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Determination of soil loss on agricultural land based on field measurements in the Czech Republic

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Abstract: The current erosion protection set up in the Czech Republic (CZ) is based on the long-term soil loss due to water erosion using the Universal Soil Loss Equation (USLE). The range of recommended values of tolerable soil loss by water varies among different authors and approaches, depending on the specific area and its parameters. It is, therefore, important to ask the following questions. What is the real range of soil loss by water erosion in CZ. To determine the range of soil loss, a model extrapolation was carried out. The model extrapolation was based on the results from two main experimental measurements. Both from the evaluated volume soil loss of real erosion events and field experiments based on measurements of erosion induced by artificial rainfall. The results of modelled extrapolation of the range of long-term soil loss are in the range 6.9–13.8 t/ha per year.

Keywords: eroded volume; erosion events; soil loss tolerance; soil water erosion

Soil erosion by water is one of the major threats to soils in the European Union. It has a detrimental impact on vital ecosystem services, crop yields, drinking water quality and carbon stocks. Such a widespread process accounts for the greatest loss of soil in Europe compared to other erosion processes (e.g. wind or tillage erosion) (Panagos et al. 2015). Water erosion occurs under different conditions, but its occurrence is mainly determined by the character of land use and the links between climate, soil properties and topography (Auzet et al. 2005). Although this is a natural phenomenon, human activity is significantly increasing its intensity, especially in the last 70 years (Lobb et al. 2007; Zádorová et al. 2013), with negative impacts on the environment. The conventional agriculture typically increases erosion rates by 1–2 orders of magnitude (Montgomery 2007).

Globally, soil erosion is causing both on-site and off-site effects. On-site impacts redistribute material, resulting in a change in topsoil thickness, loss of soil quality and productivity because of loss of the nutrient-rich upper soil layers (Lal 2001). When soil particles wash off a field, they may be transported by runoff until discharged into a water body, urban areas, or contribute to the degradation of ecosystems. Once agricultural pollutants enter a water system,

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they lower water quality and impose economic losses on water users (Di Stefano & Ferro 2016).

Despite the significant progress in erosion control that has been made in recent years, soil loss through erosion is still one of the biggest threats to sustainable agriculture in CZ.

One of the keys to solving this problem is to set an allowable value of soil loss tolerance (SLT) that minimises environmental damage while maintaining soil productivity and ensuring food production. An overview of soil loss tolerance and proposals for solutions have been discussed in detail by many studies in the recent years (Li et al. 2009; Verheijen et al. 2009; Bagarello et al. 2015; Carollo et al. 2023; Di Stefano et al. 2023).

The problem of determining the value of SLT is important since these values are subsequently taken as the basis for assessing the results of a quantitative assessment of erosion risk and actual erosion losses, and making environmental and land policies. Establishing quantitative values for maximum allowable erosion losses depends on the final goal. Either it is scientific knowledge and environmental protection or ensuring sustainable production and life of society.

For the theoretical scientific approach, it is important, foremost, to search for objective truth and, as a practical implementation of the acquired knowledge, to preserve the environment unchanged as much as possible (i.e., such an approach can be called the environmental). A typical example of the scientific approach is based on the generalisation of literature data, according to which the maximum allowable losses from erosion do not exceed 0.3–1.4 t/ha per year (based on the rate of soil formation, on average 1 t/ha per year) (Verheijen et al. 2009).

With a second approach, the main goal is to ensure the sustainable functioning of society and, foremost, economic processes in a certain foreseeable period. This is called by various authors the planning horizon, the evaluation period etc.

Morgan (2005) defines the maximum permissible rate of erosion at which soil fertility can be maintained is over 20–25 years. Sparovek and Schnug (2001) reported that 50 to 100 years was reasonable for the determination of SLT value.

The focus is primarily on maintaining stable soil productivity and preventing catastrophic situations such as landslides, floods, destruction of infrastructure, etc. An example of such a pragmatic approach is the U.S. level of acceptable soil loss. According to the definition of the United States Department of Agriculture (USDA), the soil loss tolerance is "the maximum rate of annual soil loss that will permit crop productivity to be sustained economically and indefinitely on a given soil" (USDA 2020). Values of soil loss tolerance range from 2.2 to 11.2 t/ha per year (USDA 2022).

SLT are currently 2 t/ha per year for soils below 30 cm and 9 t/ha per year for medium and deep soils (> 30 cm profile) in CZ (Decree No. 240/2021 Coll.). The area of arable land in the Land Parcel Identification System (LPIS) is 2 521 542 ha (1.6. 2024), of which 96.7% is under SLT 9 t/ha per year and only 3.3% is under SLT 2 t/ha per year. SLT, as it is now determined, represents a consensus among policy-makers and soil conservation experts.

Soil conservation strategies have traditionally relied on estimating average annual soil loss, often calculated using models like the Universal Soil Loss Equation (USLE) (Wischmeier & Smith 1978), or its revised version, the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997). Multiple studies analysing the accuracy of these erosion models in the world show that the modelled soil loss values do not match the actual measured values, with a tendency to underestimation or overestimate (Trimble & Crosson 2000; Boardman & Evans 2020; Fiener et al. 2020).

