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SEDIMENT OUTFLOW FROM PADDY MULCH AT VARYING LAND SLOPES UNDER SIMULATED RAINFALL CONDITIONS

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ABSTRACT : Soil erosion in India is really need of hour as to improve soil health is on main agenda. Various measures are used by researchers to reduce soil loss due to runoff and best one is found to be biological measures. In biological measures, organic mulches are very effective in preventing soil erosion, to reduce sediment transport rate, runoff and increasing infiltration. The study was carried out with the objectives to observe the sediment outflow during paddy mulch treatments at selected land slopes with different rainfall intensities under simulated rainfall conditions, just to count soil loss. The quantity of mulch was taken as, 6 ton/ha, 8 ton/ha and 10 ton/ha and for each mulch treatment, three rainfall intensities *viz.* 11cm/h, 13cm/h and 14.65cm/h at 0%, 2% and 4% land slopes were selected. The average sediment concentration and outflow was found to be increasing with the increase in land slope, but 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 to paddy straw mulch treated lands. Mathematical relationships were developed for relating sediment outflow rate, sediment concentration, land slope and rainfall intensity for a particular mulch treatment. It was observed that values of sediment outflow rate and average sediment concentration had a good correlation with rainfall intensity and land slope for each mulch treatment. The correlation coefficients of developed models were found to be more than 90% which supports mulching as the best biological measure.

Keywords : *Paddy mulch, sediment outflow, land slope, simulated rainfall.*

Soil erosion and sediment outflow from agricultural lands isquiet serious global problem (Wolancho, 19). The soil resources of the world are finite, functionally non-renewable and prone to different forms of degradation due to over-exploitation and faulty management practices. Topsoil erosion is a global problem that causes environmental pollution of waterways and loss of soil fertility (Cerdà *et al.,* 1, 2 and 3). Soil degradation has reached alarming proportions in many parts of the world, especially in the tropics and sub-tropics regions. Soil erosion caused by water is a major factor contributing to land degradation in India. The estimates suggest that globally about 24 billion tonns of soil is lost annually through water erosion while formation of natural rate of soil regeneration is less. In India, the problem of soil erosion is quite serious as about 18.5% of the world total soil erosion occurs here. India loses about 16.4 t of soil/ha/yr, of which 29% is lost permanently into the sea, 10% gets deposited in the reservoirs reducing their capacity by 1–2% every year and the remaining 61% gets displaced from one place to another (Dhruvanarayana, 4). There are several stages or type of water erosion including splash, sheet, inter-rill, rill, gully and stream bank erosion. These processes are governed by a large number of variablesfactors pertaining to rainfall, soil system, land topography, crop cover condition and management practices (Wischmrier and Smith, 18). The sediment generation is governed by the erosivity of erosive agents and the erodibility of the soil system, while the transportation process is mainly influenced by the transport capacity of runoff. Erosion by water is prime cause while that in form of rainfall and runoff becomes erosive agents, because rainfall energy is expanded in detaching soil particles and transportability of the sediment depends upon its velocity of runoff.

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The top layer of soil provides nutrients and a physically and biologically environment important to plant growth. So it is important to reduce the rate of soil erosion by use of crop and cover condition. The vegetation on surface helps in controlling the kinetic energy of falling raindrops, binding the soil particles and binding soil material by the root system which resists the detachment of soil aggregates (Wischmeier and Smith, 18). Change soil and water behaviour

(Huang *et al.,* 7).There are various methods of soil conservation which exhibit different performance and mechanism. The various natural and organic mulches, viz. crop residues leaf litter, wood chips, bark chips, biological geotextiles gravels and crushed stone are used for conservation of soil (Gilley *et al.,* 6; Ruy *et al.,* 12; Ruiz-Sinoga *et al.,* 11; Smets *et al.,* 15; Moreno-Ramón *et al.,* 9). Therefore mulches have extraordinary potential in soil erosion, sediment control and runoff reduction (Poesen and Lavee, 10). When vegetation is not established, we can be use organic mulches to quickly protect the soil surface against the erosive forces of rainfall (Smets *et al,* 16). Found that the grass mulch significantly reduced sediment yield at large plot scale. (Liu *et al.*, 8).

