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Runoff and Sediment Reduction using hay mulch treatment at varying land slope and Rainfall intensity under simulated rainfall condition

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ABSTRACT

Organic mulching provides important information in soil and water conservation in soil natural environment. Proper application of hay mulch not only reduces the runoff but also holds the soil particles and hence reduces the soil erosion. The sediment outflow and runoff from various mulch treatments at selected land slopes under simulated rainfall conditions have been measured in this study over the locally available soil material collected from Pantnagar. Three mulch rate viz. 6 ton/ha, 8 ton/ha and 10 ton/ha, three rainfall intensities viz. 11cm/h, 13cm/h and 14.65cm/h and three land slopes 0%, 2% and 4%, were selected. The duration of rainfall was fixed for 10 minutes for every treatment. The total runoff volume was found to be varying with different mulch rates for particular rainfall input and land slope. The runoff distribution pattern was observed to be increasing with the increase in land slope. The average sediment concentration and outflow was found to be increasing with the increase in land slope, whereas sediment concentration and outflow decreased with increasing mulch rate for particular land slope and rainfall intensity. The sediment outflow rate for no mulch treated land was higher as compared hay mulch treated lands. The grass plot has a 10–18% less runoff and an 82–93% less sediment in comparison to control soil plot. The conclusion states that hay mulch treatment has an important role in the reduction of runoff and soil loss for sandy loam soil.
***Key word**: Rainfall simulator**,** land slope, hay mulch, runoff and sediment outflow.*

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INTRODUCTION

Soil erosion is a crucial environmental process because it can lead to water pollution [10]. There are several practices available to reduce soil erosion under agronomical measures and engineering measures, between these two, agronomical measures are more preferable for controlling soil erosion. Agronomical practices for soil and water conservation help to intercept raindrops and reduce the splash effect, help to obtain a better intake of water rate by improving the content of organic matter and soil structure, help to retard and reduce the overland runoff through the use of contour cultivation, mulches and strip cropping. Surface application of organic mulches is useful to reduce soil erosion and evaporation and to improve infiltration, soil structure, organic matter content and crop yields. Many researchers have found that mulching absorbs the kinetic energy of raindrops and covers a large proportion of the soil to slow down runoff, and keeps the soil surface porous. Mulching is used worldwide as field management practices [1] and it protects soil from the direct action of rainfall and reduces sediment yield as well as runoff. Xin-Hu *et al.*, [25] revealed that runoff and sediment yield was occurred lowest in case of the Bahia grass mulch plot then grass cover plot and highest occurred in the bare plot.

Surface mulching practices can efficiently conserve water and soil by reducing surface runoff and increasing the infiltration of water [19-22]. Mulching also reduces soil crusting caused by rainfall impact and reduces erosion by absorbing the kinetic energy of raindrops [15]. It is well adapted to subtropical regions with high rainfall intensity, especially on sloping land [19, 23]. According to Jordan *et al.*, [8] mulch is any material, other than soil, placed or left on the soil surface for soil and water management purposes.

The favorable effects of mulching on soil can be reviewed as follows-: i) expanded water intake and storage [4, 13], ii) conservation of soil against raindrop, decreasing erosion rates [8, 13], iii) reduce sediment and nutrient concentrations in a runoff [2, 7, 16], iv) decreased runoff rates and surface flow velocity by enhancing roughness [3, 8], v) improved infiltration rate [8, 21], vi) enhanced activity of some species of earthworms and crop production [24], vii) increased soil physical conditions such as soil structure and organic content [6, 9], viii) reduced topsoil temperature for more ideal growth and root development [5, 14] and (ix) reduced evaporation [20]. Straw mulch is considered one of the most successful in attending the above-mentioned benefits [5]. Therefore, objective of this paper is to assess the effect of grass (hay) mulch on sediment yield and runoff under simulated heavy rainfall condition.

MATERIAL AND METHODS

Rainfall Simulation System and Tilting Hydraulic Flume

Experiments were conducted in tilting hydraulic flume on three constant slopes of 0%, 2% and 4% installed in the Department of Soil and Water Conservation Engineering, college of Technology GBPUA&T, Pantnagar, Uttarakhand. The hydraulic flume has 10 m length × 1.2 m width × 0.5 m depth and a 1 m long settling chamber at its upstream end (Fig. 2). The flume bed was about 1 m height from ground which can be subjected to a longitudinal slope up to 6%. The bottom holes at 1 m intervals were provided with plugs to collect seepage water. The study was conducted under laboratory conditions due to the possibilities of simulating different rainfall intensities with the necessary repetition as well as the minute study of the sediment outflow and runoff processes. The experiments were performed using simulated rainfall at intensities of 11, 13, 14.63 cm/h. The rainfall simulator (Fig. 1) laboratory consists of a 6000 L water tank and the needles were 5.08 cm in length with a metal square pipe. In the entire simulation unit, a total of 336 needles were used. The needles were fitted on 10 mm × 10 mm square cross-sectioned aluminum laterals at a needle to needle spacing 20 cm × 20 cm. This rainfall simulation system produces rainfall almost similar to the natural rainfall, with its intensity varying from 6.50 cm/h to 17.50 cm/h and raindrop sizes vary from 3.05 mm to 4.76 mm. The uniformity coefficient of the generated rainfall ranges from 87.54% to 92.10% and the terminal velocity of falling raindrops vary from 7.674 m/s to 9.496 m/s at the selected operating pressure from 0.1 kg/cm^2 to 0.6 kg/cm^2.