It's important to note that, in many cases, most of the soil erosion occurs during a few intense events over an extended period (Larson et al. 1997). In such instances, conservation practices solely based on average annual soil loss may prove inadequate. Therefore, the erosion information from specific sites and events is much needed and required (Evans 2013) as it offers data on specific erosion events versus model estimates and calculations. They can thus represent a necessary and indispensable addition to the information base used for soil conservation design.

In CZ, the monitoring of the erosion (MoE) has been carried out continuously since 2011 (Žížala et al. 2015). The MoE aims to gather, record, and evaluate information on erosion events affecting agricultural land to create a spatial database. This database will support the development of preventive measures and new policies for effective erosion control. The database provides valuable statistics about the process and great source of data for many other applications.

The aim of this paper is to compare the values of allowable SLT used with the measured soil loss in CZ. The comparison is expressed as long-term soil loss in t/ha per year, as used in the ULSE equation used

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worldwide. Measured soil loss values are taken from two available sources in CZ. The first is measured soil loss from real erosion events. The second are the results of experimental measurement with a rainfall simulator. Our main research question is: What the realistic range of soil loss by water erosion in CZ is.

MATERIAL AND METHODS

Study area. The study was conducted in CZ, characterised by diverse field structures, varying slopes, and annual precipitation levels. The annual sum of precipitations in CZ is in the range 601–934 mm per year (Czech Hydrometeorological Institute 2024). CZ still has a large land block size; according to the Land Parcel Identification System (LPIS; Ministry of Agriculture 2024), almost 70% is larger than 20 ha and with a slope in the range of 0–23° on arable land. Arable land occurs at altitudes ranging from 129 to 1 035 meters above sea level (Ministry of Agriculture 2024). In the Czech Republic, according to the analyses of the Research Institute for Soil and Water Conservation (RISWC), more than 50% of agricultural land is threatened by water erosion and more than 10% by wind erosion (https://encyklopedie.vumop.cz). Soil degradation due to erosion has increased at an accelerated rate over the past 30 years. The predominant rationale for this phenomenon is the intensification of agriculture and the shift in preferences toward cultivating specific crops.

The crop sequence in CZ. The cropping practice is expressed in the USLE/RUSLE equation by the cover management factor – C factor. The sowing practice thus has a direct influence on the erosion hazard rate.

The long-term distribution of crop groups in crop rotations is known from LPIS records. Data are based on the analysis of declared crops for the years 2015 to 2022 (Podhrázská et al. 2024). The average areas of the main crops grown during this period are in the Table 1. Winter wheat is dominant crop in CZ, followed by winter rape, corn and spring barley.

Additionally, the percentage of crop groups in crop rotations is as follows (Table 2).

The data analysis shows that the most represented crop sequence in CZ is 3–5 years (Figure 1).

Precipitation characteristics in CZ. Erosion events are defined as episodic events triggered by a rainfall episode – an erosive rainfall event, as defined by the USLE, with a rainfall greater than 12.5 mm or an intensity greater than 6.25 mm in 15 min. In the USLE equation, it is expressed by the rainfall-runoff erosivity factor (R factor). For the conditions of CZ, it is determined according to the methodology of Podhrázská et al. (2024). By analysing the spatial radar data of rainfall totals processed by Bližňák et al. (2022) and Bližňák and Zacharov (2023), it is possible to determine the R factor, and its characteristics derived from a 30-year series: the distribution in the year and the number of occurrences of erosion-hazardous rainfall on arable land in CZ. The representation of erosion-hazardous

Table 1. Average annual area of crops grown in the Czech Republic (years 2015–2022)

Crop	Average area (ha)
Winter wheat	786 987
Winter rape	343 780
Corn	289 761
Spring barley	207 065
Winter barley	122 576
Alfalfa	74 155

Table 2. Percentage of crop groups in crop rotations in in the Czech Republic

Crop group	Percentage in crop rotations
Cereals	37.5
Corn	25.0
Winter rape	25.0
Fodder crops	12.5

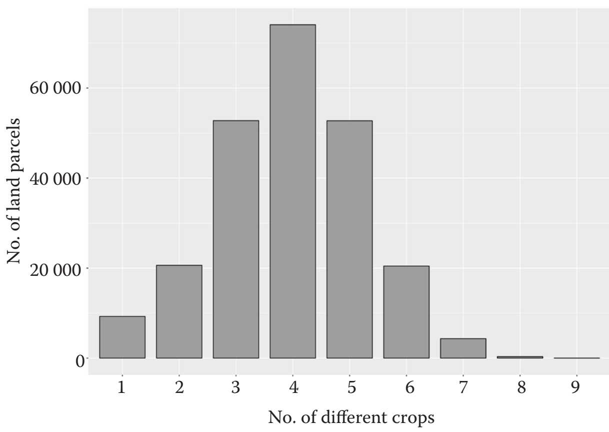

Figure 1. Number of land parcels by number of different crops grown in the period 2015–2022; processed by the authors using GIS overlay analysis; thus, it expresses the number of different crops grown for 8 years (2015–2022) on land parcel

