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Evaluation of Effect of Different Crop Types On Soil Water Erosion: Case Study of the Myjava Hill Land, Slovakia

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Abstract. The main objective of the study is to model and evaluate the effect of different types of crops on soil water erosion by using the physically-based EROSION-3D model. The EROSION-3D model is based on physical principles and simulates surface runoff, erosion, the deposition of material, and the detachment of soil particles for a single rainfall event. The erosion model was applied to a small catchment of Svacenicky Creek (6.86 km^2), which is situated in the Myjava Hill Land in the western part of Slovakia; it is known for its quick runoff responses and related erosion processes. The parts most prone to erosion processes are located in the northern part of the Svacenicky Creek catchment on slopes with a more than 20% angle. Three crop types (winter wheat, silage corn and sugar beets) were chosen in consideration of their growing periods in order to assess the dynamic character of the erosion processes, especially during the growing period of each single crop. The modelling was performed for design rainfall events that were derived separately for each month and which were inputs to the model according to the growing period of the selected crops; six scenarios of the initial soil moisture in a range of 10-40% were designed. The results demonstrated the differences between the erosive effects of the crops selected during their growing periods. Finally, the results were statistically evaluated to determine the differences between the various scenarios of the initial moisture, different rainfall events, and selected crop types.

1. Introduction

Because soil erosion is directly connected with food production, the quality of drinking water, ecosystem services, muddy floods, eutrophication, biodiversity and carbon stock shrinkage, it has become part of the environmental agenda in the European Union during the past decade [1]. Soil erosion by water is responsible for the greatest soil losses in Europe compared to other kinds of erosion processes. Land degradation due to soil erosion is not a new threat [2], but it has turned into one of the dominant and most extensive environmental problems worldwide [3]. Various soil threats and preventive measures aimed at their elimination have various impacts on soil functions and as well as ecosystem services. These measures decrease changes in soil characteristics and have an influence on other indicators (e.g. bio-physical indicators and socio-economic indicators) [4].

It is well known that erosion is a natural process, but it is strongly stimulated by human activities. That is the reason why it is necessary to decrease its intensity and impact, especially in areas prone to erosion processes. An example of this type of area is represented by our study site, i.e., the Myjava Hill Land, where erosion processes have occurred since the late 16th century, thanks to the transformation of the landscape from forest to farmlands together with the rapid settlement of this region [5].

In the past, much research has been conducted at the Myjava Hill Land that described the erosion processes in the area and their consequences on the landscape. These studies have mainly been based on calculating soil water erosion using empirical models based on the USLE equation. However, empirical models are based primarily on an analysis of observations and mainly use topographic and precipitation information to model soil processes. On the other hand, physically-based models calculate soil erosion through mathematical and physical equations, and the models are able to calculate the actual processes more accurately [6], [7]. Only a few studies have focused on quantifying water erosion by physically-based models [8], [9].

There are many factors affecting water erosion and surface runoff generation. Crops are one of the main factors that can influence the negative impact of soil erosion in fields. Crop canopies can effectively reduce the kinetic energy exerted by raindrops and protect the soil surface from the impact of raindrops and erosion processes [10]. Different types of crops have different effects on reducing or preventing soil erosion processes and the generation of surface runoff, mainly due to differences in the crop coverage and growth status of crops, which is directly connected with hydraulic conductivity and the soil´s water retention [11]. Other factor that can strongly influences the soils' hydrophysical properties is content of rock fragments. Soils containing a significant fraction of rock fragments can affect soil water movement, infiltration and the occurrence of runoff [12].

The main scope of the study is an assessment of the effect of different types of crops, i.e., silage corn, sugar beets and winter wheat on erosion processes and runoff generation with a consideration of their growing periods. The calculations were performed using the physically-based EROSION-3D model.
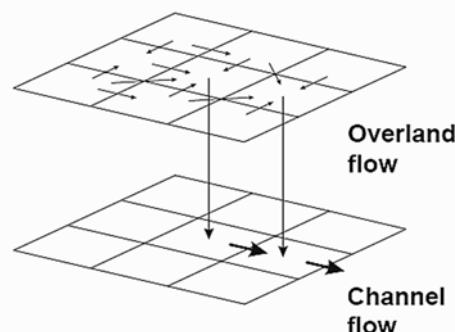
2. Methodology

2.1. Erosion-3D model

The physically-based EROSION-3D model has been developed since 1995 by Michael von Werner at the University of Freie in Berlin [13]. The model was analysed and validated on agricultural land in Saxony from 1992 to 1996 during comprehensive rainfall simulation studies. The Erosion-3D model can be used to predict the amounts of soil loss, surface runoff, and depositions from natural or design rainfall events.

