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Evaluation of soil erosion risk and identification of soil cover and management factor (C) for RUSLE in European vineyards with different soil management

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ABSTRACT

Vineyards show some of the largest erosion rates reported in agricultural areas in Europe. Reported rates vary considerably under the same land use, since erosion processes are highly affected by climate, soil, topography and by the adopted soil management practices. Literature also shows differences in the effect of same conservation practices on reducing soil erosion from conventional, bare soil based, management. The Revised Universal Soil Loss Equation (RUSLE) is commonly adopted to estimate rates of water erosion on cropland under different forms of land use and management, but it requires proper value of soil cover and management (C) factors in order to obtain a reliable evaluation of local soil erosion rates. In this study the ORUSCAL (Orchard RUSle CALibration) is used to identify the best calibration strategy against long-term experimental data. Afterwards, ORUSCAL is used in order to apply the RUSLE technology from farm based information across different European wine-growing regions. The results suggest that the best strategy for calibration should incorporate the soil moisture sub-factor (S_m) to provide better soil loss predictions. The C factor, whose average values ranged from 0.012 to 0.597, presented a large spatial variability due to coupling with local climate and specific local management. The comparison across the five wine-growing regions indicates that for the soil protection management, permanent cover crop is the best measure for accomplishing sustainable erosion rates across the studied areas. Alternate and temporary cover crops, that are used in areas of limited water resources to prevent competition with vines, failed to achieve sustainable erosion rates, that still need to be addressed. This raises the need for a careful use of C values developed under different environmental conditions.

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1. Introduction

Vine is the second most extended perennial crop across Europe with 3.2 million ha in the EU28, only surpassed by olives (Gómez,

2017), but, as opposed to other perennial crops that tend to be located in specific regions, vines are grown in southern and central Europe, covering a broad range of soils and climate conditions. Vineyards are usually managed with agronomic practices, such as tillage or weed control with herbicides, that leave the bare soil exposed to rainfall and runoff during all or part of the year. These practices result in a degradation of soil structure and in accelerated water erosion, particularly for those located on slopes (Ruíz-Colmenero et al., 2013; Salomé et al., 2016). Although the

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reported erosion rates in vineyards across Europe present a large variability (Prosdocimi, Cerdà, & Tarolli, 2016) they tend to be higher than tolerable soil loss levels when measured in vineyards on sloping areas managed with bare soil. For instance, Tropeano (1983) measured soil losses of 33 t ha⁻¹ year⁻¹ in a deeply plowed vineyard in Piemonte, and (Casalí et al. (2009)) measured an average long-term erosion rate of 30 t ha⁻¹ year⁻¹ in N Spain on vineyards managed with tillage.

The use of cover crops in vineyards is widely considered as an effective agricultural conservation measure, providing various ecosystem services such as reduction of runoff and erosion processes, increasing soil organic matter, weed control, pest and disease regulation, water supply, water purification, improvement of field trafficability, and conservation of biodiversity (García et al., 2018; Winter et al., 2018; Hall et al., 2020). Several studies indicated a large reduction of erosion rates in vineyards when a cover crop is used. In Italy, after a 14-years monitoring experiment, Biddoccu et al. (2016) demonstrated how the use of a permanent grass cover reduced the average soil losses on large runoff plots one order of magnitude, from 13.85 t ha⁻¹ year⁻¹ (average of the two tillage treatments considered) to 1.8 t ha⁻¹ year⁻¹. Measurements carried out during 3-year long experiment from large runoff plots on vineyards located in Portugal and France reported 58% reduction in soil losses, from an average of 48.1 t ha⁻¹ y⁻¹ on tilled plots to 27.9 t ha⁻¹ y⁻¹ in the cover crop plots (Gómez et al., 2011). The relatively large losses reported for the cover crop treatment by Gomez et al. (2011) was explained by the occurrence of an extreme storm in one of the experiments. Furthermore, it was difficult to implement a good temporary ground cover during all the rainy season, due to the need to minimize competition for soil water with the vines under Mediterranean dry conditions. Due to divergent soil and climate conditions in wine-growing areas, there are differences in the implementation of agronomical practices across Europe that can be overlooked in the literature. In the Mediterranean region wine growers are reluctant to use permanent cover crops due to concerns over soil water competition with the vine, which is supported by experimental data (Celette et al., 2008; Ruiz-Colmenero et al., 2011). As a result, most wine growers that use cover crops in Mediterranean conditions tend to establish bare soil vineyards or use temporary cover crops, defined by Salomé et al. (2016) as those providing ground cover between 4 to 7 months per year. In contrast, in more humid conditions in central Europe, permanent cover crops are more commonly implemented.

Evaluation of soil losses due to the adoption of different soil management techniques in vineyards has been carried out with different methods (Rodrigo Comino, 2018), and results can help in addressing local soil management policies in the wine-growing sector. Among the adopted methodologies, direct soil loss measurements require some years of observations, adequate equipment, they are limited to some selected vineyards, and the results are not always comparable because obtained at different temporal and spatial scale. Furthermore, most of the available studies and results are related to some specific areas in some European countries (and few in the rest of the world), thus they don't cover the high variability of soil, topographical, management, and climate conditions that characterize the European wine-growing regions. An alternative to experimental measurements to evaluate the impact of changes in soil management on soil erosion risk under contrasting situations is the analysis with simulation models. The Revised Universal Soil Loss Equation RUSLE (Renard, Foster, Weesies, McCool, & Yoder, 1997) remains as the most widely used tools for this.

The model estimates average annual erosion using rainfall, soil, topographic, and management, using the following equation:

$$A = R * K * C * LS * P$$

where *A*: annual average soil loss (t ha⁻¹ yr⁻¹), *R*: rainfall erosivity factor (MJ mm ha⁻¹h⁻¹yr⁻¹), *K*: soil erodibility factor (t ha h ha⁻¹MJ⁻¹mm⁻¹), *C*: cover-management factor (dimensionless), *LS*: slope length and slope steepness factor (dimensionless), and *P*: support practices factor (dimensionless).

Despite its relative simplicity, proper RUSLE calibration for a given situation outside the modeling community can be challenging, especially in situations outside of those widely covered in the USA. To overcome this problem some authors have proposed simplified procedures, such as the summary model proposed by Gómez et al. (2003) for the use of RUSLE in olives, the determination of USLE C factors from cumulative field measurement soil erosion in vineyards (e.g. Novara et al., 2011) or calibration of the parameters required to determine the USLE C (soil cover and management) factor (Auerswald & Schwab, 1999). However, the values derived following these approaches are sometimes difficult to extrapolate beyond the conditions for which they were developed. For instance, Novara et al. (2011) developed their C values as the ratio of soil losses between the cover crops and the bare soil plots, providing no C values for bare soil management. Auerswald and Schwab, 1999 provide a comprehensive evaluation of annual crop and management factors (C) values from bare soil by tillage to permanent cover crop. Nevertheless, their values are valid for rainfall conditions similar to those or which they were developed, given the interaction with seasonal rainfall erosivity in C-factor determination (Auerswald et al., 2015). Some of the assumptions made in the determination of these C factors can be far from the assumptions and equations used by the most recent RUSLE version 2 (Dabney et al., 2012), that has been incorporated in the recent water erosion map of Europe by Panagos et al. (2015c). In that study the authors obtained C factors for tree crops, such as vineyards, based on the calibration from the fraction of ground cover derived from MERIS satellite images, as explained in Panagos et al. (2015b). In this approximation they update the seasonal C values based on a linear relationship between a range of maximum C_{max} (for zero ground cover) and minimum C_{min} (for full ground cover) with these extreme values taken as 0.45 and 0.15 respectively from a review of published values. The analysis carried out by Panagos et al. (2015b) resulted in an average C values for vineyards across Europe of 0.35.

To our knowledge, no attempt has been made to evaluate RUSLE based on long-term soil loss measurements in vineyards, neither a calibration strategy based on a comprehensive analysis of vineyard conditions across Europe. Our hypothesis is that this evaluation can provide relevant information to orientate its future applications for local and regional studies, as well as to provide insight for adapting current soil conservation strategies in vineyards, best suited for the different environmental conditions in Europe. This manuscript presents a study with these objectives:

- 1 To present an Excel tool to facilitate calibration of RUSLE2 in vineyards in hillslope applications.
- 2 To evaluate the performance of several calibration strategies of RUSLE for permanent cover crop and bare soil by tillage using a long-term experimental record previously published.
- 3 To identify C values and to compare soil erosion risk for the most common soil management operations in four different wine growing areas in Europe (S. Spain, NW France, NW Italy, E Austria and central Romania)

2. Materials and methods

2.1. Model description

An EXCEL tool, ORUSCAL (Orchard RUSLE CALibration), was built

to allow the calibration of RUSLE2 by assuming the simplified situation of a hillslope with a regular slope profile for tree crops such as vines, olives, almonds or citrus (Gómez Calero, Biddoccu, & Guzmán, 2020). The structure and main input data of the tool is shown in Fig. 1. Each of the factors of RUSLE is calculated in one of the Excel sheets, e.g. soil erodibility (K), or in several ones from each of the corresponding subfactors, e.g. cover and management factor (C). Each factor is accompanied by a set of explanations and accompanying information to allow their determination, indicating, when necessary, sources of this information (for example rainfall erosivity) or data taken from the RUSLE2 database (e.g. root biomass for different orchard management system). This allows their use in situations with limited data in a straightforward way for users with limited programming or modelling training, facilitating the use of a combination of field measurements (for instance evaluation of ground cover) complemented with data from other sources. It makes it a convenient use for education or training on evaluation of water erosion through RUSLE, facilitating the understanding the erosion risk of different management by stakeholders, or other applications such as comparison of erosion risk among different management, soil, temperature and rainfall regimes. ORUSCAL can be downloaded with its instructions from: <https://digital.csic.es/handle/10261/216656>. For more complex situations, e.g. complex slope profiles, any interested user should use the full RUSLE2 software.

Within this approach, for the determination of the rainfall erosivity factor (R factor), there is the option of using the quarter erosivity for the location of interest which are usually available from several sources (e.g., ICONA, 1988; Panagos et al., 2015a), calculating this from the correlation of daily rainfall and daily rainfall erosivity, which is also a common approach where these correlations have been developed (e.g. Domínguez Romero, Ayuso Muñoz, & García Marín, 2007) since daily rainfall is a commonly available data or upload the quarter rainfall erosivity calculated externally from high resolution rainfall data using software such as RIST (Rainfall Intensity Summarization Tool) (ARS-USDA, 2015).

