Method Article

Tools for USLE-CP-factor calculation and actual erosion risk on field block level for Switzerland

P. Bircher [a,b,*], H.P. Liniger [a,b], P. Kupferschmied [b,c], V. Prasuhn [c]

[a] Centre for Development and Environment (CDE), University of Bern, Mittelstrasse 43, 3012 Bern, Switzerland
[b] Institute of Geography (GIUB), University of Bern, Hallerstrasse 12, 3012 Bern, Switzerland
[c] Agroscope, Agroecology and Environment, Reckenholzstrasse 191, 8046 Zurich, Switzerland

A B S T R A C T

The calculation of the cover management factor (C-factor) and support practices factor (P-factor) is an important element in the Universal Soil Loss Equation (USLE). In Switzerland, a potential soil erosion risk map of arable land and a field block map that represents the basis of the agriculturally used areas in the country are available. A CP-factor tool was developed adapted to Swiss agronomic and environmental conditions, which allows to calculate CP-factors easily for various crop rotations and management practices. The calculated CP-factor values can be linked to any field block in the potential soil erosion risk map to determine the actual soil erosion risk for the field block. A plausibility check with other C-factor tools showed a sound match. This user-friendly calculation makes the CP-Tool and the actual erosion risk more accessible for authorities and GIS users. With Python and QGIS as open source resources, it is also possible to easily improve the tools. Linking the two tools provides substantial added value for education and training, advising farmers and policy, as well as scientific research, and can serve as a reference for other countries.

- USLE-CP-factor and actual erosion risk calculation on small scale field block level.
- Developed and programmed based on open source resources for further improvements.
- Both tools increase the knowledge of management practices for GIS- and non GIS users.

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* Corresponding author at: Centre for Development and Environment (CDE), University of Bern, Mittelstrasse 43, 3012 Bern, Switzerland.
E-mail address: pascal.bircher@unibe.ch (P. Bircher).

Specifications table

Subject Area:	Agricultural and Biological Science
More specific subject area:	Soil erosion modelling
Method name:	Calculation of USLE-CP-factor and actual erosion risk
Name and reference of original method:	Universal Soil Loss Equation (USLE)
	Wischmeier W.H., Smith D.D., 1978. Predicting rainfall erosion losses – A guide to conservation planning. USDA Agriculture Handbook No. 537, U.S. Department of Agriculture (Hrsg.), Washington D.C. 58 p.
Resource availability:	Links available in Supplementary S1 and S2

Introduction

The Universal Soil Loss Equation (USLE) [26] and its successor, the Revised Universal Soil Loss Equation (RUSLE) [22], are the most widely used erosion models worldwide [7]. In this erosion model, the cover and management factor (C-factor) and the support practice factor (P-factor) are the two dynamic factors that a farmer can determine for himself through his management and modify in the short term. However, the detailed assessment of the C-factor in particular is very complex and time-consuming, as many interrelated factors have to be taken into account. Therefore, standard values are often used in the literature when C-factors for specific land use types (arable land, grassland, vineyards) [9] or crop-specific C-factors (cereals, maize, sugar beet, potatoes, oilseed rape) are in use [17]. In arable farming, however, C-factors should not be determined for specific crops but instead only for entire crop rotations, because the intercropping period between the two main crops is very important for soil loss rates and carry-over effects exist between preceding and succeeding crops. Furthermore, regionally adapted and up-to-date input data should be used, as socio-economic and natural conditions differ geographically and are subject to rapid change. Changes in crop rotations, farming methods, growing periods, crop development and seasonal distribution of erosive rainfall modify the erosion potential of a given crop [3].

Recently published articles about the USLE C-factor calculation include, for example, the forested regions of southern China [15] or remote sensing approaches for tropical regions [1], and are therefore not comparable with the CP-Tool described in this paper due to climatic and crop conditions. In contrast, Brychta et al. [8] developed a similar C-factor-tool to ours for the Czech Republic in ArcGis, but they did not include the P-factor and used less detailed datasets. To our best knowledge, the only two tools that can be compared with CP-tool described in this paper are the program ErosionCH by Mosimann and Rüttimann [16] for Switzerland and the Excel application for C-factor calculation by the GIS-supported Erosion Control Management in Agriculture (EMiL) at the Chamber of Agriculture North Rhine Westfalia (NRW) in Germany [12]. The advantage of the present tool is that it contains more up-to-date basic data on crop calendars and rainfall erosivity, determines the C-factor as well as the P-factor and can be linked in the GIS with the potential erosion risk to illustrate the actual erosion risk. It allows to improve the potential risk map by calculating the actual erosion risk and to analyse hot spots of erosion and to identify impact of possible mitigation measures/scenarios to reduce erosion risks.

In this paper the application of the newly developed tools for calculating the actual erosion risk in Switzerland were explained. The first tool, the CP-Tool, allows the calculation of both the cover and management factor (C) and the support practices factor (P) from the USLE approach. With user input of the main and cover crops, soil management practices (ploughing, reduced tillage, mulch seeding, strip-till, no-till), direction of management and choice of location (low or hilly land), the CP-factor is calculated. This tool was programmed in the programming language Python. The second tool is a GIS application of calculated CP-factor, which enables the CP-Tool to be linked to the potential erosion risk map of Switzerland in order to obtain the actual erosion risk. It is designed as a QGIS model, but is also available as a Python script. By entering the previously calculated CP-factor, it allows the calculation of the actual erosion risk for a selected area, which is defined by the field block number. Both tools are available for download free of charge (see supplementary S1) and available for further development and application through the use of open source software. This paper describes the methodological framework and provides all the necessary input data.

