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SPATIAL AND TEMPORAL ANALYSIS OF THE AVAILABLE NUTRIENTS OF THE TOPSOIL IN A PILOT AREA: MACRO- AND MICROELEMENTS AS INDICATORS OF EROSION

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Abstract

The aim of the present study was to shed light on the laws governing the spatial and temporal variations of available nutrients in the topsoil in a pilot parcel located in a subbasin of the catchment area of Lake Velence. The choice of the site is based on the utilization of the lake as a recreation area. The majority of the land in the catchment area is in agricultural use and the water quality of the lake is highly sensitive to the intensive exploitation of the soils due to the relatively large catchment area compared to the size of the water body.

The following tasks were to be carried out as part of the present study:

- the recording of the distribution of micro and macro elements along with the major soil characteristics on the pilot parcel at three different times;
- the analysis of the potential correlations between the soil parameters and the element content with the help of statistical tools;
- the modeling of erosion for a given slope segment with the help of an erosion modeling software (Erosion 2D) in order to distinguish the slope areas where accumulation or intensive erosion is present;
- finally these erosion and accumulation segments were compared to the nutrient profiles in order to determine the group of elements most suitable as indicators of erosion.

Introduction

The hypothesis according to which the "fate of a lake is in the hands of its catchment area" is especially true for Lake Velence. Agricultural production on the catchment area along with the intensity of fertilization as well as the implementation of water- and soil-friendly approaches in the agricultural production and fertilization play a crucial role in the deceleration of eutrophization and the improvement of water qualities within a lake system used mainly for recreation as Lake Velence. The catchment area of the lake covering approximately 602.4 km^2 is about 23 times of the water surface. An estimated 713,000 t of soil is eroded from the catchment area annually, 20% of which gets into streams and reservoirs; i. e. approximately 143,000 t/year. The reservoirs of Zámoly and Pátka capture about 60,000 t of the above, yielding a final load of 83,000 t transported into Lake Velence every year (KARÁSZI K., 1984). The lack of any natural obstacles on the catchment area enables practically undisturbed transportation for the sprinkled nutrients towards the base of erosion because water flows down the slopes carrying soil and sediments into the creeks, since the wet meadows adjacent to the creeks were put under agricultural production in the 1970s. These 50-70-m-wide wet habitats served as some sort of physical and chemical traps for the eroded nutrients. In order to create larger parcels, suitable for production using high-capacity machines (BÓDIS - DORMÁNY, 2000), shelter belts were eradicated.

These have also served as erosion traps for eroded soil particles in case of sloping parcels, thus enabling the preservation of water quality in Lake Velence in addition to soil protection.

Several researchers have recognized the potential dangers resulting from the loss of nutrients in the topsoil of lands under agricultural production via erosion and sheet flow. DÉRI (1986) developed a method for estimating the rate of N and P discharge and erosion with regards to the vegetation cover by investigating the 14 subbasins of the catchment area of Lake Balaton. According to his observations the decrease of the ration of woodlands below 30-40% of the total vegetation cover results a sudden increase in nutrient discharge and erosion. As DEBRECZENI et al. (1983) have pointed out in their lysimeter investigations the following factors are of crucial importance in the transportation and loss of nutrients: type, physical composition and pH of the soil. HEATHWAITE et al. (2003) have developed a method for the estimation of P loss in case of the soils of minor catchment areas and ploughfields covering a couple of hectares. DUTTMANN (1999) and Isringhausen (1997) after modeling the process of soil erosion in several minor catchment basins using Erosion 3D and AGNPS software models, created maps of P redeposition based on their findings. The potential role of morphology concerning the distribution of heavy metals within the soil for a minor catchment was investigated by KERÉNYI and SZABÓ (1997).

The present study involved the analysis and discussion of several aspects in relation to the catchment area of the Cibulka creek, covering an area of approximately 14 km^2. This is a subregion of the catchment of the Vereb-Pázmánd waterflow, which is largely responsible for the contamination of Lake Velence. The following aspects were considered (**Fig.1.**):

- to shed light onto the spatial and temporal variations of the nutrition cycle of soils in the area;
- to investigate how the morphology, the organic content as well as the cohesion of the soils influence the spatial variance;
- to decide which micro- or macroelements can be considered as indicators of soil erosion;
- to determine those slope segments, which are most exposed to soil erosion, nutrition leaching, and accumulation in the pilot area, running parallel with the slopes and utilized for vine growing and acting as a major source of nutrition contamination to the lake;
- to correlate the erosion and accumulation slope segments, received as an output from the modeling software Erosion 2D, with the variations of the metal content along the slope.

