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Review papers

The unit plot of the Universal soil loss equation (USLE): Myth or reality?

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ABSTRACT

Soil erosion by water is a natural phenomenon involving landscape changes that can be accelerated by anthropogenic actions. Notwithstanding many mathematical models have been developed to estimate soil loss at different spatial and temporal scales, the Universal Soil Loss Equation (USLE) and its revisions remains the most applied one. The mathematical structure of the USLE was deduced using a reference condition, named *unit plot*, that was defined as a 22.1 m long plot, with a 9% slope, maintained in a continuous, regularly tilled, fallow condition with up and down hill tillage. The unit plot concept was used to compare soil loss data collected on plots having different slopes, lengths, cropping and management and conservation practices. The importance of the unit plot concept and its centrality in the field measurement of the dimensionless factors of the USLE has received little attention. In particular, the availability of soil loss measurements on unit plots is somewhat uncertain. This paper gives an overview on the unit plot concept, its origin, the availability of soil loss measurements in the unit plot conditions and its use for the determination of the USLE factors.

1. Introduction

According to the European Commission's thematic strategy on soil (European Commission, 2006), soil is a finite resource. Few centimeters of topsoil can be formed over hundreds to thousands of years under regular agricultural land use (Bazzoffi, 2009). Conversely, the rate of soil loss due to water soil erosion processes is high and can be accelerated by human activity (Raclot et al., 2018) as a result of improper farming practices and overgrazing (Dengiz et al., 2015; Carollo et al., 2018; Serio et al., 2019; Hagras, 2023; Carollo et al., 2023b). In many regions of the European Union, the rate of soil erosion exceeds that of soil formation, and the annual cost of repairing damages caused by water erosion phenomena is approximately $20 billion (Panagos et al., 2015; Carollo et al., 2023a).

In the early 1900 s, studies on soil erosion started with the activity of Ewald Wollny, that was a pioneer in soil and water conservation studies even if his research was seriously considered after the mid-1930 s (Meyer, 1984). Since then, establishing equations and soil erosion prediction models (empirical, conceptual, and physically based or process oriented) has become a research need (Bagarello et al., 2018).

In 1954 Wischmeier and Uhland, under the supervision of Smith, put together more than 7000 plot-years and 500 watershed-years of precipitation, soil loss, and related data, collected in different research locations throughout the United States (Wischmeier et al., 1958; Meyer, 1984). Meyer (1984) documented that, from 1956 to 1970, several thousands of plot-years and watershed-years data were added to this dataset. These data resulted from both natural rainfall studies and erosion-plot research using simulated rainfall. The Universal Soil Loss Equation (USLE), in its final form, was the result of the statistical analysis of more than 10.000 plot-years of data from about 50 locations in 24 USA states and was presented in the Agricultural Handbook of the USDA in 1978 by Wischmeier and Smith.

The USLE is an empirical model that currently represents the most applied model for predicting average annual soil loss per unit area (Panagos et al., 2012). As it is known, the simple mathematical structure is given by the product of five driving factors resulting in the following expression:

$$A = RKLSCP \tag{1}$$

in which A (t ha^{-1} y^{-1}) is the average annual soil loss per unit area due to rill and interrill erosion, R (MJ mm h^{-1} ha^{-1} y^{-1}) is the rainfall erosivity factor or rainfall aggressiveness index, K (t ha h ha^{-1} MJ^{-1} mm^{-1}) is the soil erodibility factor, L is the slope-length factor, S is the slope-steepness factor, C is the cover and management factor and P is the support practice factor. The mathematical structure of the USLE was defined using a reference condition, named *unit plot*, that is a 22.1 m

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long plot, with a 9% slope, maintained in a continuous, regularly tilled, fallow condition with up and down hill tillage. The unit plot was used to compare soil loss data collected from plots with different slopes, lengths, cropping and management and conservation practices.

The soil erodibility factor K is defined as the soil loss measured on a unit plot per unit of rainfall erosivity factor. According to Wischmeier and Meyer (1973), the soil erodibility synthesized effects of the soil to store water and its susceptibility to detachment and transport by rainfall and runoff.

The dimensionless factors (L, S, C and P) of Eq. (1) allow operating the passage from the reference condition, for which they are equal to 1, to that of any plot characterized by different topographic conditions, cover and management and support practices. Each dimensionless factor is defined as the ratio of soil loss values. Specifically, the slope-length factor L indicates the ratio of soil loss from the field slope length λ (m) to that from a 22.13 m length under identical conditions, and S is the ratio of soil loss from the field slope gradient s (%) to that from a 9% slope under identical conditions. The cover and management factor C is determined as the ratio between soil loss from an area with specific cover and management and that obtained from an identical area in tilled continuous fallow and P is the ratio of soil loss under a support practice to that with up and down hill tillage. Therefore, the unit plot conditions are relevant for the definition of the USLE dimensionless factors and their field measurement.