The runoff processes in Erosion-3D are stored on two separate grids:
- a) overland flow with a divergent flow distribution (one cell can distribute the flow to one or more lower lying cells), and
- b) channel runoff, where only one flow direction is allowed.

When the overland flow meets a cell which is defined as a channel, it will be passed to the channel flow (Figure 1). Then the surface runoff is moved from the grid´s overland flow to the channel flow.

Figure 1. Flow splitting in the Erosion-3D model

The EROSION-3D model consists of two major components:

An erosion model, which describes soil erosion in three processes, i.e., detachment of soil particles by the impact of raindrops and their transport and deposition. The equation of the erosion module is predominantly based on the momentum flux approach [14]. The momentum flux caused by overland flow can be expressed by the equation:

$$\varphi_q = \frac{q * \rho_q * v_q}{\Delta x}$$
(1)

where

φ_q momentum flux exerted by an overland flow,
q   flow [m^3/(m*s)],
ρ_q fluid density [kg/m^3],
v_q the mean flow velocity according to Manning [m/s],
Δx the length of a specified slope segment [m].

An infiltration model, where the process of infiltration is expressed by the Green-Ampt approach. The basis of the Green-Ampt approach is created by fundamental physics and gives results that match empirical observations [15]. In the Erosion-3D model, the following modified Green-Ampt infiltration equation is used to calculate the excess rainfall [16];

$$i = -k_s * \frac{\Delta * (\psi_m + \psi_g)}{x_f(t)}$$
(2)

where

i   infiltration rate [m/s],
k_s saturated hydraulic conductivity [kg*s/m^3],
ψ_m matrix potential [J/kg],
ψ_g gravity potential [J/kg],
$x_f(t)$ depth of penetration [m] depending on the time [s].

The saturated hydraulic conductivity is defined by an empirical equation according to [17] and can be estimated by the following equation:

$$k_s = 4*10^{-3} * (1.3*10^{-3}/\rho_b)^{1,3b} * \exp(-0.069T - 0.037U)$$
(3)

