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The USLE soil erodibility nomograph revisited

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ABSTRACT

The nomograph by Wischmeier et al. (1971) for calculating the *K*-factor in the USLE was extremely useful when there was low access to calculators. However, the generalised calculation of this factor requires the development of analytic procedures. This paper presents a detailed analysis of the nomograph and its underlying equation, which is applicable only when the silt plus very find sand fraction does not exceed 70%. We also examined the quality of fit on the nomograph of the adaptations to the equation that have been proposed, as a means of dealing with those areas where the original equation is not applicable. All models are shown to have areas where the fit is deficient or even unacceptable. Besides, the family of curves on the nomograph for the various values taken by the organic matter are not coincident with the mathematical function from which they presumably derive. The study also identifies those areas of the textural triangle in which the soils originally used in developing the USLE are located, with a view to according a lower predictive value to the contrasting areas in which calculations of the *K*-factor will necessarily be extrapolations. Finally, a new equation for calculating the *K*-factor is presented, which accurately reproduces the different sections of the nomograph, and allows the poorly functioning graph to be dispensed with. The paper ends with a link to a tool in R for simplifying the procedure for calculating the *K*-factor, taking into account varying situations of data availability.

1. Introduction

A lot of water has passed under the bridge since Hugh Hammond Bennett, considered by many to be the father of soil conservation, laid the foundations for research into erosional processes in the 1920s. He was the architect behind the political commitment and economic support implemented by the US government in the fight against erosion through institutions such as the USDA Soil Conservation Service and the National Runoff and Soil Loss Data Center (Laflen & Moldenhauer, 2003; Meyer, 1984). The result, after several decades of research, was the development of the Universal Soil Loss Equation (USLE), which along with its successors, the Revised Universal Soil Loss Equation (RUSLE) version 1 (RUSLE1; Renard et al., 1997) and the RUSLE version 2 (RUSLE2; Agricultural Research Service, 2013), are currently the most widely used tools worldwide for estimating soil loss (Alewell et al., 2019; Auerswald et al., 2014; Bagarello et al., 2015; Borrelli et al., 2021; Kinnell, 2010; Laflen & Moldenhauer, 2003; Panagos et al., 2014).

The success of the USLE is due, among other reasons, to the fact that it is a conceptually simple and easy to use model (Bagarello et al., 2008; Ostovari et al., 2016), and that it strikes a balance between applicability, in terms of the input data required, and the reliability of its estimates (Risse et al., 1993). Although it is an empirical model developed from data from the United States (Wischmeier & Smith, 1978), there are no geographical restrictions for its application, provided that, it goes without saying, the necessary information is available to evaluate its factors (Meyer, 1984). All this has made the USLE and its revised versions very attractive models from a practical point of view, and highly useful for continental and country-wide evaluations (Teng et al., 2016), with currently 109 countries registering its use (Alewell et al., 2019). They are also the most frequently cited erosion prediction models in scientific journals (Alewell et al., 2019; Auerswald et al., 2014; Bezak et al., 2021).

The USLE was designed to calculate the long-term average soil loss from sheet and rill erosion under specified conditions, and computes the soil loss for a given site as the product of six factors (Wischmeier & Smith, 1978). One of these factors is the *K*-factor,

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Abbreviations: VFS, very fine sand; NVFS, not very fine sand.

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which quantifies the erodibility of the soil, that is, the susceptibility of the soil to erosion. The USLE soil erodibility factor, or *K*-factor, represents the rate of soil loss per unit of rainfall erosivity index as measured on a unit plot, which is defined as a 72.6 ft length of uniform 9% slope continuously in clean-tilled fallow (Wischmeier & Smith, 1978).

As well as the USLE model, the *K*-factor is the most commonly used and cited prediction tool for estimating susceptibility of soil to erosion (Auerswald et al., 2014; Panagos et al., 2014), and can be applied at regional, national and continental levels (Ostovari et al., 2018). Recent examples of its application include the creation of the map for estimating the *K*-factor in the European Union by the European Soil Data Centre (Panagos et al., 2012, 2014), with the addition of the erodibility map for Switzerland (Schmidt et al., 2018); the map of Australia developed by Teng et al. (2016); and the *K*-factor map for the East Africa region (Fenta et al., 2020).

In addition, the *K*-factor has been included in a series of modifications and extensions to the USLE (Auerswald et al., 2014), such as MUSLE (Williams, 1975), dUSLE (Flacke et al., 1990) or USPED (Mitasova & Mitas, 1999). It has also been integrated into other more complex erosion prediction models based on USLE/RUSLE technology (Auerswald et al., 2014; Laflen & Flanagan, 2013), such as EPIC (Williams et al., 1983), SWAT (Arnold et al., 1998), AGNPS (Cronshey & Theurer, 1998; Young et al., 1989), Watem/Sedem (Van Rompaey et al., 2001) and CSLE (Baoyuan et al., 2002), among others. These models are also frequently used, as testified by the greater number of citations in the literature in comparison with other types of models independent of USLE/RUSLE technology (Alewell et al., 2019; Auerswald et al., 2014).

The full version of the USLE was first published in a USDA handbook in 1965 (Wischmeier & Smith, 1965), although it had previously been announced in a special report by the Agricultural Research Service (Agricultural Research Service, 1961). Initially, the *K*-factor values were obtained from tables, in which the soil, or closest match, had to be identified from among the 23 values available (Wischmeier & Smith, 1965). The first equation which enabled the *K*-factor to be estimated for any soil was developed in 1969 (Wischmeier & Mannering, 1969). It was an equation with 24 terms, obtained from 15 soil properties and their interactions (Wischmeier et al., 1971), which inevitably made it impractical as a tool for fieldwork, but interesting nevertheless as it represented the first attempt to identify the soil properties that best predicted erodibility (Wischmeier & Meyer, 1973). Wischmeier et al. (1971) succeeded in reducing this equation to an expression with just five parameters, which they originally presented in the form of a nomograph. The equation underlying this nomograph was published two years later (Wischmeier & Meyer, 1973). The USLE was updated in 1978, and a new USDA handbook was published to replace the original 1965 version. This updated version included both the nomograph and the equation in order to enable the calculation of the *K*-factor (Wischmeier & Smith, 1978).

As advances in research into soil erosion were made, and the limitations of the USLE were recognised, it became clear that a new update would be necessary. Work on this began in 1985, and ended up becoming a full-scale revision, which was given the name RUSLE1 (Renard et al., 1997). One of the most notable incorporations was the development of a computer program for implementing the equation. Among the improvements introduced for estimating the *K*-factor were the possibility of taking into account seasonal variability, a new set of equations for making the calculation in very specific contexts (for example, tropical volcanic soils), and a correction that takes into account rock fragments in the soil profile.

The most recent version, RUSLE2, was released in 2003. This incorporated new more complex mathematical equations, expanded the associated database, and improved the graphical interface of the computer program. Unlike its predecessors, RUSLE2 can also compute sediment deposition and transport capacity, although it continues to use the underlying USLE framework for estimating soil loss (Agricultural Research Service, 2008). With respect to estimating the *K*-factor, the most notable improvements were the development of an equation to estimate the very fine sand (VFS) fraction, and the setting aside of the equations for very specific situations which had been included in RUSLE1 (Agricultural Research Service, 2013). New routines were also incorporated to describe seasonal variation, as well as a modified nomograph for highly disturbed soils (Renard et al., 2011). Further interesting incorporations will be discussed below.

The best way to obtain the *K*-factor is by direct measurement of long-term soil loss on natural runoff plots. Nevertheless, the economic and temporal limitations involved in setting up this type of plot have prompted the use of plots with simulated rainfall (Römkens et al., 1997). At present, the USDA-NRCS database provides *K*-factor values for the majority of soils in the US (Agricultural Research Service, 2008). Should the data not be available, whether because the conditions are specific or because the location is outside the US, the most widely used tool to estimate the value of the *K*-factor is still the soil erodibility nomograph proposed by Wischmeier et al. (1971).

Using the nomograph correctly means understanding its limitations, which in large part derive from its empirical-statistical origins. Hence, it cannot be applied to all types of soils, as it is likely to return inaccurate estimates if it is used with, for example, volcanic soils (Agricultural Research Service, 2008), or if it is applied to calcareous soils in arid and semi-arid regions (Vaezi et al., 2008). In fact, various studies have developed new equations expressly to estimate the *K*-factor in situations and contexts which diverge from those contemplated by the original nomograph. These kinds of studies tend to focus on small areas as collecting the experimental data requires a great deal of time and is very costly. Currently, specific equations for calculating the *K*-factor are available for certain areas of Iran (Ostovari et al., 2016, 2018; Shabani et al., 2014; Vaezi et al., 2008), Italy (Bagarello et al., 2012), China (Wang et al., 2016) and Uruguay (Beretta-Blanco & Carrasco-Letelier, 2017).

