Soil Erosion by Water in Perennial Plantations of the Ilok Region

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Summary

Soil erosion by water is a natural process, in which soil particles get detached from soil mass, transported and deposited at a distance. Erosion depends on a number of natural factors, such as terrain slope, amount and intensity of precipitation, soil (structure, mechanical composition, permeability, infiltration, etc.), wind, crop rotation, and plant cover. Soil erosion by water is one of the most dangerous soil damaging processes. In the hilly part of the studied region, erosion causes great problems to fruit and wine production. The principal goal of this work is to find ways of reducing erosion by applying appropriate agricultural management practices, different methods of plant residue management, and radical conservation practices. Research results indicate that erosion cannot be prevented (especially in case of extreme weather conditions – very intensive precipitation), but it may be reduced to a tolerable level by selecting optimal agricultural practices.

Key words

soil erosion, perennial plantations, type of soil, grass covered inter-row space

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Introduction

The main research goal is to attempt to determine the most reliable system of soil tillage and plant production practices under the conditions of multiple land utilization - optimal from the aspect of perennial plantation production in the wider area of Ilok. Thus defined goal of soil erosion investigations within this work can be summarized in a few sentences.

Investigate the effects of the tillage method that is commonly applied or could be applied in this region, as well as of different treatments of forecrop residues on erosion intensity, i.e., determine the “conservation value” of perennial plantations - indicator C (soil surface covering). Considering the natural spatial distribution of soils, pedogenetic uniformity of soil units, and agro ecological valorisation of potential land use in agriculture, soil erosion was calculated for three soil types and six lower systematic units that are susceptible to erosion because of natural physical factors, notably relief (slope). Investigations were done on the following soil types: Regosol on loess (according to WRB – Haplic Regosols); Eutric cambisol typical on loess (according to WRB – Eutric Cambisols); Eutric cambisol luvic on loess; Chernozem calcaric (according to WRB – Kastenozems); Chernozem, luvic and Chernozem cambic on loess. The described soil and climate factors will be used to check the reliability of the prognostic method - USLE (Universal Soil Loss Equation - Wischmeier and Smith, 1978), which is generally regarded as standard, though it is being revised and revalidated.

Materials and methods

Research methods included field investigations of soil properties, their spatial distribution, laboratory analyses and data processing, climate analysis of the Ilok region and relevant calculations according to the USLE method. To complement the data of the Basic Soil Map of the Republic of Croatia, scale 1: 50000, for sheet sections Vukovar 1 and 2; Bačka Palanka – 3 (Bogunović et al., 1971), additional field investigations were conducted in the summer of 1998 (Šalinović et al., 1999), while the first-named author performed personal investigations in the spring and summer of 2001 (Kustura, 2002). Field and laboratory investigations were carried out according to the recommendations given in the Manual for permanent soil monitoring in the Republic of Croatia (Mesić et al., 2006); customary methods were applied as shown in Table 1.

Erosion was calculated using the Universal Soil Loss Equation: **A = R x K x L x S x C x P,** where: (**A** = average soil loss in t/ha/year; **R** = rain erosivity – rain intensity

Table 1. The list of applied methods

Parameter	Method
Soil sampling	ISO 11074-2:1998
Soil sample preparation for the chemical and physical analyses	HRN ISO 11464:1994
Determination of organic matter content - Vario MACRO CHNS Elemental Analyzer	HRN ISO 10694:1995
Determination of pH value ($KCl/CaCl_2/H_2O$)	HRN ISO 10390:2005
Determination of P_2O_5 and K_2O value	AL method
Determination of total nitrogen content by dry combustion - Vario MACRO CHNS Elemental Analyzer	HRN ISO 13878:1998
Determination of total carbon (TC) content by dry combustion - Vario MACRO CHNS Elemental Analyzer	HRN ISO 10694:1995
Determination of soil mechanical content	HRN ISO 11277:1998

