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Temporal Variation of Surface Runoff and Inter-Rill Erosion in Different Soil Textures of a Semi-Arid Region, Iran

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Abstract**—**Inter-rill erosion is the detachment and transfer of soil particles between the rills which occurs due to the impact of raindrops and the shear stress of shallow surface runoff. This erosion can be affected by some soil properties such as texture, amount of organic matter and stability of soil aggregates. Information on the temporal variation of inter-rill erosion during a rainfall event and the effect of soil properties on it can help develop better methods to soil conservation in the hillslopes. The importance of this study is especially grate in semi-arid regions, where the soil is weakly aggregated and vegetation cover is mostly poor. Therefore, this research was conducted to investigate the temporal variation of surface flow and inter-rill erosion and the effect of soil properties on it in some semi-arid soils. A field experiment was done in eight different soil textures under simulated rainfalls with uniform intensity. A total of twenty four plots were installed for eight study soils with three replicates in the form of a random complete block design along the land. The plots were 1.2 m (length) × 1 m (width) in dimensions which designed with a distance of 3 m from each other across the slope. Then, soil samples were purred into the plots. Rainfall simulation experiments were done using a designed portable simulator with an intensity of 60 mm per hour for 60 minutes. Runoff production and soil loss were measured during 1 hour time with 5-min intervals. Soil properties including particle size distribution, aggregate stability, bulk density, exchangeable sodium percentages (ESP) and hydraulic conductivity (K_s) were determined in the soil samples. Correlation and regression analysis was done to determine the effect of soil properties on runoff and inter-rill erosion. Results indicated that the study soils have lower both organic matter content and aggregate stability. The soils, except for coarse textured textures, are calcareous and with relatively higher ESP. Runoff production and soil loss did not occur in sand texture, which was associated with higher infiltration and drainage rates. A strong relationship was found between inter-rill erosion and surface runoff ($R^2 = 0.75$, $p < 0.01$). The correlation analysis showed that surface runoff was significantly affected by some soil properties consisting of sand, silt, clay, bulk density, gravel, K_s, lime (calcium carbonate), and ESP. The soils with lower K_s such as fine-textured soils, produced higher surface runoff and more inter-rill erosion. In the soils, surface runoff production temporally increased during rainfall and finally reached a peak after about 25-35 min. Time to peak was very short (30 min) in fine-textured soils, especially clay, which was related to their lower infiltration rate.

Keywords**—**Erosion plot, rainfall simulator, soil properties, surface flow.

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I. Introduction

SOIL erosion by water is a serious environmental problem worldwide. This erosion leads to the degradation and pollution of the inside and outside the land. Outcomes of this erosion attract the attention of many soil and environmental scientists [1]. Inter-rill erosion is one of the types of surface erosion in hillside and consists of the detachment of soil particles by the kinetic energy of raindrops and the transfer of soil particles by surface flow and its delivery to the rills [2]. Due to the large contribution of inter-rill erosion in the transfer of fine particles, this process is mainly the cause of reduction in soil productivity and pollution of surface water [3]. In addition, inter-rill erosion increases sediment load by increasing the shear stress of the flow and induces the condition of rill formation in the soil [4]. This erosion is affected by some factors such as rainfall and runoff characteristics, soil properties, soil shear strength and soil antecedent moisture content [2], [5].

The conditions of the soil vary continuously during the rainfall event, and therefore, even in a rainfall under uniform intensity, the production of surface flow is not constant. Thus, runoff and soil loss can vary temporally during rainfall event. Soil texture plays an essential role in this field [6], [7]. The reviews of [8] showed that soil loss increased gradually in fifth consecutive event but there was no significant difference among last events. The soil erosion rate under the influence of the erosive factor differs over time. Inter-rill erosion, which is the amount of soil lost per unit of surface and unit of time, also varies during the rainfall falling. Surface runoff is the main factor influencing particle transportation in inter-rill erosion and consequently temporal variation of inter-rill erosion can depend on the variation of runoff production during rainfall.

