Designing of crop management for reducing soil loss according to geographic location using STD-C factor tool

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Abstract: Crop-management factor (C) is essential part of average annual soil loss calculation by USLE. Several methods were developed due to lack of optimal data required in original methodology. For designing optimal crop rotation expressed by C factor is presented methodology of calculation average annual soil loss over permissible limits for representative drainage subbasins of land parcel and C factor limits in combination with STD-C tool. This methodology brings a good opportunity for erosion control measures designing in land use planning with reflecting geographic location and local climate conditions and enables adequate allocation of financial expense for erosion control.

Key Words: USLE, C factor, P factor, STD-C factor, erosion control measures

INTRODUCTION

The equations USLE (Wischmeier and Smith 1978) and RUSLE (Renard et al. 1997) are widely used and accepted methods over the world for calculating average annual soil loss. Protective influence of vegetation cover and crop management are expressed by crop-management factor C. Many authors developed different methods of C factor estimation and calculation due to lack of optimal data defined in original methodology. Brychta et al. (2018) divided approaches for C calculation into these groups – based on:

1) long-term monitoring of runoff plots (Janeček et al. 2012, Wischmeier and Smith 1978),
2) defining subfactor values (Dissmeyer and Foster 1981, Renard et al. 1997, Wischmeier and Smith 1978),
3) simulated rainfalls (Garcia-Orenes et al. 2009, Janeček et al. 1995),
4) land cover classification method and average values (Panagos et al. 2015),
5) satellite multispectral data and vegetation indexes (Van der Knijff et al. 2000, De Jong 1994),
6) regression and correlation analyses with climate data (Toman and Kadlec 2003).

Groups 1–3 require time-consuming terrain measurements and are basic source of data for deriving any other methodology of C factor estimation. *Group 4* leads to constant values for large areas, enables only low spatial and temporal resolution and does not reflect spatial and temporal variability. Often used are methods based on linear regressions with vegetation spectral properties expressed by normalized difference vegetations index NDVI *(group 5)* even according to De Jong (1994) this relationship exhibits quite low correlation. The most commonly used method in land used planning in the Czech Republic according to Toman and Kadlec (2003) is based on linear regression between C factor and climatic regions, determined by annual temperature and rainfall totals, sums of temperature over 10 °C, probability of dry growing periods and moisture guarantee during growing period *(group 6)*. This method is useful for average annual soil loss calculation but does not enable reflecting changes of soil loss by designing of optimal crop rotation or erosion control measures. For this purposes can be used quite time-consuming original methodology according Wischmeier and Smith (1978). Brychta et al. (2018) developed revised methodology were all steps of time-consuming C calculation were automated in GIS environment with innovative procedure of R factor weights determination for each agro-phase. This method respects original methodology based on division into 5 agro-phases and determination of weights of R factor distribution throughout the year (Wischmeier and Smith 1978) but using fully distributed monthly R factor maps (Brychta et al. 2018, Ballabio et al. 2017) which enable determination weights of R factor distribution throughout the year according to land parcel geographic location and therefore local conditions are reflected (see Figure 1 and 2).

MATERIAL AND METHODS

Average annual soil loss over permissible limits were calculated for cadastral area Kostomlaty pod Milesovkou using USLE equation (Wischmeier and Smith 1978):

$$G_{RISK} = (R \cdot LS \cdot K \cdot C \cdot P) - G_P, \tag{1}$$

where: G_{RISK} – average annual soil loss over G_P (t/ha/yr), G_P – permissible soil loss limit (t/ha/yr), *R, L, S, K, C, P* – USLE factors. For *LS* factor calculation was used DMR 5G (LiDAR data from CUZK) and resolution 10 m. Calculation were performed according to Renard et al. (1997) and McCool (1987) using equations:

$$L = \left(\frac{l_d}{22.13}\right)^m, \tag{2}$$

$$S = 10.8 \sin(s_1) + 0.03, \tag{3}$$

$$S = 16.8 \sin(s_2) - 0.5, \tag{4}$$

where: *LS* – topographic factor, l_d – horizontal projection of uninterrupted slope length, s_1 – slope (rad) < 9%, s_2 – slope (rad) ≥ 9%, m – exponent determined by equation:

$$m = \frac{\beta}{(\beta+1)}, \text{ where: } \beta = \frac{\left(\frac{\sin s}{0.0896}\right)}{3(\sin s)^{0.8}+0.56}. \tag{4}$$

