THE EXPERIMENT
INTERNATIONAL JOURNAL OF SCIENCE AND TECHNOLOGY

ISSN-2319-2119

RESEARCH ARTICLE

Habib Palizvan et al, The *Experiment, 2014, Vol.24 (2)1656-1662*

RELATION OF SEDIMENT LOAD SOURCE TO RAINFALL INTENSITY

ABSTRACT

Soil erosion is a complex phenomenon and aggregate stability and soil texture are two influential factors governing soil erodibility. Previous studies have shown that at the transport-limited regime, pre-detached particles and at the detachment-limited regime, soil structure control sediment delivery. This study tried to analyze rule of factors and mechanisms governing interrill erodibility at different rainfall intensities. Samples from 36 soil series with contrasting properties were collected from northwest of Iran. A rainfall simulator with drainable tilting flume (1×0.5 m) at slope of 9 % was employed and interrill erodibility (K_i) was calculated for 20, 37, and 47 mm hr^{-1} simulated rainfall intensities. Results showed a positive correlation (r = 0.286 - 0.804) between K_i and clay content. In contrast to textural variables, the r values of K_i to the structure related indices (wet aggregate stability (WSA), mean weight diameter (MWD) and geometric mean diameter (GMD)) turned to be greater and significant at higher rainfall intensities. These probably imply that at higher rainfall intensities, soil detachment by raindrops limits sediment yield, but at lower intensities, transport limits sediment delivery. The correlation of K_i to GMD was greater than that to MWD, implying that the proportion of smaller aggregates in sediment load was greater than larger aggregates.

Keywords: Detachment-limited regime, Erosion rate Interrill erosion, MWD, Soil texture

INTRODUCTION

Soil erosion is a complex phenomenon and aggregate stability and soil texture are two influential factors governing soil erodibility. Aggregate stability is considered to be one of the main soil properties regulating soil erodibility in semiarid environments (Dunne et al. 1991, de Ploey and Poesen 1985, Cerdá 1998). Aggregate stability not only decreases particles detachment and transport by raindrop impact and overland flow but also reduces formation of surface seal (Martinez-Mena et al. 1998). Soils with high content of silt and very fine sand (0.05 to 0.10 mm), or expanding clay minerals tend to have high erodibility. Erodibility is low for clay-rich soils with a low shrink-swell capacity. Clay particles mass together into larger aggregates that resist detachment and transportation (O'Geen 2006). Aba Idah et al. (2008) stated that sandy soils have low cohesive force and, therefore, are more prone to detachment and transportation by water and wind

Depending on whether detachment or transport is limiting sediment yield, soil surface interrill area can be dominated by soil aggregates or pre-detached particles (Kinnell 1993a). Several authors have distinguished between the detachment-limiting sediment delivery, controlled by topsoil properties such as soil strength and aggregate stability, and the transport-limiting sediment delivery, controlled by the size and density of pre-detached particles (Huang 1998, Agassi and Bradford 1999). This study tries to analyze the rule of factors and mechanisms governing interrill erodibility at different rainfall intensities.

MATERIALS AND METHODS

Soil sampling and analysis

In order to provide wide ranges of particle size and aggregate size distribution, 36 soil series with diverse properties were selected from the northwest of Iran and samples were taken from the A_p or A horizon of each soil profile. The samples were air dried at room temperature. A sub-sample of about 2 kg of each soil was sieved using a 2-mm sieve aperture. Soil texture, organic matter, pH, EC, CEC, SAR, TNV, and $CaSO_4$ were determined using the standard laboratory methods (Gee and Or 2002, Sparks 1996). Wet aggregate stability (WAS) was measured by Kemper and Rosenau (1986) method.

For computing mean weight diameter (MWD) and geometric mean diameter (GMD) of aggregates 30 g of air dry soil sample (< 4.75 mm) was placed on a nest of sieves with opening sizes of 2.00, 1.00, 0.50, and 0.250 mm arranged from top to bottom respectively, and slowly submerged in tab water (EC= 0.5 dS m^{-1} and SAR=1.2) while connected to a wet-sieving apparatus. The apparatus had a vertical stroke (the vertical distance that the sieve set moved up and down in water) of 38.1 mm and was operated for 10 minutes at a speed of 30 cycles min^{-1}. The mass remained on each sieve were separately collected, oven-dried and weighed (W_i). Each dry mass was dispersed by adding sodium hexametaphosphate (HMP) solution and hand stirring, and then passed through the same sieve from which it was collected. The remained mass again was gathered, dried and weighed (W_{si}). The difference W_i-W_{si} was regarded as water stable aggregates in the ith size class and they were used to compute MWD and GMD of the aggregates using the appropriate equations (Kemper and Rosenau 1986).