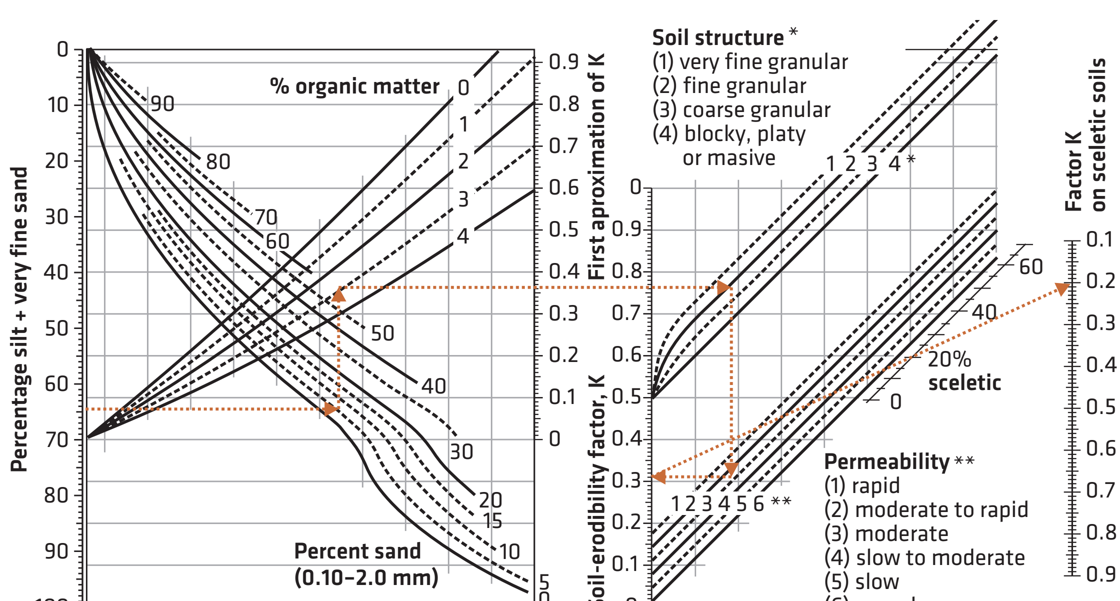


Figure 1.
Soil erodibility
(K) nomograph

indicator calculated on the basis of rain kinetic energy causing surface runoff ($V/m^2/h$); **K** = soil erodibility – soil properties; **L** = slope length (m); **C** = plant cover and soil management; **P** = measures of soil protection against erosion (contour ploughing, belt sowing, terracing, etc.).

Rain erosivity (R) indicator depends solely on rain characteristics (amount and intensity) and cannot be influenced by agrotechnical or conservation practices. To calculate rain erosivity indicators, the datas from the meteorological station Ilok were use for the studied period 1966-1985, according to the Fournier equation (1960):

$R=\sum p^2 : P$

Where: **p** – mean monthly precipitation in mm, **P** – annual precipitation u mm, and according to Schwertman et al., (1987):

$R = 0.083 * N - 1.77$

Where: R–annual rain erosivity, **N**–annual amount of precipitation

Soil erodibility (K) was determined using the nomogram (Wischmeier, 1971) shown in Figure 1.

Table 2. Tolerable erosion in the Ilok region

Type of soil and lower systematic unit	Soil loss tolerance - T, t/ha/year
Regosol on loess	4
Eutric cambisol luvic on loess	7
Eutric cambisol typical on loess	8
Chernozem luvic on loess	9
Chernozem cambic on loess	9
Chernozem calcaric on loess	10

$C = T / RKLS$

Soil loss tolerance (T) is the amount of soil annually lost through erosion that is considered acceptable or tolerable for the studied region and soil type (Table 2). Soil loss tolerance was estimated according to the criteria of Kisić et al., (2003).

Results and discussion

Erosion was calculated for three soil types and six lower systematic unit which are susceptible to erosion due to natural spatial factors, notably the relief (inclination). Table 3 provides a list of soils, according to the effective soil classification (Škorić et al., 1985), with areas in hectares and percent share in the studied region (Kustura, 2002).