Table 1

Used tools, programming languages and libraries. For detailed explanations/tools see download Links in supplementary S1.

Tool	language	Libraries/ Database system / other information	Operating System (OS)
C-Tool Prototype [14]	Python 3.5.x	PostGIS 2.4.4 under PostgreSQL 9.6.10 Psycopg2 2.7.3.2 pgAdmin 3 1.22.x	Developed on Ubuntu 16.04
CP-Tool [13]	Python 3.6.8	PyQt5 (5.10.1) SQLite3 (3.22.0) PyInstaller (3.4)	Developed on Ubuntu 18.04
Calculation of actual erosion risk with QGIS-model [6]	Python 3.7.x modelling Tool in QGIS 3.8	Available as Python (3.7) script and QGIS model (model3)	Developed on Fedora 30

Methods

The USLE model approach

The empirical USLE model uses six factors to calculate the actual erosion risk (A) in tonnes per hectare by multiplication (Eq.1). The factors are defined as follows. The LS-factor is the topography factor and takes into account the topographic conditions. The K-factor, the soil erodibility factor, integrates soil properties such as texture, humus content, aggregate stability and water permeability. The R-factor, the soil erosivity factor, reflects the precipitation characteristics and erosivity. In the C-factor, the land use and the type of management practices are represented. The P-factor is a protection factor that covers, for example, the tillage direction [26,22].

$$\text{USLE} - \text{approach A} = LS^*K^*R^*C^*P \tag{1}$$

The multiplication of the factors LSRK reveals the potential erosion risk, which is a rather static factor in the USLE equation. To show this potential erosion risk, a high-resolution map (2 m grid) was recently produced for Switzerland's arable land [5] and published in the official repository of Switzerland (potential erosion risk map: see supplementary S2). The potential erosion risk map of arable land of Switzerland (ERM2 2019) and the field block map of Switzerland form the basis for calculating the actual erosion risk. With the ERM2 2019, a calibrated and validated potential erosion risk map for arable land – based on long-term field assessments of soil loss rates from Prasuhn [19] - is available [4,5,6]. The LS-factor was based on a high-resolution digital elevation model of 2 metres [25] and calculated with a multiple flow direction algorithm [4]. The K-factor was derived from the soil property data of soil maps with different qualities [5]. The R-factor calculation was based on 10-min rainfall values over a 20-year period from 86 rain stations distributed throughout Switzerland and was interpolated with covariates (digital elevation model, altitudes of snow) [23]. The field blocks comprised an average size of 5 h and have been described by Bircher et al. [4] as follows: "*The agricultural area of Switzerland is represented in the field blocks and covers grassland, meadows, pastures, crop fields, and grapes. Field blocks were delineated by surrounding hydrological barriers like roads, railways, forests, villages, rivers, lakes, and other objects that prevent a continuous water flow. A field block can thus contain several cultivation plots, feature different types of use (arable land, permanent grassland, vineyards, or different field crops), and be cultivated by different farmers.*"

The multiplication of the potential erosion risk with the C- and P-factors produces the actual erosion risk, which is specifically dependant on the crop and the management practices. The tools are designed to calculate the two land management dependant and variable factors, C and P, and reflect the actual erosion risk.

Used programming languages and tools

For programming the following tools and languages were used with various libraries implemented (Table 1).
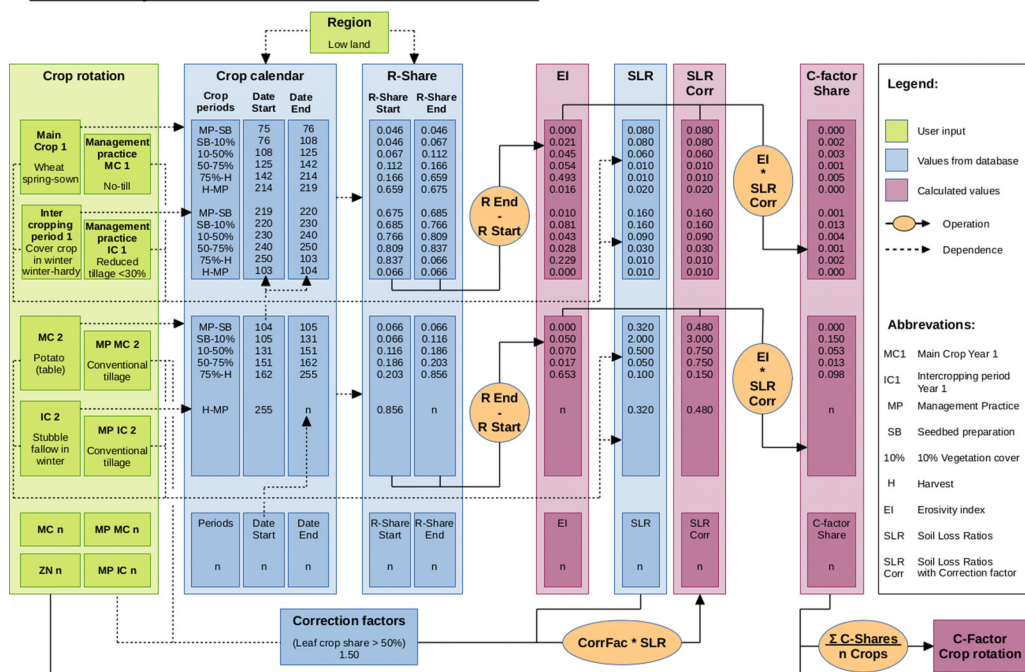
Fig. 1. Schema of calculation of the C-factor for a specific crop rotation. Crop calendar dates as Julian day calendar values. R-shares and C-shares per year are the shares within the crop stages. n acts as a place-holder for further crop sequences and their stages for following years.