Preparation of test plots

Soil was sandy loam in texture having 51.6 % Sand, 31.8% clay, bulk density 1.72g cm-3, permeability 3.4×10^{-5} cm/sec, infiltration rate 1.0 cm/h, water holding capacity 29.10%, porosity 40% and ph. 7.8. A uniform depth of 20 cm soil has been prepared over hydraulic flume. Efforts were made to create the condition in the test plot (Fig. 2), as similar as to natural site condition. The natural downward drainage condition was created by providing a coarse sand filter layer of about 5 cm before filling the soil. Air-dried Hay (grass) mulch used in three quantities viz. 600 g/m^2, 800 g/m^2, 1000 g/m^2 and spread on the soil surface as a treatment. Experiments were conducted under four treatments viz. no mulch, 600 g/m^2, 800 g/m^2 and 1000 g/m^2 hay mulch.

Fig. 1. Rainfall simulation unit

Fig. 2. Experimental Set-up with uniform hay mulch treatment over soil surface

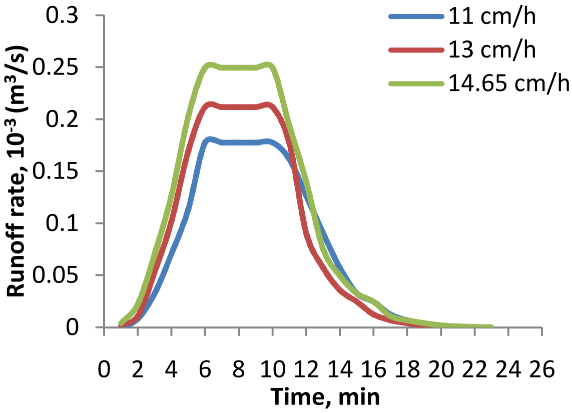
Runoff volume and Sediment yield measurement

The runoff commencement time and volume were measured at the outlet of plot. The time of runoff commencement and its regular measurement was done using the stopwatch. Runoff volume was measured with hook gauge by measuring the depth of water flowing over the V-notch weir crest at regular intervals. This static head was then converted to the rate of flow by applying head-discharge relationship for 90˚ V-notch and discharge were obtained at the different instant of time. The sediment yield at the outlet of plot was measured before mulching as a control treatment at 10 min rainfall duration and at intensities of 11, 13 and 14.65 cm/h. Sediment yield was also measured for plots covered with hay mulch. The amounts of sediment yield were then determined by taking 3 samples of 100 ml from completely stirred sediment. Samples were oven dried at 105°C for 24 h and weighed by means of high-precision scales.

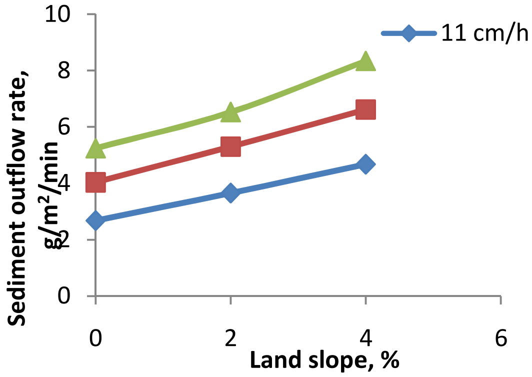
RESULTS AND DISCUSSION

Runoff hydrograph, SC and outflow for no mulch

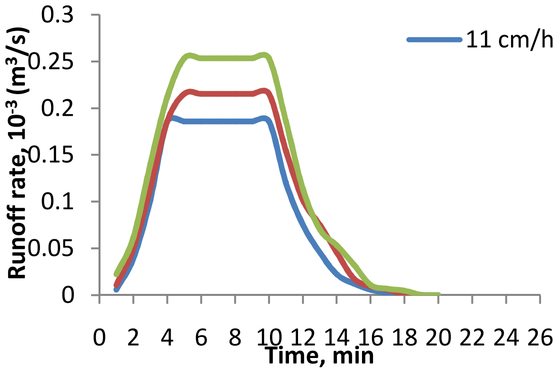
It was observed that the volume of runoff increased from 84350 cm^3 to 137760 cm^3 and the total SOR increased from 2.671 $g/m^2/min$ to 5.242 $g/m^2/min$ when rainfall intensity increased from 11 cm/h to 14.65 cm/h at 0% land slope. At other selected land slopes, the total runoff volume for 11cm/h rainfall intensity was found to be 84350 cm^3, 93170 cm^3 and 95550 cm^3 at land slope 0%, 2% and 4% respectively (Table 1). In Fig. 3, it was observed that as the land slope increases, the time taken to attain peak gradually decreases. The length of recession segment was found to be decreasing with the increase in land slope. Also the time taken by the runoff to attain peak gets reduced as land slope increases.



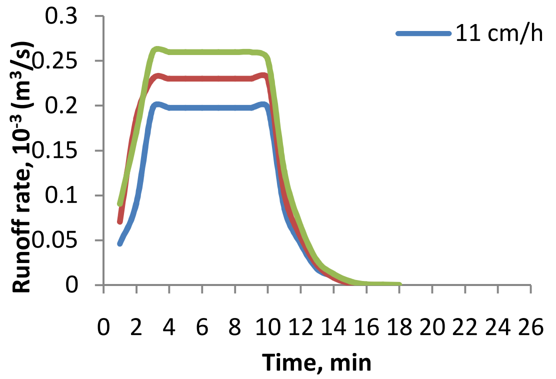
(a) 0% land slope



(a) Land slope vs Sediment outflow...