The geographical position of the investigated plots, limited to US locations, raised criticism about the term "universal" in the USLE acronym. In 1972 Wischmeier stated that this term was proposed to distinguish "*this prediction model from the highly regionalized models that preceded it*". In fact, Eq. (1) is able to predict soil loss, being each factor free from any geographically oriented base (Meyer, 1984). Moreover, the empirical nature of the USLE and the accuracy of field measurements used to develop the model have often drawn criticism (Alewell et al., 2019; Ciesiolka et al., 2004, 2006).

With respect to the first aspect, however, Ferro (2010) pointed out that the multiplicative form of the USLE can be theoretically deduced by using the representative variables of the soil erosion process, the concept of unit plot and the dimensional analysis and self-similarity theory (Barenblatt, 1979, 1987).

With respect to the accuracy of field measurements, Ciesiolka et al. (2004, 2006) stated that the experimental data collected in the United States (Wischmeier and Smith, 1965, 1978) were obtained considering the suspended sediment concentration in the measurement tanks as coincident with that of a single sample extracted from a single sampling point. Accordingly, the sediment amount was calculated by multiplying the sample concentration by total runoff volume. Different researchers (Wischmeier and Smith, 1965, 1978; Edwards, 1987; Hudson, 1971; Rosewell, 1993) considered this procedure reliable as, if the water–sediment mixture was well mixed (complete mixing condition), the measured concentration was independent of the sampling point and equal to the actual one of the entire suspension. However, Bagarello and Ferro (2016) and Ciesiolka et al. (2004, 2006) suggested that this procedure gave inaccurate soil loss measurements. Therefore, the sampling procedure could have affected noticeably the calibration of the empirical model (Bagarello and Ferro, 2016).

The importance of the unit plot concept in the USLE approach is well known, but its actual role in the field determination of the USLE dimensionless factors has been little investigated and the existence of soil loss measurements from unit plots has even been questioned.

This paper aims to give an overview on the origin of the unit plot concept and the availability of soil loss measurements in the unit plot condition to determine the USLE factors, starting from the early studies, that led to the model development, to the most recent ones.

2. An historical perspective of the unit plot concept

2.1. The definition of unit plot and the availability of soil loss measurements in the reference condition

Different authors (Olson and Wischmeier, 1963; Meyer, 1984; Wischmeier, 1984) involved with the USLE development and its revision (Renard et al., 1997) pointed out that the selected geometric characteristics of the unit plot ($\lambda = 22.13$ m, $s = 9\%$) have no theoretical basis but the only merit of being the most applied slope length and the average gradient of the erosion plots supporting the USLE development. The 22.13 m plot length resulted from the selection of 1/100 acre (≈1/250 ha) plot area. Indeed, most of the early plots had a width of 1.83 m (6 feet), therefore the ratio λ of plot area to plot width resulted in 22.13 m (Renard et al., 1997; Nearing, 2013).

According to Meyer (1984) and Wischmeier (1984), continuous fallow was selected as a base because no particular crop system would have been adaptable to all regions. The choice of continuous fallow was also needed to eliminate effects of land use residual, crop management and vegetal cover on the soil erodibility determination. Since all existing plot data had been obtained considering rows and tillage parallel to the land slope, the latter was considered for the unit plot.

Doubts on the existence of unit plots were raised by Laflen and Moldenhauer (2003) and Laflen and Flanagan (2013). For Laflen and Moldenhauer (2003) "*The unit plot concept, while very useful, was apparently a myth as far as soil erosion measurements were concerned. A unit plot never existed! Or if it did, data from it was never reported.*" Laflen and Flanagan (2013) confirmed that, while the unit plot concept was widely used in establishing the USLE factors, "*there is little evidence that there ever existed an actual "Unit Plot", or if one ever existed, data from it has not been found*". Accordingly, another question is whether Wischmeier and Smith (1978) have really used data from unit plots or regressed values from calibrated relationships to deduce the USLE factors. For example, the soil loss in the reference condition may have been calculated by applying, for $s = 9\%$, a relationship calibrated by soil loss values measured in plots with different steepness.

Currently, the unit plot is not widespread in the field studies on soil erosion. To the best of our knowledge, unit plots have been recently equipped only in Iran (Vaezi et al., 2008; Ostovari et al., 2016) and Sparacia experimental area, South Italy (Bagarello et al., 2022).

2.2. Unit plot and deduction of the USLE factors

According to Wischmeier and Smith (1978), the most accurate measurement of K is obtained in the plot unit condition, by the following equation, deriving from Eq.(1) with $L = S = C = P = 1$

$$K = \frac{A}{R} \quad (2)$$

in which A results from soil losses measured in the unit plot under natural rainfall for at least five years, beginning two years after the clean-fallow condition was established. This recommendation permits averaging the interactions of soil erodibility with antecedent soil moisture, storm size, and other variables.

