Five decades of soil erosion research in “terroir”. The State-of-the-Art

Article *in* Earth-Science Reviews · February 2018

DOI: 10.1016/j.earscirev.2018.02.014

Jesús Rodrigo-Comino
University of Malaga

Earth-Science Reviews 179 (2018) xxx–xxx

Contents lists available at ScienceDirect

Earth-Science Reviews

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

Five decades of soil erosion research in "terroir". The State-of-the-Art

Jesús Rodrigo-Comino

Instituto de Geomorfología y Suelos, Department of Geography, University of Málaga, 29071, Málaga, Spain
Physical Geography, Trier University, 54286 Trier, Germany

ARTICLE INFO

Keywords:
Soil erosion
Vineyards
Bibliographic review
Natural factors
Anthropogenic factors

ABSTRACT

Although soil erosion in vineyards is key to understanding the sustainability of agricultural management, there is not a worldwide definitive state-of-the-art review. It is accepted that soil erosion in vineyards has been more a scientific issue than an agronomic and environmental concern, and this review will point out key issues that will allow the designing of new and advanced research projects. It is demonstrated that soil erosion in vineyards is well assessed in the scientific literature with a diverse array of studies in Europe, but there is a lack of similar studies on other continents such as America and Oceania and no research in Africa or Asia. Chile and Germany were the pioneer research countries with professors Gerold Richter and Riquelme Chaparro leading early erosion work in vineyards, but the most surveyed countries are France, Italy and Spain, with Greece and Germany also having a large number of studies. Most of the research has been based on modelling, rainfall simulation and erosion plots. The survey concludes that soil erosion rates in vineyards are higher than those in other land uses and represents a worldwide threat to sustainability in vineyards. This is due to intense tillage, planting of vineyards on steep slopes and in poor soils. There is a need to find management practices that are socially and economically acceptable to farmers and that will achieve sustainability through reduction of soil losses via nature-based solutions.

1. Introduction

Soil is a key sphere of Earth's ecosystems (Duchaufour 1970; Fitzpatrick 1980; Jenny 1961). They regulate Earth's biogeochemical cycles and influence hydrological and erosional processes (Aradottir and Hagen 2013; Mol and Keesstra 2012; Rodrigo-Comino et al. 2018a). Soils supply goods, services and resources to humankind that are key to achieving sustainable civilizations (Mase et al. 2015; Riding et al. 2015). Soils also play a central part in the United Nations Sustainable Development Goals (Keesstra et al. 2016a), and a sustainable society needs healthy soils to keep humans healthy (Steffan et al. 2018).

Soil erosion is a major threat to achieving sustainability in agroecosystems. High erosion rates disturb natural cycles and crop production (Alewell et al. 2015; Muluneh et al. 2017a), making soil erosion one of the most important issues that needs to be solved by humankind to achieve sustainability (García-Ruiz et al. 2015; Panagos et al. 2017).

Intensive land management practices in agricultural fields such as maintaining bare soils through the use of herbicides and heavy machinery induces high erosion rates (Jie et al. 2002). Another key factor is high rainfall erosivity (Nearing et al. 2017; Feng et al., in press) that triggers splash and surface wash erosion (Fernández-Raga et al. 2017). This in turn results in sheet and rill erosion that leads to a decrease in soil quality and crop productivity (Keshavarzi et al. 2018; Khaledian et al. 2017). Soil erosion rates in vineyards have high values in comparison to other types of orchards such as olives (Ibáñez et al. 2014; Kairis et al. 2013; Taguas et al. 2015), almonds (Martínez-Hernández et al. 2017), apricots (Keesstra et al. 2016b), citrus (Jianjun et al. 2017; Cerdà et al. 2018) and avocados (Atucha et al. 2013) as well as cereal crops (Munodawafa 2011; Schweizer et al. 2017).

Studies of soil erosion in vineyards have primarily focused on three specific countries: France, Italy and Spain, which are known as "Mediterranean vineyards" in the scientific literature. The International Organization of Vine and Wine (O.I.V.) estimated a total worldwide surface area for vineyards at about 7516 kha, of which Spain (975 kha), France (785 kha) and Italy (690 kha) represent 13.0, 10.4 and 9.2%, respectively (Table 1) (O.I.V., 2017). These same three countries also represented the highest wine production (50%) and wine exportation in terms of volume (18%) and monetary value (57%). However, there are several other countries that also have large areas of vineyards such as China, Turkey, USA, Argentina, and Iran (Table 1) and that represent a high percentage of world grape production (39.1%). This shows that grape production is not just a Mediterranean issue; although the perception of much of the population is that wine is synonymous with Mediterranean areas. On the contrary, vineyards are widespread worldwide and the environmental problems they cause are also widespread. Vineyards also show a clear trend of growing area due to

E-mail address: rodrigo-comino@uma.es.

https://doi.org/10.1016/j.earscirev.2018.02.014
Received 20 October 2017; Received in revised form 12 February 2018; Accepted 16 February 2018
Available online 24 February 2018
0012-8252/

Table 1
Statistics from relevant vitivinicultural countries in 2015–2016. *Data were reported fort the countries with > 100 kha, > 1 Mg * 10–6, > 1 hl * 10–6 and > 0.5 billion €. Numbers in brackets mean the total variation from 2015.
Source: O.I.V., (2017).

Country	Surface area (kha)	Grape production ($Mg * 10^{-6}$)	Wine production ($hl * 10^{-6}$)	Wine consumption ($hl * 10^{-6}$)	Wine exportation ($hl * 10^{-6}$)	Export (billion €)
Spain	975 (+1)	6 (0)	39.3 (1.6)	9.9 (−0.1)	22.9 (−1.8)	2.6 (0)
China	847 (+17)	14.5 (+0.8)	11.4 (−0.1)	17.3 (+1.1)	–	–
France	785 (0)	6.4 (0)	43.5 (−2.5)	27 (−0.2)	14.1 (+0.2)	8.2 (−0.1)
Italy	690 (+8)	7.9 (−0.3)	50.9 (+0.9)	22.5 (+1.1)	20.6 (+0.5)	5.6 (+0.2)
Turkey	480 (−17)	4 (+0.4)	–	–	–	–
USA	443 (+13)	7.1 (−0.2)	23.9 (+2.2)	31.8 (+0.8)	3.8 (−0.4)	1.4 (0)
Argentina	224 (−1)	1.8 (−0.6)	9.4 (−4)	9.4 (−0.9)	2.7 (−0.1)	0.7 (0)
Iran	223 (0)	2.2 (0)	–	–	–	–
Chile	214 (0)	2.2 (−0.9)	10.1 (−2.8)	2.2 (+0.1)	9.1 (+0.3)	1.7 (+0.1)
Romania	191 (0)	–	3.3 (−0.2)	3.8 (−0.1)	–	–
Portugal	190 (−9)	–	6 (−1)	4.6 (−0.2)	2.8 (0)	0.7 (0)
Australia	148 (−1)	1.8 (+0.1)	13 (+1.1)	5.4 (+0.1)	7.5 (7.4)	1.5 (0)
Moldova	140 (0)	–	1.7 (0)	–	1.2 (0)	–
South Africa	130 (0)	1.9 (−0.1)	10.5 (−0.7)	4.4 (+0.2)	4.3 (+0.1)	0.6 (0)
Uzbekistan	127 (0)	1.3 (−0.1)	–	–	–	–
India	120 (0)	2.6 (0)	–	–	–	–
Greece	105 (−2)	–	2.6 (+0.1)	2.3 (−0.1)	–	–
Germany	102 (−1)	1.2 (0)	9 (+0.1)	19.5 (−0.1)	3.6 (−0.1)	0.9 (−0.1)
World	7516 (+1)	75.8 (−1.5)	267 (−9)	241 (+1)	104 (−0.1)	29 (+0.1)

increasing wine consumption, which was estimated to be > 1 hl 10^6 in 2016 (O.I.V., 2017).

Soil erosion is a problem that affects vineyards worldwide. This is well documented in the scientific literature, but there is not a current review that shows the state-of-the-art. In general, it is accepted that soil erosion is high in vineyard fields and catchments (e.g. Raclot et al. 2009) and historically this has mainly been a Mediterranean issue (Prosdocimi et al., 2017b). It is well-known that there is an increasing expansion of vineyards in other regions and it is necessary to assess what the scientific community knows so we will be able to better plan future research. In addition, information about soil erosion in vineyards has often failed to reach farmers, and we can affirm that soil erosion in vineyards has been more a scientific issue than an agronomic or environmental concern. Two possible reasons can be hypothesized for this: i) there is no soil erosion and it is a pure scientific issue that the stakeholders avoid, or ii) there is an important lack of information, and thus, lack of interest by farmers, policy makers and wineries concerning its consequences. Therefore, a review has been carried out to assess: i) where and how soil erosion studies have been conducted; ii) which methods have been applied to measure soil erosion rates; iii) an estimation of soil erosion in vineyards around the world; iv) which factors are enhancing soil and water losses; v) who did the research and where it is published; and, vi) which solutions were found to reduce soil losses and achieve sustainable crop management.

2. Bibliographic review

Ninety-one publications on soil erosion in conventional vineyards were assessed. These references were compiled from ISI-Web of Knowledge, Google Scholar, PubMed, ResearchGate and Scopus. Pioneers in researching soil erosion in vineyards were also contacted personally. The search was performed in English using the terms "vineyards" and "soil erosion". The reference lists of every study on the topic were also reviewed for possible eligible studies about soil erosion research in vineyards. Several researchers cited local studies in languages such as French, Spanish, Italian and German, therefore, a new search was done using the terms *érosion du sol* and *vignobles*, *erosión del suelo* and *viñedo, erosione del suolo* and *vigneto*, and *Bodenerosion, Weinberg* or *Weinbau*, respectively. Books (4), proceedings (4) and PhD Theses (6) and several papers in other languages related to the topic were found, but were not used because they sometimes duplicated the data in papers and most of them are difficult to find; only some of them are available to the public.

A data base compiling authors, title, year of publication, journal, region, method, soil loss rates ($g\,m^{-1}$, $g\,m^{-2}\,h^{-1}$, m^3, $Mg\,ha^{-1}$, $Mg\,ha^{-1}\,h^{-1}$ and $Mg\,ha^{-1}\,yr^{-1}$), runoff coefficient (%), sediment concentration ($g\,l^{-1}$) and main conclusions was developed. Depending on how data were obtained, adjustments had to be performed: i) when monthly or yearly data were presented in tables, mean values were calculated; and ii) if more than one study area was surveyed in the same article, all of them were treated as different study cases. However, for our soil erosion survey only data in $Mg\,ha^{-1}\,yr^{-1}$ was used because this is the most comparative and representative unit. The other data with different units were disregarded, assuming that generalization was problematic.

