Geoderma 319 (2018) 34–42

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

The effect of exclosure management on the reduction of SOC loss due to splash erosion in gypsiferous soils in Southwestern Iran

A. Yaghobi[a], B. Khalilimoghadam[a,*], T. Saedi[b], M. Rahnama[c]

[a] Department of Soil Science, Ramin Agriculture and Natural Resources university of Khuzestan, Ahvaz, Iran
[b] Department of Soil Science, Isfahan University of Technology, Isfahan, Iran
[c] Department of Agricultural Machine and Mechanization Engineering, Ramin Agriculture and Natural Resources university of Khuzestan, Ahvaz, Iran

ARTICLE INFO

Editor: Edward A Nater

Keywords:
Soil splash erosion
Gypsiferous soils
Exclosure
Loss of SOC

ABSTRACT

An understanding of the effect of exclosure on soil organic carbon (SOC) content changes and its loss due to soil erosion in arid and semi-arid rangelands is essential to the establishment of stable ecosystem conditions. The aim of this study is to investigate the loss of SOC during natural rainfall due to splashed particles of gypsiferous soils. Accordingly, a three-factor factorial experiment is performed within a completely randomized design with a splash cup under natural rainfall over three replications. The first factor is exclosure at two levels (exclosure and non-exclosure); the second factor is rainfall erosivity factor at three levels (EI_{30}: 1153.5, 4307.6, and 7714 J m^{-2} cm^{-1}); and the third factor is slope percent at three levels (0%, 5%, and 15%). The results showed that exclosure had a significant impact on soil splash erosion rate in terms of upslope splash erosion (USE), downslope splash erosion (DSE), total splash erosion (TSE), and loss of SOC. In non-exclosure conditions, the USE, DSE, and TSE increased by 32.4%, 13.5%, and 17.8%, respectively, compared to exclosure conditions. The amount of organic carbon lost due to splash in non-exclosure conditions was 1.29 times higher than in exclosure conditions. In addition, by increasing the slope and the rainfall erosivity index, a significant reduction was observed in USE and a significant increase was observed in TSE, DSE, and the loss of SOC. As a result of increasing the index EI_{30} from 1153.5 to 4307.6, the loss of SOC increased by a factor of 1.3, and as a result of increasing the rainfall erosivity index ($EI3_0$) from 1153.5 to 7714, the loss of SOC increased by a factor of 1.4. Organic carbon loss in the slope of 0–5% was approximately 0.061%, and by increasing the slope to 5–15%, and then 15–30%, carbon loss increased by factors of 1.5 and 1.34, respectively. Therefore, the exclosure treatment had a significant impact on reducing soil and organic carbon loss in the fields. It seems necessary, therefore, to consider exclosure treatment as a major part of renewable natural resources projects, especially in watershed management plans involving the gypsiferous soils of Iran.

1. Introduction

Soil organic matter (SOM) is a heterogeneous mix of organic components such as plant, animal, and microbial residues in various stages of decomposition (Post and Kwon, 2000), which make up the majority of soil organic matter. Soil organic matter improves the aggregation, infiltration, and water retention capacity of soil; it has a significant impact on soil quality and fertility. As a consequence, the amount of SOC is commonly used as an indicator of soil quality (Sinoga et al., 2012). SOM also has a high capacity for the storage and exchange of atmospheric carbon dioxide through plant photosynthesis, and thus plays an important role in the global carbon cycle. The balance between the SOC inputs, through the addition of plant products and dead animal material, and its output (loss) through mineralization or physical removal (erosion), is required to maintain soil quality (Lal et al., 2004). At the field scale, large spatial differences exist in SOC content due to soil erosion processes and redistribution. In many agricultural and natural landscapes, water erosion is the main cause of redistribution of SOC (Jacinthe et al., 2004). Organic carbon loss due to water erosion reduces the aggregation and the aggregate stability of soil; the exacerbated effects of the erosion processes may eventually lead to a loss of soil fertility and desertification.

Water erosion is a complex process that involves several other processes. Splash, which refers to soil detachment and its transport as the result of raindrop impact, can be considered the first step in the detachment process and the transport of soil particles (Quansah, 1981). SOC moves via the splashed and leached soil particles impacted by rainfall (Gregorich et al., 1998). Splash, therefore, plays a fundamental

* Corresponding author.
E-mail address: khalilimoghadam@ramin.ac.ir (B. Khalilimoghadam).

https://doi.org/10.1016/j.geoderma.2017.12.037
Received 6 February 2017; Received in revised form 12 December 2017; Accepted 30 December 2017

role in SOC dynamics, especially within arid conditions. However, there is very little information about the amounts of organic carbon released by splash under different conditions. It has been proven that splash is not equally effective on all soil particle sizes, and that splash rate is subject to the size, compaction, and aggregation of soil particles. The splash process in particular is more frequent for fine particles such as those with high organic carbon content (Kuhn, 2007; Jin et al., 2008; Martínez-Mena et al., 2002). In any case, splash erosion reduces the SOC input and affects the carbon exchange balance between the soil and the atmosphere. Vegetation-cover management is an effective factor for influencing splash erosion, but so far, no study has been conducted on the impact of exclosure on SOC loss as the result of splash particles. It is thus necessary to study the relationship between organic matter and splash erosion under different management systems and exclosures to choose sustainable land management practices. Raindrop energy is capable of detaching soil particles and even breaking down some aggregates during impact with the soil surface during rainfall or an irrigation event. Meyer and Wischmeier (1969) showed that rainfall's capacity to transport soil through splash depends on factors such as the slope degree, intensity and amount of rainfall, soil characteristics, micro-topography, and wind speed during the rainfall event. The results of Saedi et al. (2016) showed that slope, rainfall intensity, and soil characteristics (especially aggregate stability, particle size distribution, and soil shear strength) are the most important factors affecting splash. Gharemani et al. (2001) found that the amount of splashed soil differs based on land use; the highest splash erosion rate occurs in arid lands, and the splash rate depends on the type and percentage of vegetation cover. KhaliliMoghadam et al. (2015) found that land use and soil management practices have a significant effect on the splash erosion rate in farmlands. The effects of grazing and vegetation cover on water infiltration and runoff amount in the rangelands have been studied by some researchers, including Busby and Gifford (1981), Wood and Blackburn (1981) and Mwangi et al. (2016). The results indicated that land exclosure, followed by increased vegetation cover, reduces the runoff factor. In addition, Tavakoli and Ghodoosi (2001) studied the effects of exclosure management on watershed restoration and concluded that exclosure treatment has a positive effect on surface runoff and erosion reduction. Despite the importance of the influence of vegetation-cover management on soil splash erosion rate, the effect of exclosure treatment on splashed particles has thus far not been studied.

