation of RSM and RSN was undertaken using a rainfall simulator developed by Maruto Testing Machine Co., Ltd., Tokyo, Japan. The soil test box used had a dimensions of 40 x 20 x 10 cm and can be tilted to a desired angle of inclination (Figure 2). Through out the test, sandy loam soil was used as sample.

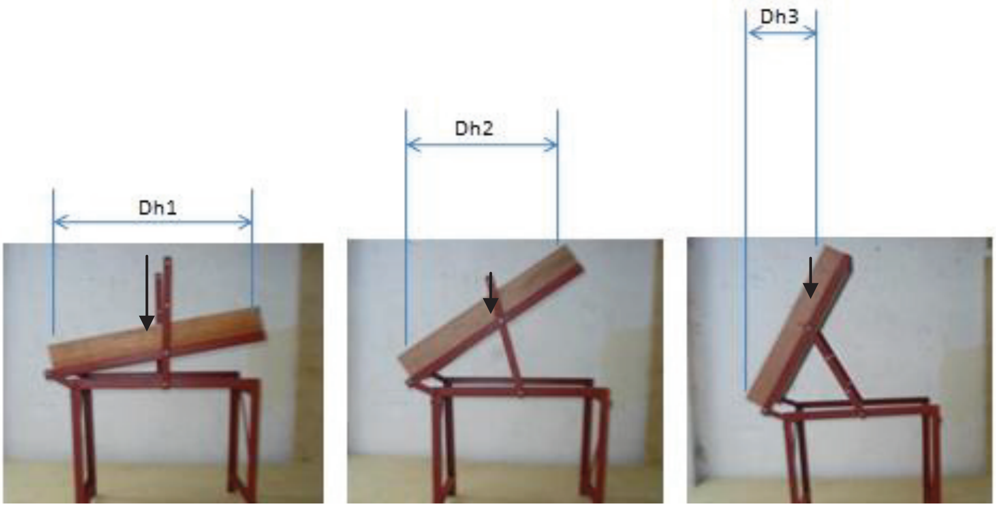

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Figure 2. Schematic diagram of the soil test box illustrating a decreasein the horizontal distance (Dh) as the angle of inclination was increasesed to a) 10°, b) 35° and c) 60°.

3.3 Treatments

Rice straw mat and RSN were evaluated alongside with coco coir net (CCN) and no ground cover (NGC) as treatment arranged in three separate set-ups. Each set-up was subjected into three different simulated storm intensities of 75 mm/hr for 23 minutes, 100 mm/hr for 12-minutes and 125 mm/hr for only 6 minutes.

The treatments were as follows:

A. Main Factor: Slope Gradient (S)
  S_1= 10°
  S_2= 35°
  S_3= 60°

B. Sub-Factor: Geotextile (GT)
  GT_1 – RSM as ground cover
  GT_2 – RSN as ground cover
  GT_3 – CCN as ground cover - check
  GT_4 - NGC – control

3.4 Data Analysis

Data gathered was analyzed in split-plot design with three replications. Comparison among treatment means to identify any differences if found significant in the analysis of variance (ANOVA) was done using the Duncan's Multiple Range Test (DMRT) at 5% level of significance.

Different regression analyses were likewise employed to determine the relationship between slope gradient versus sediment concentration, sediment yield and soil erosion at different level of rainfall intensity.

3.5 Collection of Runoff

During the simulation process, runoff was allowed to flow and collected at the downstream end of the soil test box by means of a polyethylene (PE) bag pinned to the edge of the wooden test box (Figure 3).

The collected runoff was first weighed after which, it was allowed to stand overnight in order for the sediment to precipitate at the bottom. The sediment was separated and collected through filtration using a silk cloth. Filtered sediment was air dried then oven dried to 105 °C for 10 hours to determine the sediment concentration, sediment yield, and amount of soil erosion.