Water erosion is the main factor of land degradation, especially in semi-arid agricultural regions where soil productivity is usually low and lower soil quality can severely reduce crop yield [9]. Most soils in these regions are calcareous with lower amount of organic matter. They are weakly aggregated and vegetation cover is poor during season especially in dry years [10]. In these areas, agricultural soils are more susceptible to water erosion processes. Information on the effects of soil properties on surface runoff and inter-rill erosion and temporal variation of surface runoff during a rainfall event is important in understanding the process of soil loss in hillslopes. Therefore, this research was carried out to investigate the dependency of surface runoff on soil properties and find the temporal variations of surface flow and inter-rill erosion in some semi-arid soils.

II. Materials and Methods

This study was conducted in a slope (about 10%) in the area of Zanjan University, located between 35°25′ to 37°15′ N and 49°52′ to 47°1′ E in north west of Iran. The area has semi-arid climate with a mean annual precipitation (for a statistical period of 33 years from 1984 to 2016) of 309 mm and average annual temperature of 10.3 °C [10]. The average rainfall in the statistical period of 33 years is about 309 mm and the average annual temperature is 23.3 °C. The average height of the area is about 1500 meters above sea level. Different soil textures were studied in a semi-arid region in Zanjan province. Geographical coordination of the study soils was determined using a Global Positing System (GPS). The studied soil samples were: sand (48°33′57″ E, 36°46′57″N), loam sand (48°23′51″E, 36°41′22″N), sandy loam (48°24′18″E, 36°41′2″N), loam (48°32′36″E, 36°47′42″N), silt loam (48°33′22″E, 36°47′8″N), sandy clay loam (48°31′53″E, 36°47′17″N), clay loam (48°24′16″E, 36°40′41″N) and clay (48°3′43″E, 36°59′11″N). About 300 kg of each soil from 0-30 cm depth was collected and transferred to a slope land in the University of Zanjan.

In order to prepare a uniform surface in the study land, firstly the soil surface of the study land was smoothed using a leveling machine and accordingly crop residues were removed from the land. Then, 24 plots with dimensions of 1.2 × 1 m were installed with a distance of 3 m from each other across the land (Fig. 1). The plots were surrounded with a galvanized sheet with a height of 30 cm and a length of 4.4 meters. Two holes with a diameter of 5 cm and 30 cm depth were created at the end of each blocked plot, to place the runoff and sediment transfer pipe and collector. Then, each soil sample (300 kg) was poured into the plots. Two rills with 5 cm width and 1 m length and 60 cm interval each other were created in each plot. In order to delete the impact of shear stress on soil loss from the rills (rill erosion), soil surface of the rills were sealed using cement (Fig. 2). The soils from the plots were wetted in several stages, so that a natural compaction of the soils occurred to make soil bulk density similar to their natural bulk density in the area.

In order to set up of rainfalls, a rain simulator was designed in according to the rainfall properties in the study area. The characteristics of rain were extracted from the analysis of data on the intensity and duration of rain in the region during a period of 20 years. The rain simulator height was 2.25 m., the water falling plate was 1.4 m × 1.4 m which contained three nozzles and could produce water drops with an average diameter of 2.56 mm. Simulated rainfall with intensity of 60 mm per hour for 60 minutes was used to investigate runoff production and inter-rill erosion. A plastic cover was used around the simulated frame to prevent the impact of the wind on falling water drops. Five simulated rainfalls with a constant intensity of 60 mm h^{-1} for 60 minutes with a time interval of five days were set up at 24 plots. Runoff was measured at the outlet of the plots for 5 min. intervals from the beginning of the rainfall event. Inter-rill erosion was determined based on the soil loss per area unit and per rainfall duration unit.

