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Plot Treatments and Sediment Yield Relation

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Abstract: Soil erosion plots are widely used to investigate both the process and the factors affecting the amount of soil erosion. The main objective of this research was to study the relation between rainfall parameters and different plot treatments. For this purpose, rainfall events were monitored and the amount of surface runoff and soil loss associated with storm events were recorded over the hill slopes in Zanjan province, Iran. Two plowing treatments of along and across the contour lines were compared on three slope classes of 0-12% (class *i*), 12-20% (class *ii*) and 20-40% (class *iii*) in a triple replication and randomized complete block design in a regional wheat cropping and fallow, during the first and second year, respectively. Sixty one different rainfall erosivity indexes based on rainfall amount and intensity were computed. The correlation between soil losses, as a dependent variable and rainfall erosivity indexes, as independent variable, were computed and analyzed. Results demonstrated that the mean diameter size of rainfall drops multiplied by the rainfall intensity (*dI*) had the most significant correlation with average soil loss of all plots. Also results showed that no any plot treatment has significant impact on the relation between soil loss and rainfall erosivity indexes.

Key words: Correlation · Erosivity index · Moisture · Rainfall and soil loss

INTRODUCTION

The first step in the erosion process begins with raindrop impacts on soil surface. Falling raindrops break the holding bonds of soil particles and throws them a short distance. These detached particles are then carried away much more easily by water flowing over the soil surface. Rainfall kinetic energy has widely been used as the raindrop index controlling soil splash detachment [1-6], although other suggested indexes have included raindrop momentum [7, 8] and the kinetic energy and drop circumference [9].

Salles and Poesen [10] reported that the momentum multiplied by drop diameter was the best raindrop index for soil splash detachment. However, no study has estimated the soil splash detachment by several raindrop indexes in the field measurements.

The subject of rainfall erosivity has been studied worldwide and various properties of raindrops such as intensity, velocity, size and kinetic energy are among the most frequently used parameters to develop erosivity indexes. Some indexes, such as A_rI_m (rainfall amount × maximum intensity), EI_{30} (rainfall energy × maximum 30 minute intensity) and $KE > 1$ (total kinetic energy of all rains with more than 25 mmh^{-1} intensity) are the most important rainfall erosivity indexes. These indexes were introduced by Lal [11], Wischmeier and Smith [12] and Hudson [13], respectively where they are suggested for some geographical locations with specific climatic and local conditions.

A regression model of erosivity (EI_{30}) with daily rainfall amount was constructed after log transformation of the data point from a 7-year rainfall recorded in Cape Verde island, Central East Atlantic [14]. A multiple linear regression (r=0.89) involving monthly EI_{30}, monthly rainfall for days with rain$\geq$10 mm and monthly number of days with rain$\geq$10 mm, for the Algrave region, Portugal has been suggested by Loureiro and Coutinho [15]. In fact, the empirical EI_{30} index, which is frequently used, has a number of limitations and requires some adaptations

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for different climatic regions [16], however, use of annual precipitation cancel off the bimodal variability of rainfall. Hoyos [17] developed two regression models between the annual EI_{30} and the rain amount, one for the wet and the other for dry seasons in a tropical watershed of the Colombian Andes.

Boix-Fayos *et al*. [18] showed that scale issues, disturbance and the representation of natural conditions (continuity, connectivity and heterogeneity of natural systems) and the complexity of the ecosystem interactions (connectivity, patterns and processes operating across scales) are key-questions when trying to collect representative field data using erosion plots. This index has been computed by erosion plot data and widely tested, adopted and used in some countries and regions where rainfall is mainly characterized as moderate to high intensity [19]. Khorsandi *et al*. [20] using two erosion plot stations data, aiming at determining the appropriate rainfall erosivity index for Northern Iran, found that EI_{30} and sediment had the most significant correlation.