Soil Erosion Test

A rainfall simulator with a single scanning nozzle located 4 meters above the soil surface, and a drainable tilting flume (1-m-long, 0.5-m-wide and 0.1-m-depth) were employed for erosion tests. The flume provided sufficient runoff and soil erosion for interrill erodibility analysis, but could not concentrate flow and produce bed shear stress sufficiently to induce rill erosion. To prepare erosion test, flume was laid in a horizontal position and a water-permeable mat with 1 cm thickness was placed on the flume bed. Air-dried soil that passed through a 4.75-mm sieve was loosely packed in the flume with 0.09 m-thick layer and then was saturated from the bottom by a constant-head water supply for a 24 hr. After this period slope of the flume was adjusted to 9 percent and was subjected to simulated rainfall for 90 minutes. Rainfall intensities were 20, 37 and 47 mm hr^{-1}, which will be designated hereafter as I_A, I_B and I_C, respectively. Outflow runoff samples continuously were collected manually at different time intervals being less than 60 seconds at the commencement of runoff up to 15 minutes near the end of the test. At the end of experiment, the volumes of runoff samples (V) were measured and they allowed to evaporate. The remained mass was oven dried at 105 °C for 24 hr and weighed (M_d), allowing to determine the sediment load at each time interval during the erosion test. Sediment concentration in each runoff sample was computed as M_d/V. These data were used to calculate runoff and erosion rates. The observed interrill erodibility values were calculated using Eq. [1] (Foster et al. 1995):

$$K_i = \frac{D_i}{I_e \sigma_{ir} S_f} \qquad [1]$$

where K_i is interrill erodibility (kg s m^{-4}), D_i is interrill erosion rate (kg m^{-2} s^{-1}), I_e is rainfall intensity (m s^{-1}), σ_{ir} is interrill runoff rate (m s^{-1}) and S_f is slope factor (dimensionless) calculated as (Liebenow et al. 1990)

$$S_f = 1.05 - 0.85 \exp^{(-4 \sin[\theta])} \qquad [2]$$

where θ is the slope angle (degrees). D_i and σ_{ir} were considered, respectively, as the ratios of mean sediment mass ($\overline{M}_d$) and the mean runoff volume ($\overline{V}$) per unit area to the mean time intervals ($\bar{t}$) at which steady-state conditions were realized.

Statistical Analysis

Statistical analysis of the experimental data was accomplished using the SPSS software package (SPSS Inc. 2007). It was included normality analysis of the data distribution using Kolmogorov-Smirnov test and correlation analysis.

RESULTS AND DISCUSSION

Soil properties

Table 1 summarizes range, mean and standard deviation of some physical and chemical properties of the examined soils. There were considerable differences in SAR, EC, organic matter, TNV, clay, silt and sand contents among the soils used in the experiment. The two highest coefficients of variation related to SAR (130.3%) and EC (98.7%). The wide range of physico-chemical properties of the soils imparts a generality to the findings and makes them to be applied with greater reliability to other soils.

Interrill erodibility

Interrill erodibility factor (K_i) of the examined soils calculated using Eq.[1] are listed in Table 2 for the three rainfall rates. Lack of significant difference between K_i values at the three rainfall rates, implies that K_i is independent of rainfall intensity and only is affected by the soil properties. In other words according to Eq. [1] it appears that changes in D_i and σ_{ir} become almost proportional to the variation in the rainfall rate in a way that keeps K_i unaltered. Kinnell (1993b) and Foster et al. (1995) have also considered K_i as an independent factor from rainfall intensity in the steady- state condition of soil erosion. However Asadi et al. (2008) reported that K_i changes with rainfall rate and concluded that there is a structural uncertainty in Eq. [1].

Relation between soil erodibility (K_i) and textural and structural parameters

Table 3 shows that the correlation coefficients (r) of K_i with sand, silt and clay content are greater at low (I_A) rainfall intensity than at high (I_C) rainfall intensity. These results imply that with increasing rainfall intensity other soil properties rather than texture dominantly control K_i. Asadi et al. (2008) also reported a bias and systematic error in predicting K_i from WEPP-recommended equations using soil texture fractions at higher rainfall intensities. They concluded that neglecting the dominancy of flow-driven erosion at high rainfall rates and ignoring the effect of water depth on interrill erosion are probably the most important problems concerning the interrill component of the WEPP model.

