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Soil Microaggregation as an Index of Erosion Resistance

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The relationship between the erosion resistance of different soils of the European USSR and their microaggregation is established, the aggregating role of humus is evaluated, and a conclusion is formed about the validity of a two-level system of indices.

Among the zonal factors determining the formation of the water-erosion process on cultivated lands, the evaluation of erosion resistance remains insufficiently developed. At present, relative coefficients of erodibility have been proposed for different genetic types and subtypes of arable soils of the European USSR [5], which are required for the application of soil-erosion equations used in the United States to soils of our country. Values of bottom scouring velocities have been obtained [4] which allow a hydromechanical model of erosion [6] to be used in designing many large irrigation systems. Material has accumulated on erosion resistance of soils of Ukraine and Moldova [7], obtained by the artificial sprinkling method. However, the highly laborious nature of the experiments, errors in interpolating values for soils of different granulometric composition and individual degrees of erosion, the need for periodic updating of the data in conjunction with the strengthening of processes of agrophysical degradation, and other factors have prompted a search for a dependence of soil erosion resistance on diagnostic indicators that do not require complex determinations. We have tried to establish a relationship between the soil-erosion resistance and microaggregation and also to evaluate the aggregating effectiveness of humus for different soil types.

Erosion resistance (or its inverse characteristic, erodibility) of soils was evaluated by artificial sprinkling using a continuous-drip irrigation device. A standard technique [8] was used to conduct the experiments and process the results. The artificial sprinkling experiment, which lasted more than three hours, was repeated once. Applied as criteria for erosion resistance of the studied soils were the mean flow turbidity in the concluding phase of the test with a precipitation intensity of 2.5 mm/min (ρ_0, g/l) and the sediment flow rate in g/s from a 1-m-wide portion of the slope under conditions of a quasi-steady regime (R_0).

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Table 1

Indices of Aggregation and Erodibility of Soils of the Botna-Byk Interfluve (Moldova)

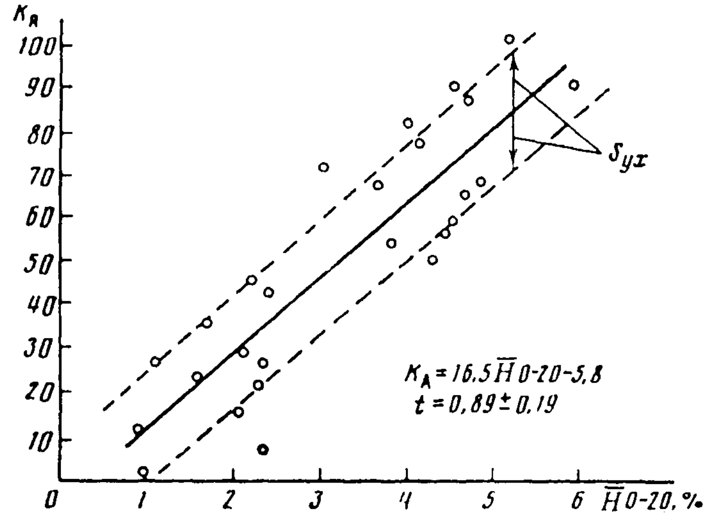
Soil, soil preparation (June)	K_A, %	ESP, %	$\bar{d}$, mm	ρ_0, g/l	R_0, g/s•m
Carbonate heavy loam Chernozem, irrigation, barley with an additional sowing of alfalfa after maize	43	9.6	0.55	3.87	0.16
Carbonate heavy loam slightly eroded Chernozem, maize after maize:					
Irrigation	38	13.6	0.45	4.84	0.24
Dry farming	42	14.9	0.30	6.95	0.24
Carbonate heavy loam Chernozem, irrigation, potato after winter wheat	43	11.1	0.54	3.00	0.24
Carbonate heavy loam Chernozem, dry farming, maize after maize	44	12.0	0.88	8.30	0.22
Conventional heavy loam Chernozem, dry farming, sunflower after maize	36	14.3	0.43	5.16	0.27