For the determination of soil erodibility (K factor), ORUSCAL uses the standard RUSLE equation based on the textural composition and organic matter of the soil, corrected by soil infiltration capacity and soil structural class. It allows the use of a K values externally calculated, for instance from the global pedotransfer function of Borselli et al. (2012) or the soil erodibility map of Europe by Panagos et al. (2015a). From this baseline value, it gives the opportunity to use this as constant annual value or use the empirical correction proposed by RUSLE2 to calculate a quarter K value, based on daily T^3 and rainfall (USDA-ARS, 2013).

For the determination of the slope steepness (S) and length (L) factors, the simplified model uses the standard equations used by RUSLE2, differentiated for steepness lower or greater than 9% (standard USLE unit plot steepness). The steepness of most of the investigate plots is lower than 18%, the range for which the standard RUSLE2 equations have been developed, but for those that are steeper, for the sake of simplicity, we have kept the original RUSLE equations, which implies a slight overestimation (Liu et al., 1994). There is also an option to attribute a value to the *m* factor, used for determination of L to incorporate the relative importance of rill and interrill erosion, or let the model calculate it based on the ratio of rill to interrill erodibility and the evolution of ground cover using the equations described in RUSLE2 documentation (USDA-ARS, 2013).

For the determination of the cover and management factor (C), ORUSCAL calculates each of the seven subfactors from which this factor depends, giving the option (as done by RUSLE2) of not considering some of them in the determination. The first subfactor is the soil consolidation subfactor, S_c which takes into account the decrease in soil erodibility with time after a mechanical

disturbance (like tillage). It can be used in the transition period from tillage to a management with no mechanical disturbance of the soil surface, such as a permanent cover crop, but in most situations it is not used. The second considered subfactor is the canopy cover subfactor, C_c which takes into account the reduction of soil erosion due to the provision of ground cover by living vegetation. It is calculated from the height and shape of this vegetation (which in the case of the vineyards can be the vines plants and the herbaceous vegetation in the lanes) and the ground cover provided by this vegetation in each quarter. The third subfactor is the surface roughness subfactor, S_r , which includes the decrease of erosion with increasing roughness. This section provides values of the recommended roughness and disturbance values for the most common tillage operations and surface conditions from the RUSLE2 database and it calculates quarter S_r values considering reduction due to rainfall after tillage. The soil biomass subfactor, S_b , considers the reduction of erosion due to the presence of residues and root biomass within the top 25 cm of the soil. Since this is a value that it is usually difficult to obtain, the information sheet includes information on the amount of root (live and dead) and residues for the most common situations in vineyards and other tree crops. The fifth subfactor is the ground cover subfactor, G_c , which considers the reduction of erosion due to the presence of mulch or residues over the soil surface directly in contact with it. The ridge subfactor, h_r , considers the increase in erosion due to flow concentration occurring when there are well formed ridges oriented in up-down slope. Although it is not commonly used, it is included to provide all the possibilities allowed by RUSLE2. Furthermore, in vineyards the row orientation assumes a primary role in forcing the direction of tractor traffic and tillage implementation and thus ridge formation. In any case, it must not be confused with the contour tillage which is included in the support (P) factor. The final subfactor, S_m , is a subfactor which is optional in RUSLE to introduce the modification of the erosion risk due to changes in the soil moisture content, been higher when close to saturation and close to zero when it is close to totally dry. It cannot be used in combination with the seasonal adjustment of soil erodibility mentioned above, and the model give the opportunity to use one of these two corrections or none. The ORUSCAL formulation gives the opportunity to introduce measured soil moisture values or to estimate these values using daily rainfall and ETo (or estimating these using Hargreaves equation) and the ET from the vineyard determined using the FAO method (Allen et al., 1998). The use of this factor has improved the determination of C values for olive trees in Mediterranean conditions (Gomez et al., 2003) which has resulted in erosion prediction capable to reproduce the experimental measurements (Marin et al., 2014). For this reason, the model incorporates explicitly this option. Once all these factors are calculated ORUSCAL presents their annual and quarter values for each RUSLE factor, as well as the calculated soil loss.

2.2. Experimental data for evaluation

The Italian soil erosion dataset was derived from the Cannona Data Base (Biddoccu et al., 2016) collected in the Tenuta Cannona Erosion Plots. The monitored plots are part of a larger vineyard, within the Experimental Vine and Wine Centre of Agrion Foundation, which is located in the Alto Monferrato hilly area of Piemonte, North-West Italy. The climate is Hot-summer Mediterranean (Csa in the Köppen climate classification, Kotttek et al., 2006). At the study site the average annual precipitation in the period 2000–2016 was 852 mm, mainly concentrated in October, November and March, with the driest month been July. The Cannona vineyards lies on Pleistocenic fluvial terraces in the Tertiary Piedmont Basin, including highly altered gravel, sand and silty-clay deposits, with

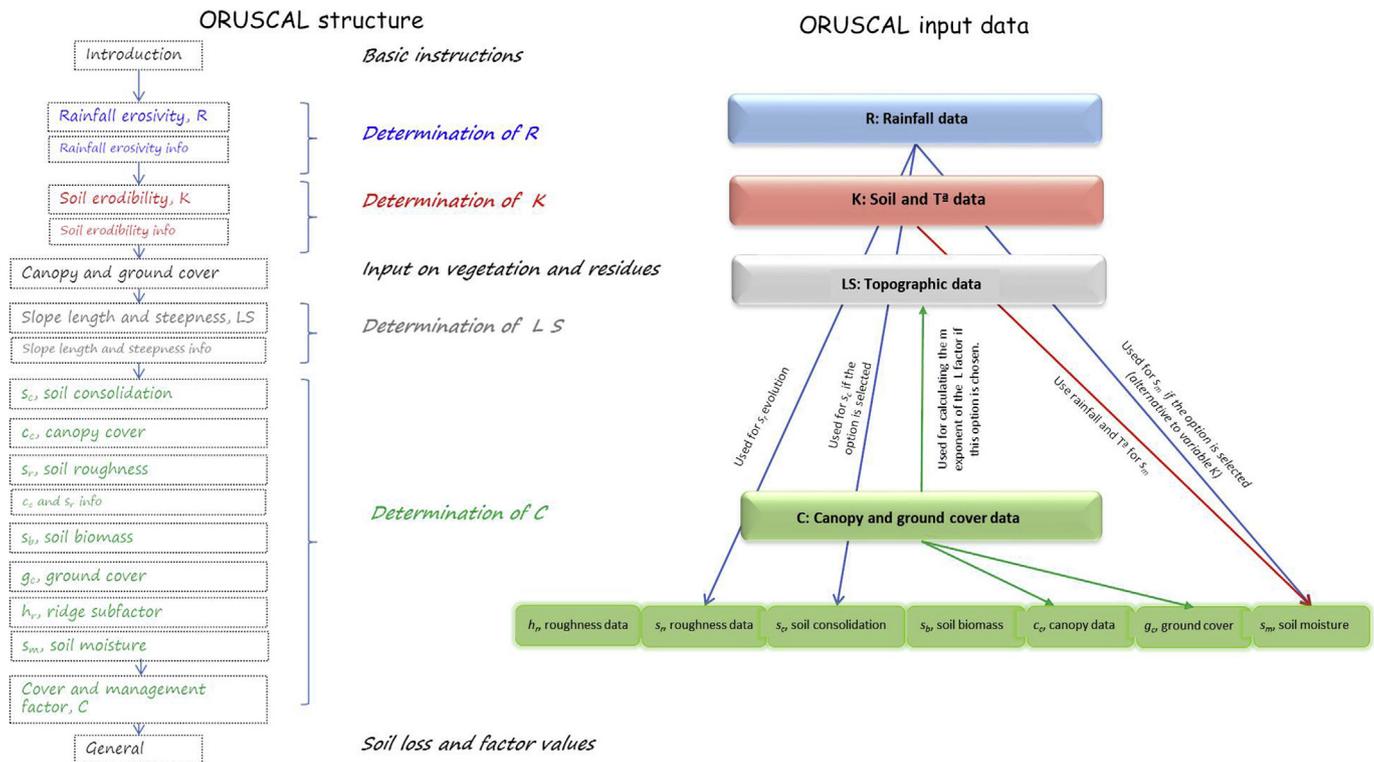


Fig. 1. Structure of the simplified calculation procedure in ORUSCAL (left side) and essential input data with indication of factors/subfactors where they are used (right side).

red alteration products. Soil is classified as *Typic Ustorthents, fine-loamy, mixed, calcareous, mesic* (Soil Survey Staff, 2010).

The measurements concern two vineyard plots on a hillslope with SE aspect, that are managed in according conventional farming for wine production. The two plots have the same length, width and slope, but the inter-rows have been differently managed for the 14 monitored years, with conventional tillage (CT) and permanent grass cover (GC), as summarized in Table 1. Each plot was hydraulically bounded: a channel at the top of the plots collected upstream water, in order to measure separately runoff and sediment yield generated from each rainfall event. The measurements have been conducted since 2000 and they are currently ongoing, with methods indicated in Table 1 and fully explained in Biddoccu et al. (2016). For this analysis a careful evaluation of the operation management and experimental records was made using only the years in which there was complete information to calibrate RUSLE without large uncertainty in any of the required information (such as for instance number of tillage operations, etc ...).

2.3. Evaluation of different calibration strategies

One of the objectives of the study was to evaluate the performance of different calibration strategies of RUSLE among those that might be used. For this purpose, a subset of the Cannona dataset, which passed the requirements of having all the available information, was used in the calibration step of the model (years 2004, 2005, 2007, 2008, 2010, 2011, 2012, 2013). The calibration was performed following four different calibration strategies described in Table 2, which in short result from using a constant or variable K-factor and considering, or not, the soil moisture subfactor, S_m .

The best calibration of the model was determined on the basis of both quarter and annual values, through the following statistics: the efficiency coefficient of Nash and Sutcliffe (NSE), root mean square error of residuals (RMSE) and the coefficient of

determination of the linear regression (R^2), see Nash and Sutcliffe (1970) and Moriasi et al. (2007).

2.4. Calibration of RUSLE for five wine growing regions across Europe

Afterwards, ORUSCAL was fully calibrated for different kind of typical, or possible, soil management in five contrasting wine growing regions across Europe. This calibration was made combining field surveys to characterize vineyard conditions, publicly available data and information provided by wine growers. These regions were: S Spain, NW France, NW Italy, E Austria and Central Romania. In all cases each farm and management was simulated for 15 or 16 consecutive years to capture temporal variability in rainfall.