- The C-Tool prototype was programmed by Kupferschmied [14] and finally released as the CP-factor tool on the Agroscope website (see supplementary S1).
- The application for calculating the CP-factor based on the new erosion risk map (ERM2 2019) by Bircher et al. [6] was released on the Agroscope website (see supplementary S1).

Study area

Switzerland's arable land is located in the low land and the hilly land. These regions are situated between the mountains of the Jura and the Alps covering a range from gentle to medium and hilly slopes. The arable land covers 408,000 ha. The main crops are winter wheat, temporary ley grass, winter barley, maize, sugar beet, oilseed rape and potatoes. There are about 50,000 farms, most of which are mixed farms with livestock and arable farming. The mean annual rainfall is 1105 mm in the low land and 1218 mm in the hilly land, the mean annual temperature is 9.3 °Celsius in the low land and 8.7 °Celsius in the hilly land. The soils were formed by glacial moraine and gravel soils, predominantly sandy-loamy to clayey-loamy cambisols and luvisols.

CP-Tool and calculation of CP-factor

The main focus of the CP-Tool is the calculation of the C-factor; this calculation is made by multiplying the factors C and P. In the CP-Tool, the user also needs to choose between the three options for management practice direction in order to define the P-factor. The calculation of the C-factor is quite complex; Fig. 1 shows a simplified concept. In the following section, this calculation approach is explained, with more detail about the individual steps of the calculation. The CP-Tool

Fig. 2. User interface of the CP-factor tool. Example of a crop sequence of seven years with calculated C-factor and CP-factor values.

was written with Python 3.6.8; the user interface with PyQt5 can be run from the script or with an executable file created with PyInstaller for Windows and Linux Ubuntu (Fig. 2).

Input data and P-factor calculation

The P-factor is a non-dimensional factor between 0.1 (terracing) and 1 (up-and-down-slope tillage); for the application in Switzerland, it is restricted to the direction of soil management practices like tillage. Other structural measurements for preventing soil loss such as terrace systems are not included, because terracing is not relevant to arable farming in Switzerland.

For the P-factor, the tool allows three different options for the direction of tillage with predefined P-factor values. One option is up-and-down-slope tillage practice, which, according to the definition of Wischmeier and Smith (p. 34) [26], does not reduce soil loss and therefore accounts for a P-factor value of 1.0. Another option is a tillage practice exactly on the contour, which significantly reduces soil loss. Based on a methodological approach by Auerswald [2], which takes into account the slope gradient, the slope length and the proportion of potatoes with ridge cultivation in the crop rotation, Prasuhn and Grünig [20] found an average *P*-factor value of 0.73 for tillage practice on the contour in field research in Frienisberg, Switzerland. Based on that study, a P-factor value of 0.7 was used for this option. The third option is a tillage practice in between up-and-down-slope tillage and contour tillage, used when a field slopes in different directions. This option is the most commonly used in most cases due to the hilly relief in Switzerland. Prasuhn and Grünig [20] found some reduction in soil loss, and proposed a P-factor value of 0.9, which was used for this option. This coarse classification into three determined P-factor values entails some uncertainties. However, this assignment of the tillage direction of a plot is simple and easy to select by the farmer or an advisor. More complicated approaches with formulas that take into account the crucial factors such as slope steepness, slope length and ridge height of the tillage lanes impede a practical approach by farmers. In many other USLE-based studies, the P-factor is therefore generally omitted or set to 1.0 [9]. The present classification in three values is thus a clear improvement, even if it entails some uncertainties and inaccuracies.

Input data and C-factor calculation

The C-factor is defined as a non-dimensional number and range between zero (no crop cover) and one (best crop cover). The calculation of the C-factor is based on the method of Schwertmann et al. [24] which likewise is based on Wischmeier and Smith [26]. The methods for calculating C-factors are based on tabular approaches where the user reads the corresponding values for each variable (e.g. Erosivity Index, Soil Loss Ratios) from tables and manually calculates the C-factor. With the CP-Tool, this process is automated with a Python script. The challenge was that the logic of the tabular approach, with its many references between the variables, could not be directly converted to the technical linear logic of a simple Python script. Thus the calculation of the C-factor was revised to be programmable in Python.