The horizontal projections of uninterrupted slope lengths (l_d) were calculated as unit contributing area raster (Moore and Wilson 1992) generated using flow accumulation raster derived from flow direction raster calculated using algorithm D∞ (Tarboton et al. 1997). Resulting LS values are shown on Figure 3. K factor values were determined according to Vopravil et al. (2007), C factor according to Toman and Kadlec (2003), R factor according to (Brychta and Janeček 2017, 2019) and permissible soil loss limits (Gp) according to Janeček at al. (2012). Resulting average annual soil loss for each pixel 10 x 10 m is shown on Figure 3. Using representative parts of land parcels derived according prevailing flow direction (Figure 4) were calculated G_{RISK} values using zonal statistics (Figure 4). According to G_P limits were created a raster with C factor limit values using equation (Wischmeier and Smith 1978, Novotný et al. 2014):

$$C_{LIMIT} \cdot P = \frac{G_P}{R \cdot LS \cdot K}, \tag{5}$$

where: C_{LIMIT} – C factor limit values, G_P – soil loss limits (t/ha/yr), *R, LS, K, P* – USLE factors. Resulting C_{LIMIT} values for each pixel were reclassified according Table 1. This map serves for framework recommendations for planning crop management and farming methods (Table 1, Figure 5). According these maps (Figure 4, 5) can be evaluated and designed several possibilities of crop-management or erosion control measures for each land parcel or its parts. For more detailed planning of crop rotation or agrotechnical management can be used STD-C factor model created by Brychta et al. (2018) and also erosion control measures expressed by P factor (Table 2). Model STD-C factor is based on revised methodology which respects original principles with accordance to Wishmeier and Smith (1978) based on division into 5 phases (Figure 1) and improved method of determination of weights of R factor distribution throughout the year.

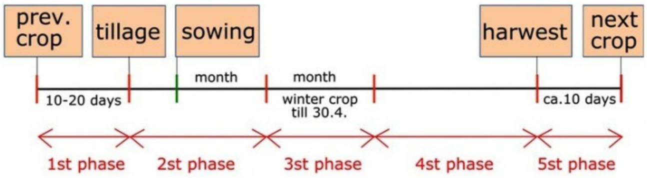
Table 1 Recommendation for planning crop management according to C factor limit values

C_{LIMIT} values	Risk	Recommendation	Symbol
≤ 0.005	extreme	Conversion to permanent grassland.	PG
0.005–0.02	high	Planting perennial fodder plant e.g. clover and alfalfa.	PF
0.02–0.2	medium	Exclusion of wide-row crops, narrow-row crops can be plant only with the use of erosion control technology.	NR
0.2–0.6	low	Planting narrow-row crops without limitation, wide-row crops only with the use of erosion control technology.	NRCM
> 0.6	no risk	Planting without limitation.	no limit

Table 2 Erosion control measures derived by P factor according to Wishmaier and Smith (1978)

Erosion control measures	Slope (%)			
	2–7	7–12	12–18	18–24
maximal flow length for contour cultivation	120 m 0.6	60 m 0.7	40 m 0.9	- 1
width and number of strips for strip cropping	40 m 6 strips	30 m 4 strips	20 m 4 strips	20 m 2 strips
– root crops and perennial forage	0.3	0.35	0.4	0.45
– root crops and winter cereals	0.5	0.6	0.75	0.9
contour furrow ploughing	0.25	0.3	0.4	0.45

Figure 1 The timeline of 5 agro-phases for C factor calculation



All steps of time-consuming C calculation were automated in GIS environment with innovative procedure of R factor weights determination for each agro-phase using fully distributed monthly R factor maps and land parcel geographic location and therefore local conditions are reflected. User interface of STD-C factor model and example of calculation are shown on Figure 2. The resultant weighted STD-C factor value is calculated according to following equations (6–8):