Despite of several approaches used to estimate rainfall erosivity from some indexes on the basis of rainfall intensity, there are no comprehensive research on the form of soil erosion treatments and their impacts on rainfall erosivity studies. The main objectives of this study were to determine an appropriate rainfall erosivity index for the study area and to study the effectiveness of the most important rainfall parameters in soil erosion and the effect of different plot treatments on rainfall erosivity indexes.

MATERIALS AND METHODS

Study Site Description: The research plan was implemented on steep lands of Sohrain Gharacharian floodwater spreading research station located in northwest, 30 km from Zanjan city, Iran. Covering an area of 15,000 ha the station lies on quaternary sediments beside the Gharacharian River with maximum and minimum elevations of 1900 m and 1500 m above sea level. Most of lands in this area are under wheat rain fed farming. Annual precipitation is between 350 and 400 mm in lower and upper lands respectively with Mediterranean to cold semiarid climates. Two treatments of plowing across and along the contour line on three slope classes of 0-12, 12-20 and 20-40% with three replications and randomized complete block design were studied under regional wheat planting for first year and fallow conditions in second year for 18 erosion plots of 1.8 wide by 22.1 m long. Plowing treatments in the plots were carried out manually by shovel with plow depth of 25-30 cm and furrow space of 35-40 cm similar to those of the actual field done by conventional tractor-drawn moldboard plow. For enrichment, ammonium phosphate of 50 kg ha^{-1} was added at the time of preparation in the first year and conventional amount of 100 kg ha^{-1} wheat seeds was used for planting. Soil samples for grain size analysis (sand, silt and clay percentage), organic carbon and saturation percentage were collected from 0-5, 5-20 and 20-40 cm depths of a soil profile over each slope classes on the first year.

Data Acquisition: A total of 21 rainfall events which produced surface runoff were monitored by a recording rain gauge in the station. After each rainfall event, the volume of surface runoff and the amount of sediment were measured in the tanks located at the lower end of each plot. Two 220 L volume collection tanks were connected to each other by means of a pipe to ensure enough capacity to collect all produced runoff in each rainfall. Using a pipe, these tanks were connected to the plots to receive surface runoff and sediment. A 10 L volume bucket was installed under the carrying pipe, within the main collection tank, to trap coarse materials.

Rainfall Erosivity Indexes: From the literature, 61 rainfall indexes based on intensity and amount of rainfall were collected for computing and investigating the issue. Table 1, shows these indexes which are classified in six different groups. The calculation methods of total kinetic energies are presented in Eqs. (1) to (14).

RESULTS AND DISCUSSION

All 61 rainfall erosivity indexes were computed for 21 rainfall events, using Eqs. (1) to (14) and Table 1 resulted in a 21 rows by 61 columns matrix. The amount of sediment yield resulted from all 21 recorded rainfall events are indicated in Table 2. Plot number of 1 to 6, 7 to 12 and 12 to 18 are located on 0-12 (class *i*), 12-20 (class *ii*) and 20-40 percent slope (class *iii*) respectively. Using Table 2 and computed rainfall erosivity indexes matrix, the correlation coefficients between soil loss and erosivity indexes were calculated and analyzed. The output of this calculation was also a 22 rows by 61 columns matrix.