To calculate the C-factor, several datasets for different variables were used (Figs. 1 and 2). Those variables were: (a) geographic region; (b) crop rotation or crop sequence, and crop calendar with crop stage periods for different regions; (c) intercropping period; (d) tillage practice of a given main crop and cover crop; (e) soil loss ratio values (SLR) for each crop, crop stage and tillage practice; (f) erosivity index (EI) for different regions; and (g) correction factors of carry-over-effects. All input data used had recently been prepared for the assessment of the agri-environmental indicator "soil erosion risk" [21].

The computed SLR values for each crop stage period were finally calculated automatically with the correction factors of the carry-over effects (see supplementary Table S14). With the corrected SLR values, the tool was able to calculate the C-factor-share of each crop stage period by multiplying the erosivity index (EI) and the corrected SLR value of the corresponding crop stage period. To calculate the C-factor of the whole crop rotation, the C-factor-shares were summed up and divided by the number of years of the crop rotation period. With this revised calculation of the C-factor, it was possible to write a Python script and automate the calculation.

Geographical region

For the geographical region, the tool offers two options: low land and hilly land. Arable land is rarely found in mountainous areas in Switzerland. The classification follows a map of the agricultural zone boundaries in Switzerland [11]. The subdivision is based on climatic condition, traffic of agricultural machinery and relief characteristics. The choice affects the crop-specific calendar dates (phenology) and the annual distribution of rainfall pattern, which are expressed in the erosivity index.

Crop rotation or crop sequence and crop stage periods

The specification of the crop rotation for each year consists of an input for the main crop and its management practice, as well as the land use of the intercropping period and its management practice. The CP-Tool allows for crop rotations of up to ten years; a minimum length of three years is needed for a reliable output. The tool offers 55 choices for main arable crops. Vegetables could not be considered. In the first step, the program creates the crop calendar according to the user input for the crop rotation. Each main crop and cover crop has individual calendar dates for the following six crop stages based on Wischmeier and Smith (1978) [26]:

- Initial tillage operation to final seedbed preparation;
- Seeding/planting to 10% soil cover;
- 10% to 50% soil cover;
- 50% to 75% soil cover;
- 75% soil cover to harvest;
- Harvest to mouldboard ploughing or sowing of the successive crop.

The crop calendar data for all main crops are given in Table S1 for low land and Table S2 for hilly land in supplementary. The crop calendar data are based on information from Swiss agri-environmental monitoring, where data on the time of sowing and harvesting of all crops is available for fields from around 300 typical farms in Switzerland over many years [21]. From these data, the other crop stage periods were derived. The resulting crop calendars were then submitted for review to various agronomic experts with a broad knowledge of crop management and finalised.

Inter-cropping period

For the time between two main crops, several options are available including no intercropping period, different kinds and lengths of fallows, cover crops and temporary grassland. In total, the tool offers nine options for the intercropping period, with corresponding SLR values:

• Sowing of the subsequent main crop within a few days;
• Stubble fallow until sowing of a winter crop;
• Stubble fallow in winter;
• Ploughing and bare fallow over autumn and winter;
• Cover crop in winter, winter-killed;
• Cover crop in winter, winter-hardy;
• Cover crop in autumn followed by fallow land in winter;
• Temporary grassland, autumn-sown;
• Temporary grassland, spring-sown.

The calendar data for cover crops for low land are listed in Table S3, and the respective autumn cover crops in Table S4. The calendar data for cover crops for hilly land are listed in Table S5, and the respective autumn cover crops in Table S6 (see supplementary).

Tillage practices of a given crop and cover crop

There are four different tillage practices, according to Mosimann and Rüttimann (2006) [16] and Prasuhn (2012) [18], that can be selected for each main crop and each cover crop to calculate SLR values:

• Conventional tillage with mouldboard plough or ploughless tillage with < 10% soil cover;
• Reduced tillage with 10 to 30% soil cover;
• Mulch seeding with > 30% soil cover;
• No-till or strip-till.

Soil loss ratio (SLR)

The SLR indicates the ratio of the soil loss of a given crop during a given crop stage period to the soil loss of an identical area under the standard conditions of clean-tilled continuous fallow [26]. The SLR values of the different crops for the crop stage periods and tillage practices were taken from the literature by Mosimann and Rüttimann [16]. For crops with no values available in the literature, values were determined by analogy to similar crops. No data were available, except for a few crops that are very rarely cultivated in Switzerland and thus do not have a major impact on the soil loss rate. The similarity of the plants was assessed by the type of crop (e.g. winter spelt similar to winter triticale; winter oats similar to winter barley; spring rye similar to spring wheat; fodder beet similar to sugar beet) and the corresponding tillage practice. Only for potatoes were other, significantly higher SLR values used. These higher values were based on the runoff concentration effect of the potato ridges [10] and long-term field observations by Prasuhn [19]. For each main crop and cover crop, as well as for each crop tillage practice, separate SLR values for each of the six crop stage periods were stored in an sqlite-database and automatically accessed by the script (Table S9 to S12 in supplementary).