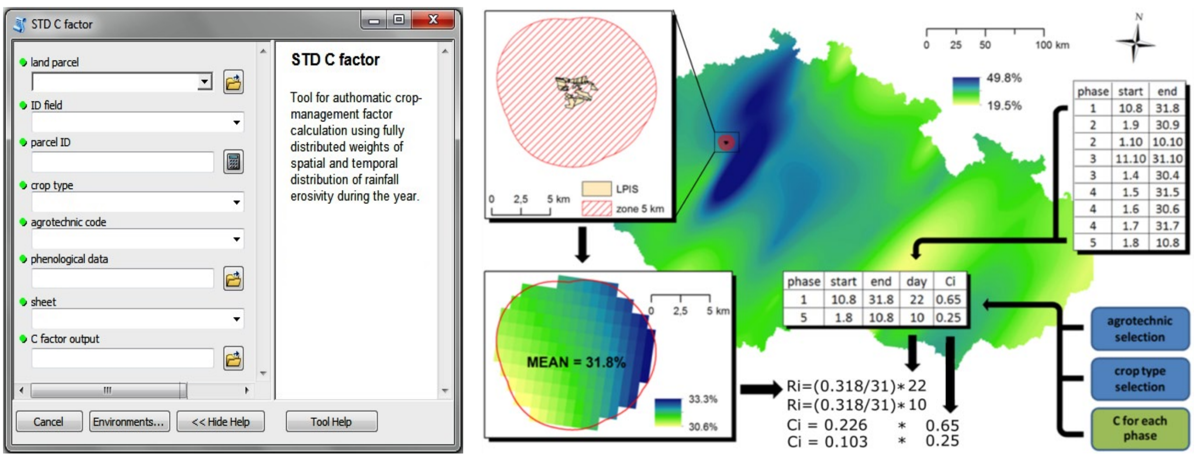
$$STD\ C = (\textstyle\sum_{i=4}^{n=10} Ci)/yr \qquad (6)$$

$$Ci = Ri \times Cp \qquad (7)$$

$$Ri = (Rd/Nm) \times Np \qquad (8)$$

where: STD-C – spatial-temporal distributed C factor, i, n – sequential number of months where erosive rainfalls were detected (April–October), Ci – C factor values for each month that occurs in a given phase, yr – number of years, Cp – soil loss ratio between given vegetation conditions and black fallow (SLR) (Wischmeier and Smith 1978) for each agro-phase (according to Figure 1), Ri - R factor weights for each month that occurs in a given phase, Np – number of days that occurs in a given month and agro-phase, Rd – percentage distribution of R throughout the year (decimal number), Nm – number of days in a month (e.g. 31 for August, 30 for April etc.) A detailed example of generating Ri and Ci for August and geographic location of land parcel is described in Figure 2.

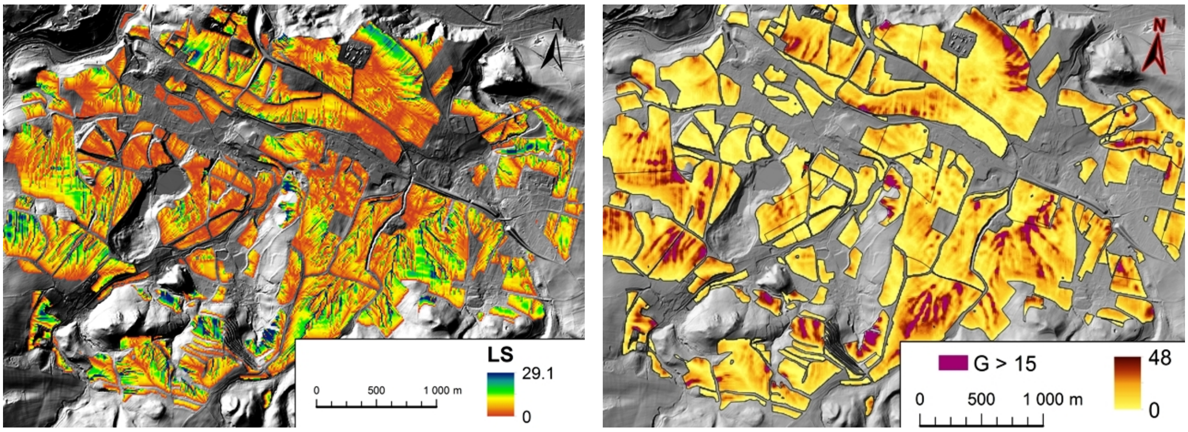
Figure 2 User interface of STD-C factor model and example of generating Ri and Ci for August according to geographic location (see details in Brychta et al. 2018)