A field study is conducted to determine the splash erosion rate and the amount of SOC in the splashed particles under two different types of vegetation-cover management (exclosure and livestock grazing) under natural rainfall. Most studies that have addressed the amount of SOC in the splashed particles have thus far been conducted in labs or under rainfall simulation in fields (Polyakov and Lal, 2004; Jin et al., 2008). Very little research has been conducted under natural rainfall, and studies that have been performed under the aforementioned conditions did not focus on exploring splash (Martínez-Mena et al., 2008). Recently, Beguera et al. (2015) investigated the amount of SOC loss by splash erosion under natural rainfall. The present study is focused on splash erosion and aims to further this objective by collecting the produced splash after each rainfall event in splash cups. The aim of this study is to (1) determine the effect of exclosure on soil splash erosion and loss of SOC by the splash erosion, and (2) obtain the effect of slope and rainfall intensity on soil splash and determine the total organic carbon released by the soil due to splash.

2. Materials and methods

2.1. The area under study

The area under study is the representative catchment of Susa in the Khuzestan province in southwestern Iran (Fig. 1). Representative catchments (Iranian Forests, Range and Watershed management Organization, 2006; Hosseinalizadeh et al., 2017) are defined as the hydrologic units that are determined and established in homogeneous areas in terms of climate, geology, vegetation cover and pedology. These catchments exist in areas with different land uses. The testifier and sample sub-watersheds are defined as a pair in a representative catchment, and are thus called 'paired watersheds'. The paired watersheds are formed of two sub-watersheds that are analyzed comparatively against each other. The testifier sub-watersheds are used to study the trends of the sample sub-watershed and remain untouched; in the sample sub-watershed, however, biological and mechanical practices are used to control erosion. The Susa-representative watershed involves a paired watershed that includes two sub-watersheds of the sample and the testifier. In the sample sub-watershed, the exclosure has been sustained for 8 years, whereas the testifier sub-watershed is a grazing area or non-exclosured. Exclosure, therefore, refers to the pasture site where grazing has not been allowed for an 8-year period, and non-exclosure refers to a pasture site where normal grazing activity has been conducted over the same time period. The sub-watershed is equipped with a synoptic station. Rainfall and rainfall intensity are, therefore, recorded by a rain gauge, and the rainfall erosivity index is calculated for the three consecutive events (Tables 1 and 2). Most soils in the Susa-representative catchments are gypsiferous and belong to large groups of Typic Haplogypsids and Typic Petrogypsids. The role of the parent materials in soil formation is quite obvious and dominant even in old soil and advanced stages of development, owing to little weathering and shallow soil wetting. The sources of gypsiferous soils in the area are, therefore, the Mishan, Aghajari, and Bakhtiari formations. The Mishan formation is composed of two members: a thick to massive, rock-forming hard limestone called the Guri member, and a very thick, unnamed green or gray marl, with intercalated thin to medium bedded limestone, called the Maly member as an informal member for the purposes of this research. The Aghajari formation comprises varicolored marls and siltstones with beds of sandstones and grits. Occasional beds of freshwater limestones (with ostracods and charophytes), lacustrine clays, and bentonites are also present. The Bakhtiari formation was applied to the chert and limestone conglomerates interbedded within the sandstone. The gypsiferous soils are poor in phosphorus and their pH range is 7.5–8.4. In addition, in terms of physiography, this catchment is hilly, and the slope of the area is 0 to 20%. The dominant plant species of this region are *Astragalus fasciculifolius* and *Stipa capensis*.

2.2. Soil splash erosion measurement

In this study, the splash cup used by Morgan (1982; shown in Fig. 2) was used to measure splash erosion. This device has two cylinders: the collector and the single sample cylinders. The collector cylinder is 25 cm in height and the sample cylinder, with a diameter of 2.5 cm, is located inside it; the erosion caused by rainfall is collected by this cylinder. The sample cylinder is divided into upslope and downslope by two blades that can distinguish between the splash in the upslope and downslope. In the bottom of the collector cylinder, in each of the upslope and downslope areas, holes are placed to collect the runoff separately from the upslope and the downslope. Using this device, it is thus possible to measure the TSE rate, the USE and the DSE across different slopes and rainfall intensities.

2.3. Soil sampling and analysis

In this study, the splash cups were first designated in three replications under three average slopes (0%, 5%, and 15%) in the exclosured and non-exclosured lands. The horizon A of these lands was subsequently sampled. The soil samples were transported to the laboratory and exposed to the air to dry, then passed through a 2-mm sieve. Physical properties including clay, silt, and sand percentage were measured using the pipette method (Gee and Bauder, 1986); the aggregate stability was measured by the Kemper and Rosenau (1986); and the soil cohesion was measured by a shear vane set. Some soil chemical

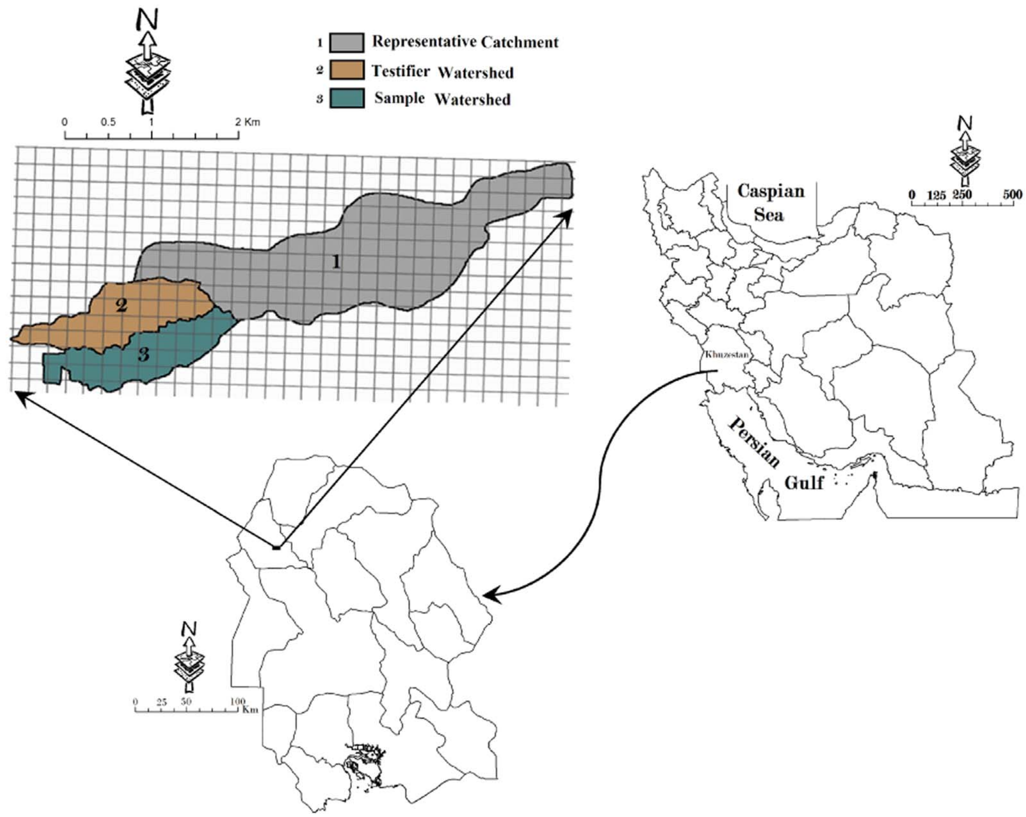

Fig. 1. Geographical location of the area under study.

properties, such as soil reaction in saturated paste, were determined by a pH meter; the electrical conductivity was measured by a conductivity meter device; the organic carbon was calculated by the Walkley–Black method (Nelson and Sommer, 1982); and the equivalent calcium carbonate percentage was measured by 1 N hydrochloric acid neutralization (Nelson, 1982).