To determine the degree of aggregation, we sieved the soil sample for 30 s through a tower of screens which had cell diameters of 0.25, 0.20, 0.16, 0.10, 0.065, and 0.05 mm. We used an instrument designated "Model 029 laboratory device for determining functional composition." The determinations were repeated 24 times. Then with an MBS-9 microscope (98× magnification) in reflected light, the content of fragments of rocks and minerals—that is, elementary soil particles (ESP, percent) and also microaggregates—was determined by direct count. As a result, we calculated the coefficient of aggregation, percent:

$$K_A = \frac{a - b}{a} \cdot 100 \quad (1)$$

where a is the content of particles and aggregates with diameter (d, mm) $0.25 > D > 0.05$, and b is the content of ESP of the same sizes.

Table 1 presents results of studies conducted in 1988. In conjunction with the different degree of soil erosion, the thickness of the humus horizon varies broadly: 36–120 cm. Individual physical indices of the solid phase (degree of structure, water resistance, water strength of aggregates after Andrianov-Kachinskiy, etc.) in the investigated soil also differ greatly. Especially vari-



Dependence of coefficient of aggregation (K_A) on humus content in layer of 0–20 cm of zonal soils of the Russian Plain. $K_A = 16.5$, $\overline{H} = 5.8$, $r = 0.89 \pm 0.19$.

able are the values of the weighted mean diameter of water-resistant aggregates (d), primarily due to differences in soil preparation and precursors. Data on the degree of variability $\bar{d}$ are presented below. However, the clearly expressed stability of the value of K_A (coefficients of variation are less than 5 percent) suggests that microaggregation is a fully defined hierarchic structural level of the soil as an independent natural body. This confirms the conclusion made by Voronin [2]: the relationship between unaggregated ESP and microaggregates on similar pedogenic rocks depends on the type of pedogenesis. The Shvebs technique [8] is aimed at evaluating erosion resistance due primarily to the genetic features of soils; therefore, along with K_A the sediment flow or stream load also turned out to be an indicator that varies little (Table 1). Thus the coefficient of aggregation may be viewed as a quantitative indicator of the erosion resistance due to genetic features of soils and their steady variations under the influence of the directed development of the modern pedogenic process. Unlike K_A, for the same soil, the sum of ESP is subject to greater variability; the coefficient of variation may reach 30 percent. It is enough to state that it may vary by a factor of 2 or more as a result of the processing technology alone; in terms of information, this is a substantial addition to K_A.

Earlier studies [7] demonstrated that in zonal soil series of the European USSR in correlating erodibility (R_0) with the Kachinskiy coefficient of dispersion, the Fageler structural factor, and the aggregation index after Beiver and Roades (K_A) the best relationship exists between R_0 and K_A (correlation ratio –0.94 ± 0.05). These materials were supplemented by the results of studies in Moldova (Table 1). As a result of approximation, we obtained an exponential function of the form

$$R_0 = 0.47 \cdot K_A^{-0.25} \quad (2)$$

Table 2

Variation of Humus Content, Microaggregation, and Erodibility of Arable Soils of Zonal Series of European USSR

Soil type, subtype	Humus content interlayer,0–20 cm	K_A	R_0, g/s•m
	%		
Regraded, typical, conventional Chernozems	4–6 or more	≥77	0,14–0,16
Dark Gray, Gray Forest	3,0–5,7	36–77	0,16–0,19
Podzolized, leached, southern Chernozem	2,0–3,5	15–36	0,19–0,24
Carbonate Chernozems of Moldova	2,0–2,7	20–27	0,22–0,24
Dark Chestnut and Chestnut	1,5–2,0	3–11	0,27–0,30

Because the source data reflected a zonal soil series with wide variation of K_A (from 2 to 97 percent), function (2) is adequately substantiated. This lets us predict the erodibility of soils by evaluating their aggregation.