RESULTS AND DISCUSSION

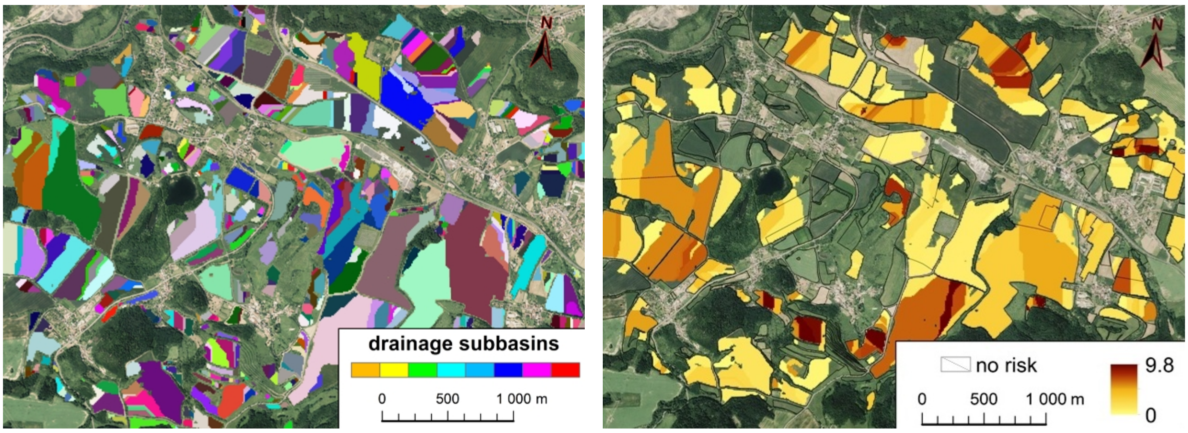
According to above mentioned methodology were created rasters with values of each factors of USLE equation. Resulting rasters with LS factor values and resulting average annual soil loss values for each pixel of size 10 x 10 m are shown on Figure 3.

Figure 3 Resulting raster with LS factor values (left) and G values (right) for pixel size 10 m



The USLE is not defined for calculation of soil loss for such small area represented by pixel and the soil loses have to be calculated for agricultural land parcel respectively from its representative parts. These representative drainage parts of land parcel were determined according prevailing flow direction (Figure 4 left). Using these representative parts of land parcels, derived similar as representative flow paths in original methodology (Wischmeier and Smith 1978), were calculated G_{RISK} values (t/ha/yr) (Figure 4 right). According to Figure 4 (right) there are several land parcels where limits are exceeded by 0.1–9.8 t/ha/yr. According to G_P limits were created a raster with C_{LIMIT} values (Wischmeier and Smith 1978, Novotný et al. 2014). Raster with resulting C_{LIMITS} values is shown on Figure 5 (left). Using classification by Novotný et al. (2014) in Table 1 were designed basic organisational erosion control measures (Figure 5 right). In the solved cadastral area Kostomlaty pod Milešovkou the soil loss values reached even 9.8 t/ha/yr over the soil loss limit 4 t/ha/yr. The basic recommendation by Table 1 and resulting Figure 5 right) should be respected. So that conversion to permanent grassland and planting perennial fodder plant e.g. clover and alfalfa were designed. Next places with exclusion of wide-row crops and narrow-row crops only with the use of erosion control technology were determined. Next these places have to be solved in more detail and crop rotation system should be designed with respecting C_{LIMITS} respectively soil loss limits values (G_P).

Figure 4 Representative drainage parts (left) and exceeded soil loses over permissible limits (right)



An example of C and P factors designed by STD-C factor model (Brychta et al. 2018) is shown on Figure 6. The most advantage of STD-C model is that user can quickly indentify the new C factor values and the rest percentage of soil loss reduction can be designed using P factor values according to Table 2 (Janeček et al. 2012, Wischmeier and Smith 1978). For the purposes of methodology demonstration was performed calculation for only one year (otherwise at least 5 year crop rotation should be used) and only one endangered land parcel were selected. The resulting soil loss for selected land parcel were in range of 0.3–21.4 t/ha/yr (see Figure 6).

Figure 5 Raster with C factor limits values (left) and determined erosion control (right)