where

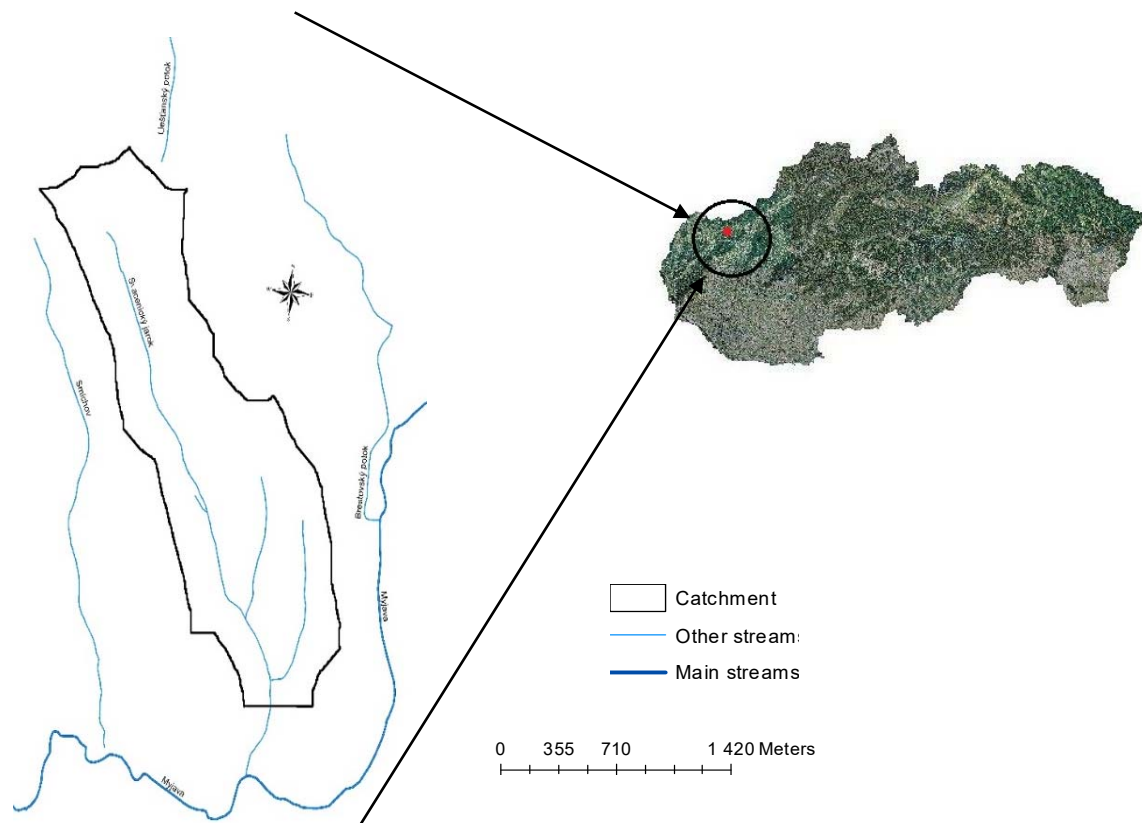k_s saturated hydraulic conductivity [kg*s/m^3],
ρ_b bulk density [kg/m^3],
T   clay content [kg/kg],
U   silt content [kg/kg],
b   parameter [−].

2.2. Study area

The Svacenicky Creek catchment is located in the Myjava Hill Land in the western part of Slovakia. Svacenický Creek is a right tributary to the Myjava River, and its confluence with the Myjava River is in the town of Turá Lúka (Figure 2). The whole catchment area of the Svacenicky Creek covers 6.86 km^2, and the entire catchment is drained by several small unnamed streams on the left; there is only one small tributary on the right side (Figure 2). The climate of the study area is characterized by mild winters and warm summers with a continental, warm, and moderately humid climate. The mean annual precipitation ranges from 650 to 700 mm with monthly temperatures from −5°C (January) to +20°C (July). The entire catchment is covered by a flysh belt formed by sand and clay layers. The prevailing soil types are loamy (Figure 3). The Svacenicky Creek catchment has variable land uses; it is

predominantly represented by agricultural areas, and only 4.2% of the whole catchment is covered by forest (Figure 4). In the upper part of the catchment, some small settlements can be found together with small urban areas.
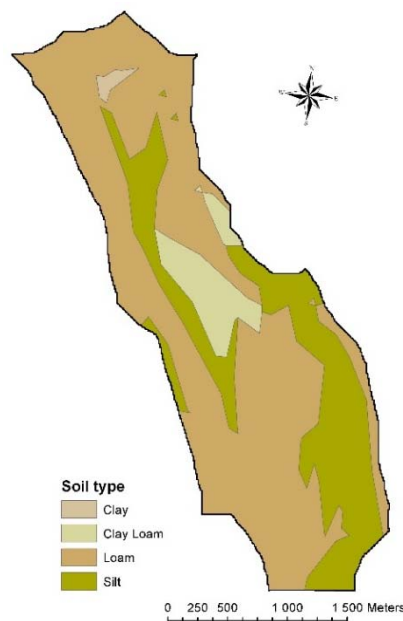

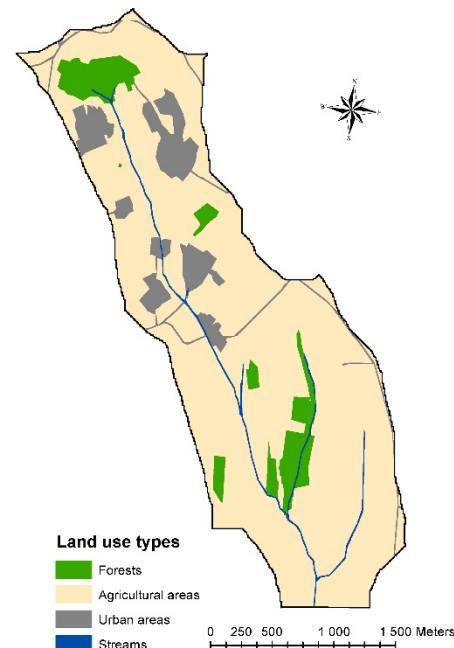**Figure 2.** Location of the Svacenicky Creek catchment