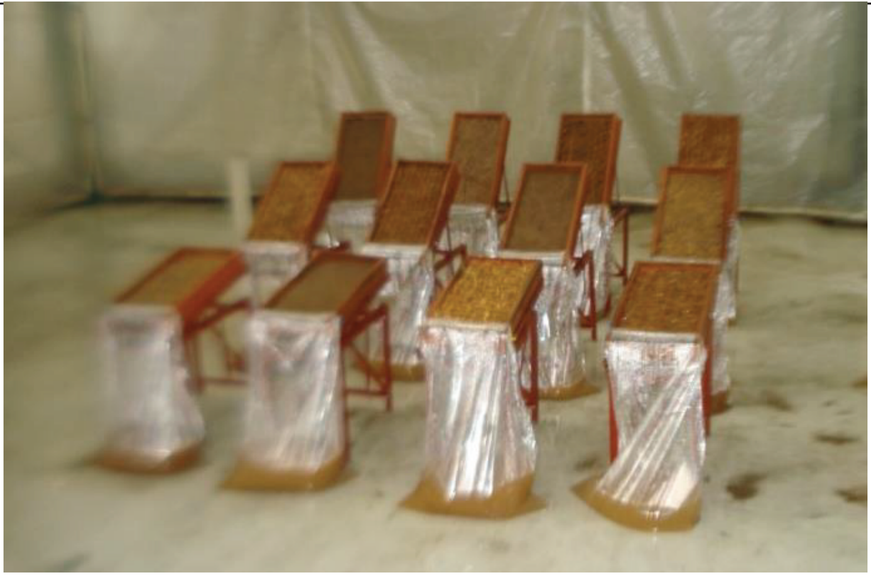

Figure 3. Polyethylene plastic bags

3.6 Performance Indicators

In order to assess the technical feasibility of the rice straw mat and rice straw net, the following performance indicators were determined:

3.6.1 Sediment Concentration (SC) – it is the ratio of the mass of the oven-dried sediment collected per soil test box to the volume of runoff (water + sediment) collected on the same soil box. Sediment concentration was calculated using the ASCE (2008) equation:

$$SC = \frac{S_m}{W_v} \quad (1)$$

where, SC = sediment concentration, g/L
S_m = mass of oven-dried sediment collected, g
W_v = volume of water collected, L

3.6.2 Sediment Yield (SY) - it reflects the total amount of erosion over a specific area at a given time. In this particular study, it is the mass of the oven-dried sediment collected over the area of the soil test box and duration of simulation. It was estimated using the formula adopted by Berboso, et al. (2008) as cited by Junio, et al. (2009).

$$SY = \frac{S_m}{A_b t} \quad (2)$$

where, SY = sediment yield, g m^2-hr
S_m = mass of oven-dried sediment collected, g
A_b = area of soil test box, m^2
t = duration of simulation, hr

3.6.3 Amount of soil erosion (SE) – is the total amount of soil erosion or loss generated from a given watershed. In this experiment, the amount of soil loss is the difference between the total runoff collected from the soil test box and runoff water from the same soil test box. The amount of soil erosion (oven-dried) is calculated using the following expression:

$$SE = RO_t - R_{ow} \quad (3)$$

where, SE = amount of soil erosion (oven-dried), g/cc
RO_t = total runoff collected/soil test box, g/cc
R_{ow} = total runoff water collected/soil test box, g/cc

4. Results

4.1 Soil Erosion Under Different Rainfall Intensities

Table 1 shows the main and interaction effects of slope gradient and geotextile. It can be noted that RSM registered the lowest soil erosion at rainfall intensities of 75 and 100 mm/hr, followed by RSN, CCN and NGC or bare plot. At 125 mm/hr rainfall, RSM had also the lowest soil erosion followed by CCN, RSN and NGC. As to the main effect of slope gradient, lowest soil erosion at all levels of rainfall was noted at 60° slope gradient followed by 10 and 35°.

On the other hand, the interaction effects of geotextile and slope gradient were observed to be higher at 75 mm/hr rainfall while lower interaction effects were noted at 125 mm/hr rainfall.

Table 1. Soil erosion as affected by different geotextiles and varying levels of slope gradient under different rainfall intensities, g/m^2

SLOPE	TREATMENT				MEAN
degree	RSM	RSN	CCN	NGC	(S)
			I1 = 75 mm/hr		
10	27.33t	47.0uv	62.0v	655.33y	197.92b
35	48.0uv	88.33w	95.67w	882.0z	278.50a
60	21.67t	34.33tu	33.67tu	506.33x	149.00c
MEAN (GT)	32.33i	56.55j	63.78j	681.22k	
			I2 = 100 mm/hr		
10	25.67w	43.33w	45.0w	512.0y	156.50b
35	35.33w	64.67w	63.67w	871.0z	258.67a
60	17.67w	28.0w	28.0w	325.0x	99.67c
MEAN (GT)	26.22i	45.33j	45.56j	569.33k	
			I3 = 125 mm/hr		
10	15.0w	35.67w	36.67w	447.0y	133.59b
35	20.67w	43.67w	42.33w	678.33z	196.25a
60	13.0w	25.67w	24.0w	252.0x	78.67c
MEAN (GT)	16.22i	35.00j	34.33j	459.11k	

4.2 Relationship of Slope Gradient vs. Sediment Concentration

The relationship between slope gradient and sediment concentration is shown in Figure 4. Regression analysis indicated that sediment concentration best fitted ($R^2 = 0.977$) in a quadratic model in the form of a second-degree polynomial equation. That is,

$$SC = 0.551 + 0.626S - 0.008S^2 \qquad (4)$$

where: SC = predicted sediment concentration, g/L
S = slope gradient, degree

while 0.551 is the intercept of the line on the Y-axis as the predicted amount of sediment concentration when the slope is equal to zero, while 0.626 and -0.008 are the amount of change in sediment concentration for every unit change in slope.