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Table 3. Distribution of the rainfall-runoff erosivity factor (R factor) for individual months in the Czech Republic (Podhrázská et al. 2024)

Month	Monthly R factor (%)
IV.	5.9
V.	15.5
VI.	22.6
VII.	23.1
VIII.	17.1
IX.	7.0

rainfall in each month is presented in Table 3. The distribution of the R factor in the year corresponds to the distribution of the occurrence of real erosion events. Erosion events in CZ occur most in May, June, August and September (Kapička et al. 2023).

The frequency of occurrence of erosion hazard rainfall on cropland is given in Figure 2. The frequency of occurrence of erosion hazard rainfall on cropland is 9.3 (median) and 9.4 (mean).

Erosion events in CZ. Czech soil erosion legislation is predominantly based on USLE, the long-term average soil loss equation. However, soil erosion is an episodic process depending on the combination of a single rainfall event under current soil and vegetation conditions and relief. Erosion events are time-limited occurrences where the impact of rainfall causes the agitation and transport of soil particles from agricultural land, leading to the sedimentation of the transported material (Kapička et al. 2019). To get broad knowledge about where, when and why soil erosion events occur, a project of the MoE supported by the State Land Institute started in 2011 in CZ. The project involves the concept of citizen science to build a spatial database of erosion events. The website, available on https://me.vumop.cz, is used as a tool to keep records and browse through the information about the monitored events. Until now, around 3 970 events were announced across CZ and analysed by authorised workers covering information about localisation, rainfall, vegetation, applied erosion measures and protection requirements given by law, together with photo documentation. To maintain accuracy, records are inspected and edited at the RISWC. The database provides valuable statistics about the process and great source of data for many other applications.

Thanks to the long-term collection of MoE data, we can record the repeated erosion events with the highest frequency within 3 years of the first event (Figure 3). For more than 80% of the recorded erosion events, higher forms of erosion (i. e. erosion rills or furrows) predominate (Kapička et al. 2023). These results are important in the context of the number of occurrences of erosion events in the crop rotation and the possible extrapolation of the extent of soil loss. In CZ, the same crop occurs repeatedly on a land parcel, most often in the 3rd to 5th year of the cropping sequence (Figure 1). Erosion events recur on the same land parcel most often in the 2nd to 5th year of the cropping sequence. For example,

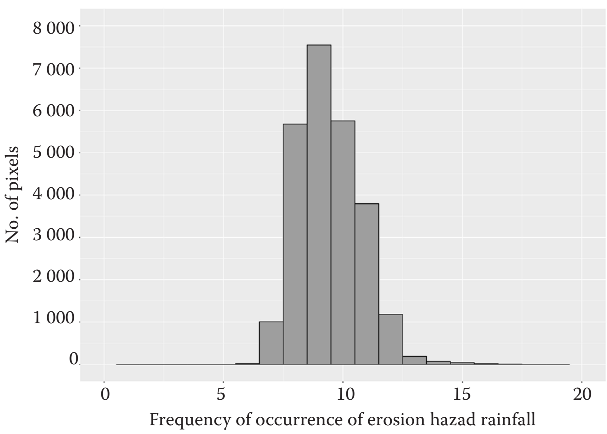

Figure 2. The graph shows the average frequency of erosive rainfall events (according to the Universal Soil Loss Equation (USLE) definition, a total of more than 12.5 mm or an intensity of more than 6.25 mm per 15 min) for the period 2002–2021 on arable land in the Czech Republic; the analysis was performed for a pixel size of 1 × 1 km; the frequency is therefore relative to the pixel

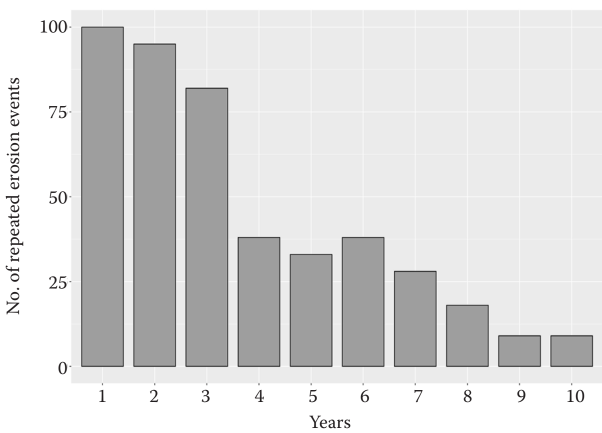

Figure 3. Number of repeated erosion events according to the number of years when the first occurrence of another erosion event occurred on the same place

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location where: 1st year winter rape with erosion event, 2nd year winter wheat without erosion event, 3rd year winter rape with erosion event. This overlap shows that the occurrence of erosion events is significantly influenced by the rotation of the same crops in the rotation sequence.