3. Data dissemination

Several studies applying a wide range of methods have been carried out to assess and quantify soil erosion in vineyards over the last 50 years. Ninety-one articles were assessed, of which 86.7% were published since 2000 and only 13.3% between 1977 and 2000 (Fig. 1). The earliest measurements of soil erosion in vineyards took place in South America, in the Ñuble Province of Chile from 1971 to 1974, after high soil losses were observed in a tilled vineyard. The data was published in Merino et al., (1979) in Spanish by the Chilean Journal of Agricultural Research. It resulted from research at the Department of Agronomy of the Universidad de Concepción that formed the PhD

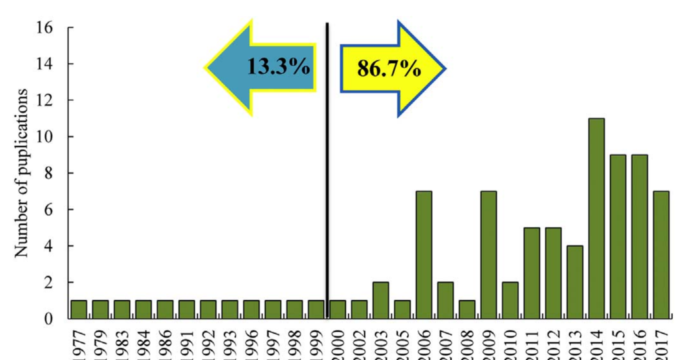


Fig. 1. Number of published papers from 1977 through September 2017.

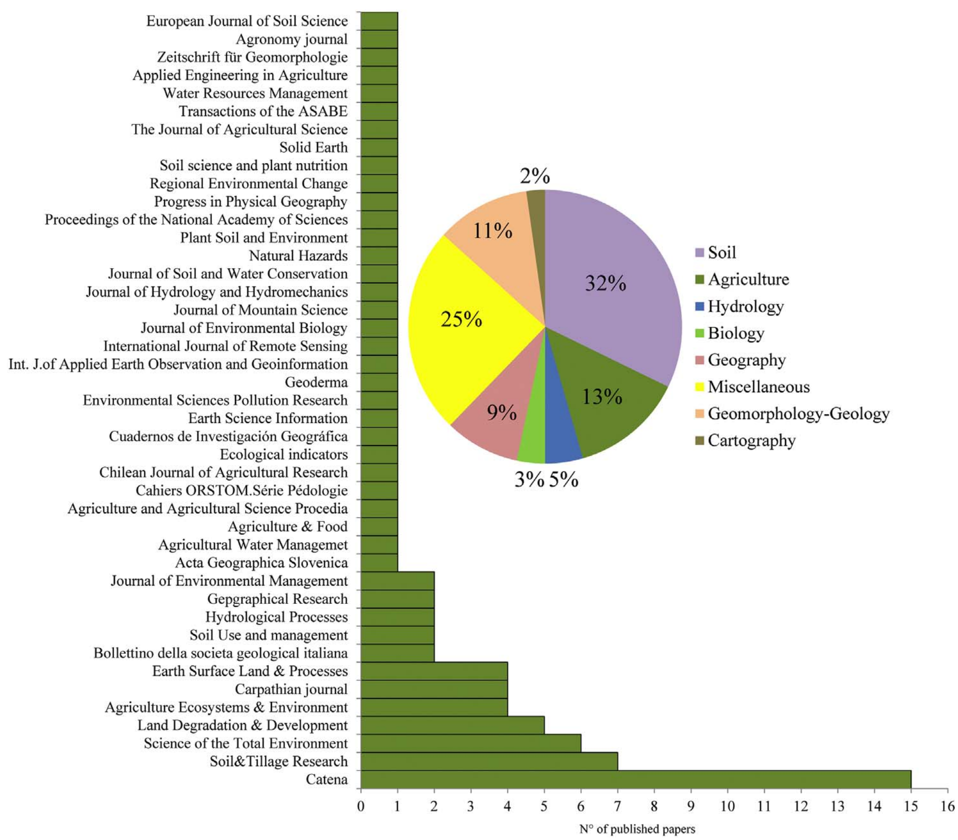


Fig. 2. Journals that have published papers related to soil erosion in vineyards.

Thesis of Prof. Riquelme Chaparro, which focused on soil water properties (Riquelme Chaparro 1970) and some other studies conducted from an agronomic point of view (Riquelme Chaparro et al. 1972).

The first paper published in an international (English language) peer-reviewed journal was by Richter and Negendank in 1977 investigating soil erosion in old and young vineyards in Germany using 13 erosion plots. This research was conducted in the sloping vineyards (> 20°) of the Ruwer-Mosel Valley from 1974 to 1975. After this publication, several research papers (Richter 1980, 1983) and books (Richter 1975, 1979, 1989, 1991), most of them in German, were published at the experimental research station designed by Trier University.

The German group from Trier University started to highlight the importance of two driving factors of soil erosion that have been highly assessed during the 21th century: i) activation of geomorphic processes due to extreme rainfall events (Biddoccu et al. 2016; Martínez-Casasnovas et al. 2002; Rodrigo-Comino et al. 2017a); and ii) the influence of the age of vineyards on soil erosion (Cerdà et al. 2017a; Rodrigo-Comino et al. 2017b). On the other hand, the Chilean research group established the first research into the use of cover crops in vineyards in 1971, which is the main topic of research groups such as IMIDRA (Instituto Madrileño de Investigación y Desarrollo Rural, Agrario y Alimentario) (Marques et al. 2010; Ruiz-Colmenero et al. 2011, 2013), SEDER (Soil Erosion and Degradation Research Group) (Prosdocimi et al., 2016a, 2017a; Cerdà et al., 2017a, b), the Italian National Research Council (Biddoccu et al. 2016, 2017a) and the University of Palermo (Novara et al. 2011, 2013, 2018). The two approaches (geomorphological and agronomical) are due to the fact that the two groups come from different disciplines. The German research group is based on a physical geography foundation (Gebhardt et al. 2012) and the Chilean group on an agronomy foundation. Both teams worked in isolation and their findings never reached the other team. Only now, with this review, have Trier researchers found the contributions of the Chilean team and interviewed the authors of the Chilean research. The Trier group agrees that the Chileans were the pioneers of soil erosion research in vineyards, but that both teams developed vineyard erosion research programs on their own.

During the 1980s, research teams from Italy, France and Spain published the first studies about soil erosion in vineyards related to the influence of bare soils and parent material (Tropeano 1984), management practices (Augustinus and Nieuwenhuyse 1986) and inherent soil properties such as soil texture and soil water retention capacity (Lasanta 1985; Ortigosa and Lasanta, 1984). During the end of the 1980s and early 1990s, the first modelling techniques based on Landsat remote sensing (Jürgens and Fander 1993a, 1993b) were conducted in Trier and Champagne (France) (Gourbesville 1997). The datation techniques with Caesium-137 (Loughran et al., 1988, 1992; Loughran and Elliot 1996) were introduced to study soil erosion in the Hunter Valley viticulture region in New South Wales, Australia.

Soil erosion in vineyards has been a relevant topic that is bringing new ideas to the scientific community during the 21st century. Concerns are being addressed from different perspectives and points of views than those used by the Chilean and German pioneer research teams. Different groups have published several articles combining soil erosion monitoring, modelling and experimental techniques in the viticulture regions of Pènedes by Lleida University (Martínez-Casasnovas et al. 2005; Ramos, 2006, 2016; Ramos et al. 2000) and Málaga (Martínez Murillo and Ruiz Sinoga 2003; Rodrigo-Comino et al. 2016a, 2017c; Ruiz Sinoga 1987) in Spain. Other research groups are located in the Chianti (Napoli et al. 2013, 2016, 2017) and Sambuca-Sicily (Novara et al. 2011, 2013, 2015, 2016, 2018) regions in Italy and Burgundy (Brenot et al. 2006, 2008; Quiquerez et al. 2008, 2014) and Montpellier-Nancy (Blavet et al. 2009; Le Bissonnais et al. 2002; Raclot et al. 2009) in France.

It is also important to stress the potential unpublished studies that have been performed. For example, scientists interviewed indicated that many research projects on vineyards were started few decades ago in Portugal, Italy, France and Spain, but the data are not available to the general public or is published in their respective native languages, making it less assessable to the international scientific community as a whole. Therefore, it is important to investigate the distribution of results from different countries over the last 20 years, when the number of publications in vineyard erosion research increased considerably. Fig. 2 shows the number of published papers per journal and the primary areas they reported on. Thirty-two and 25% of the total papers reporting on soil erosion in vineyards were published in soil science and miscellaneous journals, respectively. Agricultural (13%), geomorphological-geological (11%), and geographical (9%) journals have also published papers related to soil erosion in vineyards. Erosion is a topic that has also drawn interest in hydrological, biological and cartographic journals. In total, the papers for this review were compiled from 45 different journals. This shows a healthy and diverse distribution of the science. Catena was the journal with the highest number of papers published on soil erosion in vineyards (15), followed by Soil & Tillage Research (7), Science of the Total Environment (6) and Land Degradation & Development (5).

4. Methods to assess and quantify soil erosion in vineyards

At least seventeen different methods have been applied to assess and quantify soil erosion in vineyards. Fig. 3 shows that the largest category of research projects was based on soil monitoring methods with direct measurements, followed by modelling. Smaller numbers of projects used field and laboratory experiments.

Fig. 4 shows the different methodological approaches that have been used to investigate soil erosion in vineyards. The most utilized technique to assess and quantify soil erosion has been soil erosion plots, used in twenty papers (Fig. 4a). Erosion plots are characterized by either an open and uncertain area (Rodrigo-Comino et al. 2017a, 2017b) or closed and well-known area (Komac and Zorn 2005; Ramos et al. 2015; Vrsic et al. 2011) with a sediment collector or Gerlach trough (Gerlach 1967). The main advantage of both methods is that the soil erosion units used are usually common and easy to compare to other studies. In open plots, $g\,m^{-1}$ or $l\,m^{-1}$ are typically used while in closed plots the units are usually $g\,m^{-2}\,yr^{-1}$ or $Mg\,ha^{-1}\,yr^{-1}$. The plot sizes ranged from $0.5\,m^2$ to $10\,m^2$.

A total of nine papers were published using soil erosion pins to measure the lowering of the soil surface. Erosion pins (Fig. 4.b) function as passive indicators of soil erosion/deposition (Bazzoffi et al. 2006; Novara et al. 2011, 2018; Vršič 2011). Other researchers used

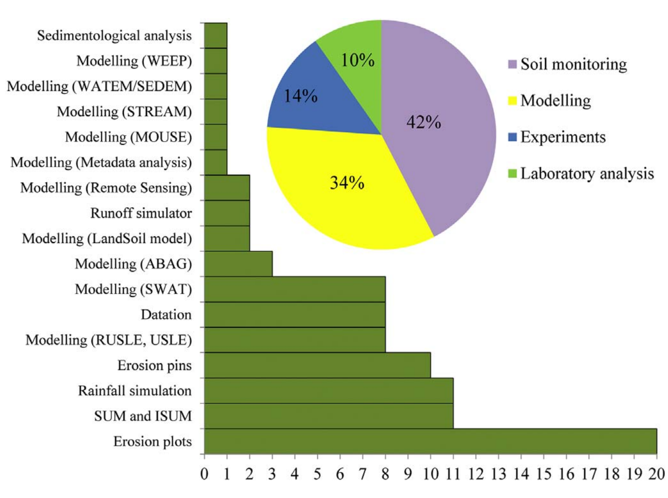


Fig. 3. Methodological approaches per published paper on soil erosion research in vineyards.

techniques based on modelling the terrain (Fig. 4c). Ten studies were published based on the USLE (Universal Soil Loss Equation), its various improvements (e.g., MUSLE, RUSLE, RUSLE2) (Napoli et al. 2016; Panagos et al. 2014; Zdruli et al. 2016; Brevik et al. 2017) and regional adaptions such as the German version (ABAG, Allgemeine Bodenabtragsgleichung) (Hacisalihoglu 2007; Tetzlaff and Wendland 2012). Other studies focused on including other soil-water parameters such as LandSoil (Ciampalini et al. 2012; David et al. 2014), MOUSE (Gourbesville 1997), STREAM (Paroissien et al. 2015), SWAT (Martínez-Casasnovas et al. 2016; Napoli et al. 2013), WATEM/SEDEM (Lieskovský and Kenderessy 2014) or WEEP (Ramos 2016). The authors typically confirmed the difficulties in obtaining predictions for soil erosion processes due to the high variability of rainfall, the contribution of extreme events to annual soil losses, and human impacts that make it difficult to predict soil dynamics. However, the biggest advantage is that these methods allow the prediction and assessment of erosion at large scales and over long-time periods.