The USLE, or any of its factors, should not be used for any purposes for which it was not conceived, nor in any conditions which differ significantly from those of its development. Even so, on occasion references can be found to its inappropriate use (Kinnell, 2010; Wischmeier, 1976). Auerswald et al. (2014) foregrounded this situation when they demonstrated that, of the papers which referred to the *K*-factor published between 2003 and 2012, only 10% cited the original paper by Wischmeier et al. (1971).

This brings us to the aim of this study: a detailed analysis of the nomograph developed by Wischmeier et al. (1971), and its underlying equation, presented in Wischmeier and Meyer (1973), in order to establish the limits of how it can be applied, and to facilitate its correct use. At the same time, we will review the extensions and modifications to the original equation which have been proposed in order to overcome their limits, and develop a new set of equations which fit the nomograph and allow it to be completely dispensed with.

2. Description of the *K*-factor nomograph and original equation

2.1. The general equation

When a database with the values of the *K*-factor is not available, it can be calculated either by using the nomograph developed by

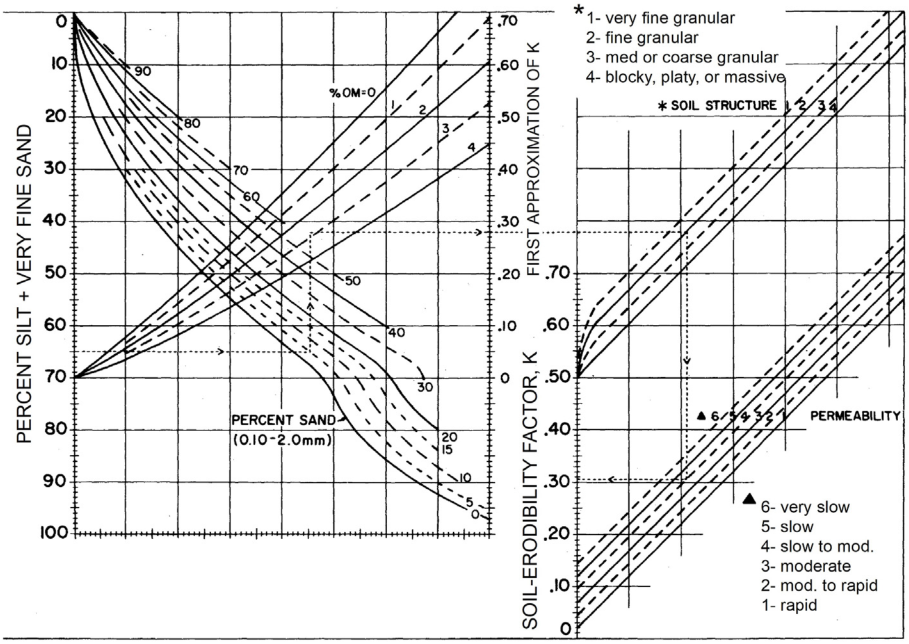

Fig. 1. Nomograph for calculating the *K*-factor of soil erodibility (Wischmeier et al., 1971).

Wischmeier et al. (1971), shown in Fig. 1, or by using the equation presented in Wischmeier and Meyer (1973). The equation consists of three addends, which correspond to the three sections making up the nomograph:

$$K = K_1 + K_S + K_P \ , \qquad (1)$$

where K_1 is the first approximation of *K*, K_S is the soil structure subfactor, and K_P is the permeability subfactor. The first two terms refer to the surface soil layer of the profile, while the third refers to the whole profile. These three addends are analysed in detail in the following sections.

In their original formulation, the versions under analysis here, both the equation and the nomograph return *K*-factor values in terms of the customary US units, specifically (0.01 · ton · acre · h)/(acre · ft-tonf · in). In order to convert these to the International Metric System of Units (SI), for example (t · ha · h)/(MJ · ha · mm), it is necessary to multiply the resultant *K*-factor by 0.1317 (Foster et al., 1981).

2.2. The first approximation of K

The value taken by the *K*-factor when the K_S and K_P subfactors are null is known as the first approximation of K, or K_1. This value can be obtained either, using the two families of curves represented in the left-hand block of the nomograph, or by multiplying the two subfactors given in the following equations:

$$K_1 = k_t \cdot k_O \qquad (2)$$

$$k_t = 2.1 \cdot 10^{-5} \cdot M^{1.14} \qquad (3)$$

$$k_O = (12 - a) \cdot 10^{-1} \qquad (4)$$

where k_t is the soil texture subfactor, k_o the organic matter (OM) subfactor, *M* the particle size parameter and *a* the content in OM expressed as a percentage. More specifically, k_t is the value taken by K_1 when *a* is 2%, such that the k_o subfactor can be considered a modifier of k_t.

2.2.1. The M parameter

Various studies had already demonstrated that, in terms of erodibility, the VFS fraction was more similar in behaviour to the silt fraction than to the rest of the sand fraction (Wischmeier & Mannering, 1969). It was for this reason that Wischmeier et al. (1971) decided to recombine the textural fractions and define a new parameter, designated *M*, to refer to the soil particle size distribution. The mathematical expression for the *M* parameter is the following (Wischmeier & Meyer, 1973):

$$M = (t + v) \cdot (100 - y), \qquad (5)$$

where *t* is the silt fraction, *v* the VFS fraction, and *y* the clay fraction, all expressed as percentages.

Of the two new textural fractions, the first consisted of particles with diameters between 0.002 and 0.1 mm – that is, an amalgamation of the silt and VFS fractions – and the second, the sand subfraction with diameters higher than 0.1 mm, denominated henceforth as not very fine sand (NVFS). This new distribution saw an improvement in the capacity of the textural data to predict soil erodibility (Wischmeier et al., 1971).

There is a certain degree of ambiguity when it comes to naming these two new fractions, as Wischmeier et al. (1971) use the terms silt (0.002–0.1 mm) and sand (0.1–2 mm), and hence redefine them with respect to the ranges set down in the USDA particle-size classification system. This is further complicated by the inclusion of both classifications in the same document. Thus, for example, when the term silt is used in the nomograph, it refers to particles of 0.002–0.05 mm (as in the USDA classification), while in the exposition for calculating the *M* parameter it refers to particles of 0.002–0.1 mm. This ambiguity is maintained in both Wischmeier and Meyer (1973) and Wischmeier and Smith (1978). On the other hand, in RUSLE1, Römkens et al. (1997) refer to the two new fractions as “modified silt” and “modified sand”, while the RUSLE2 manual (Agricultural Research Service, 2013, Chapter 4) uses the terms solely according to the definitions given in the USDA classification system. This is the criterion which will be followed in this paper.

Given that 100 minus the percentage of clay y is identical to the sum of the silt t and sand d fractions, that is, $100 - y = t + d$, Eq. (5) can be expressed as:

$$M = t' \cdot (t + d) = t' \cdot (t' + d'), \tag{6}$$

where t' is the silt plus VFS fraction, and d' the NVFS fraction, both expressed as percentages. In this way, it is easy to superimpose the parabolas that represent Eq. (6) on the nomograph for different values of the fraction of NVFS (see Fig. 2). In this case, the vertical axis corresponds to the input variable – the silt plus VFS fraction – and the horizontal axis corresponds to the output variable – the M parameter – which takes values between 0 and 8000. Note that, for the sake of simplification, the authors did not specifically identify the M parameter on the nomograph (Wischmeier et al., 1971).

Only parabolas for values of the silt plus VFS fraction lower than 70% were drawn, as this was the limit set by Wischmeier and Meyer (1973) for applying the equation (Fig. 2). Beyond this limit, the relationship between the M parameter and erodibility is different, as the authors underlined by a change in curvature in the lines on the nomograph. According to the RUSLE2 manual, Wischmeier et al. (1971) drew the extensions to the curves based on their expert judgement (Agricultural Research Service, 2013, Chapter 4). Because the new curves were not based on any kind of equation, the only option available for obtaining the M parameter for soils with a silt plus VFS content above 70% was to resort to the nomograph.

2.2.2. The organic matter subfactor

Once the value of the M parameter is known, the next step is to estimate the first approximation of K, either by directly applying Eq. (2), or via the next family of curves on the nomograph. This is the point at which the effect of OM in reducing erodibility is included in the calculation of the K-factor. The presence of OM favours the formation of aggregates, which reduce the susceptibility of the soil to the impact of raindrops and favour infiltration (Agricultural Research Service, 2008, Chapter 7).

