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SPATIAL ORGANISATION OF AGRICULTURAL LANDSCAPE AND SOIL CONSERVATION

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Abstract. Selected landscape indicators (soils, rainfall, slope angle, slope length, and current land-use pattern) were interpreted from the aspect of water and material motion dynamics on a slope in the model area of Dolná Malanta (near the town of Nitra, Slovakia). The interpretation focused on the specification of soil erodibility. On the basis of the expected dynamics of water and material motion and their integration along the slope it was possible to propose five alternative solutions for protecting arable soil against erosion. The proposals aim at conserving the fertility of soil and are based on a thorough evaluation of the natural conditions and the current use of the area.

Key words: water erosion, soil protection, modelling

INTRODUCTION

The ecologically optimal use of land is a complex process of mutual harmonisation of the spatial demands of economic and other activities of man with the landscape--ecological conditions. At the same time, it ensures suitable ecological stability of the spatial structure of landscape; protection and rational utilisation of the nature and natural resources; shaping and protection of the environment.

The existing erosion models are usually based on topic landscape indicators such as substrate, soil, slope, climate, and land-use pattern, which are mostly valid for homogeneous conditions of a particular slope, preferably within one plot. In ecological landscape planning, which should provide data for proposals concerning the ecologically optimal functional division of an area, the whole landscape and not only individual plots should be considered. In the landscape's heterogeneous conditions, however, individual slopes are most frequent.

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The erosion models currently used in Slovakia concern homogeneous slopes, probably for the lack of empirical data from heterogeneous slopes. Only few models allow for the modification of features along a slope. Nevertheless, some features the effect of which on the erosion process is theoretically known, especially relief curvature and forms [Ivanov and Lopyrev 1979], do not appear even in these models. Difficulties are also encountered in practical applications, e.g. the measurement of the length of orthogonal lines in larger areas.

The objective of the present work is to determine potential erosion, i.e. the erosion in a standard situation where the relief features (slope, curvature, topographic position), soil properties (grain size, humus), geology and climate are stable, while the elements of the present use of the landscape (forests, verdure belts, roads, dams, etc.) are partially stable. These elements modify the overall length of a slope. Homogeneous areas (defined as types of partial landscape-ecological complexes, LECs, in which we wish to determine erodibility besides other functional properties) are created by synthesising these stable features. The LEC types are considered as basic spatial operational units for the proposals concerning the allocation of different types of agricultural activities.

This paper is a shortened version of the works by Hrnčiarová and Miklós [1999], Hrnčiarová [2000, 2001], and Šimonides [1996, 1999]. The morphometric indicators are evaluated according to Krcho [1991]. The evaluation of erosion processes is based on various forms of the Wischmeier-Smith erosion model [Wischmeier and Smith 1978].

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MATERIAL AND METHODS

Landscape-ecological analyses of the model area

Dolná Malanta is located in the lower part of the basin of Selenec Creek and its tributaries, in the central part of the Nitra river basin. The area studied (612.68 ha) lies to the east of the city of Nitra on the Žitavská Upland. It is of a maize-barley agricultural type and almost the whole of it is under intensive cultivation.

For the objectives of our work, the parametric features of soil and relief were of prime importance. In the study, we used the existing analytical data and the data obtained by our own procedures. The scope of the data is described below.

Climate. The region belongs to the warm, mildly wet zone with a moderate winter. As regards climatic data, we were especially interested in the number and intensity of downpours and their distribution during the vegetation season.

Substratum and soil. The geological substratum has a small proportion of older rocks with a large amount of fine materials. Young Neogene deposits are composed of various clays, loams, sands and gravels on which loess was deposited in Pleistocene. Ninety percent of the model area is covered with Eutric Cambisols. Hydromorphic soils occur only in a small area. According to grain size, the soils fall into two categories:

– loamy sands and sandy loams (medium heavy soils),

– loamy soils (heavy soils).

Morphometric indicators of relief. The relief is smoothly modelled with an altitude of 160–220 m. From the southeastern to eastern part, the dissection of the area increases. Special attention was paid to the relief conditions, especially the relief morphometric indicators, which form the most important group of indicators in our area. Relief was evaluated in terms of topic and choric relations analysed by using morphometric procedures from topographic maps.