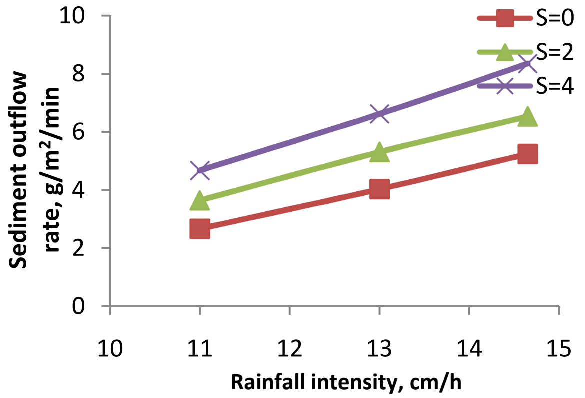


(b) 2% land slope

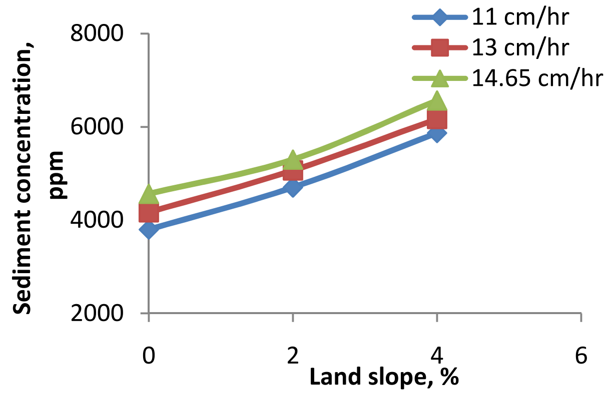


(c) 4% land slope

Fig. 3. Observed runoff hydrograph at different land slopes and rainfall intensities for no mulch



(b) Rainfall intensity vs Sediment outflow rate



(c) Land slope vs Sediment concentration

Fig. 4. Observed SOR and concentration at different rainfall intensities and land slopes for no mulch

Table 1 : Observed runoff volume, SC and outflow rate at different rainfall intensities and land slopes for without mulch

S, %	I, cm/h	Volume of runoff, cm^3	Weight of sediment in a 100 cm^3 representative sample, g				Average SC, ppm	Total sediment outflow, g	SOR, $g/m^2/min$
			I	II	III	Average			
0	11	84350	0.38	0.39	0.37	0.38	3800	320.53	2.671
	13	116200	0.41	0.42	0.42	0.417	4166.67	484.167	4.034
	14.65	137760	0.46	0.45	0.46	0.467	4566.67	629.104	5.242
2	11	93170	0.46	0.47	0.48	0.47	4700	437.899	3.649
	13	125650	0.5	0.51	0.51	0.507	5066.66	636.627	5.305
	14.65	147735	0.54	0.53	0.52	0.53	5300	782.995	6.525
4	11	95550	0.58	0.59	0.59	0.586	5866.66	560.56	4.671
	13	128800	0.62	0.62	0.61	0.616	6166.67	794.267	6.618
	14.65	152600	0.66	0.65	0.66	0.656	6566.67	1002.073	8.350

The observed SOR at 0% land slope was found to be between 2.671 $g/m^2/min$ to 5.242 $g/m^2/min$ at rainfall intensities 11cm/h to 14.65 cm/h respectively, a similar trend was observed at 2% and 4% land slopes too (Fig. 4 (a, b)). Regression equation was obtained as:

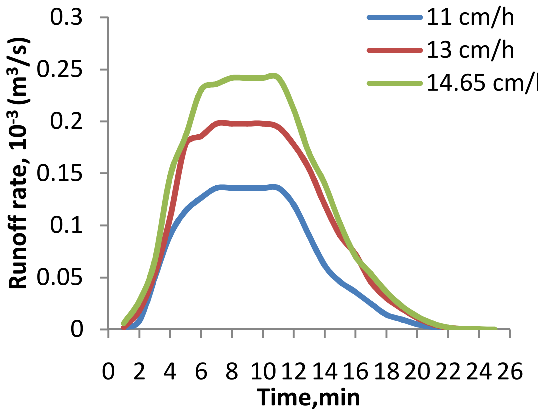
$$SOR = 0.641\ S + 0.833\ I - 6.787;\ R^2 = 98.52\% \qquad (1)$$

Where, *SOR* is in $g/m^2/min$, *S* is in percentage and *I* is in cm/h. The observed values of average SC were found to be varying with rainfall intensities at selected land slope for no mulch (Fig. 4 (c)). It was observed that the SC increases in with the increase in land slope at particular rainfall intensity. The SC was found to be 3800 ppm, 4166 ppm and 4566 ppm at 0% land slope for 11cm/h, 13cm/h and 14.65 cm/h rainfall intensities, respectively. A similar trend was also observed for 2% & 4% land slopes. Regression equation for SC (ppm) was obtained as:

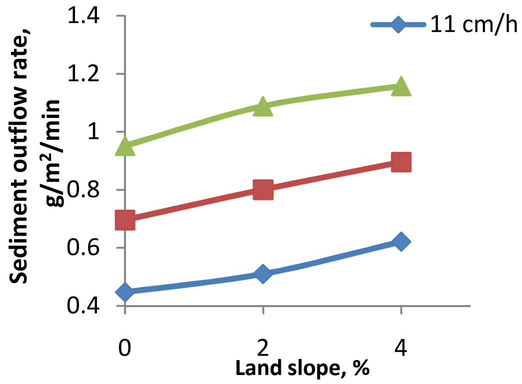
$$SC=505.555\,S + 188.159\,I + 1698.094;\ R^2 = 98.11\ \% \quad (2)$$