Eq. (1) was used to compute the kinetic energy of rain (Wischmeier and Smith, 1978). In addition, according to Table 1, among the recorded events, three rainfalls at different intensities were selected and the rainfall erosivity index was calculated by Eq. (3).

$$KE = 210.2 + 89*Log_{10}(I) \quad (1)$$

$$E = KE*P \quad (2)$$

$$EI_{30} = \left(\sum_{t=1}^{D} E\right)*I_{30}*2 \quad (3)$$

where I is the rainfall intensity ($cm\ h^{-1}$), P is the precipitation amount (cm), KE is the kinetic energy of rain in the precipitation amount ($J\ m^{-2}\ cm^{-1}$), E is the kinetic energy of rainfall ($J\ m^{-2}$), I_{30} is the maximum rainfall intensity in 30 min during the event, D is the total of rainfall duration, and EI_{30} is the erosivity index ($J\ cm\ m^{-2}\ h^{-1}$).

The upslope and the downslope splashed soil were collected individually. The splashed soil in the tray was rinsed, and after deposition of the sediment, the fluid was discharged, the sediment was oven-dried at a temperature of 60–70 °C, and the sediment was subsequently weighed. The total splash erosion rate and its components were obtained according to Eqs. (4), (5), and (6).

$$TSE = \frac{S_u + S_d}{A} \quad (4)$$

$$DSE = \frac{S_d}{A} \quad (5)$$

$$USE = \frac{S_u}{A} \quad (6)$$

where TSE, DSE, and USE are, respectively, the total splash erosion rate, the downslope splash erosion rate, and the upslope splash erosion rate in grams per square meter; S_u is the splashed soil in the upslope in grams; S_d is the weight of the splashed soil in the downslope in grams; and A is the cross section of the sample cylinder in meters.

To investigate the loss of SOC, the splashed soil was air dried after applying each rainfall time. Carbon loss per event was obtained thereafter via the difference between the SOC of the splashed particles and the original soil.

2.4. Statistical analysis

The factorial experiment was conducted as a completely randomized base design with three factors and three replications. The first factor was vegetation cover management at two levels (exclosure and non-exclosure), the second factor was rainfall at three levels (EI_{30}: 1153.5, 4307.6, and 7714), and the third factor was the slope at three levels (0%, 5%, and 15%).

3. Results and discussion

3.1. Chemical and physical properties of soils

Some of the physical and chemical properties of the soils in the area under study are shown in Table 3. Based on Table 3, these soils have low levels of organic matter. According to the averages of clay, silt, and sand in the soils under study, the soil texture is loamy sand. The phosphorus content of the soils under study is low. According to the geological formations of the area, this is the same as that of the Gachsaran, Aghajari, and the Mishan formations; the soils in the area are gypsiferous. The high level of T.N.V. in the soils showed high levels of gypsum and lime. In gypsiferous soils, soil structures are not formed well, and therefore, aggregate stability, soil peds, mean weight, diameter, and soil cohesion are low. According to the pH of these soils, the phosphorus content is limited, and they are faced with the phosphorus

Table 1
The properties of rainfall events recorded by synoptic station and calculated kinetic energy of rainfall events.

Event 1				Event 2				Event 3			
Date	Time	I (mm min^{-1})	E (J m^{-2})	Date	Time	I (mm min^{-1})	E (J m^{-2})	Date	Time	I (mm min^{-1})	E (J m^{-2})
20.03.2015	14:00	0.9	247.84	19.02.2015	03:20	0.2	43.45	24.11.2014	18:30	0.2	43.45
20.03.2015	14:10	0.7**	18.60	19.02.2015	03:30	0.2	4.34	24.11.2014	18:40	0.1	1.90
20.03.2015	14:20	4**	133.22	19.02.2015	03:40	0.3	6.99	24.11.2014	18:50	0.1	1.90
20.03.2015	14:30	1.5**	44.27	19.02.2015	03:50	0.2	4.34	24.11.2014	19:00	0.1	1.90
20.03.2015	14:40	0	0.00	19.02.2015	04:00	0	0.00	24.11.2014	19:10	0.3	6.99
21.03.2015	14:20	1.2	34.38	19.02.2015	04:10	0	0.00	24.11.2014	19:20	0.4	9.76
21.03.2015	14:30	0	0.00	19.02.2015	04:20	0	0.00	24.11.2014	19:30	0.6	15.58
21.03.2015	14:40	0	0.00	19.02.2015	04:30	0	0.00	24.11.2014	19:40	0.5	12.63
21.03.2015	14:50	0	0.00	19.02.2015	04:40	0	0.00	24.11.2014	19:50	0.5	12.63
21.03.2015	15:00	0	0.00	19.02.2015	04:50	0.1	1.90	24.11.2014	20:00	0.2	4.34
21.03.2015	15:10	0	0.00	19.02.2015	05:00	0	0.00	24.11.2014	20:10	0.4	9.76
21.03.2015	15:20	0	0.00	19.02.2015	05:10	0	0.00	24.11.2014	20:20	0.4	9.76
21.03.2015	15:30	0	0.00	19.02.2015	05:20	0.1	1.90	24.11.2014	20:30	0.3	6.99
21.03.2015	15:40	0	0.00	19.02.2015	05:30	0	0.00	24.11.2014	20:40	0.1	1.90
21.03.2015	15:50	0	0.00	19.02.2015	05:40	0	0.00	24.11.2014	20:50	0	0.00
21.03.2015	16:00	0.1	1.90	19.02.2015	05:50	0.1	1.90	24.11.2014	21:00	0.1	1.90
21.03.2015	16:10	0	0.00	19.02.2015	06:00	0.4	9.76	24.11.2014	21:10	0	0.00
21.03.2015	16:20	0	0.00	19.02.2015	06:10	0.1	1.90	25.11.2014	03:50	0.7	18.60
21.03.2015	16:30	0	0.00	19.02.2015	06:20	0.4	9.76	25.11.2014	04:00	0.1	1.90
21.03.2015	16:40	0	0.00	–	–	–	–	25.11.2014	04:10	0	0.00
21.03.2015	16:50	0	0.00	19.02.2015	07:40	0.1	1.90	25.11.2014	04:20	0	0.00
21.03.2015	17:00	0	0.00	19.02.2015	07:50	0.1	1.90	25.11.2014	04:30	0	0.00
21.03.2015	17:10	0	0.00	19.02.2015	08:00	0.1	1.90	25.11.2014	04:40	0.1	1.90
21.03.2015	17:20	0	0.00	19.02.2015	08:10	0.1	1.90	25.11.2014	04:50	1	27.95
21.03.2015	17:30	0	0.00	–	–	–	–	25.11.2014	05:00	2.2**	68.18
21.03.2015	17:40	0	0.00	19.02.2015	23:50	0.3	6.99	25.11.2014	05:10	1.4**	40.94
21.03.2015	17:50	0	0.00	19.02.2015	24:00	0.1	1.90	25.11.2014	05:20	0.9**	24.78
21.03.2015	18:00	0	0.00	20.02.2015	00:10	0	0.00	25.11.2014	05:30	0.8	21.67
21.03.2015	18:10	0	0.00	20.02.2015	00:20	0	0.00	25.11.2014	05:40	0.7	18.60
21.03.2015	18:20	0	0.00	20.02.2015	00:30	0.1	1.90	25.11.2014	05:50	0.7	18.60
21.03.2015	18:30	2	61.25	20.02.2015	00:40	0.1	1.90	25.11.2014	06:00	0.5	12.63
21.03.2015	18:40	0.2	4.34	20.02.2015	00:50	0.1	1.90	25.11.2014	06:10	0.4	9.76
21.03.2015	18:50	0.1	1.90	20.02.2015	01:00	0.4	9.76	25.11.2014	06:20	0.2	4.34
21.03.2015	19:00	0.1	1.90	20.02.2015	01:10	0.3	6.99	25.11.2014	06:30	0.1	1.90
21.03.2015	19:10	0	0.00	20.02.2015	01:20	0.1	1.90	25.11.2014	06:40	0.2	4.34
21.03.2015	19:20	0	0.00	20.02.2015	01:30	0.1	1.90	25.11.2014	06:50	0.7	18.60
21.03.2015	19:30	0.7	18.60	20.02.2015	01:40	0	0.00	25.11.2014	07:00	1	27.95
21.03.2015	19:40	0.8	21.67	20.02.2015	01:50	0	0.00	25.11.2014	07:10	0.5	12.63
21.03.2015	19:50	0.4	9.76	20.02.2015	02:00	0.2	4.34	25.11.2014	07:20	0.1	1.90
21.03.2015	20:00	0.1	1.90	20.02.2015	02:10	0	0.00	25.11.2014	07:30	0	0.00
21.03.2015	20:10	0.4	9.76	20.02.2015	02:20	0.1	1.90	–	–	–	–
21.03.2015	20:20	0	0.00	20.02.2015	11:20	1.9**	57.81	–	–	–	–
………….	……….	…………		20.02.2015	11:30	0.7**	18.60	–	–	–	–
………….	……….	………....		20.02.2015	11:40	0.1**	1.90	–	–	–	–
………….	……….	…………..		20.02.2015	11:50	0	0.00	–	–	–	–
21.03.2015	24:00	0	0.00	20.02.2015	12:00	0	0.00	–	–	–	–