Organic mulches can be very effective in preventing soil erosion to absorb the impact of raindrops and reduce the detachment of soil aggregates. It also reduces soil erosion, sediment transport rate and increases soil organic matter and hence improves surface aggregation in environmental friendly manner (Sur and Ghuman, 17). Mulch covers are effective in increasing infiltration and reducing evaporation, runoff rate and sediments transport rate. (Shi *et al.,* 13) verified the positive effects of mulch cover on reduction of soil loss. (Fernandez and Vega 5). It is difficult to conduct such studies on mulches under actual field conditions, simply because of the reason that in actual conditions, it may not be feasible to obtain requisite number of rain storms of desired intensity and duration. In such situations, the conduct and replication of experiments under a particular set of combinations of variables are not practically possible as it will require huge financial, labour and time resources. Soil loss under laboratory conditions were considered by Sadeghi *et al.* (14).

As an accepted alternate approach, this study can be conduct conveniently under controlled conditions of laboratory using simulated rainfall, whose parameters could be regulated as per requirements of the experiments. The experimental set-up was developed in the Department of Soil and Water Conservation Engineering, College of Technology, GBPUA&T Pantnagar. Keeping the above facts in consideration, a study was undertaken with the help of rainfall simulation system and a tilting hydraulic flume of 10 m $\times$ 1.2 m size with the objective to study the effect of varying land slopes, rainfall intensities and mulch quantities on the sediment outflow rate and sediment concentration.

MATERIALS AND METHODS

Rainfall Simulation System

The experiments were conducted in The Department of Soil and Water Conservation Engineering, College of Technology, GBPUA&T, Pantnagar Uttarakhand as shown in Fig.1. The study was conducted under laboratory conditions due to the possibilities of simulating different rainfall intensities with the necessary repetition as well as minute study of the sediment outflow, runoff processes and data collection. The rainfall simulator consisted of a 6000 L water tank attached to a pump and rainfall simulation unit. The rainfall simulation unit comprised of hypodermic needles which were 5.08 cm in length fixed on a square metal pipe. In the entire simulation unit a total of 336 needles were used. The needles were fitted on 10 mm $\times$ 10 mm square aluminum laterals at a needle to needle spacing of 20 cm × 20 cm.This rainfall simulation system produced rainfall almost similar to the natural rainfall, with its intensity varying from 6.50 cm/h to 17.50 cm/h having raindrop size in the range of 3.05 mm to 4.76 mm. The uniformity coefficient of the generated rainfall ranged from 87.54% to 92.10% and the terminal velocity of falling raindrops varied from 7.67 m/s to 9.50 m/s in the selected operating pressure range of 0.1 kg/ to 0.6 kg/. In this study, three rainfall intensities, *i.e.* 11 cm/h, 13cm/h and 14.65 cm/h obtained at respective operating pressures of 0.2 kg/ cm^2, 0.3 kg/cm^2 and 0.4 kg/cm^2 were considered.The rainfall simulator was operated for a specified duration of 10 minutes and the generated runoff is allowed to pass through a multi-slot divisor with divisor ratio of seven. The runoff passed through the middle slot and was collected in a runoff collection tank to obtain small representative samples for determining sediment outflow rate and sediment concentration. To obtain the total runoff volume and also to obtain temporal distribution of runoff for various combinations of variables, the remaining runoff was allowed to pass through a V-notch. The observations were made for depth of flow over the crest every minute and the rate of flow was calculated to obtain runoff hydrograph and its total volume. In this way, the sediment outflow and sediment concentration were obtained for every combination of selected land slope, rainfall intensity and mulching treatment including no mulch treatment. The mathematical relationship were established between sediment outflow rate, sediment concentration, rainfall intensity and land slope for simulated rainfall condition and land slope in order to quantify the effects of these parameters on sediment

concentration and sediment outflow rate for different mulching treatments.

Tilting Hydraulic Flume

The hydraulic flume used in this study was of 10 m $\times$ 1.2 m $\times$ 0.5 m size. The flume bed was 1 m high from ground which could be subjected to a longitudinal slope upto 6%. The bottom were provided with plugs to collect seepage water at one meter interval used was soil sandy loam in texture having 51.6 % Sand, 31.8% clay, bulk density 1.72 g cm^{-3}, permeability 3.4 $\times$ 10-5 cm/sec, infiltration rate 1.0 cm/h, water holding capacity 29.10%, porosity 40% and pH 7.8. Efforts were made to create the condition in the test plot, 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.

