Catena 118 (2014) 220–225

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Use and misuse of the K factor equation in soil erosion modeling: An alternative equation for determining USLE nomograph soil erodibility values

Karl Auerswald [a], Peter Fiener [b,*], Walter Martin [c], Dirk Elhaus [d]

[a] Lehrstuhl für Grünlandlehre der TU München, D-85350 Freising, Germany
[b] Institut für Geographie, Universität Augsburg, D-86135 Augsburg, Germany
[c] Bayerisches Landesamt für Umwelt, D-86179 Augsburg, Germany
[d] Geologischer Dienst Nordrhein-Westfalen, D-47707 Krefeld, Germany

ARTICLE INFO

Article history:
Received 24 April 2013
Received in revised form 9 January 2014
Accepted 20 January 2014
Available online 12 February 2014

Keywords:
USLE
RUSLE
Organic matter
Silt
Very fine sand
Rock fragments

ABSTRACT

The K factor of the Universal Soil Loss Equation is the most important measure of soil erodibility that was adopted in many erosion models. The K factor can be estimated from simple soil properties by a nomograph. Later, the classical K factor equation was published to assist the calculation of K. This equation, however, does not fully agree with the nomograph, which still has to be used in these deviating cases. Here we show for a large soil data set from Central Europe (approximately 20,000 soil analyses) that the equation fails in considerably more than 50% of all cases. The failure can be large and may amount to half of the K factor. To facilitate the K factor calculation, we developed a set of equations that fully emulates the nomograph and supersedes the cumbersome reading of the nomograph.

1. Introduction

The Universal Soil Loss Equation USLE (Wischmeier and Smith, 1978) and its successors the Revised Universal Soil Loss Equation RUSLE, version 1 (Renard et al., 1997) and version 2 (Foster, 2005), are by far the most often used models for soil erosion predictions. An ISI query (http://apps.isiknowledge.com/) for the years 2003 to 2012 yielded 844 hits for the keywords 'Universal Soil Loss Equation', 'USLE', 'Revised Universal Soil Loss Equation', and 'RUSLE'. Apart from the USLE/RUSLE itself there is a large number of other erosion models (approximately 600 hits between 2003 and 2012 for the most prominent ones), which can be subdivided in those using USLE/RUSLE technology to estimate erosion and those following other approaches. The most well-known ones based on USLE/RUSLE technology are SWAT (Arnold et al., 1998, 151 hits), (Ann) AGNPS (Cronshey and Theurer, 1998, 36 hits), Watem/Sedem (Van Rompaey et al., 2001, 35 hits), and EPIC (Williams et al., 1983; 21 hits), while approaches independent from the USLE are followed by WEPP (Laflen et al., 1997, 172 hits), LISEM (De Roo et al., 1996, 42 hits), EUROSEM (Morgan et al., 1998, 30 hits), STREAM (Cerdan et al., 2001, approx. 10 hits), and PESERA (Kirkby et al., 2008, 10 hits).

Soil erodibility is reflected in the K factor of the USLE and its successors. A nomograph to estimate the K factor was derived by Wischmeier et al. (1971) from rainfall simulation experiments and validated with data from long-term soil erosion plots under natural rain. The K factor was also included in a number of USLE modifications or extensions like MUSLE (Williams, 1975), USLE-M (Kinnell and Risse, 1998), or dUSLE (Flacke et al., 1990) and was also integrated into the more complex model approaches using USLE/RUSLE technology to estimate erosion (e.g. SWAT, ANGPS, Watem/Sedem and EPIC). Hence, the K factor is the most important tool for soil erodibility estimation in erosion modeling. In contrast to this importance, Wischmeier et al. (1971) were only cited 120 times between 2003 and 2012 according to ISI. Only about 10% of those articles using the K factor thus refer to the original article.

The K factor was originally derived from five variables, namely the silt plus the very fine sand content, the clay content, the organic matter content, an aggregation index, and a permeability index that have to be combined in a K factor nomograph (Wischmeier et al., 1971). Later, a sixth variable, namely rock fragment cover, was added by Wischmeier and Smith (1978), who also provided the classical K factor equation to allow calculation of the K factor instead of reading the nomograph. This equation, however, does not exactly match the nomograph. It differs from the nomograph for soils that have high silt content, low erodibility or high organic matter content. Also the rock fragment effect is not included in the K factor equation. Wischmeier and Smith (1978) stated that their equation did not fully reflect the nomograph and that

* Corresponding author. Tel.: +49 821 598 26 65; fax: +49 821 598 22 64.
E-mail address: peter.fiener@geo.uni-augsburg.de (P. Fiener).

0341-8162/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.catena.2014.01.008

in cases of deviation between the results of the equation and the nomograph, the latter has to be used. Given the strong increase in computing power and computer accessibility and at the same time the cumbersome reading of the nomograph combined with the low citation rate of the original publication by Wischmeier et al. (1971) implies that in many modeling exercises the K factor equation was used neglecting those cases where the nomograph has to be used.

In this study we firstly will develop a set of equations, which allows in mimicking the original K factor nomograph and which hence is applicable to the full range of soil characteristics without the limitations of the classical equation, which was provided by Wischmeier and Smith (1978) and which is used in almost all USLE based erosion models. Secondly, we will test the relevance of extending the original equation while using a large data set of soils.