Table 3. The list of soils

Type of soil and lower systematic unit	The area of lower systematic unit		The area of soil type	
	ha	%	ha	%
Chernozem calcaric on loess	2.242.22	18.7		
Chernozem luvic on loess	1.712.7	14.3	4.896.7 40.8	
Chernozem cambic on loess	941.3	7.8		
Regosol siliceus calcaric	1.364.2	11.4	1.364.2	11,4
Eutric cambisol typical on loess	1.020.6	8.5	2.760.4 23.0	
Eutric cambisol luvic on loess	1.739.8	14.5		

Topographic indicator (LS) shows the influence of slope length (L) and slope inclination (S) compared to the standard length of 22.1 meters and uniform inclination of 9%. For standard conditions, the LS indicator amounts to 1. The latter value decreases on smaller inclinations and flatter slopes, while its value increases with increased inclinations and slope lengths. In this study, indicator LS was calculated by the equation of Schwertman et al., (1987):

$\mathbf{LS = (S/9)\surd\ (L/22)(S/9)}$

Where: L–slope length and S–slope inclination in %

Minimum tolerated soil surface covering **(indicator C)** for the studied soils was calculated by the equation of Alberts et al., 1985 and Kisić et al., 2005:

(1) Due to war activities, no meteorological data for Ilok are available for the period 1991-1998. Older data are used for this reason)

Climate conditions and soil types of the studied region

Climate conditions are among the most important factors that directly influence the direction and course of pedogenesis, as well as agricultural production of a region. The climate of a region is the most strongly affected by precipitation and air temperature. Further text deals with the major meteorological elements obtained from the agro-climatological station Ilok for a period of twenty years (1966-1985). Air temperature influences soil erosion in two ways. On the one hand, it affects on formation of different soil types, which in turn prevent intensive erosion in different ways and, on the other hand, air temperature influences formation of vegetation cover,

Table 4. Average monthly temperatures (°C) and monthly sums of precipitation (mm) in the research period from 1966 to 1985

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Aver./Σ
Temperature	-0.4	2.5	6.9	10.9	16.2	19.0	20.5	20.0	16.5	11.5	6.0	1.9	11.0
Precipitation	44	43	41	51	59	91	78	70	45	49	51	52	674
	Maximum daily precipitation (mm)												Max.
	32	40	34	33	35	112	56	65	51	34	24	46	112

Table 5. The rain erosivity at the Ilok meteorological station (1966–1985)

Year	Schwertman	Fournier	Year	Schwertman	Fournier
	The value of R indicator			The value of R indicator	
1966	56	76	1978	50	81
1967	50	64	1979	51	63
1968	59	78	1980	59	77
1969	66	110	1981	63	85
1970	63	74	1982	45	66
1971	33	42	1983	50	67
1972	59	108	1984	54	65
1973	46	85	1985	55	71
1974	54	76	Average	54	77
1975	60	106	Minimum	46	42
1976	51	71	Maximum	66	110
1977	57	71			
Average (Schwertman et al.) = 54			Average (Fournier) = 77		

which is an essential factor of halting soil erosion. Large amounts of snow and its sudden thawing will cause intensive surface runoff, thereby increasing soil loss. This especially applies to soils with less expressed structure, which are abundant in this region (regosol or rendzina). This, however, is not a significant problem because there has been no heavy snow in the region lately. A survey of mean monthly and annual temperatures and precipitation in the 20-year research period in the Ilok region is given in Table 4. The highest daily precipitation was recorded in the warm part of the year (June-August), while maximum daily precipitation was recorded in June. It was in the period May-June that the highest soil erosion occurred, most recently soil erosion by wind.

