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The effect of soil physical parameters on soil erosion

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Introduction

The factor *K* of the Universal Soil Loss Equation (WISCHMEIER, W.H.–SMITH, D.D. 1978) is the most widely used quantitative value to characterise the erodibility of soils. However, calculations based on the nomogram seemed to overestimate soil erodibility in Hungary. Within the framework of a bilateral scientific cooperation between the German Research Society (Deutsche Forschungsgemeinschaft) and the Hungarian Academy of Sciences (KERTÉSZ, Á.–MÁRKUS, B.–RICHTER, G. 1995) an attempt has been made to determine the K -factor by long term soil erosion plot measurements under natural rainfall events and applying rainfall simulation experiments. Comparing these values with those calculated by the USLE a considerable overestimation by the latter became evident. The experiments to determine the *K* factor offered also a very good opportunity to monitor changes in soil characteristics and soil erodibility.

The main objective of this paper is to demonstrate on the basis of plot measurements how soil erodibility changes over time. Rainfall simulation experiments as well as soil loss measurements after rainfall events were carried out on the plots during 8 years.

The K-factor

According to WISCHMEIER, W.H.–SMITH, D.D. (1978) the K-factor, i.e. the soil erodibility factor in the Universal Soil Loss Equation (USLE) is a quantitative value determined experimentally. "For a particular soil, it is the rate of soil loss per erosion index unit, as measured on the 'unit' plot ... " (i.e. standard plot).

As it is well known, the factor *K* is easy to calculate if rainfall and soil loss measurements are available. In this case

$$K = A\,R^{-1}$$

where A is soil loss (t ha^{-1} $year^{-1}$) and R [kJ m^{-2} mm h^{-1}] is the rainfall and runoff factor of the USLE. K is given in (t ha kJ^{-1} mm $^{-1}$), as L = S = C = P = 1 for the standard plot.

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Rainfall and soil loss can be measured either during natural rainfalls or by rainfall simulation experiments. .

The factor *K* can be calculated by an empirical equation, or it can be determined from a nomogram. The equation is as follows:

$$K = 2{,}77 \bullet 10^{-6} \bullet M^{1{,}14} \bullet (12\text{-}OS) + 0{,}043\ (A\text{-}2) + 0{,}033 \bullet (4\text{-}D)$$

Where M = (silt + very fine sand)* silt + sand, OS = % organic matter, A = Aggregate class, D = Permeability class.

Experiment sites and methods

Soil erosion plot measurements were carried out on the plots of Csákvár Research Station *(Photo 1).* 4x2 of the 5x2 plots (the latter is for control) of the Station represent typical soils of the northern catchment of Lake Balaton, 1x2 plots were established on the *in situ* soil. In case of the four other soils the upper 25 cm was removed from the soil profile, transported to the station and built in after removing the original, *in situ* upper 25 cm of the soils. The slope angle is 8° and the plots are 1 m wide and 10 m long. *Table 1* shows the original physical properties of the soils.

Photo 1. The plots of Csákvár Research Station

Table 1. Changes in soil properties (1990–2000)

Plot	Organic matter (per cent)		$CaCO_3$ (per cent)		pH		Clay		Silt		Very fine sand		Sand	
	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
A	2.71	1.83	15.13	8.3	7.76	7.70	22.6	9.8	40.3	61.4	8.5	11.4	37.1	28.8
B	11.09	1.67	1.56	0.00	7.39	7.55	15.8	15.8	13.6	24.7	12.8	16.3	70.6	59.5
C	7.54	2.42	46.22	27.55	7.80	7.70	29.5	13.9	50.4	72.3	5.5	5.3	20.1	13.8
D	6.18	4.25	7.35	2.35	7.61	7.30	43.9	32.1	45.0	61.9	4.5	3.6	11.1	6.1
E	6.36	3.87	27.63	6.15	7.73	7.55	32.3	23.9	55.6	71.6	9.5	3.1	12.1	4.5

The soil of Plot A is the *in situ* soil at the station, a skeletal soil (Lithosol, sandy silt) developed on weathered dolomite. The percentage of rock fragments in the soil is rather high (11 per cent). Plot B represents volcanic soils formed on a tertiary sand full of weathered basalt fragments (7 per cent). It is an eroded brown earth (Inceptisol, silty sand). Plot C is covered by an eroded brown earth (Inceptisol, silty clay) coming from the upper slope of a vineyard the original parent material of which is limestone and marl. The share of rock fragments is 7 per cent. The soil of plot D (Rendzina, rendoll, silty clay) was developed on a weathered limestone. It has been used for pasture over a long time. The soil of Plot E comes from the lower part of the same vineyard as Plot C. The upper horizons of the soil profile have a colluvial character. The type of the soil is the same as that on Plot C, but the texture is slightly different (the percentage of silt and clay is somewhat higher resulting from the different texture of the soil layers, eroded from the upper part of the soil).