In agreement with the large number of studies, which use the K factor, we assume that the K factor nomograph is the best existing prediction tool to estimate erodibility that lumps the different aspects of erodibility like runoff disposition, detachability and transportability. We acknowledge that these predictions may be far from perfect in many cases, e.g. by ignoring seasonality or interaction with climate. Our rational, however, is that the prediction error likely increases considerably if this tool is erroneously applied by using the K factor equation in cases where the K factor nomograph is recommended. We quantify how often the use of the K factor equation by Wischmeier and Smith (1978) leads to results deviating from the K nomograph by Wischmeier et al. (1971) and how large these errors will be that result from a misuse of the equation.

2. Material and methods

We choose ($t\ ha^{-1}\ h\ N^{-1}$) as metric unit for the K factor, which requires one decimal less than the often used unit ($t\ MJ^{-1}\ h\ mm^{-1}$). Despite the apparently contrasting units, conversion can easily be done by ($t\ ha^{-1}\ h\ N^{-1}$) = 10 ($t\ MJ^{-1}\ h\ mm^{-1}$). For simplicity we omit the K factor unit in the following text and just report values.

The K factor equation by Wischmeier and Smith (1978), when adapted to metric units, reads as:

$$\begin{aligned} &K = K_1 * K_2 + 0.043 * (A-2) + 0.033 * (P-3) \\ &\text{and } K_1 = 2.77 * 10^5 * \left(f_{Si+vfSa} * (100-f_{Cl})\right)^{1.14} \\ &\text{and } K_2 = (12-f_{OM})/10 \end{aligned} \tag{1}$$

where:

$f_{Si+vfSa}$ mass fraction (in %) of silt plus very fine sand Si + vfSa (2…100 μm) in the fine earth fraction
f_{Cl} mass fraction (in %) of clay (<2 μm) in the fine earth fraction
f_{OM} mass fraction (in %) of organic matter in the fine earth fraction
b soil structure index (1…4) increasing from very fine granular to blocky, platy or massive (for definition of the classes see Wischmeier et al., 1971)
c permeability index (1…6) increasing from rapid to very slow (for definition of the classes see Wischmeier et al., 1971).

Ks with subscript numbers are used here to indicate intermediate steps in the calculation of K. These subscripts were not used by Wischmeier and Smith (1978). The product of K_1 and K_2 has been termed "first approximation of K" by Wischmeier et al. (1971).

Eq. (1) has four restrictions for different soil characteristics:

Soils with high silt content

Wischmeier et al. (1971) write: "The relation of K… changes when the silt content approaches 70 percent. The effect of this change was brought into the nomograph by bending the percent-sand curves near the 70-percent-silt line. This modifies the graphically… K and thereby eliminates the need for an additional set of curves" (Fig. 1). This change has not been described by a numerical equation (Wischmeier and Smith, 1978). In consequence, the nomograph has to be used in these cases because the equation does not apply. Fitting an equation to the readings taken from the nomograph above 70% Si + vfSa leads to the following equation:

$$\begin{aligned} K_1 = 0.631 * 2.77 * 10^5 * \left(\left(f_{Si+vfSa}\right) * (100-f_{Cl})\right)^{1.14} + 0.0024 \\ * f_{Si+vfSa} + 0.161. \end{aligned} \tag{2}$$

An equation with similar effect has recently been incorporated in the draft of the RUSLE2 (Foster, 2005). Eq. (2) allows calculation of the first approximation of K over the entire textural range.

Soils with low erodibility

There is another deviation of the nomograph curves from the K factor equation that has never been mentioned by Wischmeier but it is reasonable to assume that the same recommendation as for the high silt soils applies and the nomograph has to be used in these cases as well. This deviation occurs with soils of low erodibility, for which the first approximation of K is lower than 0.2 (Fig. 1). For these soils the influence of the aggregate class changes, which has been described as knee in the aggregate relationship by Foster (2005).

Fitting an equation to the readings taken from the nomograph for soils with the first approximation being lower than 0.2 leads to the following equation:

$$\begin{aligned} K = 0.091–0.34 * K_1 * K_2 + 1.79 * (K_1 * K_2)^2 + 0.24 * K_1 * K_2 * A \\ + 0.033 * (P-3) \end{aligned} \tag{3}$$

High organic matter soils

Wischmeier et al. (1971) write "organic matter percentages … are about 1.72 times the percent carbon. … Earlier studies concluded that within an organic matter range of 0 to 4 percent … soil erodibility tends to decrease appreciably as organic matter increases … Our recent analyses confirmed these conclusions … Whether, or how much, K declines further when organic matter levels exceed 4 percent has not been determined." In consequence their nomograph ends at 4% organic matter and Wischmeier et al. (1971) recommend interpolating between plotted curves although the soils used for the development had up to 5.5% organic matter (Wischmeier and Mannering, 1969). Also Trott and Singer (1983) found no additional effect of organic matter content exceeding 4%. The conservative assumption in agreement with Wischmeier et al. (1971) hence is that the K factor equation should also be restricted to 4% organic matter content.