Another method is chronological dating, which has been used in eight publications (Fig. 4d). The use of isotopes in vineyards started at the end of the 1980s in Australia (Loughran et al. 1988, 1992). These methods have also led to one publication in Germany for Bavarian plantations (Schmitt et al. 2003) and Italy for Sicilian ones (Novara et al. 2015). The main drawback to this method is its cost and the high number of samples that are necessary (Loughran and Elliot 1996).

Rainfall simulators were used in eleven papers (Fig. 4e). These devices allow quantification of initial soil erosion processes at the pedon scale (Cerdà, 1999a, b), and the soil erosion units that are typically used (g, $g\,m^{-2}$, $g\,m^{-2}\,h^{-1}$, $Mg\,ha^{-1}\,h^{-1}$) make it difficult to compare results from different places. The use of different simulators or the same one to compare soil erosion across different viticultural regions (France, Spain and Germany) has also been tested (Rodrigo-Comino et al. 2016b, 2016c). Plots from $0.1\,m^2$ to $1\,m^2$ and rainfall intensities from $40\,mm\,h^{-1}$ to $120\,mm\,h^{-1}$ were the most frequently used in soil erosion studies in vineyards. Other research groups have used rainfall simulators to conduct experiments in soil erosion under different soil managements (Arnaez et al. 2007; Blavet et al. 2009; Morvan et al. 2014), ages of plantation (Cerdà et al. 2017a) or slope positions (Rodrigo-Comino et al. 2016a).

The use of runoff simulations is not so common in studies of soil erosion in vineyards. Actually, only two papers have been published, both of them in Spain, and with two very different goals. García-Díaz et al. (2017a, 2017b) applied runoff experiments (≈ 120 l) to measure losses of nutrients and the runoff generation in Campo Real (Madrid, Spain) under different vegetation covers (Fig. 4f.1). Rodrigo-Comino et al. (2017c) assessed the capacity of two anthropogenic rills (≈ 1000 l), called agri-spillways, to canalize soil and water losses after extreme rainfall events ($> 130\,mm\,h^{-1}$) in the sloping vineyards of the Axarquía region (Málaga, Spain) (Fig. 4f.2).

Finally, eight papers have been published related to the Stock Unearthing Method (SUM) (Fig. 4g). This method is a dendro-geomorphological tool that is based on measurement of the distance from the topsoil to the grafted vine stock union (Brenot et al., 2006, 2008; Casalí et al. 2009). SUM has been confirmed as a passive indicator of topsoil movement since the initial planting of vine stock and used to estimate soil erosion with GIS and models (Biddoccu et al. 2017c; Chevigny et al. 2014; Paroissien et al. 2010) or Gerlach collectors (Rodrigo-Comino et al. 2016d). Recently, new improvements (ISUM) related to increased measurements in the inter-row areas are being developed taking into account several factors such as the age of plantation or the time since tillage (Rodrigo-Comino et al., 2018b, 2018c; Rodrigo-Comino and Cerdà 2018).

5. Studied areas

Fig. 5 shows the locations of European sites where soil erosion in vineyards has been studied. The country with the most studies is

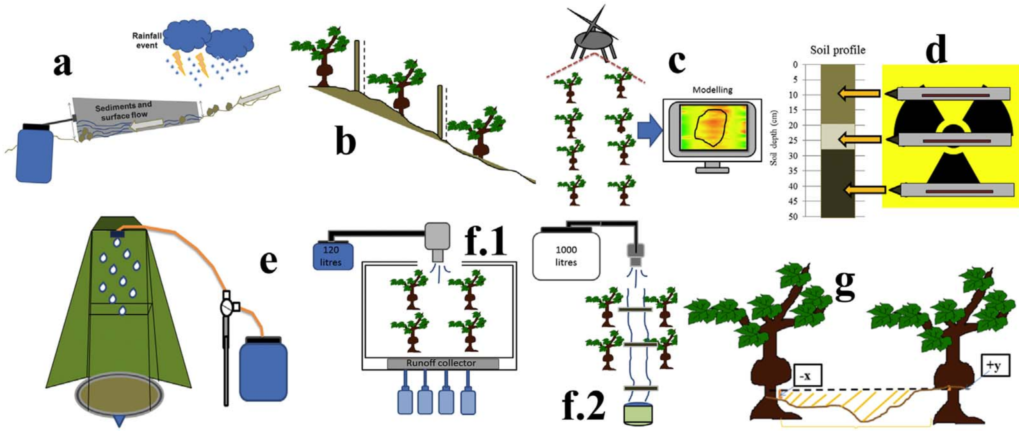


Fig. 4. Representations of the different methods applied to study soil erosion in vineyards. a: plot erosion; b: pins; c: remote sensing; d: datation; e: rainfall simulations; f.1: runoff simulation with close plots; f.2: runoff simulation with open plots; g: SUM (stock unearthing method) and ISUM (improved stock unearthing method).

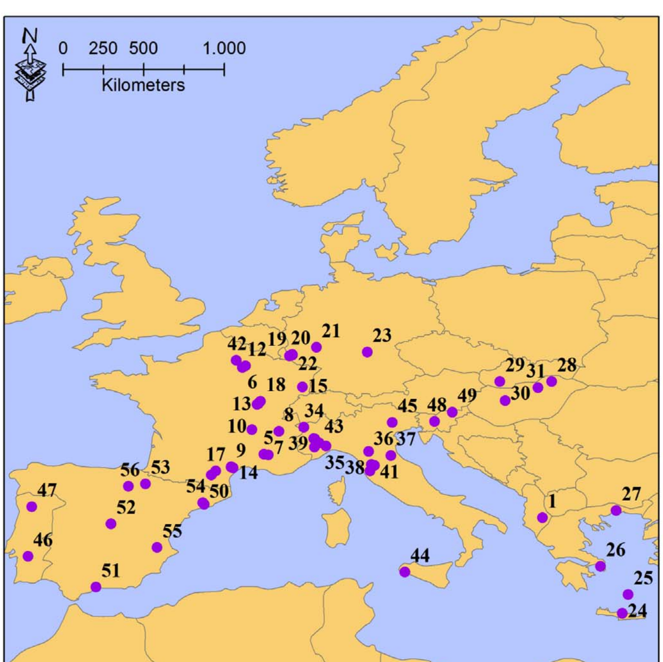
France, with a total of 18 different studies in areas such as Bourgogne, Ardèche, Vaucluse, Champagne, Languedoc-Roussillon, Alsace, Burgundy and Aude. The country with the second most studies is Italy with 14 different groups in the Piedmont, Tuscany, Emilia Romagna, Picardy, Agrigento and Venice regions. The third country is Spain, with seven places distributed in Penedès, Axarquía-Málaga, Campo Real, Navarre, Terres dels Alforins (Valencia) and La Rioja. In Germany, five different locations have been studied in the Ruwer-Mosel Valley, Hesse and Bamberg. Four different places have been studied in Hungary (Tokaj, Horny Oha; Fejér, and Nagy-Eger regions) and Greece (Crete, Santorini, Spata and Rhodes regions). Two regions have been studied in Portugal (Evora and Alto Douro) and Slovenia (Besnica Valley and Maribor) as well as one location in Albania (Korçë region).

Fig. 6 shows six sites where soil erosion studies took place outside of Europe. Four different places in the USA, in California and the Lower Yakima River Basin of Washington, have been studied. The Maxwell's Maluna Vineyards in New South Wales (Australia) and the Ñuble province of Chile have also been investigated. It must be emphasized that no research has been conducted (at least published) in Africa, where South Africa is a large producer along with the countries of the Magreb. In addition, Iran and China, which both have growing raisin and wine production, have not contributed any publications to the vineyard soil erosion literature.

6. Soil erosion rates according to methods and study areas

The soil erosion rates found by different investigation methods are shown as box plots in Fig. 7. They show the wide variability in results obtained. Pins showed the highest soil erosion rates in vineyards followed by chronological dating and SUM. Soil erosion plots and RUSLE/USLE recorded similar mean rates, although soil erosion plots had higher maximum values. Similar rates were also found by the remote sensing and metadata analyses. The lowest values of mean soil erosion were estimated by the modelling analysis techniques. Only LandSoil registered values as high as $10\,Mg\,ha^{-1}\,yr^{-1}$ ($10.6\,Mg\,ha^{-1}\,yr^{-1}$), while SWAT, WATEM-SEDEM and ABAG mean values were lower.

Fig. 8 shows the results of vineyard erosion studies by country or region. The country with the highest erosion rates is Italy. Erosion rates in Australia, Albania, Slovakia, USA, and the Mediterranean were similar, as were erosion rates in Hungary, France, and the rest of Europe.



Albania	
1	Korçe region
France	
2	Aloxe-Corton, Bourgogne
3	Cévennes-Vivarais, Ardèche
4	Côtes-de-Beaune area, Burgundy
5	Entrechaux, Vaucluse
6	Fort-Chabrol à Epernay, Champagne
7	La Romane, Auvergne-Rhône-Alpes
8	Lake Saint André, High Provence
9	Languedoc-Roussillon
10	Le Pradel, Ardèche
11	Limoux, Aude
12	Montagne de Reims, Champagne
13	Monthelie, Burgundy
14	Peyne, Languedoc
15	Rouffach, Alsace
16	Roujan, Languedoc-Roussillon
17	Villarzel-Cabardès, Languedoc-Roussillon
18	Vosne-Romanée, Burgundy
Germany	
19	Konz, Trier
20	Mertesdorf, Ruwer-Mosel Valley
21	Rheingau, Hesse
22	Waldrach, Ruwer-Mosel valley
23	Wolfsgraben, Bamberg
Greece	
24	Crete
25	Santorini
26	Spata
27	Thalassia, Rhodes
Hungary	
28	Abaújszántó, Tokaj
29	Horný Oha
30	Lake Velence, Fejér
31	Nagy-Eged
Italy	
32	Albugnano, Piedmont
33	Alto Monferrato, Piedmont
34	Aosta valley, Piedmont
35	Carpeneto, Piedmont
36	Castelfiorentino, Tuscany
37	Cesena, Emilia Romagna
38	Chianti, Tuscany
39	Cinzano, Piedmont
40	Florence, Tuscany
41	Greve area, Tuscany
42	Laonnois, Picardy
43	Mongardino, Piedmont
44	Sambuca di Sicilia, Agrigento
45	Vittorio Veneto, Venice
Portugal	
46	Evora
47	Vila Real, Alto Douro
Slovenia	
48	Besnica Valley
49	Maribor
Spain	
50	Anoia, Penedés
51	Axarquía, Málaga
52	Campo Real, Madrid
53	Eslava, Navarre
54	Piera, Penedés
55	Les Alcusses, Valencia
56	Villamediana de Iregua, La Rioja

Fig. 5. Location of the areas where soil erosion research has been conducted in Europe.