2.4.1. Brief description of the five study area

The five study areas include vineyards from wine-growing regions located from the southern and western to the eastern countries of Europe (Fig. 2), and ranging from a variety of soils, landscapes and climatic conditions, that represent the variety of growing conditions for grapevine across Europe (Table 3). These areas are: a) the Montilla-Moriles wine-growing region in southern Spain (Andalusia), b) the Coteaux-du-Layon in Anjou, in north-western France (Loire Valley), the Carnuntum and Leithaberg region in eastern Austria (Lower Austria and Burgenland), the Târnave wine-growing region in Central Romania (Transylvania), and the Alto Monferrato and Gavi wine-growing regions in north Italy (Piedmont). The climate varies from the summer-dry (Spain) and hot-summer Mediterranean (Italy) climate, to temperate oceanic (Austria) and warm-summer humid continental (Romania). Viticultural landscapes also differ: from viticulture and olive dominated landscape in Andalusia (Spain) and the sloping vineyards dominating the hilly landscape of the Italian area to the

Table 1
Summary of the experiment used to evaluate the calibration strategies for ORUSCAL.

Location	Carpeneto (AL), 296 m asl, 44°40'57.45"N, 8°37'35.24"E	
Soil texture	Clay to Clay-loam	
Plot slope & size	slope: 15% area: 1221 m ² length: 74 m, width: 16.5 m	
Management	Conventional Tillage (CT) , depth 0.25 m, cultivated in spring and autumn	Controlled Grass (GC) , spontaneous vegetation mulched in spring and autumn. In autumn 2011, the inter-rows of the GC plot were tilled and a grass mixture was sown
Soil losses Average (\pm st.dev) (t ha ⁻¹ year ⁻¹)	7 (\pm 12.5)	1.8 (\pm 1.6)
Rainfall measurements	Automatic rainfall gauge (resolution 0.2 mm), hourly data	
Runoff measurements	Runoff is collected at the bottom of each plot by a channel, connected to a sedimentation trap and then to a tipping bucket device (0.1 mm resolution) to measure the hourly volumes of runoff from each plot.	
Soil loss measurements	A portion of the runoff-sediment mixture is sampled for each tip and, after each erosive event, a 1.5 L sample of runoff-sediment mixture was collected. Sediments deposited along drains and in the sedimentation traps are also collected and dry-weighed	

Table 2
Summary of the four calibration strategies evaluated.

	K factor	s _m subfactor
Option 1	constant (standard RUSLE nomograph)	Considered
Option 2	constant (standard RUSLE nomograph)	not considered
Option 3	variable, using the empirical function based on T ^a and rainfall included in RUSLE and baseline K calculated from soil properties from the nomograph	not considered
Option 4	constant, calculated from soil properties based on the model proposed by Borselli et al. (2012)	Considered

vineyards stretching from flat areas up to the forests at the hill-tops with interspersed arable fields, semi-natural elements in E Austria, the valley of the river Layon with very steep slopes (up to 60%) and the plateaux area with vine and crop fields in NW France, and finally the vineyards mixed with other agricultural crops, pastures and woods in the Romanian area. The investigated vineyards lie on a variety of soils, from the finest clay to clay-loam soils of the Monferrato, from sandy silt to sandy loam soils in eastern Austria, from clay to sandy-loam in Transylvania and in the DGO Coteaux du Layon.

2.4.2. Description of the vineyards and management operations in vineyards of the study areas

The investigated vineyards were chosen to represent the most common vineyard management practices in each region. Table 4 summarizes the main vineyard characteristics and management options, including the specifications of the soil management techniques employed in the area. In all study areas tillage was simulated as following the maximum slope as this was the dominant implementation when plowing was used in the region. In Spain, France, Austria and Romania, detailed determination of soil management, soil properties and ground cover was carried out experimentally for a whole season for two group of farms. One including farms applying the usual low soil protection management (with 7 or 8 farms in this group depending on the country) and the second group implementing common the soil protection management (with 7 or 8 farms depending on the country) in the respective area (Figs. 2 and 3). In Italy, the dataset includes 7 vineyards with low protective management and 5 vineyards with high protective management (Figs. 2 and 3). This resulted, as expected, in a multiplicity of soil management strategies that can be grouped in 5 classes: by decreasing intensity: 1- bare soil obtained by herbicide application and no tillage (NT); 2- bare soil using conventional tillage (CT); 3- partial soil cover, using temporary cover crops (TCC), defined as those grown during the rainy (fall and winter) season killed at the onset of the dry season period (early spring); 4- or

partial cover using alternate cover crops (ACC) defined as permanent cover crop every two lanes with the intercalated lane having the CT typical of the area; 5- permanent cover crops (PCC), resulting in complete cover of the inter-rows. Management information was collected in the form of personal semi-structured interviews with wine growers in all countries but in Italy, where this was made with direct consultation to farm managers. These interviews allow to classify the existing management as high or low soil protecting strategies. Furthermore, interviews provided information about the perception of farmers and stakeholders of these practices, and the identification of two additional soil management techniques that had been implemented recently in the region or that it might be introduced (or reintroduced) in the future, see Table 4. For each management scenario and identified vineyard soil losses were predicted using the ORUSCAL to apply the RUSLE2 methodology through 16 consecutive years (2000–2015) for Spain, Austria and Romania and France, and for 15 years (2004–2018) in Italy, obtaining a total of 2246 years of simulated scenarios, 1097 for currently used scenarios and 2149 years for hypothetical scenarios.

2.4.3. Sources of information for calibration of the different RUSLE parameters

Daily temperature and rainfall depth was obtained from a weather station located within each of the study area for the whole study period. To minimize bias due to different calibration of the rainfall erosivity, we standardize the rainfall erosivity among areas to the long-term average R values (annual and monthly) provided by Ballabio et al. (2017). To do this, we calculated daily rainfall erosivity from daily rainfall using an exponential function $R = \alpha P^{\beta}$, adjusted to match long-term monthly and annual average with those of Ballabio et al. (2017). We did not use this approach for the evaluation of calibration strategies, where daily rainfall erosivity was calculated using the RUSLE2 methodology (Dabney et al., 2012).

The topographic, soil, cover and management information required for calibration of ORUSCAL for the study areas other than

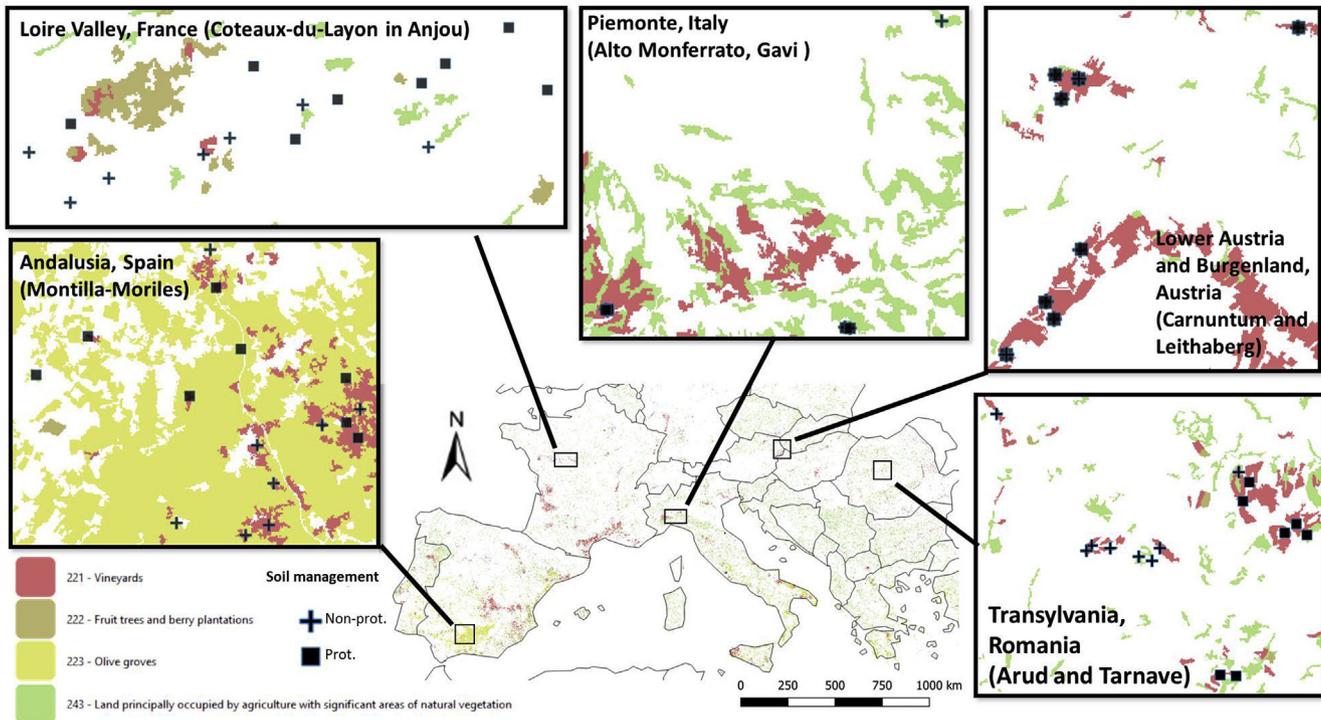


Fig. 2. Locations of study areas in Spain, France, Italy, Austria, and Romania. Symbols in each box indicate the investigated vineyards, with the currently implemented soil management (non protective or protective for soil). The background shows the land use according to CORINE land cover.

Table 3

Basic information of the five wine growing study regions. For each study region average values, standard deviation (in brackets) and minimum and maximum values are indicated for soil organic matter content (OM), vineyards length and slope.