Soils with rock fragments

Wischmeier et al. (1971) write "One soil parameter that can be significant is not included in the nomograph: percent of coarse fragments. Limited data suggest that the K factor… may be reduced about 10 percent for soils with stratified subsoils that include layers of small stones or gravel without a seriously impeding layer above them. Beyond some limiting density, stones on the surface would be expected to reduce erosion by providing protective mulch. However, no data are available from which to determine the minimum density required or to establish numerical relationships for rates of stone cover above that amount." Wischmeier and Smith (1978) then found a solution for the stone cover effect: "Coarse fragments are excluded when determining percentages of sand, silt, and clay. If substantial, they may have a permanent mulch effect which can be evaluated from the upper curve of the

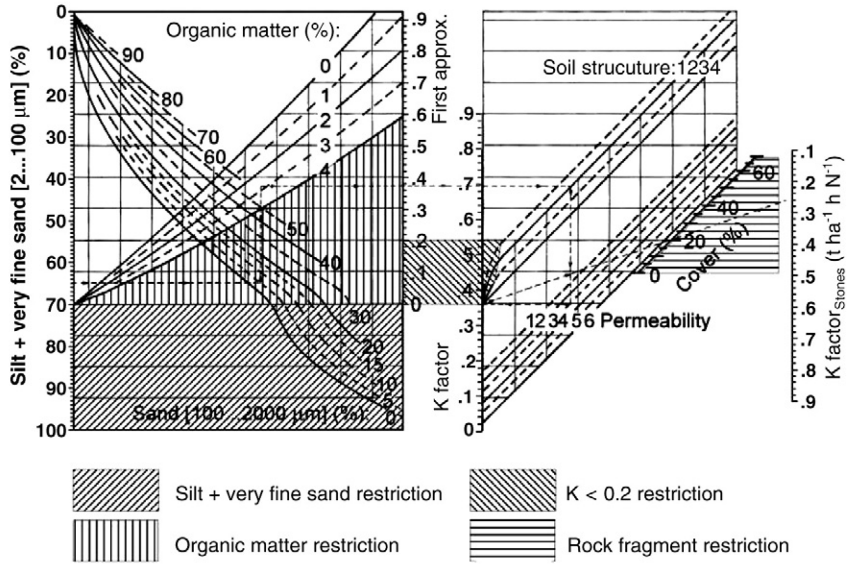

Fig. 1. K factor nomograph (Wischmeier et al., 1971) and areas of restrictions where the K factor equation by Wischmeier and Smith (1978) does not apply; note that the original nomograph did not use metric units and the influence of rock fragment cover was not included but added as a separate chart by Wischmeier and Smith (1978).

chart on mulch and canopy effects (p. 19, fig. 6) and applied to the number obtained from the nomograph solution."

Converting Fig. 6 from Wischmeier and Smith (1978) into an equation yields:

$$\begin{aligned} &c = 1 && \text{for } f_{rf} < 1.5\% \\ &c = 1.1 \ \exp(-0.024 * f_{rf}) - 0.06 && \text{for } f_{rf} > 1.5\% \end{aligned} \tag{4}$$

where c is the soil loss ratio needed for the calculation of the C factor and f_{rf} is the fraction of the soil surface covered with rock fragments.

In the case of soils that are not under bare fallow f_{rf} is not the total fraction of rock fragments on the soil surface but only the fraction that is not covered by vegetation or plant residues (Foster, 2005) because otherwise the protection of the soil surface from the incipient raindrops would be counted twice. Again, a similar equation was used for the RUSLE (Römkens et al., 1997) and the RUSLE2 (Foster, 2005). However, the equation used there does not have a minimum rock cover below which there is no effect (1.5% in the case of Eq. (4)). This deviates from the statement by Wischmeier et al. (1971) that there should be a limiting density. Without this limiting density, measurement of the rock fragment cover becomes mandatory even in the case of very little rock cover and due to the fact that the curve is steepest at $f_{rf} = 0\%$ K will almost always be lower than predicted from the nomograph.

Incorporating the restrictions of the K nomograph to the K factor equation thus leads to the following extended K factor equation that requires four steps of calculation:

$$\begin{aligned}
&1)\ K_1 = 2.77 * 10^5 * \left(f_{Si+vfSa} * (100 - f_{Cl})\right)^{1.14} && \text{for } f_{Si+vfSa} < 70\% \\
& K_1 = 1.75 * 10^5 * \left(f_{Si+vfSa} * (100 - f_{Cl})\right)^{1.14} && \text{for } f_{Si+vfSa} > 70\% \\
& + 0.0024 * f_{Si+vfSa} + 0.16 && \\
&2)\ K_2 = (12 - f_{OM})/10 && \text{for } f_{OM} < 4\% \\
& K_2 = 0.8 && \text{for } f_{OM} > 4\% \\
&3)\ K_3 = K_1 * K_2 + 0.043 * (A - 2) + 0.033 * (P - 3) && \text{for } K_1 * K_2 > 0.2 \\
& K_3 = 0.091 - 0.34 * K_1 * K_2 + 1.79 * (K_1 * K_2)^2 && \\
& + 0.24 * K_1 * K_2 * A + 0.033 * (P - 3) && \text{for } K_1 * K_2 < 0.2 \\
&4)\ K = K_3 && \text{for } f_{rf} < 1.5\% \\
& K = K_3 * (1.1 * \exp(-0.024 * f_{rf}) - 0.06). && \text{for } f_{rf} > 1.5\%
\end{aligned} \tag{5}$$

We evaluated the failure of using the K factor equation instead of the K factor nomograph by analyzing 19,055 soils obtained during soil surveys throughout Germany likely providing a spatially representative sample. The textural fractions and organic matter contents were analyzed following the accepted methods. The German particle size classes in our dataset follow the 2/63 system (Ad-hoc-Arbeitsgruppe Boden, 2005) in contrast to the 2/50 system of the US taxonomy (Burt, 2004). Within the 2/63 system, vfSa ranges from 63 μm to 125 μm. For about half of the soils vfSa had been determined with an upper limit of 100 μm according to the definition by Wischmeier et al. (1971) and thus allowed in determining the Si + vfSa fraction accordingly. Assuming a log-normal distribution of particle sizes (Shirazi et al., 1988), the class width lg(125)–lg(2) is 6% larger than the class width lg(100)–lg(2). The Si + vfSa fraction of those texture analyses that had used 125 μm as the upper boundary were multiplied by 0.94 and the respective sand fractions were increased accordingly to yield the Si + vfSa fraction in agreement with Wischmeier et al. (1971).