In Fig. 3 we have superimposed the curves provided by Eq. (2) onto the nomograph for five levels of OM (fuchsia lines). The abscissa corresponds to the input variable – the M parameter – and the ordinate to the output variable, the first approximation of K. Wischmeier et al. (1971) noted that this relationship between the value of K_1 and M had not been determined for OM values above 4%. As can be seen, there is a surprising discrepancy between this representation and the curves on the nomograph, an issue we will tackle in depth in sections 4 and 5.

2.3. The soil structure subfactor

The second addend in Eq. (1), K_S, takes into account the influence of soil structure on erodibility. Its mathematical expression is the following (Wischmeier & Meyer, 1973):

$$K_S = 3.25 \cdot 10^{-2} \cdot (b - 2), \tag{7}$$

where b is the code assigned to the soil structure.

Soil structure refers to the grouping of primary particles into aggregates, which affects the resistance to impact detaching and the infiltration capacity of the profile (Agricultural Research Service, 2008, Chapter 7). Structure is described in terms of three qualities: type, which concerns the shape and disposition of the aggregates; class, which categorises the soil aggregates in terms of size; and grade, which indicates the distinctness of units (Soil Science Division Staff, 2017, Chapter 3). Wischmeier et al. (1971)

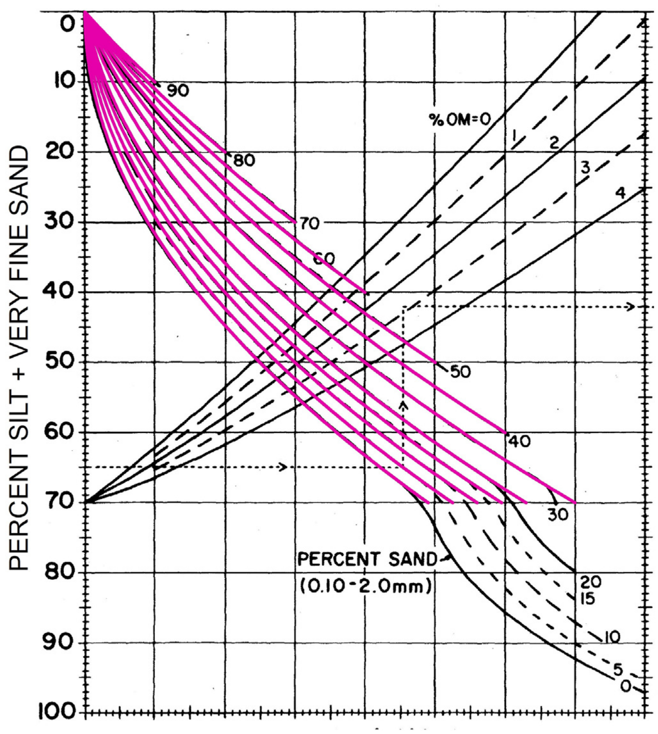

Fig. 2. Superposition on the nomograph by Wischmeier et al. (1971) of the equation by Wischmeier and Meyer (1973) for calculating the M parameter, for different values of the not very fine sand fraction.

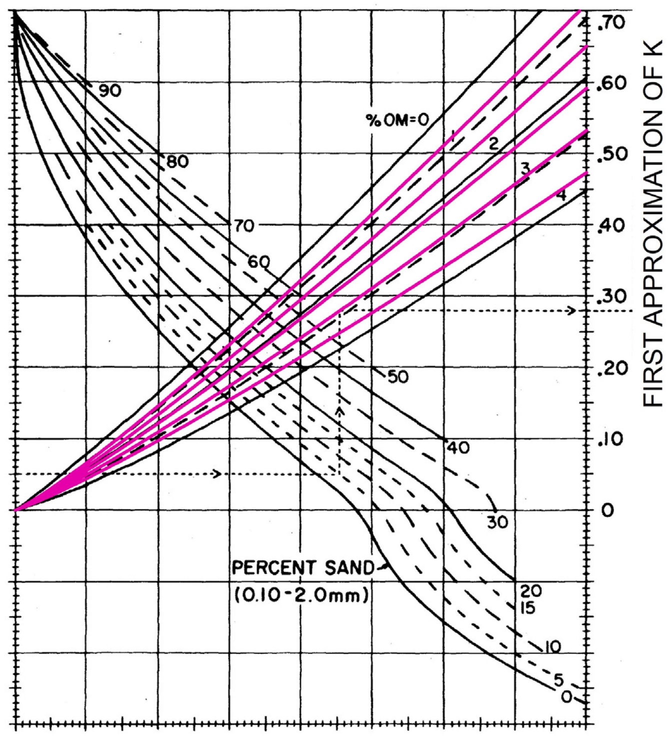

Fig. 3. Superposition on the nomograph by Wischmeier et al. (1971) of the equation by Wischmeier and Meyer (1973) indicating the relationship between the M parameter and the first approximation to K, for five levels of OM.

concluded that grade had no significant effect on erodibility, such that they took into account only the type and class when they established the four categories of the soil structure code indicated on the nomograph, defined according to the descriptions in the Soil Survey Manual from USDA (Soil Survey Staff, 1951).

The family of straight lines in the top right-hand corner of the nomograph represent these relationships based on the structure code, the equation for which is as follows:

$$K_{1S} = K_1 + 3.25 \cdot 10^{-2} \cdot (b - 2)\ , \tag{8}$$

where we have denominated K_{1S} as the value obtained after applying the information of the structure to the first approximation of K.

In Fig. 4 we have drawn the lines provided by Eq. (8) for the four values of the structure code. For the sake of clarity, we have also added the coordinate axes passing through the point of origin (0,0). As can be seen, the abscissa, corresponding to the output variable K_{1S}, coincides with the axis as drawn on the nomograph. However, the ordinate, corresponding to the input variable K_1, is 0.07 units to the left of the vertical axis on the nomograph. In other words, the coordinates of the point of origin of the four lines representing soil structure are (0.07, 0). In the area proximal to the point of origin, corresponding to low values for the first approximation of K, the values returned by Eq. (8) do not coincide with those represented on the nomograph, a defect of the equation which receives no mention in Wischmeier and Meyer (1973).

2.4. The soil profile permeability subfactor

The final addend in Eq. (1) concerns the permeability of the profile. Its mathematical expression is as follows (Wischmeier & Meyer, 1973):

$$K_P = 2.5 \cdot 10^{-2} \cdot (c - 3), \tag{9}$$

where c is the permeability class of the soil profile.

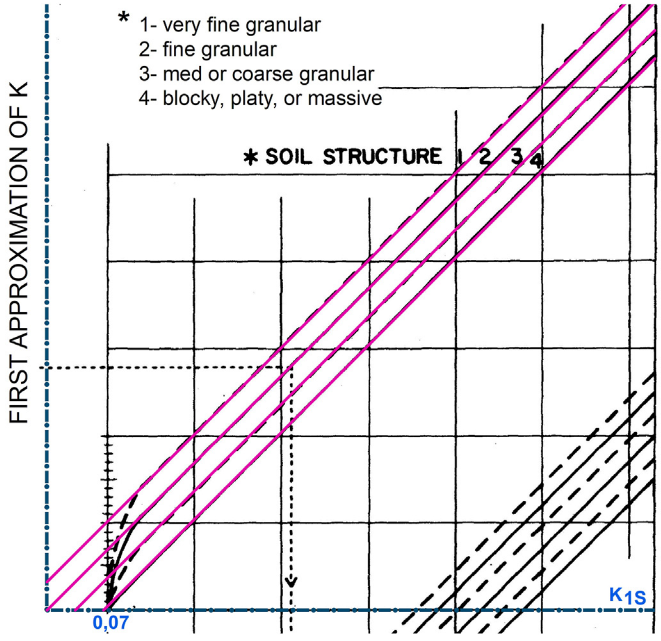

Fig. 4. Superposition on the nomograph by Wischmeier et al. (1971) of the part of the equation by Wischmeier and Meyer (1973) which includes the effect of the soil structure on erodibility.

There are six classes of permeability, intended to describe the capacity of precipitation to infiltrate the soil profile and reduce surface runoff, always under standard conditions (Agricultural Research Service, 2013, Chapter 4). This classification is that originally proposed in the USDA Soil Survey Manual (Soil Survey Staff, 1951), although certain specifications were later added for codes 4, 5 and 6 (Wischmeier et al., 1971). When estimating permeability, it is necessary to consider the full soil profile, unlike in the case of the other subfactors, where only the surface soil layer is taken into account. Indeed, in the case of there being any kind of restrictive layer, the permeability code should be adjusted to take this circumstance into account (Agricultural Research Service, 2013, Chapter 4).