The degree of aggregation after Beiver and Roades [3], proposed in 1932, is structurally similar to Eq. (1), but for its application we need the results of granulometric and microaggregate composition (content of mechanical elements and microaggregates > 0.05 mm). The correspondence of the values of K_A determined from results of granulometric and microaggregate composition to the values calculated according to Eq. (1) has been established for Chernozem soils based on 32 pairs of determinations in the range values of 28–56 percent. A stable linear relationship has been established, and the correlation coefficient was 0.97 ± 0.22. Comparative evaluation of modifications of the index by the difference method according to conjugate sets demonstrated that the differences are within the limits of random fluctuations. However, it seems more productive to evaluate soil aggregation according to the new modification from the viewpoint of technical implementation.

Moreover, the fact of accelerated movement of particles with diameter ≥ 0.05 mm in water is essential [2]; this exceeds the real of application of Stokes' law, which is the basis for determining the granulometric composition of the soil.

In the zonal cross section (from Sod-Podzolic to Dark Chestnut soils), we identify the close dependence of the coefficient of aggregation of the 0- to 20-cm layer of arable soils (K_A) with the humus content (H) in it (see figure). The established paired relationships between erodibility and the coefficient of aggregation and that between the latter and the humus content let us identify general principles of the predisposition for the water erosion process to appear on cultivated lands with consideration of the geographic soil zoning (Table 2). In analyzing a related series of soils with differences in humus content caused by other factors, for example, by the change in the humus content within a single soil type (subtype), but different degrees of erosion, the index K_z may involve analysis of other indices of the agrophysical state.

In examining virgin and irrigated soils as well as soils that restore the humous state, a question arises not only about the quantity, but also the quality of the humus, particularly its aggregating effectiveness. We proposed that it be evaluated according to the ratio K_A/H, which shows what percentage of aggregation corresponds to 1 percent of the given humus. Investigations in the Southern Steppe of the Ukrainian SSR (Table 3) established that humus is more effective in the aggregation of arable soils than in virgin soils. This is due to the fact that, with the worse wetness regime of virgin soils and slower velocity of mineralizing processes, as the detritus and pre-humus material accumulates, they significantly distort the true participation of specific humous materials in the formation of biomineral complexes.

At the stage of creation of the humus profile of young soil on a hill, we note the input of a large amount of plant material with litter fall and dying roots, as under virgin soil conditions. However, as a result of the relative equilibrium of the processes of humification and mineralization of organic material, the rejuvenated humus is no less effective in the soil aggregation than in a plowed field. It is interesting to note that, in studying initial pedogenesis on recultivated lands [1], a similar conclusion is made: In soil fertility, a decisive role is played not by humus in general, but its biologically active portion. Upon irrigation of Dark Chestnut soils, the substantial transformation of many processes, primarily physico-colloidal and biological, leads to formation of a water-resistant structure in the optimal range. In our view, this fact is closely related to the recently established principle of an increase in erosion resistance of Chernozem and Dark Chestnut soils in irrigated systems of southern Ukrainian SSR [9].

The interpretation of the data is well complemented by the total content of unrelated ESP, which first was defined without any destructive impact on microaggregates, and second also includes fractions which do not consider the structural formula of K_A (that is, > 0.25 and < 0.05 mm). Thus, in irrigated sandy loam soils, along with the high aggregating effectiveness of humus, we note a high content of unaggregated particles (51 percent), probably due to the low effectiveness of humus for particles > 0.25 mm (comparison with the data in Table 1 for heavy loam soils is indicative).

Discussion of the results obtained suggests a conclusion about the validity of a two-level system of indices that determine soil-erosion resistance. In an interzonal comparison of the magnitudes of erosion on cultivated lands with similar agricultural crop levels, the erosion resistance is obtained fairly easily by such indices as the aggregation coefficient and humus content. At the regional level, the appearance of features caused by specific natural and anthropogenic processes determines the need to involve more specific, but also more sensitive, processes (degree of structure, water resistance, water permeability, aggregating effectiveness of humus, etc.). In this regard, it is advisable to examine some calculation methods for predicting water-erosion losses of soil and considering its anti-erosion properties in a concrete example.

