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## Assessment of Soil Erosion and its Impact on Humus Spatial and Temporal Dynamics. Study Case: Dobrovăț Basin (Eastern Romania)

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Abstract. The purpose of this study is to quantify soil surface erosion using the Universal Soil Loss Equation in GIS environment and to assess its impact on soil humus reserve. The quantifying of soil surface erosion was performed by integrating in GIS the thematic raster representations of the erosion control parameters which exhibit spatial variability within the limits of the study region (Dobrovăț Basin, The Central Moldavian Plateau, eastern Romania). Soil erodibility was computed according to ICPA (1987) standards, on the basis of soil type, texture and erosion degree, using a soil map of the basin at scale 1: 5000. Slope length was derived from a 20m resolution digital elevation model using SAGA-GIS software, while slope factor was determined according to the Romanian methodology by raising the slope values at the power of 1.5. Finally, the vegetation factor was computed on the basis of the normalized difference vegetation index derived from a 2001 Landsat image, using the equation proposed by Van der Knijff et al. (1999). Subsequently, we derived the potential soil erosion, controlled exclusively by soil-relief factors and the effective soil erosion, by integrating the effect of vegetation. The potential soil erosion show a mean value of 15.6 t/ha yr and a standard deviation of 16.6 t/ha yr. The integration of the vegetation effect decreases the mean value to 5.4 t/ha yr and the standard deviation to 6.7 t/ha yr. Most of the basin's surface (48.7%) falls into the reduced erosion risk class (2-8 t/ha yr), while the high and very high erosion risk classes group 7.3% of the basin. The assessment of the erosion impact on soil carbon stock was performed by coupling the USLE model with a Hénin-Dupuis mono-compartmental humus evolution model. The simulation was performed for the first 20cm of the soil profile, using a database of 224 soil profiles. The results of the simulation show that 76% of the soil profiles display a regressive evolution of the humus reserve under the impact of the soil erosion. The mean humus loss for these profiles is 36.3 t/ha for 100 years of simulation.

### Keywords: USLE, humus, GIS

#### **INTRODUCTION**

Soil humus constitutes an important fertility factor. It also represents an important carbon sink. Its spatial and temporal dynamics is controlled by 2 categories of processes: the pedogenetic production of humus and the erosion process. The former represents the input in the soil humus balance and it is a slow and complex process. The latter may be a much more active process, especially when it is human induced, leading to fast humus, and therefore fertility, decline.

The present study attempts to estimate soil humus dynamics by coupling a humus evolution model with a soil erosion model. The study area in the Dobrovăț basin situated in north-eastern Romania, in the Central Moldavian Plateau, with a surface of  $186 \text{ km}^2$  (Fig. 1).



Fig. 1. Geographical position of Dobrovăț basin

## MATERIALS AND METHODS

Soil erosion modeling is based on the Universal Soil Loss Equation, developed initially by (Wischmeier and Smith, 1978):

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

where:

- E: is the average annual erosion rate (t/ha yr);
- R: is the rainfall erosivity;
- K: is the soil erodibility;
- L: is the slope length influence;
- S: is the slope steepness influence;
- C: is the correction coefficient for the effect of vegetation;
- P: is the correction coefficient for the effect of erosion control measurements.

The equation has been tested and adapted in many regions of the World including Romania (Motoc M. et al., 1975, ICPA, 1987). The development of GIS techniques have stimulated the 3D approach of soil erosion. Software packages such as ArcGIS, TNTmips, IDRISI, GRASS, SAGA-GIS, TAS-GIS, ILWIS etc. generally include modules for computation of various geomorphometrical indices, including the slope factor and slope length factor (LS), which is quantified on the basis of flow accumulation (Mitasova *et al.*, 1996). The IDRISI software includes a dedicated module for soil erosion modeling according the revised universal soil loss equation (RUSLE, Renard *et al.*, 1991, 1997). Apart from these complex GIS programs, there have been developed programs specialized on soil erosion computation: USLE2D, which allows the computation of flow accumulation and LS factor using several algorithms; WATEMSEDEM, which allows the application or either USLE or RUSLE; WEPP, which applies RUSLE at local level (e.g. farm level); RUSLE, which also applies RUSLE locally. The last 2 programs are assisted by very detailed databases

concerning the USA territory, but they cannot be applied directly to other regions mainly because the impossibility of editing the climate data, the creation of new such files being quite a difficult operation.