The station disposes of a relatively wide range of texture classes, from clayey sand and sandy loam to low and high silty clay.

Two parallel plots were built up at each experimental site in order to provide control. From all sites the vegetation was removed to simulate conditions prior to sowing (seedbed preparation).

Results

Changes in soil properties are presented in *Table 1*. The plots were free of any vegetation, i.e. black fallow for 10 years of observation. As a consequence of this the organic matter content of the soils diminished on each plot. A very remarkable change (more than 50 per cent) could be detected on plots B and C where the original soils were strongly eroded. In the case of a strongly eroded soil the organic matter is probably of recent origin therefore its humification is in an early stage and the relation of the organic matter with other soil components is loose. The removal of the organic matter of an eroded soil is therefore much easier than in the case of a non-eroded soil.

The decrease of the $CaCO_3$ content could be proved on each plot. The relatively high $CaCO_3$ values of plot C are due to the high content of the uppermost soil horizon of this strongly eroded soil which partly consists of parent material, i.e. loess.

Plot E has also a high calcium carbonate content for the same reason. The calcium carbonate is partly removed by overland flow. The greater part of it infiltrates into the soil due to its relatively high solubility in water. The amount of leached calcium carbonate depends also on soil permeability. In case of plots D and E the decrease of calcium carbonate was much more than 50 per cent pointing to good permeability and conductivity.

The pH of the investigated soils hardly changed during 10 years of observation. Because of the remarkable decrease of calcium carbonate content there is a slight decrease of pH.

Changes in soil texture were also investigated. Four texture classes were identified to provide a basis to determine the *K* factor by the nomogram of Wischmeier. The four classes were as follows (mm):

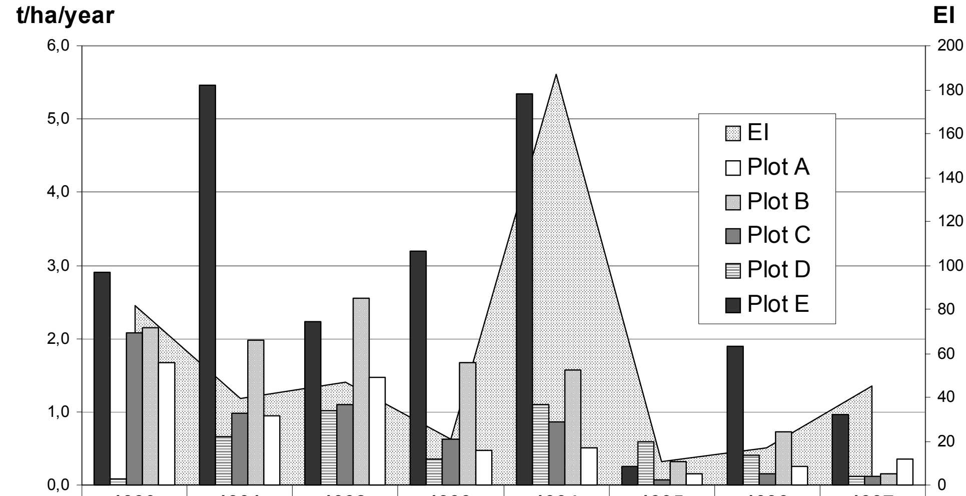
Clay	0–0.002
Silt	0.002–0.1
Very fine sand	0.05–0.1
Sand	0.1–2.0

The data presented in *Table 1* prove that there has been a significant change during the 10 years of observation in soil texture properties of all the plots. The general trend is a decrease of clay and sand content with a concomitant increase of silt content. The explanation for this is cultivation. A thin structureless layer develops on the surface after each rainfall event of high intensity, which keeps the water on the surface owing to its bad permeability. This layer was loosened to a depth of 5 cm by mechanical methods after each event.