Country	Coordinates (extremes of the area)	Wine-growing region (administrative region/district)	Climate (Köppen climate classification)	Landscape and land use	Prevalent soil and OM (% average \pm SD)	Vineyards length (m)		Vineyards slope (%)	
						Average (\pm SD)	Min-Max	Average (\pm SD)	Min-Max
Spain	37° 38'–29°N, 4° 45'–31'W	Montilla-Moriles (Andalusia)	Hot-summer Mediterranean climate (Csa)	Agricultural area. Rugged relief, 220–682 m a.s.l.	Clay to sandy-loamOM: 1.6 (\pm 0.3)	43.7 (\pm 64.8) Min: 53.4, Max: 279	5.8 (\pm 3.3) Min: 0.5, Max: 11.0		
Italy	44° 39' – 44° 52' N, 8° 37' – 8° 54' E	Alto Monferrato, Gavi (Piemonte)	Hot-summer Mediterranean climate (Csa)	Mix of vineyards with arable fields and woods, hilly region with flat areas, 270–300 m a.s.l.	Clay to clay-loamOM: 1.2 (\pm 0.3)	87.9 (\pm 32.9) Min: 72.4, Max: 169	16.7 (\pm 6.9) Min: 5.0, Max: 26.3		
France	47.41–47.04°N, 0.85–0.24°W	Coteaux-du-Layon in Anjou (Loire Valley)	Temperate oceanic climate (Cfb)	16% Vineyards (1435 ha for the DGO label, total 10900ha), 44% arable fields with mainly cereals and sun flowers or pastures, 30% semi-natural elements, 8% urban areas, 2% water	Sandy-LoamOM: 2.0 (\pm 0.7)	106.3 (\pm 43.5) Min: 50.0, Max: 175.0	7.1 (\pm 8.8) Min: 0.4, Max: 32.3		
Austria	47° 54'–48° 7'N, 16° 38'–16° 73'E	Carnuntum and Leithaberg (Lower Austria and Burgenland)	Temperate oceanic climate (Cfb)	Mix of vineyards and arable fields, hilly region with flat areas, 120–235 m a.s.l.	sandy silt to sandy loamOM: 3.2 (\pm 1.0)	301.3 (\pm 100.5), Min: 160.0, Max: 440.0	8.6 (\pm 5.3), Min: 2.0, Max: 15.0		
Romania	46° 02'–46° 19'N, 23° 43'–24° 01'E	Arud and Tarnave (Transylvania)	Temperate continental climate (Dfb)	Vineyards surrounded by other agricultural, forest and seminatural areas, 280–440 m a.s.l.	Clay to sandy-loamOM: 1.4 (\pm 0.9)	168.8 (\pm 92.9) Min: 54.0, Max: 296.0	8.9 (\pm 4.8) Min: 0.7, Max: 17.9		

Table 4

Characteristics of vineyards evaluated in each of the five study areas, soil management, type and number of real and simulated scenarios. Number in brackets are number of farms simulated for each management scenario.

Country	Vine-growing management (training, mechanization)	V varieties	Row orientation (and width)	Mechanical soil management techniques, operation/tools, depth, times	Management technique family (number of vineyards)	Number of real scenarios (single management x year x vineyard)	Management technique family and number of simulated scenarios
Spain	Globet and trellis, mechanized	Pedro Ximenez	Up-and-down (2.85 m)	Conventional tillage, cultivator, 0.15 m, 1-4	CT (8)	128	NT (16), 256
				Temporary cover crops, cultivator, 0.15 m, 1–2; mowing, 1–2.	TCC (8)	128	PCC (16), 256
Italy	Single Guyot, mechanized (tired and tracked tractors)	BarberaDolcettoGavi	Up-and-down (2.5–2.75 m)	Conventional tillage, ripper, 0.25 m, 2–3	CT (7)	105	ACC (6), 90
				Reduced tillage, rotocultivator, 0.15 m, 2	PCC (5)	75	
France	Trellis, mechanized	Large variety from red to white wine varieties	Up-and-down	Bare soil with herbicide, 2–4	NT (7)	112	CT (15), 240
				Spontaneous controlled grass, mulching, na, 2–3	PCC (8)	128	ACC (15), 240
Austria	Trellis, mechanized	Large variety from red to white wine varieties	Up-and- down	Tillage in every second inter-row with different types of machinery (chisel, disc harrow, rotary, plough), 0.05–0.15 m, 1–3; mulching in the other inter-row, 2–5	ACC (8)	128	NT (16), 256; CT (16), 256
				Permanent cover crop, mulching in every inter-row, 2–5	PCC (8)	128	
Romania	Trellis, mechanized	Large variety from red to white wine varieties	Up-and-down (2.0–3.0 m)	Bare soil management through frequent soil tillage in all inter-row. Tillage depths ranged between 5 and 30 cm and the number of application per year (in inter-row) ranged between 2–5 time/year across the vineyards.	CT (8)	128	NT (16), 240
				Alternate cover crop. The inter-row vegetation cover (alternative) was mowing/mulched approximately 2–4 times per year	ACC (7)	112	PCC (16), 240

Abbreviations in **bold** are management scenarios considered by stakeholders at each area less soil protecting scenarios, and those in *italics* more soil-protecting scenarios. Abbreviation used for soil managements are: NT = no tillage, CT = conventional tillage, TCC = temporary cover crop, ACC = alternate cover crop, PCC = permanent cover crop.

Italy was taken from field survey carried out during the VineDivers project (<https://short.boku.ac.at/vinedivers>). Information for Italian vineyards derived from previous studies (Biddoccu et al., 2016; Bagagiolo, Biddoccu, Rabino, & Cavallo, 2018; Capello et al., 2019), field surveys, interviews to farmers and vineyard's technicians. Soil measurements were used to calculate the erodibility (K-factor) and includes, for each investigated vineyard, soil particle fraction and organic matter content, class of soil structure and soil permeability.

Topographic data, namely field length and steepness, necessary to define the LS-factor, were obtained by GIS analysis or Google Earth, in the gaps where it was not possible to be measured directly in the field. The different farm-derived management information was used to calibrate the different C subfactors. So C_c and G_c subfactors were determined from measurements made during a whole growing season (see for instance Guzmán et al., 2019) or estimated from available measurements in hypothetical scenarios projecting

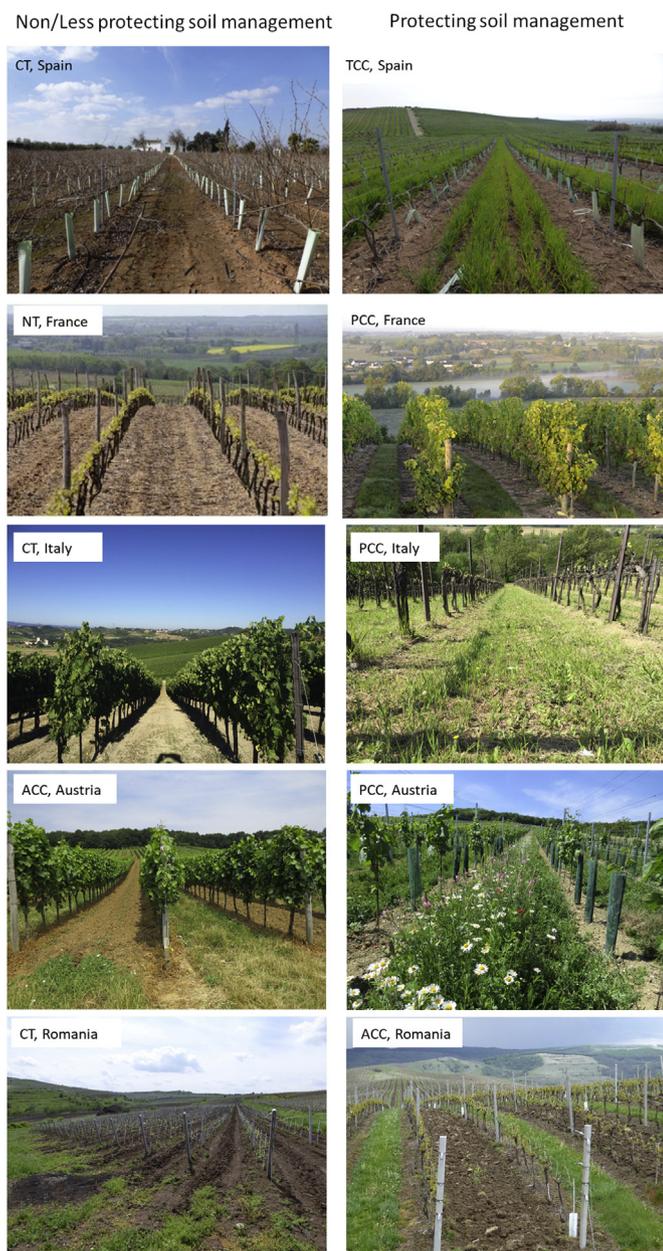


Fig. 3. Some of the investigated vineyards, in Spain, France, Italy, Austria, and Romania, representing some of the most currently implemented soil management (non/less protective or protective). (Photo credits: Jean-Paul Gislard for France, Davide Ferrarese (VignaVeritas) for Italy).

expected vegetation and residue cover. Soil management operations were used to determine the soil consolidation and soil roughness subfactors (S_c and S_r , subfactors of the C-factor). Data about residues and biomass, also needed to calculate the S_b subfactor, were taken from RUSLE database. The soil moisture (S_m) subfactor was calculated internally by ORUSCAL using the simplified water balance model incorporated in the model using daily rainfall and ET, based on Allen et al. (1998).

2.5. Data statistical analysis

Differences among regions in values of SL and RUSLE factors for the currently adopted non-protecting and protecting soil managements were determined using ANOVA (with $\alpha = 0.05$). The same

test was used to compare SL and C-factor among regions for the same management class (currently adopted or hypothetical), and among management for each studied region. For identifying factors that play the major role in differentiating the currently adopted soil management in the considered study areas an exploratory analysis using a Principal Component Analysis (PCA) was performed. This was complemented with stepwise multiple linear regression (MLR) to evaluate the relative contribution of each variable to differences in determining soil losses. The cumulative probability distribution functions of soil loss and C factors were determined. In all cases STATA SE 14.0 was used.

3. Results and discussion

3.1. Evaluation of calibration strategies

The comparison of the statistics obtained with the four different calibration strategies (Table 5) showed that the performance of the model was unsatisfactory (Moriassi et al., 2007) for the two option 2 and 3, both for yearly and for quarter results ($NSE < 0$). The introduction of variable K in option 3 (using the empirical function based on daily temperature and rainfall, included in RUSLE, and baseline K calculated from soil properties) improved the performance of the model with respect to the model with constant K (option 2, Table 3) but remains performing poorly in predicting soil losses. Using the two options that include the determination of a soil-moisture subfactor, option 1 and 4, the performance of the model improved both for yearly and for quarter values. The simulation resulted in predictions that give acceptable values for NSE (between 0.35 and 0.82) and satisfactory values for RMSE ($> 1/2 s_m$), with exception of yearly values for CT ($NSE = -0.48$). The best performance of the model was obtained for CT, quarter values, using option 4, that resulted in $NSE = 0.82$, $RMSE = 0.34 \text{ t ha}^{-1}$, $R^2 = 0.82$. Considering the annual values the same option gave $NSE = 0.67$, $RMSE = 2.44 \text{ t ha}^{-1}$, $R^2 = 0.79$. The performance was generally poorer for GC, with satisfactory results that were obtained only with option 1, for yearly values ($NSE = 0.58$, $RMSE = 0.44 \text{ t ha}^{-1}$, $R^2 = 0.65$) (Table 5). The corresponding quarter results resulted in $NSE = 0.43$, $RMSE = 0.10 \text{ t ha}^{-1}$, $R^2 = 0.46$.