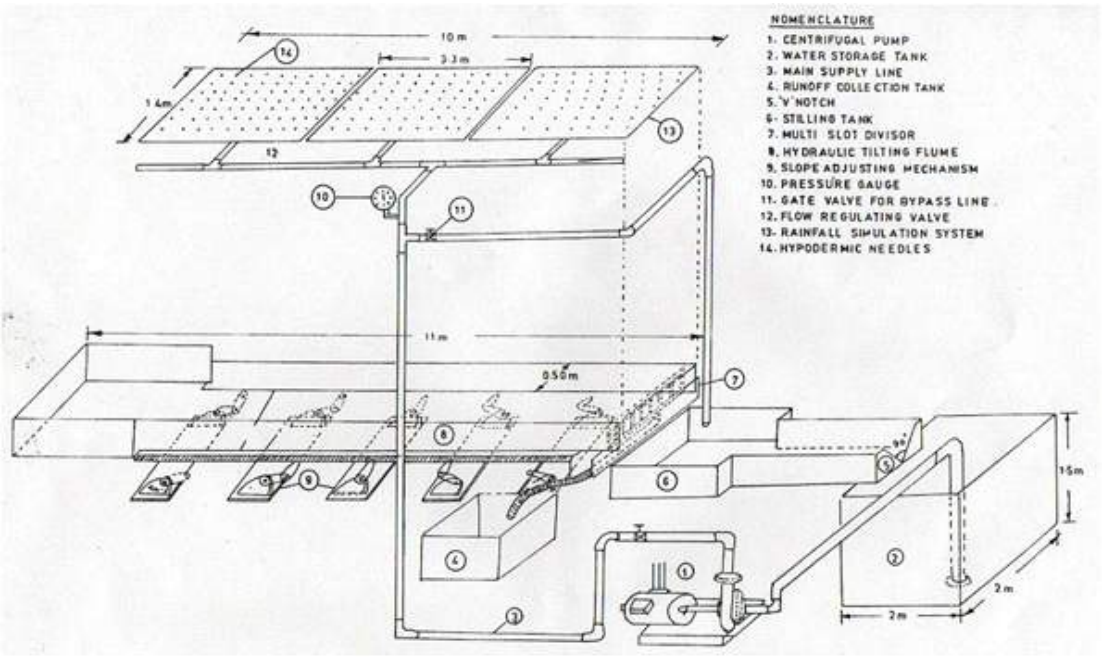


Fig. 1. Experimental Setup

Paddy Straw Mulch

To conduct the experiments, the air-dried paddy straw mulch was selected.Three quantities of mulch rate as 600 g/m^2, 800 g/m^2, 1000 g/m^2 were selected for this study. The mulch was spread evenly on the soil surface for each set of mulch for conducting experiments.

Determination of Runoff Volume

The runoff commencement time and volume were measured at the outlet of the test plot. The time of runoff commencement and regular measurement as well as runoff volume was measured by a standard gauged cylinder. For this purpose the depth of water flowing over the weir crest was measured with the help of hook gauge at regular intervals. The rate of flow was calculated by applying head discharge relationship for 90° V-notch.

Sediment Outflow Measurement

The sediment yield at the outlet of each plot was measured before mulching as a control treatment for 10 min duration for rainfall intensities of 11, 13 and 14.65 cm h^{-1}. Sediment yield was also measured for plots covered with paddy straw mulch. The amounts of sediment yield were then determined using oven dried method at 105°C for 24 h, and weighed by high-precision (0.001^{-g}) scales.