** Maximum consecutive rainfall in 30 minutes for calculation of EI_{30}.

Table 2
The amount of calculated erosivity index by using method of Wischmeier and Smith (1978).

Date	Time	I (mm min^{-1})	P (cm)	I_{30} (cm h^{-1})	ΣE (J m^{-2})	EI_{30} (J cm m^{-2} h^{-1})
20.03.2015	14:10	0.7	0.7	12.4	622.10	7714.07
20.03.2015	14:20	4	4			
20.03.2015	14:30	1.5	1.5			
20.02.2015	11:20	1.9	1.9	5.4	213.61	1153.50
20.02.2015	11:30	0.7	0.7			
20.02.2015	11:40	0.1	0.1			
25.11.2014	05:00	2.2	2.2	9	478.62	4307.6
25.11.2014	05:10	1.4	1.4			
25.11.2014	05:20	0.9	0.9			

RI is the rainfall intensity, P is the precipitation amount, KE is the kinetic energy of rain in the precipitation amount, E is kinetic energy of rainfall, I_{30} is maximum rainfall intensity in 30 min during the event, and EI_{30} is erosivity index.

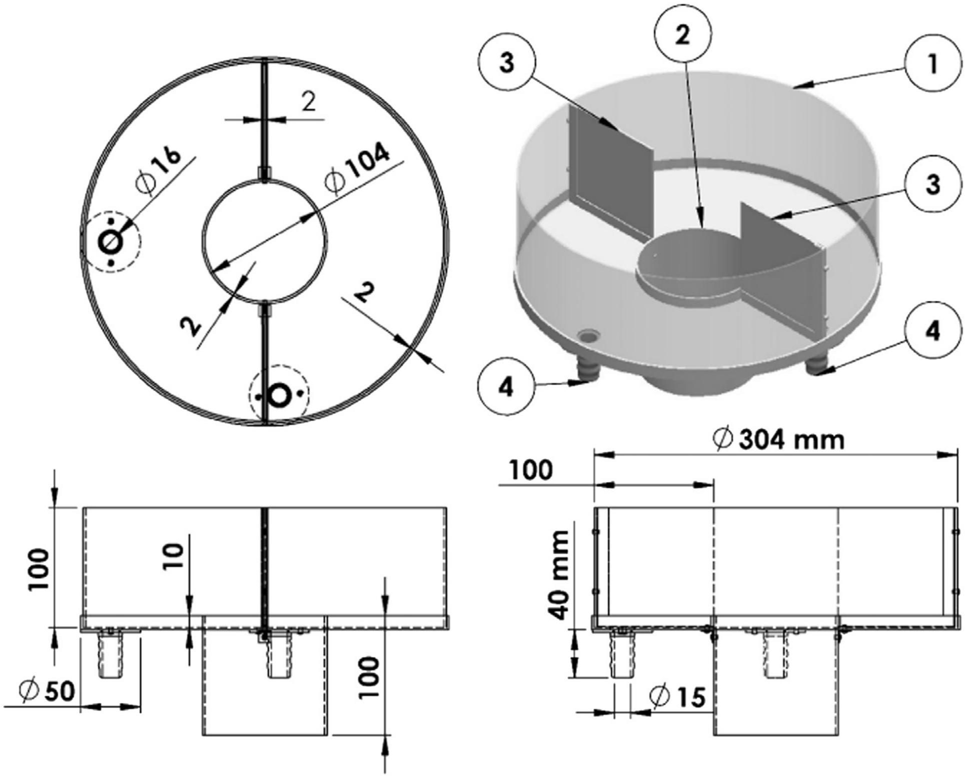

Fig. 2. Schematic view of the splash cup and the insertion of the device and collect sediment. 1) Sediment cylindrical collector, 2) sample cylinder, 3) Separators and 4) outlets.

Table 3
Summary of statistics (maximum, minimum, mean and coefficient of variations, CV) for soil properties.

Property	Mean	Maximum	Minimum	CV
Organic carbon (%)	0.36	0.4	0.27	0.1
T.N.V (%)	38.5	39	38	0.014
Clay (%)	10.20	16	4	0.34
Silt (%)	25.75	50.50	16	0.37
Sand (%)	64.05	80	33.5	0.19
Phosphorus (%)	0.27	0.41	0.2	0.23
Electrical conductivity (ds/m)	2.66	3.28	2.03	0.15
Soil acidity	7.31	7.50	7.13	0.016
Mean weight diameter (mm)	0.25	0.3	0.21	0.12
Soil shear strength (KPa)	16.40	21	14	0.15

Table 4
Analysis of variance (mean squares) of the parameters studied.