Using plot measurements to apply Eq. (2) was also advised by other authors (Renard et al., 1997; Shabani et al., 2014; Ostovari et al., 2016). However, the installation of runoff collecting systems and the measurement of sediment stored in the system is cumbersome and expensive (Renard et al., 1997). Therefore, other estimate methods such as the soil erodibility nomograph (Wischmeier and Mannering, 1968; Wischmeier et al., 1971; Wang et al.,2013; Wang et al., 2016) and pedotransfer functions (Römkens et al., 1997; Vaezi et al., 2008; Shabani et al., 2014) were developed using readily available soil properties.

Olson and Wischmeier (1963) first used plot soil loss measurements carried out in experimental stations of the U.S. Department of

Agriculture to perform 28 K measurements for 20 soil types from different US locations. The plots were maintained in fallow condition or cropped. The former had the same length (22.13 m) and varied in slope from 5 to 19%, but only in a few cases s was close to the reference value of 9%. The cropped plots differed both in slope and length and, only for two locations, had the unit plot steepness and length. To adjust plot data from actual to unit plot conditions, Olson and Wischmeier (1963) applied the relationships provided by Smith and Wischmeier (1957) for P, Wischmeier et al. (1958) for LS, and Wischmeier (1960) for C.

Renard et al. (1997) listed the American soil types for which the soil erodibility factor was experimentally determined in fallow runoff plots. Table 3-1 of that paper shows the K factor and the related slope and length of the erosion plots used by Olson and Wischmeier (1963), McGregor et al. (1969), Lombardi (1979) and Mutchler et al. (1976). Although 22.13 m was the prevailing plot length, the slope ranged from 4.5 to 19%. For a single soil type out of 16, the erosion plot was coincident with the unit plot. Therefore, the determination of K values nearly always required standardization processes and empirical relationships (Smith and Wischmeier, 1957; Fig. 1 from Wischmeier et al., 1958; Wischmeier, 1960) that allowed passing from a generic plot condition to unit plot one.

The suggested observation period for K determination is 20–22 years, but it has been rarely satisfied on fallow plots both in early and recent studies. On the other hand, Wischmeier and Smith (1978) have previously indicated a monitoring period of at least five years. For example, the K values reported by Olson and Wischmeier (1963) and Renard et al. (1997) are based on an observation period of 3 to11 years depending on the site, while those related to the investigation by Vaezi et al. (2008) are based on measurements performed in a single year. Conversely, many other K values were obtained from long-term measurements on cropped plots, after adjustment for the C factor (Renard et al., 1997).

Zingg (1940) first studied the effect of slope steepness s and horizontal slope length λ on soil erosion considering field data obtained under natural rainfall (Duley and Hays, 1932; Diseker and Yoder, 1936; Hays and Palmer, 1937; Hill et al., 1937; Musgrave and Norton, 1937; Woodruff et al., 1937) and data from a rainfall simulation experiment collected on 4 to 12% sloping plots with length of 2.44 and 4.88 m. Assuming a power relation between soil loss, steepness and length, the author proposed the following empirical equation

$$A = \alpha s^{1.4} \lambda^{0.6} \tag{3}$$

where α is a constant and the values of the exponent were determined by rainfall simulation data. Wischmeier and Meyer (1973) reported that, on slopes less than 20% and with moderate length, the soil loss per unit plot area is expressed as

$$A = \alpha_1 \lambda^m \tag{4}$$

where α_1 is a constant, $m = 0.5$, and λ is the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough for deposition to start, or runoff reaches a channel (Smith and Wischmeier, 1957). Eq. (4) is very similar to Eq. (3) applied for a given steepness value. The exponent 0.5 resulted from 532 plot years of data collected on 15 studies in 9 USA states.

Table 1
Coefficients of Eq. (9) for each erosion event.

Number of event	a	n
1	0.07	1.05
2	10529.0	5.69
3	248.28	3.14
4	255.74	2.21
5	4956.0	4.54
6	729.58	1.54
7	6804.3	4.63
8	58684.0	4.78