Unlike the Shvebs model, in the model of Ts.E. Mirtskhulava, the soil block is an indicator of a different hierarchic level than the absolute and relative characteristic of erodibility, that is, the size of eroded particles and aggregates.

The weighted mean diameter of water-resistant aggregates is a parameter that varies significantly in terms of space and time. Even in a stationary field experiment (Donets Erosion Control

Table 3

Aggregating Effectiveness of Humus for 0- to 20-cm Layer of Different Soils

Soil and sampling type	Humus (H)	K_A	ESP	$\frac{K_A}{H}$
	%			
Southern sandy loam Chernozem				
Virgin	2,80	43	29,5	15
Plowed	1,51	37	36,0	25
Dark Chestnut light loam forest strip of acacia	3,88	36	31,5	9
Dark Chestnut light loam irrigated plowed field	1,78	59	50,8	33
Young soil on hill, grass cover	1,51	40	35,4	27

Experimental Station, conventional low-humus slightly eroded Chernozem), the variability (1986–1987) caused by cycles of application of agrotechnology and the time factor defines the value of the coefficient of variation: 24 percent. For example, we point to a ranked series of observed values ($\bar{d}$, mm): 0.38, 0.41, 0.43, 0.44, 0.46, 0.50, 0.51, 0.52, 0.53, 0.53, 0.56, 0.58, 0.61, 0.61, 0.61, 0.64, 0.68, 0.70, 0.72, 0.79, 0.86, 0.91. Thus, when using Mirtskhulava's mechanical model of soil erosion, we must take statistically substantiated values of the weighted mean diameter of the aggregates. In selecting a concrete value of $\bar{d}$, we believe it is advisable to begin from the general logical rule that, to ensure the reliability of the designed complex of erosion-control measures, the numerical substantiation of the parameters of the calculation scheme should let us predict the result for a worse combination of conditions of occurrence of water erosion. Thus it seems justified to use the weighted mean diameter of water-resistant aggregates of 10 percent security or, in the terminology of serial statistics, the values of the lower decile (value of $\bar{d}_{\alpha}$, where α = 0.1). For the discussed example, it was 0.42 mm.

Calculations by both techniques were carried out for the Bobrinets district of the Kirovograd Oblast of the Ukrainian SSR. The predominant soil is conventional thick low-humus Chernozem. The area of the cultivated field is 114,200 ha, of which the soils which were not subjected to erosion occupy 57,700 ha, while the slightly, moderate, and highly eroded soils occupy 44,500, 11,200, and 800 ha, respectively. The weighted mean values of the slope of the arable lands comprise 2.3 percent of the length of the elementary slope of 992 m.

The values of the indices of the formula for the mean annual modulus of storm erosion of the soil after Shvebs [8] are as follows: hydrometeorological parameter of 10 percent security (K_{hm}, Bobrinets Weather Station) 7.6 t/ha, and weighted mean value of the relative characteristic of erodibility (j_R) 1.39.

For the parameters of the Mirtskhulava hydromechanical model of surface runoff [6], we have adopted the following values: coefficient of runoff of 10 percent security (σ) 0.4, duration of erosionally hazardous portion of storm of 10 percent security (T) 2640 s, mean intensity of this storm (I) 1.4 mm/min, density of soil structure (γ) 1.3 t/m^3, weighted mean diameter of eroded particles and aggregates (d) 0.001 m, weighted mean diameter of water-resistant soil aggregates ($\bar{d}$) of 10 percent security 0.0005 m, coefficient of irregularity (n_0) 0.0116; $n_0 = (0.7\,\bar{d})^{1/c}/22.2$, permissible velocity $\left(V_{\Delta_{per}}\right) = 0.062$ m/s, $w = 10$ s^{-1}.

The calculations have demonstrated that, for a fallow surface, the erosion from arable lands of the Bobrinets district is 14.8 t/ha according to the Shvebs formula and 14.3 t/ha according to the Mirtskhulava formula. The convergence of these results shows that the evaluation of the erosion resistance of soils with respect to agrophysical indices of different hierarchic levels is not contradictory, and preference in the application of a given level should be determined by the purpose of the investigations.

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