Adjusting the $CP_{\text{max}}$ factor in the Universal Soil Loss Equation (USLE): areas in need of soil erosion protection in the Czech Republic

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1. Introduction

Water erosion is caused by destructive rain activity and surface run-off with subsequent transport of soil particles. Water erosion intensity is dependent on the character of rainfall and surface run-off, soil, terrain and vegetation conditions, and methods of farming on agricultural land. As stated in the Report by the European Commission on ‘Implementing Soil Thematic Strategy for Soil Protection’ (European Commission, 2012), soil erosion is one of the most significant and widespread degradation soil factors, which causes irreversible damage in Europe. Moreover, degradation processes are accelerated in many places (European Environment Agency, 2002) and this is made worse by high relief and cultural land and this is made worse by high relief and terrain attributes. The considerable size of agriculture plots, caused by land consolidation, soil compaction by heavy machinery and usage of unsuitable farming methods means there is no protection against the effects of accelerated erosion (Dostál et al., 2007).

Soil losses greater than 1 t ha$^{-1}$ year$^{-1}$ are generally considered irretrievable because they are higher than the rate of soil formation – and are thus unacceptable rates of soil erosion (Verheijen, Jones, Rickson, & Smith, 2009). Table 1 and Figure 1 show the distribution of areas exceeding these values in the Czech Republic. As shown by records from the Database on Monitoring Soil Erosion of Agricultural Land (Kapička & Žížala, 2013), in some cases of intense rain, there are losses in excess tens of tons per hectare and it is not uncommon for soil losses greater than 100 t ha$^{-1}$ to occur. The rates differ according to terrain attributes and soil type, with Chernozems and Luvisols in loess regions being most threatened because of their high erodibility (Zádorová et al., 2015; Zádorová, Penížek, Šefrna, Rohošková, & Bortůvka, 2011; Zádorová, Žížala, Penížek, & Čejková, 2014).

The Czech Republic is in central Europe and has a land area of 78,866 km$^2$ of mainly hilly and highland character. The Czech Republic has a temperate continental climate with predominantly westerly circulation. Annual mean precipitation fluctuates within the range of 400–1500 mm depending on location, with peak rain in the summer months. Arable land covers approximately 42% of the area. The main soil units are: Cambisols (45%), Haplic Luvisols and Albic Luvisols (18%), and Chernozems (12%).

The map of the maximum tolerable CP factor value (the cover-management and the support-practice factors) – $CP_{\text{max}}$ was established in order to assess the erosion hazard of land. It estimates the requirements of conservation practices that would prevent soil erosion...
rising above the tolerable limit of annual soil loss. This approach has been described by a number of authors (Baja & Nurmiaty Arif, 2014; Benitez, 2007; Pinto, Valerio Filho, & Donzeli, 1992; Pudasaini et al., 2004; Rodríguez & Andrade, 2001). Nine classes clustered in five groups are established according to conservation requirements based on erosion risk.

The Main map is based on the calculation using the adjusted Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1965, 1978). This equation was used in the Czech Republic as a basis for creating the map of erosion threat for the purposes of defining Standards of Good Agricultural and Environmental Conditions (GAECs), within Cross Compliance (Novotný et al., 2014). The Revised Universal Soil Loss Equation (RUSLE), proposed by Renard, Foster, Weesies, McCool, and Yoder (1997) is still in the testing stage in the Czech Republic according to Janeček, Kubátová, and Tippl (2006). In particular, the complete database of revised soil erodibility and the cover-management factors have not yet been compiled for local conditions. Jakubíková, Janeček, and Tippl (2006) dealt with field determination of the specific characteristics necessary for the computation of the C factor in RUSLE.

However, the basic characteristics have been determined only for selected crops. The USLE is thus applied for conditions in the Czech Republic, using an improved algorithm for the LS factor, to reflect the ratio of rill to interrill erosion, as used in RUSLE.

### 2. Materials and methods

Water erosion is most frequently quantified using average annual soil loss ($A$) ($\text{t} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$), which is calculated on the basis of USLE (Wischmeier & Smith, 1965, 1978). It is used in the same way in the Czech Republic:

$$ A = R \times K \times L \times S \times C \times P, $$

where $R$ is the rainfall erosivity factor, defined as a product of rainfall kinetic energy and its highest 30-minute intensity. Thus, for the particular task (aggregated for the period of the whole year) this factor is dependent on the frequency of rainfall occurrence ($\text{MJ} \cdot \text{ha}^{-1} \cdot \text{cm}^{-1} \cdot \text{h}^{-1}$, respectively, after adjustment $\text{N} \cdot \text{ha}^{-1}$). Since 2012, the value 40 $\text{N} \cdot \text{ha}^{-1}$ has been used as a mean factor of erosion rainfall efficiency in the Czech Republic (Janeček et al., 2012, 2013). The factor has not been regionalized due to a very small number of rain-gauges used for its derivation. However, recalculation of this factor and its regionalization is currently being undertaken (Středová, Krása, Štěpánek, & Novotný, 2014).