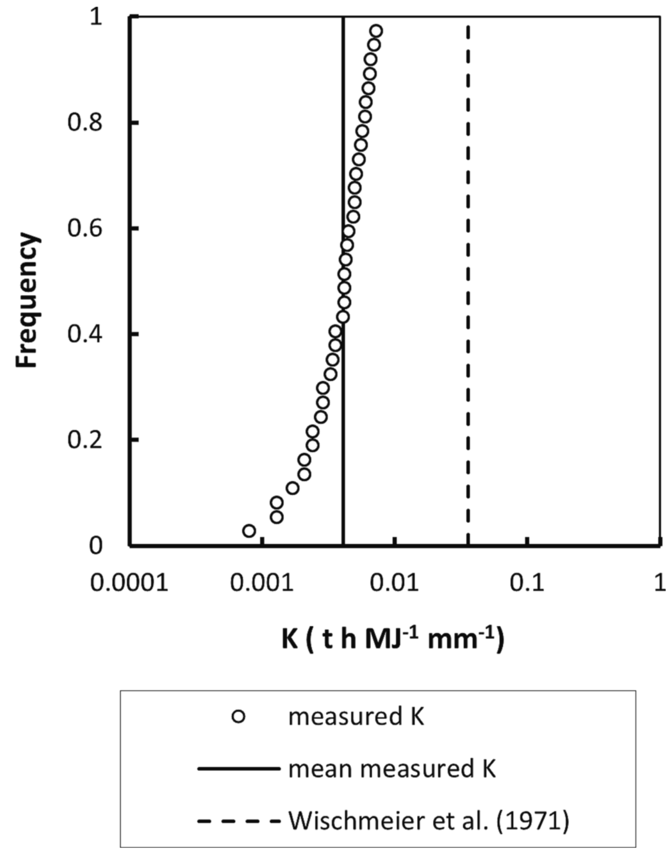

Fig. 1. Comparison between frequency distribution of the K values measured by Vaezi et al. (2008) and those estimated by the nomograph of Wischmeier et al. (1971).

Considering the definition of the L factor and applying Eq. (4) for $\lambda = 22.13$ m, one obtains

$$L = \frac{\alpha_1 \lambda^m}{\alpha_1 22.13^m} = \left(\frac{\lambda}{22.13}\right)^m \tag{5}$$

where the exponent m is equal to 0.5 for $s \geq 5\%$, 0.4 for $s = 4\%$, 0.3 for s of 1% – 3% and 0.2 for $s < 1\%$ (Wischmeier and Smith, 1978; Mitchell and Bubenzer, 1980).

Smith and Wischmeier (1957), using the data assembled at the National Runoff and Soil Loss Data Center of USDA-ARS, proposed the following equation

$$A = 0.043s^2 + 0.30s + 0.43 \tag{6}$$

in which s is expressed in percent and A in t acre^{-1}. Eq. (6) resulted from fitting a parabolic equation to data collected by Hays on cropped plots (continuous barley for the first five years and corn-oats-meadow rotation for the succeeding 12 years), data by Zingg (1940) and from other two locations adjusted for similar cropping conditions. Moreover, these data were obtained for slope steepness ranging from 3 to 18%. The dimensionless factor S of the USLE was derived dividing Eq. (6) by the soil loss value (6.613) calculated with Eq. (6) for $s = 9\%$ (Wischmeier and Smith, 1965)

$$S = \frac{0.043s^2 + 0.30s + 0.43}{6.613} \tag{7}$$

that, for s varying from 3 to 40%, is practically coincident with the following power equation (Ferro, 2010):

$$S = \left(\frac{s}{9}\right)^{1.6} \quad (8)$$

The *C* factor expresses the anti-erosive effect of the vegetation cover that varies with the crop rotation, agronomic practices, level of soil productivity, the duration of the different vegetative phases and the temporal distribution of rainfall. Wischmeier (1960) suggested the procedure to evaluate the *C* factor. More than 8.000 plot years data of runoff, soil loss and corresponding precipitation and management, detected at 37 locations in 21 states over 30 years of observation, were assembled at Purdue University by the Soil and Water Conservation Research Division of the Agricultural Research Service. To consider the interrelated effect of rainfall and the stage of vegetation growth, five crop stage periods (rough fallow, seedbed, establishment, growing crop, and residue or stubble) were established to be used along with the rainfall erosivity distribution through the year. For each stage period, ratios of soil loss from specified cropping and management systems to corresponding losses from basic long-term fallow were determined from analysis of about a quarter million observations (Wischmeier and Smith, 1978).

In this analysis, the soil erosion from clean-tilled continuous fallow plot, in which no prior crop residues or organic matter application for at least three consecutive years occurred, was selected as benchmark (Wischmeier, 1960). This choice was derived from the circumstance that most of the early research measured soil and water losses from continuous-fallow plots. The procedure to evaluate the *C* factor consisted of making direct comparisons between plots cropped and in fallow condition, characterized by identical soil type and slope, or indirect comparisons between cropped plots and plots in continuous fallow at other locations. In some cases, measured soil losses from cropped plots were compared with those of *hypothetical* continuous-fallow plots, where soil loss was estimated for the same soil type, slope, and rainfall. Therefore, for the evaluation of the *C* factor, measurements of soil loss from continuous-fallow plots were used by Wischmeier (1960), but no information is available regarding measurements from unit plots.

The *P* factor expresses the influence of anti-erosion practices on soil loss which can be performed through specific crop arrangements and crop rotations, retention of residues, fertilization treatments or contour ditches. The practice giving the greatest soil loss is that in which the soil is plowed along the lines of maximum slope which was selected as the reference condition.

The pioneering study by Smith (1941) evaluated the effect of contouring from two 82.3 m plots of rotation strip cropping from six 82.3 m plots, and terracing using an original slope length of 213.36 m. In all cases, the investigated lengths were far from that of the unit plot (22.13 m).