		Mean squares			
Treatment	Df	USE	DSE	TSE	Loss of SOC
Exclosure (Ex)	1	1066.67**	1779.63*	5400**	0.0056**
Erosivity Index (EI)	2	1468.52**	9950**	18,368.52**	0.0036**
Slope (S)	2	1279.63**	35,116.67**	23,190.74**	0.0045**
Ex * EI	2	72.22^{ns}	1035.18^{ns}	1105.56^{ns}	0.0001^{ns}
Ex * S	2	50^{ns}	135.18^{ns}	50^{ns}	0.0008^{ns}
EI * S	4	87.96^{ns}	608.33^{ns}	262.96^{ns}	0.0001^{ns}
Ex * EI * S	4	113.89^{ns}	199.07^{ns}	188.89^{ns}	0.0002^{ns}
Error	36	7.81	19.44	21.08	0.02
CV		24.54	21.46	17.2	24.37
R-squares		0.77	0.88	0.85	0.66

**: significant difference at 1% level, *: significant difference at 5% level, ns: non-significant.

deficiency.

3.2. The effects of exclosure management on USE, DSE, TSE, and SOC loss

According to Table 4, the results of variance analysis indicate that splash shows significant differences at the 1% level in USE, TSE, and the loss of SOC under exclosure and non-exclosure conditions. The splash rate also shows significant differences between these conditions at the 5% level in DSE. Fig. 3 shows the relationship between exclosure conditions, USE, DSE, TSE, and the loss of soil organic matter. According to Fig. 3a, b, and c, the rate of USE, DSE, TSE, in terms of non-exclosure, is higher than under exclosure conditions. Under non-exclosure conditions, the USE, the DSE, and the TSE increased by 32.4%, 13.5%, and 17.8%, respectively, in comparison to erosion under exclosure conditions. Little research has been performed on the effects of exclosure on soil particle splash thus far; most of the research on the effects of exclosure on soil erosion (Jeddi and Chaieb, 2010; Su et al., 2004; Lavado and Alconada, 1994), however, indicates that soils under exclosure are conserved by vegetation cover. Exclosure management increases soil organic matter and plant growth, and soil erosion decreases due to both the improvement of soil structure and the increase in soil infiltration capacity over time. One of the reasons to reduce the amount of splash in non-exclosure conditions in comparison to exclosure conditions is, therefore, due to the greater presence of organic matter, followed by better soil structure and aggregate stability. Organic matter with a hydrophobic coating around aggregates reduces the water infiltration rate and increases the aggregates' resistance to the stresses caused by wetting (Leelamanie et al., 2013).

Results (refer to Fig. 3d) have shown that the amount of SOC loss as the result of splash in non-exclosure conditions is 1.29 times higher than in exclosure conditions. Several studies have been conducted based on the changes in SOC storage in the watershed as a result of water erosion and runoff. Boix-Fayos et al. (2009) showed that on the watershed scale, SOC storage is reduced by 4% as a result of water erosion. These researchers indicated that a significant portion of the organic carbon is removed by the erosion process. A significant quantity

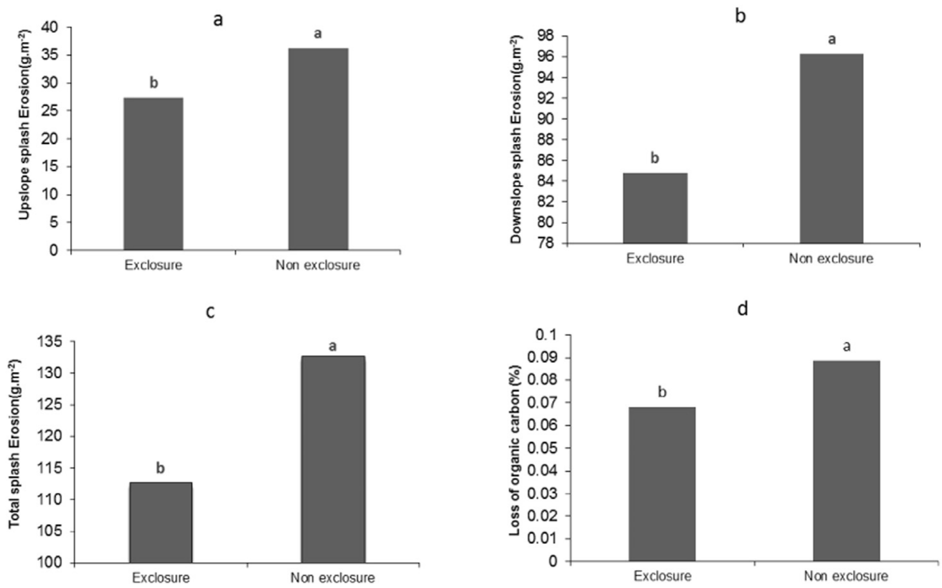

Fig. 3. The mean comparison between the exclosure and non-exclosure for upslope, downslope, total splash erosion rate and soil organic carbon loss rate using Duncan test at 1% level probability. The different letters (a, b and c) at the tops of the bars indicate significant differences.

of humus is often present at the soil surface; surface erosion caused by runoff, therefore, carries a significant amount of humus. The results of Beguera et al. (2015) indicate high concentrations of SOC in the splashed particles in comparison to the original soil. They stated that splash plays an important role in the movement of SOC and may have a significant impact on the carbon cycle and other soil erosion processes (runoff) through the removal of SOC. No study has, however, been conducted in the field of SOC loss due to exclosure-effected splash erosion. One of the reasons to reduce the carbon loss in exclosure versus non-exclosure conditions is the higher aggregate stability against raindrops present in exclosure conditions in comparison to non-exclosure conditions. Reduced soil organic matter can be counted among the physical and chemical effects of grazing on the soil properties. Soils under exclosure are conserved by vegetation, and over time, they increase the soil's organic matter and improve the soil structure and its aggregate stability; thus, soil erosion is reduced (Jeddi and Chaieb, 2010). In fact, owing to the removal of a significant part of vegetation cover in fields through the activity of livestock grazing, followed by the reduction of crop residues returned to the soil, the carbon input to the ecosystem was less than the carbon output. In addition, through the reduction of vegetation cover, the pasture plants' strong roots, which are considered to be places for the accumulation and formation of larger aggregates, are lost when the recurrent livestock returns to the area; this leads to soil compaction and soil structure degradation. Thus, the mean weight diameter of the aggregates is reduced, soil physical quality is reduced in the long term, and erodibility increases.

Since splash erosion is a selective process and leads to splash and particle transport in silt and fine sand, organic matter in soils exists as non-complex (particulate organic matter) and complex matter, with primary mineral materials splashed and transported along with the splashed particles (Christensen, 2001). In fact, the raindrop force breaks the coarser aggregates down into finer particles and leads to the loss of SOC (which was surrounded by the aggregates and had physical protection). In exclosure conditions, due to the higher organic matter followed by greater aggregate stability, the soil particle splash is lower, and thus SOC loss is lower, as a result of the lower splash.