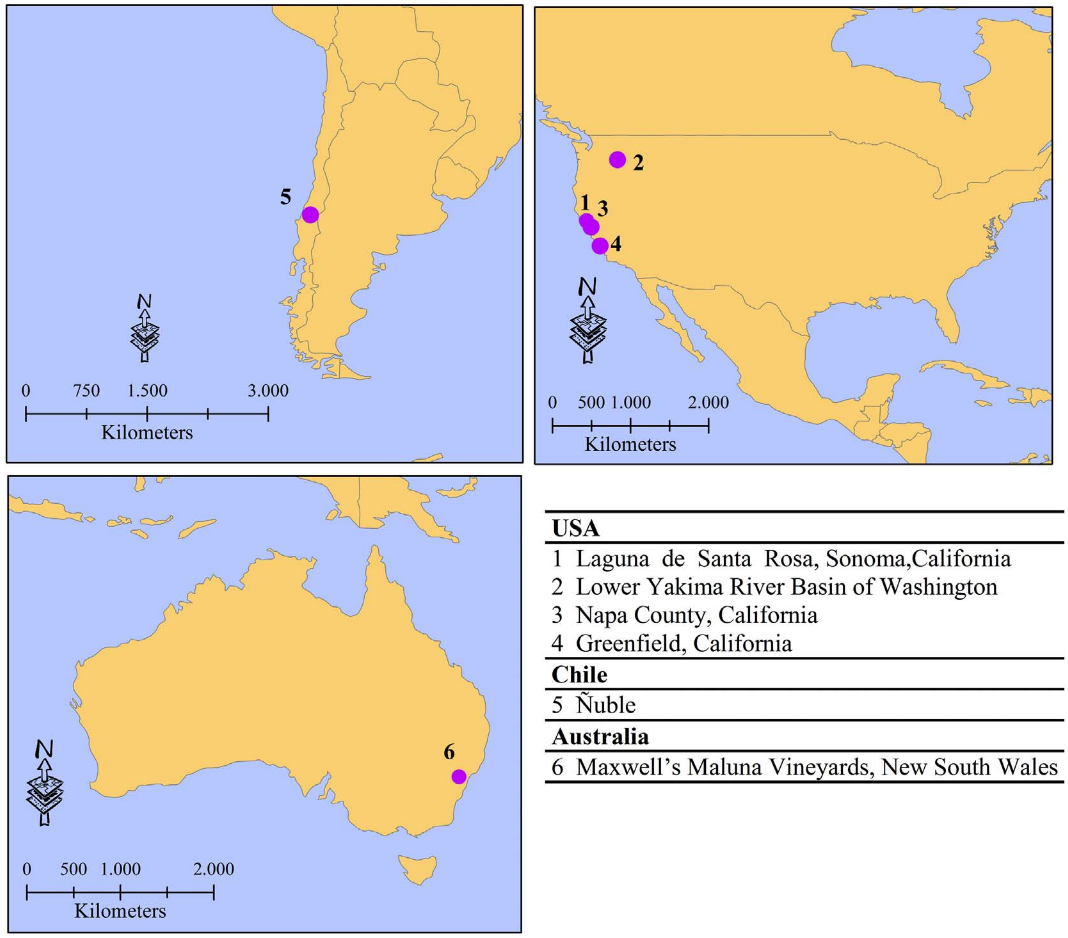


Fig. 6. Location of the areas where soil erosion research has been conducted in North America, South America and Australia.

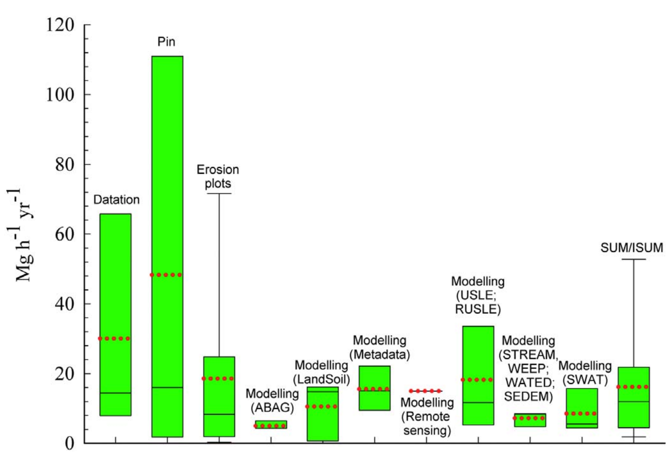


Fig. 7. Soil erosion rates in vineyards per methodological approach.

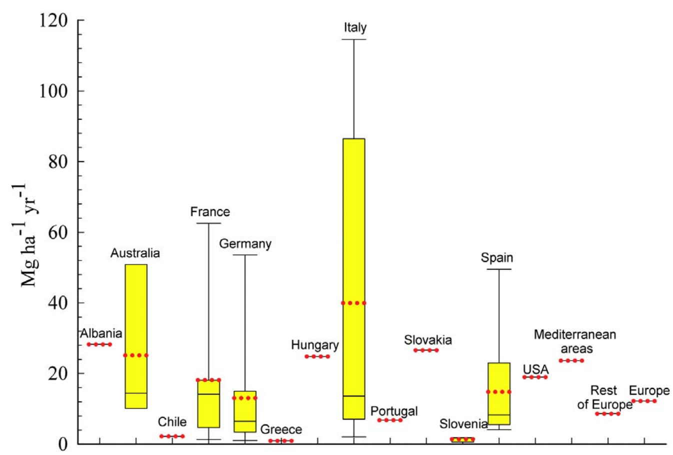


Fig. 8. Soil erosion rates in vineyards by country or regions.

Spain, Germany, and the European continental average showed similar soil erosion rates. Overall, the Mediterranean is more threatened by soil erosion than the rest of Europe.

7. Discussion

7.1. Driving factors of soil erosion processes and associated problems

Review of soil erosion research in vineyards shows that there are some factors that accelerate soil erosion rates and there are several driving factors that determine the sustainability of grape and wine production. These factors are either man-driven or nature-driven.

7.1.1. Nature-driven factors

Vineyards are usually found on steep slopes as they are located on less productive soils (Fig. 9a and b). The influence of the inclination on gravitational transport has been widely studied under natural and laboratory conditions (Fox et al. 1997; Nadal-Romero et al. 2014). In vineyards, there seems to be a general consensus that inclinations > 10 to 15% can be considered a factor driving erosion (Battany and Grismer 2000; Ruiz-Colmenero, 2012; Vrsic et al. 2011). Nonetheless, wine- and vine-growers keep planting vineyards on extreme hillslopes, some

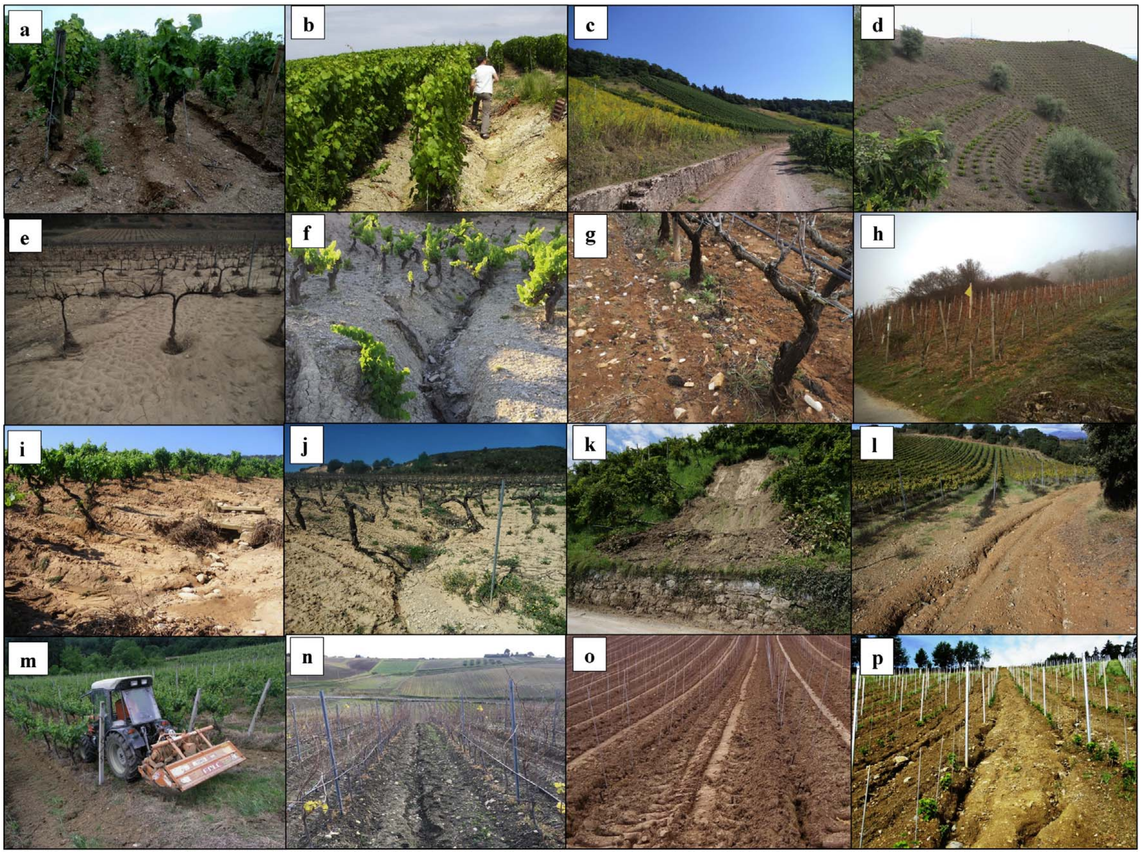


Fig. 9. Examples of different European conventional vineyards collected thanks to diverse research groups. a: Vosne Romanée, France (Jérôme Brenot); b: Champagne, France (Xavier Morvan); c: Saar valley, Germany (Jesús Rodrigo-Comino); d: Axarquía, Spain (Jesús Rodrigo-Comino); e: Valencia, Spain (Artemi Cerdà); f: Navarre, Spain (Javier Casalí); g: Valencia, Spain (Saskia Keesstra); h: Luxembourg (Jesús Rodrigo-Comino); i: La Rioja, Spain (Teodoro Lasanta); j: Pènedes, Spain (María Concepción Ramos); k: NE Italy, Prosecco vineyards on terraces (Paolo Tarolli); l: Huesca, Spain (Manuel López-Vicente); m: Zagreb, Croatia (Igor Bogunović); n: Sicily, Italy (Agata Novara); o: Trier, Germany (Jesús Rodrigo-Comino); and, p: Maribor, Slovenia (Stanislav Vršič).

reaching > 50% such as in the Saar and Mosel valley (Fig. 9c) or in the Montes de Málaga (Fig. 9d).