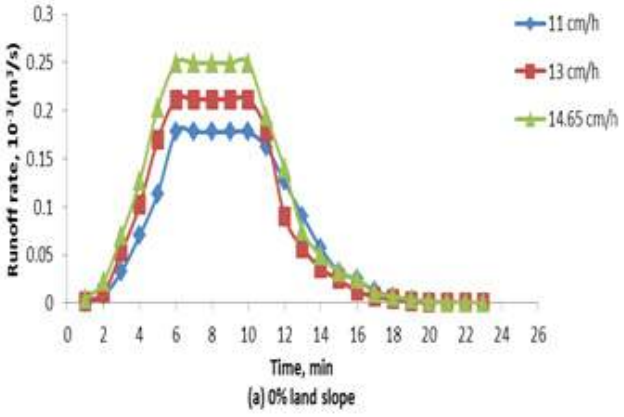
RESULTS AND DISCUSSION

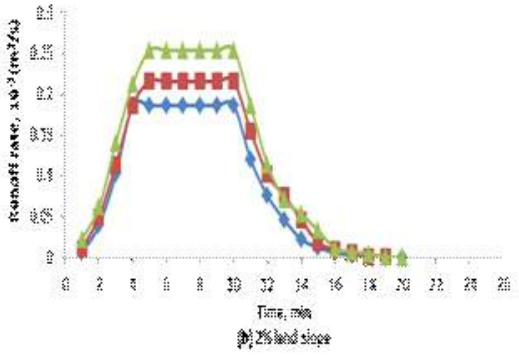
This research was carriedout to determine the efficiency of paddy straw mulch as a conservation treatment in changing runoff commencement time, runoff volume and sediment outflow. The experiments were conducted under laboratory conditions at simulated rain intensities of 11, 13 and 14.65 cm h^{-1} and a slope of 0%, 2% and 4%. Experiments were conducted to observe sediment outflow under different

type of mulch treatments such as no mulch, paddy straw mulch 6 ton/ha, 8 ton/ha and 10 ton/ha for 10 min rainfall duration.

Runoff, Sediment Outflow and Concentration

The observation on runoff volume, sediment concentration and sediment outflow rate at selected rainfall intensities and land slopes for no mulch treatment were first performed to observe its effect. It was observed that the volume of runoff increased from 84350 cc to 137760 cc and the total sediment outflow rate 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 cc, 93170 cc and 95550 cc at land slope 0%, 2% and 4%, respectively. The graphical representation showing temporal distribution of runoff rate due to three different intensities at a particular land slope is shown in Fig. 2. It indicates three single flat peaked isolated runoff hydrographs for three different rainfall intensities at three land slopes. 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.





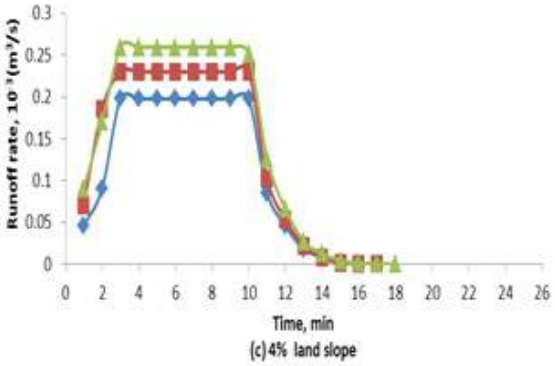


Fig. 2 : Observed runoff hydrograph at different land slopes and rainfall intensities for no mulch

Observed Runoff Hydrograph, Sediment Outflow and Sediment Concentration at Different Land Slopes and Rainfall Intensities for Paddy Straw Mulch

The effects of various rate of paddy straw mulch (6 ton/ha, 8 ton/ha and 10 ton/ha) at different rainfall intensities (11 cm/h, 13 cm/h and 14.65 cm/h) for selected land slopes of 0, 2 and 4% were observed under simulated rainfall conditions on runoff, sediment outflow rate and concentration.

For 6 ton/ha paddy straw mulch treatment

The observation on runoff volume, sediment concentration and sediment outflow rate at selected rainfall intensities and land slopes is studied through experimental set up . The runoff was measured using 900 v-notch at every minute till recession complete. It was observed at 0% land slope that the volume of runoff increased from 70861 cc to 129584 cc and the total sediment outflow rate increased from 0.335 g/m2/min to 0.683 g/m^2/min when rainfall intensity increased from 11 cm/h to 14.65 cm/h. At other selected land slopes, the total runoff volume for 11cm/h rainfall intensity was found to be 70861 cc, 81571 cc and 89670 cc at land slope 0%, 2% and 4% respectively. The graphical representation in Fig. 3 indicates three single flat peaked isolated runoff hydrographs for three different rainfall intensities and at different land slopes. Study reveals that time taken to attain peak gradually decreases on increasing land slope.