Fig. 1 A view of the plots created on the examined land

Some soil properties were determined in eight study soils in the laboratory [11]. The particle size distribution was determined using the Bouyoucos hydrometer method [12]. To determine the percentage of gravel, the soil samples were weighed and then sieved using 2and 8 mm sieves. The amount of gravel that remained between the two sieves was weighed and accordingly gravel weight percentage in the soil was computed. To determine bulk density (BD), soil samples were taken from by a cylinder of 200 cm^3 volume with 6 cm diameter and 7.1 cm height. The stability of aggregates into water was determined based on the weight percentage of water-stable aggregates using wet-sieving method in the aggregate samples with 4-6 mm in diameter. A set of sieves (4.75, 2, 1, 0.5, 0.25, 15. 0 and 0.05 mm) was used for one minute time and the weight average diameter of water-stable aggregates (mm) was determined [13]. Saturated hydraulic conductivity (K_s) was determined in the soil samples by a style core with 12 cm. A constant head method was used to determine water drainage rate from the soil column and K_s was computed using volume of drained soil per unit of column cross section and time [14]. A pH meter was used to measure the reaction of the soils [15]. ESP was calculated using the proportion of exchangeable sodium to the CEC multiplied by 100 [16]. Total organic carbon amount was determined using the Walkley–Black wet dichromate oxidation method [17] and converted to organic matter through multiplying it by 1.72. In order to determine lime, the equivalent calcium carbonate was measured using acid acetic volume consumed to neutralize carbonate [18].

Fig. 2 Runoff and sediment collecting equipment at the out let of the plot

III. Results and Discussions

The results showed that the soils have lower organic matter (between 0.22 and 1.24%) and aggregate stability (0.69 mm). The highest amount of organic matter (1.24%) and aggregate stability (1.86 mm) was in loam. The amount of saturated hydraulic conductivity in the soils varied from 0.21 cm/h (in clay) to 8.1 cm/h (in sand). Amount of lime (calcium carbonate equivalent) in the soils varied from 0.5% in sand to 15.2% in clay. The electrical conductivity of soil varied from 12.6 dS/m in clay to 1.24 dS/m in sand. Clay and loam have higher electrical conductivity (EC > 4 dS/m) and so were classified as saline soils. The highest amount of ESP (11.6) was in clay and the lowest value (5.6) was in sand (Table I).

Runoff production was significantly differed among the soil textures. Sand did not produce runoff and clay produced the highest surface runoff (Fig. 3). The correlation analysis showed that surface runoff is significantly affected by some soil properties, particularly sand, silt, clay, bulk density, gravel, hydraulic conductivity, calcium carbonate, and ESP. The soils with lower hydraulic conductivity (K_s) such as fine-textured soils produced higher surface runoff and inter-rill erosion (Table II). A strong relationship was found between inter-rill erosion and surface runoff ($R^2 = 0.75$, $p < 0.01$). This result confirmed that runoff is an important factor causing inter-rill erosion in the soils (Fig. 4).

Fig. 5 shows the temporal variation of surface flow during rainfall in the study soils (clay, clay loam, sandy clay loam, sandy loam, sandy loam, silt loam, loam and sand). Surface runoff at the first time after rainfall simulation sharply increased in all soils and reached to a pick after 25-35 min. This status for runoff production showed at the pick time, the soil condition for rain water infiltration rate is relatively constant. This soil condition is related to decreases in soil tension and aggregate breakdown. Surface runoff rate and time to pick were very short (30 min) in fine textured soils especially in clay.