3.3. The effect of slope percentage on USE, DSE, TSE and SOC loss

Slope percentage is one of the main factors behind particle detachment and transport. In Fig. 4a, b, and c, the effect of the slope percentage on the USE, DSE, TSE, and loss of SOC is determined. The results of a mean comparison with Duncan's test (Fig. 4) show that by increasing the slope percentage, a significant increase is observed in the DSE, TSE, and the loss of SOC at the 1% level. By increasing the slope, the USE rate is, however, significantly reduced. The average splash rates in the slope of 0–5% in the USE, DSE, and TSE are 39.45, 46.11, and 85.56 g m^{-2}, respectively. In slopes of 5–15%, the average slope rates of the USE, DSE, and TSE are 33.33, 91.11, and 125 g m^{-2}, respectively. The average splash rates in slopes of 15–30% are 22.78, 134.44, and 157.22 g m^{-2}, respectively. The USE and DSE to TSE rates in slopes of 0–5% are, respectively, 0.46 and 0.54; in slopes of 5–15%, they are, respectively, 0.27 and 0.73; and in slopes of 15–30%, they are, respectively, 0.15 and 0.85.

The results show that in all the three slopes, the amount of splash in the DSE is higher than the USE. On steep surfaces, more particles are thrown down by raindrop impact than thrown upwards; thus, the materials are transported to the DSE. As the degree of the slope increases, this ratio increases. Ghadiri and Payne (1986) stated that compared to splash on horizontal surfaces, for steep surfaces (1) the dropping angle of the drops to the downslope is lower than the upslope and (2) the coarser droplets are thrown down the slope. The splash is thus downwards, and this ratio is increased by the slope. The results of Torri and Poesen (1992) showed that when increasing the slope, the size of particles affecting splash at the upslope grow smaller, as if gravity is along the downslope and the separator forces' direction is along the upslope; thus, gravity increases the resisting forces and reduces the upslope separator forces. By increasing the slope, therefore, upslope separator forces are reduced. Conversely, coarser particles require more force to detach, and by reducing the upslope separator forces, the size of the splash particles is reduced. Legout et al. (2005), quoting van Dijk et al. (2002), stated that the geometric mean diameter of the splashed aggregates in the upslope is less than the splashed aggregates in the downslope; by increasing the slope angle, the aggregate geometric mean in the upslope is significantly reduced. By increasing the slope, therefore, the splash increases on the downslope and is reduced on the upslope. Sadeghi et al. (2017) analyzed the splash erosion along slopes of 5, 15, and 25 degrees in the Kojour rangeland watershed of northern Iran. They indicated that the average downward splash was greater than the upward splash. Saedi et al. (2016) achieved similar results by studying the slope effect on splash erosion in the Vanak catchment lands.

The loss of organic carbon (Fig. 4d) for slopes of 0–5% is 0.061; the amount of SOC lost is increased by 1.5 and 1.34 times by increasing the slope to 5–15 and 15–30%, respectively. When increasing the slope from 5 to 15% to 15–30%, no significant SOC loss is observed. By

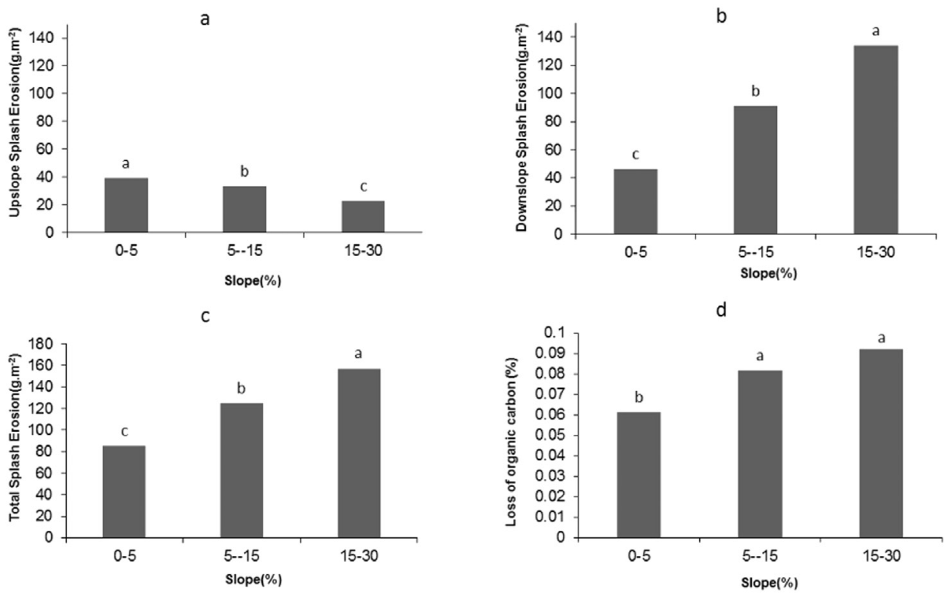

Fig. 4. The mean comparison between the slope degree on the upslope, downslope, total splash erosion rate and soil organic carbon loss rate using Duncan test at 1% level probability. The different letters (a, b and c) at the tops of the bars indicate significant differences.

increasing the slope and the gravitational force, the particles move downwards with greater weight in comparison to other particles. In addition, the number of particles that are thrown down due to splash is higher than the number of particles thrown upwards because of gravitational force; particles thus require much greater power to move upslope (Torri and Poesen, 1992). The steep slope detachments of all detachable particle sizes (sand and silt) towards the downslope are increased in comparison to those of the low slopes, but this increase is higher for coarser particles (Ghadiri and Payne, 1986). By increasing the slope, the number and the rate of splashed particles increase, and the organic material complexed with the particles is splashed downwards. Therefore, on steep surfaces, SOC loss increases through particle splash.

3.4. The effect of erosivity index (EI_{30}) on USE, DSE, TSE and SOC loss

According to the results of analysis of variance (Table 4), there is significant difference between the erosivity index at the 1% level for the USE, DSE, TSE, and SOC loss rates. According to Fig. 5a, b, and c, by increasing the erosivity index, splash erosion and its components significantly increase. By increasing the erosivity index from 1153.5 to 4307.6, the DSE, USE, and TSE rates are increased 1.27, 1.61, and 1.36 times, respectively. By increasing the erosivity index from 4307.6 to 7714, the DSE, USE, and TSE rates are increased 1.32, 1.11, and 1.26 times, respectively. In addition, by increasing the erosivity index from 1153.5 to 7714, the DSE, USE, and TSE rates are increased by 1.68, 1.80, and 1.70 times, respectively.