The area under investigation

A *150 x 300-m-parcel was chosen as the site of a detailed, high resolution analysis* on the catchment of Cibulka creek. The aspect of the parcel was north-eastern, with an average slope angle of 4°, 1° and 6°.

The mean annual precipitation at the site is between 550-600 mm, 50-55 % of which comes during the summer (MAROSI - SOMOGYI, 1990), very often as heavy thunderstorms. The *genetic soil type* of the parcel is forest-residued chernozom developed on a loess bedrock (**Fig. 2.**), , which belongs to the category of average or weakly eroded considering the rate of erosion. The *thickness of the productive topsoil* exceeds 150 cm. The pH of the topsoil is slightly alkaline with values ranging between 7.21–8.5. Vegetation cover, one of the key factors influencing soil erosion in the area, was around 35% in average during the period of the analysis. The pilot parcel was selected carefully in order to represent an area where landscape utilization is similar to that of the slopes of the catchment area; namely, where large-scale vineyards are present.

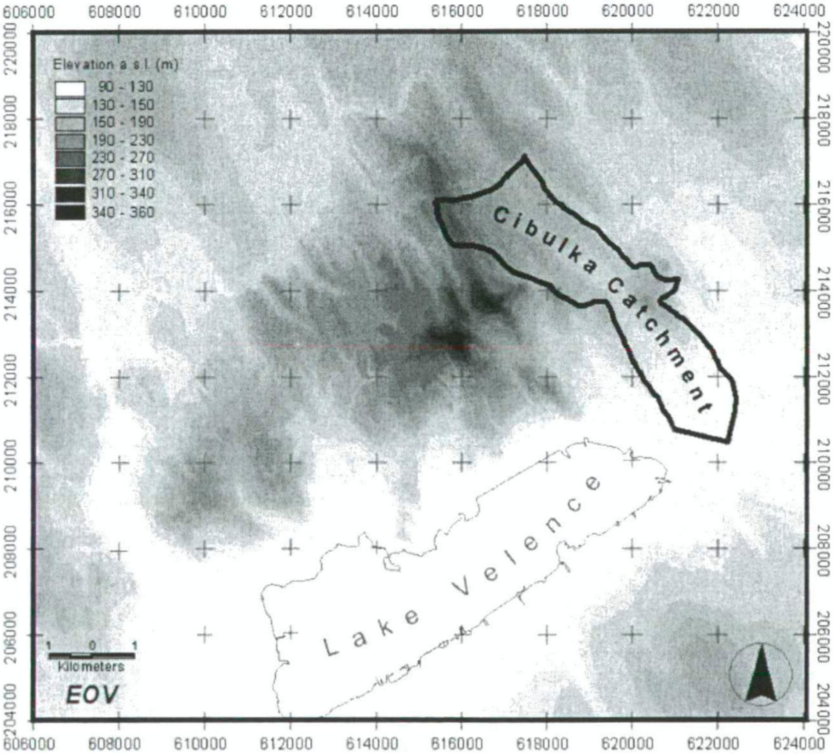


Figure 1. The location and relief conditions of the analyzed catchment area and the Velence Mts.

Among the changes of landscape utilization on the catchment of Cibulka creek during the past 20 years the transformation of ploughfields into vineyards was of primary importance. The Hungarovin viticulture (Pázmánd) purchased arable lands in several steps from the Agromark Producer's Cooperative in the late 1980s, early 1990s and planted vine-stocks into the newly gained areas, introducing large-scale intensive production.

These changes in the landscape utilization resulted in an increase of vine-stock covered areas, influencing the rate of soil erosion and the amount of discharged nutrients as well by changing the ration of vegetation cover. According to our measurement data concerning vegetation cover (collected from 14 different parcels of the catchment between April and October) the ratio of annual vegetation cover is lower in the area of parcel No. 7, similar to other vine-growing areas, compared to other parcels with a different landscape utilization (**Table 1.**). This vegetation cover data has been also used for the calibration of our model for the pilot parcel in the soil erosion modeling system Erosion 2D/3D.

Table 1. The rate of vegetation cover for the major land types on the catchment between April-October 2001.