It is apparent, in our evaluation analysis, that the introduction of the temporal evolution of soil moisture improved the predictions, and that this temporal impact cannot be introduced using the empirical correction offered as a possibility in the K factor (option 3). This contrasts with the results of Khaleghpanah et al. (2016) who observed a considerable improvement of RUSLE2 model efficiency using a calibrated and variable K-factor. This difference might be related to the different climate conditions of our study areas, more contrasting to those of the empirical K value adjustment of RUSLE2 than those of the study of Khaleghpanah et al. (2016). It is also worth noting that the better predicting capabilities of RUSLE2 incorporating the S_m subfactor for Mediterranean conditions was also noted by Marin et al. (2014) for a similar analysis in olive orchards.

Comparing the model performance between options 1 and 4 considering the S_m subfactor, the model predicted the low values of erosion in quarters better than for options 2 and 3, and regression lines showed intercept (n) and slope (m) closer to 0 and 1, respectively, than those obtained without considering the S_m subfactor. However, for option 1, the improvement in prediction of low amounts of soil losses was not enough to give good annual values for CT, that were more overpredicted than in option 4 and led to low performance of the model. The performance of the model considering quarter values for GC was similar to those obtained for quarters with WEPP (Zhang et al., 1998), and with models of the USLE family for event values (Di Stefano et al., 2016; Khaleghpanah et al., 2016; Kinnell, 2017; Spaeth, 2003). Quarter results in CT were

Table 5
Summary of the evaluation of the calibration results.

	Yearly values					Quarter values				
	Measured	Option 1	Option 2	Option 3	Option 4	Measured	Option 1	Option 2	Option 3	Option 4
CT										
Mean SL (t ha ⁻¹)	4.22	8.19	24.42	18.14	5.51	0.18	0.37	1.04	0.77	0.25
St.Dev. (t ha ⁻¹)	4.20	5.89	15.52	10.6	3.95	0.79	1.03	2.75	1.95	0.7
NSE	–	–0.48	–33.69	–14.7	0.67	–	0.64	–7.29	–2.55	0.82
RMSE (t ha ⁻¹)	–	4.78	23.12	15.55	2.24	–	0.47	2.27	1.48	0.34
R ²	–	0.80	0.77	0.71	0.79	–	0.83	0.72	0.67	0.82
M	–	1.26	3.24	2.13	0.83	–	1.16	2.95	2.01	0.78
N	–	2.89	10.77	9.16	1.99	–	0.14	0.5	0.4	0.09
GC										
Mean (t ha ⁻¹)	0.63	0.74	2.4	2.22	0.59	0.03	0.03	0.12	0.1	0.03
St.Dev. (t ha ⁻¹)	0.74	0.47	1.54	1.26	0.33	0.13	0.07	0.24	0.2	0.06
NSE	–	0.58	–13.41	–7.02	0.46	–	0.43	–1.99	–1.04	0.35
RMSE (t ha ⁻¹)	–	0.44	2.62	1.95	0.51	–	0.10	0.23	0.19	0.11
R ²	–	0.65	0.19	0.14	0.56	–	0.46	0.2	0.2	0.43
M	–	0.51	0.94	0.63	0.33	–	0.33	0.78	0.65	0.24
N	–	0.42	2.29	1.83	0.38	–	0.02	0.1	0.08	0.02

SL = soil losses, NSE = Nash-Sutcliffe efficiency, RMSE = root mean square error, R² = coefficient of determination, m and n = Regression coefficients: Predicted SL = m*Measured SL + n.

satisfactory for option 1, but yearly results gave negative values for the Nash-Sutcliffe coefficient and were not satisfactory in terms of RMSE. For yearly values simulated in the CT plot with option 4, the NSE, slope (m) and R² are in the range of those obtained with RUSLE (or RUSLE2) by other authors (Risse et al., 1993; Tiwari et al., 2000; Zhang et al., 1996). The low performance of the model in prediction for the GC plot, could be due to difficulty of the model in predicting low amounts of soil losses, as was observed by Spaeth et al. (2003) on relatively undisturbed rangeland sites (with soil losses <0.5 t ha⁻¹). Finally, the model version using constant K obtained from RUSLE2 equations, and including the S_m subfactor, was chosen as the best option to apply to the selected study areas and different management options. Overall, by introducing the S_m subfactor, the model was able to capture the differences observed experimentally between the bare (CT) and ground covered (GC) treatment with an accuracy similar in analogous exercises by other erosion models, although it shows difficulties when predicting accurately situations with low erosion rates (quarter or GC annual values), a situation also previously noted in erosion models by previous studies (e.g. Risse et al., 1993).

3.2. Comparison of the predicted water erosion under current soil management across the five different wine growing areas

The differences in water erosion predictions using ORUSCAL among the fine wine growing areas across Europe and currently implemented managements are summarized in Fig. 4 and Table 6. In this comparison there is always a soil protective management, using total or partial cover crop (PCC in Austria, France and Italy; ACC in Romania, TCC in Spain) and one that considers a non or less soil protective management in the study area, which were bare soil, namely NT (in France) or CT (in Romania, Spain and Italy), with the only exception of Austria, where the less conservative management was ACC (partially bare soil).

The comparison of the less conservative managements currently adopted in each region provides an overview of the maximum erosion rates across these different areas, based on a modelling analysis using the best possible farm information. In this respect, SL predicted in different countries showed significant differences, according to 1-way ANOVA ($\alpha = 0.05$). The traditional vineyard's management with bare soil (CT) resulted in the highest predicted

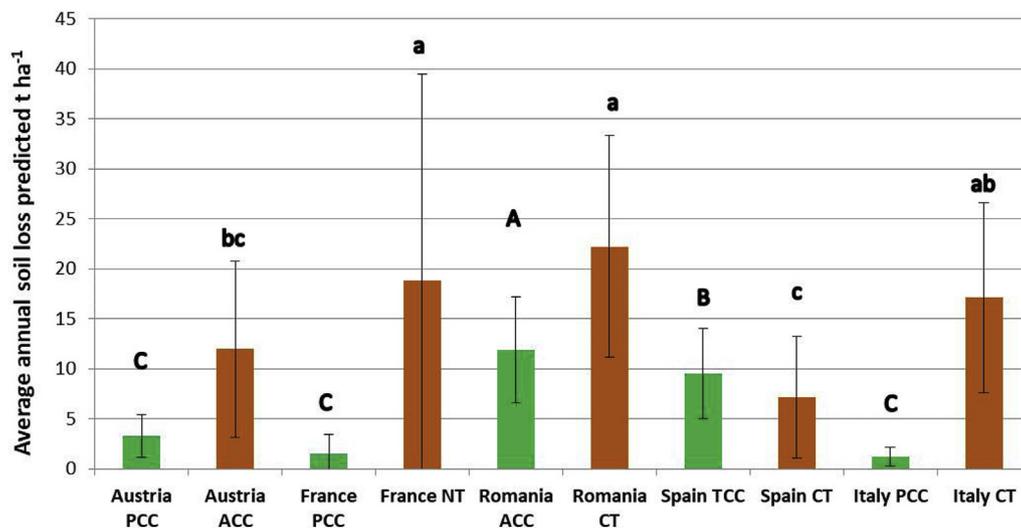


Fig. 4. Average annual soil losses predicted by area and by current management implemented in the area. Brown bars are non-protecting soil management and green bars are soil protected management. Error bars indicate standard deviation. Letters indicates significant differences at $\alpha = 0.05$, according to ANOVA within the same class of management. Capital letters for non-soil protective management and lower case letters for soil protective management.

Table 6
Average annual soil losses and factors (and standard deviations) for different soil managements in each region. § indicates current most adopted soil managements. Different letters indicate statistical different values according to ANOVA ($\alpha = 0.05$): capital letters indicate differences among managements (currently adopted or hypothetical) for the same area, lowercase letters indicate differences among areas for the same management (currently adopted or hypothetical).

	Austria				Romania				France				Italy				Spain				
	NT	CT	ACC [§]	PCC [§]	NT	CT [§]	ACC [§]	PCC [§]	NT [§]	CT	ACC	PCC [§]	NT	CT [§]	ACC	PCC [§]	NT	CT [§]	ACC	PCC [§]	
Annual soil loss t/ha	67.99	21.2	11.98	3.31	32.43	22.24	11.92	1.75	18.87	17.58	9.41	1.48	34.61	17.13	8.57	1.22	26.35	7.14	8.57	1.22	9.53
st dev	44.31	15.29	8.83	2.11	23.4	11.13	5.29	1.36	20.57	19.95	10.78	1.98	16.21	9.51	5.26	0.96	19.92	6.05	5.26	0.96	4.5
Average rainfall erosivity, R	371.9	371.9	371.9	371.9	635.4	635.4	635.4	635.4	467.8	467.8	467.8	467.8	1527.6	1527.6	1527.6	1527.6	1049.7	1049.7	1527.6	1527.6	1049.7
st dev	191.9	191.9	191.9	191.9	228.7	228.7	228.7	228.7	305.7	305.7	305.7	305.7	816	816	816	816	7.8	7.8	816	816	7.8
Average soil erodibility, K	0.067	0.064	0.051	0.04	0.058	0.06	0.045	0.033	0.041	0.046	0.039	0.036	0.029	0.025	0.024	0.024	0.037	0.027	0.024	0.024	0.031
st dev	0.02	0.02	0.011	0.004	0.024	0.03	0.017	0.011	0.009	0.018	0.013	0.009	0.004	0.004	0.004	0.004	0.008	0.009	0.004	0.004	0.007
Average slope length coeff, L	4.73	3.59	3.22	2.81	3.26	2.66	2.42	2.17	2.57	2.15	1.99	1.82	1.99	1.28	1.22	1.18	3.01	2.42	1.22	1.18	2.56
st dev	0.98	0.66	0.53	0.41	1.14	0.92	0.41	0.52	0.68	0.46	0.38	0.31	0.35	0.13	0.07	0.06	0.81	0.47	0.07	0.06	0.66
Average slope steep coeff, S	1.08	1.09	1.08	1.08	1.1	1.27	1.09	1.1	0.69	0.93	0.93	1.13	2.32	2.32	2.08	2.09	0.67	0.48	2.08	2.09	0.67
st dev	0.7	0.71	0.73	0.73	0.67	0.77	0.46	0.67	0.8	1.23	1.24	1.56	1.12	1.12	1.01	1.13	0.37	0.36	1.01	1.13	0.29
Average cover and manag., C	0.597	0.24	0.157	0.079	0.268	0.222	0.127	0.034	0.584	0.54	0.294	0.049	0.163	0.133	0.073	0.012	0.321	0.211	0.073	0.012	0.134
st dev	0.013	0.056	0.03	0.006	0.005	0.012	0.005	0.005	0.014	0.004	0.007	0.01	0.047	0.04	0.023	0.003	0	0.048	0.023	0.003	0.066