2.3. Input data

Three input parameters are needed for the Erosion-3D model, i.e., the relief (a digital elevation model), precipitation (duration and intensity), and the soil parameters (bulk density, organic carbon content, erodibility, roughness coefficient, cover, grain size distribution, and skin factor).

A digital elevation model with a spatial resolution of 10 x 10 m in the form of a square grid was used. According to the growing periods of the crops selected (from April to October), the modelling was performed for design 100-year rainfall events of a duration of one hour, which were derived separately for each month using a simple scaling approach. Simple scaling is a method for processing rainfall data for a time period shorter than one day and is used for determining the design values of rainfall intensities for durations shorter than one day and for selected time periods by using daily rainfall records that are commonly available. The method is applied to the relationship between the intensity, duration and periodicity of the precipitation, i.e., the "IDF (intensity duration frequency) properties". The scaling exponents were estimated with a linear regression from a slope between the logarithmic moment values and the scaling parameters for the different orders of the moments. The method is called simple scaling due to the scaling of the statistical moments. Results from simple scaling method were also published in case study for the Oravská Lesná station, where the detecting of trends and scaling exponents [18].

Figure 3. Soil types in the Svacenicky
Creek catchment

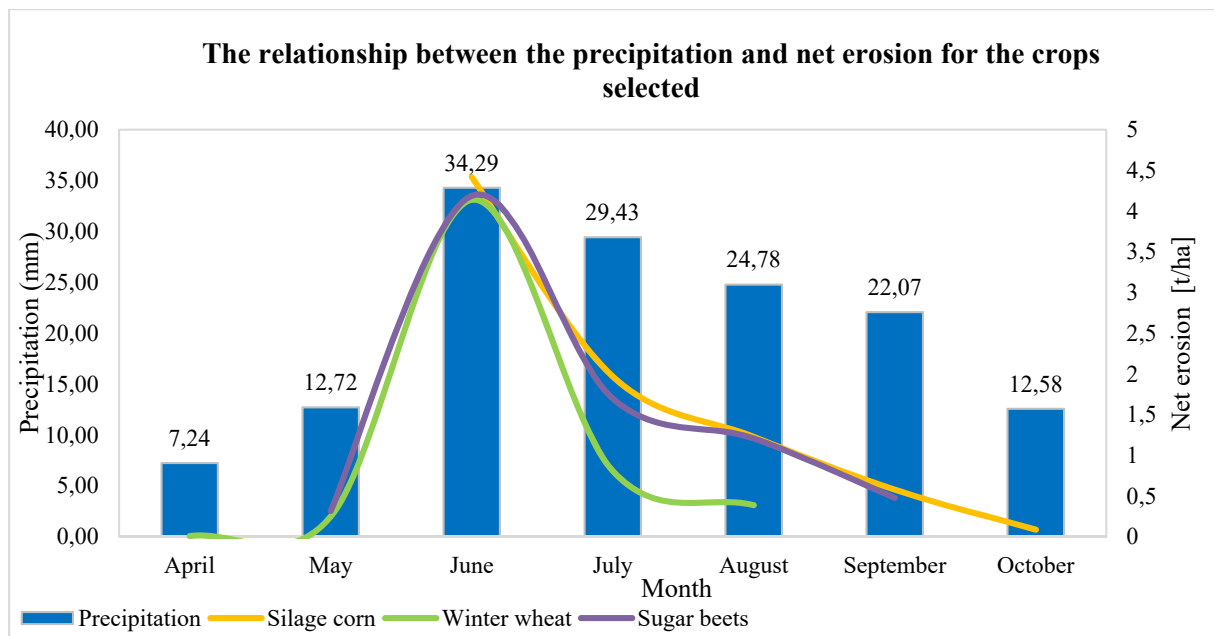**Figure 4.** Land use types in the Svacenicky
Creek catchment

