The Pharma Innovation

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A portable rainfall simulator used for sediment and runoff studies with different land treatments

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Abstract
Sediment outflow and soil erosion is concern in worldwide. This study was conducted in the open field on experimental plots using different soil treatments and its effects on sediment outflow and runoff parameters under varying rainfall intensities and land slope conditions. The study involved large number of field experiments for various combinations of urea applications, surface vegetative conditions, land slopes, periods after urea application and rainfall intensities. To create controlled conditions of rainfall, artificial rainfall was generated by developing a portable rainfall simulation system. Five number of experimental plots of 3 m length and 1 m width were constructed and the soil of known properties was filled to create land slopes of 0%, 2%, 4%, 8% and 12% in these five number of experimental plots. As per mandate of this study, apart from control (No crop i.e., bare soil), maize crop land and marigold crop land and the conclusion states that maize crop and marigold crop treatment has an important role in the reduction of runoff and sediment outflow.

Keywords: portable rainfall simulator, land slopes, sediment outflow, runoff, rainfall intensity

Introduction

Rainfall and runoff are major causes of nutrient loss and soil erosion. Water erosion occurs in various forms such as splash, sheet, interrill, rill, gully and stream bank erosion. These processes are governed by a large number of variables pertaining to rainfall, soil type, land topography, crop cover condition and management practices (Wischmier and Smith, 1965) [11]. The vegetation above the surface helps in controlling the kinetic energy of falling raindrops and runoff by reducing its flow velocity and the root system below the surface helps in binding of soil material (El Kateb *et al.,* 2013 and Sadeghi *et al.*, 2015) [13, 8]. In case of erosion by water, rainfall and runoff are the erosive agents, rainfall energy is expended in detaching soil particles and transportability of the sediment depends upon velocity of runoff (Singh *et al.* 2020) [9]. Sediment outflow through runoff, being the important channel among all channels of nitrogen losses, deserves to be given an important emphasis for conducting specific studies in detail (Lal and Mishra, 2015) [7]. To conduct scientific studies in detail on relationships between input system parameters and runoff, sediment outflow and nutrient losses and use the available knowledge to apply appropriate control measures to check these losses under various climatic, agronomic and geographic conditions will be of high relevance in present scenario.

It is difficult to conduct such studies on varying inputs under actual field conditions, simply because of the reason that in actual conditions, it may not be feasible to obtain requisite number of rainstorms 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 these require huge financial, labour and time resources. Alternatively, as an accepted approach, in this study, an artificial rainfall was generated by developing a rainfall simulation system which is portable and capable of generating artificial rainfall similar to the natural rainfall. Portable rainfall simulation system helped to conduct these studies under actual field conditions with enhanced quality of hydrologic control over various constraints faced with natural rainfall (Clarke and Walsh 2007, Fazlina *et al.,* 2018, and Singh and Kumar, 2020) [2, 4, 10]. The 3.4 m long and 1.4 m wide portable rainfall simulation system has been developed by using hypodermic needles fixed at a specified spacing. The rainfall generation unit is placed at 6.0 m height from the ground on a frame made of mild steel pipes. The entire rainfall simulation system consists of three units as the base, supporting structure, rainfall generation and water supply units. The entire assembly can be dissembled and assembled

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easily and was mounted on wheels to facilitate easy movement from one place to another.

Keeping above facts in consideration, this study was conducted in the open field on experimental plots with maize and marigold crop treatments to know the effects of vegetation cover by crops on sediment outflow and runoff under varying rainfall intensities and land slope conditions (Han *et al.* 2018) [6]. Experiments were conducted for large number of combinations of input variables considering bare land as well as maize and marigold crop land conditions (Ghosh *et al.*, 2015 and Bran*t et al.* 2017) [5, 1]. Runoff samples were collected and analyzed for sediment outflow and runoff from different combinations of rainfall as 3.77cm/h, 8.82 cm/h and 12.7 3cm/h and land slopes as 0%, 2%, 4%, 8% and 12% with the help of five number of experimental plots of 3 m x 1m size and portable rainfall simulator system.

Materials and Methods
This study was conducted under controlled conditions in the Department of Soil and Water Conservation Engineering, College of Technology, GBPUA&T, Pantnagar Uttarakhand using a portable rainfall simulator and experimental plots. The experimental set-up as shown in Fig. 1, basically includes a portable rainfall simulator of 3.4 m × 1.4 m size for generating simulated rainfall and five experimental plots of 3 m × 1 m size. 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 under varying hydrologic and land treatment conditions.