A very important indicator for calculating potential and actual soil erosion is rain erosivity. Thus, high-intensity rain during the growing period has a smaller erosion effect on soil than lower-intensity rain in the period without growing. This indicator is influenced by soil covering, tillage method, soil physical and chemical properties, etc. Table 5 provides the values of indicator R for the studied twenty-year period. Rain erosivity varies from 33, which is very low erosivity, to 110, which is medium erosivity. The mean value of indicator R is 54 (Schwertmann et al., 1987) or 77 (Fournier, 1960), which are very low erosivity values. In further calculations of soil erosion by water, the highest value (110) of indicator R, which was recorded for the studied period at the meteorological station Ilok (1966-1985) will be use. The said mean value belongs to the class of medium rain erosivity values. In general, rain erosivity values after Schwertman et al. (1987) are lower compared to those calculated according to Fournier (1960).

Soil erodibility (K) represents the long-term average soil mass in t/ha/yr., that gets detached per unit of rain erosivity under standard conditions (bare, unsown soil, tilled up and down the slope, inclination 9%, on a plot 22.1 m long and 4 m wide). It is assessed by considering the soil properties that can influence particle detachment, such as mechanical composition (notably content of sand and silt fractions), organic matter content, structure and its stability, infiltration and water permeability. Values of soil erodibility indicator K varied in a wide range from 0.01 to 1.0. Theoretically, K of 1.0 corresponds to water impermeable material, where surface runoff corresponds to total precipitation. On the other side, K of 0.01 practically corresponds to unerodible soil with an almost 100% descending flow of precipitation water.

Physical and chemical analyses of the studied soil parameters provided the values of indicator K, erodibility score and resistance to erosion, as shown in Table 6. Indicator K values range from 0.28 to 0.47, classifying the studied soils according to erodibility score as medium (chernozem calcaric) to highly erodible (other soils studied) and according to resistance to erosion as medium resistant (chernozem calcaric) to unresistant soils (other soil types studied).

Indicator (LS) For regosol on loess and eutric cambisol typical, indicator LS was calculated for inclinations of 3,

Table 6. The value of soil erodibility – K indicator

Pedosystematic soil unit	The value of K indicator	Erodibility classification	Resistance to erosion
Regosol on loess	0.47	Highly	Unresistant
Chernozem,calcaric	0.28	Medium	Medium resistant
Chernozem, luvic	0.30	Highly	Unresistant
Chernozem, cambic	0.31	Highly	Unresistant
Eutric cambisol, typical	0.35	Highly	Unresistant
Eutric cambisol, luvic	0.35	Highly	Unresistant

Table 7. The value of topographic indicator for Regosol on loess and Eutric cambisol typical soil

Slope inclination - S, %															
3				6				9				15			
Slope length - L, m															
2.5	5	7.5	10	2.5	5	7.5	10	2.5	5	7.5	10	2.5	5	7.5	10
Topographic indicator – LS															
0.06	0.09	0.11	0.13	0.18	0.26	0.31	0.36	0.33	0.48	0.58	0.67	0.71	1.02	1.25	1.43

Table 8. The value of topographic indicator for Eutric cambisol luvic and Chernozem

Slope inclination - S, %															
3				6				9				15			
Slope length - L, m															
25	100	200	300	400	25	100	200	300	400	25	100	200	300	400	25
Topographic indicator – LS															
0.21	0.41	0.58	0.71	0.82	0.58	1.16	1.64	2.01	2.32	1.07	2.13	3.02	3.69	4.26	0.21

6, 9 and 15% and for four different slope lengths: 2.5, 5, 7.5 and 10, while for eutric cambisol luvic, chernozem calcaric, chernozem luvic and chernozem cambic, the topographic index was calculated for slope lenghts of 25, 100, 200, 300 and 400 m, and for inclinations of 3, 6 and 9%. These inclinations and slope lenghts were chosen because of the terrain, that is, location of soil types determined by field investigations. Table 7 provides the obtained indicator LS values for regosol and eutric cambisol typical; Table 8 provides the indicator LS values for eutric cambisol luvic, chernozem luvic, calcaric and cambic.