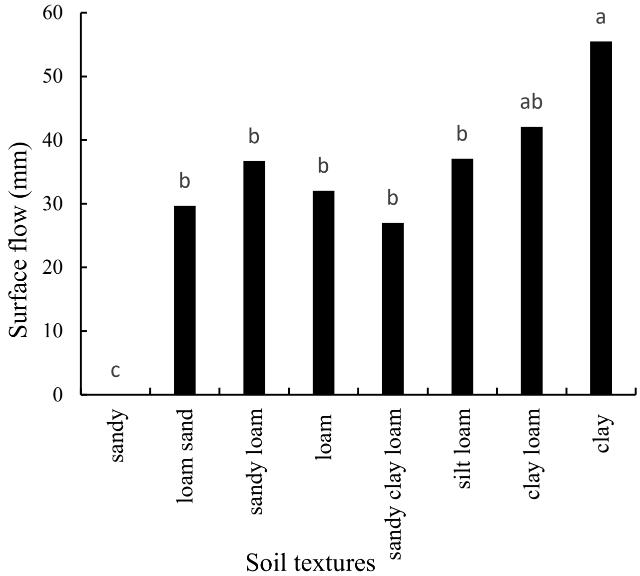

Fig. 3 Average of surface flow in soil textures

Increasing runoff in the first time after runoff generation was associated with the change of soil condition by the raindrop impact [21]. Raindrops disrupt soil surface and cause sealing on the soil which induced runoff generation in the soils. The loss of soil infiltration rate during runoff was the main factor influencing surface runoff flow at the plots. Effect of raindrop impact on the loss of infiltration rate is dependent on soil properties and rainfall intensity [5].

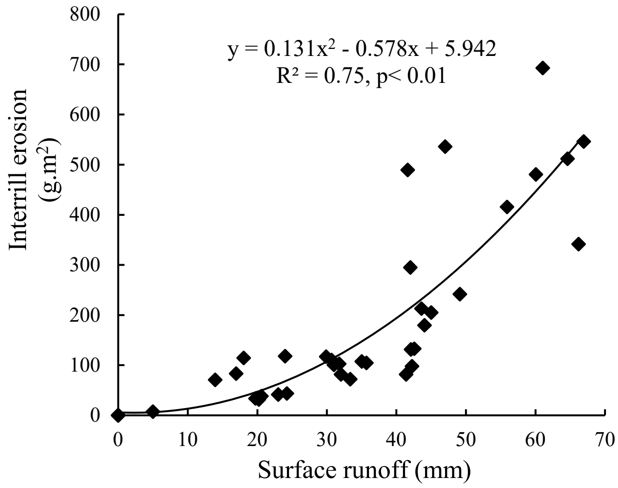

Fig. 4 Inter-rill erosion versus surface runoff

The study of temporal variation of surface flow and inter-rill erosion in the soils showed that amount of surface runoff and inter-rill erosion reached to a constant level after a pick level. This result indicates that steady state flow and soil erosion occurred at the plots during this time [19]. The process of surface flow variation during rainfall in clay was more severe than other soils. This was due to its lower aggregate stability and higher detachability, so that the soil structure was steadily destroyed in the early of rainfall [20].

TABLE I
THE PHYSICOCHEMICAL PROPERTIES OF THE SOILS.

Soil properties	Soil textures							
	Sand	Loam sand	Sandy loam	Loam	Silt loam	Sandy clay loam	Clay loam	Clay
Sand (%)	92.1	78.7	69	43.7	23.6	46.5	44.5	4.0
Silt (%)	5.4	13.2	12.5	32.5	50.6	27.3	22.5	39.2
Clay (%)	2.6	8.1	18.5	23.8	25.8	26.2	33.0	56.7
BD (g/cm^3)	1.7	1.4	1.4	1.4	1.3	1.5	1.2	1.3
MWD (mm)	0.0	0.5	0.6	1.9	0.7	0.6	0.7	0.5
K_S (cm/h)	8.1	3.8	0.9	1.7	0.6	0.7	0.3	0.2
Gravel (%)	24.0	14.3	19. 1	10.4	10.2	16.1	15.2	4.3
pH	7. 6	7.4	7.4	7.5	7.5	7.5	7.4	7.5
ESP	5.5	6.3	7.6	7.8	9.7	8.2	10.7	11.6
OM (%)	0.2	0.7	0.9	1.2	0.7	0.8	0.7	0.5
$CaCO_3$ (%)	5. 1	9.7	10.5	10.5	11.5	11.4	11.9	15.3

TABLE II
THE CORRELATION COEFFICIENT BETWEEN SURFACE RUNOFF AND SOIL PROPERTIES

	Sand	Silt	Clay	Gravel	BD	K_s	$CaCO_3$	ESP	Runoff
Sand	1								
Silt	-0.9**	1							
Clay	-0.9**	0.6**	1						
Gravel	0.8**	-0.6**	-0. 8**	1					
BD	0.5**	-0.5*	-0.5*	0.6**	1				
MWD	0.4	0.5*	0.3	-0.6**	-0.3				
K_s	0.8**	-0.7**	-0.7**	0.7*	0.6**	1			
OM	-0.4	0.5*	0.2	-0.5*	-0.2	-0.3			
$CaCO_3$	-0.8**	0.6**	0.8**	-0.7**	-0.63**	-0.8**	1		
ESP	-0.8**	-0.6**	0.8**	-0.7**	-0.6**	7-0.	0.7**	1	
Runoff	-0.7**	0.6**	0.7**	-0.8**	-0.6**	-0.7**	0.8**	0.7**	1