Portable rainfall simulation system
To generate artificial rainfall a portable rainfall simulation system was developed to facilitate, conduct and replicate experimentation under controlled conditions. The portable rainfall simulation system was 3.4 m long and 1.4 m wide developed by using hypodermic needles fixed at 20cm x 20cm spacing.

Fig 1: Experimental set-up view

The entire rainfall simulation system consists of four units as the base, supporting structure, rainfall generation, and water supply units. The whole simulation system and accessories were mounted on moving frame supported by wheels for easy movement from one plot to other. The rainfall generation unit was kept at 6.0 m height from the ground surface and its supporting structure was fabricated by using mild steel square pipes. It was ensured to make it light weight and strong enough to bear the load of the rainfall generation unit. The system can be operated for a water supply pressure of 0.120 kg/cm^2 to 0.800 kg/cm^2 to produce varying intensity of simulated rainfall in the range of 3.77 cm/h to 12.73 cm/h with raindrop size in the range of 3.05 mm to 4.76 mm. The uniformity coefficient of the generated rainfall ranged from 82.81% to 93.52% in the selected operating pressure range.
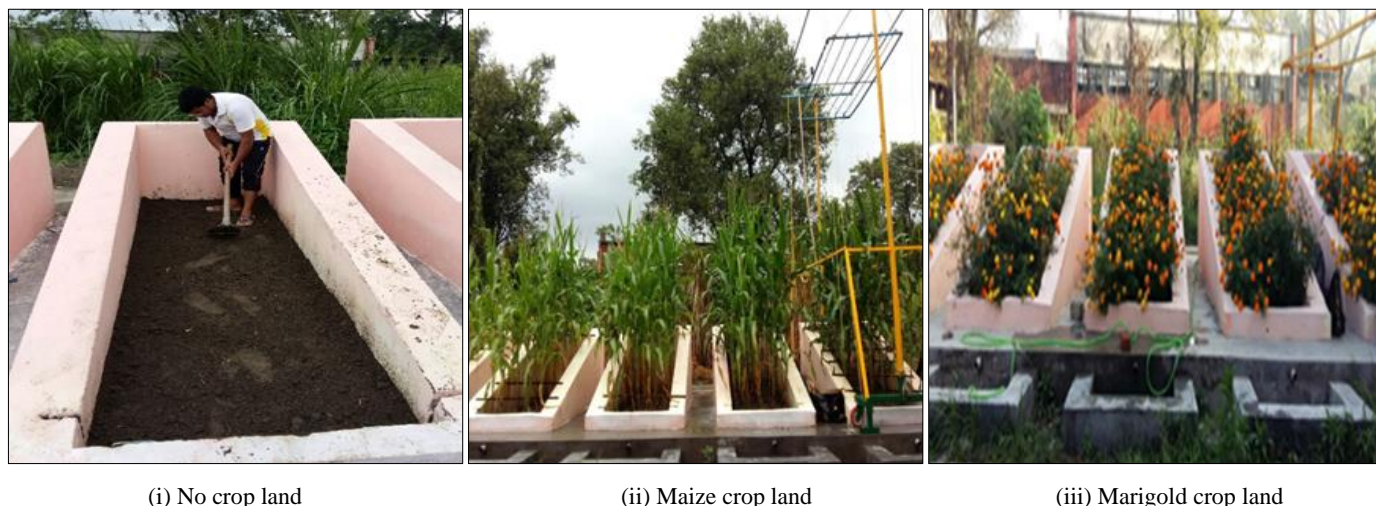
Experimental plots
The experimental plots of 3 m length and 1 m width constructed with brick masonry were used for conducting this study. In this study, five land slopes as 1%, 2%, 4% 8% and 12% were provided in these 5 number of experimental plots. The efforts were made to create the conditions in the test plot, as similar as possible, to natural site conditions.

Growing of crops
The study was conducted to observe the nutrient loss and sediment outflow from selected cropping system. As a control condition, nutrient loss and sediment outflow were also observed for no crop system. As per mandate of this study, apart from control (i) No crop i.e., bare soil), (ii) maize crop land and (iii) marigold crop land shown in Fig.2. The maize seeds of Pioneer 1844 variety and Marigold seeds of Pusa Narangi were planted at a depth of 4 to 5 cm with a row spacing of 50 cm and plant to plant spacing of 20 cm of each separate cropping system.