Table 1: Computed rainfall erosivity indexes

Group	Index	Description
Rainfall kinetic energy	KE_1, KE_2, KE_3, KE_4, KE_5, KE_6, KE_7, KE_8, KE_9 KE_{10}, KE_{11}, KE_{12}, KE_{13}, KE_{14}, $KE > 1$, $KE > 2.5$, $KE > 5$, $KE > 10$, $KE > 25$,	KE_2 is rainfall total kinetic energy ($J/m^2.mm$) calculated by different equations
Rainfall intensity	I_{max5}, I_{max10}, I_{max15}, I_{max30}, I_{max60}, I_{max120}, $I^{1.5}$ I^2	I is rainfall intensity (mmh^{-1})
Rainfall amount and intensity	R_{10}, R_{20}, R_{30}, PI_m, PI_{30}, PI^2_{30}, $PI^{0.5}_{30}$, PI_{60}, PI^2_{60}, $PI^{0.5}_{60}$, $P^{0.5}$, I_{30}, $P^{0.5}$ I^2_{30}, $P^{0.5}$ I_{60}, $P^{0.5}$ I^2_{60}	R is the ΣPI, I is one of I_{10}, I_{20} or I_{30} and P is the amount of rainfall (mm)
Rainfall energy and intensity	EI_5, EI_{10}, EI_{15}, EI_{30}, EI_{60}, $EI_{120,}$	E is total kinetic energy calculated by Wischmeier and Smith equation ($J/m^2.mm$)
Rainfall amount and duration	p, P_{max10}, P_{max20}, P_{max30}, $P\sqrt{t}$, $P^{0.5}$ t^2, P^2 $t^{0.5}$, Pt	P is the amount of rainfall (mm) and t is the duration of rainfall (h)
Rainfall drop size	KE/d, KE/d^2, , $KE/\sqrt{d}$, KEd, Ked^2, $KE\sqrt{d}$	d is the mean diameter size of drops (mm) $D_{50} = 1.238 \times I^{0.182}$ of Laws and Parson [21]
$KE_I = 8.95 + 8.44 log\ I$	Marshal and Palmer [21]	(1)
$KE_2 = 29.8 - 127.5/I$	Hudson [22]	(2)
$KE_3 = 11.87 + 8.73 log\ I$	Wishmeier and Smith [12]	(3)
$KE_4 = 9.81 + 11.25 log\ I$	Zanchi and Torri [21]	(4)
$KE_5 = 29.22 - 26.12 exp(-0.034I)$	Kinnell [21]	(5)
$KE_6 = 9.81 + 106 log\ I$	Onaga *et al.,* [21]	(6)
$KE_7 = 8.95 + 8.73 log\ I$	Brandt [21]	(7)
$KE_8 = 35.9 - 20.07 exp(-0.0341)$	Cutinho and Tomas [21]	(8)
$KE_9 = 38.4 - 20.66 exp(-0.0291)$	Cerro *et al.* [21]	(9)
$KE_{10} = 36.8 - 25.43 exp(-0.0381)$	Jayawardena and Rezaur [23]	(10)
$KE_{11} = 10.2 + 8.9 log\ I$	Alizadeh [24]	(11)
$KE_{12} = 36.65 - 21.99 / I$	Nyssen *et al.* [25]	(12)
$KE_{13} = \sum_{r=1}^{k} 0.29 - 0.21 exp(-0.05I)$	Brown and Foster [26]	(13)
$KE_{14} = 28.3(1 - 0.52^{-0.0421})$	Van Dijk *et al.* [27]	(14)