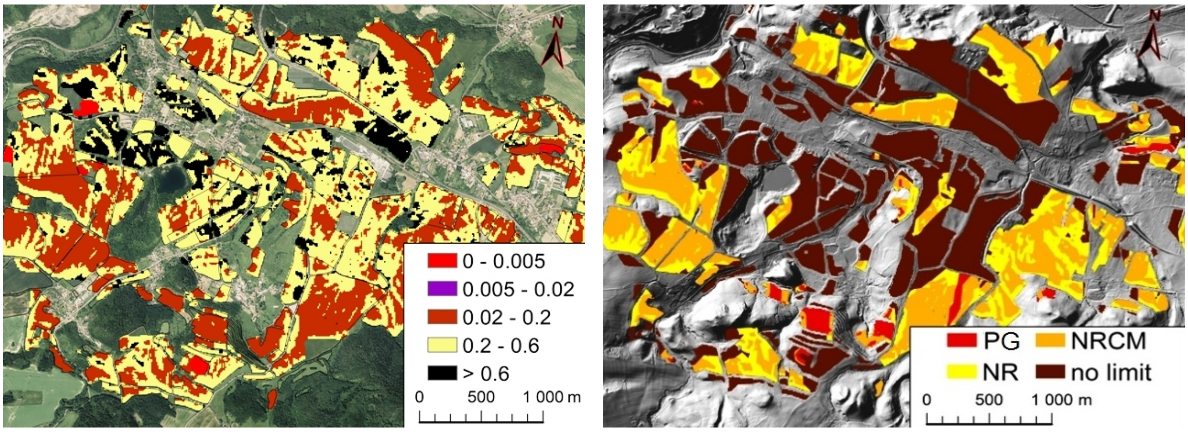
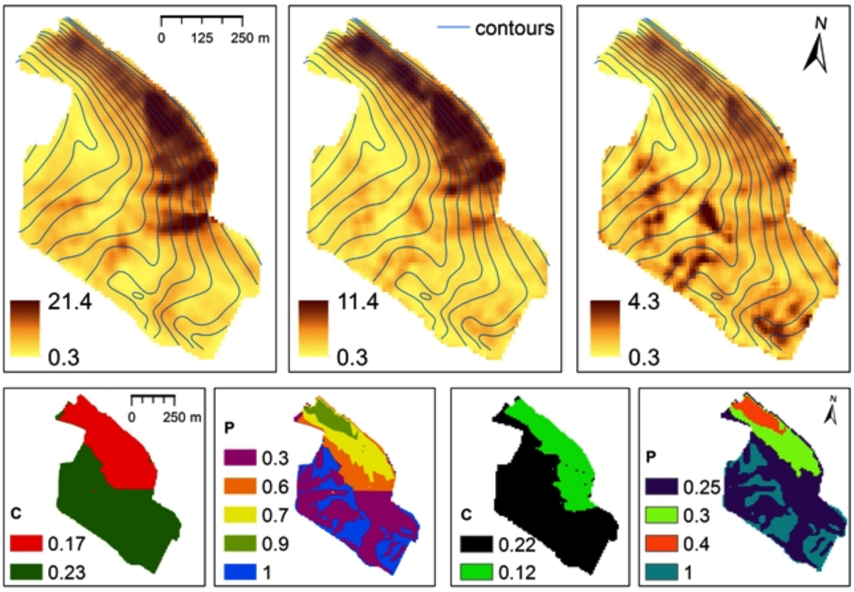


Figure 6 An example of evaluating soil loss according to designed C and P factor values



For part of the parcel where G_{RISK} > 4 t/ha/yr was defined C = 0.17 (winter barley) by using STD-C model. It reduced G by 83% for this part of parcel. For next reduction of G were designed contour cultivation with P = 0.6–0.9 according to slope which reduced G by 10–40%. For the rest of parcel were G_{RISK} < 4 t/ha/yr were designed and calculated C = 0.23 (potatoes and perennial forage) and P = 1 and 0.3 (strip cropping). Resulting G after these reductions were in range of 0.3–11.4 t/ha/yr. So that this crop management and erosion control measures were not satisfactory. Other management was designed. For the part of parcel where C_{LIMIT} = 0.02–0.2 was calculated by STD-C model C = 0.12 (winter wheat) which reduced G by 88%. For the rest of parcel where C_{LIMIT} > 0.2 were calculated C = 0.22 (winter oilseed rape) which reduced G by 78% and P = 0.25–1 (contour furrow ploughing) according to slope which reduced G by 0–75%. These crop management expressed by C factor and erosion control measures expressed by P factor resulted in G in range of 0.3–4.3 t/ha/yr.

CONCLUSION

Described methodology of calculation average annual soil loss over permissible limits for representative drainage parts of land parcel (respectively hydrologically closed unit) and C factor limits in combination with STD-C tool brings a good opportunity for erosion control measures designing in land use planning with reflecting geographic location and local climate conditions. The reflectance of local geography and climate conditions enables more accurate allocation of financial expense of erosion control measures.

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