As already said, **potential erosion (RKLS)** indicates what would happen to some soil in the so called standard conditions: if the soil was left bare, unsown, tilled down the slope, on a plot 22.1 m long, 1.87 m wide, and of 9% inclination. The goal is to determine on such a plot the maximum possible erosion for perennial plantations around Ilok. It must be emphasized that there is no such soil in nature, for natural soils are not cultivated, and agricultural soils, if tilled, are sown or planted or covered with weeds. All interventions (agrotechnical or hydrotechnical) that will be considered will reduce potential erosion.

Potential soil erosion by water is affected by some indicators, on which man cannot have much influence (Bini et al., 2006; Arnaez et al., 2007). Rain erosivity is determined by climate conditions and precipitation (amount and, particularly, intensity of precipitation), while the topographic indicator is determined by the slope length and inclination, so man can have no direct influence on it. The only indicator that can be influenced is soil erodibility, and that only to a certain extent by enriching the soil with organic matter, as seen from the papers of Augustinus and Nieuwenhuyse (1986), Gago et al. (2006) and Ramos and Martinez-Casasnovas (2006), by agrotechnical practices – deep tillage, liming, as indicated in the papers of Ferrero et al. (2005) and Van Dijck (2002).

Potential erosion according to particular soil types is represented in Graphs 1–6. It can be seen form these graphs that in all cases potential erosion ranges within extreme values, namely, that it greatly surpasses the maximum allowable loss for a particular soil type. As small plots prevail in the studied region (which is characteristic of the whole of Croatia), rows of perennial plantations are, for agrotechnical reasons, positioned down the slope. For these reasons, all production involving down-the-slope rows is highly risky without establishing grass between the rows. It would be opportune to define the sustainable surface of soil particles for the studied region. Further fragmentation of soil particles below this surface area should be prohibited by law.

With respect to this factor (slope downward rows and grass covered inter-row space - RKLSC), erosion values remain within tolerated limits on small slopes whereas on steeper slopes erosion again exceeds tolerable loss. This is especially marked on regosol (Graph 1), in which an increased content of sand particles was found.

Soil surface covering and crop production practices (indicator C)

This indicator valorises the effect of crop rotation (type and density of plant cover on soil surface) and different agrotechnical practices on erosion reduction, such as soil tillage – direction and depth, irrigation, fertilization, management of forecrop residues, etc. Indicator C amounts to 1 for standard conditions, while each crop found on soil surface reduces its value, and thereby also soil erosion. The lower the C value, the more efficient are the plant-production practices in terms of soil protection against erosion. The lowest C value, thus also the most efficient soil protection against erosion, will be that of the soil surface under a thick grass cover.

Table 9 shows the values of indicator C, under different tillage systems, plant residue management and different crop rotations, as well as on areas under natural vegetation (Wischmeier and Smith, 1978).

The least costly measure of soil protection against erosion is to apply a soil covering so as to obtain a suitable indicator C value, which is called the target C value. Target value of indicator C is dependent on potential erosion; the higher is the potential erosion, the more significant is indicator C, which means that the indicator C value must be lower, the higher is the value of indicator RKLS. Target C value can be used to determine which crop is suitable to be grown on appropriate slopes and lengths on the studied soils if indicator value P=1, or if no conservation practices are applied on the determined soils and if soil is tilled down the slope. As perennial plantations prevail in the hilly part of the studied region, indicator C value was calculated on the basis of physical and chemical analyses of determined soils, and following the recommendations (Štafa, 1999) for establishing grass as cover crop between the rows for soils spread in western Srijem, as shown in Table 10. The given values are in agreement with those recommended in Slovakia (Malisak, 1992, after Fulajtar and Janski, 2001) for perennial plantations.