In order to demonstrate the unstable character of the initial soil moisture, five scenarios of the parameters ranging from 10%-30% were created. Other soil input parameters were taken from a parameter catalogue, which was quantified for the Slovak soil system [9].
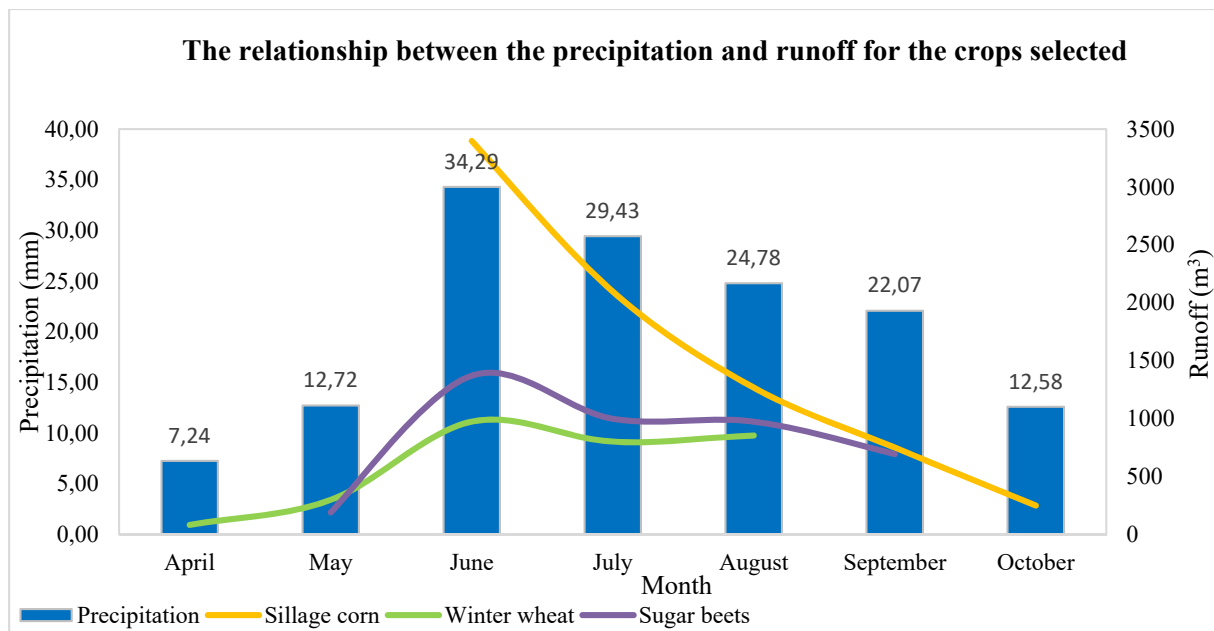
3. Results and discussions

The assessment of the soil water erosion and runoff generation in the small catchment was quantified using the physically-based Erosion-3D model. The calculation of the soil erosion was based on five scenarios of the initial soil moisture and three different crop types, i.e., silage corn, winter wheat and sugar beets.

Figure 5 represents the changes in the net erosion (difference between total erosion and deposition) calculated for the three crop types according to their growing periods, i.e., silage corn from June to October, winter wheat from April to August, and sugar beets from May to September. The results show the differences in the net erosion values between the selected crop types, which correspond to changes in the precipitation depths. The highest value of the net erosion was reached in June for all the crops when the amount of precipitation exceeded a depth of 30 mm. The intensity of the net erosion (the difference between the total erosion and deposition) in the Svacenicky Creek catchment is in a range from 0.01 (10% of the initial soil moisture) to 4.42 tons per hectare (30% of the initial soil moisture). The most intensive erosion processes were detected for the silage corn (the yellow line) as opposed to the winter wheat (the green line), where the effect of the net erosion rapidly decreased in the catchment. The winter wheat covers the soil surface and therefore create a barrier to the generation of surface runoff and erosion processes.