The loss of $CaCO_3$ and organic matter content and the continuous leaching of material binding the aggregates destroy the structure and sooner or later lead to the total decay of aggregates. The material of the decomposed aggregates will be rearranged under the impact of water. A low intensity rainfall mobilises the silt fraction first, which is removed very easily. The mobilised silt fraction infiltrates into the underlying soil layers. As a consequence, the texture of the surface layer is changed toward the prevalence of sand and clay content. As the rainfall event proceeds the surface layer of the soil will be saturated with growing clay minerals and infiltration stops. Saturated overland flow mainly transports sand and clay. As mentioned above the thin surface layer is loosened and destroyed by each event and the process restarts with the next rainfall.

As a consequence of this process series the sand and clay fractions leave the plots with the overland flow and the silt fraction migrates into the deeper layers of the soil resulting in a higher percentage of silt along these deeper horizons.

The comparison of the annual soil loss averages of the five different soils over the 8 years of measurement shows a decreasing tendency *(Figure 1)*. The lowest value is 0.1 t/ha (Plot D, 1997), where the original silt content of 45 per cent raised to 62 per cent. Due to differences in rainfall intensity, and especially as a consequence



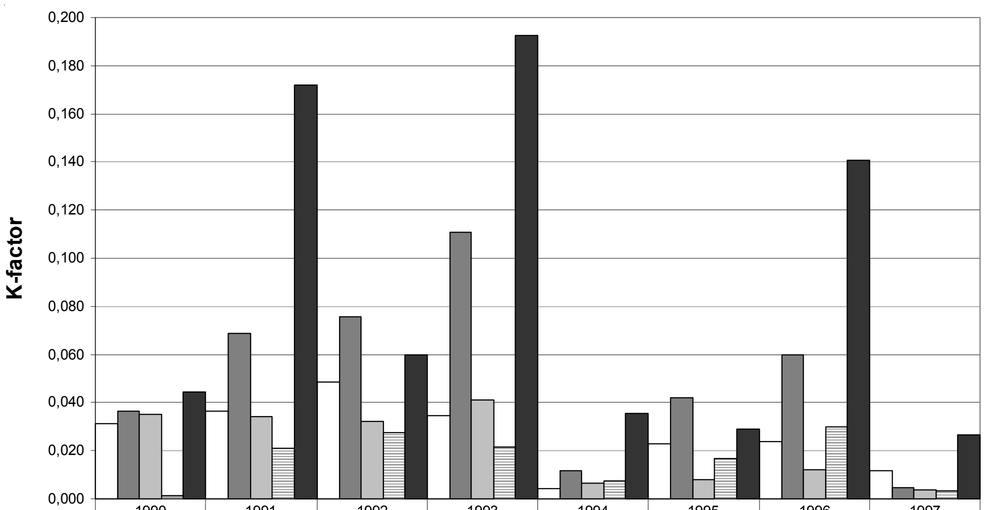
	1990	1991	1992	1993	1994	1995	1996	1997
▨ EI	**81,863**	**39,654**	**46,629**	**20,782**	**186,857**	**10,512**	**16,778**	**45,156**
□ Plot A	**1,670**	**0,946**	**1,477**	**0,469**	**0,505**	**0,158**	**0,260**	**0,349**
░ Plot B	**2,152**	**1,976**	**2,555**	**1,666**	**1,577**	**0,319**	**0,728**	**0,156**
▓ Plot C	**2,080**	**0,979**	**1,093**	**0,617**	**0,854**	**0,061**	**0,148**	**0,126**
▤ Plot D	**0,091**	**0,667**	**1,020**	**0,358**	**1,107**	**0,591**	**0,402**	**0,111**
■ Plot E	**2,900**	**5,452**	**2,230**	**3,199**	**5,338**	**0,245**	**1,888**	**0,962**

Fig 1. Rain energy (EI) and soil loss values 1990–1997

of extreme events (e.g. in 1994) there were differences in soil loss, too. Plot E is a good evidence to this. High soil loss values were measured on Plot E from the beginning of the measurements because of the low rock fragment content of this plot.

Changes of soil loss year by year are presented in *Figure 1.* In most cases the highest soil loss values were calculated for plot E. The same is true for the *K* factor values (*Figure 2*), i.e. the highest *K* factor values were measured on this plot. Plot E has a colluvial soil with sediment layers originating from the upper part of the slope where a strongly eroded soil can be found. The high erodibility of Plot E is therefore obvious. In most cases Plot B has the second highest value. Plot B has a volcanic soil with loose structure and high sand content (70.9 per cent in 1990) providing the explanation. The soil plot C is the strongly eroded soil from the upper part of the same slope where the soil of plot E is originated. Probably because of its high clay and silt content this plot does not show high values of soil loss.