Abbreviation used for soil managements are: NT = no tillage, CT = conventional tillage, TCC = temporary cover crop, ACC = alternate cover crop, PCC = permanent cover crop.

soil losses in Romania (22.24 ± 11.13 t ha⁻¹ year⁻¹), and lowest values in Spain (7.1 ± 6.05 t ha⁻¹ year⁻¹). In Austria, annual soil losses estimated with implementation of the ACC, reached 11.98 (± 8.83) t ha⁻¹ year⁻¹ even if this management considers partial cover crop. The predicted average soil losses are comparable with values measured at field or hillslope scale in some vineyards managed with bare soil (CT or NT). Indeed, Brenot et al. (2006) estimated soil losses from 7.61 to 14.94 t ha⁻¹ year⁻¹ on 32–54 years-old vineyards in Burgundy (France), and Gomez et al. (2011) measured soil losses from 4.47 to 90 t ha⁻¹ year⁻¹ over 4-years experiment in different locations in southern France. These differences across areas can be better understood having a closer look to the different components of the erosion predictions, namely the RUSLE factors, which present a high variability among regions (Fig. 5) with significant differences among countries, according to ANOVA (at $\alpha = 0.05$ significance level). Despite having a higher rainfall erosivity, Italy and Spain present farms with slight lower soil erodibility, shorter or gentle slopes than other countries. In addition, CT soil management can present relatively higher ground cover due to vegetative growth between tillage passes, as noted for Spain by Guzman et al. (2019), which explain differences in the predicted erosion values across countries and raised the need for a proper calibration based on the actual situation at the vineyards.

The exploratory analysis using the PCA for the RUSLE calibrated factors (R, K, L, S and C) showed that 60.6% of the variance among soil losses can be explained by two components (Table 7). The first component PC1 represented 42.3% of the variance and the variables with highest loadings are L (0.559) and K (0.475), followed by S and R, that showed negative correlation (-0.440 and -0.423 , respectively). The second component PC2, represents 18.3% of the variance and has a good correlation (0.868) with the C-factor. PC1 is more related to local topographical and climate conditions, and soil characteristics, whereas PC2 indicates primarily the differences related to soil management. Fig. 6 depicts the individual scores on PC1 and PC2 of the average simulation by farm and management type for the five areas. As expected there was a clear shift among different areas for similar management class (protecting and non-protecting soil) and between management classes for the same area. Among the non-protecting soil managements, the values related to NW Italy predictions are placed on the left side of the plan, since they are associated to the lowest values for L and K and highest R; they are followed towards the right side by the clouds representing simulations made for S Spain, Austria and central Romania, and finally then the ones from France to the most right side, likely following the decreasing trend of R-factor, with the latter showing very high values also for PC1. The stepwise multiple linear regression analysis (MLR) for non-conservative soil managements, Table 8A, shows that the first parameter included (the one with the highest explanatory value) was the slope factor, linked to local topographical conditions, followed by variables depending on management (C-factor) and soil properties (K-factor). Rainfall erosivity and slope length were less relevant in determining soil losses in this comparative analyses across 5 areas in Europe. These results suggest that soil losses predictions with adoption of less conservative managements are not only dependent on the local conditions (topographical, soil and climate characteristics), but also on the specificities of local management and soil properties. Indeed, the less protective managements in most regions contemplate bare soil during some months, have a significant role in determining the soil erosion risk. Bare soil is obtained by herbicides or by tillage, with a variety of passages and tools, so the resulting ground cover, and associated C-factor values, showed very high variability among but also within regions. Although R-factor is a key parameter for estimating soil erosion risk and larger soil loss predictions are usually expected with higher rainfall erosivity, e.g.

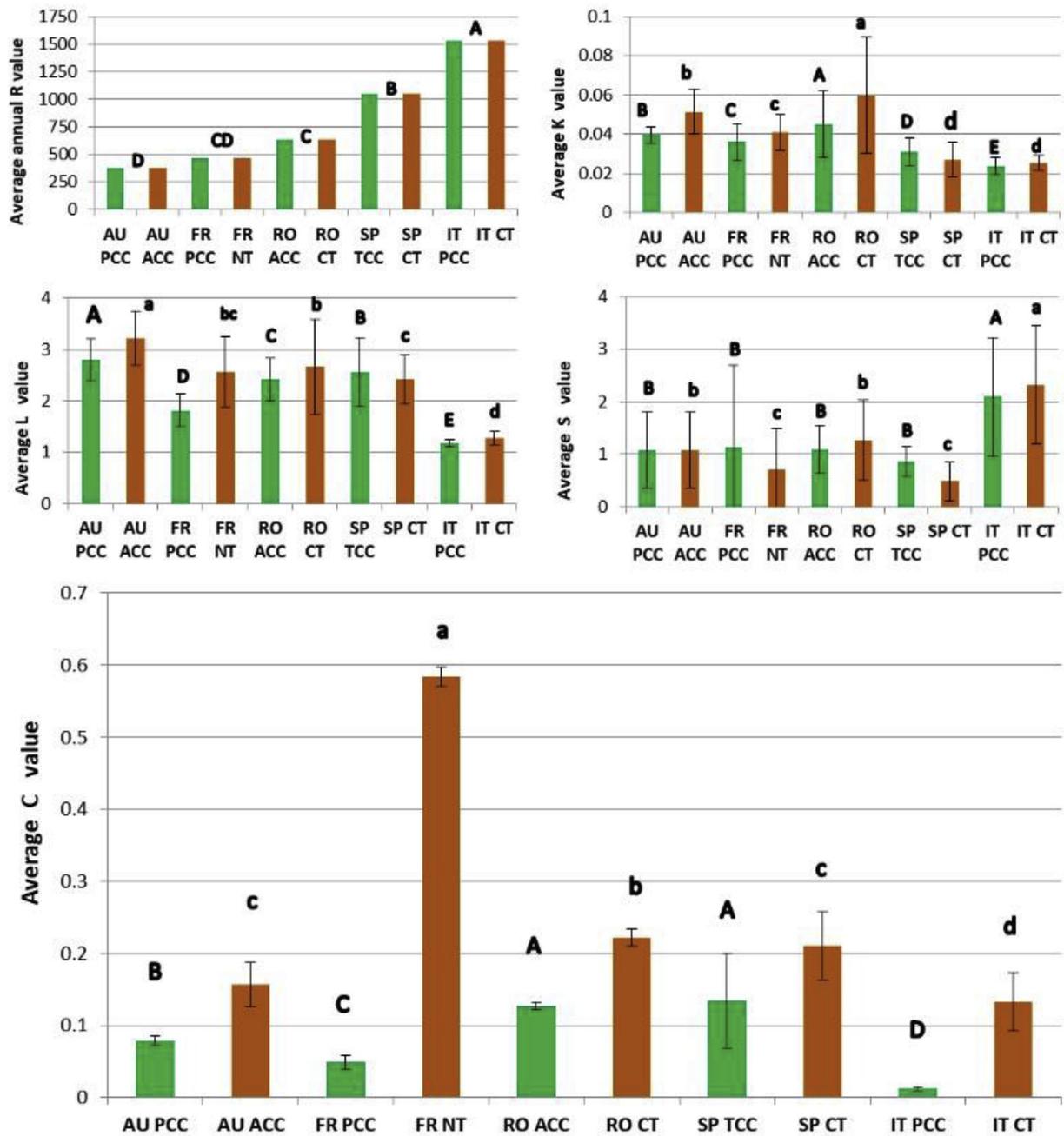


Fig. 5. Average and standard deviation (error bars) of estimation of RUSLE factors value for non-soil protective (brown) and soil protective (green) soil managements in each region. Letters indicate significant differences among regions for non-soil protecting (lowercase) and soil protecting (capital) managements, according to ANOVA ($\alpha = 0.05$).

Panagos et al. (2015b) in their large scale analysis, our results suggest that when the characteristics of the specific farms (in this case vineyards) are introduced our overall vision of the relative differences among different areas change dramatically. This is not totally surprising, since it is well known that hillslope scale topographical factors likely have greater importance, because they can be drivers for the relative dominance of rill erosion rather than interrill, especially on bare soil (Bagarello & Ferro, 2010; Bagio et al., 2017; Prosdocimi et al., 2016). Also the ground cover, a major driver in water erosion, can vary largely within apparently similar management due to local specificities like (climate, seed bank, tillage intensity) that need to be properly appraised, see for instance Guzman et al. (2019). Our results are a reminder that overlooking

these local factors can bias large scale analysis and the policy decisions relying on such analysis. The RUSLE technology, in our case with a relative simple tool like ORUSCAL, can be a powerful instrument to capture local conditions, when properly calibrated combining several sources of information capturing the local reality. ORUSCAL, as a simple tool based on the RUSLE technology, allow its application to a wide range of situations, namely at field or farm level, and can be a powerful instrument to capture local conditions. Indeed, it does not necessarily need expensive or detailed datasets, on the contrary it can be properly calibrated combining publicly available information, field surveys and farmers' interviews, which in our opinion remain a fundamental element in this calibration phase.

Table 7

A) Results of the Principal Component Analysis using the 5 factors of RUSLE as variables. B) Loadings for the first two components for these five factors.