Data sources. In the Czech Republic, two sources of data on measured soil loss due to water erosion are available. The first is based on the processing of real erosion events and the measurement of the volume of soil carried away. The second is based on experimental measurements with a rainfall simulator, the principles of which correspond to the original USLE methodology.

By integrating these datasets, we will achieve a comprehensive and precise assessment of the water erosion range.

Erosion events data. Data from detailed photogrammetric monitoring of erosion events were used to evaluate the volume of soil eroded in recorded erosion events.

A total of 135 campaigns have been carried out so far, which were subsequently evaluated for systematic photogrammetric evaluation. All datasets consist of UAV-based monitoring campaigns conducted at locations where rainfall intensity reached at least 10 mm within 24 hours. Out of the total, 36 campaigns included systematic photogrammetric surveys. Ideally, all campaigns would be suitable for volumetric analysis; however, practical constraints in the field make this challenging. Erosion events must be sufficiently intense to produce identifiable rills while minimising the influence of interrill processes. This differentiation is crucial to distinguish between surface microrelief changes caused by raindrop impact (typically interrill erosion) and more substantial soil losses occurring in rills and gullies. The dataset includes imagery from both older unmanned aerial vehicle (UAV) models (Phantom 4) and the more advanced DJI M300, with an average ground resolution of 2.5 cm per pixel.

Only a limited part of the data was suitable for determining the actual volumes of soil transported in rills and gullies (Figure 4). Datasets were taken on real erosion events located: on the Cambisol of western Bohemia, climate region MT4 (the definition follows the approach of Středová et al. 2021); on the Chernozems of southern Moravia, climate region T3; on the Cambisol of central Bohemia, climate region MT4.

The method based on a GIS tool consists of deriving the volume of rills from a calculation over a digital model of relief (DMR) (Báčová et al. 2019). The input to the tool is a DMR created from an UAV overflight and a manually digitised polygon layer with the boundaries of the furrows. As the next step, the tool creates a triangular irregular networks (TIN) model and performs a differential analysis of the surface. An example of a monitoring survey on the Nesovice location to obtain high-resolution data for volumetric assessments is shown in Figure 5.

The Table 4 shows how much soil loss occurs during higher forms of erosion during one event. The process of computation of volumetric analyses is as described above – UAV photogrammetric evaluation of field campaign images in Agisoft Metashape, creating detailed DMR; manual identification of higher erosion form areas (rill, gullies) in ArcMap/ArcGIS; volumetric analyses computing DMR differences in specific areas. Most telling (and comprehensible in "USLE language" for practitioners) is the conversion to the enclosed erosion area (EEA) that is defined

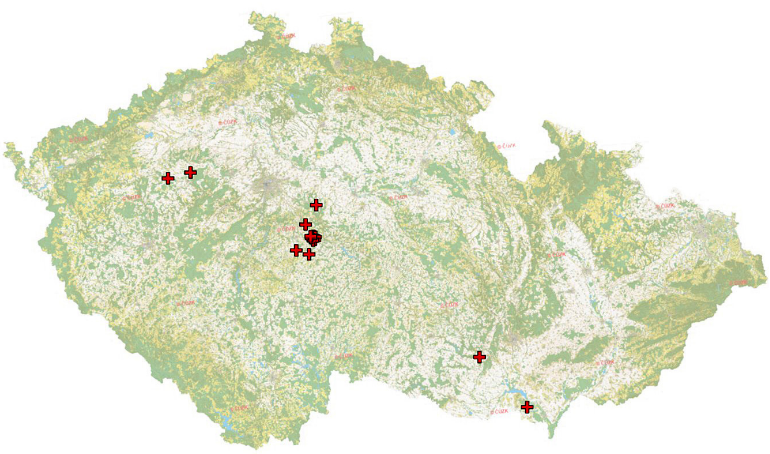

Figure 4. Map showing locations imaged with unmanned aerial vehicles (UAVs) and available data for volumetric analysis of higher forms of erosion

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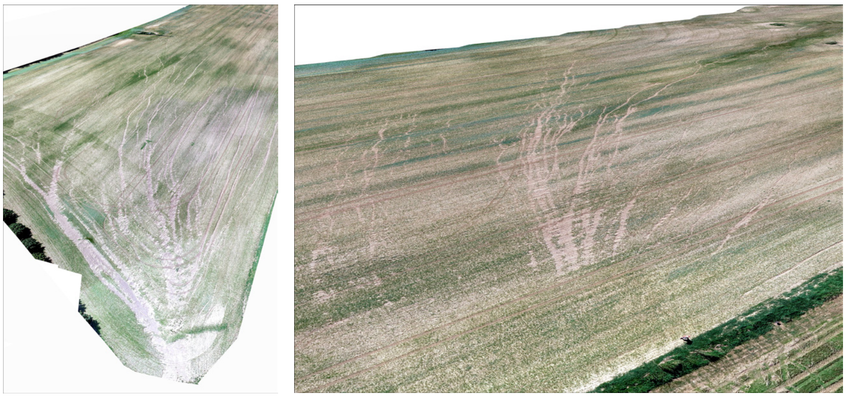

Figure 5. Location Nesovice – 23. 8. 2023 (ID 3241, 3242, 3243), an unmanned aerial vehicle (UAV) campaign to obtain high resolution data for volumetric assessments

as a connected area of land with locally enclosed erosion processes (Holý 1994). It helps to understand the severity of the scale of processes in a specific risky area.