Table 3 also shows significant positive correlation between K_i and silt content. This is due to the fact that silt-sized particles are small enough to reduce the permeability of soil and to be carried away easily by runoff (Anonymous 1988). Gunn et al. (1988) also reported that soils with high contents of silt are generally most erodible.

Unlike finding of Elliot et al. (1989), Table 3 shows a high significant positive correlation between clay percent and K_i. The difference in the nature of clay minerals between the two experiments (Elliot et al. 1989) may have contributed to the contradiction in results (Lado et al. 2004). Khormali and Abtahi (2005) and Samadi et al. (2008) reported that expanding clays are the major clay minerals in the soils of west and northwest of Iran. These clays swell markedly and adversely affect resistance to erosion (Gunn et al. 1988, Romkens et al. 1995, Mermut et al 1997). Under such conditions K_i may be positively correlated to clay content. Positive correlation between K_i and clay content in Table 3, however, coincides with the finding by Udeigwe et al. 2007 who reported positive relationship between soil clay content and soil erosion. They noticed that clay mineralogy could have an important effect on erodibility.

Negative correlation between sand fraction and K_i in Table 3 means that it takes more energy to transport sand particles. There was no correlation between very fine sand (vfs) and K_i. Duiker et al. 2001 reported that very fine sand content alone is not an appropriate parameter for predicting interrill erodibility. Our findings (Table 3) also show that K_i have higher correlation with vfs+silt than vfs alone.

Table 3 also depicts correlation coefficient (r) of K_i to WAS, MWD and GMD. In contrast to textural variables, the r values of K_i to the structure related indices (WAS, MWD and GMD) turned to be greater and significant at higher rainfall intensities implies that at higher rainfall intensities soil structural status or stability becomes dominant factor in K_i, and texture effect declined. Yan et al. 2008 also found that interrill erosion rate well related to MWD, for the results obtained at high rainfall intensity (61.2±2.2mm h^{-1}). These imply that detachment-limiting conditions may be prevailed at high and transport-limiting sediment process may be dominated at low rainfall intensities (Huang 1998, Agassi and Bradford 1999).

Among three aggregate stability indices GMD had the greatest correlation coefficient with K_i at all three rainfall intensities whereas K_i correlated to WAS and MWD just at the highest rainfall intensity (I_C=47 mm h^{-1}). It implies that a) K_i is more related to the size distribution of water stable aggregates than that to aggregate stability; b) some of aggregates may be transport without disintegration; and c) the proportion of smaller aggregates in sediment load was more than larger aggregates, because MWD is an estimator of the size distribution of larger aggregates (Castro Filho et al. 2002). Igwe et al. (1995) also found that correlation of soil loss with GMD is greater than that with MWD.

With increasing rainfall intensities correlation of K_i with WAS increased more rapidly than that with MWD. This indicates that with increasing rainfall intensity the role of particle detachment on interrill erosion is increased.

Although the correlation coefficient between K_i and MWD rise with increasing rainfall intensity, but the correlation coefficient between K_i and GMD decreased with increasing rainfall intensity from I_B to I_C, these imply that the proportion of lager aggregates in sediment load increased with increasing rainfall intensity.

CONCLUSION

In contrast to textural variables, the r values of K_i to the structure related indices (WAS, MWD and GMD) turned to be greater and significant at higher rainfall intensities. This implies that at the higher rainfall intensities soil structural status or stability becomes dominant factor in K_i and the effect of soil texture declines. These probably indicate that at higher intensities, detachment-limited sediment regime, and at lower intensities transport- limited sediment regime dominated.

Unlike the results reported by several researchers, our findings showed a significant positive correlation between K_i and clay content. It may be due to the difference in clay mineralogy.

Importance of size distribution of water stable aggregates is higher than aggregate stability alone, especially, at lower (20 mm hr^{-1}) rainfall intensities.

The correlation of K_i to GMD was greater than that to MWD, probably implying that the proportion of smaller aggregates in sediment load was greater than larger aggregates.

REFERENCES

1. Aba Idah, P., Mustapha, H.I., Musa, J.J., and Dike, J. 2008. Determination of erodibility indices of soils in Owerri west local government area of Imo State, Nigeria. AU J.T. **12**:130-133.
2. Agassi, M., and Bradford, J.M. 1999. Methodologies for interrill soil erosion studies. Soil Tillage Res. **49**:277–287.
3. Anonymous. 1988. The Florida Development Manual: A Guide to Sound Land and Water Management (Chapter 2). Tallahassee, FL.