Figure 6 describes the total surface runoff generated for the entire catchment together with the three crops and 30 % of the initial soil moisture. Similarly to the previous results of the net erosion, the highest values were achieved in June, when the amount of precipitation exceeded 30 mm. In the case of the crops selected, the silage corn was exposed to the greatest amount of runoff in contrast with the winter wheat, which reached the lowest values (Figure 7 and Figure 8). The results also confirmed that the soil erosion rate in the catchment is sensitive to rainfall and that the monthly rainfall represents a good indicator of the variations in the soil erosion rate and runoff generation [19], [20].

Figure 5. Net erosion for the types of crops selected and 30% of the initial soil moisture

Figure 6. Runoff generation for the types of crops selected at 30% initial soil moisture

Table 1. The runoff and net erosion calculated by the EROSION-3D model for the silage corn and five scenarios of the initial soil moisture

Soil initial moisture scenario	June		July		August		September		October	
	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]
1. (10%)	355.75	0.01	299.69	0.00	251.04	0.00	222.87	0.00	126.73	0.00
2. (15%)	435.90	0.38	351.10	0.15	291.07	0.08	252.69	0.03	132.39	0.00
3. (20%)	587.49	0.97	458.53	0.38	377.58	0.22	318.28	0.11	143.94	0.01
4. (25%)	846.23	2.43	633.47	1.05	525.96	0.62	435.04	0.28	177.65	0.04
5. (30%)	3397.45	4.42	2095.61	1.97	1267.15	1.23	749.33	0.58	249.22	0.09

Table 2. The runoff and net erosion calculated by the EROSION-3D model for the winter wheat and five scenarios of initial soil moisture
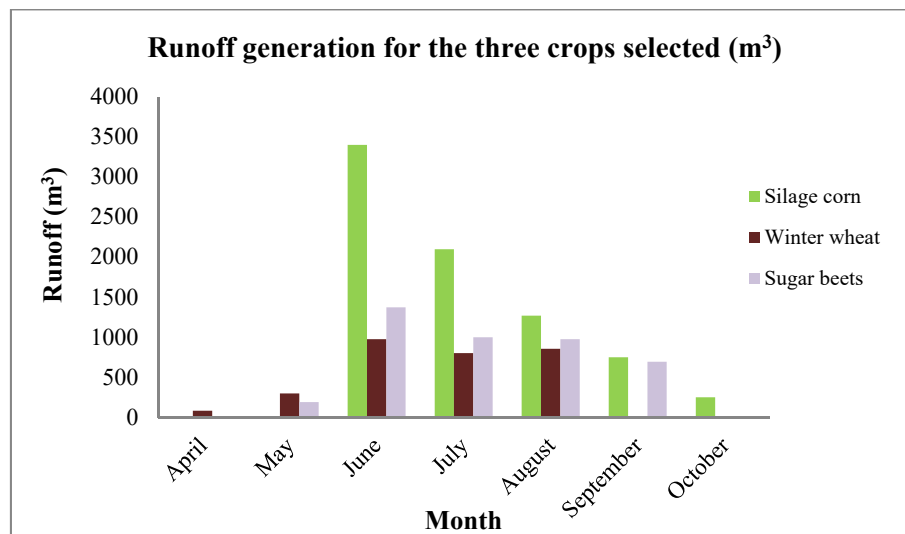
Soil initial moisture scenario	April		May		June		July		August	
	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]
1. (10%)	72.81	0.00	128.12	0.00	374.17	0.02	311.71	0.00	255.85	0.00
2. (15%)	72.81	0.00	137.84	0.01	516.21	0.25	406.49	0.05	315.21	0.03
3. (20%)	72.85	0.00	153.91	0.03	785.11	0.85	590.00	0.17	434.67	0.08
4. (25%)	75.00	0.00	196.93	0.08	846.23	1.51	725.17	0.32	663.84	0.19
5. (30%)	81.74	0.01	298.11	0.25	974.56	4.14	801.07	0.81	854.47	0.39