For 8 ton/ha paddy straw mulch treatment

Again experiment was done for 8 ton/ha paddy straw mulchand outcomes is observed as increase in runoff from 68670 cc to 125055 cc , total sediment outflow rate increased from 0.229 g/m2/min to 0.486 g/m2/min on increasing rainfall intensity from 11 cm/h

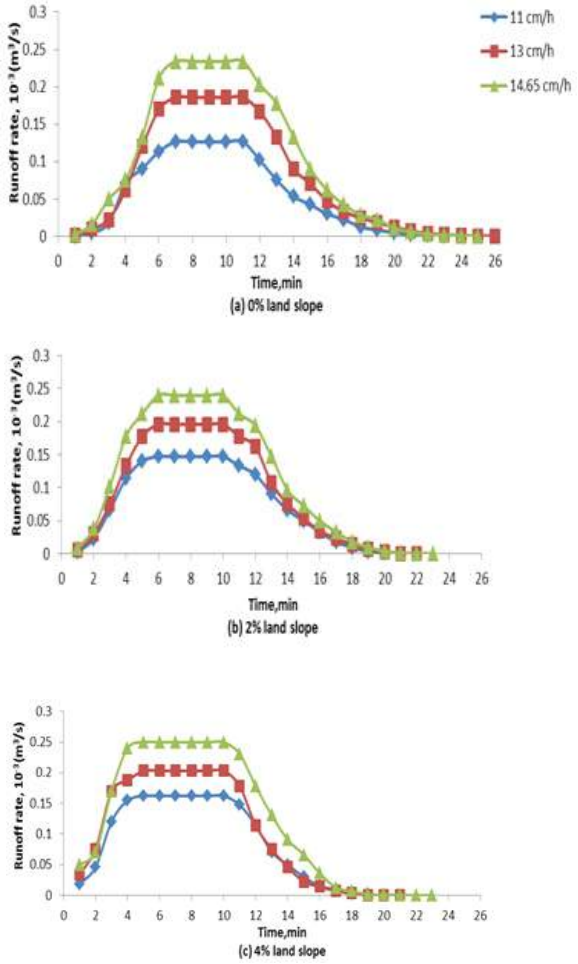


Fig.3 : Observed runoff hydrograph at different land slopes and rainfall intensities for 6 ton/ha paddy straw mulch

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 68670 cc, 78477 cc and 93170 cc at land slope 0%, 2% and 4%, respectively. The graphical representation in Fig.5 shows that as the land slope increases, the time taken to attain peak gradually decreases and again justifies that length of recession segment is found to be in decreasing trend with increase in land slope. Time taken by the runoff to attain peak gets reduced as land slope increases.

For 10 ton/ha paddy straw mulch treatment

It was observed that the volume of runoff increased from 71050 cc to 125650 cc and the total sediment outflow rate increased from 0.131 g/m^2/min to 0.314 g/m^2/min when rainfall intensity increased from 11 cm/h to 14.65 cm/h at 0% land slope. The graphical representation showing temporal distribution of runoff rate due to three different intensities at a