A			
PC	Eigenvalues	%Variance	Cum % Variance
PC1	2.117	0.423	0.423
PC2	0.914	0.183	0.606
PC3	0.812	0.162	0.769
PC4	0.686	0.137	0.906
PC5	0.472	0.094	1.000
B			
Variable	Load in PC1	Load in PC2	
R-factor	-0.4284	0.3414	
K-factor	0.4746	-0.3021	
L-factor	0.5589	-0.0783	
S-factor	-0.4397	-0.1808	
C-factor	0.2925	0.8679	

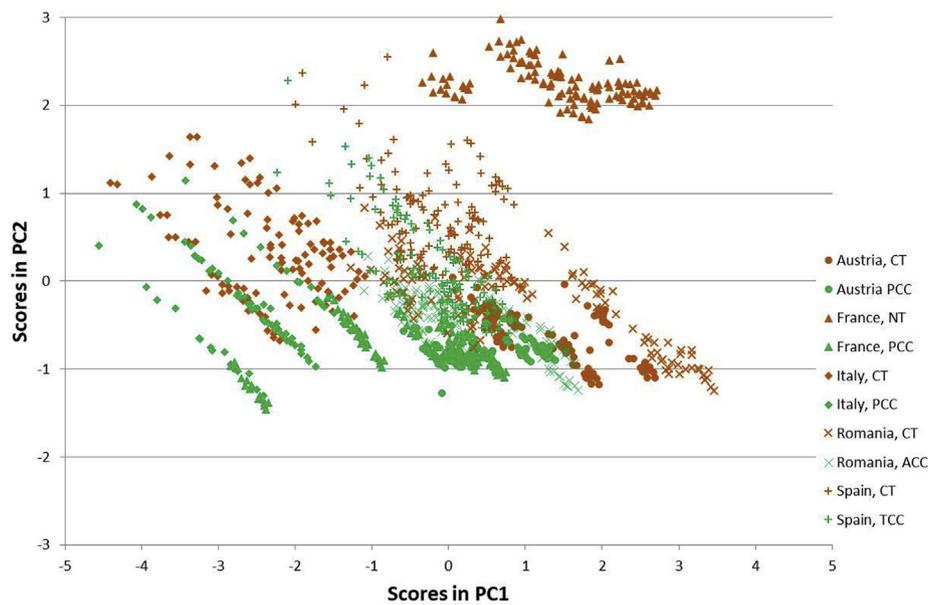


Fig. 6. Representation on components 1 and 2 of the Principal Component Analysis of predicted annual soil losses as individuals on the principal component plan, classified non-soil protective (brown) and soil protective (green) in each study area.

Table 8

Summary of the stepwise multiple linear regression models for soil losses predicted for the currently most adopted managements, for A) non-protecting and B) soil protecting management.

(A)		
Model for less conservative managements	R ²	RMSE
SL = Constant + α_1 S _{factor}	0.228	14.02
SL = Constant + α_1 S _{factor} + α_2 C _{factor}	0.314	13.21
SL = Constant + α_1 S _{factor} + α_2 C _{factor} + α_3 K _{factor}	0.399	12.37
SL = Constant + α_1 S _{factor} + α_2 C _{factor} + α_3 K _{factor} + α_4 R _{factor}	0.526	11.02
SL = Constant + α_1 S _{factor} + α_2 C _{factor} + α_3 K _{factor} + α_4 R _{factor} + α_5 L _{factor}	0.590	10.22
(B)		
Model for more conservative managements	R ²	RMSE
SL = Constant + α_1 C _{factor}	0.361	5.58
SL = Constant + α_1 C _{factor} + α_2 R _{factor}	0.507	4.91
SL = Constant + α_1 C _{factor} + α_2 R _{factor} + α_3 L _{factor}	0.537	4.76
SL = Constant + α_1 C _{factor} + α_2 R _{factor} + α_3 L _{factor} + α_4 S _{factor}	0.577	4.54
SL = Constant + α_1 C _{factor} + α_2 R _{factor} + α_3 L _{factor} + α_4 S _{factor} + α_5 K _{factor}	0.591	4.47

SL = soil losses, RMSE = root mean square error, R² = coefficient of determination.

A comparison of the currently used more soil-protecting managements can provide an assessment of the best possible situation in terms of soil losses reduction under current conditions (Table 6 and Fig. 4). As expected, results showed a reduction of the predicted annual soil losses for four of the study areas, with exception of Spain where predicted soil losses were slightly higher for TCC ($9.53 \pm 4.50 \text{ t ha}^{-1} \text{ year}^{-1}$) than for CT. This later result can be explained by the fact that ground cover in TCC was extremely low in the study area, since most of the farmers opted for natural vegetation as the alternative for cover crop and this, in combination with higher soil compaction a low nutrient content, resulted in a poor ground cover as noted by Guzman et al. (2019). In other study areas, predictions show that the implementation of PCC reduced soil losses by 87% to 93% with respect to CT management, reaching values close to sustainable erosion rates, from 3.31 ± 2.11 in Austria, to $1.21 \pm 0.96 \text{ t ha}^{-1} \text{ year}^{-1}$ in Italy. The predicted values and reduction are similar to those observed in the already cited monitoring experiment in north Italy (Biddoccu et al., 2016), where the average soil losses in a vineyard with permanent grass cover resulted in $1.8 \text{ t ha}^{-1} \text{ year}^{-1}$, showing 74%–91% reduction with respect to tilled vineyards. The lowest values for SL estimated with PCC management are mostly related to lower C-values, lower than 0.1 only for this treatment and up to 91% smaller than in the higher intensity management in the same region (Fig. 5). It is also worth noting, and in the line of the discussion above on the need to proper local calibration, that different management classes differed in some of the topography related model parameters, because farms with different management tend to be located in areas with slightly different topography. In Italy PCC vineyards showed also the lowest values of K and L, in Austria and France the same factors presented at least 12% reduction compared to the high intensity management.

The exploratory analysis using PCA shows (Table 7, Fig. 6), as expected, differences between the conservative and the non-conservative soil managements. In Fig. 6 there is a clear distinction between management classes with the non-protecting soil management, showing both higher PC1 and PC2 values. For the same area, the soil protective managements were associated to lower values of C-factor, resulting in lower PC2 values, and also higher S-factor and lower K and L-factors, resulting in smaller value for PC1. Different distribution of points across the graph is also evident among regions: on the most left side of the graph (with negative PC1 values), the plot shows again the Italian values (lowest values for K and L and highest values for R and S) together with some values from French vineyards. Increasing values for PC1 are associated to points corresponding to SL estimations that were made for other vineyards in France, and then Spain, Romania and Austria, which tend to overlap. Such distribution reflects primarily the increasing values of the L-factor, which is lower than 2 in Italy and France, and greater than 2.4 in other areas, and also the variability among regions of K and R factors. Stepwise multiple linear regression (Table 8) showed that in predicting the soil losses for the soil protecting managements, the highest determination coefficient (and so the explanatory power) was found for the C-factor ($R^2 = 0.383$), and secondarily for average annual erosivity (increase of $R^2 = 0.136$), which is characteristics of each region, followed by local topographical conditions (L and S factors) and by soil erodibility. This reflects the fact that once achieved a high ground cover, as is the case of PCC treatments, the differences due to management tend to be minimized across different areas (as the C values tend to converge) and differences due to topography and rainfall erosivity tend to be relevant for explaining variability among areas.

3.2.1. Soil loss predictions for hypothetical alternative soil managements

This exercise allows the evaluations of the potential impact of alternative soil management that might reduce, or increase soil losses as compared to current management, and it is summarized in Table 6. In Romania and in Spain the simulations that considered PCC as alternative soil management resulted in a reduction of annual SL by 85%, with respect to those predicted with partial cover crop, reaching values close to the upper limit of the tolerable soil erosion rates ($1.4 \text{ t ha}^{-1} \text{ year}^{-1}$) proposed for Europe by Verheijen et al. (2009): $1.8 \pm 1.4 \text{ t ha}^{-1}$ in Romania and $1.5 \text{ t ha}^{-1} \pm 1.1$ in Spain. Such reductions in predicted soil losses are consistent with those estimated for real scenarios, and above mentioned in-field measurements. In combination with the unsustainable erosion rates predicted for both real managements resulting in partial and total bare soil in Spain (TCC and CT) and Romania (ACC and CT), these results highlight the need to keep working in the regions for soil management that maximize ground cover, as close as possible to PCC. For this, considering the seeding of cover crops and improvement of soil conditions should be a priority. Also, they highlight the need in continuing research in minimizing and properly appraise the risk of competition for soil water with the vines under these improved ground cover based management (e.g. Gómez & Soriano, 2020). In all cases, as expected, the hypothetical shift to a bare soil using herbicide management, NT, resulted in a substantial increase in predicted soil losses as compared to the non-protective soil management currently used in the area, with increases of 3.7, 2.0, 1.5 times as compared to CT in Spain, Italy and Romania, respectively. This is in the range of the observations of Raclot et al. (2009) in southern France: they compared soil losses measured during 18 rainfall events in two vineyards, finding average soil losses 4.5 times higher in NT than in CT. Similarly, the alternative soil managements with bare soil that were simulated in Austria resulted in worsening of predicted soil erosion risk by 5.7 and 1.8 times with respect to ACC, for NT and CT, respectively. The results suggest the relevant effect of adoption of agro-environmental schemes related to the CAP promoting soil conservation measures to reduce soil erosion, as those implemented in the last 15–20 years in Austria.

3.2.2. C factor estimation for different managements and countries

The cover and management C factor of RUSLE is the main factor where changes due to soil management in erosion risk are introduced and then proper predictions can only be made if this parameter actually conforms to the situation to be predicted. To the authors, one of the most interesting results of our analysis in this section is to provide a first attempt to appraise variability in determination of this C factor at local level for a give management definition, and among different areas for similar management definitions. They are summarized in Fig. 7, where the cumulative probability distribution appears by different soil management and study area. In all the graphs it is apparent a lower variability for hypothetical scenarios (e.g. NT for areas other than France) which reflects the bias towards a lower farm to farm variability than when this variability is appraised with actual farm surveys (e.g. CT in Spain). A more relevant observation from Fig. 7 is that same management under different rainfall erosivity distribution presents different C values, which is not a novel result but again tend to be overlooked in large scale studies. This is quite apparent in Fig. 7, showing the C cumulative distribution for C values for NT soil management, showing clearly two different, non-overlapping, distributions for central Romania and S Spain from one side, with lower C values probably due to lower values of the S_m subfactor, and E Austria and NW France with higher C values. Italian C-factor values for NT show are the lowest, with higher variability than