The determined indicator C values shown in Graph 1 indicate that on regosol on loess, on which most vineyards are found in the studied region, vineyards or orchards can be cultivated on slopes up to 9%, while conservation measures should be applied on steeper slopes. Vineyards and orchards with grass covered inter-row space on eutric cambisol typical can be cultivated in all the studied combinations (Graph 2). On eutric cambisol luvic, perennial plantations can be established on slopes up to 6% and up to 200 meters long. On steeper and longer slopes, more radical agrotechnical practices should be applied (Graph 3). Similar situation was recorded on all studied types of chernozem (Graphs 4 – 6). Slopes inclined more than 6% and longer than 200 meters require regulation of water ways, that is, installation of dividing canals.

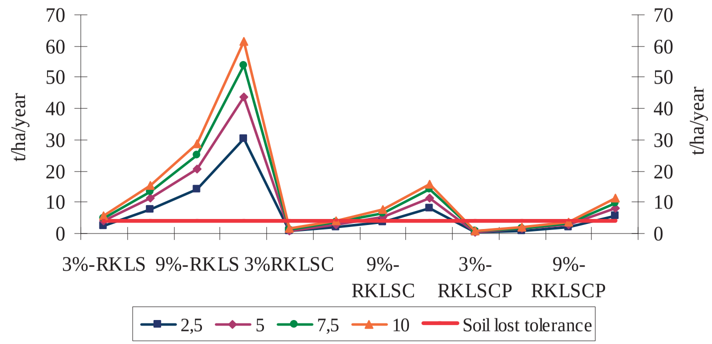
Maximum slope length (Table 11) actually defines the distance at which the slope under crop or plantation should be cut by building a terrace, digging a canal, constructing contour dams or grass covered contour canals (Szilassi et al., 2006; Milašin, 2007). Slope length represents the width of the inter-canal space on a production plot, from which soil loss accumulates during intensive erosional rains – spring and summer showers, which are a regular phenomenon in this climate. It is desirable to make these distances as long as possible in order to minimize the loss of production area, to have as few obstacles to machinery as possible, and to simplify armature installation in modern plantations.

Table 9. The value of C indicator

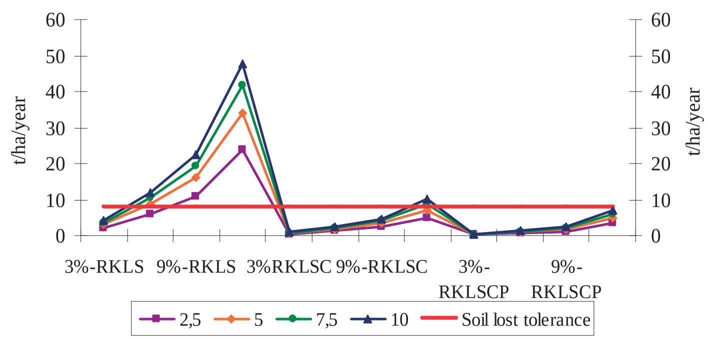
Type of vegetation	Value of C indicator
Perennial grass cover high density	0.08 – 0.12
Field crops	
Winter grain crops	0.35 – 0.40
Row crops	0.45 – 0.60
Vegetables	0.55 – 0.75
Perennial crops without grassing traces	
Apple and pear	0.75
Peach and Apricot	0.60
Cherry, sour cherry and plum	0.70
Nut, hazel	0.70
Grape vine	0.75
Undamaged wood, 90-100 % of soil cover by organic matter, 75-100 % cover by trees	0.001

Table 10. The value of C indicator for determined soils

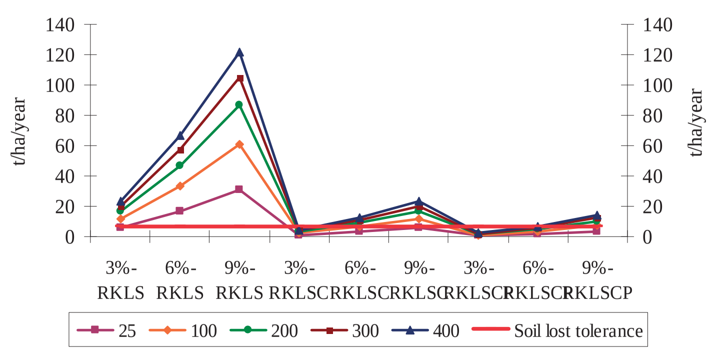
Soil type	Type of vegetation	Value of C indicator
Regosol on loess	vineyard + grassing traces with grass-clover mixtures	0.26
Eutric cambisol, typical	vineyard + grassing traces with grass-clover mixtures	0.21
Eutric cambisol, luvic	vineyard + grassing traces with grass-clover mixtures	0.19
Chernozem, calcaric	vineyard + grassing traces with grass-clover mixtures	0.15
Chernozem, luvic	vineyard + grassing traces with grass-clover mixtures	0.16
Chernozem, cambic	vineyard + grassing traces with grass-clover mixtures	0.17