The sites represented by the dataset comprise grassland and arable land on a large range of parent rocks within a temperate humid climate (mean annual precipitation varying between 450 and 2000 mm yr^{-1}; mean annual temperature varying between 5 and 10 °C). For the evaluation of the effect of organic matter we restricted the dataset to top soils under arable use because according to the definitions of the USLE and its successors, the K factor should be determined after 3 to 4 years of continuous bare fallow to remove those effects, which are accounted for in the C factor (Wischmeier and Mannering, 1969). Our soils were not under continuous bare fallow but under ordinary arable use. It is reasonable to assume that the organic matter content would decrease during 3 to 4 years of continuous bare fallow. We did not account for this decrease because for a set of soils that had been selected by the soil survey authority to represent the soils used in this study (Martin, 1988), the decrease in organic matter content during five years of continuous bare fallow was small (on average 7% of the initial content; Auerswald et al., 1996) because microbial biomass decreased under continuous bare fallow (Weigand et al., 1995). Consideration of this slight decrease in organic matter content would not have changed the findings of this study.

Surface cover by rock fragments varies from site to site in otherwise identical soils (Römkens et al., 1997) and hence is usually not included in soil surveys and respective analyses taken from soil profiles. To evaluate the influence of rock fragment cover we used a large data base of rainfall simulations on small plots (Fiener et al., 2011a; Seibert et al., 2011) distributed over Germany following the recommendation by Foster et al. (2003) that rock cover should best be determined after rainfall has exposed the fragments. For 606 plots the rock fragment cover was available. All plots were situated on arable soils. This restriction is reasonable as rock fragment cover becomes ineffective under spatio-temporally continuous vegetation cover (e.g. grassland).

K factor calculations were carried out with the classical K factor equation and with the set of equations (Eq. (5)) developed here. Subsequently we will refer to the K factors calculated with this set of equations nomograph K factors because the equations mimic all properties of the nomograph.

3. Results and discussion

The tested soils covered a wide range (Table 1) of soil properties. Only clay contents >88% and Si + vfSa contents >99% were not included. Rock fragment cover reached nearly 60%. Remarkably, even the narrow fraction vfSa (63 … 100 μm) covered a range from 0 … 75% (mean: 6%). Omitting this fraction during texture analysis can thus potentially cause a large error in the calculation of the K factor. Even the slight difference in the upper boundary of either 100 μm or 125 μm seems not to be tolerable in cases where soil erosion has to be predicted. The log class width of vfSa varies by almost 50% [lg(125)–lg(63) vs. lg(100)–lg(63)] and thus can potentially create a large difference in the vfSa content even though the imprecision of sieves (e.g., due to wear) or differences in mechanical intensity during fractionation presumably causes errors of the upper boundary in the same order of magnitude.

About 25% of our soils were beyond the textural range of the Wischmeier soils (Table 2). We only compared the clay content that used the same particle size definition in both cases. However, a similar percentage would also result for the silt fraction or the sand fraction because also either extreme silt or sand contents existed in those cases where the range of clay contents covered by the Wischmeier soils (8 … 71%) was exceeded. It is not surprising that our data set exceeded the range of the Wischmeier soils given the more than two orders of magnitude larger data set. Another 12% of our arable soils were beyond the range of organic matter (Table 2). However, it is remarkable that Wischmeier and co-workers had covered with only 55 soils most of the range of our much larger data set.

3.1. High silt restriction

About 20% of all soils had more than 70% Si + vfSa (Table 3) and thus had a lower nomograph K factor than the equation K factor. This percentage depended on the landscape and was considerably higher in loessial landscapes. The deviation from the nomograph already started at a first approximation of about K = 0.5 (Fig. 2). On average of all soils, the nomograph K factor was lower than the equation K by 0.03 but the effect was much stronger (up to 0.18) for individual soils.

Table 1
Sample size, texture and organic matter ranges (percentages denote mass in the fine earth fraction) and rock fragment cover.

	n	Minimum (%)	Mean (%)	Maximum (%)
Clay < 2 μm	19,055	0	20	88
Silt + very fine sand 2… 100 μm	19,055	0	58	99
Sand without very fine sand 100… 2000 μm	19,055	0	31	100
Organic matter (C_{org} ∗ 1.74)	1709	0.4	4.7	18
Rock fragment cover	606	0.0	8.4	58

Table 2
Range of properties of the 55 soils used by Wischmeier and Mannering (1969) and Wischmeier et al. (1971) for the development of the K factor and range of soils used in this study (reported as mass percentage in the fine earth fraction); 'outside' denotes the percentage of soils used in this study that were beyond the range of the Wischmeier soils.