Plants grown on the given parcels	The ratio of vegetation cover in percentage				
	April	*May*	*June*	*August*	*October*
1. fallow	53	62	98	99	100
2. winter wheat	46.6	98	100	89.6 (stubble field)	100 (stubble field)
3. winter wheat	88	100	100	2 (ploughfield)	65 (sugar beet)
4. winter wheat	65.6	100	100	96 (stubble field)	100 (stubble field)
5. winter wheat	65.6	100	100	56.3	25
6. grape	51	51.3	55.6	47	100
7. grape	**41**	**35.6**	**52.6**	**59**	**49.3**
8.corn	-	24.6	74.6	100	100
9. corn	-	14.6	46.3	100	100
10. hay	-	98	99	100	100
11. corn	-	16	63.6	100	100
12. oat	-	78	98	22.6 (stubble field)	58.6
13.grape	16	16.3	22	51	50
14. corn	-	15.3	40,3	100	100

Sampling and analysis material and methods

Detailed sampling and the laboratory analysis of the collected samples for the selected pilot parcel (**Fig. 2.**) was carried out in three steps: samples were collected on two occasions in 2001 (May and June) and once in May 2003 for each slope segment. Sampling was carried out in a 25 by 25 meter grid. The exact location of the sampling sites was recorded with theodolite in order to help repeated sampling. Sampling was performed by taking average samples for the uppermost 10 cm of the topsoil. The following soil parameters and nutrients have been examined in detail:

pH(KCl), **K_A** (Arany-type cohesion index), **$CaCO_3$**, **humus** content (%) and **available micro- and macroelements** (NO_2-NO_3-N, P_2O_5, K_2O, Na, Mg, Ca, Mn, Zn, Cu, Fe, Mo, B, Al, As, Cd, Co, Cr, Hg, Ni, Pb).

The analysis of nutrients was constrained only to those retrievable by plants. After extraction with acetic acid solution of ammonium-lactate for macroelements, and Lakanen Erviö extraction for the microelements, measurements were performed with an ICP Thermo Jarell Ash ICAP 61E device (BÚZÁS, 1988).