Runoff hydrograph, SC and outflow for hay (grass) Mulch

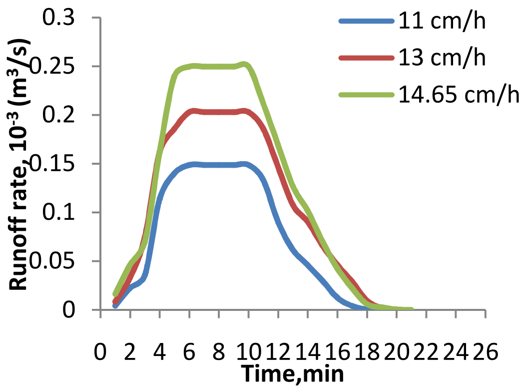
For 6 t/ha hay (grass) mulch treatment (Table 2), it was observed that the volume of runoff increased from 76650cc to 131824 cc and the total SOR increased from 0.447 g/m²/min to 0.952 g/m²/min when rainfall intensity increased from 11 cm/h to 14.65 cm/h at 0% land slope. At other selected land slopes, the total runoff volume for 11cm/h rainfall intensity was found to be 76650 cc, 83510 cc and 93240 cc at land slope 0%, 2% and 4% respectively (Fig. 5). The observed SOR at 0% land slope was found to be between 0.447 g/m²/min to 0.952 g/m²/min at rainfall intensities 11cm/h to 14.65 cm/h respectively at 0% land slope, A similar trend was observed at 2% and 4% land slopes (Fig 6). In Fig. 6 (c), SC was found to be 700 ppm, 767 ppm and 866 ppm at 0% land slope for 11cm/h, 13cm/h and 14.65 cm/h rainfall intensities, respectively. Similar trend was also for 2% & 4% land slopes. For 8 t/ha hay (grass) mulch (Fig. 7), it was observed that the volume of runoff increased from 7200 cc to 129521 cc and the total SOR increased from 0.340 g/m²/min to 0.719 g/m²/min when rainfall intensity increased from 11 cm/h to 14.65 cm/h at 0% land slope. At other selected land slopes, the total runoff volume for 11cm/h rainfall intensity was found to be 72100 cc, 81347 cc and 90391 cc at land slope 0%, 2% and 4% respectively. In Fig. 8 (a) and 8 (b), the observed SOR at 0% land slope was found between 0.340 g/m²/min to 0.719 g/m²/min at rainfall intensities 11cm/h to 14.65 cm/h respectively at 0% land slope. The SC was found 566 ppm, 600 ppm and 666 ppm at 0% land slope for 11cm/h, 13cm/h and 14.65 cm/h rainfall intensities, respectively (Fig. 8 (c)).



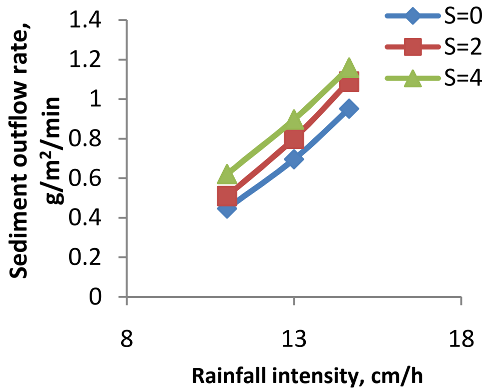
(a) 0% land slope



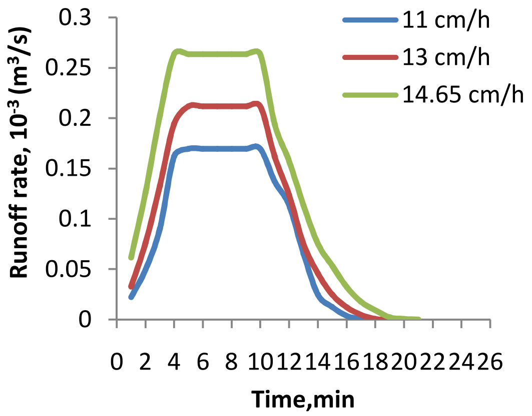
(a) Land slope vs Sediment outflow rate



(b) 2% land slope

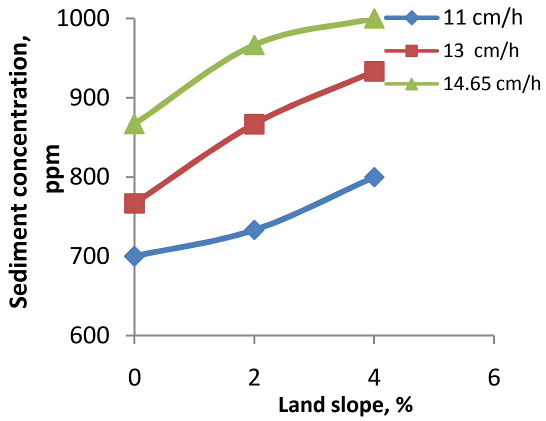


(b) Rainfall intensity vs Sediment…



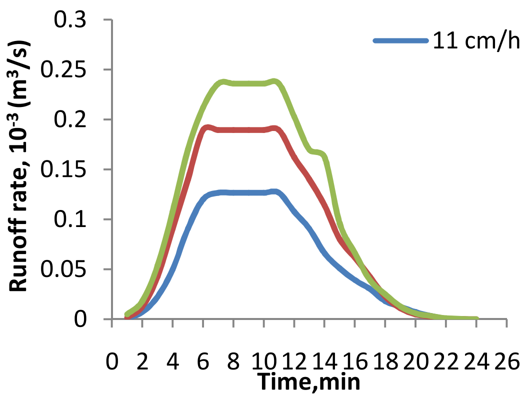
(c) 4% land slope

Fig. 5 Observed runoff hydrograph at 0%, 2%, and 4% land slopes using simulated rainfall intensities for 6 ton/ha hay (grass) mulch