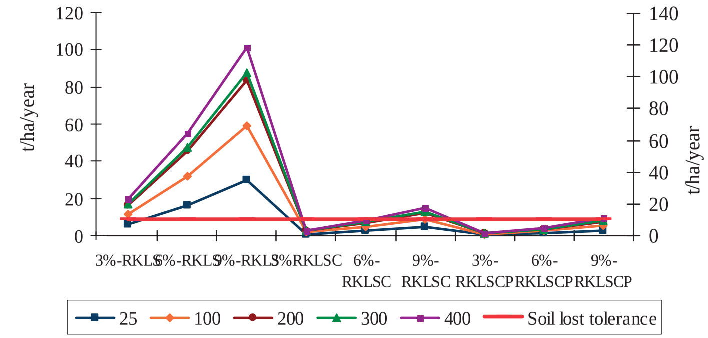
Graph 1. Ratio between potential and effective water erosion for Regosol



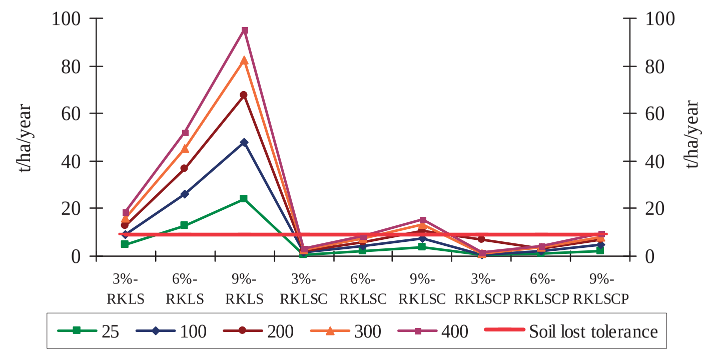
Graph 2. Ratio between potential and effective water erosion for Eutric cambisol typical on loess



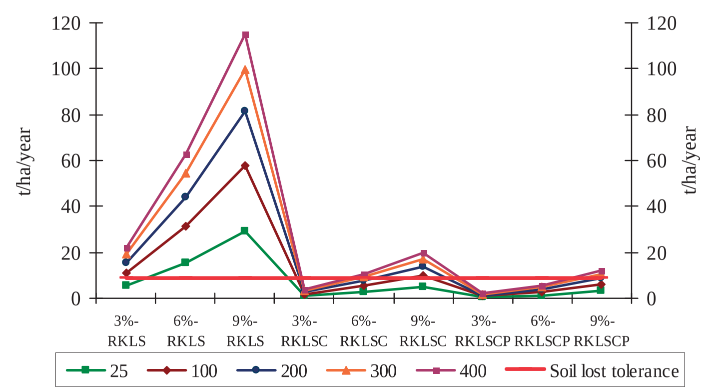
Graph 3. Ratio between potential and effective water erosion for Eutric cambisol luvic on loess



Graph 4. Ratio between potential and effective water erosion for Chernozem calcaric on loess



Graph 5. Ratio between potential and effective water erosion for Chernozem luvic on loess



Graph 6. Ratio between potential and effective water erosion for Chernozem cambic on loess

Table 11. The value of P indicator and maximum slope length for contour tillage and planting