The aerial images are processed using Agisoft Metashape software. The processing procedure begins with the alignment of individual images (Align photos), in the case of using control points, their manual or automatic detection (Detect markers) and the assignment of coordinates and selection of the reference system for images, control points, and output (Set reference system). The next step is to create a point cloud (Build Dense Cloud), which should be cleaned using a filter based on the reliability of individual points (Filter by Confidence) or cleaned manually (e.g., removing high-voltage wires, etc.). Subsequently, a digital terrain model (Build DEM) and orthophoto map (Build Orthomosaic) can be created. These are then exported in TIFF format together with a report on the basic calculation parameters. All resulting digital terrain models and orthophotomaps are created and exported in the S-JTSK coordinate system (EPSG: 5514) and the Bpv height system (EPSG: 5705). These outputs are further processed in a GIS environment (ArcMap/ArcGIS Pro) to identify signs of erosion (gullies, ruts, surface erosion, sedimentation, etc.). In most cases, UAV contains Real-Time Kinematic (RTK) in the latest campaigns, which helps to the precise process of evaluation.

Rainfall simulator data. To evaluate the volume of soil erosion in field crops, data obtained by experi-

Table 4. Overview of the evaluated volume of soil eroded in real erosion events

Location/subbasin	EEA (ha)	Soil loss within EEA (t/ha)
Býkovice 1A (ID 33a)	7.1	56.8
Býkovice 1B (ID 33b)	1.6	46.3
Býkovice 1C (ID 33c)	16.2	8.5
Býkovice 2A (ID 33d)	6.5	42.9
Býkovice 3A (ID 33e)	31.4	9.5
Býkovice 3B (ID 33f)	30.7	5.5
Býkovice 4A (ID 33 g)	4.0	8.8
Býkovice 5A (ID 124a)	8.0	27.9
Býkovice 6A (ID 124b)	5.4	30.5
Smilovy Hory (ID 2884)	21.7	13.9
Vysoké (ID 2608)	7.9	21.9
Vrhaveč u Klatov (ID 2981)	7.5	15.5
Mlékovice u Neveklova (ID 2980)	22.9	15.2
Kořen (ID 781)	6.7	54.8
Nesovice (ID 3241, 3242, 3243)	14.3	23.0

EEA – enclosed erosion area

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mental measurement with a rainfall simulator were used (Mistr et al. 2016). This is a device for generating artificial rainfall on an area of up to 8 × 2 m. The rainfall can be adjusted on the device according to the needs of the experiment, but for all the experiments presented here, a rainfall of 60 mm/h with an average kinetic energy of 10 J/m^2/mm was used (Kavka et al. 2018; Neumann et al. 2022).

The rainfall simulator allows to measure runoff, infiltration, erosion, and other soil properties under controlled rainfall conditions. This helps in understanding how different soil management practices affect water movement.

The experiments were conducted throughout the year on following areas: Řisuty (central Bohemia, district Kladno), climatic region T1 (definition according Středová et al. 2021), soil type: Chernozems; Býkovice (central Bohemia, district Benešov), climatic region MT4, soil type: Cambisol; Puclice (western Bohemia, district Domažlice), climatic region MT2, soil type: Haplic Luvisols; Nové Strašecí (central Bohemia, district Rakovník), climatic region MT2, soil type: Cambisol; Třebešice (central Bohemia, district Kutná hora), climatic region T3, soil type: Haplic Luvisols. The measurements were conducted on a set of crops:

Cultivated fallow – an area without vegetation, tilled before each experiment on soil at natural moisture levels; broad row – sorghum, corn, sunflower; cereals – wheat, oats, rye; winter rape; fodder crops – mustard, pea, buckwheat, phacelia; and soil conservation technologies: direct seeding, contour tillage, strip-till, use of intercropping and shallow tillage. The total number of experiments evaluated exceeded 300 individual rainfall simulations from five locations as a basis for data evaluation.