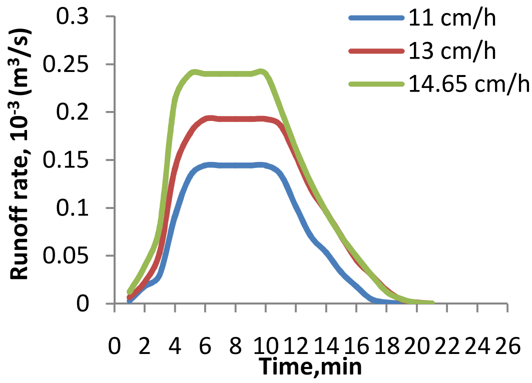


(c) Land slope vs sediment concentration

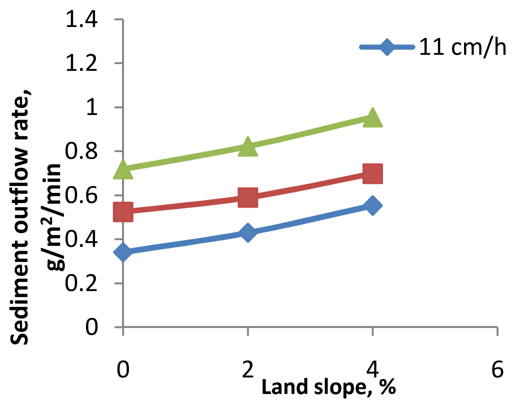
Fig. 6 Observed SOR and concentration with varying rainfall intensities and land slopes for 6 ton/ha hay (grass) mulch



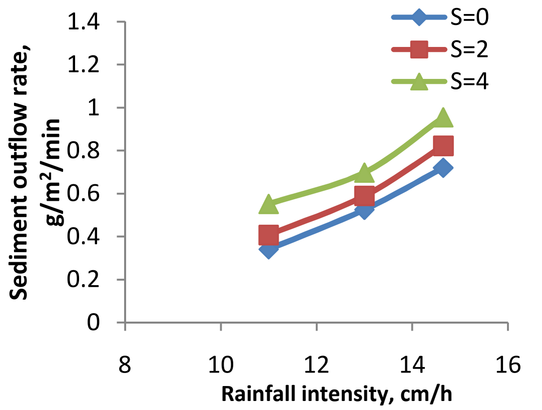
(a) 0% land slope



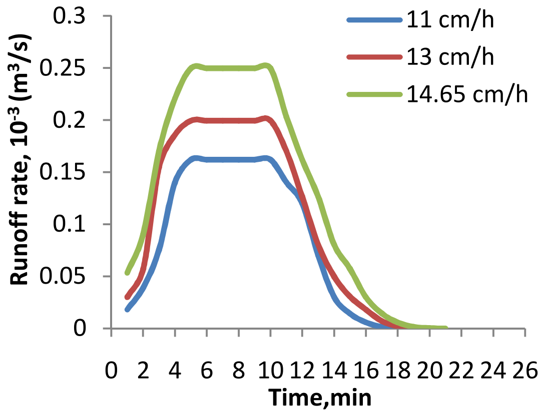
(b) 2% land slope



(a) Land slope vs Sediment outflow rate

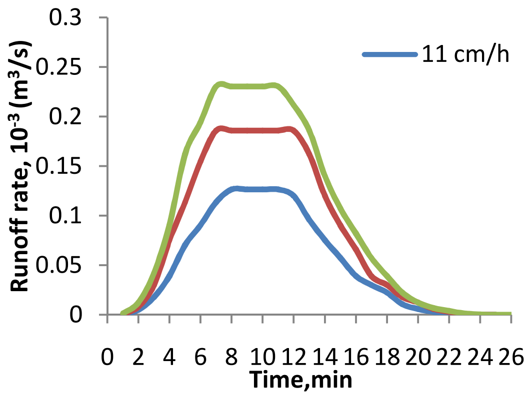


(b) Rainfall intensity vs Sediment outflow rate

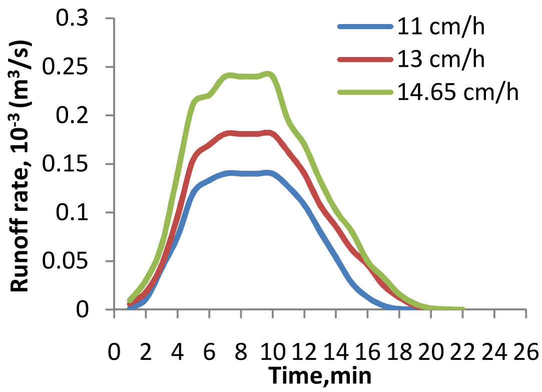


(c) 4% land slope

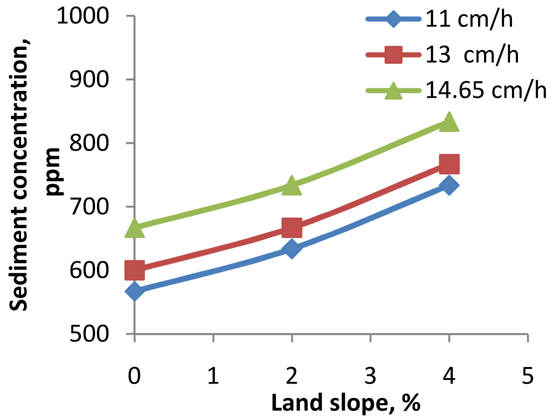
Fig. 7 Observed runoff hydrograph at 0%, 2%, and 4% land slopes using simulated rainfall intensities for 8 ton/ha hay (grass) mulch