Slope. Slope was determined at each point of orthogonal lines [Krcho 1991]. The orthogonal lines were plotted at a density appropriate for a sufficiently precise characterisation of the relief. The measured slopes were classified into four categories as follows: slopes up to 1°; 1°1′ to 3°; 3°1′ to 7°; and 7°1′ to 12°. This means that isoclines with values of 1°, 3°, 7° and 12° were plotted. The areas between the isoclines were characterised by specified categories of slope. Slopes to 3° prevailed, while the last category was poorly represented.

Slope length of orthogonal lines. Slope length was measured on orthogonal lines. The basic interval was 100 m of slope length. Isoclines of the same length were always plotted from the top to the thalweg, from the semi-natural boundaries (forest stands), from both the line and spatial anthropogenic elements (field roads, fences, built-up areas) towards the valley. In the area studied, nine categories of slope length were identified with prevailing 500–600 m-long slopes. This indicator has a substantial effect on the dynamics of water and material motion along a slope. The varying course of orthogonal lines on slopes, however, creates various prerequisites for the integration and disintegration of runoff along the slope, thus making the interpretation of slope length questionable.

Current landscape structure. The natural conditions described above have an impact on the dynamics of water and material motion along slopes. The surface of the model area is very monotonous: 90% of it is vast arable fields, the rest is built-up areas, waters, forests, perennial grass stands and roads. This dynamics is also affected by anthropogenic effects, among them the selection of agricultural crops arranged into a 5-year crop rotation (spring barley–silage maize–winter wheat–alfalfa–alfalfa), the way of cultivation and fertilisation, etc. If all these indicators are inappropriately selected and applied to arable fields, they may accelerate erosion processes. On the other hand, their correct selection may restrict or retard erosion.

Landscape-ecological syntheses

These imply the creation, characterisation and classification of spatially homogeneous areas with nearly the same landscape-ecological properties. The syntheses, made by gradual superposition of analytical maps, yield the types of landscape-ecological complexes (LECs) as a result. The latter form the basic spatial database for a further process.

Landscape-ecological interpretation

When making interpretations, we considered the expected dynamics of water and material motion and the estimated soil losses (determined on the basis of some erosion models).

The soil loss under the expected individual anthropogenic effect was computed by using stable soil and morphometric indicators. The quantitative effect of erosion processes was determined employing the adapted erosion model of Wischmeier and Smith [1978]. Six indicators are usually used to compute the potential erosion of soil from the formula:

$$G = R \cdot K \cdot S \cdot L \cdot C \cdot P$$

where:

G – soil loss ($t \cdot ha^{-1} \cdot yr^{-1}$),

R – rainfall and runoff factor,

K – soil erodibility factor,

S – slope-steepness factor,

L – slope-length factor,

C – cover and management factor,

P – support practice factor.

The soil loss according to the erosion model was established for three alternatives:

1) soil without vegetation stands,
2) maize having a weak counter-erosion effect,
3) a 5-year seeding system used in the model area (on which the further work was based).

The values of other indicators were related to each particular point of their occurrence. When computing the potential soil erosion, not the existing boundaries of plots were considered but the boundaries demarcated on the basis of pedomorphotopochores (based on *K, S*, and *L* indicators). The homogeneous areas obtained in such a way provide the basis not only for the computation of soil losses but also for the actual proposals of counter-erosion measures (change of the boundaries of field strips; proposal of a new crop structure, etc.).

The extent of the exposure to erosion was defined for each homogeneous category of soil loss according to the standards of admissible soil losses. The computed amount of soil loss for a crop rotation was divided into nine categories:

- four categories with an admissible soil loss: soil loss to 9 $t \cdot ha^{-1} \cdot yr^{-1}$,
- one category at the limit of admissible soil loss: soil loss of 9.1 to 10 $t \cdot ha^{-1} \cdot yr^{-1}$ (for deep soils),
- four categories with an inadmissible soil loss: soil loss of 10.1 to 100 $t \cdot ha^{-1} \cdot yr^{-1}$.

The spatial distribution of soil losses in the area of Dolná Malanta gives an insight into the expected possibilities of soil loss generation in its parts as well as into the need for specific counter-erosion measures.

Landscape-ecological evaluation

By landscape-ecological evaluation we understand a process of determining the suitability of landscape for the location of selected social activities [Ružička and Miklós 1982]. Here, the landscape-ecological conditions required by individual activities are contrasted with the really existing landscape values by means of limits. The following factors are considered in the evaluation process:

– landscape-ecological bases,
– requirements of society (proposed activities and utilisation),
– establishment of the limits of soil erodibility (Tables 1, 2 and 3).