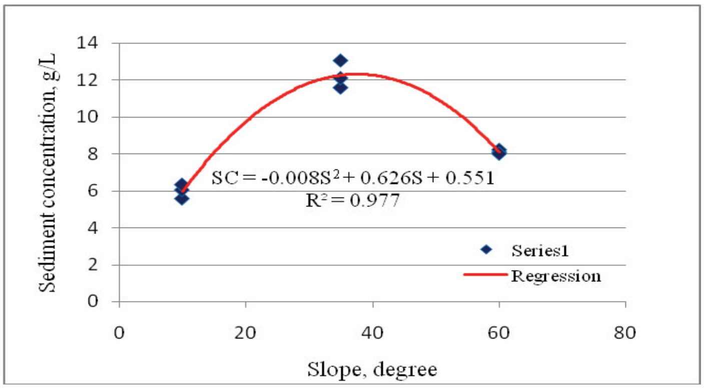

Figure 4. Relationship of slope gradient *vs*. sediment concentration.

4.3 Relationship of Slope Gradient vs. Sediment Yield

Regression analysis showed nonlinear relationship between sediment yield and slope gradient (Figure 5). The nonlinear pattern of the observed sediment yield best fitted ($R^2 = 0.954$) a second degree polynomial equation as expressed by the quadratic model:

$$SY = 356.0 + 61.70S - 0.972S^2 \qquad (5)$$

where: SY = predicted sediment yield, g/m^2-hr
S = slope gradient, degree

while 356.0 is the intercept of the line on the Y-axis as the forecasted amount of sediment yield when slope is equal to zero, 61.70 and -0.972 are the first and second degree slope of the line, respectively, or the amount of change in sediment yield for every unit change in slope.

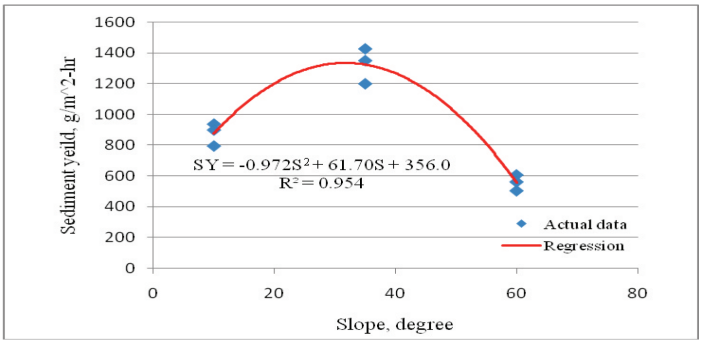

Figure 5. Relationship of slope gradient *vs*. sediment yield.

4.4 Relationship of Slope Gradient vs. Soil Erosion

Figure 6 shows a nonlinear relationship between slope gradient and soil erosion. The observed soil erosion was best modeled with $R^2 = 97.1\%$ confidence by a second degree polynomial equation. The regression model is quadratic in form and is given by the equation:

$$SE = 68.92 + 11.11S - 0.174S^2 \qquad (6)$$

where: SE = predicted soil erosion, g/m^2
S = slope gradient, degree

while 68.92 is the intercept of the line on the Y-axis and represents the modeled soil erosion at zero slope, 11.11 and -0.174 are the amount of change in soil erosion for every unit change in slope gradient.

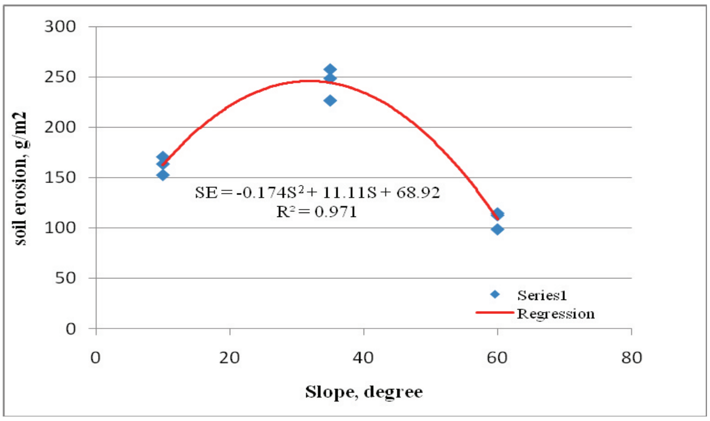

Figure 6. Relationship of slope gradient *vs*. soil erosion.

5. Discussion

5.1 Effect on Soil Erosion Under Different Rainfall Intensities

Soil erosion was significantly affected by the main effects of slope gradient. At all levels of rainfall intensity, significantly higher soil erosion was observed at slope gradient of 35° (Table 1). On the contrary, significantly lower soil erosion was noted at the highest slope gradient of 60°.