(a) 0% land slope

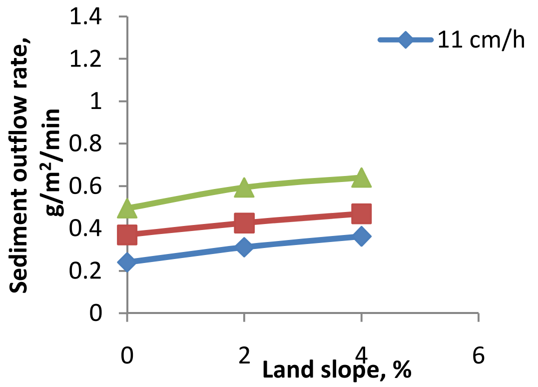


(b) 2% land slope

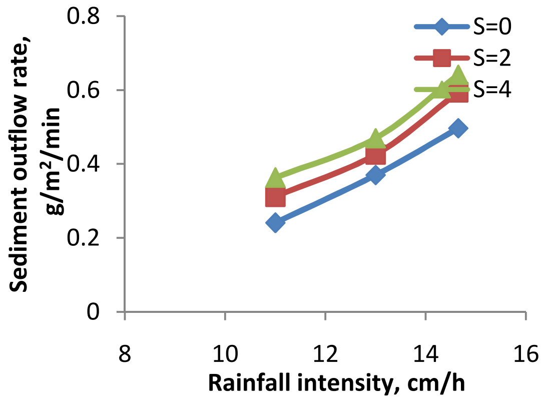


(c) Land slope vs sediment concentration

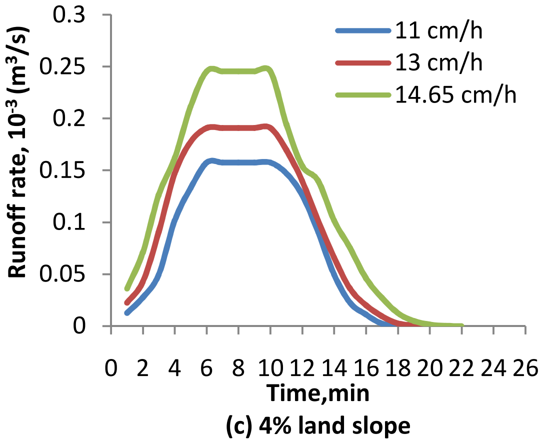
Fig. 8 Observed SOR and concentration with varying rainfall intensities and land slopes for 8 ton/ha hay (grass) mulch



(a) Land slope vs Sediment outflow rate



(b) Rainfall intensity vs Sediment outflow rate



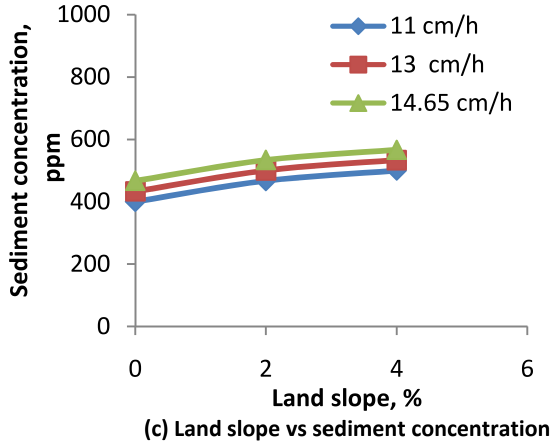
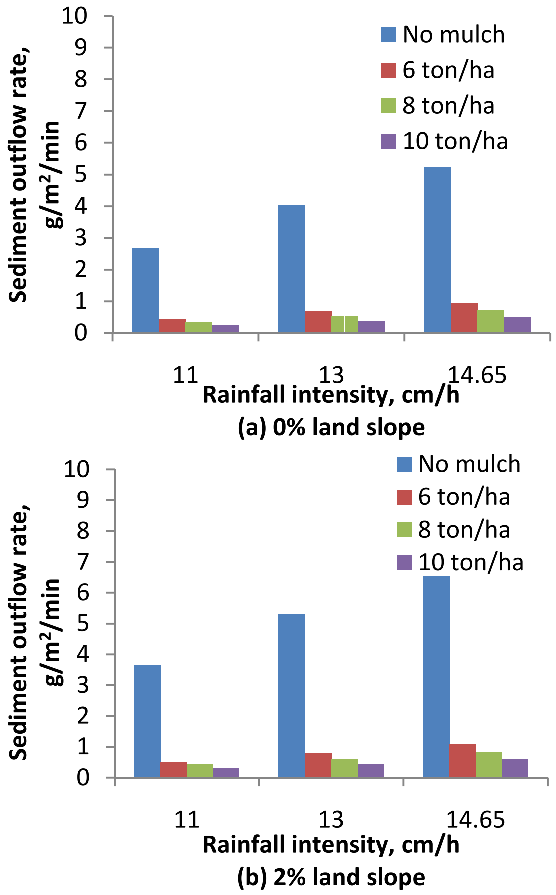
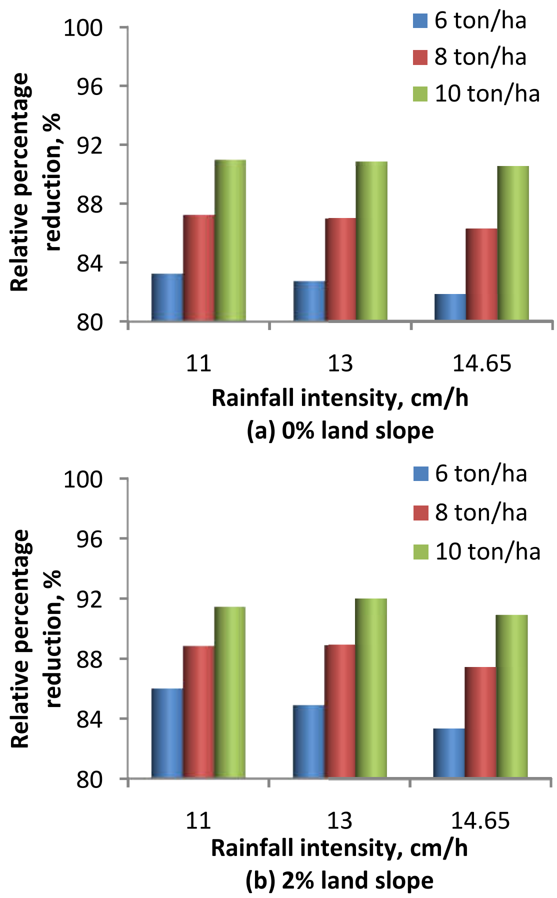