Model extrapolation of the range of soil loss based on erosion events data. The range of soil loss and the search for a relationship between long-term soil loss and an episodic phenomenon (erosion event) can be related to the number of occurrences of erosion events within a crop rotation (crop sequence), as a period for evaluation and the range of soil loss calculated from the volumes of furrows and rills created and photogrammetrically mapped for erosion events. For cases where higher forms of erosion were considered, the range of soil loss was expressed as the number of erosion events occurring within a crop rotation. To express long-term soil loss, total soil loss was distributed according to the length of the crop rotations. Thus, this equation has been developed for these purposes:

$$\mathrm{SLaEE}_n = \frac{\mathrm{NEE}_i \times \mathrm{LOS}_j}{\mathrm{LCC}_k} \qquad (1)$$

where:

SLaEE – extrapolated long-term soil loss from erosion events (t/ha per year);

NEE – number of occurrences of an erosion event, considered NEE_i (1;2;3);

LOS – soil loss per erosion event, according to the Table 4 (t/ha);

LCC – length of crop rotations, considered LCC_k (3; 4; 5).

Model extrapolation of the range of soil loss based on rainfall simulator data. The determination of the average long-term soil loss in the crop rotation is based on experimental data measured with a rain simulator. The crop composition in the crop rotation sequence was based on the long-term crop representation as recorded in LPIS (Table 2). RC, RF is based on the data from Table 3 and Figure 2.

The calculation determined the long-term erosion shear over the whole crop rotations as:

$$\mathrm{SLaCC} = \frac{\sum_{i=1}^{n}(\mathrm{SLC}_i \times \mathrm{RC}_i + \mathrm{SLF}_i \times \mathrm{RF}_i)}{n} \qquad (2)$$

where:

SLaCC – extrapolated long-term soil loss from crop rotations (t/ha per year);

SLC – measured soil loss of the crop (t/ha);

SLF – measured loss of the fallow (t/ha);

RC – frequency of the number of occurrences of erosion hazardous rainfall in the crop's vegetation phase (%);

RF – frequency of the number of occurrences of erosion hazardous rainfall in the fallow's phase (%);

n – number of crops in the rotation;

i – crop in the cropping sequence; solved for the crop representation given in Table 2.

To determine the range of soil loss across CZ, a comprehensive upscaling of the long-term soil erosion for the entire cropping sequence was conducted.

The influence of terrain morphology was included by means of a range of values (for the conditions of CZ) of the slope length and slope factor (LS) on arable land. These were 1st Qu., median, mean, 3rd Qu. The LS factor was determined by GIS analysis and using the USLE 2D tool, with the setting for calcu-

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lating the source area of runoff was the "multiple flow" method (Quinn et al. 1991), and the equation according to Nearing et al. (1997) for calculating the S factor. The influence of the soil erodibility factor (K) was not included, since experimental measurements already include different soil types. The determined values according to Equation (2) of the long-term erosion shear for the whole cropping sequence were calculated from the range of experimentally measured soil loss values for min, max, mean.

RESULTS

Extrapolated long-term soil loss from erosion events – SLaEE. The modelled extrapolation of the range of soil loss based on the occurrence of erosion events for a combination of occurrence of 1 to 3 events (NEE) within a crop sequence length (LCC) of 3 to 5 years, results in a mean SLaEE of 9.3 t/ha per year (median) and 13.3 (mean) t/ha per year. The range of results for the set of 135 values is shown in Table 5 and Figure 6.

If we consider a permissible soil loss of 10 t/ha per year, which is the standard recommended value, then using the extrapolation approach from erosion events, it can be said that if two erosion events occur in a 5-year cropping sequence, this limit will not be exceeded due to the occurrence of erosion events. In this case, the soil loss limit would be exceeded if, for example, two erosion events occurred in a 3-year rotation.

Extrapolated long-term soil loss from crop rotations – SLaCC. The modelled extrapolation of the range of soil loss, based on the determination of the average long-term soil loss under the crop rotation, results in a mean SLaCC of 6.90 t/ha per year (median) and 13.83 t/ha per year (mean). The range of results for the set of 240 values is shown in Table 6.

The results presented herein delineate the extrapolated range of soil loss under conventional management, with consideration given to the structure of the crops that are cultivated and their representation in crop rotations. Erosion events must reach a threshold of intensity sufficient to produce identifiable rills while minimising the influence of interrill processes.

The effect of the distribution of rainfall over the cropping season is included. Terrain morphology was included as a range of values of the LS factor in the conditions of CZ. These results are relevant for the Cambisol, chernozems, haplic Luvisols (the soils on which the rainfall simulator measurements were made). The results of these soil loss measurements were entered directly into the extrapolation equation.

Experimental data include measurements for crops established using soil conservation technologies. Namely, direct seeding, contour tillage, strip-till,

Table 5. Range of long-term soil loss from erosion events (SLaEE) values – extrapolated long-term soil loss from erosion events according to Equation (1)

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
SLaEE (t/ha per year)	1.10	5.13	9.30	13.26	17.76	56.80

Table 6. Range of long-term soil loss from crop rotations (SLaCC) values – extrapolated long-term soil loss from crop rotations from according to Equation (2); table shows also the reducing soil loss according to the soil conservation practices used