The USLE factors from the model adapted by Moţoc et al. (1975) for the Romanian territory differ quite substantially, by conception and quantification manners, from the same factors defined in other USLE / RUSLE variants and therefore they cannot be combined. For instance, the values of the rainfall erosivity factor in USLE – Motoc are under 1, because they express soil loss per unit of rainfall aggressiveness, while originally this factor represents the annual sum of the products between the energy of the erosive rainfalls and their maximum 30 minutes intensities (Wischmeier and Smith, 1978), with values of hundreds. The USLE – Moţoc model has been applied successfully in different areas of Romania (Patriche *et al.*, 2006, Bilaşco et al., 2009, Dumitru et al., 2010, Arghiuş *et al.*, 2011) Other studies focused on the reformulation of the USLE model (Cârdei, 2009a,b).

The first mathematical models aiming to describe the long-term evolution of soil organic matter were developed in USA by Jenny (1941) and in France by Hénin and Dupuis (1945). The latter is a simple mono-compartimental model, which has been successfully used, under different forms, for the prediction of soil organic matter balance (Andriulo *et al.*, 1999, Roussel *et al.*, 2001, Le Villio *et al.*, 2001). Other humus evolution models (Willigen *et al.*, 2008) were applied also in Romania in order to predict the annual humus balance (Sfâru *et al.*, 2011). The model shows that a fraction of the organic debris, which accumulates at the upper part of the soil, evolves towards mineralization and simple inorganic compounds (CO<sub>2</sub>, NH<sub>3</sub>, CH<sub>4</sub> etc.), while the rest suffers partial decomposition and polymerization (humification), generating the humus. The fraction of the organic debris evolving towards humus formation is expressed by the isohumic coefficient (K<sub>1</sub>), the values of which depend mainly on the chemical composition of the debris. For instance, the debris rich in celulosis, lignins generate more humus than the debris rich in aminoacids, proteins, which decompose much easier. On the other hand, the formed humus suffers a partial mineralization, process described by the mineralization coefficient (K<sub>2</sub>).

On the whole, this model of humus formation can be described by the following equation (Roussel *et al.*, 2001):

$$y_t = y_0 \cdot e^{-K_2 t} + K_1 \cdot x \cdot (1 - e^{-K_2 t}) / K_2$$

where:

- $y_t$ : humus reserve at time t (t/ha);
- $y_0$ : present humus reserve (t/ha);
- $K_1$ : izohumic coefficient (yr<sup>-1</sup>);
- $K_2$ : mineralization coefficient (yr<sup>-1</sup>);
- *x*: annual accumulation of organic debris (t/ha yr);
- *t*: time (yr)

The present soil humus reserve was calculated using the dedicated formula:

$$y_0 = H x DA x HUM$$

where:

- y<sub>0</sub>: present humus reserve (t/ha);
- H: thickness of humus horizon (H=20 cm);
- DA: bulk density (g/cm<sup>3</sup>), estimated on the basis of organic carbon (OC), using the Manrique, Jones (1991) formula: DA =  $1.66 0.318 \times \sqrt{OC}$
- HUM: humus content (%).

The mineralization coefficient depends on climate soil textural characteristics and on the nature of the organic debris and it can be estimated using the following formula (Mary and Guérif, 1994):

$$K_2 = 0.2 \cdot (T-5) \cdot fr \cdot 1200 / [(ARG/10+200) \cdot (0.3 \cdot CaCO_3/10+200)]$$

where:

- $K_2$ : mineralization coefficient (yr<sup>-1</sup>);
- *T*: mean annual temperature (°C);
- *fr:* fraction of active organic debris (evolving towards humification);
- *ARG:* clay content (%);
- *CaCO<sub>3</sub>*: calcium carbonates content (%).

### **RESULTS AND DISCUSSIONS**

The first stage of the analysis consisted in the computation of the **present soil humus reserve** for 224 soil profiles, scattered in the eastern part of Dobrovăţ basin. Because within this database the thickness of soil horizons was not recorded, the analysis was limited to the first 20 cm of soil. This assumes that the first soil horizon is at least 20 cm thick, which is the case for most of the soil profiles. It is however possible that some profiles, especially among the Erodosols, have thinner surface horizons. This situation may induce slight errors, if the humus percent in the second horizon is significantly different from the one in the upper horizon.