According to Wischmeier and Smith (1978), the *P* factor for contouring varies from 0.5 to 0.9, depends on slope steepness and is associated with a maximum slope length. The *P* factor for strip cropping varies from 0.25 to 0.9 and depends on slope steepness. In both cases, it is apparent an interdependence between the support practice and slope steepness factors.

3. Recent research on unit plots

3.1. Unit plots on Iranian erosion investigations

Vaezi et al. (2008) measured soil loss from unit plots (22.1 m x 1.83 m) and the rainfall erosivity index for 23 natural rainfall events in northwestern Iran to evaluate the soil erodibility factor and identify elements affecting *K* for the investigated calcareous and clayey soils. The study area was divided into 36 grids of 5 x 5 km^2 and three replicates of a unit plot were installed in each grid. Fig. 1 shows that the *K* values measured, i.e. determined by Eq. (2), by Vaezi et al. (2008) were significantly lower than the mean value (0.0359 t h MJ^{-1} mm^{-1}) estimated by the nomograph of Wischmeier et al. (1971).

Ostovari et al. (2016) measured individual storm and annual soil losses from 40 unit plots (22.1 m x 1.83 m) to measure *K* and develop related pedotransfer functions for calcareous soils of the Simakan watershed, southern Iran. The soils were classified as loams, clay loams, and sandy clay loams. The measured values of the soil erodibility factor were obtained by Eq. (2) in which *R* was estimated using the Modified Fournier Index and Arnoldus's (1977) equation. The measured *K* varied from 0.005 to 0.023 t h MJ^{-1} mm^{-1} with a mean of 0.014 t h MJ^{-1} mm^{-1}, while the *K* estimated by the nomograph of Wischmeier et al. (1971) varied from 0.015 to 0.045 t h MJ^{-1} mm^{-1} with a mean of 0.030 t h MJ^{-1} mm^{-1}. As shown in Fig. 2, the *K* measurements were greater than those measured by Vaezi et al. (2008).

In both experimental investigations, the use of the unit plot measurements was limited to determine the soil erodibility factor by Eq. (2), and the nomograph was inadequate to estimate *K*.

3.2. Unit plots at Sparacia experimental area

The Sparacia experimental area is situated in western Sicily (in the Sicilian hinter-land, away from the coast), southern Italy, approximately 100 km south of Palermo at 415 m a.s.l.. The climate is of Mediterranean semiarid type and is characterized by a mean annual rainfall of 700 mm. At the end of the nineties, four plots of 22x8 m^2 were realized on a hillslope having a slope steepness of 14.9%. The number and types of erosion plots increased over time and two unit plots (Fig. 3) were finally established in 2014. Currently, two plots of 44x8 m^2, two plots of 33x8 m^2, six plots of 22x8 m^2, two plots of 22x2 m^2, two plots of 11x4 m^2, two plots of 11x2 m^2 are operating on the 14.9% hillslope, and two couple of 22x6 m^2 plots are operating on a 22% and 26% hillslope, respectively (Bagarello et al., 2016).

All experimental plots are kept in continuous fallow using a powered cultivator. During each erosive event, runoff is intercepted by a gutter placed at the lower end of the plot and collected into a storage system

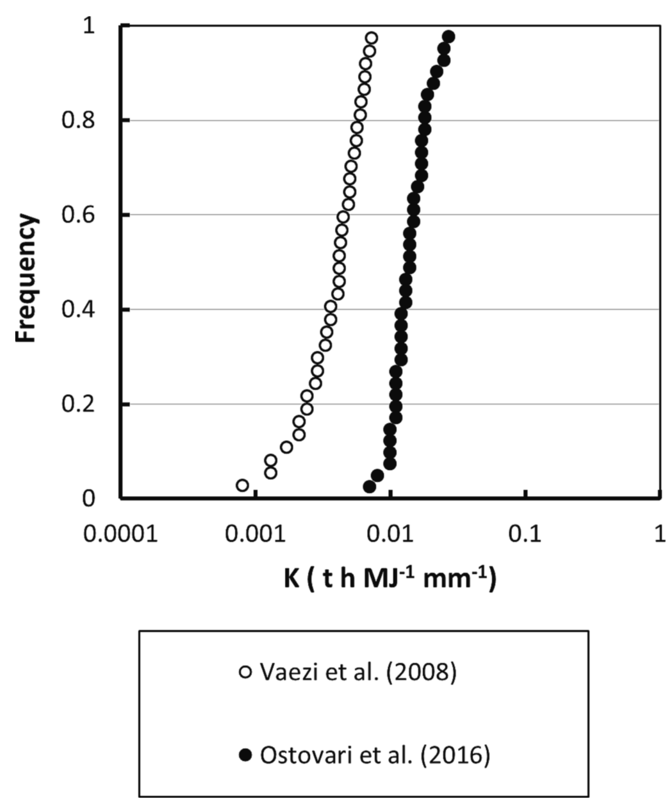

Fig. 2. Comparison between frequency distribution of K values measured by Vaezi et al. (2008) and those measured by Ostovari et al. (2016).