The family of straight lines in the bottom right-hand corner of the nomograph represent the effect of the permeability subfactor, K_P. The equation for these is the following:

$$K = K_{1S} + 2.5 \cdot 10^{-2} \cdot (c - 3) \tag{10}$$

In this instance is has not been necessary for us to superimpose the above equation on the nomograph as it matches the existing graph perfectly. It should be recalled that the vertical axis passing through the point of origin (0,0), corresponding here to the output variable K, is displaced 0.07 units to the left of the vertical axis of the nomograph. This explains why, for example, the line corresponding to a value of c of 3 cuts the vertical axis as drawn on the nomograph at the point 0.07.

3. Adaptations to the equation for calculating the *K*-factor

We have found two adaptations in the literature of the Wischmeier and Meyer (1973) equation for calculating the K-factor, which were implemented to correct certain limitations and inaccuracies. The first of these was the second revision of the USLE, the RUSLE2; the second was that undertaken by Auerswald et al. (2014).

3.1. The RUSLE2 adaptation

This section considers the innovations incorporated into the RUSLE2 for calculating the K-factor (Agricultural Research Service, 2013, Chapter 4). The equation for estimating the VFS fraction, however, is omitted from the consideration, as it has been analysed in detail by Corral-Pazos-de-Provens et al. (2018).

3.1.1. The M parameter

The RUSLE2 offers a new equation for estimating the soil texture subfactor, valid across the full range of possible values for the silt plus VFS fraction:

$$k_t = \begin{cases} 10^{-1} \cdot k_{tb} & \textit{for } \mathrm{t} \leq 68\% \\ 10^{-1} \cdot \left[k_{tb} - 0.67 \cdot (k_{tb} - k_{t68})^{0.82} \right] & \textit{for } \mathrm{t} > 68\% \end{cases} \tag{11}$$

where k_{tb} is equivalent to the soil texture subfactor in Wischmeier and Meyer (1973).

$$k_{tb} = 2.1 \cdot 10^{-4} \cdot M^{1.14} \tag{12}$$

and k_{t68} is the value of k_{tb} when the silt plus VFS fraction is 68%

$$k_{t68} = 2.1 \cdot 10^{-4} \cdot [68 \cdot (100 - y)]^{1.14} \tag{13}$$

The equation for calculating the M parameter is represented on the nomograph, not that for the subfactor k_t. In light of this, in order to check whether the extension proposed by the RUSLE2 fits the family of curves on the nomograph, we deduced the expression corresponding to the M parameter from Eq. (11) (see Appendix). The resulting graphical representation is shown in Fig. 5 for various values of the NVFS fraction. The colour fuchsia has been used for the section of the graph corresponding to the first segment of Eq. (11), which coincides with the original equation in Wischmeier and Meyer (1973) but in this instance only up to a value of 68% for the silt plus VFS fraction. The colour green has been used for the second segment of Eq. (11), introduced into the RUSLE2.

3.1.2. The soil structure subfactor

The RUSLE2 tackled the curvature displayed by the lines corresponding to the soil structure subfactor near the point of origin, and proposed the equation below to adapt to this deviation:

$$K_{1S} = \begin{cases} K_1 + K_S & for\ K_1 + K_S \geq 7 \cdot 10^{-2} \\ 7 \cdot 10^{-2} & for\ K_1 + K_S < 7 \cdot 10^{-2} \end{cases} \tag{14}$$

Fig. 6 shows the representation of Eq. (14) on the nomograph for the four possible values of the soil structure code. One again, fuchsia denotes the first segment, coinciding with the original equation in Wischmeier and Meyer (1973), and green the second segment provided by the RUSLE2.

3.2. The Auerswald adaptation

We set out below the extensions proposed by Auerswald et al. (2014) in order to fully emulate the Wischmeier et al. (1971) nomograph. Their equations provide values for the K-factor in the SI units, for which reason, in order to enable comparisons with previous studies, we have converted them into customary US units.

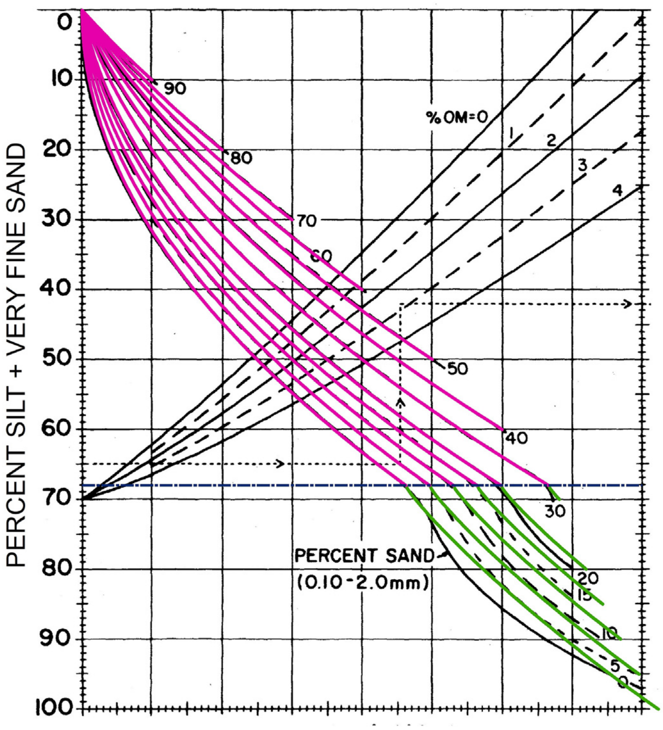

Fig. 5. Superposition on the nomograph by Wischmeier et al. (1971) of the equation for calculating the M parameter. Fuchsia indicates the segment corresponding to the equation by Wischmeier and Meyer (1973); green the RUSLE2 extension.

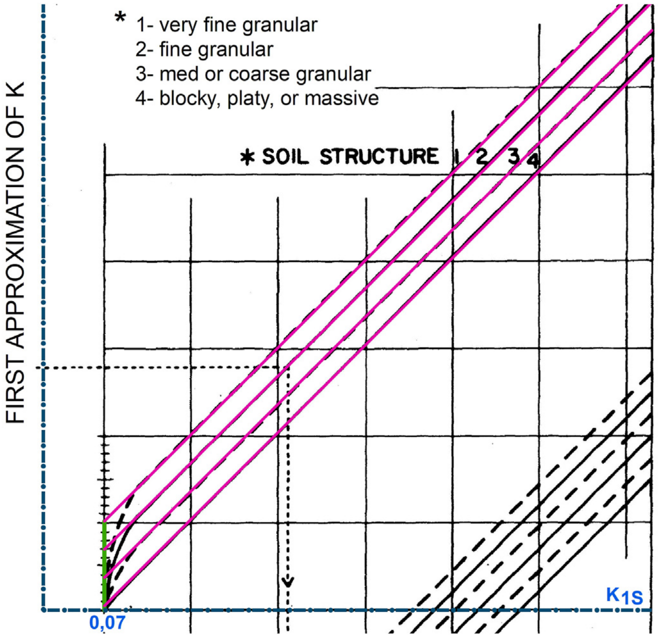

Fig. 6. Superposition on the nomograph by Wischmeier et al. (1971) of the equation which includes the effect of soil structure on erodibility. Fuchsia indicates the segment corresponding to the equation by Wischmeier and Meyer (1973); green the RUSLE2 extension.

3.2.1. The M parameter

Auerswald et al. (2014) fitted the equation for estimating the soil texture subfactor to readings taken from the nomograph for values of silt plus VFS above 70%, producing the equation below, which can be used with all possible values of the silt plus VFS fraction:

$$k_t = \begin{cases} 2.1 \cdot 10^{-5} \cdot M^{1.14} & for\ t' < 70\% \\ 1.3272 \cdot 10^{-5} \cdot M^{1.14} + 0.0018 \cdot t + 0.122 & for\ t \geq 70\% \end{cases} \tag{15}$$

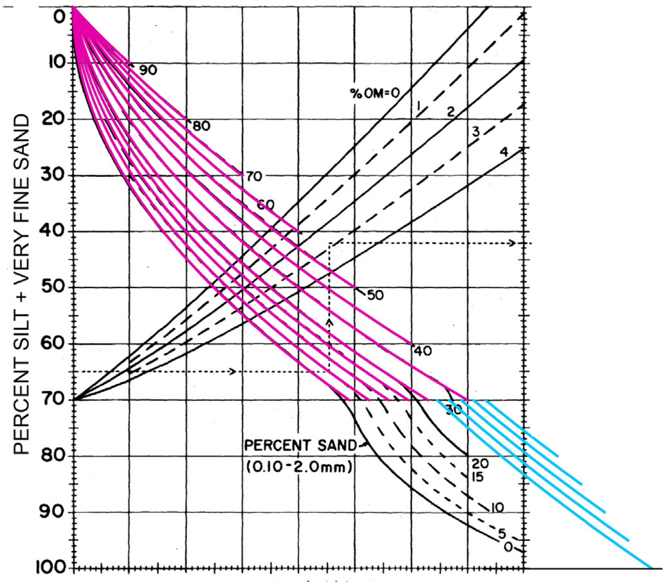

Fig. 7. Superposition on the nomograph by Wischmeier et al. (1971) of the equation for calculating the M parameter. Fuchsia indicates the segment corresponding to the equation by Wischmeier and Meyer (1973) and blue the extension by Auerswald et al. (2014).