(i) No crop land   (ii) Maize crop land   (iii) Marigold crop land

Fig 2: Experimental treatments

Determination of runoff and sediment loss

The rainfall simulator was operated for a specified duration of 10 minutes and the generated runoff collected in the runoff collection tank and to obtain small representative samples for determining sediment loss. The collected 100 cc runoff samples were put in circular aluminum containers with 75 mm diameter of 150 ml capacity and of known weight to be put in an electric oven for 24 h, at 105°C to determine the sediment concentration.

Result and Discussion

This experiments conducted in a laboratory to determine sediment loss rate with varying land slopes under selected cropping systems using simulated rainfall. Also, for these conditions' runoff was collected and analysed for sediment loss. Observations were made for bare soil, maize crop and marigold crop at 0%, 2%, 4%, 8% and 12% land slopes under simulated rainfall at intensities of 3.77, 8.82 and 12.73 cm/h. Observed sediment outflow with bare land conditions under 3.77, 8.82 and 12.73 cm/h rainfall intensity at selected land slopes.

The sediment outflow rates were observed at selected land slopes under 3.77 cm/h rainfall intensity and are tabulated in Table 4.1. The minimum and maximum sediment outflow rate were found as 2240 mg/m²/min and 9817 mg/m²/min as land slope varied from 0% to 12%.
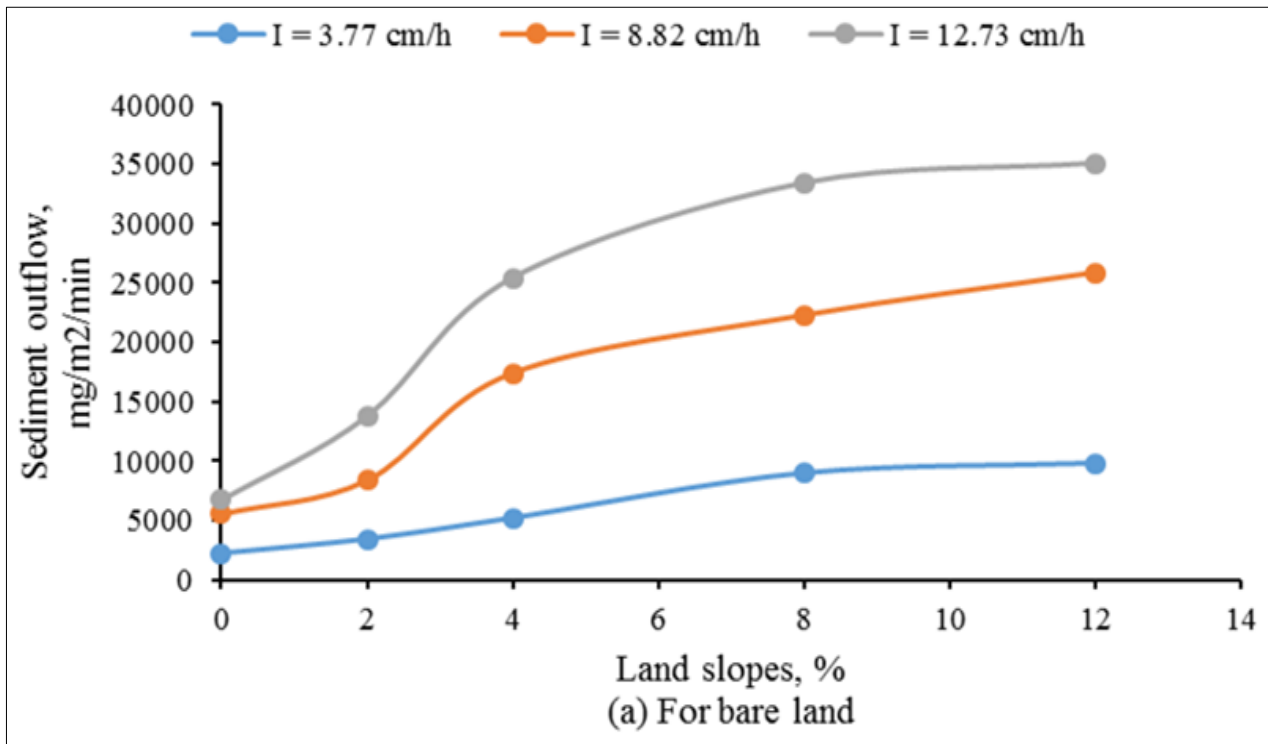
Table 4.1: Observed sediment outflow and runoff with bare soil conditions at different land slopes under simulated rainfall