Fig. 3. View of the two unit plots established at the Sparacia experimental station.

consisting of tanks of known geometric characteristics (capacity of 1 m^3), that are arranged in series at the base of each plot. After an erosive event, five suspension samples are extracted from each tank using a sampler and oven-dried to determine the mean concentration, and the water level is read to calculate the total weight of the solid particles as mean concentration by volume (Carollo et al., 2016).

To date, 18 measurements of soil loss and runoff have been performed in the two-unit plots, related to 9 erosive events occurred from February 2014 to November 2018.

These soil loss measurements and the corresponding values of the rainfall erosivity index allowed indirectly measuring (Eq. (2)) the K factor for the Sparacia clay soil (Bagarello et al., 2022). The K value was much lower (0.0038 t ha h ha^{-1} MJ^{-1} mm^{-1}) than that determined by the USLE nomograph (K = 0.021 t ha h ha^{-1} MJ^{-1} mm^{-1}) (Bagarello et al., 2012), which suggests the unsuitability of the nomograph to determine the soil erodibility of clay soils, such as that of the Sparacia area. Unit plot data also allowed parameterizing the model by determining, for the different plot types, the values of the slope steepness factor, S, and the plot length factor L. Both the topographic factors did not agree with those estimated by literature relationships usually applied with USLE and Revised Universal Soil Loss Equation (RUSLE) models.

An analysis is developed here to test the hypothesis that a unit plot soil loss can be mathematically derived by extrapolating to s = 9% the relationship of slope steepness against event soil loss determined for $s >$ 9%. In other words, this analysis could allow testing if a reference event soil loss can be estimated when the unit plot measurement is not available. For this purpose, the measurements from 14.9%, 22% and 26% sloping plots, all having a length of 22 m, which were simultaneously collected with those from the unit plots, are used. In the eight selected erosive events in the monitoring period February 2014 - November 2018, only interrill erosion occurred, except for a single event, for which all the plots were incised by rills. For each event and plot steepness, the average soil loss measured in the replicated plots, A_e, was regressed against s and the following power relationship was determined:

$$A_e = as^n \tag{9}$$

in which a and n are two event-dependent coefficients listed in Table 1. In all cases but the single one occurred in 2014, an increasing trend of A_e with slope steepness was detected. The single event with an opposite trend was not considered in the following analysis. Fig. 4 shows, as an example for two events, the pairs (s, A_e) and the curves of Eq. (9). For each event, reference event soil loss, A_{e9c}, was calculated by Eq. (9) with

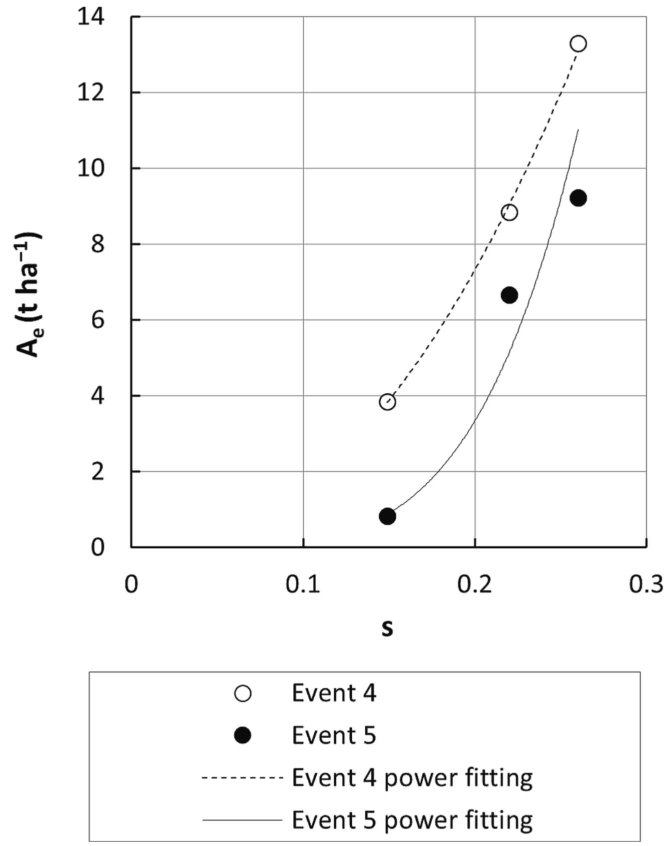

Fig. 4. Relationship, as an example for two erosion events occurred at Sparacia, between the average event soil loss, A_e, and slope steepness, s.

s = 9% and compared with the unit plot measurement A_{e9m}. Fig. 5 clearly shows that A_{e9c} is tendentially greater than the corresponding soil loss measured in the unit plot with an average ratio A_{e9c}/A_{e9m} of 2.66.