Figure 2 shows the spatial variation of the humus reserve in the first 20 cm of the soil profiles. The histogram reveals a quasi-normal distribution, with a mean value of 67.8 t/ha and a standard deviation of 25.6 t/ha. The highest soil humus reserve characterizes the Chernozems (with a mean of 79.9 t/ha), while the lowest values are found in the case of Erodosols and Aluviosols (with means of 40.2 t/ha and 43.8 t/ha respectively).



Fig. 2. Classes of humus reserve for soil profiles in relation with the main soil types

An ordinary kriging interpolation was attempted but it did not yield sound results. There are 2 reasons for this failure. On one hand, the sampling is quite clustered, with a high density of points in the central and southern part of the sampling area and low density in the northern, forested area. This is the consequence of the fact that the pedologist was mainly interested in the agricultural soils. The soils under forests are not commonly mapped by soil surveyors. On the other hand, it is to be noticed that, in certain areas, close profiles have quite different humus values, which means that there is little spatial autocorrelation in the case of this parameter.

The next stage of the analysis consisted in the **application of Hénin-Dupuis monocompartimental** model in order to estimate humus formation and its evolution under automorphic conditions.

There are 4 general land use categories associated with the analyzed soil profiles: arable land, pastures, orchards-vineyards and forests. The values of the izohumic coefficient (Tab. 1) are those determined by Guérif (1986), Balesdent et al. (1990). The authors notices that, generally, 30% of the annual organic debris evolves towards humification, but on arables land this percentage reduces to mean values around 15%, due to soil management practices which enhance organic matter mineralization. The values considered for the fraction of active organic debris and the annual accumulation of organic debris (bioaccumulation rate) are those specified by Kononova (1963, 1968), cited by Lupaşcu (1998). The bioaccumulation rate is higher under pastures and much lower on cultivated soils. The chemical composition of the organic debris accumulated on arable lands and pastures are similar, the mean value of the active debris fraction being around 0.75. Under forest vegetation, the presence of slower degradable substances, such as lignins, reduces this fraction to mean values around 0.65. The mineralization coefficient was computed using the calcium carbonate and clay contents from the soil profile analytical database, the mean annual temperatures extracted from a regressionkriging model at profiles' locations (Patriche, 2009) and the fraction of active organic debris displayed in table 1. The values of this parameter range from 0.0123 yr<sup>-1</sup> to 0.0207 yr<sup>-1</sup>, with an average of 0.0179, meaning that, on the whole, 1.79% of the soil humus is mineralized each year.

Tab. 1

Land use category	Fraction of active organic debris (fr, t/ha yr)	Annual accumulation of organic debris (x, t/ha yr)	Izohumic coefficient (K1, yr <sup>-1</sup> )
Arable land	0.75	4.0	0.15
Pastures	0.75	11.0	0.3
Orchards, vineyards	0.75	4.5	0.3
Forests	0.65	4.0	0.3

Values of input parameters in Hénin-Dupuis model depending on land use

The results of the simulation show that 163 of the soil profiles, representing 73.8% of the whole sample, display a regressive evolution of the humus reserve (Fig. 3). The mean humus loss for 100 years of simulation is 30.2 t/ha, which indicates a mean annual rate of humus loss of 0.3 t/ha yr. The other 61 soil profiles, representing 27.2% of the sample, display a progressive evolution of the humus reserve, with a mean increase of 49.8 t/ha, for 100 years of simulation and, therefore, an annual rate of 0.49 t/ha yr. The box plot representation of humus evolution according to land use (Fig. 6a) shows that the soils used as

arable lands have the highest rates of humus decline, while the soils under pastures display the highest rates of humus accumulation. Also, most of the soil profiles located in orchards, vineyards or under forests manifest progressive evolutions. These findings are a bit surprising, showing that, even under automorphic conditions, the general humus dynamics is regressive. It points out that the humus loss through mineralization processes is generally higher than the natural rate of humus formation.