Land slope, (%)	Rainfall intensity, (cm/h)	Volume of runoff, (cc)	Average sediment outflow rate, (mg/m²/min)
0	3.77	11200	2240
	8.82	24350	5544
	12.73	28450	6733
2	3.77	12400	3444
	8.82	28150	8382
	12.73	36900	13776
4	3.77	11700	5215
	8.82	31100	17397
	12.73	41300	25422
8	3.77	13950	8992
	8.82	33800	22256
	12.73	46100	33397
12	3.77	14800	9817
	8.82	36900	25830
	12.73	45650	35049

The sediment outflow rate of 5544 mg/m²/min at 0% land slope, 25830 mg/m²/min at 12% land slope, 8992 mg/m²/min under 8.82 cm/h rainfall intensity were observed. Similarly, at 12.73 cm/h rainfall intensity, the sediment outflow rates varied from 6733 mg/m²/min to 35049 mg/m²/min as land slope varied from 0% to 12%. These observations were plotted graphically and are shown in Fig. 4.1. It was in general observed that for a particular rainfall intensity, the sediment outflow rate increased with increasing land slopes with bare soil conditions

Fig 4.1: Sediment outflow from bare land at selected land slopes under varying rainfall intensity

Observed sediment outflow with maize crop land conditions under 3.77, 8.82 and 12.73 cm/h rainfall intensity at selected land slopes.

From Table 4.2, the observations taken for sediment outflow rate clearly indicated that at the specified rainfall intensity, increasing land slope resulted in increased sediment outflow

rate from bare land under 12.73 cm/h rainfall intensity. The observed data showed that the sediment outflow rates varied from 641 mg/m^2/min to 4082 mg/m^2/min under 3.77 cm/h rainfall intensity when land slope varied from 0% to 12%, while it varied from 1281 mg/m^2/min

Table 4.2: Observed sediment outflow and runoff with maize crop conditions at different land slopes under simulated rainfall

Land slope, (%)	Rainfall intensity, (cm/h)	Volume of runoff, (cc)	Average sediment outflow rate, (mg/m^2/min)
0	3.77	6750	641
	8.82	12400	1281
	12.73	16850	2340
2	3.77	10700	1320
	8.82	15300	2023
	12.73	19300	2831
4	3.77	9150	1739
	8.82	17500	3714
	12.73	22600	5198
8	3.77	9300	2588
	8.82	17300	5132
	12.73	21150	7285
12	3.77	11200	4082
	8.82	18900	7896
	12.73	24800	10829

To 7896 mg/m^2/min when land slope varied from 0% to 12% for rainfall intensity 8.83 cm/h. The sediment outflow rate at 0% land slope was 2340 mg/m^2/min, at 4% land slope it