	Wischmeier (n = 55)			This study			
	Min (%)	Mean (%)	Max (%)	Min (%)	Mean (%)	Max (%)	Outside (%)
Clay < 2 μm	8	25	71	0	20	88	22
Organic matter (C_{org} ∗ 1.74)	0.9	2.2	5.5	0.4	4.7	18	12

3.2. Low erodibility restriction

The low erodibility restriction applied in 29% of all cases (Table 3). Again, this depended on the landscape with a higher frequency of failure in landscapes of low Si + vfSa content. Hence both, the high silt restriction and the low erodibility restriction affect different landscapes. Thus, the use of the K equation causes a misjudgment of individual soils but also a misjudgment of entire landscapes. As both errors affect different soils, the probabilities of failure can be added and let us expect that in almost 50% of all cases the K equation does not agree with the nomograph. On average of all soils the nomograph K was higher by 0.02 than the equation K, but for individual soils the deviation may be up to 0.15 (Fig. 3). The erodibility of the low erodible soils depends mainly on the permeability while the first approximation and the aggregation lose importance. This causes the K factor of low erodible soils to split up into six groups reflecting the six permeability classes.

The maximum effect of aggregation above a first approximation of 0.2 is $4 * 0.043 = 0.172$. This effect is lowered to 0.064 below a first approximation of 0.2. From a practical point of view, this is advantageous because the aggregation index, which should not reflect the tillage induced clod sizes but the natural aggregation under long-term fallow, is especially difficult to predict for very sandy or very clayey soils, which usually have a first approximation <0.2.

3.3. High organic matter restriction

The mean organic matter content of the arable topsoils was 3.5% and thus, even the mean was already close to the upper boundary of the nomograph. About 30% of all arable topsoils had organic matter contents >4% (Table 3). This percentage was slightly higher for loamy soils but still rather similar for all textural classes. On average, K_2 was 0.887, 0.923, 0.922 and 0.903 for loamy, silty, clayey and sandy textures, respectively. The combined percentages of failure thus yield 64% (Table 3). On average the nomograph K was 0.02 higher than the equation K but the differences would be larger for individual soils. Ignoring the organic matter restriction may even lead to negative K factors depending on the value of the first approximation and the organic matter content. The percentage of failure and the effect of failure would become considerably larger, if also the grassland soils would have been included in this analysis. Given that grassland soils usually have higher organic matter contents

Table 3
Percentage of failure when applying the classical K factor equation in comparison to the nomograph solution combined with the chart on mulch effects.

Error type	Failure (%)	
	Individual	Accumulated
Silt + very fine sand restriction	20	20
Low erodibility restriction	29	49
Organic matter restriction	30	64
Rock fragment cover restriction	82	93

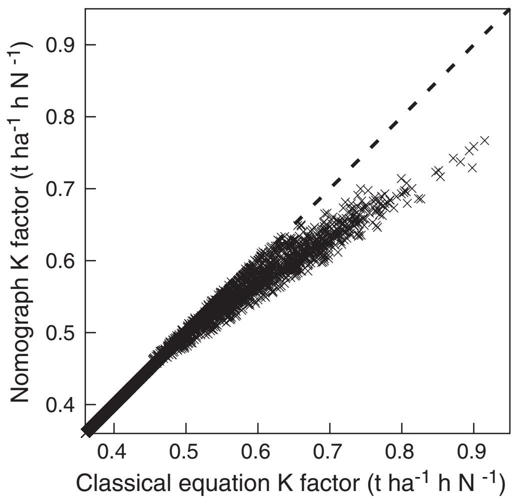

Fig. 2. Deviation of the nomograph K factor from the classical K factor equation due to the Si + vfSa restriction (first approximation of K calculated with a constant 2% organic matter content in both cases to exclude other influences); only soils with K > 0.4 are shown; dashed line denotes unity.

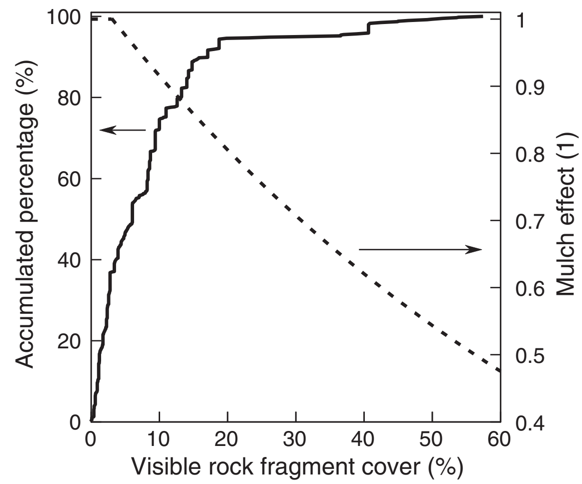

Fig. 4. Accumulated percentage of soils with increasing rock fragment cover (solid line). The dashed line indicates the relative soil loss for such rock fragment cover if visible.

because they are usually found at the wetter sites (Wiesmeier et al., 2012), an organic matter content >4% would be maintained for grassland soils even after 3 to 4 fallow years.

3.4. Rock fragment restriction

Most of the soils (82%) had a rock fragment cover >1.5% (Table 3), which would lead to an accumulated probability of failure of 93% for the equation K factor. The rock fragment restriction, however, is more difficult to assess because the cover by plants and plant residues has to be taken into account as well (Römkens et al., 1997). For most conventional rotations the mean plant cover averaged over all seasons will be about 50% (e.g., Fiener et al., 2011b). Under such a plant cover only half of the rock fragments will be effective. Thus more than 3% rock fragment cover is required for an initial effect. A cover >3% was found on 63% of all soils. At 3% cover the rock fragments start to become effective. For lowering the K factor by 10% an effective rock fragment cover of 10% would be necessary, which would be the case with a total (visible plus covered) rock fragment cover of 20%. Such cover was exceeded only by 5% of all cases (Fig. 4). The assessment of the rock fragment restriction thus depends largely on the conditions. However, the assumption that rock fragment cover is negligible seems not be given in at least Middle European landscapes. They experienced a long history of soil use during which rock fragments including brick fragments were scattered on virtually all soils by manure applications, tillage translocation and other mixing processes.

