Buletinul Ştiinţific al Universităţii "POLITEHNICA" din Timişoara

Seria HIDROTEHNICA

TRANSACTIONS on HYDROTECHNICS

Tom 55(69), Fascicola 1, 2010

Estimating erodibility of soils from the Bârzava hydrographical basin

Adia Grozav[1], **Gheorghe Rogobete**[1]

Abstract: Runoff from agricultural and forest land carries sediment and nutrients which can harm the quality of receiving waters and degrade soil productivity. A thin layer of reduced permeability forms on the surface of many soils exposed to raindrop impact. Surface seals form on bare soils exposed to rainfall as soil aggregates are broken down by impacting raindrops. Erosion plots were established and used to measure soil loss for different rainfall, soil and topographic and land use characteristics. A set of samples for all 8 soils was collected from each profile.

Keywords: soil, erosion, sediment, estimation, detachment.

1. INTRODUCTION

Runoff from agricultural and forest land carries sediment and nutrients which can harm the quality of receiving waters and degrade soil productivity. Infiltration capacity of soil is a principal factor in determining the amount of runoff resulting from a rainfall or irrigation event.

Therefore, a through understanding of the effects of agricultural practices on the infiltration process in soils is essential before recommending the best management practices to reduce runoff from agricultural and silvicultural land.

The formation of a surface seal or crust on a bare soil exposed to rainfall can reduce infiltration and increase runoff. A thin layer of reduced permeability forms on the surface of many soils exposed to raindrop impact.

This distinct layer is characterized by higher bulk density and lower porosity than the underlying by soil. The term "surface seal" is commonly used when describing the effect this layer of reduced permeability has on limiting infiltration.

Upon drying, the seal shrinks to form a hard crust which impedes seedling emergence and tears seedling roots as it cracks (Hillel, 1980). Surface seals form on bare soils exposed to rainfall as soil aggregates are broken down by impacting raindrops.

Early efforts to understand and predict soil erosion were primarily empirical. Erosion plots were established and used to measure soil loss for different rainfall, soil and topographic and land use characteristics.

The Universal Soil Loss Equation (USLE) was developed from this data base (Wischmeier and Smith, 1960). More recently, substantial improvements have been made in predicting erosion using process-based models, such as those used in the Water Erosion Prediction Project-WEPP (F0ster, 1987).

Using the WEPP approach, the soil erodibility is directly related to the detachment model. If a different detachment model is used, a different erodibility value is obtained for the same soil conditions. Additional refinements are needed to isolate those factors that are a function of the characteristics of the soil from those of the fluid flow. These refinements need to be performed at the bed boundary where soil and fluid interactions determine particle detachment.

For many years, scientists have attempted to develop an index of relative soil erodibility using soil properties. Trott and Singer (1983) used a laboratory rainfall simulator to measure runoff and sediment, production from a group of California forest soils. Laboratory tests to determine differences particle size distribution in a dispersed and an aggregated condition were performed to determine differences in textural characteristics caused by soil aggregation. Two stepwise linear regression analyses were performed on the 18 "wettable" soil using silt plus clay content as the textural index.

The index was calculated with dispersed soils and aggregated soils. For the agricultural soils from Caraş-Severin county, Covaci (2002) and Rogobete (2006) determined rainfall – Erozitester, with two slopes (10% and 15%) and a laboratory study which was conducted using a 1.04m square soil pan that was filled with soil to a depth of about 75mm. Two plots, each 0.3m wide x0.45m long were prepared side-by-side within the pan and centered beneath the rainfall simulator nozzle. One plot was uniform 20% steepness.

The other averaged 20 % steepness from top to bottom, but had a complex-shaped cross-section typical of row sideslopes in a bedded field. The latter curved sideslope was formed from two sections of an

---

[1] Faculty of Hydrotechnical Engineering Timisoara, CHIF Department, George Enescu Str. No. 1/A, 300022 Timisoara, E-mail: adiagrozav@yahoo.com

ellipse to give a smooth variation in steepness from a maximum of 40% midway to near zero at the top and at the bottom. Simulated rain was applied to both plots simultaneously, and runoff was collected in containers beneath the lower ends of the plots.

These samples were weighed and dried to obtain water and sediment loss totals for each 30 -and 15-min storm.