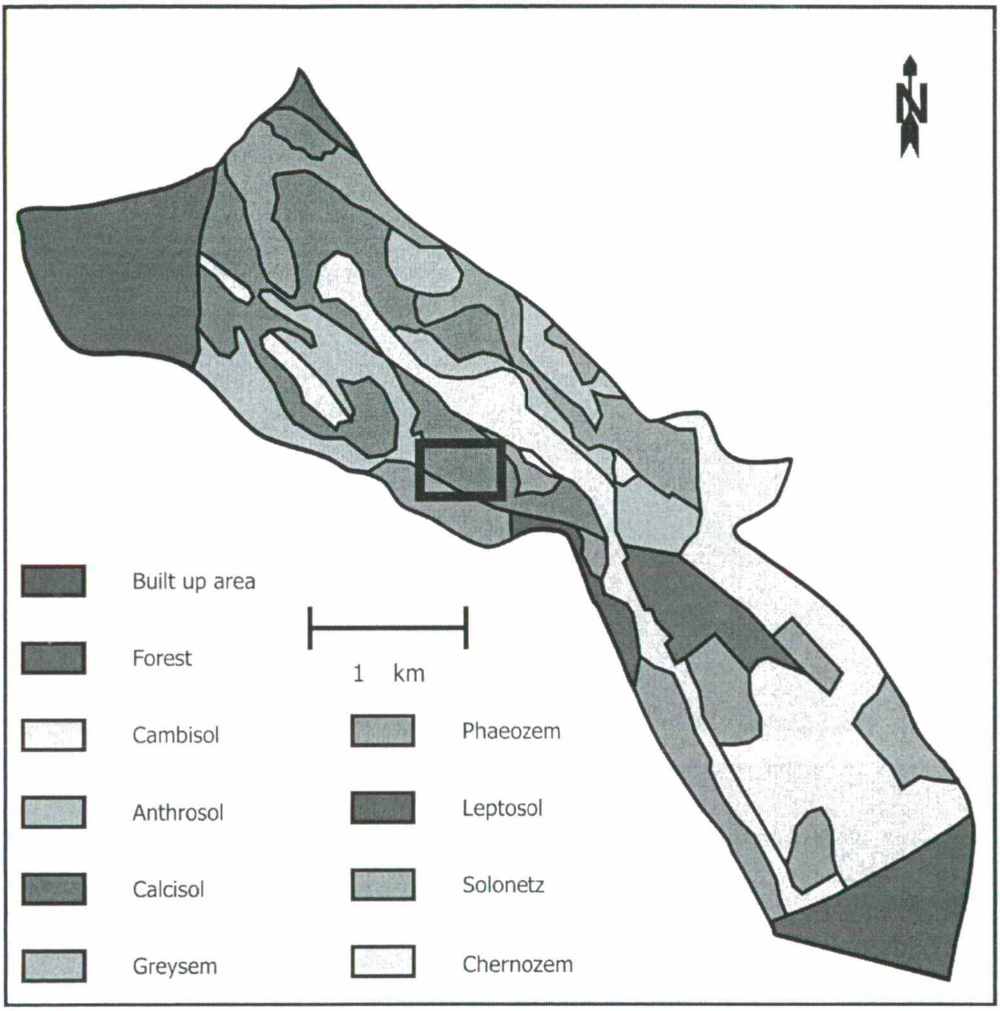


Figure 2. The prevailing soil types of the catchment basin with the pilot parcel marked

In order to determine the variations in the rate of soil erosion, and the accumulation segments along the slope, we used soil erosion modeling software Erosion 2D (SCHMIDT, 1996), which was developed in Germany.

The system is made up of three submodels: the first submodel captures topography and slope angles; the second is an infiltration submodel, while the third captures the rates of soil erosion and accumulation.

The slope profile for the analysis can be determined in the first submodel from the watershed boundary down to the valley floor in such a way, so that even minor topographic feaures and linear elements (road cuts, ditches) could be considered as well during the simulation. In describing the process of erosion two important subprocesses are distinguished in the model. One of these captures the governing rules and equations necessary for the movement, while the other captures those that are necessary for the transportation of the surface grains.

The model, parallel to the slope, simulates soil erosion occurring from a single rainfall event (MICHAEL, 2000). This *model requires less input parameters* compared to other similar modeling systems however the reliability of the output is highly sensitive to the accuracy of the input. The input involves three major categories: relief type data (height of the slope and the length of the slope base), parameters reflecting the conditions of the topsoil (bulk density, amount of organic C, erodability, surface roughness, soil moisture, vegetation cover), and finally data characterizing the intensity and temporal distribution of rainfall. Measurements of the above mentioned relief and soil parameters as well as the sampling, was carried out in May 2003 for the individual slope segments. All samples taken from a 25 × 25 m grid have been analyzed for grain-size distribution, physical properties as well as humus content. The model was run for a single rainfall event, which occurred in the area under investigation in May 2001 (duration: 1 hour, intensity: 19.3 mm/h). Data for this event was obtained from pluviometer measurements of a local meteorological station.

Results

The spatial and temporal variations of the nutrition content available to the topsoil

Based on its *physical properties* the soil in the pilot parcel can be classified as sandy loam with an Arany-type cohesion index of 32-41 (**Fig. 3.**). Regardless of regional differences, the parcel under investigation as a whole is medium or poor quality in terms of nutrition supply. The amount of organic matter, used as an indicator for the available N content, ranged between 0.8% and 2.8%. The P and K content in certain areas (e. g. the NW margin) is extremely high in all samples taken at different times (P_2O_5: 350-400 ppm, K_2O: 250-300 ppm) despite the collection of average samples. The mean macroelement content for P was 70-100 ppm, while for K it was between 100-150 ppm (Fig. 5-6.). The above-mentioned area is characterized by several extreme values for some microelements as well like e. g. Zn, Cd, Co, and Ni. None of the microelements reaches the temporary limit value (B value) (KÁDÁR, 1998), established for the characterization of the available nutrition content of the plough horizon. The available nutrition content exceeds the „A" value, i. e. the contamination background concentration (10 ppm), only in case of Cu.

The spatial distributions and variances in the micro- and macroelement concentrations of the topsoil are similar for the individual elements in the two close-timed sampling occasions (May and June 2001). The major accumulation zones can be clearly distinguished. Based on the dominant spatial variance patterns, two element groups can be identified.

The spatial distributions of P, K, Pb, Zn, Ni, Pb, Cd, and Co follow a similar pattern (**Fig. 5-6.**). The remaining group of elements does not display any similarities in their spatial distribution; i. e. while in some areas the concentration increases this is accompanied by decrease in other areas.

These elements are N, Ca, Na, Al, Fe, Cu, and Mg. The spatial distributions of the first group of elements display a close correlation with those of the humus content and the physical properties of the soils.