	Without soil conservation practices	Soil conservation practices				
		direct drilling	shallow tillage	intercrop and shallow tillage	strip till	contour farming
	(t/ha per year)					
Min	0.01	0.00	0.00	0.01	0.00	0.01
1st Qu.	0.04	0.00	0.03	0.03	0.02	0.03
Median	6.90	2.10	4.55	3.16	2.90	5.09
Mean	13.83	4.20	9.23	6.23	6.86	10.28
Mean 3rd Qu.	23.62	6.10	15.77	11.19	13.28	18.36
Max.	71.15	20.90	46.63	30.55	34.19	52.59

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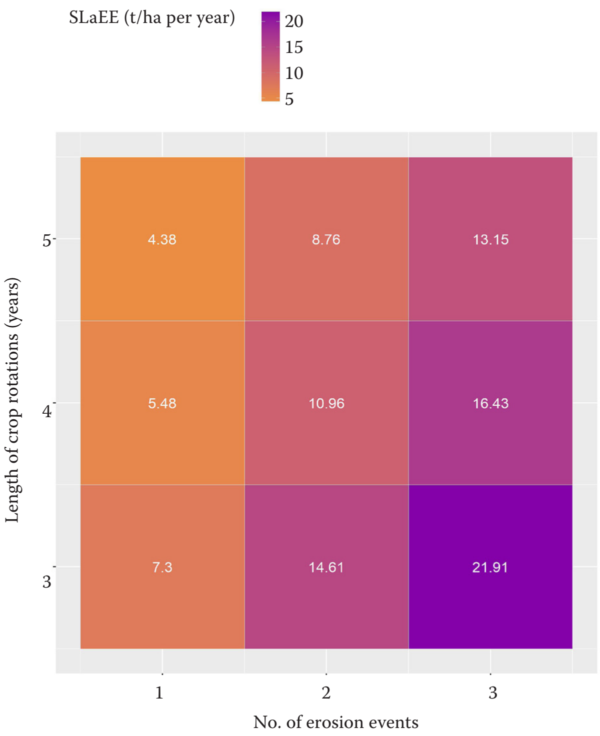

Figure 6. The long-term soil loss from erosion events (SLaEE) for combinations of the number of erosion events and different lengths of the crop rotations

The numerical values shown are the median for the combination

use of intercropping and shallow tillage. The range of long-term soil loss by erosion shear over the whole cropping sequence was determined for these soil conservation technologies according to Equation (2), so that the possible reduction of soil loss could be discussed (Table 6).

Here's a comparative boxplot visualising the range of extrapolated long-term soil loss (SLaCC) values across different soil conservation practices (Figure 7).

DISCUSSION

The results of the model-extrapolated long-term soil loss are intended to present the realistic range of soil loss by water erosion. Our resulting values are close in their mean values to the upper limit of the recommended soil loss rate.

The range of results is comparable to the largest currently compiled database of plot runoff and soil loss data in Europe, and the Mediterranean was analysed in Maetens et al. (2012). Bare soil, vineyards and tree crops have SLa (10–20 t/ha per year). Cropland and fallow show lower SLa (6.5 and 5.8 t/ha per year). Plots with (semi-) natural vegetation cover show the lowest mean annual SLa (< 1 t/ha per year). The differences in the resulting long-term soil loss values are not multiplicative and do not support the claim: as results

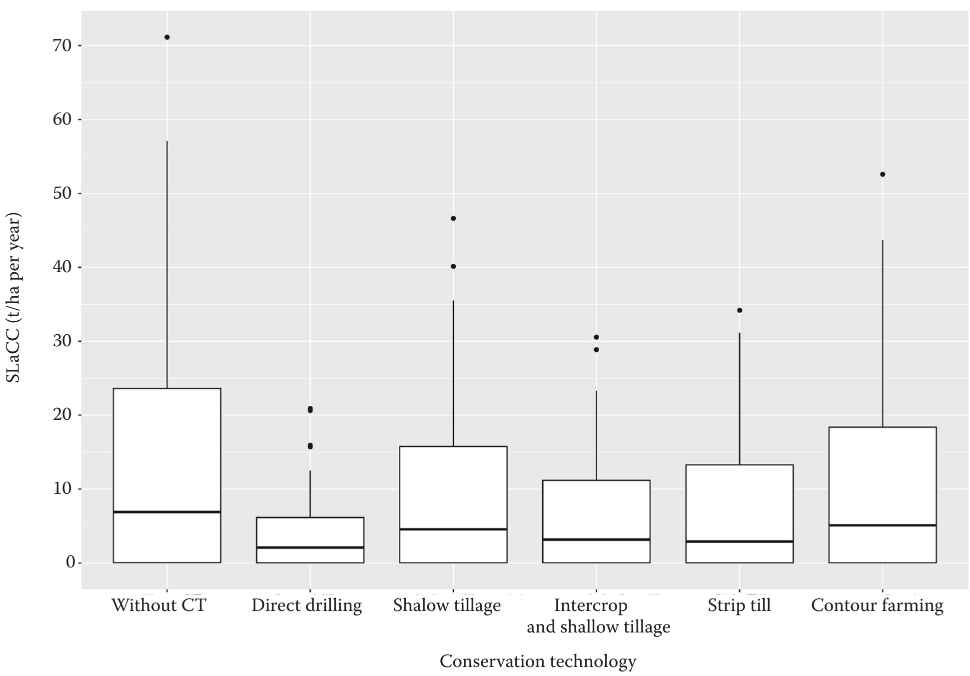

Figure 7. The range of long-term soil loss from crop rotations (SLaCC) values is determined by extrapolating long-term soil loss from crop rotations according to the soil conservation practices (CT) employed