On the other hand, the importance of inclination can be reduced by other factors such as soil properties, which are mainly affected by the parent material (Cerdà, 1999a, b; Mohammadkhan et al. 2011; Orgill et al. 2017). It is common that vine plantations occupy fragile soils (Fig. 9e and f) characterized by extreme basic or acidic pH, clay or loamy textures, low soil water retention capacity and total organic carbon values lower than 3%; these soils are often formed in marls or limestones (Blavet et al. 2009; Fernández-Calviño et al. 2016). The fragile soils often found in vineyards can contribute to high soil loss rates and overland flow discharge even when they have negligible slope angles.

Rock fragment cover has been identified as a key factor influencing erosion in vineyard soils. Rock fragments are often embebbed in the soil and act as a crust as described by Follain et al., (2012) and Poesen et al., (1990). These rock fragments are able to act as an armour from the point of view of sediment detachment and reduce soil losses and splash effect (Jomaa et al. 2012) when the rock fragment cover is > 30%. Using 96 rainfall simulations in vineyards, Rodrigo-Comino et al. (2017d) demonstrated that farmers should not remove rock fragments from their soils as they contributed to reduced soil losses, although the runoff rates were increased (Fig. 9 g). The rock fragment mulch can act as a cover that increases sustainable management as it reduces soil losses. This is a modern approach to improve environmental conditions through the use of nature-based solutions (Keesstra et al. 2018).

Other natural factors include the concentration of rainfall events and their intensity. It is well-known that these parameters have a high impact on the kinetic energy, drop size distribution and velocity of rainfall that affects the erosivity of the rainfall and with that the potential soil erosion (Feng et al., in press; Herwitz 1987) by breaking aggregates (Marzen et al. 2015) and transporting sediments downslope (Shi et al. 2012). Several authors have indicated the possibility that climate change could increase soil erosion rates and productivity losses in vineyards (Ramos 2016; Ramos and Mulligan 2005) as well as the transport of pollutants (García-Díaz et al. 2017a; Serpa et al. 2017). Finally, vegetation cover, animals and microorganisms also act as important environmental factors. Sporadic natural vegetation cover (Fig. 9h) is able to hold soil in place against sediment transport and overland flow episodes through the roots and intercept the splash effect (Belmonte Serrato and Romero Diaz 1998; Kozak et al. 2007) during heavy rains in the inter-row areas. However, vegetation is commonly eliminated due to water scarcity and the negative view of vegetated fields by farmers (Marques et al. 2015). Animals and microorganisms are recognized as the most important factor that increases organic matter, which increases aggregate stability; the processing of fresh plant material into humus can reduce soil erodibility and conserve biodiversity in vineyards (Bruggisser et al. 2010). However, farmers try to eliminate the macro-fauna such as rabbits, birds and wild boars because they damage grape production (Assandri et al. 2017; Barrio et al. 2012). Therefore, more research should focus on assessing the most effective strategies to conserve an equilibrium between biodiversity and vineyard conservation.

7.1.2. Anthropogenic factors

The most important anthropogenic factor that enhances soil erosion, as reported by almost all scientific literature related to vineyards, is the practice of keeping the soils bare (Fig. 9i and j). Conventional farming in vineyards is traditionally characterized by the application of herbicides and the use of machinery and hand tillage to eliminate weeds (Biddoccu et al. 2017b; De Santisteban et al. 2006; Vršič 2011). This land use management enhances local soil erosion, but also forms problems at the catchment scale such as landslides, floods and pollutant transport (Raclot et al. 2009; Sofia and Tarolli 2017). Due to high rainfall runoff ratios and intense tillage practices high volumes of water and associated sediments and pollutants are transported downslope, which can be dangerous for villages and forestry areas close to the outlets as was the case for several French and Spanish catchments (Martínez-Casasnovas et al. 2009; Meyer and Martínez-Casasnovas 1999; Raclot et al. 2009). Moreover, badly designed structures such as roads or terraces (Jordán-López et al. 2009; Tarolli et al. 2015) can act as efficient ways to artificially canalize water, sediments, nutrients and pollutants (Fig. 9k and l).

It is well-known that the use of machinery (Fig. 9m and n) causes soil compaction (Arnaez et al. 2007; Brevik and Fenton 2004), the generation of ephemeral gullies and rills when tillage is conducted in the downslope direction (Ferrero et al. 2005; Lieskovský and Kenderessy 2014), increased soil roughness (Prosdocimi et al., 2017a) and the retention of CO_2 fluxes (Bogunovic et al. 2017). However, in areas where pruning the vintage and tillage due to the steep slopes makes it difficult to conserve high productivity, the use of tractors is considered mandatory. The use of machinery is compulsory today due to the cost of labour but we must work to find machinery that causes less damage to the soil. Therefore, more research is needed to look for mechanization that is less invasive and dangerous for soil conservation.

One important issue that has largely been overlooked in terms of soil erosion is the age of the plantations. Although it was mentioned by the pioneer research of Richter and Negendank, (1977) in the Ruwer-Mosel valley, it has only recently been shown to be one of the main factors controlling soil erosion rates in vineyards (Fig. 9o). This is because large amounts of sediments are mobilized and the soil structure changes dramatically when the surface of the hillslope is levelled (Biddoccu et al. 2013; Pellegrini and Vanino 2006; Ramos and Martínez-Casasnovas 2006). Therefore, during the first and second year after planting the vines, the soil is not well consolidated and the impact of rain drops is larger by up to an order of magnitude (Fig. 9p) than after 5, 10 and 25 years (Cerdà et al. 2017b; Rodrigo-Comino et al. 2017a).

Finally, another important factor that needs study is the effect of trampling. This has only been mentioned in some studies by Brevik and Tibor (2014) and Quinn et al. (1980). During the vine plantation, pruning, vintage and tillage, vine-growers walk on the soil surface and compact the topsoil layer; this soil compaction causes less infiltration capacity and therefore more runoff. This higher runoff can transport more sediment and create new linear micro-features and ponds (Rodrigo-Comino et al. 2016b, 2017a).

7.2. Looking for sustainable wine production to achieve low erosion rates

The main objective of sustainable food production is to maintain production levels and quality for long periods of time without damaging the ecosystem. In vineyards, a key challenge to sustainable production is high erosion rates, which is the result of human and nature-driven factors (Vaudour 2002; Vaudour et al. 2017).

To achieve sustainable production soil erosion rates need to be $< 1\ \text{Mg}\ \text{ha}^{-1}\ \text{yr}^{-1}$ (Verheijen et al. 2009). This review demonstrates that soil erosion rates in vineyards are currently at least one order of magnitude higher. Therefore, there is a lot to be done by scientists, enterprises, farmers and policy makers to contribute to sustainable management in vineyards. A common strategy to control the high erosion rates in vineyards is the use of mulches such as barely straw (Prosdocimi et al. 2016c) or vegetation cover such as grass (Biddoccu et al. 2016; Marques et al. 2010; Morvan et al. 2014), which results in an immediate reduction in sediment and water losses. The use of geotextiles in vineyards (Kertész et al. 2007) has also demonstrated that control of soil erosion is possible. However, the main environmental challenge when straw, geotextiles, vegetation cover or seeds for catch crops are used are the potential change in species composition and invasion of plants that can modify the environmental conditions. There are also cultural challenges, as farmers view a tidy cultivated area as being indicative of good management (Cerdà et al. 2017a; Keesstra et al. 2016b). In addition, farmers often perceive soil erosion problems differently than scientists, and often don't see erosion as a problem in and of itself (Brevik et al. 2017). The strategies commonly used to avoid soil and water losses are expensive due to the treatment and origin of the materials, which often need to be transported (i.e., straw) or produced (i.e., geotextiles). It is also necessary for farmers to handle these materials, spreading, sowing, or laying them over their vineyards. Moreover, there is a need for more information regarding the efficiency of these practices (Marques et al. 2015; Martínez-Casasnovas et al. 2010). The use of soil erosion control measures can increase water competence and reduce grape production and quality, changing the taste of the wine (Ruiz-Colmenero et al. 2011). Therefore, vine and wine growers have an unsolved internal conflict: not applying soil erosion control measures may increase productivity and efficiency but lead to high soil erosion rates, reducing soil fertility over medium and long-term periods, or follow new conservationist methods and have less productive vines (García-Díaz et al. 2017b; Novara et al. 2018). Future research into this issue should not only address the biophysical approach but also social and economic constraints farmers need to face when they apply new management strategies and how to increase efficiency. Within this issue, the perception of the farmers and possible subsides to support the management strategies that are promoted will be essential to finally achieve sustainable agriculture (Galati et al. 2016).

7.3. Research challenges

In this section, several research topics related to vineyard studies that need to be addressed by scientific groups are discussed. Firstly, research should focus on developing methods that will be available to carry out soil erosion measurements and allow different study areas to be compared and contrasted, for example by applying or combining old (i.e., Gerlach collectors) and recent methods (i.e., ISUM). It is necessary to apply methods that are able to assess hydrological processes and sediment detachment, transport and sedimentation over both short- and long-term periods. Secondly, more research is needed to survey the spatial variability of soil erosion, and this should be developed at different scales such as the pedon and catchment scales, where the connection of the processes between them is not clear. This is needed to fully understand and use the concept of connectivity (Borselli et al. 2008; Poeppl et al. 2017) and dis-connectivity (Fryirs 2013; Fryirs et al. 2007) in the investigation of vineyard flow and sediments (Marchamalo et al. 2016) and to model (Masselink et al. 2016) and understand how sediment is transported along a watershed (Buendia et al. 2016). Thirdly, vineyard researchers should increase the connection between models and reality, making the results more accurate. Unfortunately, Ramos (2016) and Serpa et al. (2017) highlighted that the new climate change scenarios will not make this methodological awareness in modelling hydrological processes and land use changes easier.

Moreover, to be able to complete the global database of soil erosion in vineyards, standardization of the units and methods should be developed. The results and comparisons of this study have been limited to rates reported in $\text{Mg}\ \text{ha}^{-1}\ \text{yr}^{-1}$, undoubtedly missing other interesting values that would have given useful information about the high spatiotemporal variation of soil erosion in vineyards and its world-wide magnitude.

A very important aspect of future research needs to focus on finding suitable solutions based on inexpensive and accessible materials, and management practices that are useful and do not generate a bad perception among the wine- and vine-growers that are implementing these strategies. These solutions should be added to develop suitable land management plans that can easily be transmitted to stakeholders and policy makers. Solutions should be sought that follow the concept of nature based solutions. Management strategies based on this idea are by principle more sustainable as they are designed to improve themselves over time and create less connectivity of water and sediment, which is beneficial to the farm through conserving and improving soil and water availability. Downstream areas will also benefit from nature based solutions through reduced flooding and sediment or pollutant fluxes. In addition, these kinds of measures enhance the ecosystem services of the landscape such as improved biodiversity, a more beautiful landscape, cleaner water and of course sustainable food production.