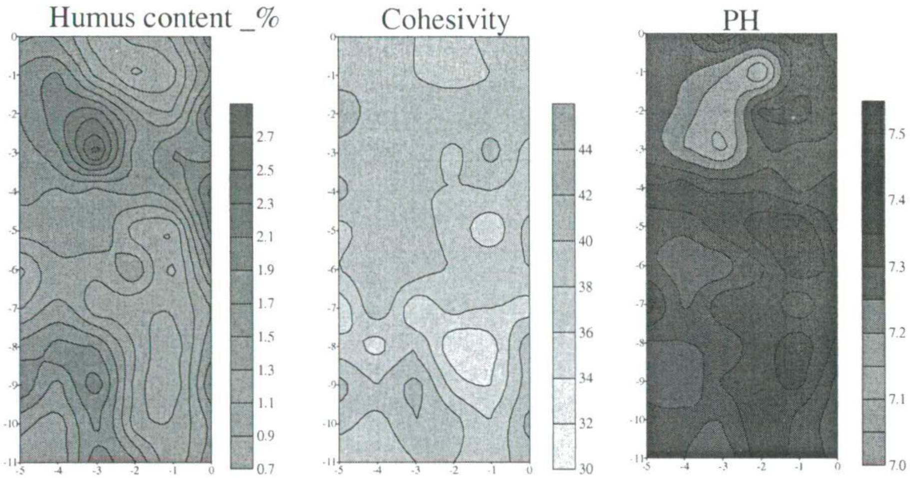


Figure 3. The spatial distribution of humus content, cohesion and pH of the soils in the pilot parcel

Macro- and microelements as indicators of erosion

Before the plantation of vine-stocks in the area (1990), the nutrition supply was even in the whole area of the pilot parcel, but there has been a major rearrangement in nutrition content during the past 10 years. The *rearrangement patterns and tendencies are different* for the individual analyzed elements, depending mainly on their chemical properties. The elements adhered to grain surfaces or to organic particles in the soil (e. g. P, K, Pb, Cd, Ni), follow a spatial distribution pattern corresponding to the variations of cohesion, and humus content of the topsoil. As changes in microrelief fundamentally determine transportation and movement of the soil grains and the topsoil, which is the richest in organic matter, the spatial distribution pattern of the latter elements is very similar to that of the relief. These correlations are depicted in Table 2. It can be clearly observed that the concentrations of the elements mentioned above are positively correlated with the organic content of the soil (r^2: 0.626-0.808), and cohesion. The other major group of elements is discharged from the topsoil following their dispersal and is transported horizontally on the soil along the profile in a soluble form (e. g. N, and Ca). The concentrations of all elements are negatively correlated with the alkalinity of the soil, because the decrease of the pH results in an increase of the available elements.

Table 2. The correlation matrix of the soil properties and the available macro- and microelement contents

	pH	Clay content	Corg	P	K	Cd	Ni	Pb	Co	Al	Cu	Zn	N
pH	1.00	-.396	-.491	-.263	-.334	-.396	-.477	-.431	-.441	-.502	-.120	-.299	-.201
Clay content	-	1.000	.533	.280	.382	.371	.326	.353	.071	.148	-.055	.279	.254
Corg	-	-	1.000	.631	.808	.739	.803	.626	.489	.426	-.061	.571	.377
P	-	-	-	1.00	.742	.649	.570	.733	.237	.066	-.279	.537	.375
K	-	-	-	-	1.00	.614	.703	.582	.415	.344	-.005	.635	.585
Cd	-	-	-	-	-	1.00	.667	.701	.356	.303	-.160	.516	.262
Ni	-	-	-	-	-	-	1.00	.550	.667	.580	-.175	.410	.273
Pb	-	-	-	-	-	-	-	1.00	.339	.188	-.253	.508	.310
Co	-	-	-	-	-	-	-	-	1.00	.800	.184	.274	.192
Al	-	-	-	-	-	-	-	-	-	1.00	.334	.149	.137
Cu	-	-	-	-	-	-	-	-	-	-	1.00	.247	.224
Zn	-	-	-	-	-	-	-	-	-	-	-	1.00	.656
N	-	-	-	-	-	-	-	-	-	-	-	-	1.000

The rearrangement and the local increases and decreases of nutrition content can be linked to the *microrelief* of the pilot parcel, indicating the initiation of a valley being formed. The markings in **figure 4.** indicate the steeper areas more susceptible for erosion (where profiles indicate degradation as far as the loessy bedrock), which were identified by field measurements (profile-degradation readings) and confirmed by detailed topographic analysis.