was found to be 7285 mg/m^2/min and at 8% land slope under 12.73 cm/h rainfall intensity.
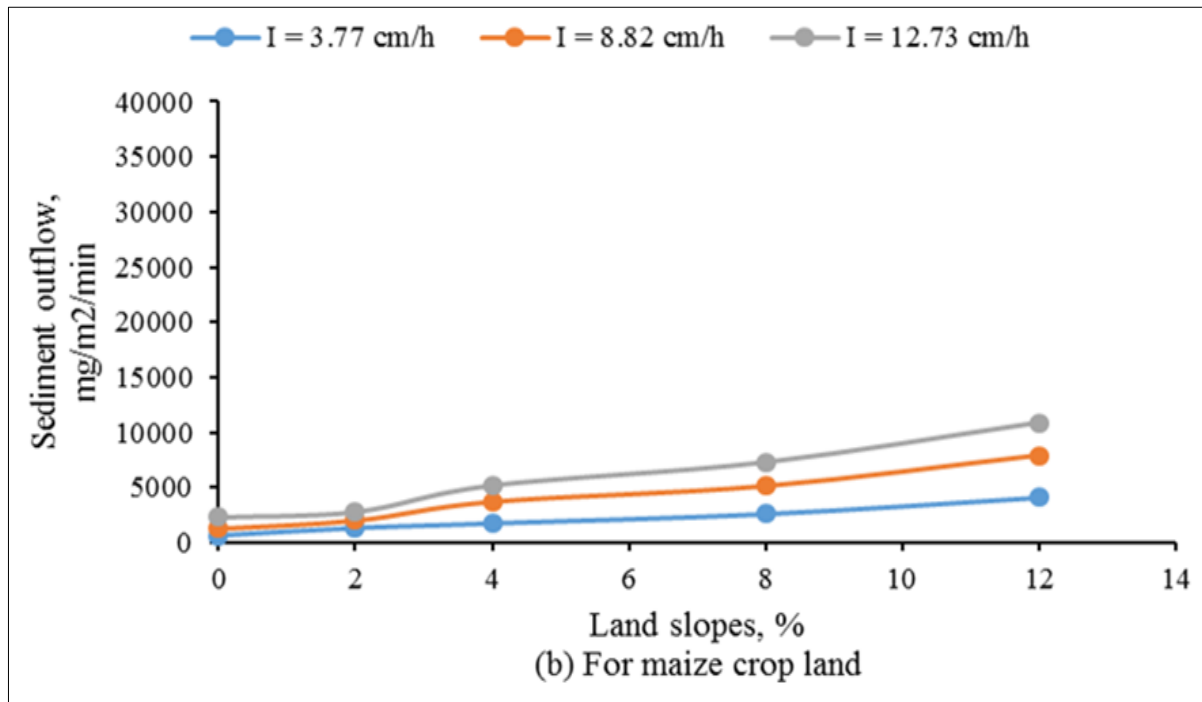
Fig 4.2: Sediment outflow from maize crop land at selected land slopes under varying rainfall intensity

Observed sediment outflow with marigold crop land conditions under 3.77, 8.82 and 12.73 cm/h rainfall intensity at selected land slopes.

The sediment outflow rates of 641 mg/m^2/min at 0% land slope, 1320 mg/m^2/min at 2% land slope, 1739 mg/m^2/min at 4% land slope, 2588 mg/m^2/min at 8% land slope and 4082

Table 4.3: Observed sediment outflow and runoff with marigold crop conditions at different land slopes under simulated rainfall

Land slope, (%)	Rainfall intensity, (cm/h)	Volume of runoff, (cc)	Average sediment outflow rate, (mg/m^2/min)
0	3.77	6300	526
	8.82	11900	1094
	12.73	17950	2154
2	3.77	9100	1107
	8.82	14900	1937
	12.73	18600	2542
4	3.77	9900	1670
	8.82	16850	3058
	12.73	21300	4142
8	3.77	11200	2377
	8.82	17400	4485
	12.73	23900	6692
12	3.77	10950	3833
	8.82	18900	7350
	12.73	25100	10793

mg/m^2/min at 12% land slope, and the minimum and maximum runoff rate were found as 6300 cc to 10950 cc as land slope varied from 0% to 12% under 3.77 cm/h rainfall intensity as shown in Table 4.3. Similarly, the sediment outflow rates found to 1094 mg/m^2/min to 7350 mg/m^2/min under 8.82 cm/h rainfall intensity while land slopes varies