Table 1. Limits of soil erodibility for selected agricultural crops and crop rotations on moderately undulated plain with Eutric Cambisols – slope 1°1′ to 3°
Tabela 1. Granice erozyjności gleby dla wybranych roślin uprawnych i zmianowań na umiarkowanie pofałdowanej równinie z glebami brunatnymi właściwymi – stok o nachyleniu od 1°1′ to 3°

Agricultural crops Rośliny uprawne	Slope length – Długość stoku, m														
	20	30	40	50	100	150	200	250	300	350	400	600	700	800	900
Maize Kukurydza															
Sugar-beet Burak cukrowy															
Spring barley Jęczmień jary															
5-year crop rotation* 5-letnie zmianowanie*															
Winter wheat Pszenica ozima															
4-year crop rotation** 4-letnie zmianowanie**															
Alfalfa Lucerna															

* spring barley–maize–winter wheat–alfalfa–alfalfa – jęczmień jary–kukurydza–pszenica ozima–lucerna–lucerna

** spring barley–winter wheat–alfalfa–alfalfa – jęczmień jary–pszenica ozima–lucerna–lucerna

Table 2. Limits of soil erodibility for selected agricultural crops and crop rotations on moderately dissected hilly land with Eutric Cambisols − slope 3°1′ to 7°

Tabela 2. Granice erozyjności gleby dla wybranych roślin uprawnych i zmianowań na umiarkowanie rozczłonkowanym terenie pagórkowatym z glebami brunatnymi właściwymi − stok o nachyleniu od 3°1′ do 7°

Agricultural crops Rośliny uprawne	Slope length − Długość stoku, m														
	20	30	40	50	100	150	200	250	300	350	400	600	700	800	900
Maize Kukurydza															
Sugar-beet Burak cukrowy															
Spring barley Jęczmień jary															
5-year crop rotation* 5-letnie zmianowanie**															
Winter wheat Pszenica ozima															
4-year crop rotation** 4-letnie zmianowanie**															
Alfalfa Lucerna															

* spring barley–maize–winter wheat–alfalfa–alfalfa − jęczmień jary−kukurydza−pszenica ozima−lucerna−lucerna

** spring barley–winter wheat–alfalfa–alfalfa − jęczmień jary−pszenica ozima−lucerna−lucerna

Table 3. Limits of soil erodibility for selected agricultural crops and crop rotations on medium-dissected hilly land with Eutric Cambisols − slope 7°1′ to 12°

Tabela 3. Granice erozyjności gleby dla wybranych roślin uprawnych i zmianowań na średnio rozczłonkowanym terenie pagórkowatym z glebami brunatnymi właściwymi − stok o nachyleniu od 7°1′ do 12°

Agricultural crops Rośliny uprawne	Slope length − Długość stoku, m														
	20	30	40	50	100	150	200	250	300	350	400	600	700	800	900
Maize Kukurydza															
Sugar-beet Burak cukrowy															
Spring barley Jęczmień jary															
5-year crop rotation* 5-letnie zmianowanie*															
Winter wheat Pszenica ozima															
4-year crop rotation** 4-letnie zmianowanie**															
Alfalfa Lucerna															

* spring barley–maize–winter wheat–alfalfa–alfalfa − jęczmień jary−kukurydza−pszenica ozima−lucerna−lucerna

** spring barley–winter wheat–alfalfa–alfalfa − jęczmień jary−pszenica ozima−lucerna–lucerna

RESULTS

Landscape-ecological proposals

The determination of the expected dynamics of water and material motion and their integration made it possible to propose various alternative solutions for protecting arable soil against erosion. Employing the indicators of slope dynamics and erodibility, we specified the ecologically most advantageous economic use of particular areas. The premises for establishing the most effective way to prevent an undesirable soil loss are:

- selection of an agricultural crop (crop rotation),
- specification of the admissible slope length for the crop.

Adopting the above approach, we formulated the following five theoretical proposals on the protection of arable soil from the adverse effects of slope dynamics for the model area of Dolná Malanta.

I. Soil protection by chosen agricultural crops

The essence of the proposal is to prevent the inadmissible soil loss exclusively through *proper selection of an agricultural crop* without taking any other counter-erosion measure. The crop should be able to prevent the inadmissible loss in a particular homogeneous topochore. At the same time, the boundaries of the current strips of fields will be changed according to topochores. Of course, this is an extreme proposal for it does not meet other objectives, e.g. shaping an ecologically stable landscape. This proposal at least indicates where the acceleration of erosion processes should be expected in the future.