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of water erosion measurement in different parts of the world showed, experimentally established values of soil loss can fluctuate dozens and even hundreds of times, even for the same site, depending on weather conditions or agricultural practices. (Van Dijk et al. 1996; González-Hidalgo et al. 2007; Rodrigues et al. 2010; Madarász et al. 2011; García-Ruiz et al. 2015; Evans & Boardman 2016; Steinhoff-Knopp & Burkhard 2018; Bekin et al. 2021; Bombino et al. 2021; Fang 2021; Zhu & Xu 2021; Upadhayay et al. 2022).

The model extrapolation of the range of soil loss, based on two approaches, describes both soil loss by sheet erosion and soil loss in higher forms of water erosion. Experimentally, these two types of erosion cannot be described simultaneously. The literature shows that the ratio between sheet and rill erosion is highly variable. Experiments conducted by Govers and Poesen (1988) reported that about 25% represented sheet erosion during one year of observations. They further note that the representation of sheet erosion increased with decreasing slope during the initial phase of gully development.

The approaches we presented were not aimed at evaluating a specific form of water erosion but were based on available data and experimental measurements. A comparison of the results of the two approaches to determine long-term soil loss (t/ha per year) shows a significant intersection in the most pronounced values of long-term soil loss (Figure 8).

CONCLUSION

In this paper, we describe the extrapolation of measured soil loss data in CZ, and we compare the allowable values with the extrapolated data. This comparison is articulated as long-term soil loss in tons per hectare per year, aligning with the globally recognised USLE equation. The data for measured soil loss is derived from two reliable sources in CZ. First, from detailed photogrammetric monitoring of real erosion events, and second, results from controlled experiments conducted with a rainfall simulator.

The modelled extrapolation of the range of long-term soil loss based on the occurrence of erosion events results in a mean SLaEE of 9.3 t/ha per year (median) and 13.26 (mean) t/ha per year. The modelled extrapolation of the range of long-term soil loss, based on the determination of the average long-term soil loss under the crop rotation, results in a mean SLaCC of 6.90 t/ha per year (median) and 13.83 t/ha per year (mean). When using soil conservation practices the results are in a mean SLaCC of 3.23 t/ha per year (median) and 7.36 t per ha per year (mean).

The mean values of soil loss by water erosion do not significantly exceed the recommended limit settings. At the maxima, soil losses are unsustainable in the long term. These maxima are largely influenced by the complex morphology of the terrain.

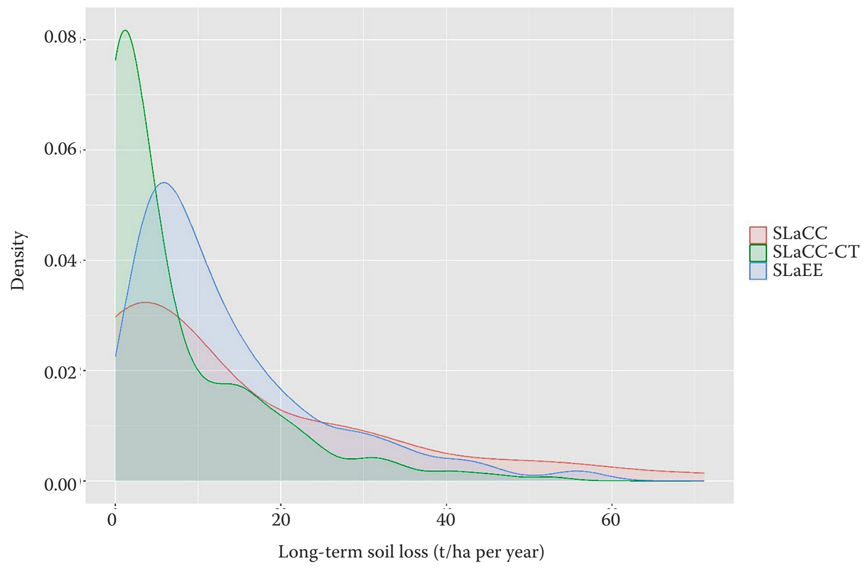

Figure 8. Distribution of model extrapolations of the magnitude of long-term soil loss according to Equation (1) extrapolated long-term soil loss from erosion events (SLaEE) and Equation (2) extrapolated long-term soil loss from crop rotations (SLaCC); SLaCC – CT with the soil conservation practices (CT)

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The use of the described extrapolation methods can be performed repeatedly with further significant extension of the measured data by the rainfall simulator and measured soil loss for real erosion events.

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