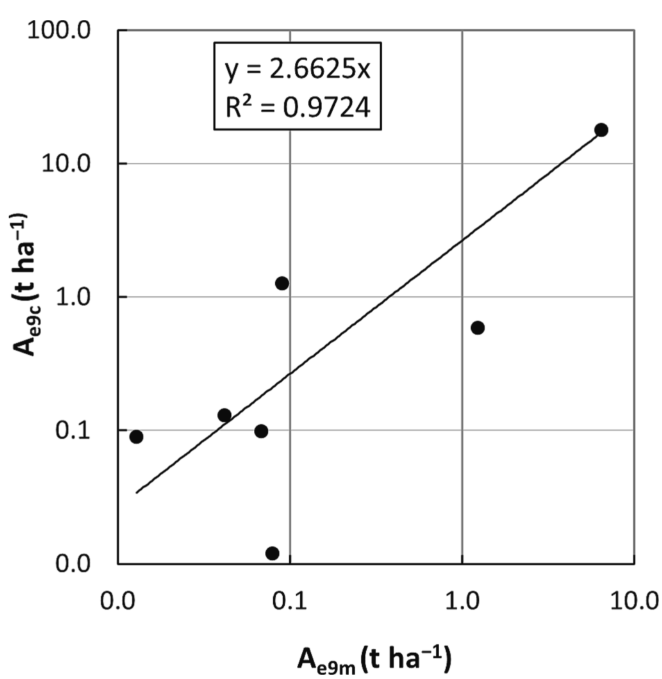

Fig. 5. Comparison between the calculated, A_{e9c}, and measured, A_{e9m}, event soil loss values in the unit plots of Sparacia.

For the years 2015, 2017 and 2018 the analysis was also developed at annual scale, using the sum of the average event soil losses occurring in a given year as annual value A_y (t ha^{-1}) (Bagarello et al., 2010; 2011). The analysis demonstrated that the following equation can be applied (Fig. 6), with specific values of n_y and a_y for each year:

$$A_y = a_y s^{n_y} \tag{10}$$

For given slope steepness, only three points are available, thus Eq. (10) does not allow for calculating the average long-term soil loss. The annual soil loss value A_{y9c} for $s = 9\%$ was calculated by Eq.(10) and compared with that, A_{y9m}, measured in the unit plot. Fig. 7 shows that A_{y9c} is greater than A_{y9m} for two out of three years and, on average, A_{y9c}/A_{y9m} is equal to 2.66. In other words, the ratio between the calculated soil loss value for $s = 9\%$ and the corresponding measured value in the unit plot can be considered independent of the temporal scale (event, year) and equal to 2.66. Therefore, the reciprocal of the latter (0.376) represents the scale factor for the estimated soil loss by Eqs. (9) and (10), extrapolated beyond the range of the experimental data, to the unit plot steepness of 9%. As the scale factor differs greatly from the unit, the soil loss for the reference condition also varies significantly between the measured and calculated value, which suggests the importance of establishing unit plots in soil erosion experimental stations for determining site-specific model factors. This result is affected by the single considered station and the limited available dataset consisting of three-year observation period. However, the extent of this monitoring period is comparable with that of the preceding investigations, reported above, aimed to determine the soil erodibility factor using fallow-plot data.

4. Conclusive remarks and research needs

The field evaluation of the soil erodibility factor was often performed using plots in which one or more of the unit plot characteristics were not met. In these cases, K estimates were affected by the accuracy of the

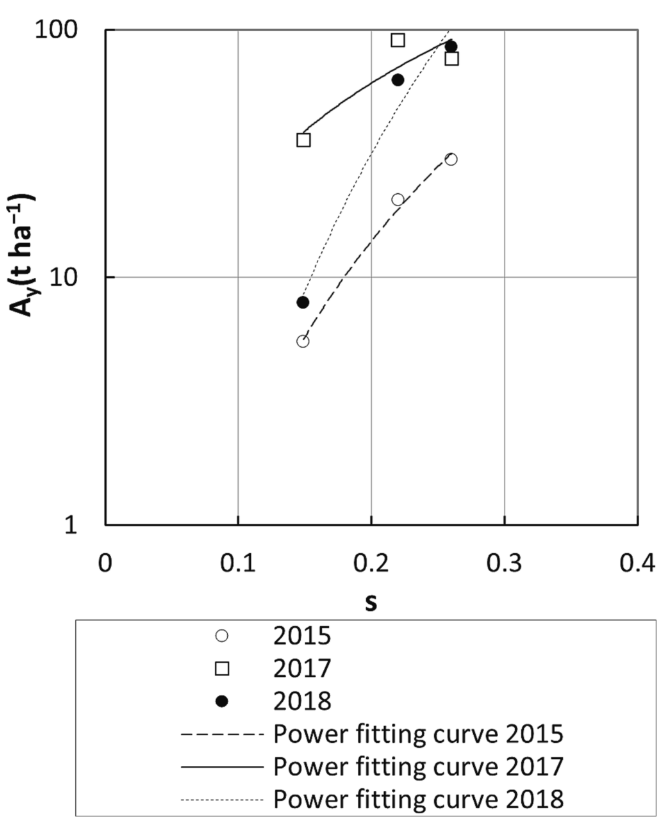

Fig. 6. Relationship between the annual soil loss, A_y, and slope steepness, s, for the Sparacia experimental area.