With all variables significant at the 95% confidence level, the resulting equation to predict sediment yield is:

$$SY=-9{,}391+25{,}298(Si+Cl)-0{,}2297(Si+Cl)^2-12{,}551(Kaolinite)+31{,}420(Smectite)-16{,}18(Humus) \quad (1)$$

were:
SY=sediment production in grams/m^2;
Si+Cl=percent silt plus percent clay;
Kaolinite=percent Kaolinite clay present in the soil;
Smectite=percent smectite clay present in the soil;
Humus=percent humus present in the topsoil.

2. METHODS

A set of samples for all 8 soils was collected from each profile.

Laboratory tests to determine particle size distribution and mineralogical clay content in a dispersed and an aggregated condition were performed to determine differences in textural and clay minerals characteristics caused by soil aggregation.

Standard methods (ICPA-Bucureşti) were used for the soil analyses.

The soil content of clay mineralogical composition was established by differential thermal analysis, X-ray analysis and infra-red analysis.

Data plotting and linear regression techniques were used to develop relationships between particles size gradation, humus content, both dispersed and aggregated and sediment production.

The analysis concentrated upon correlation between sediment production as the dependent variable and two gradation indices developed from dispersed and aggregated particle size data, together with other soil properties as independent variable.

3. RESULTS AND DISCUSSION

The study is based on a few special research works executed in the last decade in the territory Berzovia, which has 10000ha.

For the main soil profiles (9 profiles) we have made complete analyses. In the table 1 there are presented analytical data for a Luvisols.

Table 1. Analytical data-Stagnic Luvisols

Horizon	**Ap**	**AB**	**Btw**
Depth, cm	**0-22**	**22-43**	**43-60**
Coarse sand, %	8.3	6.0	2.9
Fine sand, %	33.3	33.5	26.0
Silt, %	27.8	30.1	26.8
Clay, %	30.6	30.4	44.3
Density, gcm^{-3}	2.58	2.61	2.63
Bulk density, gcm^{-3}	1.22	1.50	1.46
Porosity, %	52.71	42.53	44.49
Air capacity, %	24.5	7.88	9.49
Degree of compaction, %	-5.44	14.87	14.80
Hygroscopic coefficient, %	7.17	7.13	10.37
Wilting coefficient, %	10.76	10.69	15.56
Field capacity, %	23.12	23.10	23.97
Saturation capacity, %	43.20	28.35	30.47
Available capacity, %	12.36	12.41	8.41
Hydraulic conductivity (K, mm/h)	6.0	1.3	0.8
pH	6.03	6.22	6.10
Humus, %	4.09	2.53	1.82
Mobile Phosphor, ppm	22.0	-	-
Mobile Potassium, ppm	185	-	-
Exchangeable base, me/100g	22.65	21.63	24.48
Exchangeable hydrogen, me/100g	5.51	4.74	5.21
Cation-exchange-capacity,me/100g	28.16	26.37	29.69
Degree of base saturation, %	80.43	82.02	82.45
Clay mineral:			
Kaolinite, %	3.0	-	-
Smectite, %	14.0	-	-

The analysis (table 2) shows that the prediction equation 1 provides a reasonably accurate model to estimate interrill sediment production of soil finer than 2mm and clay mineralogy due to the inclusion of the non-linear term for Si+Cl suggested by data plotting.

Table 2. Analytical data-Berzovia

No.	Soil	Silt %	Clay %	Humus %	Kaolinite %	Smectite %	Pred. SY g/m^2
1	Stagnic Luvisols	27,8	30,6	4,09	3,0	14,0	990,65
2	Vertic Stagnic Luvisols, eroded	26,3	33,5	3,09	6,0	21,0	1216,34
3	Vertic Stagnic Luvisols	31,4	31,6	3,50	8,0	42,0	1853,31
4	Vertic Haplic Planosols	35,5	20,7	1,65	8,0	20,0	1188,16
5	Eutric Gleysols	18,4	29,2	4,84	4,0	0,0	545,84
6	Gleyic Fluvisols	34,3	47,9	2,74	5,0	3,0	505,24
7	Gleyic Fluvisols	24,8	18,6	1,84	7,0	2,0	597,17
8	Luvisols eroded phase	26,0	37,9	1,49	1,0	14,0	1072,55
9	Luvisols eroded phase	28,4	40,8	2,38	1,0	16,0	1092,87

The results presented in table 2 provide the basis for estimating the predictive sediment production for one hectare and for the all areas with the type of soils (table 3).