8. Conclusions

Soil erosion rates in vineyards show very high values. Soil erosion is a problem that affects vineyards worldwide, but particularly in the Mediterranean. This paper demonstrates that research on soil erosion in vineyards: i) is widely assessed in the scientific literature; ii) has been published in many different scientific journals; iii) is a problem in different regions of the world; and, iv) is studied using a diverse set of methodologies, which makes it difficult to form a general consensus on erosion rates and possible conservation and restoration options due to different soil erosion units and variable spatial and temporal scales. Therefore, new research must be done in order to standardize soil erosion measurements for different environments and under different natural and anthropogenic factors. Moreover, this research has to go beyond the biophysical approach to include social and economic constraints, because farmers need to be comfortable when they apply new management strategies and be convinced they will increase efficiency. Within this issue, the perception of the farmers and possible subsides to support the management strategies that are promoted will be essential to finally achieve sustainable agriculture in vineyards.

Acknowledgements

Thanks to the farmers who make it possible for vines and wine to exist and to those who have taken care of the terroir for centuries. Thanks to the scientists who determined that soil erosion research was necessary to understand the terroir and the man-made ecosystems developed by the vines and at the hands of women and men for millennia.

References

(O.I.V.), I.O. of V. and W, 2017. World Vitiviniculture Situation, Statistical Report on World Vitiviniculture. International Organisation of Vine and Wine, Paris, France, pp. 2017.

Alewell, C., Egli, M., Meusburger, K., 2015. An attempt to estimate tolerable soil erosion rates by matching soil formation with denudation in Alpine grasslands. J. Soils Sediments 15, 1383–1399. http://dx.doi.org/10.1007/s11368-014-0920-6.

Aradottir, A.L., Hagen, D., 2013. Ecological restoration: approaches and impacts on vegetation, soils and society. In: Sparks, D.L. (Ed.), Advances in Agronomy. vol. 120. Elsevier Academic Press Inc, San Diego, pp. 173–222.

Arnaez, J., Lasanta, T., Ruiz-Flaño, P., Ortigosa, L., 2007. Factors affecting runoff and erosion under simulated rainfall in Mediterranean vineyards. Soil Tillage Res. 93, 324–334. http://dx.doi.org/10.1016/j.still.2006.05.013.

Assandri, G., Bogliani, G., Pedrini, P., Brambilla, M., 2017. Assessing common birds' ecological requirements to address nature conservation in permanent crops: lessons from Italian vineyards. J. Environ. Manag. 191, 145–154. http://dx.doi.org/10.1016/j.jenvman.2016.12.071.

Atucha, A., Merwin, I.A., Brown, M.G., Gardiazabal, F., Mena, F., Adriazola, C., Lehmann, J., 2013. Soil erosion, runoff and nutrient losses in an avocado (Persea americana Mill) hillside orchard under different groundcover management systems. Plant Soil 368, 393–406.

Augustinus, P.G.E.F., Nieuwenhuyse, P.J., 1986. Soil erosion in vineyards in the Ardeche region. Catena 13, 295–304. http://dx.doi.org/10.1016/0341-8162(86)90004-4.

Barrio, I.C., Villafuerte, R., Tortosa, F.S., 2012. Can cover crops reduce rabbit-induced damages in vineyards in southern Spain? Wildl. Biol. 18, 88–96. http://dx.doi.org/10.2981/10-110.

Battany, M.C., Grismer, M.E., 2000. Rainfall runoff and erosion in Napa Valley vineyards: effects of slope, cover and surface roughness. Hydrol. Process. 14, 1289–1304. http://dx.doi.org/10.1002/(SICI)1099-1085(200005)14:7 < 1289::AID-HYP43 > 3.0.CO;2-R.

Bazzoffi, P., Abbattista, F., Vanino, S., Pellegrini, S., 2006. Impact of land levelling for vineyard plantation on soil degradation in Italy. Boll. Della Soc. Geol. Ital. Vol. Spec. 191–199.

Belmonte Serrato, F., Romero Diaz, A., 1998. A simple technique for measuring rainfall interception by small shrub: "interception flow collection box.". Hydrol. Process. 12, 471–481. http://dx.doi.org/10.1002/(SICI)1099-1085(19980315)12:3 < 471::AID-HYP586 > 3.0.CO;2-E.

Biddoccu, M., Ferraris, S., Cavallo, E., Opsi, F., Previati, M., Canone, D., 2013. Hillslope vineyard rainfall-runoff measurements in relation to soil infiltration and water content. Procedia Environ Sci 19, 351–360. http://dx.doi.org/10.1016/j.proenv.2013.06.040.

Biddoccu, M., Ferraris, S., Opsi, F., Cavallo, E., 2016. Long-term monitoring of soil management effects on runoff and soil erosion in sloping vineyards in Alto Monferrato (North–West Italy). Soil Tillage Res. 155, 176–189. http://dx.doi.org/10.1016/j.still.2015.07.005.

Biddoccu, M., Ferraris, S., Pitacco, A., Cavallo, E., 2017a. Temporal variability of soil management effects on soil hydrological properties, runoff and erosion at the field scale in a hillslope vineyard. North-West Italy. Soil Tillage Res. 165, 46–58. http://dx.doi.org/10.1016/j.still.2016.07.017.

Biddoccu, M., Ferraris, S., Pitacco, A., Cavallo, E., 2017b. Temporal variability of soil management effects on soil hydrological properties, runoff and erosion at the field scale in a hillslope vineyard. North-West Italy. Soil Tillage Res. 165, 46–58. http://dx.doi.org/10.1016/j.still.2016.07.017.

Biddoccu, M., Zecca, O., Audisio, C., Godone, F., Barmaz, A., Cavallo, E., 2017c. Assessment of long-term soil erosion in a mountain vineyard, Aosta Valley (NW Italy). Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2657.

Blavet, D., De Noni, G., Le Bissonnais, Y., Leonard, M., Maillo, L., Laurent, J.Y., Asseline, J., Leprun, J.C., Arshad, M.A., Roose, E., 2009. Effect of land use and management on the early stages of soil water erosion in French Mediterranean vineyards. Soil Tillage Res. 106, 124–136. http://dx.doi.org/10.1016/j.still.2009.04.010.

Bogunovic, I., Bilandzija, D., Andabaka, Z., Stupic, D., Comino, J.R., Cacic, M., Brezinscak, L., Maletic, E., Pereira, P., 2017. Soil compaction under different management practices in a Croatian vineyard. Arab. J. Geosci. 10, 1–9. http://dx.doi.org/10.1007/s12517-017-3105-y.

Borselli, L., Cassi, P., Torri, D., 2008. Prolegomena to sediment and flow connectivity in the landscape: a GIS and field numerical assessment. Catena 75, 268–277. http://dx.doi.org/10.1016/j.catena.2008.07.006.

Brenot, J., Quiquerez, A., Petit, C., Garcia, J.-P., Davy, P., 2006. Soil erosion rates in Burgundian vineyards. Boll. Della Soc. Geol. Ital. 6, 169–173.

Brenot, J., Quiquerez, A., Petit, C., Garcia, J.-P., 2008. Erosion rates and sediment budgets in vineyards at 1-m resolution based on stock unearthing (Burgundy, France). Geomorphology 100, 345–355. http://dx.doi.org/10.1016/j.geomorph.2008.01.005.

Brevik, E.C., Fenton, T.E., 2004. The effect of changes in bulk density on soil electrical conductivity as measured with the Geonics EM-38. Soil Horiz. 45, 96–102. http://dx.doi.org/10.2136/sh2004.3.0096.

Brevik, E.C., Tibor, M.A., 2014. Impact of Camping on Soil Properties at Strawberry Lake, North Dakota, USA. Presented at the EGU General Assembly Conference Abstracts, pp. 1137.

Brevik, E.C., Pereira, P., Muñoz-Rojas, M., Miller, B.A., Cerdà, A., Parras-Alcántara, L., Lozano-García, B., 2017. Historical perspectives on soil mapping and process modeling for sustainable land use management. In: Pereira, P., Brevik, E., Muñoz-Rojas, M., Miller, B. (Eds.), Soil Mapping and Process Modelling for Sustainable Land Use Management. Elsevier, Amsterdam, pp. 3–28. http://dx.doi.org/10.1016/B978-0-12-805200-6.00001-3.

Bruggisser, O.T., Schmidt-Entling, M.H., Bacher, S., 2010. Effects of vineyard management on biodiversity at three trophic levels. Biol. Conserv. 143, 1521–1528. http://dx.doi.org/10.1016/j.biocon.2010.03.034.

Buendia, C., Vericat, D., Batalla, R.J., Gibbins, C.N., 2016. Temporal dynamics of sediment transport and transient in-channel storage in a highly erodible catchment. Land Degrad. Dev. 27, 1045–1063. http://dx.doi.org/10.1002/ldr.2348.

Casalí, J., Giménez, R., De Santisteban, L., Álvarez-Mozos, J., Mena, J., Del Valle de Lersundi, J., 2009. Determination of long-term erosion rates in vineyards of Navarre (Spain) using botanical benchmarks. Catena 78, 12–19. http://dx.doi.org/10.1016/j.catena.2009.02.015.

Cerdà, A., 1999a. Simuladores de lluvia y su aplicación a la Geomorfología: Estado de la cuestión. Cuad. Investig. Geográfica 45–84.

Cerdà, A., 1999b. Parent material and vegetation affect soil erosion in Eastern Spain. Soil Sci. Soc. Am. J. 63. http://dx.doi.org/10.2136/sssaj1999.03615995006300020014x.

Cerdà, A., Keesstra, S.D., Rodrigo-Comino, J., Novara, A., Pereira, P., Brevik, E., Giménez-Morera, A., Fernández-Raga, M., Pulido, M., di Prima, S., Jordán, A., 2017a. Runoff initiation, soil detachment and connectivity are enhanced as a consequence of vineyards plantations. J. Environ. Manag. 202, 268–275. http://dx.doi.org/10.1016/j.jenvman.2017.07.036.

Cerdà, A., Rodrigo-Comino, J., Giménez Morera, A., Keesstra, S.D., 2017b. An economic, perception and biophysical approach to the use of oat straw as mulch in Mediterranean rainfed agriculture land. Ecol. Eng. 108PA, 162–171. http://dx.doi.org/10.1016/j.ecoleng.2017.08.028.

Cerdà, A., Rodrigo-Comino, J., Giménez-Morera, A., Novara, A., Pulido, M., Kapovic Solomun, M., Keesstra, S., 2018. Policies can help to apply successful strategies to control soil and water losses. In: The Case of Chipped Pruned Branches (CPB) in Mediterranean Citrus Plantation. Land Use Policy, http://dx.doi.org/10.1016/j.landusepol2017.12. (In press).

Chevigny, E., Quiquerez, A., Petit, C., Curmi, P., 2014. Lithology, landscape structure and management practice changes: key factors patterning vineyard soil erosion at metre-scale spatial resolution. Catena 121, 354–364. http://dx.doi.org/10.1016/j.catena.2014.05.022.

Ciampalini, R., Follain, S., Le Bissonnais, Y., 2012. LandSoil: a model for analysing the impact of erosion on agricultural landscape evolution. Geomorphology 175, 25–37. http://dx.doi.org/10.1016/j.geomorph.2012.06.014.