The significantly lower soil loss at higher slope gradient could be attributed to the differences in the horizontal surface distance of the soil test box. When the slope gradient was increased, the corresponding horizontal surface area decreased as a result of decreased in horizontal surface distance (Figure 2). And when the horizontal surface area was decreased, less rainfall will be intercepted resulting in lower runoff and eventually lower soil loss.

The main effects of geotextile as surface cover on soil erosion were highly significant. Regardless of the intensity of rainfall applied, soil test box covered with RSM yielded significantly lower soil loss as compared with the rest of the treatments (Table 1). However, RSN and CCN were comparable with each other but differs significantly with NGC.

The significantly lower soil loss under RSM could be attributed to the effect of its higher percentage of surface cover. Geotextile with higher percentage of ground cover is more effective in intercepting and reducing the impact action and erosive power of falling raindrops which is responsible in detaching and splashing soil particles. The results indicate and agree with Sutherland and Ziegler (2007) which states that geotextiles with less open space are the most effective design.

On the other hand, the interaction effects of slope gradient and geotextile on the parameter being investigated at all levels of rainfall intensity were found to be highly significant. Lowest soil erosion (13.0 g/m^2) was noted on soil test box covered with RSM and inclined to 60 degrees under rainfall intensity of 125 mm/hr while the highest soil loss (882.0 g/m^2) was observed under NGC or bare plot tilted at 35 degrees and 75 mm/hr rainfall (Table 1).

5.2 Slope Gradient vs. Sediment Concentration

A nonlinear relationship between slope gradient and sediment concentration was observed. That is, at a lower slope gradient of 10°, average sediment concentration was likewise lower. When the slope gradient was increased to 35°, average sediment concentration increased correspondingly. However, when the slope gradient was further increased to 60°, a corresponding decrease in sediment concentration was noted. The observed decreased in sediment concentration could be attributed to the smaller horizontal surface area of the soil test box when tilted to higher slope gradient of 60°.

In addition, the nonlinear relationship could be due to the differences in slope gradient. At lower slope of 10 degrees, the elevation is nearly flat, therefore the velocity of surface runoff is also slow. When the velocity is slow, shear stress which may cause detachment of soil particles could also be low. Therefore, when the velocity of runoff is slow, little amount of sediment can only be transported downslope.

5.3 Slope Gradient vs. Sediment Yield

At 10-degree slope gradient, the generated mean sediment yield was 875.80 g/m^2-hr, but went up progressively to 1,323.98 g/m^2-hr when the slope was increased to 35 degrees (Figure 5).

However, as the slope gradient was further increased to 60 degrees, a remarkable decline in the average sediment yield of 556.09 g/m^2-hr was noted. Therefore, even if the velocity of surface runoff is expected to increase rapidly at a 60-degree slope inclination, there is a probability that the amount of runoff that can be generated is lesser, and eventually lesser amount of sediment is generated. This statement corroborates the findings of Fan and Wu (1999) that sediment yield at steeper slope was less than at the milder slope.

5.4 Slope Gradient vs. Soil Erosion

A nonlinear relationship between slope gradient and soil erosion was observed. That is, at a lower slope gradient of 10^o, average soil erosion was likewise lower. When the slope gradient was increased to 35^o, average soil erosion correspondingly. However, when the slope gradient was further increased to 60^o, a corresponding decrease in soil erosion was noted. The observed decreased in soil erosion could be attributed to the smaller horizontal surface area of the soil test box when tilted to higher slope gradient of 60^o. This observation agrees with the theory on "erosion as function of slope" adapted from Pierce (1987) as cited by Anthoni (2000) which states that, erosion increases rapidly with slope, then declines after reaching a certain slope, as in this case, at 35-degree slope.

6. Conclusion

1. At any given level of slope gradient under different storm intensity, RSM and RSN were found to be effective in controlling soil erosion.
2. Under rainfall intensities of 75, 100 and 125 mm/hr, RSM had significantly lower soil loss as compared to RSN, CCN and NGC. However, RSN and CCN were comparable with each other but differ significantly with NGC.
3. The main and interaction effects of slope and geotaxtile on the different parameters tested were highly significant.
4. Generally, the relationships of slope gradient *vs*. sediment concentration, sediment yield and soil loss were found to be nonlinear and can be predicted by a quadratic model in the form of equation: $y = a + bx + cx^2$.

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Notes

Note 1. Rice straw geotextile like RSM and RSN can be a good substitute to CCN as erosion control material as proven by the data gathered at varying levels of slope gradients under different rainfall intensities.

Note 2. Rice straw mat and RSN should be evaluated under actual field condition alongside CCN to verify the results of simulation study.