Table 2: The amount of sediment yield[1] resulted from 21 rainfall events

	Rainfall Event																					
Plot No.[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
Plot 1	0.0	0.0	0.0	1.5	563.2	2287.5	1592.8	695.4	371.9	4644.0	0.0	0.6	3.5	23.7	0.0	0.0	0.0	0.0	378.2	56.8	27.5	10646.6
Plot 2	14.3	0.0	0.0	0.0	16.2	199.9	1122.4	287.3	94.7	1981.8	0.0	0.4	3.7	0.0	0.0	0.0	0.0	0.0	3.5	5.5	2.7	3732.4
Plot 3	0.0	0.0	0.0	14.5	634.7	8617.8	1673.7	1098.7	1000.8	5511.4	0.0	0.0	2.3	2.9	1.1	0.0	0.0	0.0	324.1	26.8	15.4	18924.2
Plot 4	0.0	0.0	0.0	0.5	2.9	37.3	111.3	53.2	16.8	41.1	3.5	.04	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	269.24
Plot 5	12.0	0.8	0.0	179.3	525.0	10943.3	1881.4	865.3	755.0	4501.2	0.4	1.3	1.0	12.9	0.0	0.0	0.0	0.0	2016.0	84.8	54.5	21834.2
Plot 6	9.1	0.5	0.0	0.0	0.0	0.0	229.0	96.2	3.3	5.1	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	343.7
Average S_1[3]	5.9	0.2	0.0	32.6	290.3	3681.0	1101.8	516.0	373.8	2780.8	0.7	0.4	2.3	6.6	0.2	0.0	0.0	0.0	453.6	29.0	16.7	
Plot 7	13.9	0.4	0.0	96.9	837.3	3450.9	6155.2	1805.4	599.3	7260.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	967.8	44.1	14.3	21246
Plot 8	9.5	0.0	0.0	0.0	0.0	0.0	0.4	71.2	2.5	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.9	0.0	89.9
Plot 9	14.9	0.4	0.0	0.0	339.1	2386.2	1062.0	795.2	1425.9	3526.1	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	2922.0	65.1	23.7	12562.3
Plot 10	13.1	0.2	0.0	0.0	0.0	109.3	159.5	150.0	266.8	47.8	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	747.5
Plot 11	13.9	1.7	0.0	0.0	399.9	5172.2	351.1	1022.1	1261.2	4317.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	162.4	27.8	14.5	12745.8
Plot 12	5.3	0.0	0.0	0.0	17.1	18.1	112.6	146.2	50.9	26.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	377.1
Average S_2	11.8	0.4	0.0	16.2	265.6	1856.1	1306.8	665.0	601.1	2530.2	0.3	0.1	0.3	0.0	0.0	0.0	0.0	0.0	675.5	23.3	8.7	
Plot 13	1.8	0.6	0.0	77.6	1743.3	3225.3	157.0	2092.0	3194.3	8150.3	1.7	2.4	0.0	6.5	0.0	49.2	97.4	10.4	3009.0	760.3	28.9	22608
Plot 14	5.3	0.5	10.8	1.9	104.0	828.5	70.5	119.1	737.4	438.7	0.6	0.8	0.0	1.0	0.0	0.2	2.7	0.0	2.9	14.1	1.9	2340.9
Plot 15	17.2	0.5	0.9	0.7	247.3	13221.5	42.1	211.7	317.3	2277.2	0.0	0.6	0.0	0.1	0.0	40.6	133.6	11.7	1292.1	1844.0	88.4	19747.5
Plot 16	12.8	1.8	0.1	0.0	196.1	21.9	131.9	4.0	6.5	18.9	0.1	0.5	0.0	169.5	0.0	0.2	179.0	0.0	11.9	18.0	0.0	773.2
Plot 17	4.2	0.5	0.0	8.5	102.0	4552.2	46.6	714.6	245.7	549.2	0.0	0.0	0.0	0.0	6.9	397.2	363.4	105.7	7248.0	1535.0	318.3	16198
Plot 18	5.6	1.0	0.0	2.1	151.4	2.9	19.4	3.1	1.5	1.2	0.0	0.0	0.0	0.0	0.0	1.0	34.2	0.0	0.0	0.7	0.0	224.1
Average S_3	9.8	0.9	2.0	17.8	468.3	3951.4	295.7	634.9	850.6	2327.6	0.4	0.7	.05	29.5	1.1	81.4	135.1	21.3	2039.9	699.2	74.4	
Average plots	8.5	0.5	0.6	21.3	326.6	3059.7	828.8	568.4	575.1	2405.7	0.4	0.4	0.8	12.0	0.4	27.1	45.0	7.1	1018.8	249.2	32.8	

[1] Sediment yield (gr)

[2] Plot odd numbers have up and down the slope plowing treatment and plot even numbers have contour plowing treatment.

[3] Average S_1, S_2 and S_3 is the amount of average sediment yield from plots located on 0-12, 12-20 and 20-40% slope, respectively.