Table 3. The runoff and net erosion calculated by the EROSION-3D model for the sugar beets and five scenarios of initial soil moisture
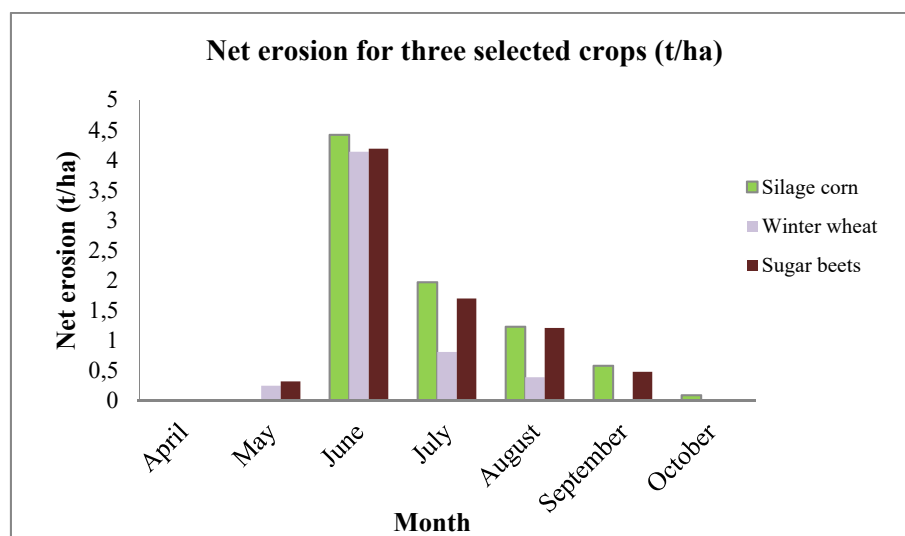
Soil initial moisture scenario	May		June		July		August		September	
	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]	Runoff [m³]	Net erosion [t/ha]
1. (10%)	128.12	0.00	352.70	0.01	299.69	0.00	251.39	0.00	222.87	0.00
2. (15%)	129.73	0.00	435.90	0.37	351.10	0.13	295.90	0.08	253.65	0.03
3. (20%)	138.53	0.03	566.98	1.41	458.53	0.33	394.44	0.21	326.01	0.09
4. (25%)	152.01	0.14	1250.15	2.42	633.47	0.91	562.38	0.59	450.31	0.22
5. (30%)	189.24	0.32	1370.71	4.19	998.07	1.70	974.24	1.21	693.25	0.48

Tables 1, 2 and 3 compare the results (runoff and net erosion) calculated for the five scenarios of the initial soil moisture (10%-30%) and design rainfall events derived separately for each month of the growing period of the crops selected. It is clear that the values increase according to the graduated initial soil moisture. The Erosion-3D model is highly sensitive to the initial soil moisture and Manning's values of the surface [21], which was confirmed by our results. The variability of the soil input parameters is mainly due to the dates of the design rainfall events (from April to October). In the case of the calculated net erosion, the winter wheat dramatically reduced the amount of soil loss compared to the silage corn and sugar beets, because the parameters of the erodibility and roughness made the soil more protective against the erosion processes (Figure 8).

Figure 7. Monthly changes in the runoff generation estimated for 30% initial soil moisture and the crops analysed

Figure 8. Monthly changes in net erosion estimated for 30% initial soil moisture and the crops analysed

4. Conclusions

The fully distributed and event-based Erosion-3D model can be considered as a useful tool for quantifying soil erosion and other characteristics after proper preparation of the soil data set. Most of the data were taken from a predefined parameter catalogue that quantifies the Slovak soil system. It is obvious that for more accurate results, it is better to use actual measured data; however, for some soil input parameters (e.g., the initial soil moisture), it is not possible to cover a wide range of unstable parameters.

Considering the variable land use types, it can be stated that the model is suitable for assessing the effects of changing agricultural management practices on the generation of runoff and the extent of soil losses. The EROSION-3D model represents a good planning tool and can be used to predict and locate

areas prone to erosion [22]. The results show a significant relationship between the precipitation and characteristics calculated, which were confirmed by several graphs. Considering the different types of crops, it can be concluded that vegetation cover plays an important role in preventing surface runoff generation and soil erosion. [23], [10] state that it represents one of the main factors affecting soil erosion and the crucial role of vegetation cover on erosion processes.

Acknowledgment

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