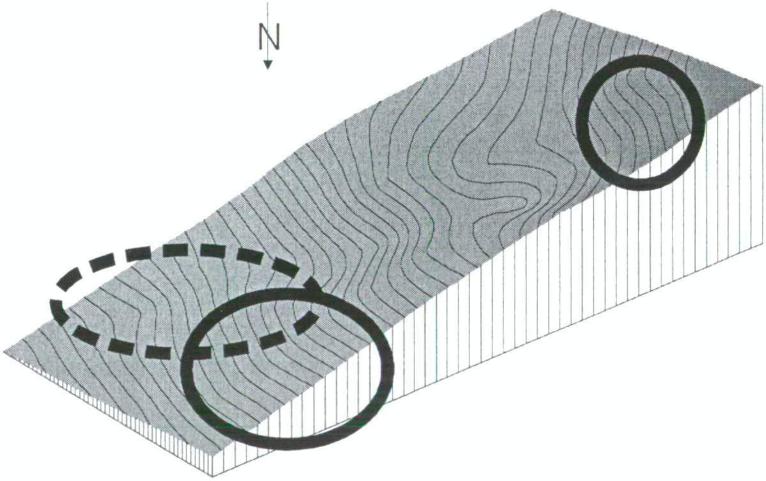


Figure 4. Relief conditions of the pilot parcel (150-300) with the areas exposed to erosion (continuous line) and accumulation (dashed line) marked (based on field observations, contour interval: 0.5 m)

Both these and the flattening areas capable of accumulation are clearly demonstrated by the spatial distribution of the individual elements (**Fig. 5-6.**).

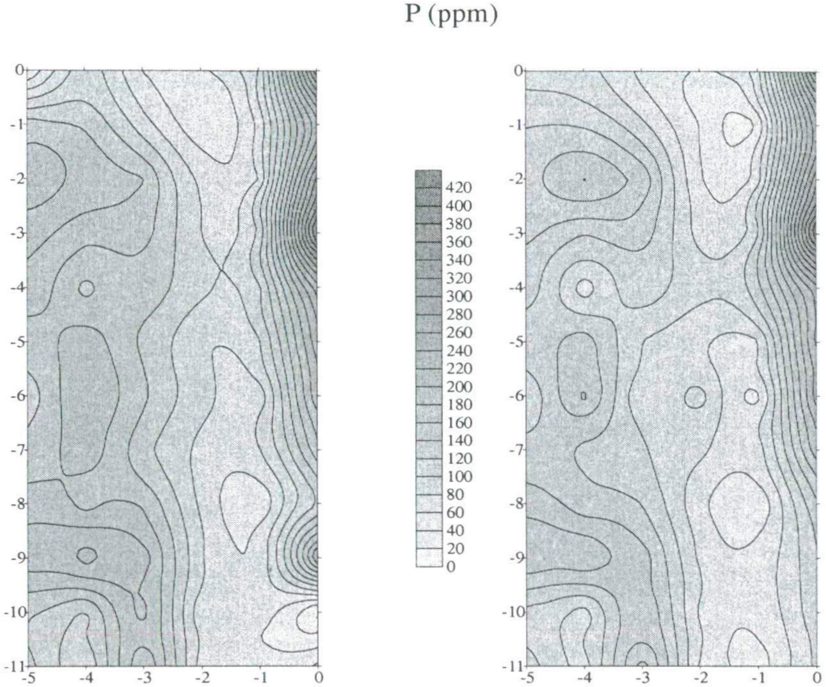


Figure 5. The spatial and temporal variations of the available P content (May and June 2001)

This is valid for both the macro- (P, K), and the microelements (Zn, Cd, Ni, Pb). In addition to the changes in microrelief, intensive ploughing in the direction of the slope also influences the spatial variations and distribution pattern of the physical properties, humus content as well as the macro- and microelement content of the soil.

Erosion modeling software Erosion 2D was run for a given slope segment of the pilot parcel in order to separate the areas exposed to intensive erosion (the curve is negative, resulting in soil removal) and those characterized by possible deposition and accumulation (with positive values of the curve). According to the output results, in two areas positive material transport (at a distance of 70-80 m, and 210-220 m from the base of the slope), and in one area (at a distance of approx. 160 m from the base of the slope) intensive erosion could have been predicted (about 1 t/ha). The area under investigation in the model has a 100% vegetation cover composed of woodlands, excluding the possibility of significant input concerning either soil particles or nutrients.