Combining all effects except for the rock fragment effect, the difference between the equation and the nomograph were close to zero only in 40% of all cases (Fig. 5). Overestimations by the equation (negative values in Fig. 5) were rather small and rare (in total 7%), because in some cases the effect of disregarding the Si–vfSa restriction that causes overestimation was (partly) compensated by disregarding the organic matter restriction that causes underestimation. Underestimations caused by disregarding the organic matter

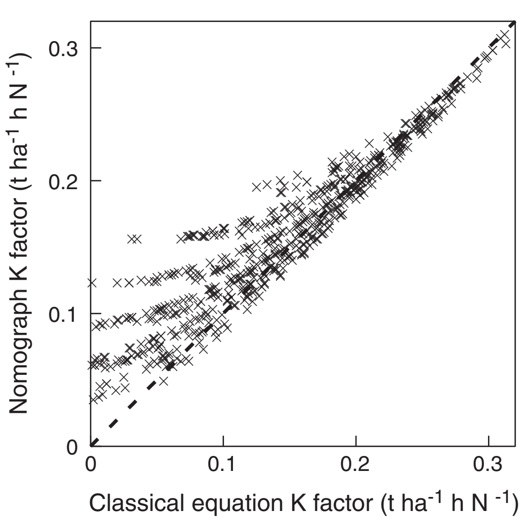

Fig. 3. Deviation of the nomograph K factor from the classical K factor equation due to the K < 0.2 restriction; only soils with K < 0.3 are shown; dashed line denotes unity.

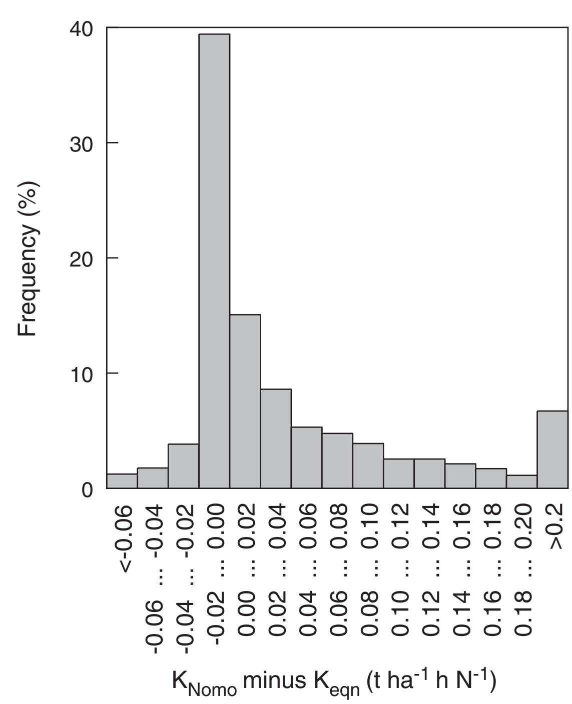

Fig. 5. Frequency distribution of the total error (K factor nomograph minus classical equation K factor) resulting from the combination of the Si + vfSa restriction, the K > 0.2 restriction and the organic matter restriction.

restriction and the K factor < 0.2 restriction thus constituted the main share of false predictions. In 20% of all cases, the underestimation was 0.1 or larger; even on average of all cases including the correct predictions, the K factor was still underestimated by 0.05. The largest deviations resulted from the organic matter restriction. It is important to note that this was not because of unusual high organic matter content. Only 11% of our arable soils were above the organic matter range of the Wischmeier soils (Table 2).

We did not consider seasonality of soil erodibility, which was first suggested by Mutchler and Carter (1983) and later confirmed and elaborated by others (Auerswald, 1993; Coote et al., 1988; Imeson and Kwaad, 1990). The seasonality of K has to be considered in addition to the baseline K factor as treated in this analysis in cases where the C factor is not derived from local and seasonal measurements. It likely depends on the local climate and land use and modifies the K factor but does not replace it (Foster, 2008).

4. Conclusions

The K factor nomograph is the most important tool in soil erosion modeling for assessing the soil erodibility. Substituting the nomograph with the classical K factor equation should be done with care because in considerably more than 50% of all cases wrong predictions will result from the classical K factor equation. Instead of using the classical equation we recommend to use a set of equations, which mimics the nomograph even in cases where the classical equation fails.