4. Asadi, H., Rouhipour, H., and Ghadiri, H. 2008. Evaluation of interrill component of the WEPP model for three contrasting soil types in Iran. Adv. GeoEcology **39**:237-246.
5. Castro Filho, C., Lourenço, A., Guimarães, M.de F., and Fonseca, I.C.B., 2002. Aggregate stability under different soil management systems in a latosol in the state of Parana, Brazil. Soil Tillage Res. **65**:45-51.
6. Cerdá, A. 1998. Soil aggregate stability under different Mediterranean vegetation types. Catena **32**:73–86.
7. De Ploey, J., and Poesen, J. 1985. Aggregate stability, runoff generation and interrill erosion. In Richards, K.S., Arnett, R.R., Ellis, S. (eds.). Geomorphology and Soils. George Allen & Unwin, London, pp. 99–120.
8. Duiker, S.W., Flanagan, D.C., and Lal, R. 2001. Erodibility and infiltration characteristics of five major soils of southwest Spain. Catena **45**:103–121.
9. Dunne, T., Zhang, W., and Aubry, B.F. 1991. Effects of rainfall, vegetation and microtopography on infiltration and runoff. Water Resources Research **27**:2271–2285.
10. Elliot, W.J., Liebenow, A.A., Laflen, J.M., and Kohl, K.D. 1989. A Compendium of Soil Erodibility Data from WEPP Cropland Soil Field Erodibility Experiments 1987 and 88. NSERL Report, Vol. 3. Agricultural Research Service, U.S. Department of Agriculture, National Soil Erosion Research Lab., West Lafayette, Indiana. 316 pp.
11. Foster, G.R., Flanagan, D.C., Nearing, M.A., Lane, L.J., Risse, L.M., and Finkner, S.C. 1995. Chapter 11. Hillslope erosion component. In: Flanagan, D.C., Nearing, M.A. (eds). USDA Water Erosion Prediction Project. Hillslope Profile and Watershed Model Documentation. USDA-ARS-NSERL Report a 10. NSERL, West Lafayette, IN, pp. 11.1–11.12.
12. Gee, G.W., and Or, D. 2002. Particle-size analysis. In Warren, A.D. (ed.). Methods of Soil Analysis. Part 4. Physical Methods. Soil Sci. Soc. Am. Inc, pp.255-295.
13. Gunn, R.H., Beattie, J.A., Reid, R.E., and van- de- Graaff, R.H.M. 1988. Australian Soil and Land Survey Handbook: Guidelines for Conducting Surveys. Inkata Press, Melbourne.
14. Huang, C., 1998. Sediment regimes under different slopes and surface hydrologic conditions. Soil Sci. Soc. Am. J. **62**:423– 430.
15. Igwe, C.A., Akamigbo, F.O.R., and Mbagwu, J.S.C. 1995. The use of some soil aggregate indices to assess potential soil loss in soils of south-eastern Nigeria. Int. Agrophysics **9**:95-100.
16. Kemper, W.D., and Rosenau, R.C. 1986. Size distribution of aggregates. In Klute, A. (ed). Methods of Soil Analysis Part 1, 2nd ed. Agron. Monogr. 9. ASA-SSSA, Madison, WI, pp.425-442.
17. Khormali, F., and Abtahi, A. 2005. Correlation of the clay mineral distributions in the sedimentary rocks of south and western Zagros, Iran. Geophysical Research Abstracts, Vol. 7, 00063, European Geosciences Union.
18. Kinnell, P.I.A. 1993a. Interrill erodibilities based on the rainfall intensity flow discharge erosivity factor. Aust. J. Soil Res. **31**:319-332.
19. Kinnell, P.I.A., 1993b. Runoff as a factor influencing experimentally determined interrill erodibilities. Aust. J. Soil Res. **31**:333–342.
20. Lado, M., Ben-Hur, M., and Shainberg, I. 2004. Soil wetting and texture effects on aggregate stability, seal formation, and erosion. Soil Sci. Soc. Am. J. **68**:1992–1999.
21. Liebenow, A.M., Elliot, W.J., Laflen, J.M., and Kohl, K.D. 1990. Interrill erodibility, collection and analysis of data from cropland soils, Transactions of the American Society of Agricultural Engineers **33**:1882-1888.
22. Martinez-Mena, M., Williams, A.G., Ternan, J.L., and Fitzjohn, C. 1998. Role of antecedent soil water content on aggregates stability in a semi-arid environment. Soil & Tillage Res. **48**:71-80.
23. Mermut, A.R., Luk, S.H., Romkens, M.J.M., and Poesen, J.W.A. 1997. Soil loss by splash and wash during rainfall from two loess soils. Geoderma **75**: 203-214.
24. O'Geen, A.T., Elkins, R., and Lewis, D. 2006. Erodibility of agricultural soils, with examples in Lake and Mendocino counties. Oakland: University of California Division of Agriculture and Natural Resources, Publication 8194. Available online: http://anrcatalog.ucdavis.edu