Fig. 7 shows the representation of the equation for calculating the M parameter on the nomograph for different values of the NVFS fraction, the expression of which was deduced from Eq. (15). As before fuchsia is used to denote the section corresponding to the first segment of the equation, coinciding with the original equation by Wischmeier and Meyer (1973), while blue indicates the extension by Auerswald et al. (2014). The procedure followed for deducing the equation for the M parameter corresponding to the Auerswald et al. (2014) extension is given in Appendix.

3.2.2. The organic matter subfactor

Auerswald et al. (2014) present their proposal for improving this subfactor in the following terms:

$$k_o = \begin{cases} (12 - a)\cdot 10^{-1} & \textit{for } \mathrm{a} < 4\% \\ 0.8 & \textit{for } \mathrm{a} > 4\% \end{cases} \tag{16}$$

In other words, they extend the OM subfactor beyond the limit of 4% established by Wischmeier et al. (1971) by assigning all soils with OM content above 4% the same value as those with 4%.

3.2.3. The soil structure subfactor

The proposal by Auerswald et al. (2014), fitted from readings taken from the nomograph, and converted into the customary US units, is the following:

$$K_{1S} = \begin{cases} K_1 + K_S & \textit{for } K_1 > 0.152 \\ 2.357\cdot {K_1}^2 + (0.24\cdot b - 0.34)\cdot K_1 + 0.07 & \textit{for } K_1 < 0.152 \end{cases} \tag{17}$$

The authors establish the moment when the straight lines begin to bend at a value of 0.152 (0.2 in the SI units) for the first approximation of K, irrespective of the value taken by the soil structure code b.

Fig. 8 is a detail of the superposition of Eq. (17) on the nomograph, for the four possible values of the soil structure code. As before, fuchsia is used to denote the section corresponding to the first segment of the equation, coinciding with the original equation by Wischmeier and Meyer (1973), while blue indicates the second segment, the modification by Auerswald et al. (2014).

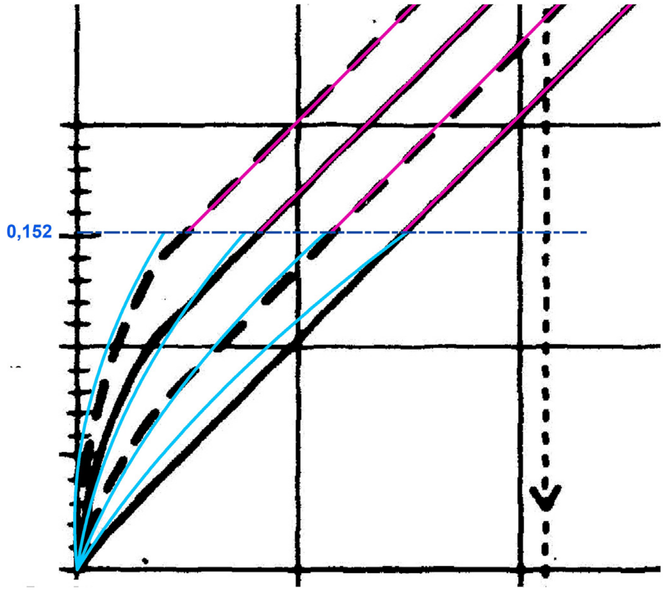

Fig. 8. Detail of the superposition on the nomograph by Wischmeier et al. (1971) of the equation which includes the effect of soil structure on erodibility. Fuchsia indicates the segment corresponding to the equation by Wischmeier and Meyer (1973) and blue the modification by Auerswald et al. (2014).

3.2.4. Soils with rock fragments

As part of their objective to improve the calculation of the K-factor, Auerswald et al. (2014) also included a factor that reduced the K-factor with respect to the soil surface cover provided by rock fragments. This concept has also been considered by other authors, for example Panagos et al. (2014) during their work on creating the K-factor map of the European Union. Alongside the map, the authors also created what they denominated a map of Soil Erodibility in Europe (incorporating Stoniness) (K_{st}-factor), in which they also incorporated the effect of surface stone cover by means of a factor which decreased the value of the K-factor.

However, both Wischmeier & Smith (1978) and the RUSLE2 argue that rock surface cover should be considered as part of the calculation for the C-factor, but never for estimating the K-factor. The RUSLE2 is even more categorical and clearly establishes that the effect of surface rock fragments should not be taken into account for estimating the erodibility factor, and that only rock fragments inside the soil profile should be considered through adjustments to the permeability classes (Agricultural Research Service, 2013, Chapter 4).

4. Methodological proposal for calculating the *K*-factor

4.1. Summary of the issues concerning the calculation of the K-factor

In the sections above we have seen how the analytical formulation for obtaining the K-factor, in both its original version (Wischmeier & Meyer, 1973) and subsequent revisions, involves contexts in which the results of the equation are markedly different from those provided by the nomograph. In this section we propose a methodological approach to be adopted in making the necessary corrections, the formulation of which will be fully explained in section 5. First, we provide a summary of the deviations that have been detected:

- Calculating the M parameter for soils with a silt plus VFS content greater than 70%: the original formulation offered no solution; the RUSLE2 model provides poorly fitting equations; the extension by Auerswald et al. (2014) provide a wrong fit in that they exhibit a manifest discontinuity with respect to the first segment of the function.
- Correction of the first approximation of K according to OM content: discrepancies between the equation and the nomograph have been detected when OM is included.
- Addition of the soil structure subfactor K_S when K_1+ K_S approaches the 0.07 limit: the original formulation offered no solution; the RUSLE2 model provides poorly fitting equations; the extension by Auerswald et al. (2014) offers equations with a relatively accurate fit, but lacking continuity with the first segment of the function.

In view of the above issues we provide an analytical methodology below aimed at minimising the errors in calculating the K-factor.

4.2. The first approximation of K

4.2.1. The M parameter

Wischmeier and Meyer (1973) established that their equation could only be applied when the silt plus VFS fraction was below 70%. Nevertheless, Wischmeier et al. (1971) were less specific, noting that the relationship between the *K*-factor and the *M* parameter changed as the silt plus VFS content approached 70%. Bearing this in mind, we decided to review this limit, with the aim of improving the fit of the equation.

In order to define a new equation that fits the family of curves involved in calculating the *M* parameter in the area which the Wischmeier and Meyer (1973) equation does not describe, we have applied the following methodology: (i) a visual analysis to define the transition limit more precisely; (ii) digitization of curves from the nomograph based on this new limit so as to obtain the coordinates of its points; (iii) a least squares regression analysis based on these points, forcing the resulting equation to provide continuity with the equation of Wischmeier and Meyer (1973) at the defined limit.

4.2.2. The organic matter subfactor

We have detected a discrepancy, never noted previously, between the curves corresponding to Eq. (2) and the family of curves on the nomograph (see Fig. 3), both of which represent the relationship between M and K_1 for different values of the OM. Although the difference is plain, it is not easy to determine the source of the error.

start of the corresponding straight lines.

Where the soil structure code *b* was 4, the procedure was modified due to the difficulty of digitising the points in the area. In this case, step (ii) was not followed, and in step (iii) we added the condition that the parabola must be tangential to the straight line at the contact point.

5. Results and discussion

5.1. The first approximation of K

5.1.1. The M parameter

The proposal we present in this paper for calculating the soil particle size parameter *M* is as follows:

$$M = \begin{cases} t' \cdot (t' + d') & \text{for } t' \leq 67\% \\ M_1 & \text{for } t' > 67\% \text{ and } M_1 \leq 8000 \end{cases}, \qquad (18)$$

where M_1 is given by

$$M_1 = 67 \cdot (67 + d') + (t' - 67) \cdot \left(-2.416 \cdot d' - 17.03 \cdot t' + 0.02491 \cdot d'^2 + 0.1103 \cdot t'^2 + 0.03238 \cdot t' \cdot d' + 730.8 \right) \qquad (19)$$

The USLE was conceived of as a tool for field-level conservation planning, and not as a research tool. For this reason it was designed to have a straightforward application, for which all the factors were available in printed tables and charts, and the calculations were done by hand (Renard et al., 2011). Likewise, Wischmeier et al. (1971) initially presented only the *K*-factor nomograph, easier to use than an equation, and manageable for both technical and non-technical users.