Erosivity index (EI)

From the 10 min precipitation data for various meteorological stations in the Swiss Plateau over a period of 20 years, the mean erosivity of the rainfall over the year was determined and presented as cumulative percentage values for each day of the year for the two selected regions based on data from Schmidt et al. [23] (Table S7 for low land, Table S8 for hilly land in supplementary). For each crop stage period, the amount of erosive rainfall occurring in that specific timeframe was calculated by accessing the R-factor data in the sqlite-database. This returned the erosivity index for each crop stage period.
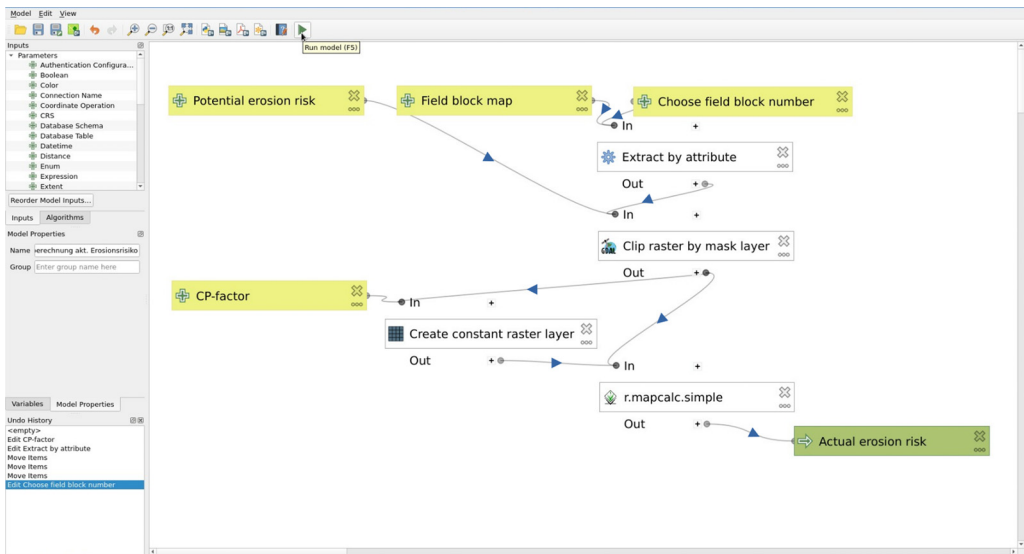
Fig. 3. QGIS-Model for calculating actual erosion risk on field block level based on field block with chosen number. r.mapcalc.simple = multiplication of constant raster layer (CP-factor) with raster (Potential erosion risk) clipped by masque layer. "In" represents essential data for the tool (e.g. Extract by attribute) to run. "Out" represents the result of the tool (e.g. Extract by attribute). Added blue arrows represent the process direction.

Carry-over effects

Depending on the crop rotation, three different carry-over effects based on the work of Wischmeier and Smith [26] and Schwertmann et al. [24] require a correction of the SLRs. These carry-over effects take into account the positive or negative effects of the preceding crop on the succeeding crops in the selected crop sequence (Tables S13 and S14 in supplementary). A high proportion of leaf crops such as sugar beet, potatoes or maize in the crop rotation leads to a stronger soil structure stress, which generally increases the risk of erosion. Cereals or oilseed rape sowing following root crops such as potatoes or late harvested sugar beets create an increased erosion risk because of the intense soil compaction during the harvest of these root crops. The residual effects of incorporated sod from temporary grassland increase aggregate stability and soil organic matter and reduce the erosion risk for the subsequent crop in the first and second year [26]. These correction factors can occur simultaneously and cumulatively.

- SLR increases if the leaf crop rate in the crop sequence is > 50%;
- SLR increases for cereals and oilseed rape after root crops;
- SLR reduces for succeeding crops in the first and second year after one or more years of temporary grassland.