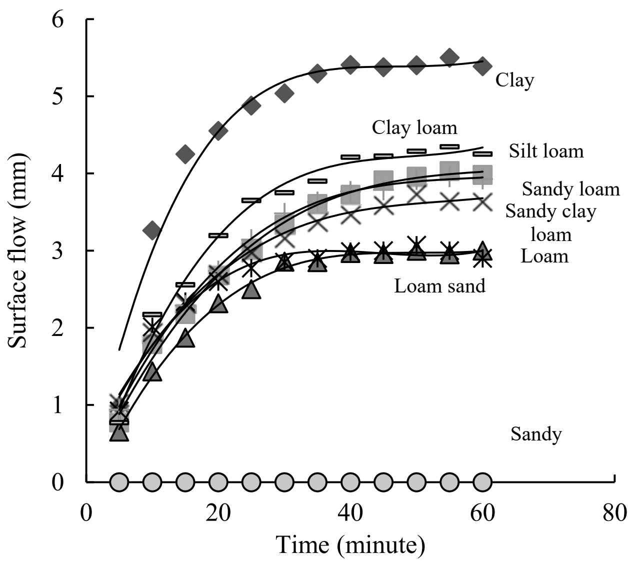

Fig. 5 Temporal variation of surface flow in the soil textures

The result on the runoff production in clay was in agreement to the study of inter-rill erosion in four different soil textures in China which showed that the sediment load is significantly influenced by soil properties and the erosion rate has a direct relationship with clay content and it was the highest in clay loam soil texture [21]. In loam, due to relatively higher organic matter as well as soil aggregate stability, the rate of surface flow gradually varied between the rills. In loamy sand lower surface runoff and inter-rill erosion occurred which was associated to higher hydraulic conductivity (K_s) [19], [22].

IV. CONCLUSION

Inter-rill erosion is one of the types of surface erosion in hillside which its rate and temporal variation can be affected by the soil types. This study was conducted in eight soil textures with three replicates in the form of a random complete block design. Soil samples taken from 0-30 cm were poured into the plots with 1 m width and 1.2 m length in dimensions installed in a uniform hillslope with 10% slope gradient. Except to sand texture, inter-rill erosion was occurred in all study soils. Inter-rill erosion was significantly associated with surface runoff. The soils with lower permeability, such as fine-textured soils, produced higher surface runoff as well as more inter-rill erosion rate. The inter-rill erosion rate was consistent with the rate of surface runoff production. Surface runoff production temporally increased during rainfall and finally reached a peak after about 25-35 min. Time to peak was very short (30 min) in fine-textured soils, which was related to their lower infiltration rate. Therefore, this study revealed that the fine-textured soils are the most susceptible soils to inter-rill erosion processes in the semi-arid regions.

REFERENCES

[1] Wang, L., Zhang, G. and Wang, X., 2022. Undecomposed litter mixed in the soil can increase inter-rill erosion on hillslopes: A laboratory study. *Soil and Tillage Research*, *219*, p.105350.

[2] Wang, L., 2023. *Advances in Soil Erosion Research.* Scientific Research Publishing, Inc. USA.

[3] Koiter, A.J., Owens, P.N., Petticrew, E.L. and Lobb, D.A., 2017. The role of soil surface properties on the particle size and carbon selectivity of inter-rill erosion in agricultural landscapes. *Catena*, *153*, pp.194-206.

[4] Cao, L., Zhang, K., Dai, H. and Liang, Y., 2015. Modeling inter-rill erosion on unpaved roads in the loess plateau of China. *Land Degradation & Development*, *26*(8), pp.825-832.