David, M., Follain, S., Ciampalini, R., Le Bissonnais, Y., Couturier, A., Walter, C., 2014. Simulation of medium-term soil redistributions for different land use and landscape design scenarios within a vineyard landscape in Mediterranean France. Geomorphology 214, 10–21. http://dx.doi.org/10.1016/j.geomorph.2014.03.016.

De Santisteban, L.M., Casalí, J., López, J.J., 2006. Assessing soil erosion rates in cultivated areas of Navarre (Spain). Earth Surf. Process. Landf. 31, 487–506. http://dx.doi.org/10.1002/esp.1281.

Duchaufour, P., 1970. Précis de pédologie, 3th ed. Masson et Cie, Paris, France.

Feng, T., Wei, W., Chen, L., Rodrigo-Comino, J., Die, C., Feng, X., Ren, K., Brevik, E.C., Yu, Y., 2018. Assessment of the impact of different vegetation patterns on soil erosion processes on semiarid loess slopes. Earth Surf. Process. Landf. http://dx.doi.org/10.1002/esp.4361. (in press).

Fernández-Calviño, D., Cutillas-Barreiro, L., Núñez-Delgado, A., Fernández-Sanjurjo, M.J., Álvarez-Rodriguez, E., Nóvoa-Muñoz, J.C., Arias-Estévez, M., 2016. Cu immobilization and lolium perenne development in an acid vineyard soil amended with crushed mussel shell. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2634.

Fernández-Raga, M., Palencia, C., Keesstra, S., Jordán, A., Fraile, R., Angulo-Martínez, M., Cerdà, A., 2017. Splash erosion: a review with unanswered questions. Earth-Sci. Rev. 171, 463–477. http://dx.doi.org/10.1016/j.earscirev.2017.06.009.

Ferrero, A., Usowicz, B., Lipiec, J., 2005. Effects of tractor traffic on spatial variability of soil strength and water content in grass covered and cultivated sloping vineyard. Soil Tillage Res. 84, 127–138. http://dx.doi.org/10.1016/j.still.2004.10.003.

Fitzpatrick, E.A., 1980. Soils: Their Formation, Classification and Distribution. Longman, London, UK.

Follain, S., Ciampalini, R., Crabit, A., Coulouma, G., Garnier, F., 2012. Effects of redistribution processes on rock fragment variability within a vineyard topsoil in Mediterranean France. Geomorphology 175–176, 45–53. http://dx.doi.org/10.1016/j.geomorph.2012.06.017.

Fox, D.M., Bryan, R.B., Price, A.G., 1997. The influence of slope angle on final infiltration rate for interrill conditions. Geoderma 80, 181–194. http://dx.doi.org/10.1016/S0016-7061(97)00075-X.

Fryirs, K., 2013. (Dis)Connectivity in catchment sediment cascades: a fresh look at the sediment delivery problem. Earth Surf. Process. Landf. 38, 30–46. http://dx.doi.org/10.1002/esp.3242.

Fryirs, K.A., Brierley, G.J., Preston, N.J., Kasai, M., 2007. Buffers, barriers and blankets: the (dis)connectivity of catchment-scale sediment cascades. Catena 70, 49–67. http://dx.doi.org/10.1016/j.catena.2006.07.007.

Galati, A., Crescimanno, M., Gristina, L., Keesstra, S., Novara, A., 2016. Actual provision as an alternative criterion to improve the efficiency of payments for ecosystem services for C sequestration in semiarid vineyards. Agric. Syst. 144, 58–64. http://dx.doi.org/10.1016/j.agsy.2016.02.004.

García-Díaz, A., Bienes, R., Sastre, B., Novara, A., Gristina, L., Cerdà, A., 2017a. Nitrogen losses in vineyards under different types of soil groundcover. A field runoff simulator approach in central Spain. Agric. Ecosyst. Environ. 236, 256–267. http://dx.doi.org/10.1016/j.agee.2016.12.013.

García-Díaz, A., Marqués, M.J., Sastre, B., Bienes, R., 2017b. Labile and stable soil organic carbon and physical improvements using groundcovers in vineyards from central Spain. Sci. Total Environ. 621, 387–397. http://dx.doi.org/10.1016/j.scitotenv.2017.11.240.

García-Ruiz, J.M., Beguería, S., Nadal-Romero, E., González-Hidalgo, J.C., Lana-Renault, N., Sanjuán, Y., 2015. A meta-analysis of soil erosion rates across the world. Geomorphology 239, 160–173. http://dx.doi.org/10.1016/j.geomorph.2015.03.008.

Gebhardt, H., Glaser, R., Radtke, U., Reuber, P., 2012. Geographie - Physische Geographie und Humangeographie. Springer Spektrum, Heidelberg.

Gerlach, T., 1967. Hillslope troughs for measuring sediment movement. Rev. Géomorphol. Dynam. 17, 173.

Gourbesville, P., 1997. Soil erosion in the vineyards of Champagne. In: Human Impact on Erosion and Sedimentation S6. Presented at the Proceedings of Rabat Symoposium, Rabat, Marrocco, pp. 3–11.

Hacisalihoglu, S., 2007. Determination of soil erosion in a steep hill slope with different land-use types: a case study in Mertesdorf (Ruwertal/Germany). J. Environ. Biol. Acad. Environ. Biol. India 28, 433–438.

Herwitz, S.R., 1987. Raindrop impact and water flow on the vegetative surfaces of trees and the effects on stemflow and throughfall generation. Earth Surf. Process. Landf. 12, 425–432. http://dx.doi.org/10.1002/esp.3290120408.

Ibáñez, J., Martínez-Valderrama, J., Taguas, E.V., Gómez, J.A., 2014. Long-term implications of water erosion in olive-growing areas in southern Spain arising from a model-based integrated assessment at hillside scale. Agric. Syst. 127, 70–80. http://dx.doi.org/10.1016/j.agsy.2014.01.006.

Jenny, H., 1961. Derivation of state factor equations of soils and ecosystems. Soil Sci. Soc. Am. J. 25, 385–388. http://dx.doi.org/10.2136/sssaj1961.03615995002500050023x.

Jianjun, W., Quansheng, L., Lijiao, Y., 2017. Effect of intercropping on soil erosion in young citrus plantation - a simulation study. Chin. J. Appl. Ecol. 8, 143–146.

Jie, C., Jing-zhang, C., Man-zhi, T., Zi-tong, G., 2002. Soil degradation: a global problem endangering sustainable development. J. Geogr. Sci. 12, 243–252. http://dx.doi.org/10.1007/BF02837480.

Jomaa, S., Barry, D.A., Brovelli, A., Heng, B.C.P., Sander, G.C., Parlange, J.-Y., Rose, C.W., 2012. Rain splash soil erosion estimation in the presence of rock fragments. Catena 92, 38–48. http://dx.doi.org/10.1016/j.catena.2011.11.008.

Jordán-López, A., Martínez-Zavala, L., Bellinfante, N., 2009. Impact of different parts of unpaved forest roads on runoff and sediment yield in a Mediterranean area. Sci. Total Environ. 407, 937–944. http://dx.doi.org/10.1016/j.scitotenv.2008.09.047.

Jürgens, C., Fander, M., 1993a. Soil erosion assessment by means of LANDSAT-TM and ancillary digital data in relation to water quality. Soil Technol. 6, 215–223. http://dx.doi.org/10.1016/0933-3630(93)90011-3.

Jürgens, C., Fander, M., 1993b. Soil erosion assessment and simulation by means of SGEOS and ancillary digital data. Int. J. Remote Sens. 14, 2847–2855. http://dx.doi.org/10.1080/01431169308904313.

Kairis, O., Karavitis, C., Kounalaki, A., Salvati, L., Kosmas, C., 2013. The effect of land management practices on soil erosion and land desertification in an olive grove. Soil Use Manag. 29, 597–606. http://dx.doi.org/10.1111/sum.12074.

Keesstra, S.D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J.N., Pachepsky, Y., van der Putten, W.H., Bardgett, R.D., Moolenaar, S., Mol, G., Jansen, B., Fresco, L.O., 2016a. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. Soil 2, 111–128. http://dx.doi.org/10.5194/soil-2-111-2016.

Keesstra, S., Pereira, P., Novara, A., Brevik, E.C., Azorin-Molina, C., Parras-Alcántara, L., Jordán, A., Cerdà, A., 2016b. Effects of soil management techniques on soil water erosion in apricot orchards. Sci. Total Environ. 551–552, 357–366. http://dx.doi.org/10.1016/j.scitotenv.2016.01.182.

Keesstra, S., Nunes, J., Novara, A., Finger, D., Avelar, D., Kalantari, Z., Cerdà, A., 2018. The superior effect of nature based solutions in land management for enhancing ecosystem services. Sci. Total Environ. 610–611, 997–1009. http://dx.doi.org/10.1016/j.scitotenv.2017.08.077.

Kertész, á, Tóth, A., Szalai, Z., Jakab, G., Kozma, K., Booth, C.A., Fullen, M.A., Davies, K., 2007. Geotextile as a Tool Against Soil Erosion in Vineyards and Orchards. WIT Press, pp. 611–619. http://dx.doi.org/10.2495/SDP070592.

Keshavarzi, A., Tuffour, H., Bagherzadeh, A., Duraisamy, V., 2018. Spatial and fractal characterization of soil properties across soil depth in an agricultural field, Northeast Iran. Eur. J. Soil Sci. 7, 35–45.

Khaledian, Y., Brevik, E.C., Pereira, P., Cerdà, A., Fattah, M.A., Tazikeh, H., 2017. Modeling soil cation exchange capacity in multiple countries. Catena 158, 194–200. http://dx.doi.org/10.1016/j.catena.2017.07.002.

Komac, B., Zorn, M., 2005. Soil erosion on agricultural land in Slovenia – measurements of rill erosion in the Besnica valley. Acta Geogr. Slov. 45, 53–86. http://dx.doi.org/10.3986/AGS45103.

Kozak, J.A., Ahuja, L.R., Green, T.R., Ma, L., 2007. Modelling crop canopy and residue rainfall interception effects on soil hydrological components for semi-arid agriculture. Hydrol. Process. 21, 229–241. http://dx.doi.org/10.1002/hyp.6235.

Lasanta, T., 1985. Aportación al estudio de la erosión hídrica en campos cultivados de la Rioja, Ciencias de la Tierra. Instituto de Estudios Riojanos, Logroño (Spain).

Le Bissonnais, Y., Montier, C., Jamagne, M., Daroussin, J., King, D., 2002. Mapping erosion risk for cultivated soil in France. Catena 46, 207–220. http://dx.doi.org/10.1016/S0341-8162(01)00167-9.

Lieskovský, J., Kenderessy, P., 2014. Modelling the effect of vegetation cover and different tillage practices on soil erosion in vineyards: a case study in Vráble (Slovakia) using WATEM/SEDEM. Land Degrad. Dev. 25, 288–296. http://dx.doi.org/10.1002/ldr.2162.

Loughran, R.J., Elliot, G.L., 1996. Rates of soil erosion in Australia determined by the caesium-137 technique: a national reconnaissance survey. In: Erosion and Sediment Yield: Global and Regional Perspectives. Procceedings of the Exeter Symposium, Exeter, Uk, pp. 275–282.