Table 3. Predictive sediment production

No.	Soil	SP g/m^2	Area ha	SP to/ha	SP total to
1	Stagnic Luvisols	990,65	136,73	9,91	1354,45
2	Vertic Stagnic Luvisols, eroded	1216,34	46,08	12,16	560,47
3	Vertic Stagnic Luvisols	1853,31	150,39	18,53	2787,18
4	Vertic Haplic Planosols	1188,16	108,62	11,88	1290,41
5	Eutric Gleysols	545,84	54,84	5,46	299,32
6	Gleyic Fluvisols	505,24	5,27	5,05	26,62
7	Gleyic Fluvisols	597,17	16,19	5,97	96,69
8	Luvisols eroded phase	1072,55	79,30	10,72	850,49
9	Luvisols eroded phase	1092,87	28,65	10,93	313,12

Table 2 and table 3 shows the wide variety of sediment production because of soil types, and as a function of textural and clay mineralogy. The greatest yield sediment is a Luvisols-Vertic and Planosols-Vertic and the smallest on the Fluvisols. It is correlated with a large content of smectite in the clay fraction. We recognize that the amount of coarse fragments can effectively reduce sediment detachment and transport, but other data will have to be used to measure this effect. The general framework for particle detachment is based on the dislodging and stabilizing forces, and associated moment lengths, shown in figure 1.

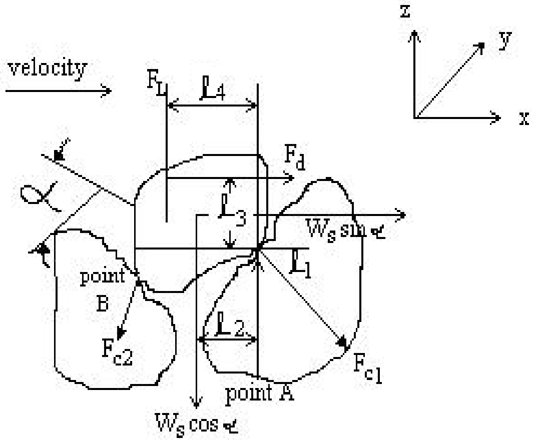

Fig. 1 Important forces and moment lengths (Wilson, 1993)

Forces acting to dislodge the particle are the z-direction lift force (F_L), the x-direction drag force (F_d) and the x-component gravity force ($W_s \sin\alpha$). Forces resisting movement are the contact forces (F_{c1}, $F_{c2} \ldots F_{cn}$) and the z-component gravity force ($W_s \cos\alpha$). Particle detachment occurs if the moment associated with dislodging forces is greater than those associated with stabilizing forces.

Consider the moments around Point A particle is at the point of incipient motion when the clockwise moments to dislodge are equal to the counter clockwise moments to stabilize. The point of incipient motion is then defined as:

$$l_1 W_s \sin \propto + l_3 Fd + l_4 F_L = l_2 W_s \cos \propto + Mc \quad (2)$$

were terms are as defined in figure 1, and Mc is the sum of moments of cohesive and frictional resistance forces defined as:

$$M_c = \sum_{i=1}^{n_c} \sigma_{ci}\, a_i\, l_i^{'} . \qquad (3)$$

where n_c is the number of contact locations, σ_{ci} is a particle-to particle stress term, a_i is the contact area and $l_i^{'}$ is the moment length for each contact location. Cohesive force is defined here informally. It would include electrochemical attraction as well as frictional forces resulting from any sliding motion between two particles. If the moments on the left side of equation 2 are larger than those on the right side, the particle is detached.

Assuming that the drag and lift forces are proportional, the moment balance of equation 2 can be rearranged as:

$$F_d = W_s (Kl_s + f_c) \qquad (4)$$

where $F_L = K_L F \frac{d}{k_f}$ is assumed and where terms on the right side are defined below. If the left side (primarily fluid flow characteristics) is greater than the right side (primarily particle and bed characteristics) the particle is detached, otherwise it is not.

In equation 4, the parameter Kl_s is a dimensionless parameter that depends on particle size, its orientation within/on the bed, and slope.