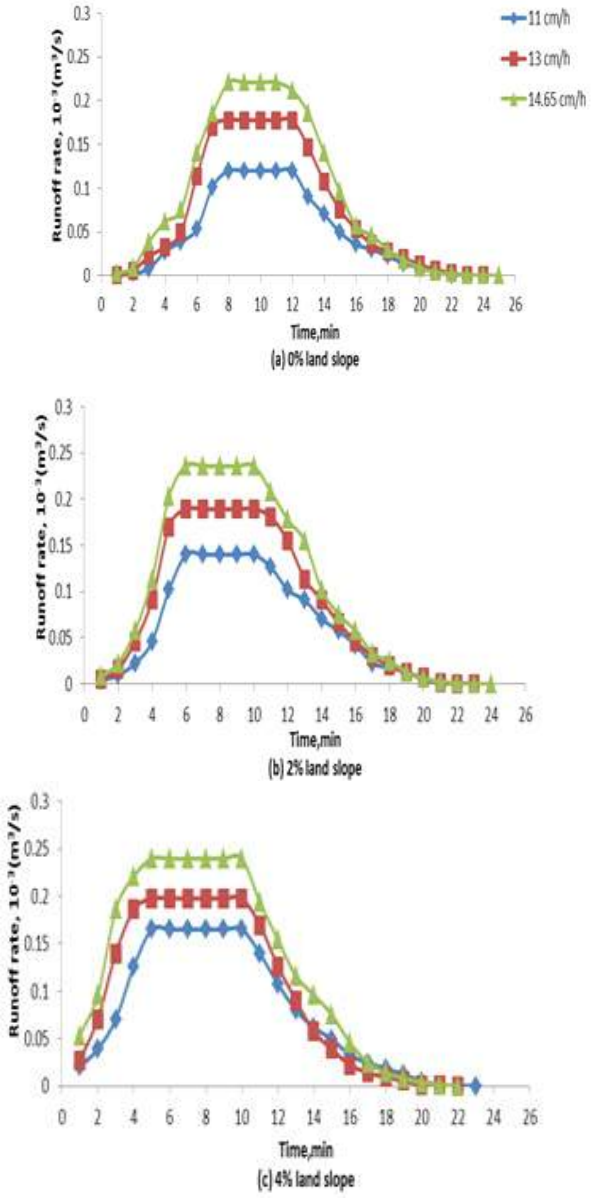


Fig. 4 : Observed runoff hydrograph at different land slopes and rainfall intensities for 8 ton/ha paddy straw mulch

particular land slope is shown in Fig. 6. It indicates three single flat peaked isolated runoff hydrographs for three different rainfall intensities at and land slopes. 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. The 10 ton/ha mulch was very affective to control sediment outflow and runoff and increasing infiltration rate.

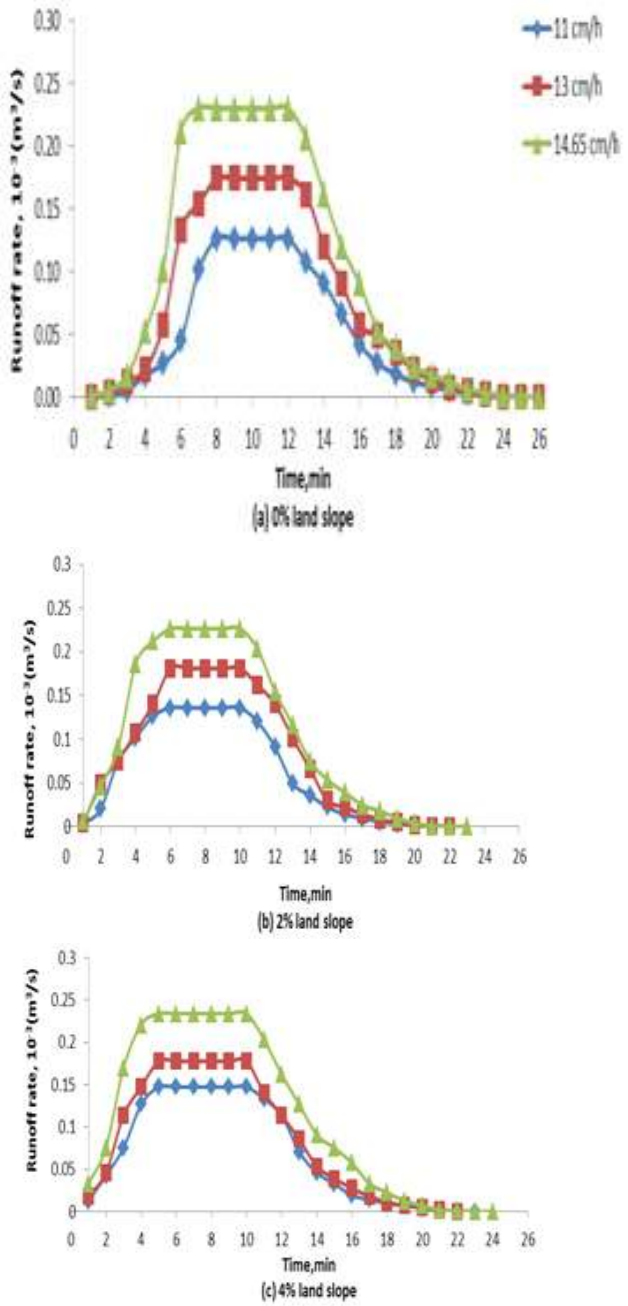


Fig. 5 : Observed runoff hydrograph at different land slopes and rainfall intensities for 10 ton/ha paddy straw mulch

Mathematical models for sediment concentration and outflow for paddy straw mulch

The observed data were put to regression analysis to establish mathematical relationships among various combinations of dependent variables. A model was developed to show a correlation among land slopes, rainfall intensity and sediment outflow, which is given as:

$$So = -0.096\ M + 0.0.047\ S + 0.080\ I + 0.104 ((r = 0.9353)$$

where So is sediment outflow rate in g/m2/min, M is mulch rate in ton/ha, S is land slope in percentage and I is rainfall intensity in cm/h.Therefore, effect of land slope and rainfall intensity on sediment concentration during paddy straw mulch treatments is estimatedby model developed which shows a correlation among rainfall intensities and sediment concentration as mentioned below:

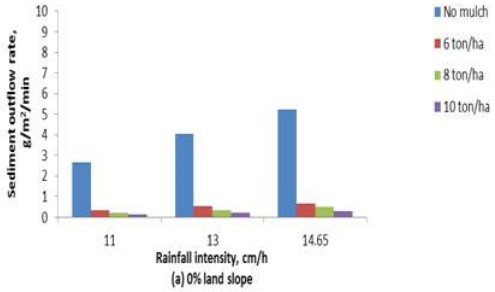
$$Sc = -100.93\ M + 40.74\ S + 24.34\ I + 932.06((r = 0.9582)$$

whereSc is sediment concentration in ppm, M is mulch rate in ton/ha, S is land slope in percentage and I is rainfall intensity in cm/h.

Comparison of Sediment Outflow Rate Using Paddy Straw Mulch with Varying Rainfall Intensities and Land Slopes

Comparison of sediment outflow rate for no mulch and other selected mulching treatment with varying rainfall intensities at 0%, 2% and 4% land slopes are reflected in Fig. 7. The observed values of sediment outflow rates for no mulch, at 0% land slopeis found to be 2.671 g/m^2/min, 4.0347 g/m^2/min, and 5.242 g/m^2/min. For 6 ton/ha paddy straw mulch, the sediment outflow rates is found to be 0.3346 g/m^2/min, 0.541 g/m^2/min and 0.683 g/m^2/min, for 8 ton/ha paddy straw mulch is 0.2289 g/m^2/min, 0.352 g/m^2/min and 0.486 g/ m2/min and for 10 ton/ha paddy straw mulch the values is found to be 0.138 g/m^2/min, 0.215 g/m^2/min and 0.314 g/m^2/min for rainfall intensities of 11 cm/h, 13 cm/h and 14.65 cm/h respectively. As observed from Fig.7a, no mulch treatment yielded highest sediment outflow rate as compared to other mulchingtreatments at any selected slope.

The similar trend was observed at 2% land slope for all rainfall intensities (Fig. 7b). The sediment outflow rate at 4% land slope for selected mulch treatment was found to have similar trend as in case of 0% and 2%



land slopes as indicated by Fig. 7c. It was also observed that the increased mulch rate reduces the sediment outflow rate and runoff volume.

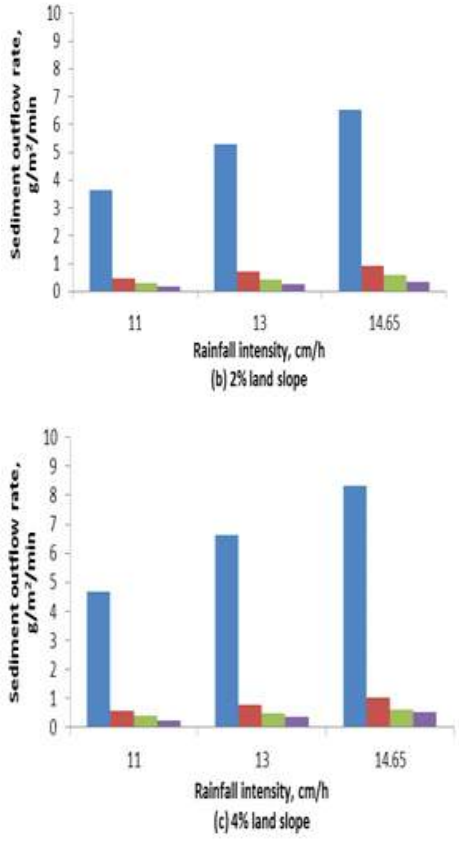


Fig. 7 : Comparison of sediment outflow rate for different paddy straw mulch at different rainfall intensities and land slopes

Relative Percentage Reduction in Observed Sediment Outflow Rate for Different Mulch Rates of Paddy Straw as Compared to No Mulch at Different Land Slopes and Rainfall Intensities