Fig. 3. Simulated evolution of soil humus reserve under automorphic conditions for all profiles

**Soil surface erosion** was quantified in GIS environment by integrating the raster representations of the erosion factor displaying spatial variability within the study area. Soil erodibility was computed according to ICPA (1987) standards, on the basis of soil type, texture and erosion degree, using a soil map of the basin at scale 1: 5000 prepared by Pîrnău (2011). Slope length was derived from a 20m resolution digital elevation model using SAGA-GIS software, while slope factor was determined according to the Romanian methodology by raising the slope values at the power of 1.5. Finally, the vegetation factor was computed on the basis of the normalized difference vegetation index (NDVI) derived from a 2001 Landsat image, using the equation proposed by Van der Knijff *et al.* (1999):

$$C = \exp\left[-\alpha \cdot \frac{NDVI}{(\beta - NDVI)}\right]$$

where  $\alpha$  has a value of 2 and  $\beta$  a value of 1, as recommended by the authors.

The rainfall erosivity map for Romania accomplished by ICPA (1987) was georeferenced and overlaid with Dobrovăţ basin area. It was found that most of the basin had a rainfall erosivity value of 0.100, with the exception of the extreme south where the value was of 0.144. The soil conservation practices factor (P) was given the value of 1, as no conservation practices are currently operational in the study area.

The potential soil erosion, given by rainfall and soil-relief factors, has a mean value of 15.6 t/ha yr and a standard deviation of 16.6 t/ha yr. According to ICPA (1987)

classification, the areas with high (16-30 t/ha yr) and very high (>30 t/ha yr) potential erosion risk represent 38.4% of the basin (Fig. 4a). The effective erosion was further computed by the integrating the effect of vegetation. This integration led to a significant decrease in soil erosion rates, the mean value for the basin being of 5.4 t/ha yr and it reduced the spatial variation, the standard deviation value being of 6.7 t/ha yr. Most of the basin's surface (48.7%) falls into the reduced erosion risk class (2-8 t/ha yr), while the high and very high erosion risk classes group only 7.3% of the basin (Fig. 4b).



Fig. 4. Estimated spatial distribution of potential (a) and effective (b) soil erosion risk

The estimated values of soil effective erosion were extracted into the points representing the soil profiles. They vary between 0 and 47.4 t/ha yr, with a mean value of 3.8 t/ha yr and a standard deviation of 5.t/ha yr.

**Coupling the automorphic evolution model with the erosion model** was achieved by subtracting the humus loss due to erosion (effective erosion x humus percent / 100) from the humus accumulation under automorphic conditions. It was found that the big picture does not change significantly. Thus, 171 of the soil profiles, representing 76.3% of the whole sample, manifest regressive evolutions (Fig. 5), with a mean humus loss of 36.3 t/ha for 100 years of simulation. For the other 53 soil profiles, showing progressive evolutions, the mean humus increase is 49.7 t/ha, which is practically equal to the humus gain computed under automorphic conditions. Again, the highest rates of humus decline are found for arable lands where, in some cases, the humus reserve in the upper 20cm of soil is depleted entirely at some point within the simulation period (Fig. 6b).



Fig. 5. Simulated evolution of soil humus reserve under erosion impact for all profiles





#### CONCLUSION

The results of the humus dynamics simulation points out that most of the analyzed soil profiles display a regressive evolution of the humus reserve in the upper 20cm even under automorphic conditions. According to the model, this fact is the consequence of the intense mineralization processes, which, in most cases, prevail over the humus formation process.

Though these findings may seem surprising, one must take into account that the general trend of humus decline is mostly associated with the soils used as arable lands, which prevail among the analyzed soil profiles (167 profiles from a total of 224). The impact of soil

erosion on humus dynamics is not very significant, the mean humus loss under erosion conditions being 6.1 t/ha higher than under automorphic conditions for 100 years of simulation. In some situations, concerning the arable lands, we noticed a much more severe impact of the erosional processes, the humus reserve in the upper 20cm reaching zero before the end of the simulation period.

Finally, we should mention some limitations of this approach. First, the results of such a simulation are difficult to validate. One way to deal with this problem would be to compare the humus contents of soils, which were subject to land use changes during the last decades, before and after these changes occurred. Another source of uncertainty is related to the input model's parameters, such as the fraction of active organic debris, the bioaccumulation rate etc., for which there are no specific determinations in the study area. T

There is also a conceptual issue, related to the Hénin-Dupuis model. The model applied in this study is a mono-compartimental one, assuming that the entire humus reserve is subject to mineralization. In reality, there is a fraction of the humus (the humines) which is more resistant and therefore it can be considered stable in time. The models taking into account this separation between active and inert humus are called bi-compartimental. Our intention is to continue the present research and to integrate a bi-compartimental model in order to improve the accuracy of the results.

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