References

Ad-hoc-Arbeitsgruppe Boden, 2005. Bodenkundliche Kartieranleitung, 5th ed. Bundesanstalt für Geowissenschaften und Rohstoffe and Staatliche Geologische Dienste, Hannover, Germany.
Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modeling and assessment. Part 1: model development. J. Am. Water Res. Assoc. 34, 73–89.
Auerswald, K., 1993. Bodeneigenschaften und Bodenerosion. Wirkungswege bei unterschiedlichen Betrachtungsmaßstäben. Relief Boden Paläoklima, 7. Gebr. Borntraeger, Berlin (208 pp.).
Auerswald, K., Weigand, S., Kainz, M., Philipp, C., 1996. Influence of soil properties on the population and activity of geophagous earthworms after five years of bare fallow. Biol. Fertil. Soils 23, 382–387.
Burt, R. (Ed.), 2004. Soil survey laboratory methods manual. Soil Survey Investigations Report No. 42. USDA Natural Resources Conservation Service, Washington, D.C.
Cerdan, O., Souchère, V., Lecomte, V., Couturier, A., Le Bissonnais, Y., 2001. Incorporating soil surface crusting processes in an expert-based runoff and erosion model: sealing and transfer by runoff and erosion related to agricultural management. Catena 46, 189–205.
Coote, D.R., Malcolm-McGovern, C.A., Wall, G.J., Dickinson, W.T., Rudra, R.P., 1988. Seasonal variation of erodibility indices based on shear strength and aggregate stability in some Ontario soils. Can. J. Soil Sci. 68, 405–416.
Cronshey, R.G., Theurer, F.D., 1998. AnnAGNPS-non-point pollutant loading model. Proceedings First Federal Interagency Hydrologic Modeling Conference, 19–23 April 1998, Las Vegas, NV, Vol. I, pp. 9–16.
De Roo, A.P.J., Wesseling, C.G., Ritsema, C.J., 1996. LISEM: a single-event physically based hydrological and soil erosion model for drainage basins. I: theory, input and output. Hydrol. Process. 10, 1107–1117.
Fiener, P., Seibert, S.P., Auerswald, K., 2011a. A compilation and meta-analysis of rainfall simulation data on arable soils. J. Hydrol. 409, 395–406.
Fiener, P., Auerswald, K., Van Oost, K., 2011b. Spatio-temporal patterns in land use and management affecting surface runoff response of agricultural catchments — a review. Earth Sci. Rev. 106, 92–104.
Flacke, W., Auerswald, K., Neufang, L., 1990. Combining a modified Universal Soil Loss Equation with a digital terrain model for computing high resolution maps of soil loss resulting from rain wash. Catena 17, 383–397.
Foster, G.R., 2005. Draft: Science Documentation. Revised Universal Soil Loss Equation version 2 (RUSLE2)USDA-Agricultural Research Service, Washington, D.C.
Foster, G.R., 2008. Draft: Science Documentation. Revised Universal Soil Loss Equation version 2 (RUSLE2)USDA-Agricultural Research Service, Washington, D.C.
Foster, G.R., Yoder, D.C., Weesies, G.A., McCool, D.K., McGregor, K.C., Bingner, R.L., 2003. User's Guide, Revised Universal Soil Loss Equation, Version 2, RUSLE2, Draft. USDA-Agricultural Research Service, Washington, D.C.
Imeson, A.C., Kwaad, F.J.P.M., 1990. The response of tilled soils to wetting by rainfall and the dynamic character of soil erodibility. In: Boardman, J.A. (Ed.), Soil Erosion on Agricultural Land. Wiley, Chichester.
Kinnell, P.I.A., Risse, L.M., 1998. USLE-M: empirical modeling rainfall erosion through runoff and sediment concentration. Soil Sci. Soc. Am. J. 62, 1667–1672.
Kirkby, M.J., Irvine, B.J., Jones, R.J.A., Govers, G., Boer, M., Cerdan, O., Daroussin, J., Gobin, A., Grimm, M., Le Bissonnais, Y., Kosmas, C., Mantel, S., Puigdefabregas, J., van Lynden, G., 2008. The PESERA coarse scale erosion model for Europe. I. — model rationale and implementation. Eur. J. Soil Sci. 59, 1293–1306.
Laflen, J.M., Elliot, W.J., Flanagan, D.C., Meyer, C.R., Nearing, M.A., 1997. WEPP-predicting water erosion using a process-based model. J. Soil Water Conserv. 52, 96–102.
Martin, W., 1988. Die Erodierbarkeit von Böden unter simulierten und natürlichen Regen und ihre Abhängigkeit von Bodeneigenschaften. Diss. thesis Techn. Univ., München.
Morgan, R.P.C., Quinton, J.N., Smith, R.E., Govers, G., Poesen, J.W.A., Auerswald, K., Chisci, G., Torri, D., Styczen, M.E., 1998. The European soil erosion model (EUROSEM): a process-based approach for predicting soil loss from fields and small catchments. Earth Surf. Process. 23, 527–544.
Mutchler, C.K., Carter, C.E., 1983. Soil erodibility variation during the year. Trans. Am. Soc. Agric. Eng. 26, 1102–1104 (1108).
Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. Predicting Soil Erosion by Water: A Guide to Conservation. Planning with the Revised Universal Soil Loss Equation (RUSLE). Agric. Handbook, 703. U.S. Department of Agriculture, Washington, D.C.
Römkens, M.J.M., Young, R.A., Poesen, J.W.A., McCool, D.K., El-Swaify, S.A., Bradford, J.M., 1997. Soil erodibility factor (K). In: Renard, et al. (Eds.), pp. 65-99.
Seibert, S., Auerswald, K., Fiener, P., Disse, M., Martin, W., Haider, J., Michael, A., Gerlinger, K., 2011. Surface Runoff from Arable Land — A Homogenized Data Base of 726 Rainfall Simulation Experiments. http://dx.doi.org/10.1594/GFZ.TR32.2.
Shirazi, M.A., Boersma, L., Hart, J.W., 1988. A unifying quantitative analysis of soil texture: improvement of precision and extension of scale. Soil Sci. Soc. Am. J. 52, 181–190.
Trott, K.E., Singer, M.J., 1983. Relative erodibility of 20 California range and forest soils. Soil Sci. Soc. Am. J. 47, 753–759.
Van Rompaey, A.J.J., Verstraeten, G., Van Oost, K., Govers, G., Poesen, J., 2001. Modelling mean annual sediment yield using a distributed approach. Earth Surf. Process. Landf. 26, 1221–1236.
Weigand, S., Auerswald, K., Beck, T., 1995. Microbial biomass in agricultural topsoils after six years of bare fallow. Biol. Fertil. Soils 19, 129–134.
Wiesmeier, M., Spoerlein, P., Geuss, U., Hangen, E., Haug, S., Reischl, A., Schilling, B., von Lützow, M., Kögel-Knabner, I., 2012. Soil organic carbon stocks in southeast Germany (Bavaria) as affected by land use, soil type and sampling depth. Glob. Chang. Biol. 18, 2233–2245.
Williams, J.R., 1975. Sediment-Yield Prediction with Universal Equation Using Runoff Energy Factor. Present and Prospective Technology for Predicting Sediment Yield and Sources, Publ. ARS-S-40. US Dept. Agric., Washington, DC, pp. 244–252.
Williams, J.R., Renard, K.G., Dyke, P.T., 1983. EPIC: a new method for assessing erosion's effect on soil productivity. J. Soil Water Conserv. 38, 381–383.
Wischmeier, W.H., Mannering, J.V., 1969. Relation of soil properties to its erodibility. Soil Sci. Soc. Am. Proc. 33, 131–137.
Wischmeier, W.H., Smith, D.D., 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agric. Handb., 537. U.S. Dep. Agric., Washington, D.C.
Wischmeier, W.H., Johnson, C.B., Cross, B.V., 1971. A soil erodibility nomograph for farmland and construction sites. J. Soil Water Conserv. 26, 189–193.