II. Soil protection by verdure belts

The essence of the proposal is to prevent the inadmissible soil loss exclusively through *planting of counter-erosion verdure belts* without restricting the current crop rotation and other counter-erosion measures. The slope length will be divided into shorter sections with verdure belts within which the soil loss limit is not exceeded even under the current crop rotation. A practical obstacle to the implementation of such a proposal is the occurrence of narrow strips of fields (15 to 40 m) in the most extreme zones of our area, making the current large-scale agricultural technology impossible.

III. Soil protection by crop rotations

The essence of the proposal is to prevent the inadmissible soil loss exclusively trough *proper selection of a crop rotation* without taking any other counter-erosion measure. The proposal is based on a counter-erosion crop rotation which would make the inadmissible loss (i.e. more than 10 $t \cdot ha^{-1} \cdot yr^{-1}$) impossible. We test successively if the inadmissible loss could be prevented by the following crop rotations:

a) the current 5-year crop rotation (spring barley–maize–winter wheat–alfalfa–alfalfa). If not, we test the proposed rotation, namely
b) counter-erosion 4-year crop rotation (spring barley–winter wheat–alfalfa–alfalfa) without maize.

Even if this rotation fails in preventing the inadmissible loss, we test another one, i.e.

c) forage rotation (with maize and cereals excluded).

At the same time, the boundaries of the present strips of fields will be changed according to topochores. This proposal does not fulfil other ecological functions, either.

IV. Soil protection by crop rotation respecting the present borders of plots

This proposal considers the preceding suggestions and aims at minimising the losses in the soil profile by a change in the crop rotation, without using counter-erosion belts and while respecting the present division of the area into plots.

V. Landscape-ecologically optimal use of the area

This proposal is a *synthesis of principles* from the preceding proposals. The combination of the following measures is considered:

- selection of appropriate agricultural plants and a crop rotation for particular topochores,
- location of counter-erosion verdure belts in critical zones of slope dynamics, and the division of the slope into shorter sections,
- location of filtering and counter-depositing verdure belts in zones of water and material concentration,
- location of verdure serving other ecological functions (biocorridors, biocentres).

Such measures would make it possible to manage the area in harmony with the natural conditions; sufficiently prevent sheet erosion, leakage of nutrients, gully erosion, deposit formation and soil loss from the fields; stabilise thalwegs with dispersed verdure; filter discharge, etc.

CONCLUSIONS

The proposals presented in the paper are based on a thorough evaluation of the natural conditions and current use of the research area with regard to the preservation of soil fertility.

As a precondition of soil protection, we suggest that the boundaries of agricultural plots should be changed to adjust them to the homogeneous natural units. Without such a change, measures of any kind will be inefficient. Mechanisation aspects should not have priority when the enlargement of cultivated plots is being considered (regardless of configuration) because this would result in increased erosion.

The counter-erosion soil protection can be done by planting counter-erosion verdure belts or converting arable soils into perennial grass stands. These measures involve reducing the area of arable soil, but not losing soil matter in the total balance. On the contrary, soil matter (particularly in the most fertile upper layer of soil) will be lost if the measures mentioned above are not implemented.

So far, unfavourable processes in the landscape have often been slow, e.g. the annual loss of arable soil has been indiscernible, but permanent. Therefore, the longterm ignorance of ecological measures may have very negative impacts on the farming economy (deterioration of soil fertility and hydrologic regime, ground water pollution, loss of soil biological activity, etc.) as well as on the overall biological balance of the landscape.

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ORGANIZACJA PRZESTRZENNA KRAJOBRAZU ROLNICZEGO A OCHRONA GLEBY

Streszczenie. Wybrane wskaźniki charakteryzujące krajobraz (gleby, opady atmosferyczne, nachylenie terenu, długość stoku oraz obecną strukturę użytkowania gruntu) zinterpretowano pod kątem dynamiki ruchu wody i materiału na stoku modelowego obszaru Dolná Malanta (w pobliżu Nitry na Słowacji). Interpretacja koncentruje się wokół zagadnień erozyjności gleby. Określenie przewidywanego ruchu wody i materiału wzdłuż stoku oraz ich kompleksowe ujęcie pozwoliło na zaproponowanie pięciu wariantów ochrony gleby ornej przed erozją. Propozycje te zmierzają do zachowania żyzności gleby, a są oparte na szczegółowej ocenie warunków naturalnych terenu i obecnej struktury użytkowania gruntu.

Słowa kluczowe: erozja wodna, ochrona gleby, modelowanie

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