The results indicate that there is a significant difference between the three erosivity indexes, and by increasing the rainfall intensity, not only the TSE but also the DSE and USE rates are increased. In high rainfall intensities, splash increases due to the increased ability of raindrops to detach soil particles and the increased detachment of coarser particles. Fernández-Raga et al. (2010) showed that rainfall intensity is related to splash erosion and splash rate is increased by increasing the rainfall intensity by analyzing the splash erosion rate and its relationship with kinetic energy, as well as the intensity of rainfall, in the Sotelo forests in North Central Portugal. Ting et al. (2008), in China, and Khaledian and Shahuei (2010), in Kurdistan, achieved similar results. Through a

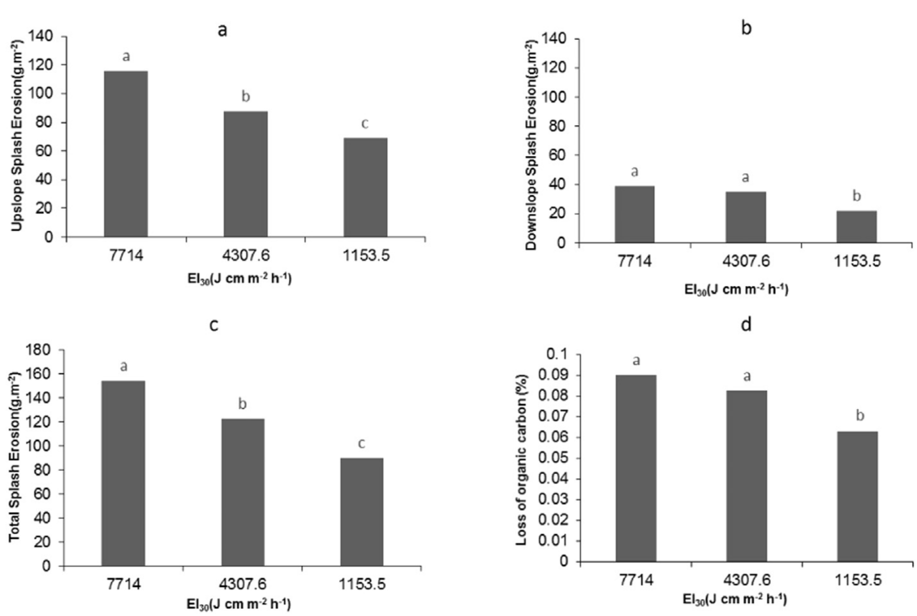

Fig. 5. The comparison between the effect of erosivity index (EI_{30}) on upslope, downslope, total splash erosion rate and soil organic carbon loss rate Duncan test at 1% level probability. The different letters (a, b and c) at the tops of the bars indicate significant differences.

laboratory study of the rainfall intensity and slope on splash erosion in the Vanak catchment watershed, Saedi et al. (2013) found that by increasing the rainfall intensity, the TSE, USE, and DSE are increased.

In addition, by increasing the EI_{30} index (Fig. 5d), the carbon in the splashed particles is increased significantly such that increasing the EI_{30} index from 1153.5 to 4307.6 leads to a SOC loss rate 1.3 times higher, and increasing the EI_{30} index from 1153.5 to 7714 leads to an SOC loss rate 1.4 times higher. No significant increase is, however, observed after increasing the EI_{30} index from 4307.6 to 7714. By increasing the EI_{30} index, the raindrops' energy upon hitting the soil surface increases, and thus the soil particles' splash and organic carbon loss increases for soil mineral particles. The results of Fernández-Raga et al. (2010) and Khaledian and Shahuei (2010) indicate that after increasing the rainfall intensity, splash erosion rate increases, and therefore, by increasing the soil loss, the loss of organic matter complex with mineral particles increases. By analyzing the effect of slope, rainfall intensity, surface flow, particle size distribution, and soil type on soil detachment, Farmer (1973) indicated that at low rainfall intensities, particles larger than 3100 μm are rarely detached, whereas at higher rainfall intensities, the detached particles are as large as 5000 μm.

4. Conclusion

The results demonstrate that while exclosure treatment is preferred in Iran due to its optimal vegetation cover, soil moisture maintenance, ecosystem dynamics, and high levels of input carbon to the soil, it is also favorable because suitable soil structure and vegetation immunity from grazing lead to less splash capability than non-exclosure areas characterized by Iran's gypsiferous soils. There is less SOC loss due to splash erosion within exclosure areas in comparison to non-exclosure areas. Splash erosion is a selective process that selects soil particles and detaches them based on the rainfall intensity and the slope of the land. By increasing the slope and the rainfall intensity, detachment of the coarser particles increases, and raindrops splash the particles with higher energy and higher transportation capacity. A change in slope and rainfall intensity changes the size of particles detached and the amount of particle detachment, and, as a result, changes the splash erosion rate. On the other hand, by increasing the rainfall intensity, the mechanical impact of raindrops is increased and thus leads to the destruction of aggregates; this, in turn, leads to a loss of carbon in soil aggregates. Increasing the slope degree also increases the splashed materials and the SOC that is transported by the splashed particles.

Exclosure treatment, therefore, has a significant impact in reducing soil and organic carbon loss in the fields by increasing the density of vegetation, litter, and plant residues, soil aggregate stability, and soil infiltration, which leads to higher storage of precipitation in the soil profile. It is an effective management measure in comparison to other methods of pasture and watershed management that prevent water and soil loss. Therefore, it seems necessary to consider exclosure treatment to be of the major programs for renewable natural resource projects (especially in watershed-management plans) conducted on the gypsiferous soils of Iran.