Although Wischmeier et al. (1971) did not include any equation in their paper, they did refer to it and stated that the nomograph they presented provided immediate solutions to it. Likewise, both Wischmeier and Meyer (1973) and Wischmeier and Smith (1978), presented their work in the same fashion, unequivocally stating that the nomograph solves the equation developed for estimating the value of the *K*-factor. It should be recalled, too, that Wischmeier and Mannering (1969) had already developed an equation, consisting of 24 terms, for estimating the *K*-factor. It seems clear, then, that the equation consisting of five parameters was already in existence in 1971, and that the graph-based solutions of the nomograph were intended to avoid manual calculation.

If we accept this idea, it follows that Eq. (2) must be accepted as valid, and that we can only assume that an error occurred during its transposition to a nomograph. Inevitably, this also means that all estimates of the *K*-factor based on the nomograph, across the full range of soil textures, have been subject to error.

4.3. The soil structure subfactor

In order to devise a new equation matching the curves that can be seen in this section of the nomograph, corresponding to low values for the first approximation of *K*, we proceeded as follows: (i) a visual estimate of the start of the curves; (ii) digitization of the curves so as to obtain coordinates for their points; (iii) the performance of a least squares regression analysis based on these points, on the assumption that they describe parabolas, and forcing the condition that they must pass through the point of origin and the

The representation of Eq. (18) on the nomograph, for different values of the NVFS fraction, can be seen in Fig. 9. The first segment, coinciding with the original equation by Wischmeier and Meyer (1973), is coloured fuchsia as in previous graphs, while the proposed extension is coloured yellow.

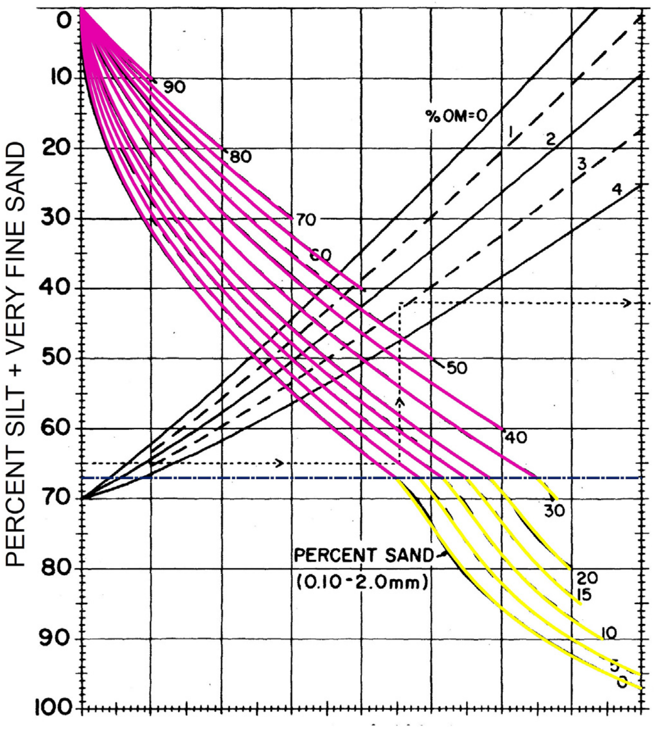

Fig. 9. Superposition on the nomograph by Wischmeier et al. (1971) of the equation calculating the *M* parameter, for different values of the NVFS fraction. Fuchsia denotes the segment corresponding to the equation by Wischmeier and Meyer (1973) and yellow our proposal.

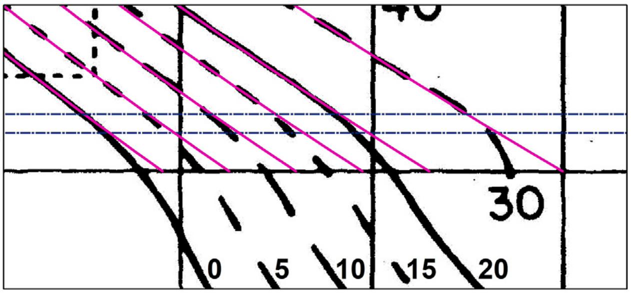

Fig. 10. Detail of the area of the nomograph by Wischmeier et al. (1971) in which the curves used for calculating the *M* parameter undergo a change. Fuchsia denotes the representation of the equation by Wischmeier and Meyer (1973) for calculating the *M* parameter.

The parabolas that represent Eq. (5) coincide almost exactly with the curves of the nomograph, as can be checked in Fig. 2, Fig. 5, Fig. 7, and Fig. 9. Apart from minor inaccuracies in their delineation, the area where the fit is least good is when they approach the limit for applying the equation, that is, for values of the silt plus VFS fraction close to 70% (see detail in Fig. 10). In view of Fig. 10, we decided to reduce the applicability limit of Eq. (5) to 67%. Modifying the limit does not imply any complications to the calculation, nor any conceptual changes, but it does allow us to reproduce the information in the nomograph with a greater degree of accuracy. In the revision which was carried out for RUSLE2, it was decided to lower the limit to 68%, a decision given support by Fig. 10. However, Auerswald et al. (2014), opted to maintain the limit at the original 70%, most likely because their work focused on the equation by Wischmeier and Smith (1978) .

A further consideration is that values of the *M* parameter above 8000 are not represented on the nomograph, which affects soils with a very high percentage of silt plus VFS, varying according to the NVFS content. As a result, we have set an upper limit to the applicability of Eq. (18) such that values of M_1 over 8000 are not valid. The significance of this limit is minimal, especially if we take into account that, according to the National Cooperative Soil Survey (NCSS) Soil Characterization Database (National Cooperative Soil Survey, 2018), of the 313,224 records including information on the VFS fraction, only 0.02% have a M_1 value above 8000.

Both the extension proposed in this paper and that incorporated into the RUSLE2 meet the desirable condition of continuity between the two segments of the equation. The advantage of our work over RUSLE2 is the better fit of the curves on the nomograph, as can be seen when Fig. 9 is compared with Fig. 5. In our proposal, the curves coincide almost exactly with those drawn on the nomograph, while in the case of the RUSLE2 extension, the curves are displaced towards the right. Hence, while our equation provides *K*-factor values identical to those obtained using this part of the nomograph, the RUSLE2 extension overestimates the *K*-factor values.

With regard to the Auerswald et al. (2014) extension, their representation on the nomograph was shown to poorly fit (see Fig. 7), presenting discontinuity with the first segment of the equation, and excessive displacement of the resultant curves towards the right. This accounts for why the *K*-factor values obtained from their extension are always higher than those provided by the nomograph, and can even exceed the established maximum. It also explains the abrupt jump of *K*-factor values when the silt plus VFS fraction exceeds 70%.

The deficiencies of these two extensions can best be illustrated with an example. We will calculate the value of the soil texture subfactor, k_t, which -it should be recalled- is the value taken by K_1 when the OM content is 2%. We will assume a surface soil layer composed of 10% sand, 85% silt, 5% clay, and 5% VFS. Entering these data into the nomograph returns a value for the *M* parameter of 7,000, essentially the same as the value we obtain from our proposed Eq. (18), which yields 7000.7. Inserting these values for *M* into Eq. (3) gives a value for k_t of 0.508 in both cases (equation and nomograph). Eq. (11), the RUSLE2 adaptation, yields a value for k_t of 0.532, while Eq. (15), the Auerswald et al. (2014) extension, gives a value of 0.689. In other words, we would be looking at a relative error of 4.7% in the case of the RUSLE2, and 35.6% in that of Auerswald et al. (2014).

The main limitation of the *K*-factor is that it was obtained from empirical measurements, and as such should not be extrapolated beyond the data used in its creation. With respect to the specific case of soil texture, 81% of the samples that were used to derive the nomograph were medium-textured soils (Renard et al., 1997, Chapter 3), so it follows that it should fit best with soils of this type (Agricultural Research Service, 2013, Chapter 4). Indeed, the *K*-factor values provided by the nomograph are in fact too high when the soils in question are very clayey, and too low when the soils are very silty (Agricultural Research Service, 2008, Chapter 7). It would be useful, then, in order to identify where the nomograph fits best, to specify more exactly what these medium textures consist of.