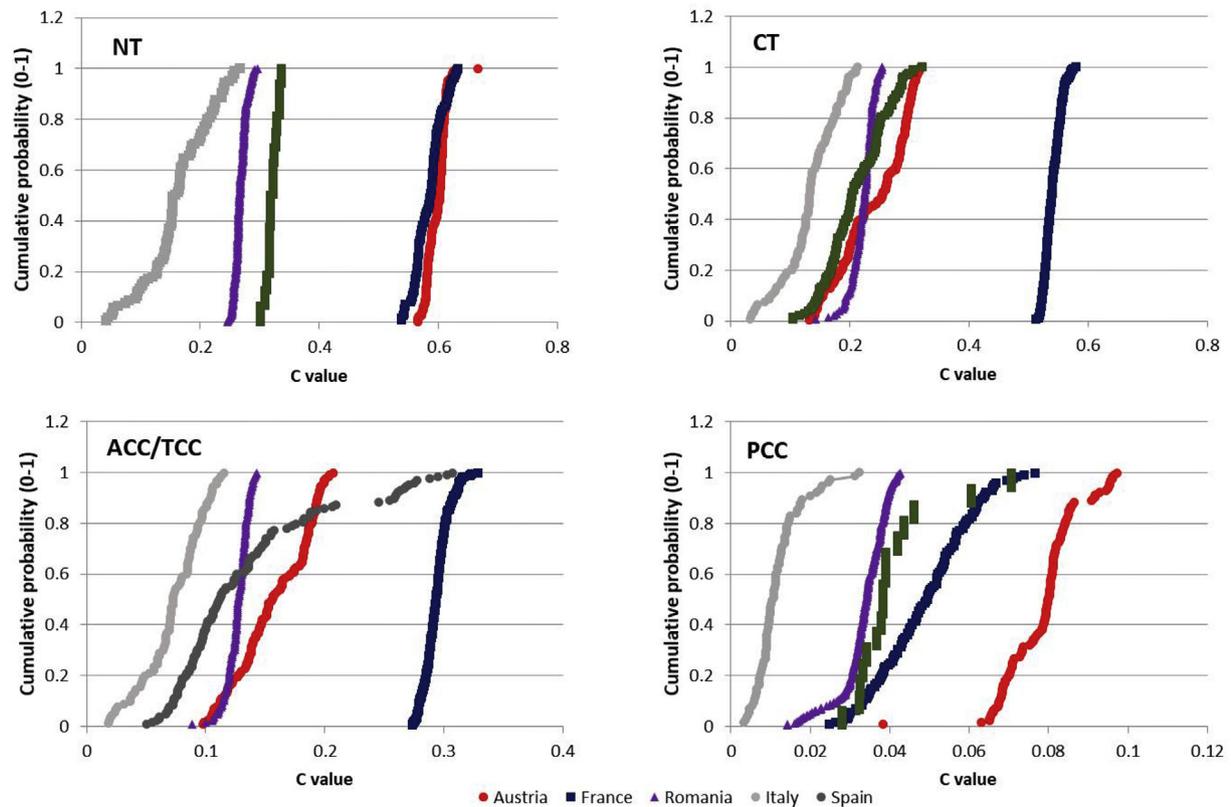


Fig. 7. Cumulative probability distribution curves for C-factor for the different management and countries.

other countries. An analogous shift in C distribution appears for PCC for the five countries, with NW Italy showing the lowest values, then S Spain and central Romania with slightly lower variability, whereas larger variability was observed for values obtained in NW France and E Austria, with the latter presenting the highest values. The cumulative probability distribution of C values for ACC-TCC and CT presents a wider distribution reflecting also the higher farm to farm variability. But despite this also presents a shift associated to the area. This shift reflects the interaction of annual distribution of rainfall erosivity and rainfall directly in the model in different subfactors, S_m , S_r , R , weighted averaged of annual C; and also the effect of rainfall depth and temperature on differential plant and vegetation growth across areas which subsequently is incorporated into the model predictions. The analysis of statistically significant differences among C values in Table 6 shows that C values differed among managements for the same area, but also that they tend to differ significantly for the same management among the areas. This result suggests again that the variability in C values among different areas needs to be properly addressed and interpreted, particularly because in most RUSLE based erosion analysis, it tends to be extrapolated from tables offering average values for various management classes (e.g. Panagos et al., 2015b). Another interesting exercise is that of comparing our array of C values with those proposed in the literature for different soil management. For instance, the C-factor values calculated for PCC managements, actually happening at the vineyards, resulted lower, up to more than 10 times smaller, than the minimum value estimated at European scale (Panagos et al., 2015b). The range of variability of C values between protecting, and non-protecting soil management found in our study tend to be slightly wider than the one used by Panagos et al. (2015b) for vineyards for RUSLE application at European scale, 0.15–0.45, although interestingly it is not far off of

those proposed by Auerswald and Schwab (1999) for Germany, who determined C-factor for vineyards with different soil management, obtaining 0.59 for bare soil and 0.03 for permanent grass. These differences with some of the published values, particularly the lower C value for PCC might be the effect of differences in rainfall distribution in comparison to the studies where previous C values have been proposed. Furthermore, the incorporation of specific values of vegetation cover, ground cover and surface roughness as well as the incorporation of the S_m subfactor in the calibration of C, contributed to extend the range of C-factor values, something that seems to be supported by the analysis of the calibration strategies against experimental data. Although the experimental dataset used in our analysis is small, this result suggests that this is point of concern in our current use of C values in vineyards across Europe, and should be further explored.

Overall, these results show clearly the importance of using C-factor obtained taking into account local management and climate, especially rainfall, which allows better soil losses prediction than using literature values, referred to unknown or very different local and management conditions, namely for a land use that is characterized for such high variability. Also the need to introduce uncertainty in proposed C values for simulation analysis based on farm management classes and/or ground cover determined by remote sensing should be considered. For instance, Baiamonte et al. (2019) estimated the inter- and intra-annual variability of C-factor in vineyards from remote sensing data, with methods using NDVI. Almagro et al. (2019) used the same method to estimate C-factor, and then calibrated it with measured data: they obtained significant improvement in soil losses estimation with RUSLE. ORUSCAL allows local estimation of C-factor for a single vineyard, by means of datasets that can be easily obtained, based on farmers' knowledge, eventually integrated with some field observations, and from local weather services.

3.3. Implications for further research, management options for wine growers and related policies

Soil erosion risk predicted by ORUSCAL was exceeding the tolerable erosion rate for most of current and hypothetical (but possible) scenarios, up to more than 48 times higher in the worst case scenario. While different regions, vineyards and management strategies resulted in high variability of RUSLE factors and soil losses estimation, predictions showed a good agreement with mid to long-term monitoring data at similar scale. Only with the use of permanent cover crop predicted soil losses were lower or close to soil formation rate in Europe. The use of partial (alternate or temporary crops) resulted in a substantial lowering of soil erosion risk (at least 43%), in agreement with the objectives of agri-environmental measures that have been implemented in the last decade in some European countries, and also in some of the studied regions. In Austria, for example, participation rates in erosion protection measures account for about 50% of the total vineyard area in Eastern Austria (BMLFUW, 2016; Österreich Wein, 2019); in Italy, 15.4% of Piedmont's agricultural area utilized for vineyards (and orchards) adopted grass covering for soil erosion prevention (Regione Piemonte, 2016). Indeed, a recent analysis included in the Impact Assessment of the post 2020 Common Agricultural Policy (European Commission, CAP 2021–2027, 2018) estimated the impact of cover crops on reducing soil erosion in permanent crops by up to 37%. In addition, other recent studies demonstrated that lower intensity managements in vineyards generally leads to improved soil properties, biodiversity and other eco-system services (Guzman et al., 2019; Winter et al., 2018). Results of this study highlight the need for maintaining and/or increasing the adoption of cover crops in order to achieve tolerable soil erosion rates in European vineyards.

To reach such objective, local soil erosion risk estimation, also at farm level is necessary, to increase awareness of stakeholders. Models of the USLE family, especially RUSLE in more recent times, have been widely used to assess the soil erosion risk in European wine growing regions, at different spatial scales (Martínez-Casasnovas & Bosch, 2000; Napoli et al., 2016; Pappalardo et al., 2019; Pijl et al., 2019; Rodrigo Comino et al., 2016). Although many authors have tried to use C values reflecting in the local management conditions most adequately, in most occasion they used reference values that were not locally defined and calibrated. The GIS map representing the C-factor assessment for EU28, at 100 m resolution (Panagos et al., 2015b), represents a widely used source for this factor. The estimation of C-factors obtained in the present study shows a great variability (also vineyard to vineyard) for this factor and led to the identification of values that are not included in the range proposed in the European map for vineyards. The implementation of ORUSCAL in different study areas across Europe shows that it could be an effective strategy for the scientific community, for calibration and identification of site-specific values for C-factor. It could also be used for the evaluation of soil erosion risk under different intensities of soil management with limited datasets, with demonstrative and technical purposes. Indeed, ORUSCAL is proposed as a simple and effective tool to simulate at field scale the effect of implementation (or not) of soil conservation measures on soil losses, based on datasets that can be obtained by a collaborative approach involving farmers and technicians. The output can assist in designing the most appropriate soil conservation measures for their commercial vineyards and into disseminating best management practices. Such approach would be crucial for increasing the participation and awareness of farmers towards soil conservation measures to implement effective soil conservation policies, as pointed by Marques et al. (2015). Indeed, the advantage of using ORUSCAL is its ability to estimate soil losses, but also the RUSLE factors taking into account of the variability in soil, topographical, climate,

management conditions by means of datasets that are low-cost, easily accessible (climate data, topographical) or that can be retrieved from field observations and farmers'/technicians' experience.

4. Conclusions

To best of our knowledge, this is the first comprehensive analysis of predicting erosion rates at hillslope scale across different wine growing regions in Europe, using the RUSLE approach with long-term experimental data and farm based information. Our findings suggest that the best strategy for calibration should incorporate the soil moisture subfactor (S_m), since it provided the best soil loss predictions. The comparison across the five wine-growing regions indicates that PCC is the only soil management practice achieving sustainable erosion rates across the areas studied, whereas ACC and TCC failed to achieve this goal. Improvements in the implementation of TCC, providing higher ground cover and/or during a longer time period, or expansion of PCC in areas where it is currently rarely implemented needs to consider the competition for soil water, particularly in more dry areas. Differences in predicted erosion rates across areas highlight the need to properly consider differences in climate, topography, soil variability, and impact of management on ground cover. This can only be made with a careful calibration incorporating local specific features in order to avoid introducing major bias in large scale studies when extrapolating RUSLE parameters, particularly the C factor. The C factor presented a large variability due to coupling with local climate and specific local management. This raises the need for a careful use of C values developed from different conditions, during RUSLE implementation. Furthermore, it is essential to consider the farm to farm variability in C values within the same soil management type, even within the same area. A probabilistic approach to the C distribution might result in more reliable data which could address the uncertainty of the erosion predictions and the statistical significance of differences in mean values among different areas and vineyard management.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.iswcr.2020.07.003>.

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