Fig. 9 Observed runoff hydrograph at 0%, 2%, and 4% land slopes using simulated rainfall intensities for 10 ton/ha hay (grass) mulch

Fig. 10 Observed SOR and concentration with varying rainfall intensities and land slopes for 10 ton/ha hay (grass) mulch





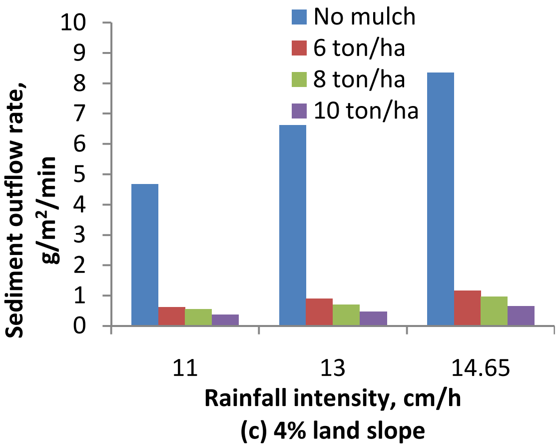


Fig. 11 Comparison of SOR for different hay mulch rate treatment using selected rainfall intensities at 0%, 2%, and 4% of land slopes

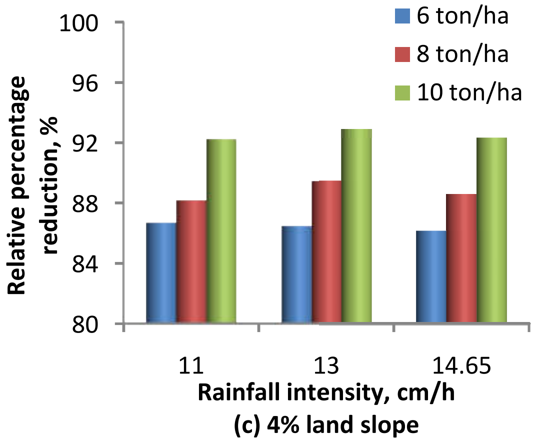


Fig. 12 Comparison of relative present reduction in SOR for different hay mulch rate treatments and rainfall intensities with respect to no mulch at 0%, 2%, at 4% of land slopes

In Fig. 9, volume of runoff increased from 72247 cc to 127750 cc and the total SOR increased from 0.240 g/m²/min to 0.496 g/m²/min when rainfall intensity increased from 11 cm/h to 14.65 cm/h at 0% land slope for 10 t/ha hay (grass) mulch. At other selected land slopes, the total runoff volume for 11cm/h rainfall intensity was found to be 72247 cc, 80150 cc and 87080 cc at land slope 0%, 2% and 4% respectively. In Fig. 10 (a) and 10 (b), observed SOR at 0% land slope was found to be between 0.240 g/m²/min to 0.496 g/m²/min at rainfall intensities 11cm/h to 14.65 cm/h respectively at 0% land slope, similarly at 2% and 4% land slopes. In Fig. 10 (c), the SC was found to be 400 ppm, 433 ppm and 466.67ppm at 0% land slope for 11cm/h, 1 3cm/h and 14.65 cm/h rainfall intensities, respectively, similarly at 2% & 4% land slopes. Mathematical models for hay (grass) mulch were calculated as:

$$SOR = -0.090\,M + 0.0435\,S + 0.109\,I - 0.163;\ R^2 = 95.19\ \% \qquad (3)$$
$$SC = -100.93\,M + 40.74\,S + 24.34\,I + 932.06;\ R^2 = 95.82\ \% \qquad (4)$$

Table 2: Observed runoff volume, SC and outflow rate at different rainfall intensities and land slopes for hay (grass) mulch

Mulch rate	S,%	I,cm/h	Volume of runoff, cm³	Weight of sediment in a 100 cm³ representative sample, g				Average SC, ppm	Total sediment outflow,g	SOR, g/m²/min
				I	II	III	Average			
6 t/ha	0	11	76650	0.07	0.07	0.07	0.070	700.00	53.66	0.45
		13	108871	0.08	0.08	0.07	0.077	766.67	83.47	0.70
		14.65	131824	0.08	0.09	0.09	0.087	866.67	114.25	0.95
	2	11	83510	0.07	0.07	0.08	0.073	733.33	61.24	0.51
		13	110824	0.10	0.08	0.08	0.087	866.67	96.05	0.80
		14.65	135100	0.10	0.10	0.09	0.097	966.67	130.60	1.09
	4	11	93240	0.08	0.09	0.07	0.080	800.00	74.59	0.62
		13	115150	0.09	0.10	0.09	0.093	933.33	107.47	0.90
		14.65	138957	0.10	0.10	0.10	0.100	1000.0	138.96	1.16
8 t/ha	0	11	72100	0.05	0.06	0.06	0.057	566.67	40.86	0.34
		13	104860	0.05	0.06	0.07	0.060	600.00	62.92	0.52
		14.65	129521	0.06	0.07	0.07	0.067	666.67	86.35	0.72
	2	11	81347	0.05	0.07	0.06	0.060	600.00	48.81	0.41
		13	106064	0.06	0.06	0.08	0.067	666.67	70.71	0.59
		14.65	134484	0.07	0.08	0.07	0.073	733.33	98.62	0.82
	4	11	90391	0.08	0.08	0.06	0.073	733.33	66.29	0.55
		13	109277	0.07	0.08	0.08	0.077	766.67	83.78	0.70
		14.65	137480	0.09	0.07	0.09	0.083	833.33	114.57	0.95