Calculation of actual erosion risk with QGIS-model

To combine the calculated CP-factor with the ERM2 2019 and calculate the actual erosion risk at the field block level, a QGIS-model (see supplementary S1 for the tools and S2 for the field block map and ERM2 2019) was developed. This model is also available as Python script. A manual on using the tool is available in German [6]. Fig. 3 represents the necessary data and tools in QGIS. The ID-number of the selected field block must be chosen; this is extracted from the ERM2 2019. In the next step, a raster layer is created using the CP-factor and multiplied with the previously extracted raster layer of the ERM2 2019 (Fig. 3). When the model is running, a user interface is open (Fig. 4) where inputs like CP-factor, field block number, field block map and erosion risk map can be chosen. An output
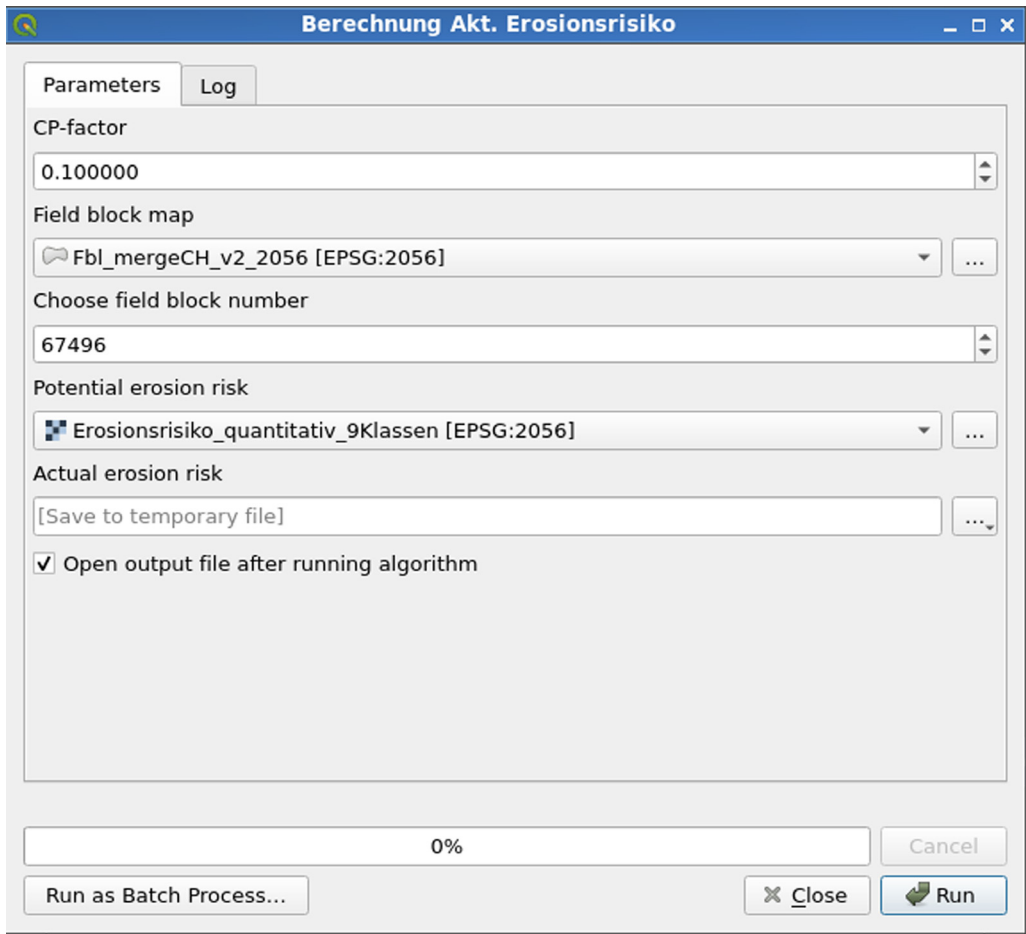
Fig. 4. User interface in QGIS. Example with standard CP-factor value 0.1 for the selected field block number 67′496.
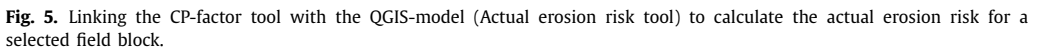
directory also has to be chosen in order to save the result (actual erosion risk for chosen field block) (Fig. 4).

Linking of the two tools

The two tools can be linked together (Fig. 5) to calculate the actual erosion risk for a selected field block. Linking the two tools is a significant improvement, makes considerable progress in policy advice, implementation of erosion mitigation measures and training, and enhances the value of both tools tremendously.

Plausibility check of CP-Tool and example calculations

For the first step of plausibility check the developed CP-Tool, the effect of four different management practices (conventional tillage, reduced tillage, mulch tillage and no-till) on C-factor values based on the same crop sequence (Fig. 6) were calculated and compared with the results from the tools ErosionCH and EmiL. The three tools provided fairly similar C-factor values for the four tillage practices. However, EmiL was not able to distinguish between reduced tillage and

Fig. 5. Linking the CP-factor tool with the QGIS-model (Actual erosion risk tool) to calculate the actual erosion risk for a selected field block.

mulch seeding. The highest difference in calculated C-factors was 0.017 for reduced tillage between ErosionCH (0.050) and EmiL (0.033). For the other management practices with the same crop rotation, the differences were lower than 0.017 (Fig. 6). The used crop sequence is situated in supplementary S4.

For the second step, C-factor values were calculated for six typical Swiss crop sequences using the three tools (Fig. 7).The differences between the crop sequences 3–6 differed only by 0.013 in crop sequence 4 or less between the different tools. In contrast, the results for crop sequences 1 and 2 with the CP-Tool showed crop sequence 1 as 0.082 higher and crop sequence 2 as 0.061 higher than with ErosionCH, due to the much higher SLR values used for potatoes in the CP-Tool. However, the higher C-factor values in the CP-Tool for crop sequences with potatoes were calculated deliberately, as the highest soil losses in Switzerland were measured for potatoes. Using EmiL, the value of the C-factor was 0.196 for crop sequence 1, which lay between those of the CP-Tool (0.242) and ErosionCH (0.160). The used input data for the calculations of the six crop sequences are presented in supplementary S5.