Slope inclination, %	Value of P indicator	Maximum slope length
1 – 2	0.60	120
3- 5	0.50	90
6 - 8	0.50	60
9 -12	0.60	40
13 -16	0.70	20
17 – 20	0.80	20
21 – 25	0.90	10

Effective or actual soil erosion (RKLSC and RKLSCP) indicates what is actually going on in nature, since in nature each soil has a covering, and the covering reduces soil erosion compared to standard conditions (bare, ploughed, but unsown soil). Actual erosion is calculated by taking into account, along with the potential erosion values, also indicators C and P, which reduce the obtained indicator RKLS values, as shown in Graphs 1-6. When all the studied indicators of soil erosion by water (RKLSCP) in the Ilok region are taken into account, it can be seen that erosion on almost all studied soil types is within tolerated limits. An exception is erosion on regosol (Graph 1) and eutric cambisol luvic on slopes of more than 15%; such soil types, however, are hardly ever found in nature in the described conditions.

Alteration of the original relief, i.e., application of some conservation measures, is a very costly practice. For this reason, it is obvious that it can be applied only in the case of highly profitable crops. The most radical and most expensive intervention is terracing, followed by various contour structures under the common name water ways (storm drains, rain or dividing canals), aimed at halting surface runoff before the mass of water assumes destructive force. In such cases, water can be stored in some water reservoirs and used for irrigation in summer, which makes construction of water ways much more cost effective.

All this indicates that soil erosion by water should be combated by all the available means. The number and type of conservation practices available in each particular case depend on numerous indicators, primarily the material resources of land users, available machinery, tools, equipment and particularly user competence. Market economy also requires economic justification and cost effectiveness of each intervention.

Conclusions

The presented results point to the following conclusions:

Application of the Revised Universal Soil Loss Equation was tested on three soil types and six lower systematic unit in the Ilok region, which are erosion prone due to natural spatial factors: regosol on loess; eutric cambisol typical on loess; eutric cambisol luvic on loess; chernozem calcaric on loess; chernozem luvic and chernozem cambic on loess.

Rain erosivity indicator was calculated for the meteorological station Ilok for the twenty-year period from 1966 to 1985. Rain erosivity ranged from 42 (low erosivity) to 110 (medium erosivity). In erosion calculations use was made of the highest rain erosivity value because the system of soil protection against erosion must be prepared for its critical maximal occurrences.

Soil erodibility indicator was calculated on the basis of physical and chemical soil analyses and ranged from 0.28 to 0.47. According to the soil erodibility score, or soil resistance to erosion, soils of the studied region were classified into two classes: medium erodible or medium resistant soils (chernozem calcaric – 0.28) and highly erodible or soils unresistant to erosion (regosol on loess, chernozem luvic; chernozem cambic; eutric cabisol typical and luvic on loess).

According to the topographic index, increase in slope inclination increases the value of indicator LS, which means that an increased indicator LS value calls for more rigorous measures of soil protection against erosion if areas are to be used for agricultural production. On the determined soils of the studied region, the degree of erosion risk ranges from moderate to catastrophic values.

Tolerated soil loss by erosion for the studied region ranges between 4-10 t/ha/yr.; for shallow soils – regosol on loess, soil loss tolerance was 4 t/ha/yr., for medium deep – eutric cambisol, typical and luvic on loess 7 and 8 t/ha/yr., and for deep soils – chernozem, calcaric, luvic and cambic 9 and 10 t/ha/ yr.

Significant potential erosion was determined on all soil types studied, indicating the need to apply soil protection measures against erosion (sowing grass between the rows, contour tillage and planting, subsoiling, mulching, etc.) if the soil is to be used for agricultural production. Regosol on loess is most susceptible to erosion while chernozem is the least erosion-prone soil.

If grass is sown between the rows on studied soil types, if plantations are established across the slope and if water ways are provided, actual erosion would be reduced to a tolerant level; vice versa, the fewer of the said practices are applied, the closer the actual erosion would be to potential soil erosion by water.

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acs73_12