10 t/ha	0	11	72247	0.04	0.04	0.04	0.040	400.00	28.90	0.24
		13	102557	0.04	0.04	0.05	0.043	433.33	44.44	0.37
		14.65	127750	0.04	0.04	0.06	0.047	466.67	59.62	0.50
	2	11	80150	0.04	0.05	0.05	0.047	466.67	37.40	0.31
		13	102235	0.05	0.05	0.05	0.050	500.00	51.12	0.43
		14.65	133763	0.05	0.06	0.05	0.053	533.33	71.34	0.59
	4	11	87080	0.04	0.05	0.06	0.050	500.00	43.54	0.36
		13	105770	0.06	0.05	0.05	0.053	533.33	56.41	0.47
		14.65	135870	0.05	0.06	0.06	0.057	566.67	76.99	0.64

Table 3: Comparison of observed SOR for selected hay (grass) mulching treatments under simulated rainfall conditions at selected land slopes

S	SOR, g/m^2 /min											
	I=11cm/h				I=13cm/h				I=14.65cm/h			
%	No mulch	6 t/ha	8 t/ha	10 t/ha	No mulch	6 t/ha	8 t/ha	10 t/ha	No mulch	6 t/ha	8 t/ha	10 t/ha
0	2.67	0.45	0.34	0.24	4.03	0.70	0.52	0.37	5.24	0.95	0.72	0.50
2	3.65	0.51	0.43	0.31	5.31	0.80	0.59	0.43	6.53	1.09	0.82	0.60
4	4.67	0.62	0.55	0.36	6.62	0.90	0.70	0.47	8.35	1.16	0.96	0.64

Table 4: Relative percentage reduction in observed SOR for 6 ton/ha, 8 ton/ha and 10 ton/ha Hay (grass) mulch compared to no mulch at selected land slopes and rainfall intensities

S%	I (cm/h)	No mulch	Hay mulch, 6 t/ha	Hay mulch, 8 t/ha	Hay mulch, 10 t/ha	7=(col.3-col.4)*100/(col.3)	8=(col.3-col.5)*100/(col.3)	9=(col.3-col.6)*100/(col.3)
0	11	2.67	0.45	0.34	0.24	83.26	87.25	90.98
	13	4.03	0.70	0.52	0.37	82.76	87.01	90.82
	14.65	5.24	0.95	0.72	0.50	81.84	86.27	90.52
2	11	3.65	0.51	0.41	0.31	86.02	88.85	91.45
	13	5.31	0.80	0.60	0.43	84.91	88.89	91.97
	14.65	6.52	1.09	0.82	0.59	83.32	87.40	90.89
4	11	4.67	0.62	0.55	0.36	86.69	88.17	92.23
	13	6.62	0.90	0.70	0.470	86.47	89.45	92.90
	14.65	8.35	1.16	0.96	0.64	86.13	88.57	92.32

In Table 3 and Fig. 11, the observed values of SOR for no mulch were observed to be 2.671 g/m^2/min, 4.0347 g/ m^2/min, and 5.242 g/m^2/min, at 0% land slope. For 6 t/ha hay mulch, the SORs were found to be 0.447 g/m^2/min, 0.695 g/m^2/min and 0.952 g/m^2/min. the values for 8 t/ha hay mulch were 0.340 g/m^2/min, 0.524 g/m^2/min and 0.719 g/m-^{2}/min and for 10 t/ha hay mulch the values were 0.240 g/m^2 /min, 0.370 g/m^2/min and 0.496 g/m^2/min for rainfall intensities of 11 cm/h, 13 cm/h and 14.65cm/h respectively. As observed from Fig. 12 (a), no mulch treatment yielded the highest SOR as compared to other mulching treatments at any selected slope. The similar trend was observed at 2% land slope for all rainfall intensities (Fig. 12 (b)). The SOR at 4% land slope for selected mulch treatment was found to have similar trend as in case of 0% and 2% land slopes (Fig. 12 (c)). In Table 4 and Fig. 11, calculated values of relative percentage reduction in observed SOR for 6 t/ha hay mulch were found to be 83.260%, 82.760% and 81.839% at 0% land slope. The values for 8 t/ha hay mulch were found to be 87.253%, 87.005%, 86.274% and 90.984%, 90.821%, 90.523% for 10 t/ha and rainfall intensities of 11 cm/h, 13cm/h and 14.65 cm/h respectively at selected land slope. It was observed that when rainfall intensity increases from 11 cm/h to 14.65 cm/h at a particular land slope, the 10 t/ha hay mulch was more effective in controlling SOR as compared to lower mulch rates (Fig. 12 (a)). The similar trend was observed at 2% land slope for all rainfall intensities (Fig. 12 (b)), the effectiveness of these mulching treatments in controlling SOR gradually decreases with the increase in mulch rate at any selected land slope. The SOR at 4% land slope for selected mulch treatment was found to have similar trend as in case of 0% and 2% land slopes. It was observed from Fig. 12 (c) that 10 t/ha hay mulch was more effective in controlling SOR as compared to 6 t/ha and 8 t/ha hay mulch at any land slope and rainfall intensity.

CONCLUSION

The study was carried out with the objectives to determine the sediment outflow and concentration for varying land slopes and simulated rainfall intensities for selected mulch treatments along with no mulch treatment. The study was conducted under laboratory conditions by using a rainfall simulator of size 10m × 1.4m and a hydraulic tilting flume of size 10m × 1.2m × 0.5m. The rainfall simulation system is capable of generating artificial rainfall almost similar to natural rainfall. It was used to produce variable rainfall intensities in range of 6.50 cm/h to 17.96 cm/h. The hydraulic tilting flume was used to create a test plot with varying land slopes, in range of 0% to 5%.The sediment outflow rate was observed for three different mulching treatments like, no mulch treatment, 6 ton/ha hay mulch treatment, 8 ton/ha hay mulch treatment, 10 ton/ha hay mulch treatment, finally keeping all factors 10 ton/ha mulch treatment having the best suitable treatment to control sediment outflow and runoff.

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