from 0% to 12%. From Table 4.3, the runoff varied from 17950 cc to 25100 cc under 12.73 cm/h rainfall intensity while land slopes varied from 0% to 12%, and similarly, the sediment outflow rate found to be 2154 mg/m^2/min to 10793 mg/m^2/min, shown as Fig. 4.3.
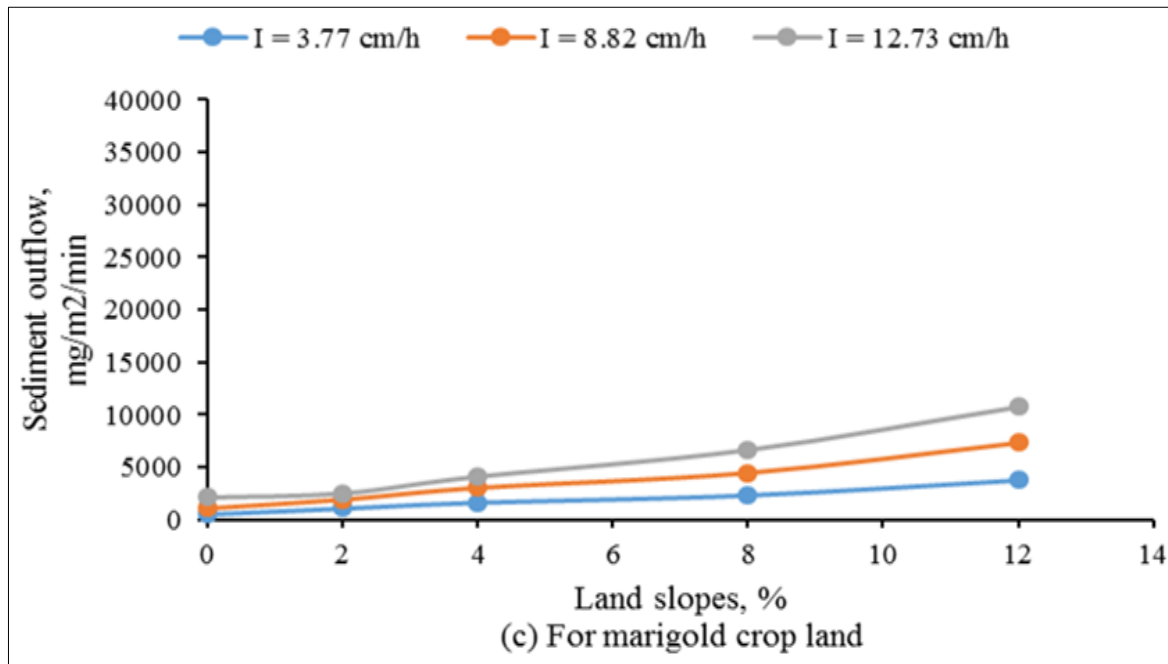
Fig 4.3: Sediment outflow from marigold crop land at selected land slopes under varying rainfall intensity

Comparison of sediment outflow from selected crop treatments at 3.77, 8.82 and 12.73 cm/h rainfall intensity on selected land slopes.

The comparative analysis of sediment outflow was performed under similar conditions. These parameters were observed for these applications considering bare land, maize crop land
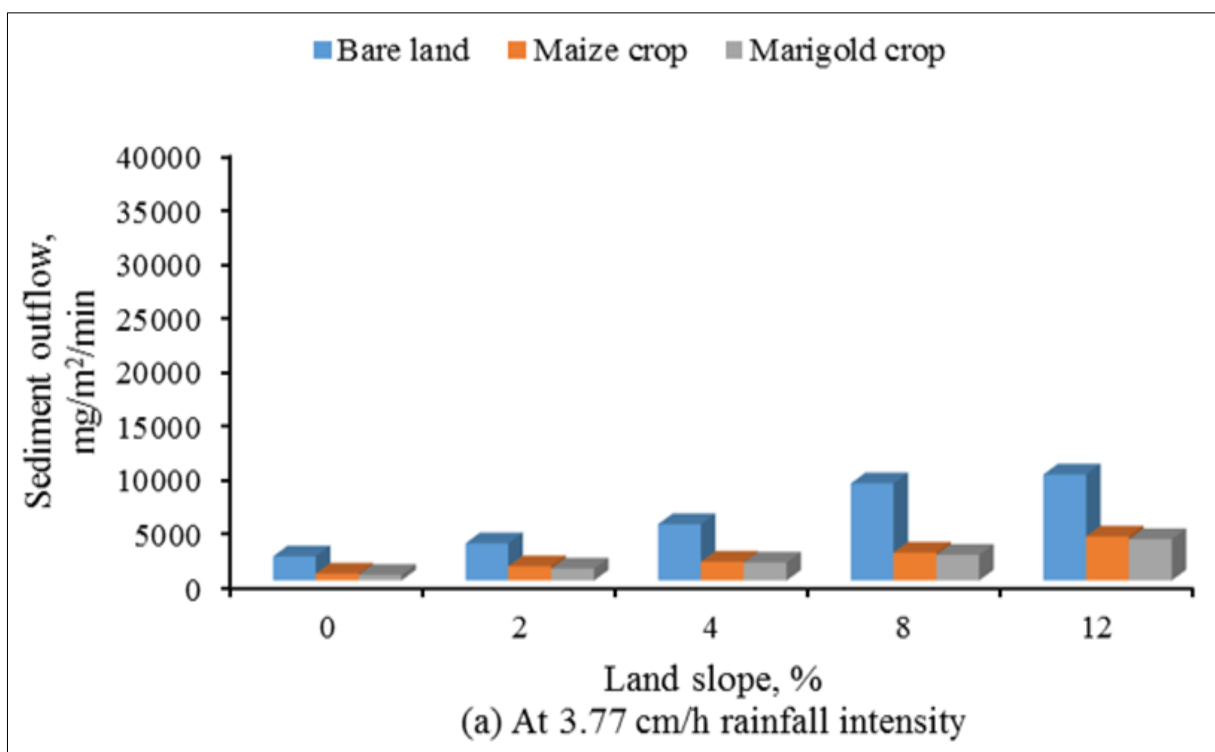
Fig. 4.4: Comparison of sediment outflow from selected crop treatments at 3.77 cm/h rainfall intensity on selected land slopes