It is defined mathematically as:

$$Kl_s = \frac{\cos \propto (l_2 - l_1 S_0)}{l_3 + {}^{l_4 K_L}/_{k_f}} \qquad (5)$$

where $S_0 = tg\alpha$ is the bed slope, K_L is the proportional constant between drag and lift coefficients as well as their respective velocities, and k_f is the ratio of the projected area for drag to than of lift forces.

Other terms are as previously defined. Values of moment lengths and k_f are given by Wilson (1993) using a simple two-dimensional representation of particles.

The cohesive moment term is difficult to determine directly. Its importance is defined relative to the weight of the particle. The parameter f_c in equation 4 is a dimensioless parameter defined as:

$$f_c = \frac{\frac{M_c}{l_3 + \frac{l_4 K_L}{k_f}}}{W_s} \qquad (6)$$

It is useful to evaluate particle volume and surface area as a function of its diameter using:

$$V_p = k_v d^3$$

and

$$A_p = k_a d^2 \qquad (7)$$

were V_p and A_p are the particle volume and projected area, respectively; d is an equivalent particle diameter; and k_v and k_a are volume and area constants defined for a sphere as $\pi/6$ and $\pi/4$, respectively.

The submerged weight of the particle can now be readily defined as:

$$W_s = g(\rho_s - \rho)k_v d^3 \qquad (8)$$

where g is the acceleration of gravity, and ρ_s and ρ are the densities of the particle and fluid, respectively.

Wilson (1993) has been developed a detachment model using a moment balance between those moments acting to dislodge particles and those acting to stabilize them. Moments associated with cohesive and resistance forces were represented by a dimensionless term defined relative to the submerged weight of the particle. Turbulent detachment forces were evaluated by assuming an extreme value type I distribution a normal distribution, and a log normal distribution. Suspended sediment was assumed to dampen turbulence reducing the coefficient of variation for turbulent detachment forces.

4. CONCLUSIONS

The results of this study provide the basis for estimating the relative erodibility of soils on sheet overland flow (interrill) areas for use in physical process-type models of sediment production.

Table 2 shows the wide variety of soil types, yet erodibility is a function of textural and clay mineralogy.

The soil type are differentiate of the fraction finer than 2 mm with a range from 18,6% to 47,9%. The great sediment production were found at Vertic Luvisols (1853,31 g/m^2) and Vertic Planosols (1188,16 g/m^2) and at eroded Vertic Luvisols (1216,34 g/m^2), what means 11 to 18 to/ha.

REFERENCES

[1] *E.R., Burroughs, CH., Luce, F., Phillips*, Estimating interrill erodibility of forest soils, Transactions of ASAE 35(5), 1992;

[2] *D., Covaci,* Cercetări privind ameliorarea solurilor erodate din județul Caraş-Severin, cu referire specială asupra bazinului hidrogafic Pogăniş, 2002, teză de doctorat, Universitatea Politehnica Timişoara;

[3] *W.D., Kemper, R.C., Rosenau*, Aggregate stability and size distribution, Method of Soil Analysis, part 1. 2 nd, 1986, Ed.Am.Soc. of Agron., Soil Sci Soc of Am;

[4]*Gh., Rogobete, I., Nemeş, A., Grozav, C., Covaci*, Erodabilitate şi scurgeri de suprafață în solurile agricole şi silvice din b.h. Bârzava, jud. Caraş-Severin, The 2nd International Symposium "Preventing and Fighting Hydrological Disasters", 29 june-01 july 2006, Timisoara, , ISBN (10) 973-638-263-X, (13) 978-973-638-263-5, pg. 66, T3.15

[5]*K.E., Trott, M.J., Singer*, Relative erodibility of 20 California range and forest soils, 1983, Soil Sci. Soc of Am J. 47;

[6]*B.N., Wilson*, Development of a fundamentally based detachment model, Transactions of ASAE 36(4), 1993;

[7]*W.H., Wischmeier, D.D., Smith*, A universal soil-loss equation to guide conservation farm planning, Proc. Of Seventh International Congress of Soil Science, 1960, 418-425;

[8] *W.H., Wischmeier, J.V., Mannering,* Relation of soil properties to its erodibility, Soil Sci. Soc. Of Am. Proc. 33, 1969, 131-137.