The relative percentage reduction in sediment outflow rate for different mulch rates of paddy straw (6 ton/ha, 8 ton/ha and 10 ton/ha) as compared to no mulch at different land slopes and rainfall intensities is estimated and is plotted graphically for visual comparison in Fig. 8.The calculated values of relative percentage reduction in observed sediment outflow rate at 0% land slope for 6 ton/ha paddy straw mulch were found to be 87.472%, 86.585% and 86.954%, for 8 ton/ha paddy mulch is found to be 91.430%, 91.260%, 90.723% and 94.827%, 94.660%, 94.008% for 10 ton/ha paddy straw mulch at rainfall intensities of 11 cm/h, 13cm/h and 14.65 cm/h respectively at selected land slope. It was observed from Fig. 8 a that when rainfall intensity increases from 11 cm/h to 14.65 cm/h at a particular land slope, the 10 ton/ha paddy straw mulch was more effective in controlling sediment outflow rate as compared to lower mulch rates.

The similar trend was observed at 2% and 4%land slope for all rainfall intensities as evident from Fig. 8 b and Fig.8c this shows that 10 ton/ha paddy straw mulch was more effective in controlling sediment outflow rate as compared to 6 ton/ha and 8 ton/ha paddy straw mulch at any land slope and rainfall intensity, considered in this study.

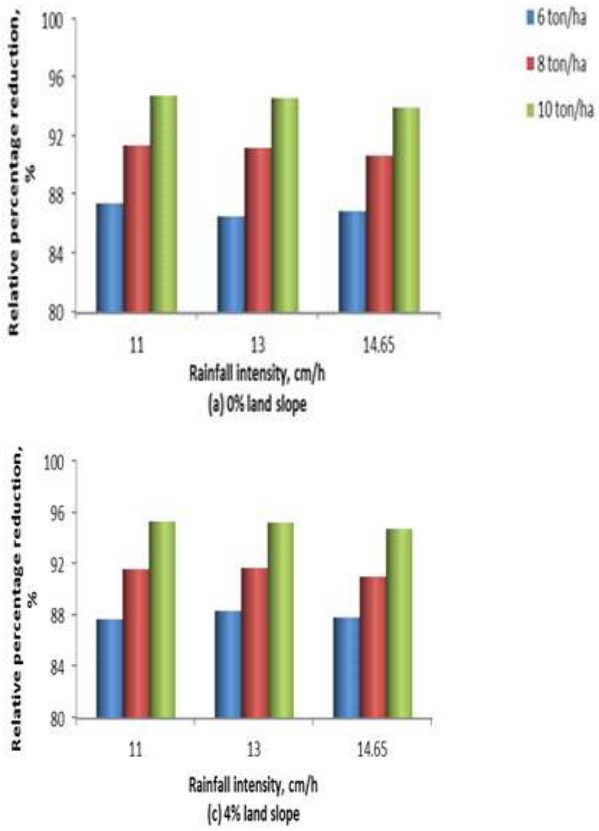


Fig. 8 : Relative percentage reduction in sediment outflow rate from paddy straw mulch with

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. Attempts were also made to compare and quantify the effects of various combinations of input variables on sediment outflow and sediment concentration.

It was observed that the values of sediment outflow rate had a good multiple correlations with land slope and value of rainfall intensity for the respective cases of simulated rainfall condition and correlation coefficient was found to be more than 90%. On the

basis of this study, following specific conclusions could be drawn:

1. The sediment outflow rate was found to be increasing with the increase in land slope and rainfall intensity for every mulching treatment.
2. It was found that 10 ton/ha paddy straw is most effective in controlling the sediment outflow rate and sediment concentration for every combination of rainfall intensity and land slope.
3. The mathematical relationships for sediment concentration (Sc, ppm) and sediment outflow (So, g/m^2/min) in terms of mulch rate (M, ton/ha), land slope (S, %) and rainfall intensity (I, cm/h) for selected mulching treatments were found to be of the following form :

For no mulch treatment

$$Sc = 505.555\ S + 188.159\ I + 1698.094 (r = 0.9811)$$

$$So = 0.641\ S + 0.833\ I - 6.787 (r = 0.9852)$$

For paddy straw mulch treatment

$$Sc = -100.93\ M + 40.74\ S + 24.34\ I + 932.06 (r = 0.9582)$$

$$So = -0.096\ M + 0.0.047\ S + 0.080\ I + 0.104 (r = 0.9675)$$

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