References

Beguera, S., Angulo-Martínez, M., Gaspar, L., Navas, A., 2015. Detachment of soil organic carbon by rainfall splash: experimental assessment on three agricultural soils of Spain. Geoderma 245–246, 21–30.
Boix-Fayos, C., de Vente, J., Albaladejo, J., Martínez-Mena, M., 2009. Soil carbon erosion and stock as affected by land use changes at the catchment scale in Mediterranean ecosystems. Agric. Ecosyst. Environ. 133, 75–85.
Busby, R.E., Gifford, G.E., 1981. Effects of livestock grazing on infilteration and erosion rates measured on chained and unchained pinygon-junipersites in Southeastern Utah. J. Range Manag. 34, 400–405.
Christensen, B.T., 2001. Physical fractionation of soil and structural and functional complexity in organic matter turnover. Eur. J. Soil Sci. 52, 345–353.
van Dijk, A.I.J.M., Meesters, A.G.C.A., Bruijnzeel, L.A., 2002. Exponential distribution theory and the interpretation of splash detachment and transport experiments. Soil Sci. Soc. Am. J. 66, 1466–1474.
Farmer, E.E., 1973. Relative detachability of soil particles by simulated rainfall. Soil Sci. Soil Sci. Soc. Am. Proc. 37, 629–633.
Fernández-Raga, M., Fraile, R., Keizer, J.J., Tiejiero, M.E.V., Castro, A., Palencia, C., Calvo, A.I., Koenders, J., Marques, R., 2010. The kinetic energy of rain measured with an optical disdrometer: an application to splash erosion. Atmos. Res. 96, 225–240.
Gee, G.W., Bauder, J.W., 1986. Particle size analysis. In: Klute, A. (Ed.), Method of Soil Analysis: Part 1. In: Agronomy Handbook No 9. SSSA, ASA, and Madison, WI, pp. 383–411.
Ghadiri, H., Payne, D., 1986. The formation and characteristics of splash following raindrop impact on soil. J. Soil Sci. 39, 563–572.
Gharemani, A., Ishikawa, Y., Gomi, T., Shiraki, Miyata, S.H., 2001. Effect of ground cover on splash and sheetwash erosion over a steep forested hillslope: a plot-scale study. Catena 85, 34–47.
Gregorich, E., Greer, K., Anderson, D., Liang, B., 1998. Carbon distribution and losses: erosion and deposition effects. Soil Tillage Res. 47, 291–302.
Hosseinalizadeh, M., Ahmadi, H., Feiznia, S., Rivaz, F., Naseri, S., 2017. Multivariate geostatistical analysis of fallout radionuclides activity measured by in-situ gamma-ray spectrometry: case study: loessial paired sub-catchments in northeast Iran. Quat. Int. 429, 108–118.
Iranian Forests, Range and Watershed management Organization, 2006. Representative Catchment Survey of Susa of Khuzestan Province. Ahvaz, Iran.
Jacinthe, P.A., Lal, R., Owens, L., Hothem, D., 2004. Transport of labile carbon in runoff as affected by land use and rainfall characteristics. Soil Tillage Res. 77, 111–123.
Jeddi, K., Chaieb, M., 2010. Changes in soil properties and vegation following livestock grazing exclusion in degraded arid environment of south Tunisia. Flora 205, 184–189.
Jin, K., Cornelis, W., Schiette, W., Lu, J., Buysse, T., Baert, H., Wu, H., Yao, Y., Cai, D., Jin, J., Neve, S., Hartmann, R., Gabriels, D., 2008. Redistribution and loss of soil organic carbon by overland flow under various soil management practices on the Chinese Loess Plateau. Soil Use Manag. 24, 181–191.
Kemper, W.D., Rosenau, R.C., 1986. Size distribution aggregates. In: Klute, A. (Ed.), Methods of Soil Analysis: Part 1. Second de. ASA Monogr. Amer. Soc. Agron. Madison. 9, pp. 425–442.
Khaledian, H., Shahuei, S.S., 2010. Splash erosion measurement and its relationship to rainfall intensity in Kordestan province. Iranian Water Research Journal. 4 (6), 19–24 (In Persian).
KhaliliMoghadam, B., Jabarifar, M., Bagheri, M., Shahbazi, E., 2015. Effects of land use change on soil splash erosion in the semi-arid region of Iran. Geoderma 241, 210–220.
Kuhn, N.J., 2007. Erodibility of soil and organicmatter: independence of organicmatter resistance to interrill erosion. Earth Surf. Process. Landf. 32, 794–802.
Lal, R., Griffin, M., Apt, J., Lave, L., Morgan, M., 2004. Managing soil carbon. Science 304, 393.
Lavado, R.S., Alconada, M., 1994. Soil properties behavior on grazed an ungrazed plots of a grassland sodic soil. Soil Technol. 7, 75–81.
Leelamanie, D.A.L., Karube, J., Samarawickrama, U.I., 2013. Stability analysis of aggregates in relation to the hydrophobicity of organic manure for Sri Lankan Red Yellow Podzolic soils. Soil Sci. Plant Nutr. 59, 683–691.
Legout, C., Leguedois, S., Le Bissonnais, Y., Malam, Issa.O., 2005. Splash distance and distributions size for various soils. Geoderma 124, 279–292.
Martínez-Mena, M., Rogel, J.A., Castillo, V., Albaladejo, J., 2002. Organic carbon and nitrogen losses influenced by vegetation removal in a semiarid Mediterranean soil. Biogeochemistry 61, 309–321.
Martínez-Mena, M., López, J., Almagro, M., Boix-Fayos, C., Albaladejo, J., 2008. Effect of water erosion and cultivation on the soil carbon stock in a semiarid area of South-East Spain. Soil Tillage Res. 99, 119–129.
Meyer, L., Wischmeier, W., 1969. Mathematical simulation of the process of soil erosion by water. Am. Soc. Agric. Eng. Trans. Asae. 12, 754–758.
Mwangi, H.M., Julich, S., Patil, S.D., McDonald, M.A., Karl-Heinz, F., 2016. Modelling the impact of agroforestry on hydrology of Mara River Basin in East Africa. Hydrol. Process. 30, 3139–3155.
Nelson, R.E., 1982. Carbonate and gypsum. In: Page, A.L. (Ed.), Methods of Soil Analysis: Part I: Agronomy Handbook No 9. American Society of Agronomy and Soil Science Society of America, Madison, WI, pp. 181–197.
Nelson, D.W., Sommer, L.E., Page, A.L., 1982. Total Organic carbon and organic matter. In: Methods of Soil Analysis. 2nd ed., ASA Monogr. Amer. Soc. Agron. Madison. 9(2), pp. 539–579.
Polyakov, V., Lal, R., 2004. Soil erosion and carbon dynamics under simulated rainfall. Soil Sci. 169, 590–599.
Post, W.M., Kwon, K.C., 2000. Soil carbon sequestration and land-use change: processes and potential. Glob. Chang. Biol. 6, 317–327.
Quansah, C., 1981. The effect of soil type, slope, rain intensity and their interactions on splash detachment and transport. J. Soil Sci. 32, 215–224.
Sadeghi, S.H.R., Kiani Harchegani, M., Asadi, H., 2017. Variability of particle size distributions of upward/downward splashed materials in different rainfall intensities and slopes. Geoderma 290, 100–106.
Saedi, T., Shorafa, M., Gorji, M., Khalili moghadam, B., 2013. Laboratory evaluation of the splash erosion on soil samples collected from different land use of the catchment area of Lordegan. Iranian Journal of Soil Research. 27 (4), 545–554.
Saedi, T., Shorafa, M., Gorji, M., Khalili Moghadam, B., 2016. Indirect and direct effects of soil properties on soil splash erosion rate in calcareous soils of the central Zagross, Iran: a laboratory study. Geoderma 271, 1–9.
Sinoga, J.D.R., Pariente, S., Daz, A.R., Murillo, J.F.M., 2012. Variability of relationships between soil organic carbon and some soil properties in Mediterranean rangelands under different climatic conditions (South of Spain). Catena 94, 17–25.
Su, Y.Z., Zhao, H.L., Zhang, T.H., Zhao, X.Y., 2004. Soil properties following cultivation

and non-greazing of semi-arid sandy grassland in northern china. Soil Tillage Res. 75, 27–36.

Tavakoli, M., Ghodoosi, J., 2001. The effect of protection management and revival in part of "Sade Raeesali Delavari" watershed, Boosher province. In: Proceeding of Rangelands and Deserts Congress of Iran, (In Persian).

Ting, M., Chenghu, Z., Tongxin, Z., Qiangguo, C., 2008. Modeling raindrop impact and splash erosion processes within a spatial cell: a stochastic approach. Earth Surf. Process. Landf. 33, 712–723.

Torri, D., Poesen, J., 1992. The effect of soil surface slope on raindrop detachment. Catena 19, 561–578.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses—a guide to conservation planning. In: USDA. Agri. Res. Serv. Handbook. 537.

Wood, M., Blackburn, E.H., 1981. Grazing systems: their influence on infiltration in the Rolling Plains of Texas. J. Range Manag. 34, 331–335.