Results demonstrated that *dI* rainfall erosivity index had the most significant correlation of 0.590 ($P < 0.01$) with average sediment yield of all plots in the study area, where *d* is the mean diameter size of drops (mm) introduced by Laws and Parson [21] in Eq. (15) and *I* is the rainfall intensity (mm/hr) as follows:

$$d = 1.238 \times I^{0.182} \quad (15)$$

This index also had a significant correlation coefficients of 0.479 ($P<0.05$), 0.483 ($P<0.05$), 0.702 ($P<0.01$) with average sediment yield of plots in class *i*, class *ii* and class *iii* respectively.

The amount of sediment yield, resulting from 21 rainfalls, was calculated in all plots over three slope classes and is presented in Table 2.

Although antecedent soil moisture has a major effect on the amount of sediment yield and soil erosion, omitting rainfall data occurring within 10 days, did not affect on the chosen rainfall erosivity index and its correlation with sediment yield. By omitting rainfall data occurring within 10 days, 12 rainfall events and their resulted sediment yields were remained in correlation analysis. Results showed that in this situation, *dI* rainfall erosivity index had the most significant correlation of 0.956 ($P < 0.01$) with average sediment yield of all plots in the study area, a significant correlation of 0.903 ($P<0.01$) with average sediment yield of plots in class *i*, a significant correlation of 0.801 ($P<0.01$) with average sediment yield of plots in class *ii* and a significant correlation of 0.979 ($P<0.01$) with average sediment yield of plots in class *iii*.

On the other hand, results showed that in spite of the effect of vegetation cover on the amount of sediment yield and soil erosion (planting wheat crop and fallow condition at the first and second years) it has no significant impact on the relations between sediment yield and rainfall erosivity indexes. Results demonstrated that with wheat cropping in the first year, *dI* rainfall erosivity index had the most significant correlation of 0.740 ($P < 0.05$) with average sediment yield of all plots in the study area, a significant correlation of 0.743 ($P<0.05$) with average sediment yield of plots in class *i*, a significant correlation of 0.765 ($P<0.05$) with average sediment yield of plots in class *ii* and a significant correlation of 0.864 ($P<0.01$) with average sediment yield of plots in class *iii*. Results showed that in fallow condition of second year, *dI* rainfall erosivity index had the most significant correlation of 0.967 ($P < 0.01$) with average sediment yield of all plots in the study area, a significant correlation of 0.989 ($P<0.01$) with average sediment yield of plots in class *i*, a significant correlation of 0.992 ($P<0.01$) with average sediment yield of plots in class *ii* and a significant correlation of 0.937 ($P<0.01$) with average sediment yield of plots in class *iii*.

Analyzing sediment yield, resulting from 21 rainfalls, by Least Significant Difference (LSD) method demonstrated that the plowing along the contour lines significantly reduced the amount of soil loss in all slope classes compared to those of across the slope plowing. The amount of reduction with 99% confidence in 0-12, 12-20 and 20-40% slopes were 92, 97 and 95%, respectively.

The correlation coefficients of the amount of sediment yield from across the slope plowing plots and contour plowing in the 18 erosion plots are presented in Table 3. As indicated in this table, contour plowing has reduced the amount of sediment yield for all slope classes. The amounts of reduction were 92, 97 and 95%, respectively. Also, the amount of sediment yield from contour plowing of the 12-20 and 20-40% slopes were significantly lower compared to those of across the slope plowing of 0-12%. Similar results were obtained when comparing the amount of sediment yield from contour plowing of 20-40% slope to those of across the slope plowing of 12-20%.

The results supported the effectiveness of different plot treatments such as slope, plowing direction and the rainfall parameters on the amount of soil erosion and sediment yield. The results also showed the successful linkage between the rainfall erosivity and the amount of sediment yield. Finally, it can also concluded that in spite of the effect of different treatments like slope classes, vegetation cover, antecedent soil moisture and plowing directions on soil erosion and sediment yield, they have no effects on correlations between rainfall erosivity indexes and sediment yield variables.

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