[5] Shen, H., Zheng, F., Wen, L., Han, Y. and Hu, W., 2016. Impacts of rainfall intensity and slope gradient on rill erosion processes at loessial hillslope. *Soil and Tillage Research*, *155*, pp.429-436.

[6] Huang, J., Wu, P., and Xining. Z. 2013. Effects of rainfall intensity, underlying surface and slope gradient on soil infiltration under simulated rainfall experiments, *Catena*, 104: 93 -102.

[7] Vilayvong, K., Yasufuku, N. and Ishikura, R., 2016. Rainfall-induced soil erosion and sediment sizes of a residual soil under 1D and 2D rainfall experiments. *Procedia-Social and Behavioral Sciences*, 218: 171-180.

[8] Cattan D., Lan Z.H. and David, A.B. 2012. Effect of soil physical on runoff and sediment concentration under rain, Soil Science Society of America Journal, 20(10): 531-539.

[9] Ochoa, P.A., Fries, A., Mejía, D., Burneo, J.I., Ruíz-Sinoga, J.D., Cerdà, A., 2016. Effects of climate, land cover and topography on soil erosion risk in a semiarid basin of the Andes. Catena 140:31–42.

[10] Vaezi, A. R., H. Bahrami, H. Sadeghi and M. Mahdian. 2008. Modeling the USLE K-factor for calcareous soils in northwestern Iran. Geomorphology 97(3): 414-423.

[11] Rowell, D. l. 1994. Soil Science: Methods and Application. Longman Group. Harlow, 345 PP.

[12] Bouyoucos, G. J. 1962. Hydromrter method improved for making particle size analysis of soils. Agronomy Journal, 56: 464- 466.

[13] Kemper, W.D. and Rosenau, R.C. 1986. Aggregate stability and size distribution. 425-442 pp, In: Klute, A. (ed.), Methods of Soil Analysis. ASA and SSSA, Madison, WI.

[14] Klute, A. 1986. Methods of Soil Analysis, part I, physical and mineralogical methods. SSSA publisher, Madison, Wisconsin.

[15] Thomas, G. W. 1996. Soil pH and soil acidity, 475-490 PP. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 3, Chemical Methods. SSSA/ASA, Madison, Wisconsin, USA.

[16] Rhoades, J. D. 1996. Salinity: Electrical conductivity and total dissolved solids, 417-436 PP. Methods of Soil Analysis. Chemical Methods. ASA/SSSA. Madison, Wisconsin, USA.

[17] Romos, M. C. and Nacci, S. 1998. Surface aggregate stability and its relationship with the soil erodibility in the Anoia-Pened (Spain). Proceedings 16th World Congress of Soil Science. Symposium 20, Ref. 1766, ISSS-AISS-IBG-SICS 1998, pp. 8, Publicacion en CD-ROM Cirad.

[18] Pansu, M. and Gautheyrou, J. 2006. Handbook of Soil Analysis, Mineralogical, Organic and Inorganic Methods. Springer, 993 p.

[19] Jin, K., Cornelis, W.M., Gabriels, D., Schiettecatte, W., De Neve, S., Lu, J., Buysse, T., Wu, H., Cai, D., Jin, J., and Hartmann, R. 2008. Soil management effects on runoff and soil loss from field rainfall simulation. Catena. 75: 191-199.

[20] Tangchuan, L., S. Mingan, J. Yuhua, J. Xiaoxu and H. Laiming. 2018. Profile distribution of soil moisture in the gully on the northern loess plateau, China. *Catena*, 171:460-468.

[21] Sun, L., Zhou, J.L., Cai, Q., Liu, S. and Xiao, J., 2021. Comparing surface erosion processes in four soils from the Loess Plateau under extreme rainfall events. *International Soil and Water Conservation Research*, *9*(4), pp.520-531.

[22] Dunne, T. and Aubry, B. F. (1986) Evaluation of Horton's theory of sheetwash and rill erosion on the basis of field experiments. In A. D. Abrahams, ed., Hillslope Processes. Boston: Allen and Unwin, 31-53.