Wischmeier et al. (1971) state only that they used 55 soil samples to derive the nomograph, the same as used by Wischmeier and Mannering (1969) to develop their equation with 24 terms, albeit with four substitutions, as they rejected four samples with incomplete analyses, and added four samples of sandy soil. The information about the soil texture classes of these 55 samples, along with the range of values for some of their properties (Wischmeier & Mannering, 1969, Table 1) has enabled us to deduce that 53 of them are drawn from the 57 samples used by Mannering (1967). Fig. 11 shows the location of these samples on the textural triangle, along with the soils texture classes used by Wischmeier and Mannering (1969). Fig. 11 also enables us to clearly identify the four samples of sandy soil added by Wischmeier et al. (1971), but does not allow us to identify which of the original samples were rejected.

Using this information, we can identify the texture classes of the soil samples that were used to develop the nomograph, which have been shaded green in Fig. 11. These are the classes in which the fit of the nomograph will be best. It follows that the calculation of the *K*-factor for soils having texture classes different to those — namely clay, sandy clay, sandy clay loam, and silt — is essentially an extrapolation. We could further narrow down this range of textures by plotting the envelope of the points represented on the graph, but the lack of certainty about exactly which of the samples were used by Wischmeier et al. (1971) advises against it.

5.1.2. The organic matter subfactor

To date, the only modification to the k_o subfactor that has been put forward is that of Auerswald et al. (2014), who proposed extending the limit beyond 4% of OM, drawing on the work of Trott and Singer (1983), and on the observation that the soils included by Wischmeier and Mannering (1969) contained up to 5.5% of OM. It should be noted once again here that the nomograph is an empirical measurement and should therefore not be extrapolated beyond the range of values that it shows. Wischmeier et al. (1971) did not determine whether the *K*-factor declined, and if so by how much, when the OM levels exceed 4%, and the RUSLE2 User Guide neither recommends nor permits OM values above 4% (Foster et al., 2003). Furthermore, as noted above in Section 5.1.1, we cannot be certain which 55 samples were used by Wischmeier et al. (1971) to develop the nomograph, as the samples they used did not fully match those used by Wischmeier and Mannering (1969), so the sample with 5.5% OM could have been among the four that were rejected.

Regarding the discrepancy noted between Eq. (2) and the family of curves in the nomograph (Fig. 3), the differences vary according

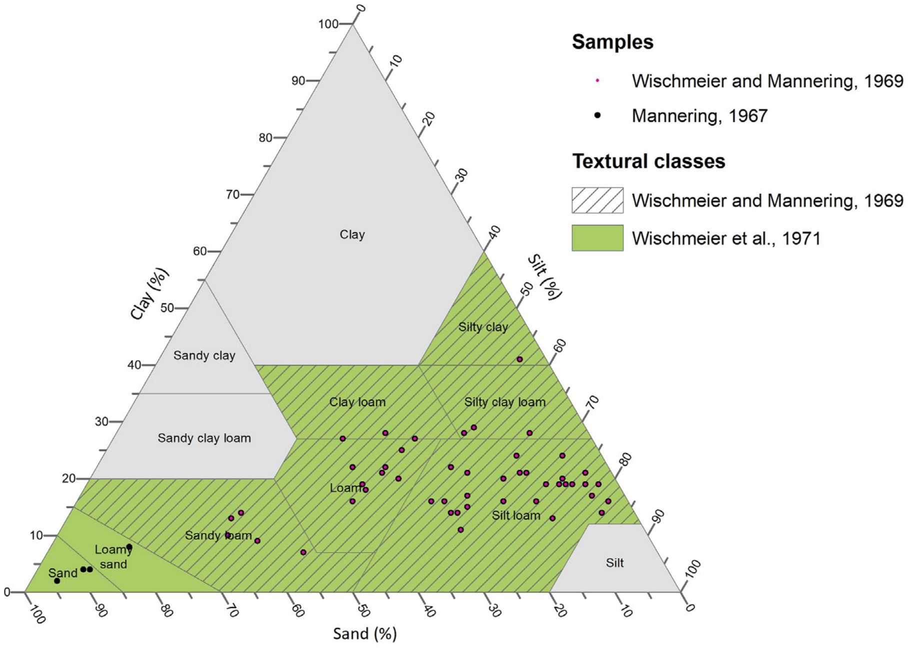

Fig. 11. Location on the textural triangle of the samples used by Mannering (1967) and by Wischmeier and Mannering (1969), along with the identification of the texture classes of the soil samples used to develop the nomograph by Wischmeier et al. (1971).

to OM content. For OM values of 3% and 2% these differences are small, but when the percentage OM decreases or increases, the differences become larger, with the result that the nomograph overestimates or underestimates the *K*-factor, respectively. Hence, for example, when OM is 0% the average absolute error in the estimate for the first approximation of *K* is 0.03, rising to a maximum of 0.054. Conversely, when OM is 4% the average absolute error in the estimate for the first approximation of *K* is −0.018, rising to a maximum of −0.023.

Eq. (2) enables K_1 to be correctly calculated from the *M* parameter and OM irrespective of whether *M* was obtained via Eq. (5) or from the nomograph curves. In fact, it is Eq. (5) that is only valid for soils containing less than 70% silt plus VFS; Eq. (2) has general validity. Conversely, the use of the nomograph for estimating K_1 is always subject to error.

We cannot know for how long and to what extent the nomogram was preferred over the underlying equation. Logically, until the use of computers was sufficiently widespread, it was standard practice to use the nomograph. Thus, in the example which Wischmeier and Meyer (1973, Table 1) give to illustrate the procedure for calculating the *K*-factor, they use the nomograph. Surprisingly, the *K*-factor values in the table, drawn from a reading of the nomograph, are not the same as the values that would be obtained by inserting the same data into the equation. It is worth remembering that it was in this paper that Wischmeier and Meyer (1973) first revealed the equation underlying the nomograph.

On the other hand, for soils with more than 70% silt plus VFS content, the usual practice has been to resort to the nomograph. At the very least, this was necessary in order to obtain the value of the *M* parameter. Given that of the 313,224 records containing information on the VFS fraction in the NCSS Soil Characterization Database (National Cooperative Soil Survey, 2018), 16.75% of them have more than 70% silt plus VFS, we can get some idea of the importance of the resultant errors.

With Eq. (18) as presented in this paper used for calculating the *M* parameter, it is now possible to completely do without the nomograph for calculating K_1, thus definitively eliminating this source of error.

5.2. The soil structure subfactor

The equation below is proposed as a replacement to the family of lines representing the effect of soil structure on the nomograph:

$$K_{1S} = \begin{cases} K_1 + K_S & for K_1 + K_S \geq 0.106 \\ K'_{1S} & for K_1 + K_S < 0.106 \end{cases}, \tag{20}$$

where K'_{1S} is given by:

$$K'_{1S} = \left(0.8726 + 1.3913 \cdot b - 0.3117 \cdot b^2 + 0.0238 \cdot b^3\right) \cdot K_1^2 + \left(-0.0843 + 0.1099 \cdot b - 0.0608 \cdot b^2 + 0.0215 \cdot b^3\right) \cdot K_1 + 0.07 \tag{21}$$

A detail of the superposition of this equation on the nomograph for the four values which the structure code *b* can take is shown in Fig. 12. Fuchsia denotes the first segment, coincident with the original equation by Wischmeier and Meyer (1973), and yellow the second segment.

In the Wischmeier and Meyer (1973) equation, the four straight lines extend beyond the vertical axis represented on the nomograph (see Fig. 4). In consequence of this defect, when the K_1 values are low – in accordance with the soil structure code – the equation yields *K*-factor values below the minimum established by the nomograph for each class of permeability. Indeed, it is even possible to obtain negative values for the *K*-factor.

The way RUSLE2 tackled this problem was to assign a constant value of 0.07 to K_{1S} in cases where the values provided by Eq. (8) were located to the left of the vertical axis of the nomograph. In effect, this is equivalent to assigning a minimum *K*-factor directly to these soils, which would vary with the permeability class. In this way, the *K*-factor values remained within the admissible range, although they would not coincide with the curves on the nomograph.

The Auerswald et al. (2014) adaptation fits the curves better, but has two drawbacks (see Fig. 8). First, it extends the second segment of the equation more than is necessary, as the authors gave a fixed value to the first approximation of *K* as the limit for the transition to the curved area. Second, there is a lack of continuity between the two segments of the equation.