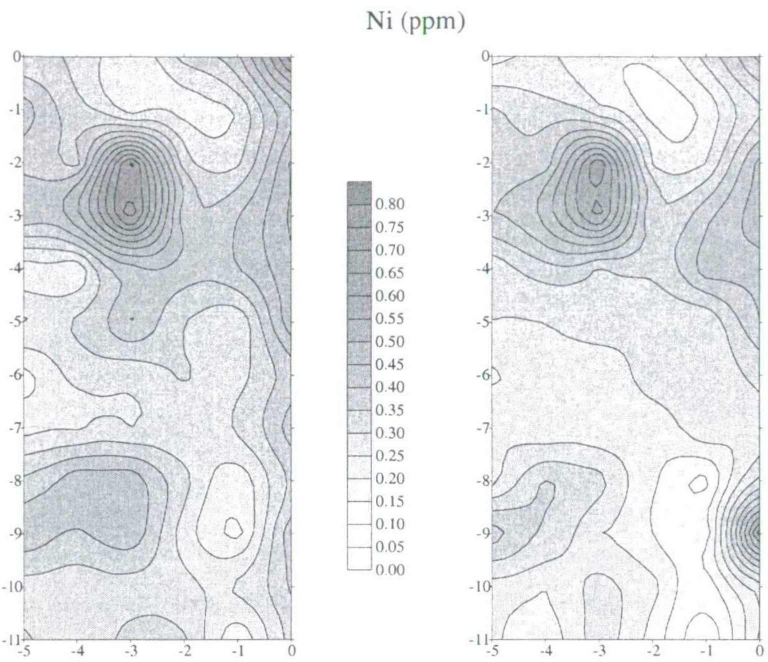
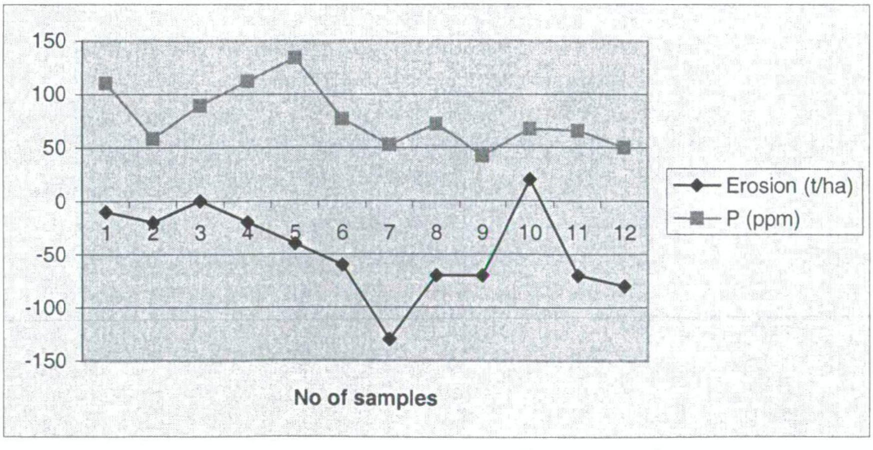


Figure 6. The spatial and temporal variations of the available Ni content (May and June 2001)

Finally these erosion and accumulation segments determined with by the model were compared to the nutrient profiles of the individual segments in order to see whether the tendencies of the elements considered as erosion indicators correspond to the results of the model (**Fig. 7-8.**).



(Values indicating soil erosion are 10x exaggerated)

Figure 7. Variations of the P content of the topsoil and the erosion-accumulation segments along the slope (the distance between the sampling sites is 25 m)

According to our findings, elements P and K from the macroelements, and Cu from the microelements appeared to be characterized by a distribution pattern along the slope similar to the one predicted by the model.

Based on the analysis of temporal variations of the nutrient profiles for individual segments (May 2001 – June 2003), the following statements can be made. After a uniform nutrient supply 13 years ago (no further fertilization or nutrient supply occurred in the area afterwards) a spatial differentiation of the nutrition content of the topsoil was initiated. This resulted in an erosion transportation of elements difficultly solved (e. g. P), adhered to the grains along the profile.