Update

Catena

Volume 139, Issue , April 2016, Page 271

DOI: https://doi.org/10.1016/j.catena.2015.05.026

Catena 139 (2016) 271

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Corrigendum

Corrigendum to "Use and misuse of the K factor equation in soil erosion modeling" [Catena 118 (2014) 220–225]

Karl Auerswald[a], Peter Fiener[b,*], Walter Martin[c], Dirk Elhaus[d]

[a] Lehrstuhl für Grünlandlehre der TU München, D-85350 Freising, Germany
[b] Institut für Geographie, Universität Augsburg, D-86135 Augsburg, Germany
[c] Bayerisches Landesamt für Umwelt, D-86179 Augsburg, Germany
[d] Geologischer Dienst Nordrhein-Westfalen, D-47707 Krefeld, Germany

The authors regret that the paper published by Auerswald et al. (2014) contains some typing errors. Eq. (1) should read as:

$$\begin{aligned} &K = K_1 * K_2 + 0.043 * (A-2) + 0.033 * (P-3) \\ &\text{and } K_1 = 2.77 * 10^{-5} * (f_{Si+vfSa} * (100-f_{Cl}))^{1.14} \\ &\text{and } K_2 = (12-f_{OM})/10 \end{aligned} \tag{1}$$

where:

$f_{Si+vfSa}$	mass fraction (in %) of silt plus very fine sand Si + vfSa (2…100 μm) in the fine earth fraction
f_{Cl}	mass fraction (in %) of clay (<2 μm) in the fine earth fraction
f_{OM}	mass fraction (in %) of organic matter in the fine earth fraction
A	soil structure index (1…4) increasing from very fine granular to blocky, platy or massive (for definition of the classes see Wischmeier et al., 1971)
P	permeability index (1…6) increasing from rapid to very slow (for definition of the classes see Wischmeier et al., 1971)

The minus that was missing in the exponent of Eq. (1) was also missing in Eq. (2) and in the first step of Eq. (5). These equations should be corrected as follows:

$$\begin{aligned} K_1 = {} & 0.631 * 2.77 * 10^{-5} * ((f_{Si+vfSa}) * (100-f_{Cl}))^{1.14} + 0.0024 \\ & * f_{Si+vfSa} + 0.161. \end{aligned} \tag{2}$$

$$\begin{aligned} K_1 &= 2.77 * 10^{-5} * (f_{Si+vfSa} * (100-f_{Cl}))^{1.14} \quad \text{for } f_{Si+vfSa} < 70\,\% \\ K_1 &= 1.75 * 10^{-5} * (f_{Si+vfSa} * (100-f_{Cl}))^{1.14} \\ &\quad + 0.0024 * f_{Si+vfSa} + 0.16 \quad \text{for } f_{Si+vfSa} \geq 70\%. \end{aligned} \tag{5}$$

Throughout the original paper of Auerswald et al. (2014), all results and figures were calculated and drawn using the correct equations. The authors would like to apologize for any confusion and inconvenience caused.

References

Auerswald, K., Fiener, P., Martin, W., Elhaus, D., 2014. Use and misuse of the K factor equation in soil erosion modeling. Catena 118, 220–225.

Wischmeier, W.H., Johnson, C.B., Cross, B.V., 1971. A soil erodibility nomograph for farmland and construction sites. J. Soil Water Conserv. 26, 189–193.

DOI of original article: http://dx.doi.org/10.1016/j.catena.2014.01.008.

* Corresponding author.
E-mail address: peter.fiener@geo.uni-augsburg.de (P. Fiener).

http://dx.doi.org/10.1016/j.catena.2015.05.026