The uppermost soil layer which was transported from the catchment to plots in 1989 became thinner and thinner being gradually removed by soil erosion and it was not refilled again with soil. After 10 years hardly any soil remained on the plots to be removed and the ratio of rock fragments grow tremendously. Their high percentage on the surface provided protection against erosion.



	1990	1991	1992	1993	1994	1995	1996	1997
□ Plot A	0,031	0,037	0,049	0,035	0,004	0,023	0,024	0,012
■ Plot B	0,036	0,069	0,076	0,111	0,012	0,042	0,060	0,005
□ Plot C	0,035	0,034	0,032	0,041	0,006	0,008	0,012	0,004
▤ Plot D	0,001	0,021	0,027	0,022	0,007	0,017	0,030	0,003
■ Plot E	0,044	0,172	0,060	0,192	0,036	0,029	0,141	0,027

years

Fig 2. K factor values 1990–1997

No general trend of soil loss could be identified for any of the plots. An explanation for this is the critical influence of the *R* factor on the actual values of the *K* factor (Römkens, M.J.M. 1985). A longer measurement period of at least 25 years would be necessary for this. The fluctuation of soil loss values follows those of the *R* factor.

Tables 2 and *3* and *Figure 2* show the close relationship between the changes in *K* factor values and the proportion of rock fragments. Calculating the *K* factor values by the nomogram leads to an overestimation. *K* factor values identified by measurements are much lower than those calculated by either the nomogram or by the equation. In case of plots A, C and E the equation could not be applied because the combined ratio of sand and very fine sand exceeded 70 per cent (see *Table 3*).

Table 2. Changes in K factor values

Parameters	Plots									
	1990					2000				
	A	B	C	D	E	A	B	C	D	E
K-factor (pre calculated)	0.29	0.13	0.25	0.18	0.27	0.73	0.42	0.57	0.30	0.38
K-factor (not corrected)	0.36	0.20	0.33	0.21	0.30	0.78	0.49	0.64	0.41	0.47
Corrected K- factor	0.28	0.17	0.28	0.20	0.29	0.63	0.31	0.32	0.24	0.28

According to the results contributed in this paper the nomogram and the equation can be applied in Hungary only if a correction factor is determined by rainfall simulation experiments.

Table 3. Changes in physical properties of the soil and in K factor values based on the equation

Year	Site, plots	Silt + very fine sand	Clay	M	Organic matter (per cent)	Aggregate class	Perme-ability class	K-factor (not corrected)	Skeleton (Correction factor)	Corrected K- factor
1990	A	48.87	22.	3782.4	2.70	3	3	0.37	11	0.28
	B	25.45	15.	2142.6	11.00	3	3	0.21	7	0.18
	C	55.91	29.	3941.6	7.00	3	3	0.35	7	0.30
	D	49.55	43.	2779.5	6.00	2	3	0.22	3	0.21
	E	60.33	32.	4084.4	6.00	2	3	0.32	3	0.30
2000	A	72.90	9.8	–	1.80	3	3	–	15	–
	B	41.10	15.	3452.2	1.67	3	3	0.38	21	0.23
	C	77.70	13.	–	2.40	3	3	–	30	–
	D	65.50	32.	4454.2	4.20	2	3	0.34	21	0.21
	E	74.70	23.	–	3.80	2	3	–	24	–

Conclusion

Soil erodibility is usually given by the K-factor of the USLE. In most cases the nomogram of Wischmeier, W.H.–Smith, D.D. (1978) is applied. An attempt has been made to determine the K -factor by soil erosion plot measurements. Comparing these values with those calculated by the USLE nomogram a considerable overestimation by the latter became evident. The experiments to determine the *K* factor offered the possibility to monitor changes in soil characteristics and soil erodibility.

The main objective of this paper is to demonstrate how soil erodibility changes over time. Rainfall simulation experiments as well as soil loss measurements after rainfall events were carried out on the plots during 10 years. Soil properties before and after the experiments were compared and evaluated.

The plots were free of any vegetation, i.e. black fallow for 10 years. As a consequence of this the organic matter content of the soils diminished on each plot. The decrease of the $CaCO_3$ content could be proved on each plot. The pH of the investigated soils hardly changed during 10 years of observation. Because of the remarkable decrease of calcium carbonate content there is a slight decrease of pH. There has been a significant change during the 10 years of observation in soil texture properties of all the plots. The general trend is a decrease of clay and sand content accompanied by an increase of silt content. No general trend of soil loss could be identified during the measurement period.

Keywords: soil erodibility, soil erosion, rainfall simulation

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