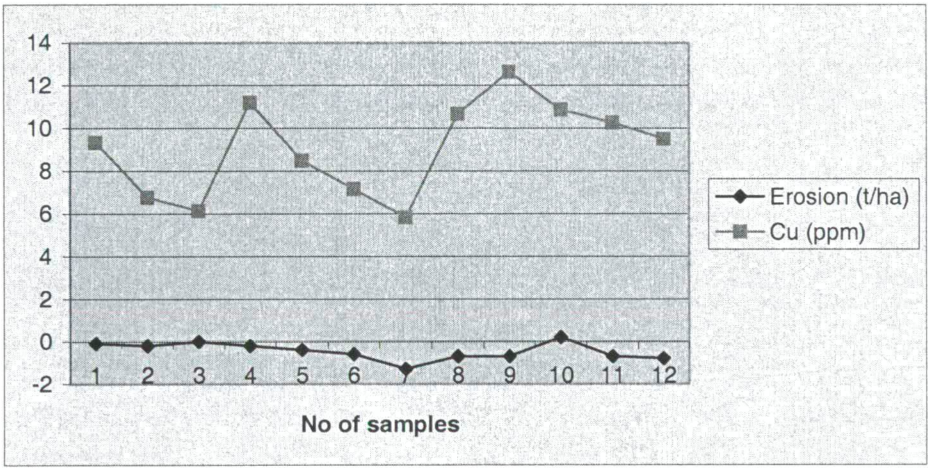


Figure 8. Variations of the Cu content of the topsoil and the erosion-accumulation segments along the slope (the distance between the sampling sites is 25 m)

According to the analysis of the P content for three consecutive sampling periods (**Fig. 9.**) the initial even distribution of nutrients along the slope starts differentiating with the pass of time; namely displaying a decrease in the segments exposed to erosion and an increase in those where accumulation occurs.

Following an artificially set up uniform nutrient supply, a state of equilibrium is reached as a result of the surface processes. This varies from slope to slope and is influenced by factors such as slope profile and other important features influencing soil erosion.

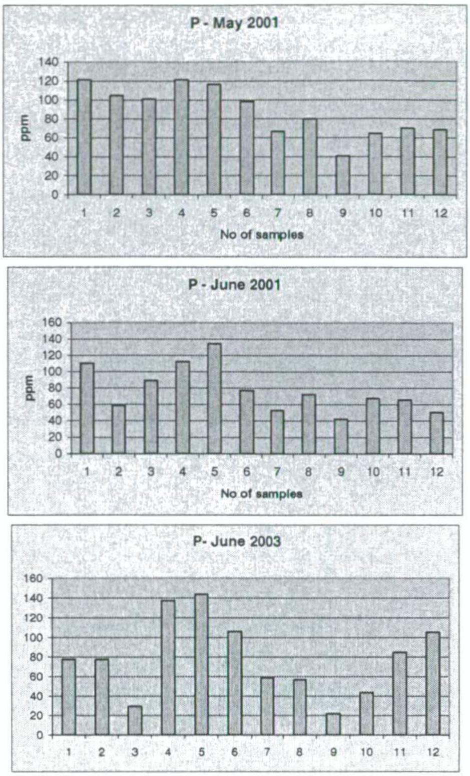


Figure 9. The temporal variations of available P content in the topsoil along the slope between May 2001 and June 2003.

Summary

The major aim of our investigations was to determine a group of elements from the micro- and macronutrients suitable to serve as indicators of soil erosion on the example of a pilot parcel selected on a sub-catchment of Lake Velence. To achieve this the following objectives were achieved:

- Distribution of macro- and microelements was mapped at two different times on the pilot parcel.
- Possible correlations of the individual soil properties and the elements were statistically evaluated. The elements correlated with the organic content and cohesion of the soil (e. g. P, K, Pb, Cd, Ni) follow a spatial distribution pattern corresponding to the variations of these latter parameters.
- Erosion was simulated for a selected slope segment with the help of the software Erosion 2D; from the output two accumulation zones and one segment suffering extensive erosion could have been identified. These erosion and accumulation segments were compared to the nutrient profiles of the individual segments.

- The group of elements most suitable as indicators of erosion was determined: these are P, K as macroelements and Cu as a microelement; their variations along the slope correspond to the results predicted by the model.
- Based on the analysis of the temporal variations of nutrient profiles for the individual segments (May 2001 – June 2003) the temporal differentiation of these elements is also well traceable, enabling the determination of the profile of equilibrium for the analyzed slope segment.

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