$K$ is the soil erodibility factor, expressing soil susceptibility in terms of erosion depending on soil texture and structure, its permeability, content of humus and other properties ($\text{t} \cdot \text{M}^{-1} \cdot \text{cm}^{-1} \cdot \text{year}^{-1}$, respectively, after adjustment $\text{t} \cdot \text{N}^{-1}$). Values used for the $K$ factor are based on the national database of Evaluated

### Table 1. Values of long-term annual soil loss ($A$).

| Average annual soil loss ($A$) ($\text{t} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$) | Distribution (%) | Area (km$^2$) |
|---|---|---|
| Very slightly threatened below 1.0 | 49.55 | 20,688 |
| Slightly threatened 1.1–2.0 | 18.26 | 7623 |
| Medium threatened 2.1–4.0 | 15.57 | 6501 |
| Heavily threatened 4.1–8.0 | 10.38 | 4334 |
| Very heavily threatened 8.1–10.0 | 2.00 | 834 |
| Extremely threatened above 10.1 | 4.24 | 1771 |
| Total | 100 | 41,753 |

Figure 1. Average annual soil loss caused by erosion in Czech Republic.
Soil-Ecological Units (ESEU), scale 1:5000 (Voprávil, Janeček, & Tippl, 2007). These data are regularly updated at up to 50,000 ha year\(^{-1}\).

\(L\) is the length factor, expressing the influence of continual slope length on the extent of soil loss (dimensionless – ratio of field soil loss to the corresponding loss from 22.13 m slope length).

\(S\) is the slope factor, expressing the influence of slope gradient on the extent of soil loss (dimensionless – ratio of field soil loss to corresponding loss from unit plot with slope steepness of 9%). The product of the \(LS\) factors is often determined using a combined formula or a common procedure and is termed the ‘topographic factor’. Determining the topographic factor is influenced mainly by Digital Terrain Model (DTM) quality and information availability for technical erosion control measures (TECM), which efficiently interrupt water run-off on agricultural land. The LS factor layer in the map takes advantage of a raster 5 × 5 m\(^2\) resolution DTM (© GEODIS – professionally created and commercially available raster DTM). This DTM uses the Baltic Vertical Datum – After Adjustment (Bpv) vertical coordinate reference system. The DTM quality and information availability for technical erosion control measures are sometimes determined and commercially available raster DTM). The raster layer of individual factors with a 5 m spatial resolution was prepared. The resulting raster of \(CP_{\text{max}}\) values was calculated using Map Algebra applying Equation (1). For map readability, the raster was generalized by resampling to a 50 m resolution based on a median aggregation strategy. The output of the calculated data is limited depending on the input data. The values were calculated on areas eligible for erosion calculation, that is, on areas of agricultural land (see the calculation of LS factor). Given the purpose of the Main map, the final layer was extracted by using the distribution of land parcels from the LPIS database.

3. Conclusions

The USLE equation has been expressed in the following form in order to assess the soil erosion threat in GAEC standards (DZES – Czech equivalent to GAEC) (Novotný, Váňová, Smolíková, Kristенová, & Pírková, 2015):

\[
CP_{\text{max}} = \frac{T}{R \times K \times L \times S},
\]

where \(CP_{\text{max}}\) is the value of required protective vegetation influence and erosion control measures in relation to tolerable mean annual soil loss. It expresses the maximum tolerable \(CP\) factor value, which, if exceeded, results in exceeding tolerable mean annual soil loss.

Aggregate factors \(R \times K \times L \times S\) related to the physical environment are sometimes called Natural Potential for Erosion (NPE) (Silva, Da, Alvares, & Watanabe, 2011; Vrieling, Sterk, & Beaulieu, 2002), where \(R, K, L, S\) are the same as in Equation (1).

\(T\) is the tolerable mean annual soil loss allowed while maintaining soil functions and its fertility, related to soil depth (t ha\(^{-1}\) year\(^{-1}\)). The values of tolerable mean annual soil loss are determined based on soil depth that is characterized by soil profile thickness, delimited by bedrock or high stoniness. Information on soil depth is based on the national database of ESEU. For calculations, the following values are used: 

\[
T = \begin{cases} 
1 \text{ t ha}^{-1} \text{ year}^{-1} & \text{for shallow soils} \\
8 \text{ t ha}^{-1} \text{ year}^{-1} & \text{for medium-depth and deep soils} 
\end{cases}
\]

Because of its high resolution, the final layer can be used as a basis for landscape design for land
consolidation purposes. Other supportive and consultancy tools are linked to the Main map as well, for example, a brochure designed for farmers and a guidebook on protection against water erosion (Novotný et al., 2014). There is also an internet application, the Erosion Control Calculator (http://kalkulacka.vumop.cz). All layers dealing with water erosion are also freely available to view on the internet map application Water and Wind Erosion of Soils in the Czech Republic (http://geoportal.vumop.cz).

The map will be made more accurate depending on data updates and their specifications, and efforts have also been made to educate experts on the map application. For example, technical checks of further soil protective technologies have been carried out, and lectures and workshops for consultants and the agricultural public have been delivered.

Software
USLE2D and Esri ArcGIS 10.2 (with Spatial Analyst and 3D Analyst extensions) were used for calculations, analysis and pre-processing. Esri ArcGIS 10.2 was used for Main map production. Graphs used in the map were prepared using the language and environment for statistical computing R (version 3.0.1) and RStudio (Integrated development environment for R). The vector graphical editor Adobe Illustrator CS5 was used for final graphic adjustments.

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