25. Romkens, M.J.M, Luk, S.H., Poesen, J.W.A., and Mermut, A.R. 1995. Rainfall infiltration into loess soils from different geographic regions. Catena **25**:21–32.
26. Samadi, A., Dovlati, B., and Barin, M. 2008. Effect of continuous cropping on potassium forms and potassium adsorption characteristics in calcareous soils of Iran. Aust. J. Soil Res. **46**:265–272.
27. Sparks, D.L. 1996. Methods of Soil Analysis. Part 3. Chemical Methods. SSSA-ASA, Madison. WI.
28. SPSS Inc. 2007, SPSS for Windows Release 16. Chicago.
29. Udeigwe, T.K., Wang, J.J., and Zhang, H. 2007. Predicting runoff of suspended solids and particulate phosphorus for selected Louisiana soils using simple soil tests. J. Environ. Qual. **36**:1310–1317.
30. Yan, F.L., Shi, Z.H., Li, Z.X., and Cai, C.F. 2008. Estimating interrill soil erosion from aggregate stability of Ultisols in subtropical China. Soil Till. Res. **100**:34–41.

Soil properties		Min	Max	Mean	SD	C.V (%)
pH		6.81	8.3	7.79	0.29	3.7
SAR	$(\text{cmol kg}^{-1})^{0.5}$	0.31	34.72	5.84	7.61	130.3
CEC	(cmole(+) per 100g soil)	6.8	59.9	23.96	11.07	46.2
EC		0.41	8.56	2.19	2.15	98.7
SP	(%)	24.01	69.08	41.81	12.94	31.0
$CaSO_4$	(%)	0	0.61	0.21	0.12	57.1
TNV	(%)	3.7	26.3	16.18	6.48	40.1
OM	(%)	0.06	4.38	1.91	1.35	70.7
Clay	(%)	8.5	50.2	26.0	10.9	42.1
Silt	(%)	1.4	53.0	34.6	11.4	33.0
Sand	(%)	6.5	90.1	39.4	20.2	51.2
Very fine sand	(%)	0.0	22.0	10.1	5.5	54.5
WAS	(%)	10.4	92.5	46.0	25.2	54.80
MWD	(mm)	0.05	1.18	0.28	0.23	82.40
GMD	(mm)	0.46	1.01	0.61	0.14	22.90

Table 1. Minimum, maximum, mean, standard deviation (SD) and coefficient of variation (C.V) of some physical and chemical properties of the 36 examined soils.

Rainfall intensity (mm hr^{-1})	Min.	Max.	Mean	SD	C.V (%)
	$\times 10^5$ (kg s m^{-4})				
20	2.10	79.71	15.35^{NS}	14.58	93.94
37	1.03	39.69	13.27^{NS}	8.75	65.95
47	3.17	44.38	15.15^{NS}	8.87	58.54

^{NS}: Not significant at the 0.05 level

Table 2. Minimum, maximum, mean and standard error of interrill soil erodibility (K_i) values.

Parameters	K_i		
	20 mm hr^{-1}	37 mm hr^{-1}	47 mm hr^{-1}
clay	0.804**	0.481**	0.286
silt	0.596**	0.466**	0.221
sand	-0.735**	-0.525**	-0.278
vfs	-0.076	-0.061	0.023
vfs+silt	0. 466**	0.464**	0.346*
WAS	-0.189	-0.267	-0.421*
MWD	-0.203	-0.320	-0.388*
GMD	-0.394*	-0.547**	-0.519**

* and ** mean significant at the 0.01 and 0.05 level

Table 3. Simple correlation coefficient (r) between interrill erodibility (K_i) at three rainfall intensities and textural fractions or aggregate stability indices of WAS, MWD, GMD

Habib Palizvan[1*], Abbas Ahmadi[1]

[1] Department of Soil Science, Faculty of Agriculture, University of Tabriz, Iran.