and marigold crop land at five selected land slopes of 0%, 2%, 4%, 8% and 12% under simulated rainfall conditions with rainfall intensities of 3.77 cm/h, 8.82 cm/h and 12.73 cm/h. The comparative analysis based on the observations recorded in Table 4.1 to Table 4.3 on different treatments is described. The sediment outflow rate at 3.77 cm/h rainfall intensity for bare land higher as compare to maize and marigold crop conditions and but In general, because of slow rainfall intensity the volume of runoff create in low quantity. The sediment outflow rate maize and marigold crop treatment not found significant different of both crop treatments as shown in Fig. 4.4.
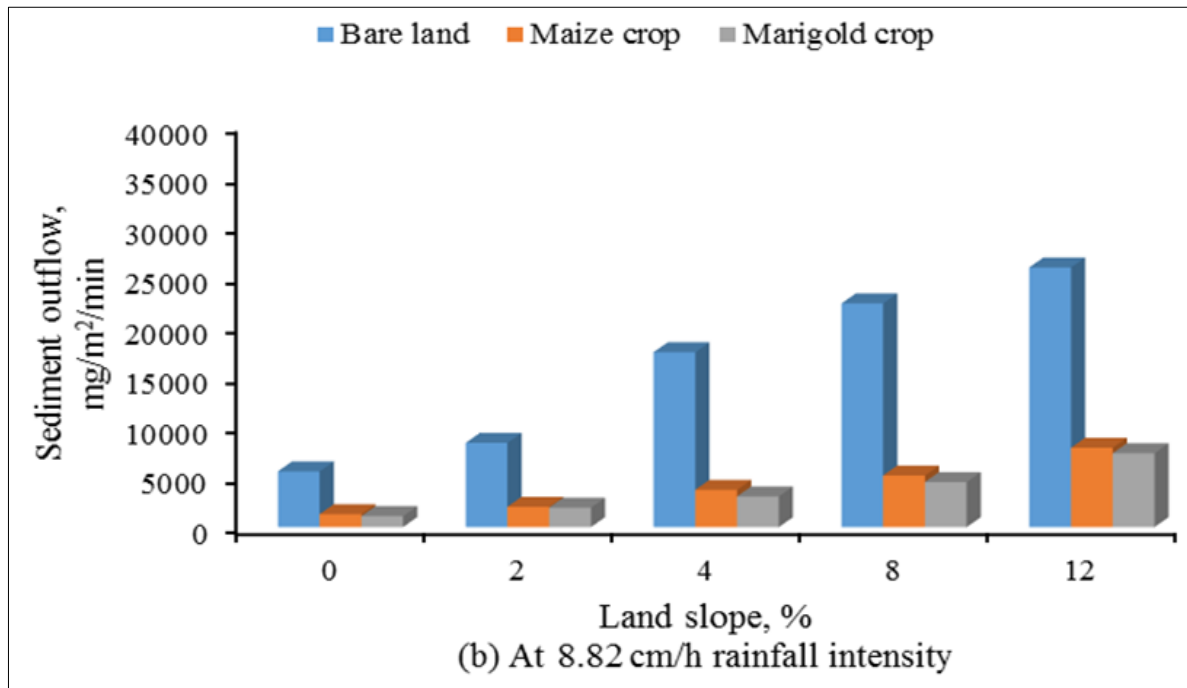
Fig 4.5: Comparison of sediment outflow from selected crop treatments at 8.82 cm/h rainfall intensity on selected land slopes
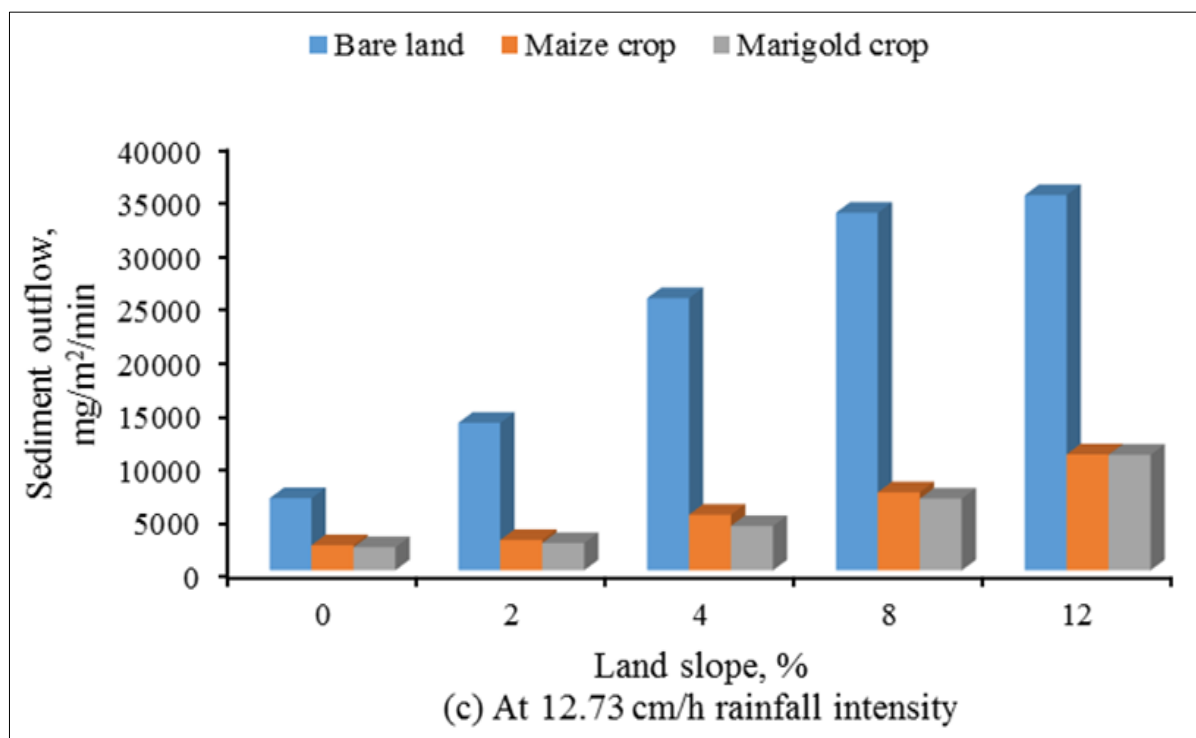

Fig 4.6: Comparison of sediment outflow from selected crop treatments at 12.73 cm/h rainfall intensity on selected land slopes

From Fig. 4.5 and 4.6, the sediment outflow rate and runoff from bare land found to be higher as compare to maize crop land and marigold crop land at 8.82 cm/h rainfall intensity and 12.73 rainfall intensity on every selected land slopes. Similarly, the sediment outflow rate from maize crop land higher as compare to marigold crop land at similar land slopes and rainfall innovation intensity.

Conclusion
In this study the sediment outflow and runoff for varying land slopes and simulated rainfall intensities for maize and marigold crop treatments along with bare land treatment were carried out. The study was conducted under simulated rainfall condition with 3.77 cm/h, 8.82 cm/h and 12.73 cm/h rainfall intensity and 0%, 2%, 4%, 8% and 12% of land slopes from bare land, maize crop land and marigold crop land. The effects of various combinations of input variables on sediment outflow and runoff were found to be the for marigold crop treatments better results as compare to maize crop land and maize crop treatments having better results as compare to bare land treatments.

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