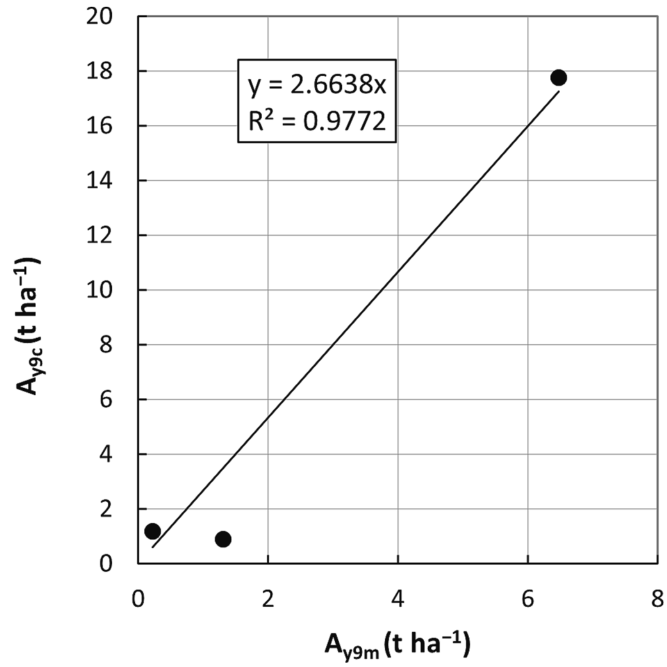

Fig. 7. Comparison between the calculated, A_{y9c}, and measured, A_{y9m}, annual soil loss values in the unit plots of Sparacia.

USLE factor relationships for L, S, C, and P, describing the effect of the variable which was not consistent with the K definition. These relationships are indicative of the average plot soil loss due to variations on the considered variable. The term average stands for both the fact that they (e.g., Eqs. (5), (7)) were derived from many plot-years of measurement and at different locations, which implies at least differences in soils and rainfalls. Therefore, the use of the factor relationships to adjust plot data to the unit plot conditions can deviate the measured erodibility factor from the value that would be measured in the unit plot according to K definition. Considering that the nomograph K values were partially obtained with plot data adjustment, the above differences between the soil erodibility values measured in unit plots in recent investigations and the corresponding ones estimated by the nomograph may be explained. Another cause of mismatching can refer to the unsuitability of the nomograph to determine soil erodibility of clay soils investigated by Bagarello et al. (2022) and Vaezi et al. (2008) as the nomograph derives from measurements collected on soils with a different texture from the clayey one.

While the representativeness of Eqs. (4) and (6) regarding the effects of plot length and steepness on soil loss is corroborated by different data sources from US locations, this is also a reason for heterogeneity, which makes the reliability of such relationships uncertain when applied in a given site, even more if located in other climatic contexts.

A further point which raises doubts concerns the definition of the factors that account for slope length, steepness, cover and management and erosion-control practice. They are defined as soil loss ratios between the actual soil loss and that from a plot having the specific unit plot characteristic associated with the factor when all other conditions are the same. Therefore, while the soil erodibility factor K has to be evaluated with respect to the unit plot, the same is not requested for L, S, C, and P. This leads to suppose that, for example, measurements to evaluate the slope effect on soil loss can indifferently be collected on bare or cropped plots, varying only slope steepness. This assumption neglects that the result can differ between the two cover conditions. Indeed, the variations of soil loss with slope steepness are expected to be dependent on the coverage extent as the latter affects runoff formation and accumulation throughout the plot and the erosive response, accordingly. In other words, the above assumption originates from the hypothesis of independence of the model factors which seems to be doubtful (Morgan, 2005).

Although the USLE is based on a large database, it was originally developed for the USA, and as an empirical model, it needs testing in other areas of the world through the use of experimental data. Following the model approach, direct measurements of the soil erodibility factor should be performed in unit plots, especially for clay soils, whose *K* value is expected to be poorly estimated by the nomograph. The soil erodibility measurement for a given site is particularly onerous since the experiment should hopefully last for about twenty years.

When literature relationships for estimating the factors are used to adjust data to the unit plot condition, *K* becomes a calibration parameter. Conversely, the availability of unit plots and bare plots with different length and steepness, as in the Sparacia station, allows for the determination of the individual factors (*K*, *L*, *S*) for the experimental site. The two alternatives can guarantee a similar accuracy of the soil loss predictions due to the multiplicative form of the USLE. However, only the second strictly adheres to the fundamentals of the model. Therefore, future investigations for parameterizing and testing the USLE/RUSLE in different areas of the world should also include experimental data from unit plots.

CRediT authorship contribution statement

F.G. Carollo: Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **M.A. Serio:** Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **V. Pampalone:** Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **V. Ferro:** Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing.

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.

Data availability

Data will be made available on request.

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