Furthermore, two recent publications confirm the plausibility of the method used to calculate the C-factors. Auerswald et al. [27] have developed a calculation of summable C-factors for Germany and neighbouring countries. They conclude that the crop development used in our study is rather similar to the crop stage dates used in their study ($r^2 = 0.9755$) and that the SLRs used in our study are identical to those used in their study. Thus, the basic data we used for the calculation of the C-factor are comparable to those of Auerswald et al. [27]. Prasuhn [28] assessed the impact of mitigation measures on arable land by comparing modelled C-factor values with the tool from Mosimann and Rüttimann [16] and measured soil losses from field observations. The C-factor values were calculated in detail for 203 fields for five different periods (1987–89, 1997–99, 1997–2006, 2003–09, 2010–14) and compared with the measured soil loss rates of the same fields from the three periods 1987–89, 1997/98–2006/07, and 2007/08–2016/17. The mean annual soil loss decreased by over two-thirds from 0.74 t ha^{-1} yr^{-1} (1997/98–2006/07) to 0.20 t ha^{-1} yr^{-1} (2007/08–2016/17), while the mean C-factor values decreased by almost half from 0.094 (1997–99) to 0.050 (2010–14). The study of Prasuhn [28] demonstrated that with an in-depth calculation of C-factors over different periods, changes in average soil loss rates for a region can be satisfactorily represented.
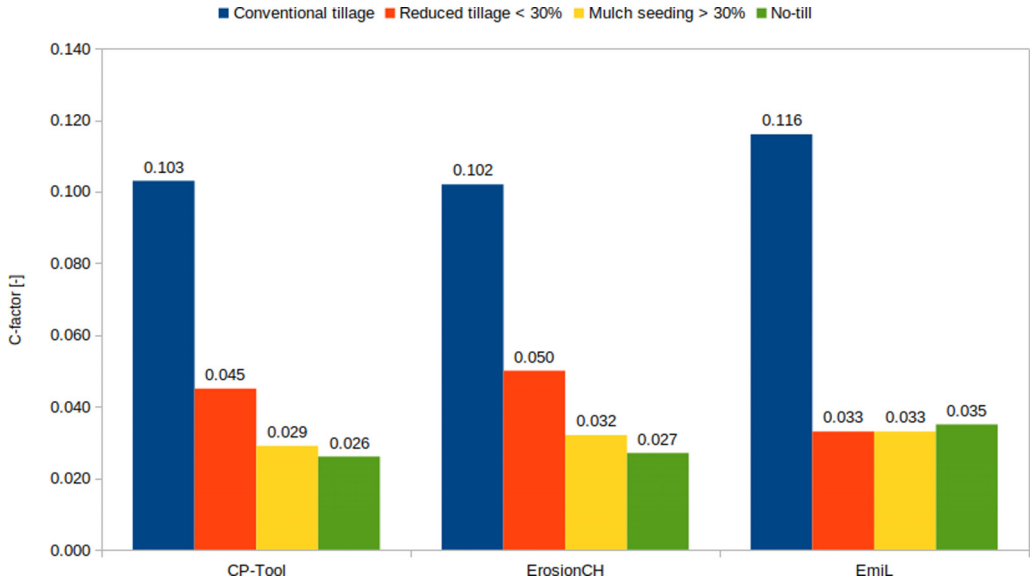
Fig. 6. Calculated C-factors according to the three different tools (CP-Tool, ErosionCH, EmiL) and four different management practices (conventional tillage, reduced tillage, mulch seeding, no-till) based on the same crop sequence. Crop sequence with 60% cereals and 40% leaf crops (see supplementary S4).
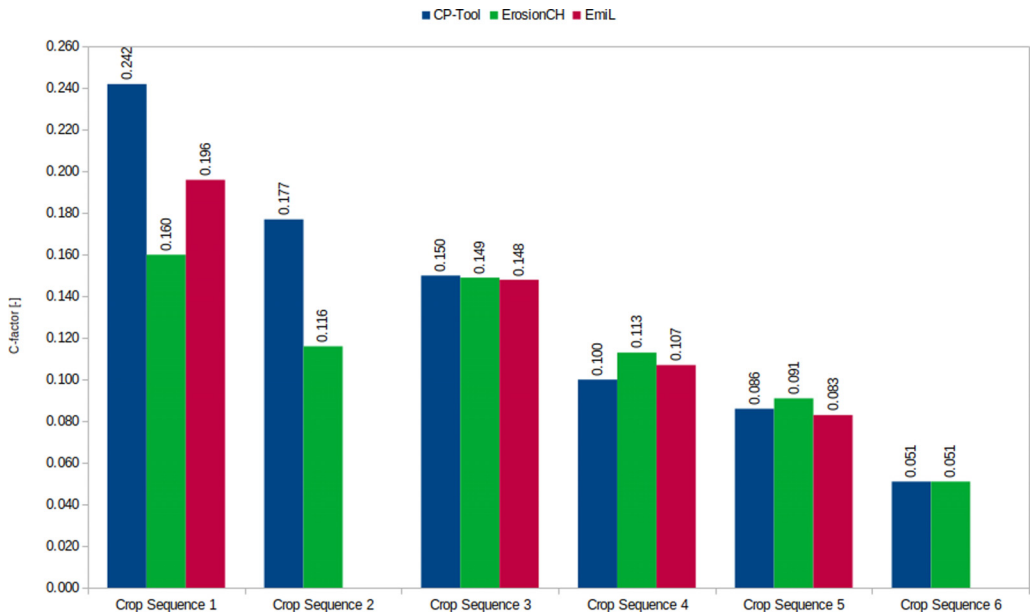
Fig. 7. Calculated C-factors according to the three different tools (CP-Tool, ErosionCH, EmiL) for six existing crop sequences, each over 10 years. EMiL does not include temporary grassland, which is why no values are available for crop sequences 2 and 6. Crop sequence 1 = crop sequence with 20% potatoes, 50% leaf crops, mouldboard ploughing; crop sequence 2 = crop sequence with 20% potatoes, 60% leaf crops, temporary grassland, partly conservation tillage; crop sequence 3 = crop sequence with 60% leaf crops, mouldboard ploughing; crop sequence 4 = crop sequence with 80% leaf crops, mostly conservation tillage; crop sequence 5 = crop sequence with 70% cereals; crop sequence 6 = crop sequence with 50% temporary grassland (see supplementary S5).
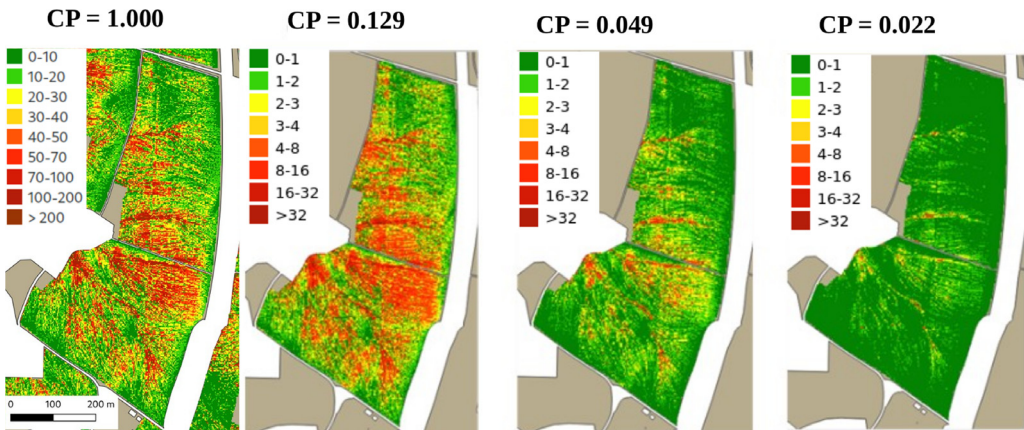
Fig. 8. Potential erosion risk from the soil erosion risk map ERM2 2019 (CP = 1.0) and example calculations with different CP-factors applied to a selected field block. Soil loss rates in t ha^{-1} year^{-1}. CP = 0.129 represents a crop rotation with ploughing; CP = 0.049 represents the same crop rotation with mulch seeding; CP = 0.022 represents an adapted crop rotation with no-till and temporary grassland in one year.