Loughran, R.J., Elliott, G.L., Campbell, B.L., Shelly, D.J., 1988. Estimation of soil erosion from caesium-137 measurements in a small, cultivated catchment in Australia. Int. J. Rad. Appl. Instrum. A 39, 1153–1157. http://dx.doi.org/10.1016/0883-2889(88)90009-3.

Loughran, R.J., Campbell, B.L., Shelly, D.J., Elliott, G.L., 1992. Developing a sediment budget for a small drainage basin in Australia. Hydrol. Process. 6, 145–158. http://dx.doi.org/10.1002/hyp.3360060203.

Marchamalo, M., Hooke, J.M., Sandercock, P.J., 2016. Flow and sediment connectivity in semi-arid landscapes in SE Spain: patterns and controls. Land Degrad. Dev. 27, 1032–1044. http://dx.doi.org/10.1002/ldr.2352.

Marques, M.J., García-Muñoz, S., Muñoz-Organero, G., Bienes, R., 2010. Soil conservation beneath grass cover in hillside vineyards under Mediterranean Climatic conditions (Madrid, Spain). Land Degrad. Dev. 21, 122–131. http://dx.doi.org/10.1002/ldr.915.

Marques, M.J., Bienes, R., Cuadrado, J., Ruiz-Colmenero, M., Barbero-Sierra, C., Velasco, A., 2015. Analysing perceptions attitudes and responses of winegrowers about sustainable land management in Central Spain. Land Degrad. Dev. 26, 458–467. http://dx.doi.org/10.1002/ldr.2355.

Martínez Murillo, J.F., Ruiz Sinoga, J.D., 2003. Incidencia de algunas propiedades físicas de suelos en su respuesta hidrológica ante diferentes usos bajo condiciones mediterráneas (Montes de Málaga). Edafología 10, 57–62.

Martínez-Casasnovas, J.A., Ramos, M.C., Ribes-Dasi, M., 2002. Soil erosion caused by extreme rainfall events: mapping and quantification in agricultural plots from very detailed digital elevation models. Geoderma 105, 125–140. http://dx.doi.org/10.1016/S0016-7061(01)00096-9.

Martínez-Casasnovas, J.A., Ramos, M.C., Ribes-Dasi, M., 2005. On-site effects of concentrated flow erosion in vineyard fields: some economic implications. Catena 60, 129–146. http://dx.doi.org/10.1016/j.catena.2004.11.006.

Martínez-Casasnovas, J.A., Ramos, M.C., García-Hernández, D., 2009. Effects of land-use changes in vegetation cover and sidewall erosion in a gully head of the Penedès region (northeast Spain). Earth Surf. Process. Landf. 34, 1927–1937. http://dx.doi.org/10.1002/esp.1870.

Martínez-Casasnovas, J.A., Ramos, M.C., Cots-Folch, R., 2010. Influence of the EU CAP on terrain morphology and vineyard cultivation in the Priorat region of NE Spain. Land Use Policy 27, 11–21. http://dx.doi.org/10.1016/j.landusepol.2008.01.009.
Martínez-Casasnovas, J.A., Ramos, M.C., Benites, G., 2016. Soil and water assessment tool soil loss simulation at the Sub-Basin scale in the Alt Penedès–Anoia vineyard region (Ne Spain) in the 2000s. Land Degrad. Dev. 27, 160–170. http://dx.doi.org/10.1002/ldr.2240.
Martínez-Hernández, C., Rodrigo-Comino, J., Romero-Díaz, A., 2017. Impact of lithology and soil properties on abandoned dryland terraces during the early stages of soil erosion by water in Southeast Spain. Hydrol. Process. 31, 3095–3109. http://dx.doi.org/10.1002/hyp.11251.
Marzen, M., Iserloh, T., Casper, M.C., Ries, J.B., 2015. Quantification of particle detachment by rain splash and wind-driven rain splash. Catena 127, 135–141. http://dx.doi.org/10.1016/j.catena.2014.12.023.
Mase, A.S., Babin, N.L., Prokopy, L.S., Genskow, K.D., 2015. Trust in sources of soil and water quality information: implications for environmental outreach and education. J. Am. Water Resour. Assoc. 51, 1656–1666. http://dx.doi.org/10.1111/1752-1688.12349.
Masselink, R.J.H., Keesstra, S.D., Temme, A.J.A.M., Seeger, M., Giménez, R., Casalí, J., 2016. Modelling discharge and sediment yield at catchment scale using connectivity components. Land Degrad. Dev. 27, 933–945. http://dx.doi.org/10.1002/ldr.2512.
Merino, R., Etcheveres, J., Peña, L., Navea, O., 1979. Efectos de sistemas de manejo de suelo sobre la erosión y producción en viñedos de secano. Chil. J. Agric. Res. 39, 35–40.
Meyer, A., Martínez-Casasnovas, J.A., 1999. Prediction of existing gully erosion in vineyard parcels of the NE Spain: a logistic modelling approach. Soil Tillage Res. 50, 319–331. http://dx.doi.org/10.1016/S0167-1987(99)00020-3.
Mohammadkhan, S., Ahmadi, H., Jafari, M., 2011. Relationship between soil erosion, slope, parent material, and distance to road (Case study: Latian Watershed, Iran). Arab. J. Geosci. 4, 331–338. http://dx.doi.org/10.1007/s12517-010-0197-z.
Mol, G., Keesstra, S., 2012. Soil science in a changing world. Curr. Opin. Environ. Sustain. 4, 473–477. http://dx.doi.org/10.1016/j.cosust.2012.10.013.
Morvan, X., Naisse, C., Malam Issa, O., Desprats, J.F., Combaud, A., Cerdan, O., 2014. Effect of ground-cover type on surface runoff and subsequent soil erosion in Champagne vineyards in France. Soil Use Manag. 30, 372–381. http://dx.doi.org/10.1111/sum.12129.
Muluneh, A., Bewket, W., Keesstra, S., Stroosnijder, L., 2017. Searching for evidence of changes in extreme rainfall indices in the Central Rift Valley of Ethiopia. Theor. Appl. Climatol. 128, 795–809. http://dx.doi.org/10.1007/s00704-016-1739-4.
Munodawafa, A., 2011. Maize grain yield as affected by the severity of soil erosion under semi-arid conditions and granitic sandy soils of Zimbabwe. In: Phys. Chem. Earth Parts ABC, 11th WaterNet/WARFSA/GWP-SA Symposium: IWRM for National and Regional Integration through Science, Policy and Practice. 36. pp. 963–967. http://dx.doi.org/10.1016/j.pce.2011.07.068.
Nadal-Romero, E., Petrlic, K., Verachtert, E., Bochet, E., Poesen, J., 2014. Effects of slope angle and aspect on plant cover and species richness in a humid Mediterranean badland. Earth Surf. Process. Landf. 39, 1705–1716. http://dx.doi.org/10.1002/esp.3549.
Napoli, M., Grifoni, D., Orlandini, S., Zanchi, C., 2013. Modeling soil land nutrient runoff yields from an Italian vineyard using SWAT. Trans. ASABE 1397–1406. http://dx.doi.org/10.13031/trans.56.9963.
Napoli, M., Cecchi, S., Orlandini, S., Mugnai, G., Zanchi, C.A., 2016. Simulation of field-measured soil loss in Mediterranean hilly areas (Chianti, Italy) with RUSLE. Catena 145, 246–256. http://dx.doi.org/10.1016/j.catena.2016.06.018.
Napoli, M., Massetti, L., Orlandini, S., 2017. Hydrological response to land use and climate changes in a rural hilly basin in Italy. Catena 157, 1–11. http://dx.doi.org/10.1016/j.catena.2017.05.002.
Nearing, M.A., Xie, Y., Liu, B., Ye, Y., 2017. Natural and anthropogenic rates of soil erosion. Int. Soil Water Conserv. Res. 5, 77–84. http://dx.doi.org/10.1016/j.iswcr.2017.04.001.
Novara, A., Gristina, L., Saladino, S.S., Santoro, A., Cerdà, A., 2011. Soil erosion assessment on tillage and alternative soil managements in a Sicilian vineyard. Soil Tillage Res. 117, 140–147. http://dx.doi.org/10.1016/j.still.2011.09.007.
Novara, A., Gristina, L., Guaitoli, F., Santoro, A., Cerdà, A., 2013. Managing soil nitrate with cover crops and buffer strips in Sicilian vineyards. Solid Earth 4, 255–262. http://dx.doi.org/10.5194/se-4-255-2013.
Novara, A., Cerdà, A., Dazzi, C., Lo Papa, G., Santoro, A., Gristina, L., 2015. Effectiveness of carbon isotopic signature for estimating soil erosion and deposition rates in Sicilian vineyards. Soil Tillage Res. 152, 1–7. http://dx.doi.org/10.1016/j.still.2015.03.010.
Novara, A., Keesstra, S., Cerdà, A., Pereira, P., Gristina, L., 2016. Understanding the role of soil erosion on co2-c loss using 13c isotopic signatures in abandoned Mediterranean agricultural land. Sci. Total Environ. 550, 330–336. http://dx.doi.org/10.1016/j.scitotenv.2016.01.095.
Novara, A., Pisciotta, A., Minacapilli, M., Maltese, A., Capodici, F., Cerdà, A., Gristina, L., 2018. The impact of soil erosion on soil fertility and vine vigor. A multidisciplinary approach based on field, laboratory and remote sensing approaches. Sci. Total Environ. 622–623, 474–480. http://dx.doi.org/10.1016/j.scitotenv.2017.11.272.
Orgill, S.E., Condon, J.R., Conyers, M.K., Morris, S.G., Murphy, B.W., Greene, R.S.B., 2017. Parent material and climate affect soil organic carbon fractions under pastures in south-eastern Australia. Soil Res. http://dx.doi.org/10.1071/SR16305.
Ortigosa Izquierdo, L.M., Lasanta Martínez, T., 1984. El papel de la escorrentía en la organización textural de suelos cultivados en pendiente: modelos en viñedos de La Rioja. Cuad. Investig. Geográfica 10, 99–112.
Panagos, P., Christos, K., Cristiano, B., Ioannis, G., 2014. Seasonal monitoring of soil erosion at regional scale: an application of the G2 model in Crete focusing on agricultural land uses. Int. J. Appl. Earth Obs. Geoinf. 27 (Part B), 147–155. http://dx.doi.org/10.1016/j.jag.2013.09.012.
Panagos, P., Borrelli, P., Meusburger, K., Yu, B., Klik, A., Jae Lim, K., Yang, J.E., Ni, J., Miao, C., Chattopadhyay, N., Sadeghi, S.H., Hazbavi, Z., Zabihi, M., Larionov, G.A., Krasnov, S.F., Gorobets, A.V., Levi, Y., Erpul, G., Birkel, C., Hoyos, N., Naipal, V., Oliveira, P.T.S., Bonilla, C.A., Meddi, M., Nel, W., Al Dashti, H., Boni, M., Diodato, N., Van Oost, K., Nearing, M., Ballabio, C., 2017. Global rainfall erosivity assessment based on high-temporal resolution rainfall records. Sci. Rep. 7. http://dx.doi.org/10.1038/s41598-017-04282-8.
Paroissien, J.-B., Lagacherie, P., Le Bissonnais, