The effects of soil clay content, surface rock fragments and their interactions on runoff and sediment yield during rainfall simulation

Mehdi Bashiri*[1], HamidReza Moradi[2], Mir Masoud Kheirkhah[3], Majid Jafari-Khaledi[4]

Abstract

In the present research, the effects of surface rock fragments and soil clay content on surface runoff and soil loss was investigated under the laboratory conditions. The aim of the test was to increase the general understanding of how soil clay content and surface rock fragments affect the soil erosion process. A rainfall simulator was added to an erosion plot and these apparatuses were used to investigate the effects of varying soil clay content (SCC) and soil rock fragments (SRF) on soil erosion by measuring runoff volume and sediment yield at regular time intervals during the simulation. The results indicated that the main effects of soil clay content and surface rock fragments were all significant at the 0.95 level ($p<0.05$) for the runoff and sediment yield. Also, the most significant factor was the quantity of soil clay content in comparison with the surface rock fragments. The interaction effect between surface rock fragments and soil clay content was not significant for the runoff volume, but in case of sediment yield it had a great influence. The repeated measures analysis of variance for time intervals revealed that the main effects of sampling time and its interactions with soil clay content and surface rock fragments were all significant ($p<0.05$) as well, although the effects of time intervals reduced gradually while the rainfall simulation proceeded. The results indicated that the main effects and interactions must be accounted for any simulation study of soil erosion and modeling, and the multiple effects should be studied in research rather than the isolated effects of single variables.

Keywords: Experimental Plot, Rainfall Simulator, Soil Erosion, Temporal Variations.

1. Assistant Professor, Department of Range and Watershed Management, Faculty of Agriculture and Natural Resources, University of Torbat Heydarieh, Razavi Khorasan, Iran, m.bashiri@torbath.ac.ir;
2. Associate Professor, Department of Watershed Science and Engineering, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Noor, Mazandaran, Iran
3. Assistant Professor, Soil Conservation and Watershed Management Research Institute, Tehran, Iran
4. Assistant Professor, Department of Statistics, Faculty of Mathematical Sciences, Tarbiat Modares University, Tehran, Iran

1. Introduction

Soil erosion is widely recognized as an important soil degradation process and is considered as one of the main factors responsible for declining soil fertility potential and desertification (Bestelmeyer et al 2006; Sadeghi et al 2011; Chartier et al 2013). Soil loss and its associated impacts, is one of the most significant and probably the least well known of today's environmental problems (Ekwue et al 2009; Ekwue. & Harrilal, 2010). Moreover, controlling soil hydrological processes and combating soil erosion are high priorities for ecological environments (Wang et al 2012).

Apart from topographic factors, the intensity of water erosion is strongly related to the presence and the density of the soil cover by rock fragments (Govers et al 2006) and due to serious soil erosion or new reclamation of regosol lithic materials, the soils containing rock fragments are comprised of a significant portion of the land surface. The presence of rock fragments modifies soil physical-chemical properties and it affects the hydrological, erosional processes as well as determining the intensity of various soil degradation processes (Poesen. & Lavee, 1994; Poesen et al 1998&1999; Wang et al 2012).

The characteristics of rock fragments, such as their position, shape, and size, play an important role in runoff sediment yielding characteristics (Gan et al 2018). The role played by rock fragments in several soil physical processes, as well as soil erosion, has been studied intensively in recent years (Poesen. & Lavee 1994; Figueiredo. & Poesen, 1998; Poesen et al 1999; Rieke-Zapp et al 2007; Chen et al 2011; Tetegan et al 2011; Jomaa et al 2012; Wang et al 2012). Most of these studies indicated that, rock fragments which can control the erosion yields are one of the major factors in soils with sparse vegetation cover. It was observed that even a small amount of rock fragments incorporated in the soil matrix or placed on the soil surface, can change the soil macropores, water movement (Meng et al 2018), sediment yields, steady-state infiltration and runoff rate (Rieke-Zapp et al 2007; Jomaa et al 2012; Mazaheri.

& Mahmoodabadi, 2012). Furthermore, quantifying the role of rock fragments in soil-water processes is crucial for the application of rock fragments in soil and water conservation practice (Gong et al 2018).

Rock fragment cover was utilized for worldwide erosion control which revealed some contrasting results (Bennewitz. & Aladro, 2017) Furthermore, the knowledge of the effects of rock fragment characteristics on interrill erosion is incomplete (Figueiredo. & Poesen, 1998). Numerous studies pointed out that the effect of SRF[1] on soil erosion delivery is complex and ambivalent and it was observed that rock fragments might either reduce or increase the erosion and runoff rates (Bunte. & Poesen, 1994; Jomaa et al 2012).

Moreover, clay soils are agriculturally significant in many parts of the world while they present unique management problems related to soil and water conservation (Richardson. & King 1995). Numerous studies revealed the role played by SCC[2] on erosion as well as on the hydrological response of soils (such as infiltration rate, surface sealing and runoff generation) (Bruce-okine. & Lal, 1975; Mbagwu. & Bazzoffi, 1998; Feng-Ling et al 2010; Moradi. & Saidian, 2010; Chartier et al 2013). Clay is the most important bonding agent for aggregation. Clay acts as a cementing material that holds particles together in an aggregate. Increasing clay content is associated with increased aggregate stability (Boix-Fayos et al 2001; Feng-Ling et al 2010). Ben-Hur et al. (1985) found that the effect of clay content on the susceptibility of soils to seal formation and soil loss was varied with clay content. Therefore, the clay content in the soil might have two opposing effects on seal formation and erosion. Previous studies thus suggest that soil clay content will have a bearing on the susceptibility of a soil to erosion processes. So, there is no general agreement regarding the relation of SCC to erosion, because the processes involved are too numerous and complex.

There has been a lack of study regarding the effects of SCCs and SRFs on soil erosion and runoff behavior and also their interaction

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1. Surface Rock Fragment
2. Soil Clay Content

effects are not treated in recent reviews of soil erosion. Therefore, a series of laboratory experiments was set up to investigate the previously reported relationships between SCC, SRFs, runoff and sediment yield by soil erosion. Also, the interactions between SRFs and SCC were reported. Thus, the objectives of the current research were: (i) to demonstrate how runoff and erosion processes vary with the soil clay contents and rock fragments; (ii) to report the results of laboratory work investigating the influence of interactions between soil clay content and surface rock fragments on runoff and sediment yield and (iii) to consider the temporal variations in runoff and erosion processes during rainfall simulation.

2. Material and Methods

In the present study, the erosion by simulated rainfall was assessed through the use of a factorial experiment involving the soils which included six clay contents (0%, 10%, 20%, 30%, 40% and 50%), and were exposed to six surface rock fragments (0%, 5%, 10%, 15%, 20% and 25%) with three replications giving a total of 108 tests.

The erosion plots (1.0 m wide and 1.5 m length) were made up of galvanized iron sheets in which a drainage hole was added to the bottom end throughout the length of the erosion plot and the slope angle was achieved by the use of a manual jack. The slope gradient (9%) was selected to represent the ones

prevalent in the universal soil loss equation standard plots (Rimal. & Lal, 2009).

Soil-clay mixtures with different compositions were utilized to form the test samples. For this aim, two soils were selected on the basis of their clay contents and similar chemical properties, and then the soil lacking clay content was combined with 0, 10, 20, 30, 40 and 50 percent of clay soil. The clay minerals in soil samples were identified by X-ray diffraction analysis and were non-expanding elite and chlorite minerals. Therefore, the mineralogical characteristics of soil do not have an influence on the soil erosion process.

A gravel filter was placed at the plot bottom to a depth of 7.5 cm and for each test, different mixtures of soils were obtained by mixing in a concrete mixer placed in the plot box. Theoretically, it is believed that by the mixture of two soil samples in regular classes, the resulting soil would also have regular changes in its texture. Although, the soil volume is high and the granulometric methods are not totally accurate, it is not practically possible to prepare soil samples in the desired textures, exactly. In addition, small amounts of samples used for granulometric methods cannot be the proper representatives for the whole soil. However, the characteristics of the combined soils (Table 1) indicate proper mixture of the soils. Soil samples were added to the erosion plots to a depth of 20 cm and the soil surface flattened utilizing a board.

Table 1: Some physical and chemical properties of the studied soils

| Soil Samples	Mechanical composition (%)			Organic Matter (%)	Gypsum (%)	PH	EC (mmoh.cm⁻¹)	CaCO₃ (Total calcium carbonate)(%)
	Sand	Silt	Clay					
Clay soil	14	36	50	0.02	10.56	8.12	3.10	16.83
The 0% mixture	50	50	0	0.12	13.80	7.99	4.79	15.66
The 10% mixture	39	56	5	0.25	13.70	7.96	4.77	17.66
The 20% mixture	33	55	12	0.10	13.74	7.96	4.57	17.66
The 30% mixture	34	50	16	0.15	13.87	7.89	4.28	16.50
The 40% mixture	33	47	20	0.01	13.59	7.96	4.15	16.91
The 50% mixture	32	46	22	0.05	14.03	7.94	4.10	16.83

The stimulated rock fragments of rectangular shape were regularly cut at 10×15 cm sizes (each one equal to 1% of plot area). Then, semi embedded rocks were distributed

in a running bond pattern on soil surface following Figueiredo and Poesen (1998). Furthermore, in order to saturate the soil mixture in the plot box, the soil layers were

saturated to reach the field capacity by its drainage hole and then were allowed to drain for 1 day (Srinivasan et al 2007; Muukkonen el al 2009).

After 24 hours, the plots were placed under the rainfall simulator and a constant rainfall with the intensity of 70 mmh^{-1} was maintained for 30 min for each test (Fig. 1). The pre-tests indicated that the adopted rainfall intensity has a desirable runoff volume and uniformity coefficient, furthermore, runoff volume and sediment yield attain a constant rate after 30 min. Artificial rainfall was produced from a spray nozzle and spinning disk-type FEL3 rainfall simulator based on the design by Armfield Ltd. (1998) with a uniformity of 80% that was assessed by employing the coefficient described by Maroufpoor et al. (2010).
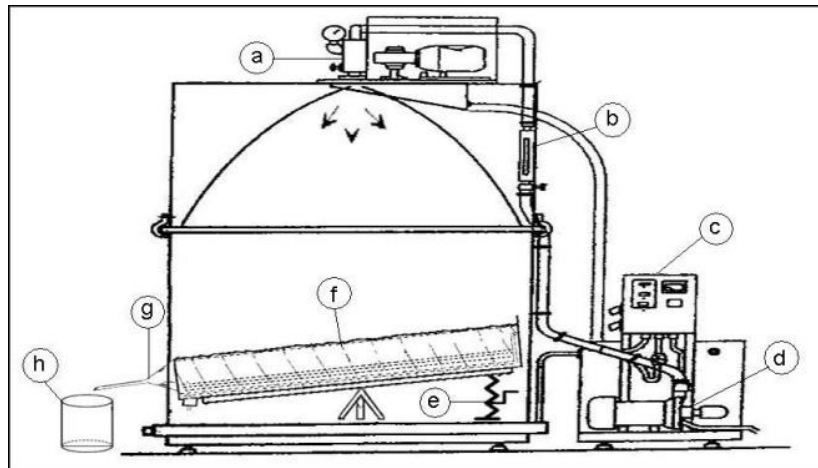
Figure 1: A schematic representation of the experimental set-up: a. Spray head assembly, b. Flow control valve, c. Electrical control panel, d. Centrifugal water pump, e. Manual jack, f. Erosion plot, g. Metal funnel, h. Plastic tank

Sediment yield and runoff volume were measured by the aid of metal funnel and plastic tank which was specially designed and constructed for the present study. During each run, plastic containers were utilized to collect the suspension samples at the outlet of each plot, manually. Total runoff and 100 ml suspension samples were taken at 2.5 min intervals to determine the flow discharge and sediment yields. The suspension samples were collected in mentioned intervals from the funnel outlet following the tests and oven dried to determine the mass of sediment yield. The volume of runoff was measured in these time intervals as well. The samples were analyzed in the laboratory for sediment concentrations and the mentioned data were runoff-weighted to determine the total sediment yield for each case.

The analysis of variance (ANOVA) of sediment yield and runoff was performed using SPSS[1] statistical software release 21.0 by IBM Corp., USA. SPSS statistics is a software package employed widely for statistical analysis. In order to investigate the temporal influences of rock cover and SCC on runoff and sediment yield during each run, the GLM[2] univariate procedure was applied to provide analysis of variance for these factors and to investigate the interaction between them. The GLM univariate procedure provides an analysis of variance for one dependent variable by one or more factors and variables. The factor variables divide the population into groups. By applying this procedure, null hypotheses can be tested in order to determine the effects of other variables on the means of various groupings of a single dependent variable and to investigate the interactions between factors as well as the effects of individual factors. Also, in order to assess the effects of both the between-subject factors and the within-subject factors for the runoff and sediment repeated measures data within twelve time intervals, the GLM repeated measures procedure was employed. The GLM repeated measures procedure provides analysis of variance when the same measurement is made

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1. Statistical Package for the Social Sciences

2. General Linear Model

several times on each subject or case. If between-subject factors are specified, they divide the population into groups. By applying procedure, the null hypotheses can be tested about the effects of between-subject factors, within-subject factors and the interactions between factors.

3. Results and Discussion
3.1. Experimental and statistical outputs

Table (2) summarizes the total values of runoff and sediment yield for different experimental factors. Total values for each factor were obtained by averaging the measured values over three replications and in each replication; the total value was obtained by adding the measured values within the twelve presented time intervals.

Table 2: Total values of runoff and sediment yield for different experimental factors

	Factor Level	Soil Clay Contents											
		0%		10%		20%		30%		40%		50%	
		R[a]	SY[b]	R	SY	R	SY	R	SY	R	SY	R	SY
Surface Rock Fragments	31358	309.52	24543	202.38	26461	234.43	26218	204.09	26860	259.06	30331	267.26	31358
	28126	495.87	24503	229.82	24541	207.19	25863	194.02	26924	201.67	29128	219.82	28126
	34670	810.51	27795	291.91	26106	207.03	25866	193.80	28289	219.52	28436	214.84	34670
	33738	613.98	26573	197.18	27003	198.44	27658	235.13	29165	232.23	28736	216.23	33738
	34820	746.84	27256	233.59	28720	184.28	27161	222.21	29175	186.90	31053	217.88	34820
	30110	480.13	29531	265.25	26320	179.05	24810	178.60	28813	222.62	29695	218.49	30110

[a] Runoff (ML), [b] Sediment yield (Gr)

According to the repeated measures analysis of variance, the probability of Mauchly's test of sphericity was significant ($p<0.05$) and therefore, it was concluded that there were significant variations between the variances of the differences, thus corrections were generated (Field, 2009). Based on the

mentioned corrections, the obtained values of "F", the significance of time intervals, their interactions with SCCs, SRFs, the "F" values in the analysis of variance for SCCs , SRFs on runoff , sediment yield and their interaction are listed in table 3.

Table 3: "F" values in the analysis of variance for runoff and sediment yield

Sources of variation	Degrees of freedom	Runoff	Sediment yield
Soil Clay Content (SCC)	5	22.084[*]	121.212[*]
Surface Rock Fragments (SRFs)	5	4.970[*]	4.833[*]
SCC×SRFs	25	1.287	6.084[*]
Time	11	2524.894[*]	161.191[*]
Time×SCC	55	9.577[*]	59.257[*]
Time×SRFs	55	2.026[*]	3.737[*]
Time×SRFs×SCC	275	1.553[*]	3.447[*]

[*] The mean difference is significant at the 0.05 level

Based on the Levene's test of equality of error variances, the obtained values of "F" and significance were equal to 2.253, 0.002 for runoff, 3.958 and 0.000 for sediment yield, respectively. Since error variances of the dependent variables were not equal across groups, the Dunnett T3 multiple comparisons

tests were used to investigate the differences between different levels of SRFs and SCCs. The results are listed in tables 4 and 5.

Finally, the profile plots (interaction plots) for comparing marginal means of soil clay contents, surface rock fragments and time intervals are illustrated in figures 2-4.

**able 4: Results of the Dunnett T3 multiple comparisons of runoff and sediment between different SCCs**

Factor Level	0%		10%		20%		30%		40%		50%	
	R[a]	SY[b]	R	SY	R	SY	R	SY	R	SY	R	SY
0%	1.000	1.000	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.004*	0.000*	0.113	0.000*
10%	-	-	1.000	1.000	0.999	0.190	0.999	0.179	0.431	0.952	0.002*	0.996
20%	-	-	-	-	1.000	1.000	0.999	0.999	0.198	0.773	0.000*	0.281
30%	-	-	-	-	-	-	1.000	1.000	0.086	0.777	0.000*	0.176
40%	-	-	-	-	-	-	-	-	1.000	1.000	0.254	0.999
50%	-	-	-	-	-	-	-	-	-	-	1.000	1.000

[a] Runoff, [b] Sediment yield, * The mean difference is significant at the 0.05 level

Table 5: Results of the Dunnett T3 multiple comparisons of runoff and sediment between different SRFs

| Factor Level	0%		5%		10%		15%		20%		25%	
	R[a]	SY[b]	R	SY	R	SY	R	SY	R	SY	R	SY
0%	1.000	1.000	0.974	0.999	0.999	0.909	0.974	0.996	0.528	0.994	0.999	0.999
5%	-	-	1.000	1.000	0.499	0.988	0.203	0.999	0.031*	0.999	0.614	0.999
10%	-	-	-	-	1.000	1.000	0.999	0.999	0.989	0.999	0.999	0.985
15%	-	-	-	-	-	-	1.000	1.000	0.998	0.999	0.999	0.999
20%	-	-	-	-	-	-	-	-	1.000	1.000	0.883	0.999
25%	-	-	-	-	-	-	-	-	-	-	1.000	1.000

[a] Runoff, [b] Sediment yield, * The mean difference is significant at the 0.05 level
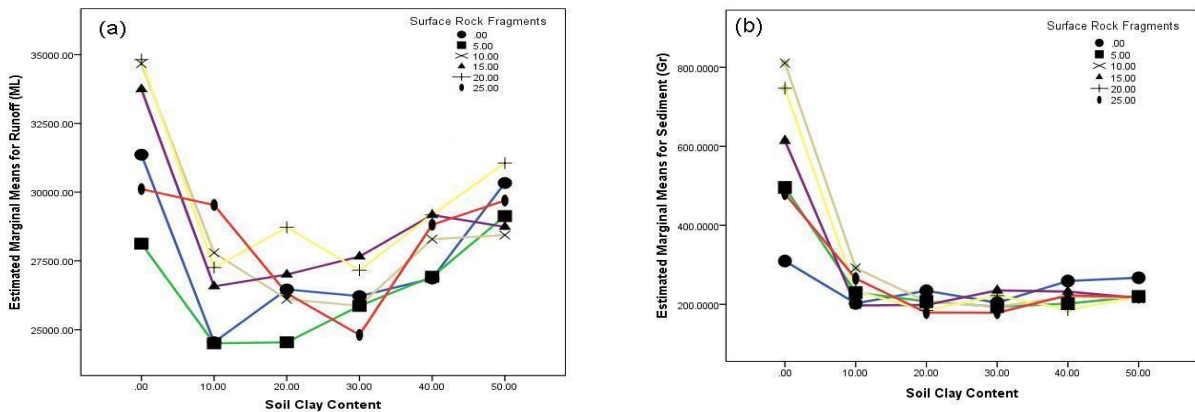
Figure 2: The effects of interaction between soil clay content and surface rock fragments on runoff (a) and sediment (b)
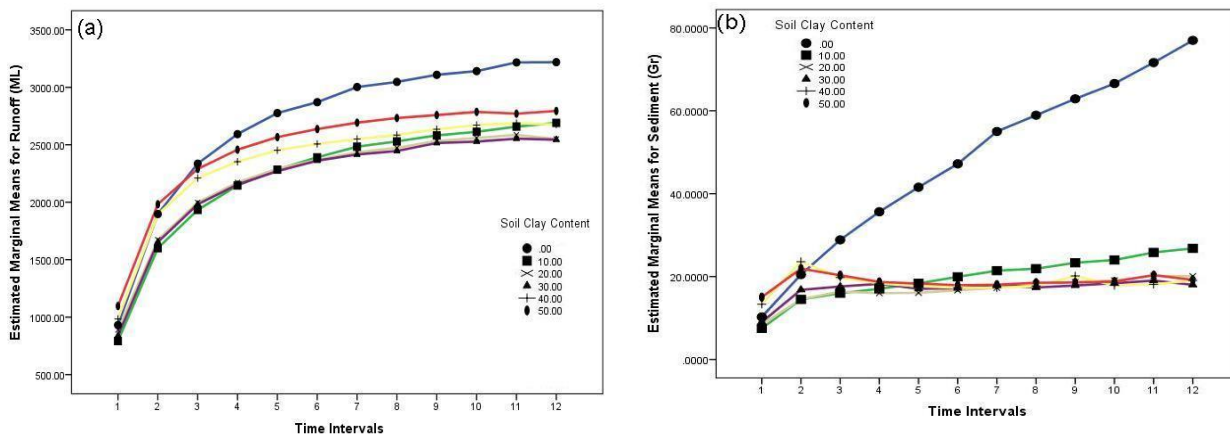
Figure 3: The effcets of interaction between time intervals and soil clay content on runoff (a) and sediment (b)
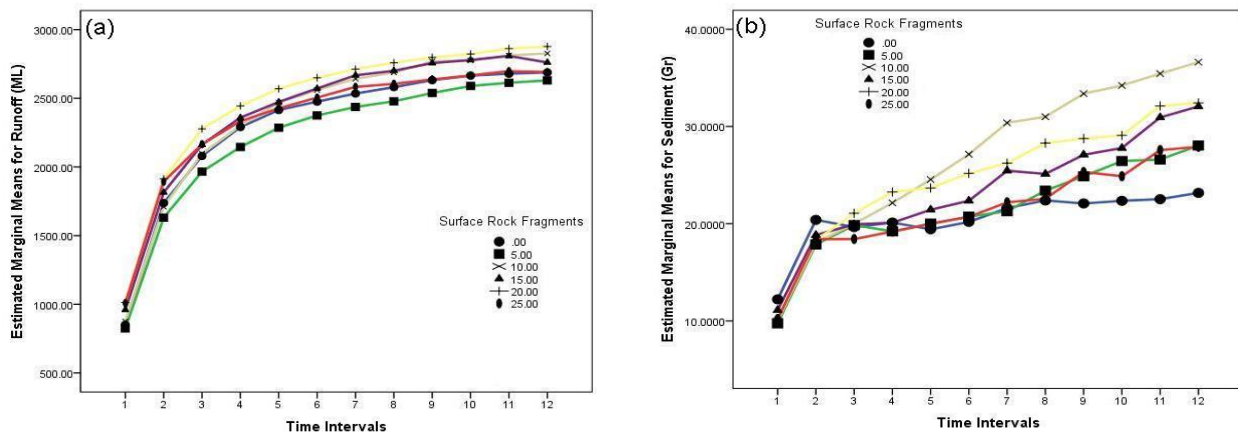
Figure 4: The effects of interaction between time intervals and surface rock fragments on runoff (a) and sediment (b)

3.2. Soil clay content and surface rock fragments

The analysis of variance (Table 3) demonstrated that the main effects and interactions of SCC and SRFs were all significant at the 0.95 level ($p<0.05$) for runoff and sediment yield parameters as depicted by the "F" values, however, the interaction between SCC and SRFs on runoff volume wasn't significant. Therefore in case of sediment yield, the effect of one of the SCC and SRF variables differs depending on the level of other variables. However, in case of runoff volume, a particular combination of variables reaches the results that would be anticipated on the basis of the simple main effects of those variables. Regarding the fact that the soil type could influence runoff (Zhang et al 2007), the results of the rainfall simulation experiments indicated significant differences in the hydrological response of soils between different SCCs. Expectedly, surface runoff increased remarkably with an increase in the duration of simulated rain. Besides, general trends in runoff volume were similar for different clay contents, because during rainfall simulation, there is a reduction in surface storage. Consequently, it accelerates seal formation processes and generates high runoff. Similar trends in surface runoff were reported by Salehi et al. (1993) and Rimal & Lal (2009).

According to the analysis of interaction effects, it can be concluded that, in case of runoff generation, SRFs by forming impervious surfaces and clay contents of soil by accelerating seal formations, have similar operations. But in case of sediment yield, SCCs by generating sediment load and SRFs by trapping sediments, have different functions. Therefore, the effects of one of these variables depend on the magnitude of the other one.

In this context, soil lacking clay content had a higher sediment yield in comparison with other levels of clay contents, significantly (Table 4), because in soils containing high clay content, the development of a cohesive layer (or crust) on the topsoil, results in surface sealing and increased roughness, which decreases the infiltration rate and reduces the soil erosion. Consequently, a higher surface roughness increases the time-to-runoff, facilitates ponding, enhances infiltration and reduces soil erosion. In this regard, Ben-Hur et al. (1985) found that the effect of clay content on the susceptibility of soils to seal formation and soil loss varied with clay content. In high clay content (50%), runoff increased remarkably due to the lower infiltration rate, but sediment yield was not significantly different, since it was observed that surface rock fragments disturb the flow field highly and act as traps for the eroded sediments. This difference suggests that initially, the heterogeneous conditions of the soil surface

resulting from remolded soils influence the short-time erosion patterns. It should be noted that in case of well-structured soils only fine material is transported, whereas the concentration is more uniform over the different size classes for soil without any aggregate (Asadi et al. 2006), similar to the soil samples utilized in the present study.

In this regard, Wischmeier and Smith (1978) declared that usually a soil type becomes less erodible with a decrease in silt fraction, regardless of whether the corresponding increase is in the sand fraction or the clay fraction. To expound these contradictions in results, it should be noted that the loss of structural stability under the impact of raindrops results in smaller and more easily transportable soil particles. So, the structural collapse aggregates associated with surface sealing and it influences both the detachability and the transportability in a direct way. The surface sealing as a result of infiltration reduction and increasing the amount of runoff water, increases the transportability of detached particles as well (Vanelslande et al 1984).

According to the results, an increase of rock fragments in soil surface, do not change the runoff and sediment yield significantly (Table 5). Consequently, although the rock fragments protect the soil from raindrop impacts, but during rainfall, water accumulates in irregular local patterns caused by rock fragments and leads to locally enhanced infiltration and re-deposition of suspended sediments which confirms the finding of Heng et al. (2011). Also, the mentioned finding supports that of Jomaa et al. (2010) who indicated that bed's geometry created barriers and obstacles for the water flow that are in turn sources and sinks of eroded sediments and runoff.

Although the fraction of surface area exposed to rainfall is one of the major factors controlling soil erosion yields for the entire duration of the erosion event (Mandal et al 2005), the runoff and sediment rates were observed for plots with different SRFs,

revealed that the presence of the rock fragments couldn't increase the runoff and sediment rates significantly, as compared with the bare soil. As Jomaa et al. (2012) concluded, the results demonstrated that initially erosion is not solely linked to the exposed surface area, but after an initial transient, the erosion rates evolve towards a steady-state condition and the proportionality to exposed area appears again. Furthermore, in addition to the exposed surface area, it is possible that runoff and soil erosion were affected by surface roughness and sealing. Also, the presence of SRFs protects the soil from raindrop splashes and sealing, therefore it preserves the original infiltration rate. Besides, in published experimental data for field soils, the cumulative soil erosion was found not to be solely proportional to the exposed surface area and the proportionality between soil erosion and thus, the exposed area is not a universal result (Jomaa et al 2012).

3.3. Time intervals

As indicated in figure 3, runoff volume and sediment yield increased in each time interval during simulation. For runoff, the generality of this statement is supported by similar findings on different soil types, but in case of sediment and its fluctuations, it should be mentioned that the behavior of suspended sediment is often a function of energy conditions. Thus, sediment is stored at low flow and transported under high discharge conditions (Beca, 2002). Furthermore, as the rainfall event continues, the soil surface evolves again towards a steady-state condition and the erosion rates are consequently modified (Jomaa etal. 2012).

According to figures 3 and 4, it should be noted that the experimental results indicated that the rainfall process resulted in high sediment concentrations at the beginning of the erosive event (higher gradients in initial part of lines), defined as the time when the overland flow appeared firstly at the end of the plot which is a ''first-flush'' effect (Jomaa et al 2010). Then, similar to findings from Asadi

et al. (2007) and Jones et al. (2008) studies, the sediment concentration values measured from the samples, decreased much more rapidly with time and approached an approximately constant value, some 5 minutes into the experiment. A similar finding was observed by Lal (1981), who stated that soil erodibility is a time dependent function and soil erodibility is influenced by the deterioration of soil structure and an accumulation of less erodible coarse fraction at the soil surface. So, the structural stability is an important controlling factor (Vanelslande et al. 1984).

Profile plots of factors indicate whether the estimated marginal means are increasing or decreasing across levels, and nonparallel lines indicate an interaction which means that the levels of only one factor cannot be investigated. As results illustrated in table 5, the interactions between sampling time intervals and SCC and SRFs were all significant, thus the time character had a substantial effect on how SCCs and SRFs combinations interact. The general forms of time variation in sediment yield and runoff which is demonstrated in Figures 3 and 4, was previously reported in the literature (e.g. Fox.

& Bryan, 1999; Asadi et al 2007). Furthermore, as the time intervals increased, the differences in runoff volume and sediment yield between the SCCs and SRFs widened. These results demonstrate very clearly that there are important and usually positive or synergistic interactions between the sampling time and SCCs and SRFs. One possible explanation for the mentioned manner is that, in non-steady-state conditions during the short period of time after the start of the rainfall simulation, these parameters cannot play their roles efficiency. Then, as the simulation continues, their effects on runoff and sediment yield become apparent.

3.4. The derivation of regression equation relating runoff and sediment to experimental factors

The runoff and sediment yield for soils with six levels of clay contents exposed to six levels of SRFs was utilized to generate a multiple linear regression equation that could be applied in order to predict the runoff and sediment yield. The equations 1 and 2 for runoff and sediment, respectively, were of the forms:

For runoff volume:

RV   =   27936.840-24.625 SCC(%)+72.898 SRF(%)   (1)
Student "t"   (41.762)   (-1.445)   (2.139)   (R=0.244; N=108)

For sediment yield:

SY   =   396.194-5.137 SCC(%)+0.783 SRF(%)   (2)
Student "t"   (13.312)   (-6.778)   (0.517)   (R=0.553; N=108)

Where RV is runoff volume (ml), SY is sediment yield (gr), SCC is the soil clay content (%) and SRF in the surface rock fragment (%). R is the coefficient of multiple regression (significant at the 0.5% level) and N is the number of experimental data points. The signs obtained from the experimental factors, confirms the manner that these factors affect the runoff and sediment yield. The relative "t" values for runoff volume and sediment yield factors also confirmed the finding in the ANOVA which indicatedthat the most significant factor is the level of SCC rather

than SRFs. Although the R values are low, especially for runoff volume, but low R values are not inherently inappropriate. In some fields, it is entirely expected that R values will be low. For example, most fields that attempts to predict runoff and sediment behaviors, typically R values are lower than 50%, because these phenomena are simply harder to predict. Furthermore, if R value is low, there are still statistically significant predictors; which can result in significant conclusions about the association between the changes in the predictor values and the response value.

Regardless of the R, the significant coefficients still represent the mean change in response for one unit of change in the predictor while holding other predictors in the model constant. Obviously, this type of information can be extremely valuable (Evans, 2017).

4. Conclusion

In the current stimulation study, the runoff and sediment yield were measured for soils with different clay contents and surface rock fragments in laboratory utilizing rainfall simulator and erosion plots. These apparatuses were employed to test the erosion of soils with six levels of clay content and six levels of surface rock fragments and were exposed to a rainfall intensity of 70 mmh^{-1} falling on the soil for 30 min. Runoff volume and sediment yield were taken at 2.5 min time intervals during simulation. Overall, the clay contents of soil were found to have a considerable influence on the potential of sediment yield and runoff volume as compared with surface rock fragments. The significance of the simple main effects of soil clay content and surface rock fragments confirms that the soil clay content parameter is an important factor that affects soil loss. Besides, multiple regression equations derived to relate runoff and sediment to the experimental factors. These equations

confirmed that the most significant factor that affected runoff and sediment is the quantity of soil clay content. Consequently, it is believed that based on the significance of the interaction effects, the solely interpretation of the simple main effects is either incomplete or misleading. The main effects of time and its interactions with soil clay content and surface rock fragments were all significant, meaning that the temporal pattern observed for runoff and sediment during simulation was clearly related to the interaction of soil clay content and surface rock fragments, thus temporal variations must be accounted for in any simulation study of soil erosion. Additionally, time had major effects on both runoff and sediment production, although these differences reduced gradually while the rainfall simulation proceeded. In addition, evidence of such interactions between surface rock fragments, soil clay content and sampling time, presents a new challenge for erosion modeling and all of these inter-relationships should be perceived well enough that it would be possible to make them into effective erosion models. Finally, the idea that multiple effects should be studied in research rather than the isolated effects of single variables is one of the significant contributions of the present study.

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