Nevertheless, a full validation of the USLE/RUSLE adapted for Swiss conditions could not be carried out so far. Some uncertainty in the results must therefore be expected. Thus, a verification in the field of the modelled erosion risk by an expert is recommended.

Fig. 8 illustrates the way the two tools can be used. The selected field block showed a very high potential erosion risk (CP = 1.000). Various small slope depressions generate concentrated runoff with a high erosion risk and soil loss values of > 50 t ha^{-1} year^{-1}. Linking the CP-factor in QGIS with the erosion risk map shows that the actual soil loss is high and frequently exceeds the tolerable soil loss of 2–4 t ha^{-1} year^{-1} with reference to the Swiss legislation (yellow and red colours in Fig. 8). A standard crop rotation with mouldboard ploughing yields a CP-factor value of 0.129 as calculated with the CP-Tool. If the tillage of the whole crop rotation is changed to mulch seeding, the calculated CP-factor decreases significantly from 0.129 to 0.049. However, there are still many areas where the tolerable soil loss is exceeded. Only when tillage is changed to no-till and an additional year of temporary grassland integrated into the crop rotation is calculated soil loss reduced to a level where the risk of erosion is almost low. This example clearly demonstrates how the two tools can be used for planning best management practices; they can be used for the implementation of agricultural policy measures or for extension and training.

Conclusion

The new tools allows to calculate the CP-factor and combine the results with the potential erosion risk map in order to derive the actual erosion risk at field block level. This provides substantial added value and makes a significant improvement to policy advice, implementation of erosion mitigation measures and training. An attempt has been made to make these tools more user-friendly than existing methods and more easily accessible for GIS users and authorities. Furthermore, the program codes are also available on request as Python scripts, which allows and simplifies improvement and further development by programmers. The CP-factor-Tool is programmed under Swiss conditions. Application in other areas of the world (i.e. in other climate zones) is not advisable, since the tool integrates precipitation characteristics and crop development and management practices from Switzerland. However, the tool can provide a basis for adaptation to other agro-ecological and climatic conditions and further land management practices in other countries.

Both tools are available to farmers and extension services, and have been submitted to all cantonal agricultural agencies for testing and reviewing. Feedback will be gathered in the next years and

the tools will be adapted and improved if necessary. Furthermore, the modelled average soil loss predicted with the tools will be compared with the long-term measured soil loss rates in the test region Frienisberg on 203 arable fields [19].

Declaration of Competing Interest

The authors have whether financial nor other conflicts of interest to disclose.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10. 1016/j.mex.2021.101569.

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