The equation proposed in this paper provides values which are completely coincident with the curves of the nomograph, in addition to maintaining continuity between the two segments (see Fig. 12). These two properties of the equation represent a clear improvement over the modifications of both RUSLE2 and Auerswald et al. (2014). The point at which the curvature starts has a different K_1 value for each of the four straight lines, while the K_{1S} coordinate is the same. A visual estimate assigned a value of 0.106 to this coordinate. The RUSLE2 revision followed a similar procedure, assigning a value of 0.07 to K_{1S}.

5.3. Proposal for calculating the K-factor

We summarise below the set of equations this study proposes for calculating the *K*-factor of erodibility for the USLE:

$$M = \begin{cases} t'\cdot(t'+d') & \text{for } t' \leq 67\% \\ M_1 & \textit{for } t' > 67\% \text{ and } M_1 \leq 8,000 \end{cases}$$

$$k_t = 2.1\cdot 10^{-5}\cdot M^{1.14}$$

$$k_O = (12 - a)\cdot 10^{-1} \; \textit{for } a \leq 4\%$$

$$K_1 = k_t \cdot k_O$$

$$K_S = 3.25\cdot 10^{-2}\cdot(b-2)$$

$$K_{1S} = \begin{cases} K_1 + K_S & \textit{for} \quad K_1 + K_S \geq 0.106 \\ K'_{1S} & \textit{for} \quad K_1 + K_S < 0.106 \end{cases}$$

$$K'_{1S} = \left(0.8726 + 1.3913\cdot b - 0.3117\cdot b^2 + 0.0238\cdot b^3\right)\cdot K_1^2 + \left(-0.0843 + 0.1099\cdot b - 0.0608\cdot b^2 + 0.0215\cdot b^3\right)\cdot K_1 + 0.07$$

$$K_P = 2.5\cdot 10^{-2}\cdot(c-3)$$

$$K = K_{1S} + K_P \tag{22}$$

where: *M* is the particle size parameter.

t' is the silt plus VFS fraction as a percentage

d' is the NVFS fraction as a percentage

k_t is the soil texture subfactor

k_o is the organic matter subfactor

a is the OM content as a percentage.

K_1 is the first approximation of *K*.

K_S is the soil structure subfactor

b is the soil structure code.

$$M_1 = 67\cdot(67+d') + (t'-67)\cdot\left(-2.416\cdot d' - 17.03\cdot t' + 0.02491\cdot d'^2 + 0.1103\cdot t'^2 + 0.03238\cdot t'\cdot d' + 730.8\right)$$

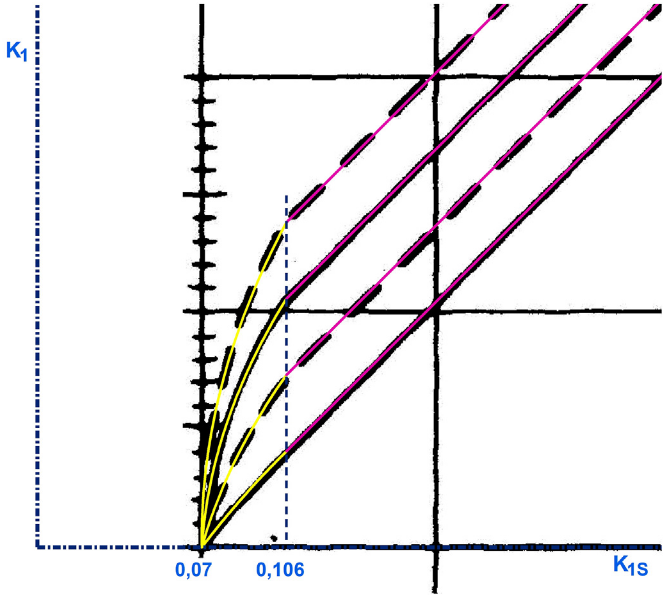

Fig. 12. Detail of the superposition on the nomograph by Wischmeier et al. (1971) of the equation incorporating the effect of soil structure on erodibility. Fuchsia denotes the segment corresponding to the equation by Wischmeier and Meyer (1973) and yellow the improvement proposed in this paper.

K_{1S} is the value obtained by applying the soil structure information to the first approximation of *K*.

K_P is the soil profile permeability subfactor

c is the soil profile permeability class.

Values of the *M* parameter above 8000 and OM values over 4% are not considered by the nomograph, and hence the equation is not applicable to these cases.

It should be noted that the values of the *K*-factor which this equation yields are expressed as (0.01 · ton · acre · h)/(acre · ft-tonf · in). In order to convert these to SI units, such as (t · ha · h)/(MJ · ha · mm), the *K*-factor should be multiplied by 0.1317.

So as to facilitate the use of these equations, we have created a programme in R language which calculates the value of the *K*-factor in two different contexts: on the one hand, when all the required input variables are known, and on the other when all variables are known except the VFS fraction. In this instance, we resort to Corral-Pazos-de-Provens et al. (2018), which enables the VFS fraction to be estimated, with a prediction interval of 50%, based on the basic texture fractions. Hence, taking advantage of the fact that the *K*-factor is a monotonic function of the VFS fraction, the programme provides an estimate of the *K*-factor with a prediction interval of 50%; it is available at the following link https://github.com/evacorral/Computing-factor-K-from-basic-texture-fractions.

6. Conclusions

This study identifies certain deficiencies in the representation of the nomograph by Wischmeier et al. (1971). Specifically, the family of curves for the various values of OM is not coincident with the mathematical function from which it is supposedly derived, in particular with respect to the curves for 0%, 1%, and 4% OM. As a result, all estimates for the *K*-factor that are made using the nomograph are subject to error.

We have specified the texture classes of the soil samples used in developing the nomograph, and have concluded that the areas of the textural triangle corresponding to clay, sandy clay, sandy clay loam, and silt all lie outside the field of definition for the *K*-factor. Hence, when calculating the *K*-factor for soils with these textures, users should bear in mind that the result is an extrapolation.

Regarding the two adaptations of the Wischmeier and Meyer (1973) equation that have been analysed, RUSLE2 was found to produce acceptable values, if not fully accurate, while the Auerswald et al. (2014) proposal was found to produce unacceptable results.

The set of equations proposed in this paper accurately reproduces the nomograph in those areas where the Wischmeier and Meyer (1973) equation cannot be applied. These areas are, on the one hand, the section of the family of curves which enable the *M* parameter to be calculated when the value of the silt plus VFS fraction exceeds 67%, and on the other hand, the curved segments of the family of lines representing the different soil structures. These new equations allow us to totally do without the nomograph for calculating the *K*-factor, and make it possible to take full advantage of computing capacity, as well as to avoid the errors identified in the representation of the OM curves. A routine programmed in R that executes the equations is available at the following link https://github.com/evacorral/Computing-factor-K-from-basic-texture-fractions.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

APPENDIX

Deduction of the expression of the M parameter in the extensions in RUSLE2 and by Auerswald

The procedure followed for deducing the expression of the *M* parameter complementing the equation in Wischmeier and Meyer (1973) was the same for both the extension presented in RUSLE2 and the proposal in Auerswald et al. (2014).

The equation developed by Wischmeier and Meyer (1973) for calculating he first approximation of *K*, Eq. (A.1), is a function of OM and the *M* parameter, for all values of *M*, irrespective of how these were obtained, whether through the application of Eq. (5), through direct reading of the nomograph, or through a new equation fitting the family of curves on the nomograph.

$$K_1 = k_t \cdot k_O \tag{A.1}$$

The OM subfactor, k_O, was not subject to any kind of modification in either of the two proposals, so we considered solely the soil structure subfactor:

$$k_t = 2.1 \cdot 10^{-5} \cdot M^{1.14} \tag{A.2}$$

Let M_A be any value of the *M* parameter when the value of the silt plus VFS fraction exceeds the limit for applying Eq. (5), namely 68% in the case of the RUSLE2, and 70% in the case of Auerswald et al. (2014). We can then express equation (A.2), for the extension, as a function of the new value M_A:

$$k_t = 2.1 \cdot 10^{-5} \cdot {M_A}^{1.14} \tag{A.3}$$

Applying logarithms to both sides of the equation, the following expression is deduced:

$$logM_A = \frac{\log k_t - \log\left(2.1 \cdot 10^{-5}\right)}{1.14} \tag{A.4}$$

The equation for calculating the values of M_A, for the section of the nomograph with values of the silt plus VFS fraction in excess of 68% and 70%, depending on the case, would take the following form:

$$M_A = 10^{\frac{\log k_t - \log\left(2.1 \cdot 10^{-5}\right)}{1.14}}, \tag{A.5}$$

where k_t is the soil texture subfactor proposed in each of the two extensions.

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