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Research article

Soil erosion control from trash residues at varying land slopes under simulated rainfall conditions

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Abstract: Trash mulches are remarkably effective in preventing soil erosion, reducing runoff-sediment transport-erosion, and increasing infiltration. The study was carried out to observe the sediment outflow from sugar cane leaf (trash) mulch treatments at selected land slopes under simulated rainfall conditions using a rainfall simulator of size 10 m × 1.2 m × 0.5 m with the locally available soil material collected from Pantnagar. In the present study, trash mulches with different quantities were selected to observe the effect of mulching on soil loss reduction. The number of mulches was taken as 6, 8 and 10 t/ha, three rainfall intensities viz. 11, 13 and 14.65 cm/h at 0, 2 and 4% land slopes were selected. The rainfall duration was fixed (10 minutes) for every mulch treatment. The total runoff volume varied with mulch rates for constant rainfall input and land slope. The average sediment concentration (SC) and sediment outflow rate (SOR) increased with the increasing land slope. However, SC and outflow decreased with the increasing mulch rate for a fixed land slope and rainfall intensity. The SOR for no mulch-treated land was higher than trash mulch-treated lands. Mathematical relationships were developed for relating SOR, SC, land slope, and rainfall intensity for a particular mulch treatment. It was observed that SOR and average SC values correlated with rainfall intensity and land slope for each mulch treatment. The developed models' correlation coefficients were more than 90%.

Keywords: organic mulching; rainfall simulator; hydraulic tilting flume system; sediment concentration; sediment outflow rate

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Abbreviation: C: Crop cover factor; I: Rainfall intensity; M: Mulch rate; ppm: Part per million; S: Land slope; SC: Sediment concentration; SOR: Sediment outflow rate; t/ha: tonnes per hectare.

1. Introduction

Land degradation is usually described as the loss of natural resources (soil, water, fauna, and flora) or by referencing the biophysical processes through which the land functions [1]. Soil erosion and sediment outflow from agricultural lands called land degradation, are serious global problems [2–5]. Land degradation is one of the main causes of low crop productivity [6–8]. The productivity of some lands has decreased by 50% due to soil erosion and desertification [9]. The world's soil resources are finite, functionally non-renewable, and prone to different forms of degradation due to over-exploitation and faulty management practices [10]. Soil degradation has reached alarming proportions in many parts of the world, especially in the tropics and sub-tropics.

Erosion occurs when the surface soil is lost or removed by moving water, wind, or ice. This negatively impacts agricultural land by affecting fertility, landscape beauty, water ecosystems, environmental management, and crop production [11,12]. Soil erosion caused by water is a major factor contributing to land degradation in India and many other countries, as it far exceeds the natural soil formation rates [13]. In the 2016 FAO reports, 75 billion tons of soil are transported annually by erosion from arable lands worldwide, which equals 400 billion dollars yearly [14]. In India, the problem of soil erosion is quite serious, as about 18.5% of the world's total soil erosion occurs here [15]. 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 [16]. Several stages or types of water erosion include splash, sheet, interracial, rill, gully, and stream bank erosion [17–20]. These processes are governed by a large number of variables about rainfall, soil system, land topography, land slope, crop cover condition, and management practices [19,21–24]. 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 [25–27]. Erosion by water, rainfall, and runoff are the erosive agents, rainfall energy is expanded in detaching soil particles, and the transportability of the sediment depends upon its velocity of runoff [25,27–30].

Generally, well-established, dense vegetation can effectively protect soils against soil erosion over the long term. However, the erosive power of rain and runoff interferes with establishing vegetation/straw cover [1,31]. As the topmost layer of the soil, it is important to provide nutrients to the plants and a physical and biological environment that helps them grow [32]. The other important factor that affects soil loss and helps reduce erosion is the presence of crop and cover conditions. The vegetation helps eliminate kinetic energy, and the plant root system reduces soil detachment capacity [21,29]. The vegetation cover factor (C) is the soil loss ratio on vegetated land under specified conditions to the corresponding loss under tilled and continuous fallow conditions [33,34].

There are various methods of soil conservation, which exhibit different performances and mechanisms. The various natural and organic mulches, viz. crop residues leaf litter, wood chips, bark chips, biological geo-textiles gravels, and crushed stone, are used for soil conservation [35,36]. Therefore, mulches have extraordinary potential in soil erosion, sediment control, and runoff reduction [36,37]. When vegetation is not established, we can use organic mulches to quickly protect the soil surface against the erosive forces of rainfall [38]. Organic mulches can be highly effective in preventing soil erosion, absorbing the impact of raindrops, and reducing the detachment of soil aggregates. It also reduces soil erosion and sediment transport rate and increases soil organic matter & hence improving surface aggregation in an environmentally friendly manner [39,40]. Mulches cover effectively increases infiltration and reduces evaporation, runoff, and sediment transport rates [41–44]. It is difficult to conduct such studies on mulches under actual field conditions because, in actual conditions, it may not be feasible to obtain the requisite number of rain storms of desired intensity and duration. In such situations, conducting and replicating experiments under a particular set of combinations of variables is not practically possible as it will require huge financial, labor, and time resources. Several studies have been conducted to determine the effectiveness and how different soil covering substances reduce surface runoff and soil loss of a variety of mulch types based on the literature., including rock fragments [45–49], biological geo-textiles [31], crop residues [50,51], grass [52–54], geo-textiles [31,55], post-fire ash and cover [56–58], tillage [50,59–61], and combined cover such as rock and litter [62–65]. In order to reduce runoff and soil loss, mulching can be attributed to three main factors contributing to its effectiveness. The first benefit of mulch is that it protects soil surfaces from raindrops directly, reduces splash erosion and soil detachment, thus reducing the amount of detached soil that can be transported by runoff, and reduces crusting, sealing, and compaction on the soil surface. Second, mulch reduces soil surface flow velocity and transport capacity by increasing the hydraulic roughness of the soil surface. Thirdly, mulch retains water and soil during rainfall, especially when it is dry and at its most effective capacity to retain water and soil [66–68].

As an accepted alternate approach, this study can be conducted conveniently under controlled conditions of a laboratory using simulated rainfall, whose parameters could be regulated as per the requirements of the experiments. In this current research, silty clay loam soil was selected to study the effects of sugarcane mulch on runoff and sediment yield in rainfall simulation experiments. The aims of the present study were: 1) to establish an equation for sediment concentration (SC) and Sediment outflow rate (SOR) by using the rainfall intensity (I) and land slope (S); 2) to quantify runoff rate in different land slope and rainfall intensity using different amount of sugarcane mulch; 3) to quantify sediment outflow rate and concentration with varying rainfall intensities and land slopes for different quantity of trash/mulch of sugarcane leaf. Considering the above, the primary objective of this work was to investigate the effect of sugarcane crop mulch/residues on and quantify runoff, sediment concentration, and sediment yield by water erosion, under simulated rainfall conditions, during successive sugarcane mulch treatments.

2. Materials and methods

The experimental setup used in this study was developed for the studies on sediment outflow under varying land slopes, rainfall intensities, and sugarcane mulch treatment conditions. The experimental setup includes a rainfall simulation system and a hydraulic tilting flume. The various components of which are described below.

2.1. Experimental design

The experiment setup (Figures 1 and 2) was developed in the Soil and Water Conservation Engineering Department, College of Technology, G. B. Pant University of Agriculture and Technology Pantnagar, Udham Singh Nagar, Uttarakhand. The variable rainfall parameter was generated using a simulation system. At the same time, the varying conditions of the land slope were obtained with the help of the hydraulic tilting flume (Figure 2). The rainfall produced by the rainfall simulation system was almost similar to natural rainfall. When sprinklers overlap, the uniformity coefficient is 100 percent, indicating a uniform application. In contrast, the water application is less uniform, with a lower percentage. Having a uniformity coefficient of 85 percent or more is considered satisfactory. In this study, the uniformity coefficient of the generated rainfall ranges from 87.54 to 92.10%, and the terminal velocity of falling raindrops has been reported to vary from 7.674 to 9.496 m/s in the selected operating pressure range of 0.1 to 0.6 kg/cm^2. This uniformity coefficient is affected by the pressure nozzle size relations, sprinkler spacing, and wind conditions. As it is a laboratory experiment, there was no wind effect, and the pressure and spacing of the sprinkler were also good and constant.

Many experiments were conducted with different types of nozzles and needles to design and develop a rainfall simulator; the best results (Uniformity coefficient, drop size, and terminal velocity) were found with Hypodermic needles with spacing 20 cm × 20 cm. Therefore, we select Hypodermic needles in this rainfall simulator system. This pressure is less than the operating pressure in the sprinkler system because we wanted a fixed backfall intensity. The 10 m long and 1.2 m wide hydraulic tilting flume filled with soil material was used as a test plot.

(a)

(b)

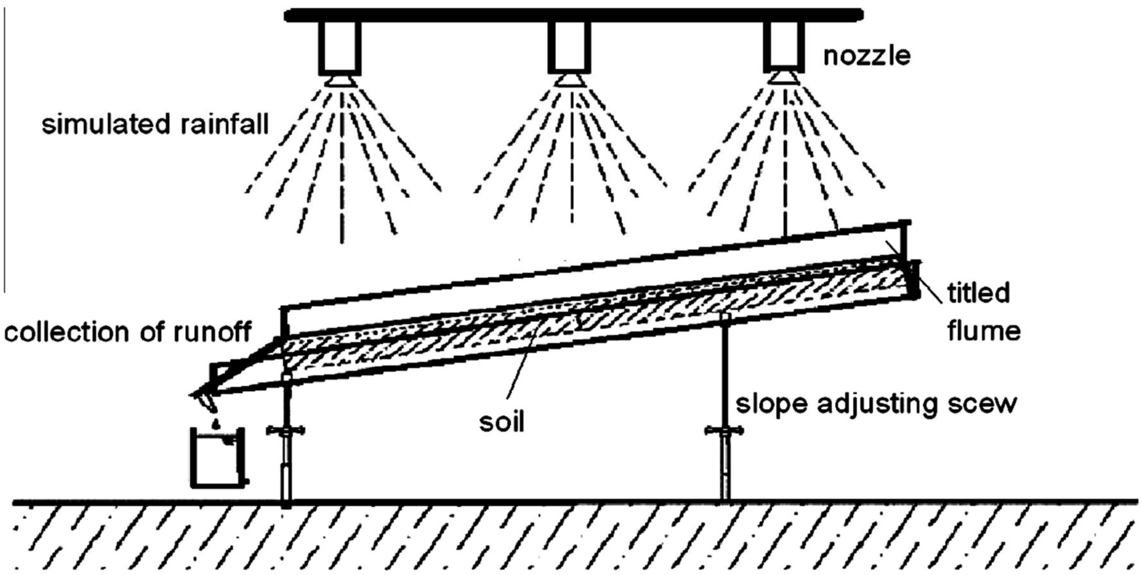

Figure 1. (a) Laboratory and (b) Rainfall simulation unit.

Figure 2. Experimental plot with trash (sugarcane leaf) mulch treatment.

The particle size distribution of soil and filter material (sand) were determined separately in the laboratory by following the standard techniques of sieve analysis. About 1 kg of dried soil material was taken and oven-dried before performing. In order to determine the density of cohesive/clayey soils used as fill, a core cutter method is used. The oven drying method is the standard laboratory method. It accurately determines the physical property of soil and water content. To determine the bulk and particle density of the graduated cylinder, the mass of the cylinder was filled with cover material and then measured. The properties were analyzed and given as: Sand-51.6%, Silt-31.8%, and Clay-16.6%. Textural class-sandy loam, Bulk density-1.72 g/cm^3, Permeability-3.4 × 10^{-5} cm/sec, Infiltration rate-1.0

cm/h, Water holding capacity-29.10%, Porosity 40%, Organic matter content-2.5 and pH-7.8. The flume was filled with 0.25 m deep silty clay loam soil. The soil was compacted uniformly to reach the target bulk density of the soil. Target soil bulk was determined by multiple and stratified sampling using a soil auger and ranged from 1.68 to 1.71 grams/cm^3.

2.2. Recording and control devices

A runoff diversion tray of 163 cm × 35 cm × 13.4 cm was placed at the downstream end of the test plot (hydraulic flume) to blow the multi-slot divisor to convey the runoff coming from the multi-slot divisor to the measuring notch. It was fitted so that the runoff water did not leak or spill. A 90^0 V-notch was installed at the end of the total runoff to obtain accurate determinations of the total runoff volume. Various other devices, such as multi-slot divisors, runoff collection tanks, and measuring cylinders, have been used. A time period of 10 minutes was used for each recording and replication. The simulator was operated at a specified operating pressure for different duration, and the volume of runoff collected in the runoff collection tank was recorded. The runoff passed through a multi-slot divisor. It was conveyed to a runoff collection tank from which 100 cm^3 samples were collected after thoroughly stirring so that collected small samples represent the entire body of runoff. The collected sample was kept in the electric oven for 24 hr at 105 ^{o}C. The amount of sediment in the 100 cm^3 sample was obtained by subtracting the empty sampler's weight from the oven-dried weight. This sediment amount in 100 cm^3 was then converted into SC, ppm, and total sediment present in the total runoff volume, and then sediment outflow rate (SOR) (g/m^2/min) was calculated.

2.3. Experimental treatments

Although the soil filled in a flume cannot resemble the natural conditions, efforts were made to create conditions in the test plot similar to natural site conditions. Once the soil was filled in the test flume and an appropriate mulch treatment was applied, the rainfall simulator was operated at a very low intensity to saturate the soil fully. After saturated soil, rainfall intensity was adjusted to the desired level. The flumes were subjected to a desired slope with the help of a slope-adjusting mechanism. The rainfall simulator was operated for a specified duration, and the total runoff generated was recorded. Many small samples were obtained from this collected runoff to determine the sediment concentration and yield. In this study, three rainfall intensities, i.e., 11, 13, 14.63 cm/h. obtained at the respective operating pressure of 0.2, 0.3 and 0.4 kg/cm^2 were used. The choice of rainfall intensities referred to the rainfall return periods of the Udham Singh Nagar part of Uttarakhand. The maximum rainfall between 1 and 6 h is 110 and 130 mm, separately in a multi-year average. The maximum rainfall within 1 h is 146.30 mm, separately in a hundred-year storm.

To observe sediment outflow, the test flume was subjected to three slopes, i.e., 0, 2 and 4%, for each mulching treatment and rainfall intensity. The choice of the random land slope referred to the geographical condition of Udham Singh Nagar part of Uttarakhand. Udham Singh Nagar belongs to the Tarai belt and is 8–25 km wide; the general slope is <1% towards the south. In this way, the total combinations for a single mulching treatment became 27. Trash (sugarcane leaf) mulch and without mulch have been used for treatments (Figure 2). Mulches were used in three quantities of mulch rate viz. 600, 800 and 1000 g/m^2. According to the ‘‘Techniques standard for comprehensive control of soil erosion in the black soil region” (SL 446 - 2009), three covers of sugarcane mulches (35, 55, and 75%

bare) were chosen. The sugarcane mulches were manually spread along the flume uniformly with a fixed amount before each rainfall event.

2.4. Preparation of test plot

This study used the hydraulic tilting flume of 10 m in length and 1.2 m in width, filled with soil material, as a test plot. Although the soil filled in a flume cannot resemble the natural institute conditions, efforts were made to create the conditions in the test plot similar to natural site conditions. For this purpose, natural downward drainage was created by providing a coarse sand filter layer of about 5 cm before filling the soil. This was done to facilitate the free infiltration of runoff water through the soil. The infiltrated water passes through the holes in the flume's bottom. Above this filter layer, the soil material was filled in six successive layers of 2 cm each. Before filling the soil, it was sun-dried and was made free from all debris. Every layer of 2 cm was compacted to a degree to obtain a bulk density almost like the field bulk density. This way, the test flume obtained a 12 cm thick layer of soil with uniform compaction. At the upstream and downstream ends of the flume, soil, and filter materials were retained by providing baffles. In the downstream baffle, two outlets were provided to allow the free lateral seepage of infiltrated water, particularly when the test flume is subjected to the slope.

2.5. Determination of sediment outflow and sediment concentration

The rainfall simulator was operated for 10 minutes. For every combination of land slope and rainfall intensity. Care was taken to keep the soil in saturated condition every time so that antecedent moisture content remained uniform throughout the experimentation. The runoff passed through a multi-slot divisor and was conveyed by a flexible pipe to a runoff collection tank from which 100 cc samples were collected after thoroughly stirring.

The collected small samples represent the entire runoff. The collected sample was kept in the electric oven for 24 hr at 105 °C. By subtracting the empty sampler's weight from the oven-dried weight using an electronic digital balance of the collected sample with the sampler weight, the amount of sediment present in the 100 CC sample was obtained. This sediment amount in 100 CC was then converted into sediment concentration. PPM and total sediment were obtained in the total runoff volume for 10 minutes. Then the sediment outflow rate (g/min) was calculated.

3. Results

Figures 3–10 illustrates the major results measured in our laboratory experiments: rainfall, runoff, sediment concentration, slope, and mulch treatment. A summary of the result obtained in the experiment and information shown in the flow graphs in these figures are provided in Tables 1–3. The significant result of observed runoff volume, sediment concentration, and outflow rate at different rainfall intensities and land slopes for trash (sugarcane) mulch is summarized and shown in Table 1. It was observed that for a 6 t/ha mulch rate, the runoff volume increased from 74480 to 137270 cm^3. The total SOR increased from 0.43 g/m^2/min to 1.26 g/m^2/min when rainfall intensity increased 11 cm/h to 14.65 cm/h at 0–4% land slope. At other selected land slopes, the total runoff volume for 11 cm/h rainfall intensity was found to be 74480, 81550, and 90300 cm^3; for 13 cm/hr, 107450, 111650, and 112350 cm^3; for 14.65 cm/hr, 132300, 132650 and 137270 cm^3 at land slope 0, 2, and 4% respectively.

Similarly, for the 8 t/ha mulch rate, the runoff volume increased from 71400 to 138240 cm^3. The total SOR increased from 0.34 $g/m^2/min$ to 0.92 $g/m^2/min$ when rainfall intensity increased 11 cm/h to 14.65 cm/h at 0–4% land slope. At other selected land slopes, the total runoff volume for 11 cm/h rainfall intensity was found to be 71400, 80850, and 91840 cm^3; for 13 cm/hr, 106050, 105700, and 107415 cm^3; for 14.65 cm/hr, 128870, 134050, and 138240 cm^3 at land slope 0, 2, and 4% respectively. The result for the mulching treatment at 10 t/ha, the runoff volume increased from 68670 cm^3 to 130340 $cm^{3.}$ ^{T}he total SOR increased from 0.25 $g/m^2/min$ to 0.76 $g/m^2/min$ when rainfall intensity increased 11 cm/h to 14.65 cm/h at 0-4% land slope. At other selected land slopes, the total runoff volume for 11 cm/h rainfall intensity was found to be 68670, 76650, and 82600 cm^3; for 13 cm/hr, 99540, 98700, and 101570 cm^3; for 14.65 cm/hr 126070, 129150 and 130340 cm^3 at land slope 0, 2 and 4% respectively. Figures 3–5 shows the measured runoff hydrograph at 0, 2, and 4% land slopes using simulated rainfall intensities (11, 13, 14.65 cm/hr) for 6, 8, and 10 ton/ha trash (sugarcane leaf) mulch. The mulching treatments were presented as percentages of deviation from the bare soil control. The runoff hydrograph decreased with 6, 8, and 10 tons per hectare mowing rates.

In Figures 6–8 and Table 1, we show the reduction in total sediment outflow and sediment yield rate in the grassplots over time-varying rainfall intensities and land slopes for the rate of trash (sugarcane leaf) mulch as compared to the bare soil plot. The results show that total sediment outflow and sediment yield rate decrease as the trash rate increases. As land slope and rainfall intensity increase, the total sediment outflow and sediment yield rate increase. However, the quantity with more mulch rate was found to be less on average. The decreases are attributed to the following aspects: 1) soil protection against raindrops; 2) higher hydraulic roughness due to the straw cover, retarding surface flow and enhancing infiltration; and 3) water retention due to the mulch cover. The runoff rate reduced significantly at the downstream end of the flume, causing the mulch adopted. During all rainfall events, mulching treatments resulted in significantly higher infiltration and abstraction (e.g., surface accumulation and water retention in the straw), reducing runoff significantly.

As shown in Figures 6–8, sediment discharge rate and concentration are presented for all rainfall intensities and land slopes for mulch trash treatments (sugarcane leaf). Table 2 summarizes the information regarding sediment dynamics. In Figure 6(a),(b), observed SOR at 0% land slope was found to be between 0.434 to 0.918 $g/m^2/min$ at rainfall intensities 11cm/h to 14.65 cm/h, respectively, at 0% land slope and a similar trend was also followed by 2 and 4% land slopes in 6 t/ha mulch treatment. In Figure 6(c), SC was found to be 700, 766, and 833 ppm at 0% land slope for 11, 13, and 14.65 cm/h rainfall intensities, respectively. Graphical behavior of treatments viz. 8 and 10 t/ha have also been shown in Figures 7 and 8.

In the past, sediment yield and runoff rates have been regarded as linear events under net detachment conditions or quadratic regressions under depositional conditions. Sediment discharge rate (SOR) and sediment concentration (SC) was a function of rainfall intensity (I) and land slope (S) for each treatment, and their relationship could be well described by the linear Eqs (1) and (2). Mathematical models for SOR and SC for this treatment have been given as follows:

$$SOR = -0.080M + 0.045 + 0.119I - 0.335;\ R^2 = 0.9611 \quad (1)$$

$$SC = -77.778M + 36.111S + 39.485I + 754.878;\ R^2 = 0.9611 \quad (2)$$

Table 1. Observed runoff volume, SC, and outflow rate at different rainfall intensities and land slopes for trash (sugarcane) mulch.

Mulch rate	S (%)	I (cm/h)	The 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			
6 t/ha	0	11	74480	0.06	0.07	0.08	0.070	700.00	52.14	0.43
		13	107450	0.08	0.08	0.07	0.077	766.67	82.38	0.69
		14.65	132300	0.09	0.08	0.08	0.083	833.33	110.25	0.92
	2	11	81550	0.09	0.08	0.07	0.080	800.00	65.24	0.54
		13	111650	0.09	0.08	0.09	0.087	866.67	96.76	0.81
		14.65	132650	0.09	0.10	0.10	0.097	966.67	128.23	1.07
	4	11	90300	0.09	0.10	0.07	0.087	866.67	78.26	0.65
		13	112350	0.10	0.09	0.10	0.097	966.67	108.61	0.91
		14.65	137270	0.09	0.12	0.12	0.110	1100.00	151.00	1.26
8 t/ha	0	11	71400	0.06	0.06	0.05	0.057	566.67	40.46	0.34
		13	106050	0.06	0.06	0.07	0.063	633.33	67.17	0.56
		14.65	128870	0.07	0.07	0.07	0.070	700.00	90.21	0.75
	2	11	80850	0.07	0.07	0.06	0.067	666.67	53.90	0.45
		13	105700	0.07	0.08	0.07	0.073	733.33	77.51	0.65
		14.65	134050	0.08	0.08	0.07	0.077	766.67	102.77	0.86
	4	11	91840	0.07	0.06	0.08	0.070	700.00	64.29	0.54
		13	107415	0.07	0.08	0.08	0.077	766.67	82.35	0.69
		14.65	138240	0.08	0.08	0.08	0.080	800.00	110.59	0.92
10 t/ha	0	11	68670	0.04	0.04	0.05	0.043	433.33	29.76	0.25
		13	99540	0.05	0.05	0.06	0.053	533.33	53.09	0.44
		14.65	126070	0.06	0.05	0.06	0.057	566.67	71.44	0.60
	2	11	76650	0.05	0.05	0.05	0.050	500.00	38.33	0.32
		13	98700	0.06	0.06	0.05	0.057	566.67	55.93	0.47
		14.65	129150	0.06	0.06	0.07	0.063	633.33	81.80	0.68
	4	11	82600	0.05	0.06	0.05	0.053	533.33	44.05	0.37
		13	101570	0.06	0.05	0.07	0.060	600.00	60.94	0.51
		14.65	130340	0.07	0.07	0.07	0.070	700.00	91.24	0.76

Table 2. Comparison of observed SOR for selected trash (sugarcane leaf) mulching treatment under simulated rainfall conditions at selected land slopes.

S (%)	SOR ($g/m^2/min$)											
	I = 11 cm/h				I = 13 cm/h				I = 14.65 cm/h			
	No mulch	6t/ha	8 t/ha	10 t/ha	No mulch	6t/ha	8 t/ha	10 t/ha	No mulch	6t/ha	8 t/ha	10 t/ha
0	2.67	0.43	0.34	0.25	4.04	0.69	0.56	0.44	5.24	0.92	0.75	0.60
2	3.65	0.54	0.45	0.32	5.31	0.81	0.65	0.47	6.53	1.07	0.86	0.68
4	4.67	0.65	0.54	0.37	6.62	0.91	0.69	0.51	8.35	1.26	0.92	0.76

Table 3. Relative percentage reduction in observed SOR for 6, 8 and 10 ton/ha Trash (Sugarcane leaf) mulch as compared to no mulch at selected land slopes and rainfall intensities.

S %	I, (cm/hr)	No mulch	Trash mulch, 6 t/ha	Trash mulch, 8 t/ha	Trash 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	0.43	0.34	0.25	83.73	87.38	90.72
	13	4.03	0.69	0.56	0.44	82.99	86.13	89.04
	14.65	5.24	0.92	0.75	0.60	82.48	85.66	88.64
2	11	3.65	0.54	0.45	0.32	85.10	87.69	91.25
	13	5.31	0.81	0.65	0.47	84.80	87.82	91.21
	14.65	6.52	1.07	0.86	0.68	83.62	86.87	89.55
4	11	4.67	0.65	0.54	0.37	86.04	88.53	92.14
	13	6.62	0.91	0.69	0.51	86.33	89.63	92.33
	14.65	8.35	1.26	0.92	0.76	84.93	88.96	90.90

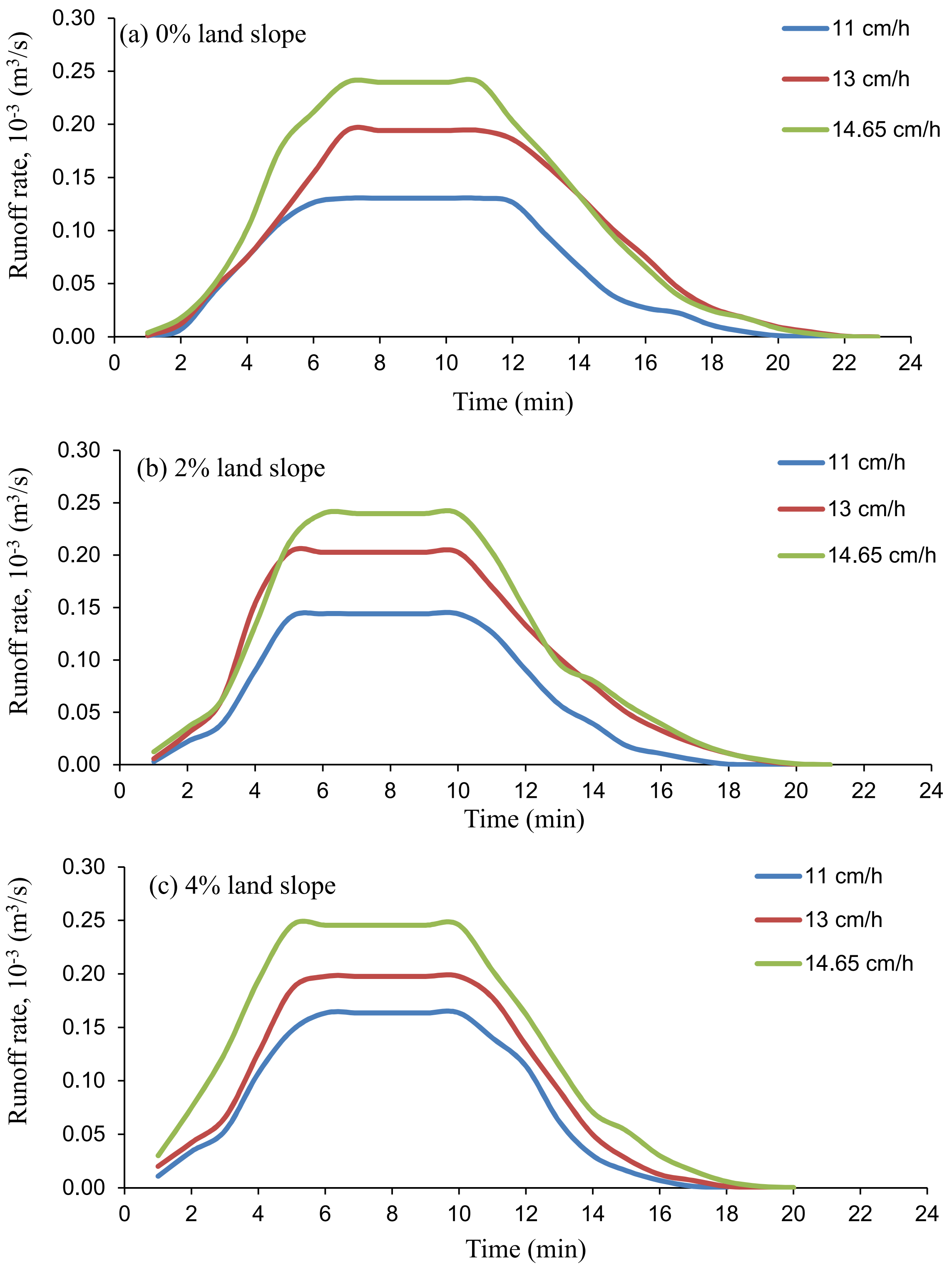

Figure 3. Observed runoff hydrograph at 0, 2, and 4% land slopes using simulated rainfall intensities for 6-ton/ha trash (sugarcane leaf) mulch.

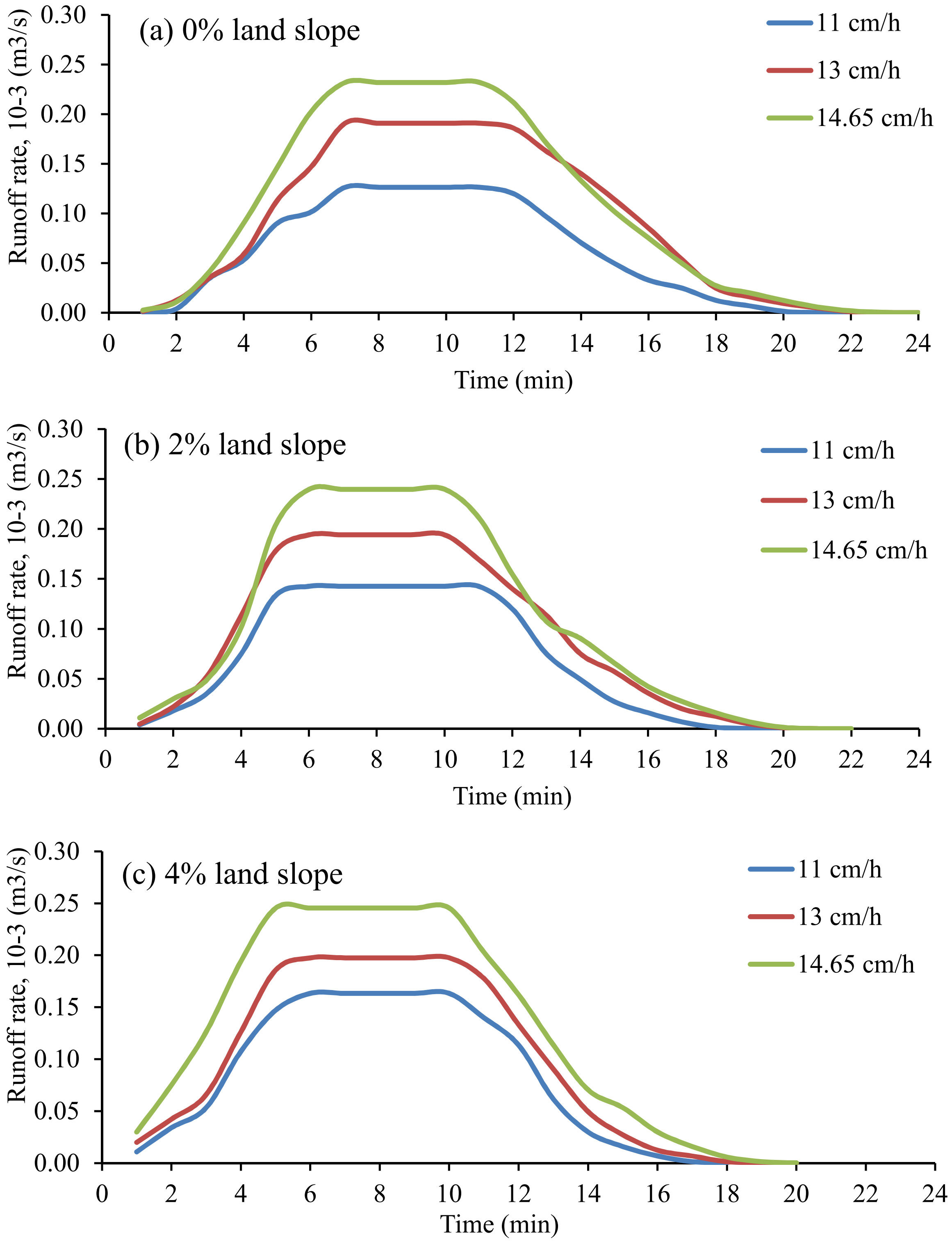

Figure 4. Observed runoff hydrograph at 0, 2, and 4% land slopes using simulated rainfall intensities for 8-ton/ha trash (sugarcane leaf) mulch.

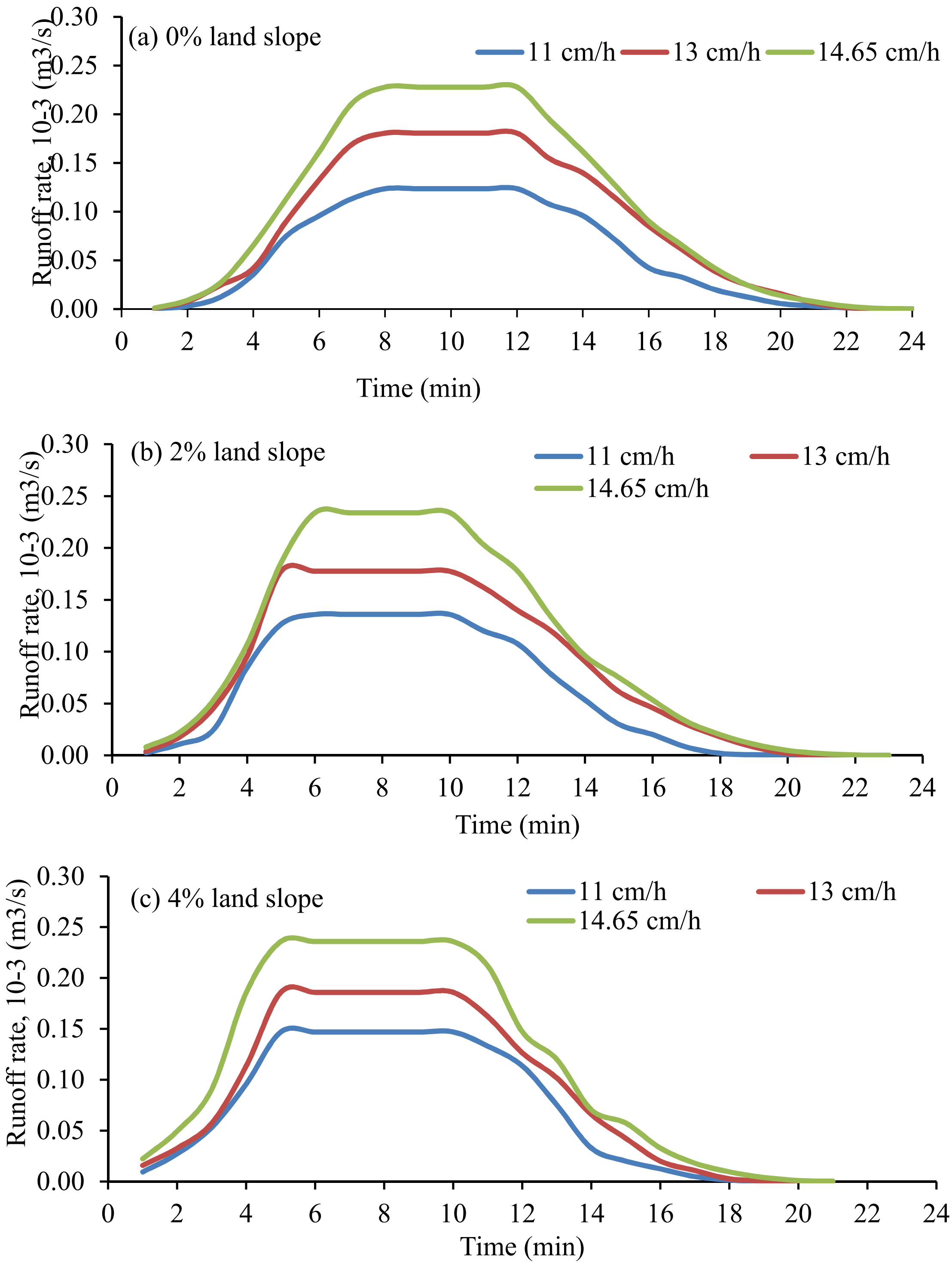

Figure 5. Observed runoff hydrograph at 0, 2 and 4% land slopes using simulated rainfall intensities for 10-ton/ha trash (sugarcane leaf) mulch.

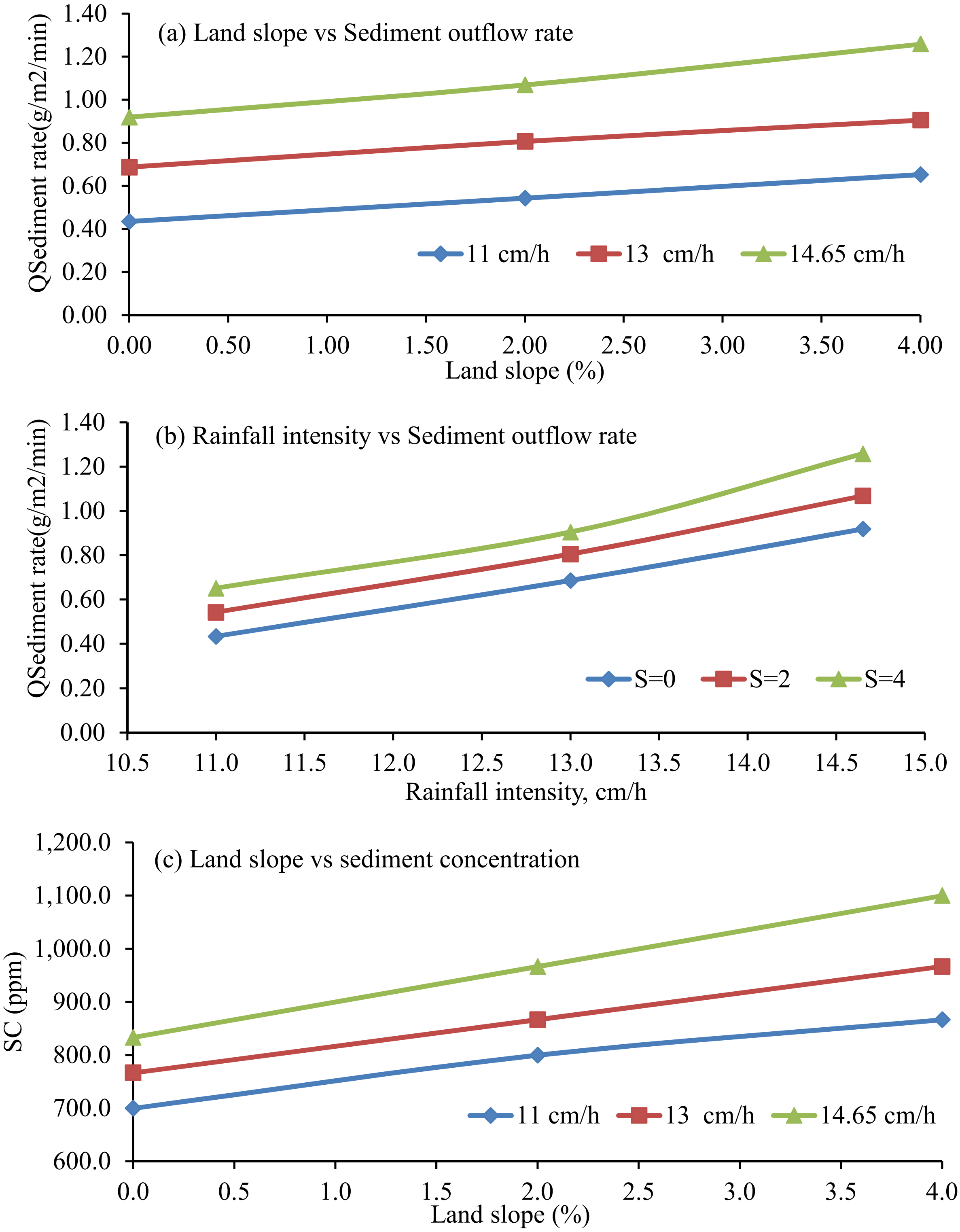

Figure 6. Observed sediment outflow rate and concentration (SC) with varying rainfall intensities and land slopes for 6-ton/ha trash (sugarcane leaf) mulch.

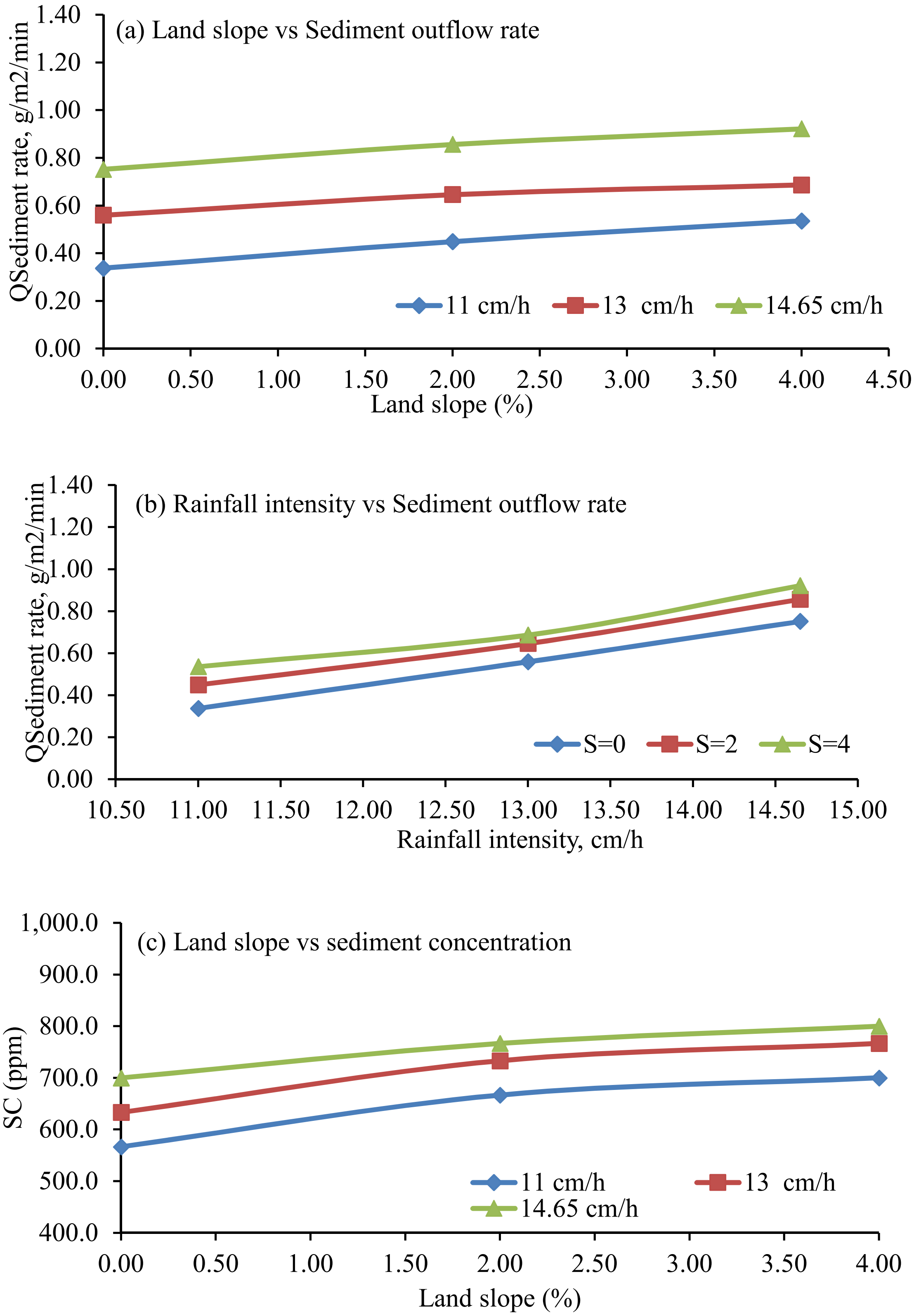

Figure 7. Observed sediment outflow rate and concentration with varying rainfall intensities and land slopes for 8-ton/ha trash (sugarcane leaf) mulch.

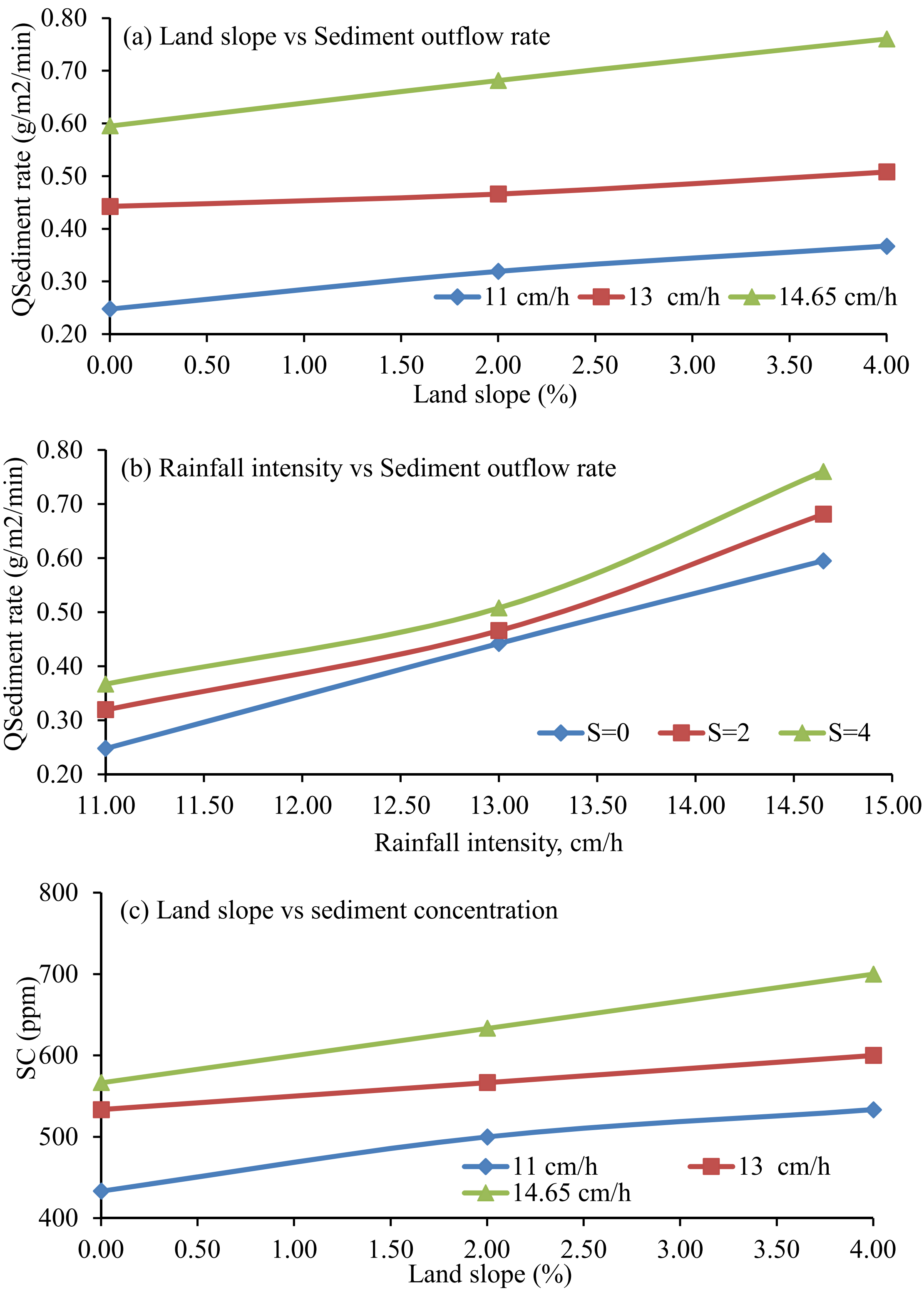

Figure 8. Observed sediment outflow rate and concentration with varying rainfall intensities and land slopes for 10-ton/ha trash (sugarcane leaf) mulch.

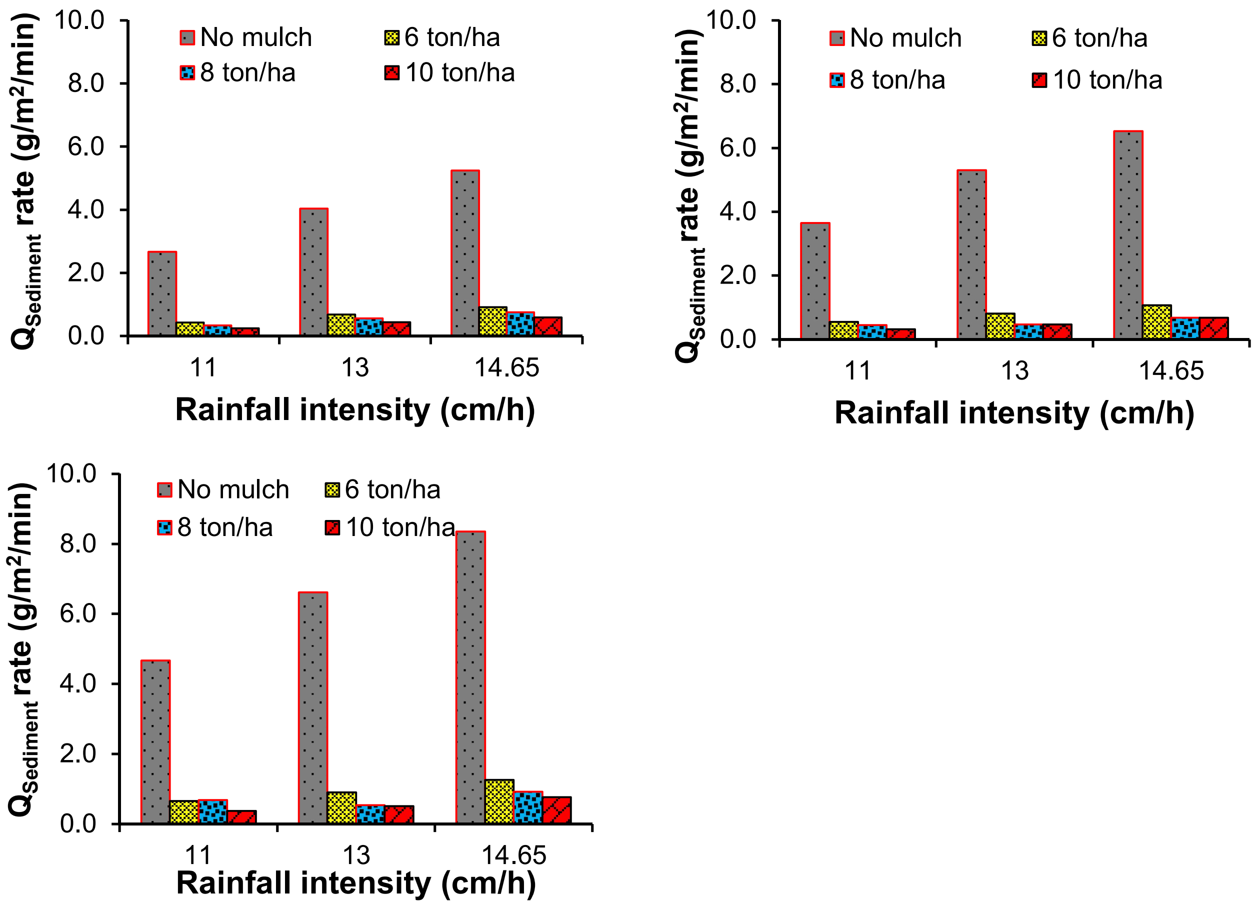

Figure 9. Comparison of sediment outflow rate for different trash mulch rate treatments using selected rainfall intensities at 0, 2, and 4% land slopes.

Results show that sediment concentration correlated negatively with mulch rate, indicating that the detachment and weathering of raindrops are important factors in controlling inter-rill transfer. Mulching significantly reduced sediment outflow rate in all land slopes and rainfall events. There was a greater difference between the sediment loss rates from low and high mulch covers when rainfall profiles were uniform. In contrast, both outcomes were similar when rainfall patterns and land slope varied over time.

In Table 3 and Figure 9, observed values of SORs for no mulch were 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 trash mulch, the SORs were found to be 0.4344 g/m^2/min, 0.686 g/m^2/min, and 0.918 g/m^2/min. The values for 8 t/ha trash mulch were 0.337, 0.559, and 0.752 g/m^2/min, and for 10 t/ha trash mulch, the values were 0.247, 0.444 and 0.595 g/m^{-2}/min for rainfall intensities of 11, 13 and 14.65cm/h respectively. Figure 9(a) shows that no mulch treatment yielded the highest SOR compared to other mulching treatments at any selected slope. A similar trend was observed at a 2% land slope for all rainfall intensities (Figure 9(b)). The SOR at 4% land slope for selected mulch treatment was found to have a similar trend as in the case of 0% and 2% land slopes, as indicated by Figure 9(c). The calculated values of relative percentage reduction in observed SOR for 6 t/ha trash mulch were 83.734, 82.985, and 82.475% at 0% land slope (Table 3). The values for 8 t/ha trash mulch were found to be 87.377, 86.127, 85.660% and 90.716, 89.035, and 88.644% for 10 t/ha trash mulch, and 11, 13, and 14.65 cm/h rainfall intensities, respectively, at the selected land slope. It was observed from Figure 10 that the 10 t/ha trash mulch was more effective in controlling SOR than lower mulch rates when rainfall intensity increased from 11 to 14.65 cm/h at a particular land slope.

Mulching reduces sediment transport and increases infiltration, making it an effective soil and water conservation technique. We recommend further field research involving different soil mulch covers in different land slopes, soil, and rainfall intensity since the distribution and characteristics of rainfall strongly influence mulching effectiveness throughout the year.

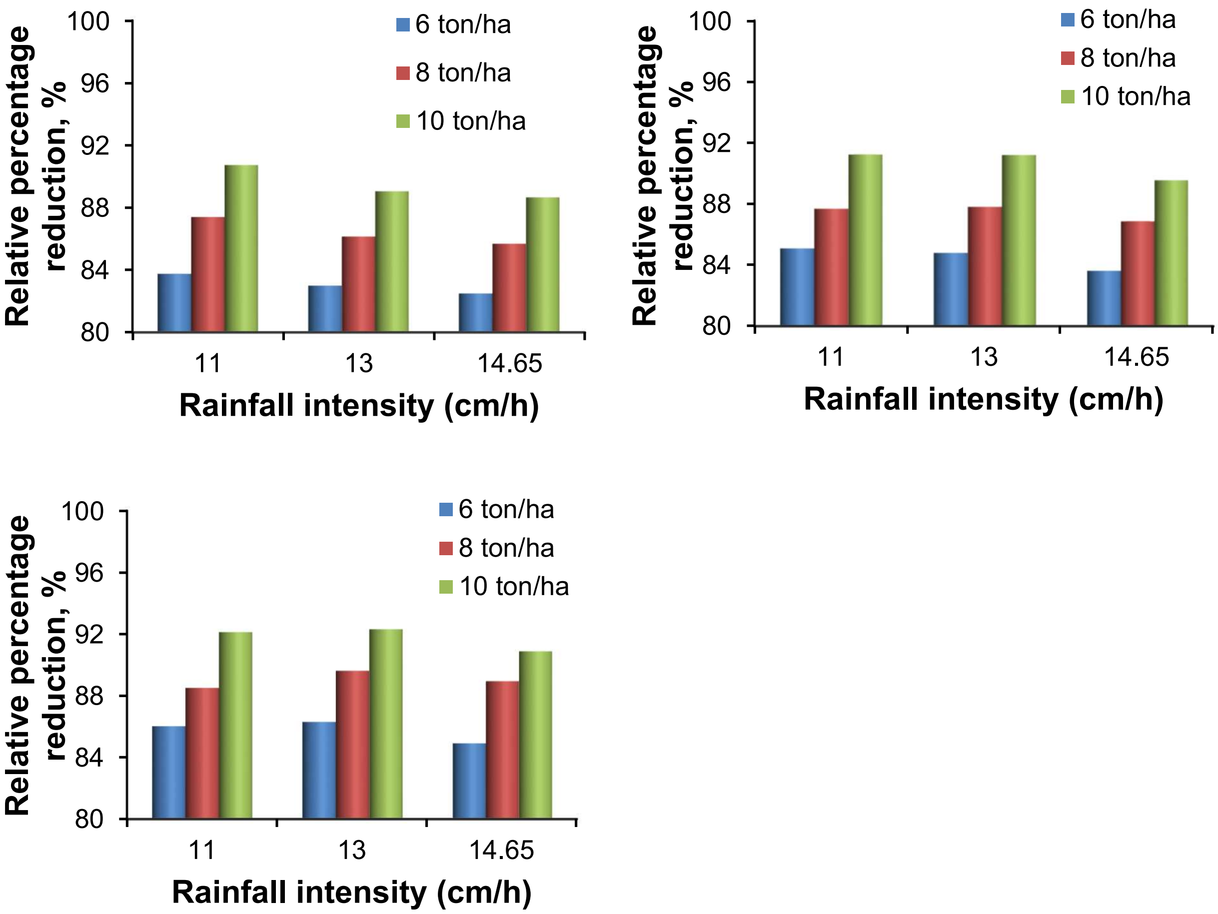

Figure 10. Comparison of present relative reduction in sediment outflow rate for different trash mulch rate treatments and rainfall intensities concerning no mulch at 0, 2, and 4% land slopes.

4. Discussion

The study used a rainfall simulator to observe the sediment outflow from sugar cane leaf (trash) mulch treatments on selected land slopes under simulated rainfall circumstances. The region grows plenty of sugarcane. Hence, the byproduct straw could be a cheap choice for soil conservation. Varied volumes of waste mulch were used to examine the effect of mulching on soil loss mitigation. The relevant work related to mulching and C factor management has been incorporated in the discussion section of the manuscript. The study suggests that a dose of 10-ton/ha mulching is most effective in managing the sediment outflow rate and sediment concentration for various combinations of rainfall intensity and land slope. Because the region grows sugarcane, the resulting straw could be a low-cost option for soil conservation. The relevant mulching and C factor management work has been integrated into the manuscript's discussion section. The vegetation helps eliminate kinetic energy, and the plant root system reduces soil detachment capacity [69]. The current study focused on quantifying sediment outflow rate and concentration with varying rainfall intensities and land slopes for different quantities of trash/mulch of sugarcane leaf. The empirical relationship between the variables has been made.

As a result of the mulch's protection against direct raindrop impact, the kinetic energy of the raindrops is dispersed more quickly, thereby preventing the destruction of soil aggregates and compaction of the surface layer. This resulted in a reduced runoff [69,70]. As a result of the mulch, a substantial amount of runoff could have been mitigated by increasing the hydraulic roughness of the soil surface as well as by increasing water retention in the soil, thus delaying runoff generation and increasing the amount of infiltration [41,71]. In a comparison, mulching effectively delayed and decreased the formation of rills, particularly by reducing the run-off velocity and the sediment transport capacity [41,44]. Several experiments were conducted, which demonstrated that mulch covers of 2 t/ha and 4 t/ha reduced runoff peak by 21 and 51%, respectively [44]. The moisture in the soil increased significantly when mulch was applied at high rates. In addition, soil temperatures were better regulated under 4 t/ha mulch cover densities. The results are displayed as a relative percentage deviation from bare (no mulch) soil conditions, showing which mulching treatments reduced the total runoff and peak runoff and soil loss more than the bare soil treatment. In general, mulching was more effective in reducing soil loss than runoff, following previous studies, both in the laboratory and in the field, which found that mulching had a greater impact in reducing soil loss than runoff found similar to our experiment [37,41,44,72–75]. The results were that the residue cover strongly affects runoff, soil loss, and infiltration rate. To keep these facts, we select the sugar cane residue as the best alternate option for reducing runoff and sediment outflow at di Sugar cane growing on a large scale in western Uttar Pradesh. In some parts of Uttarakhand, so crop residue disposal is a task. For the waste management of crop residue, we select the sugar cane leaf for experiment purposes to determine how much to reduce sediment outflow and runoff reduction.

5. Conclusions

The study aimed to determine the sediment outflow and concentration for varying land slopes, simulated rainfall intensities for selected mulch treatments, and no mulch treatment under saturated antecedent moisture conditions. This was done to save time. Observing sediment outflow rate under dry conditions required filling the soil material each time for every combination was not feasible within the limited time. Attempts were also made to compare and quantify the effects of various combinations of input variables on sediment outflow and sediment concentration. The study was conducted under laboratory conditions using a rainfall simulator that produced rainfall intensities viz. 11, 13, and 14.65 cm/h. The hydraulic tilting flume was used for a test plot with varying land slopes. The 0, 2 and 4% care was taken to compact each layer of soil filled in the test flume to attain a bulk density similar to natural field conditions. It was observed that the values of sediment outflow rate had good multiple correlations with land slope and value of rainfall intensity for the respective cases of simulated rainfall conditions. The correlation coefficient was more than 90%. The sediment outflow rate increased with the increase in land slope and rainfall intensity for every mulching treatment. The sediment outflow rate from 10-ton/ha trash mulching is most effective in controlling the sediment outflow rate and concentration for every combination of rainfall intensity and land slope.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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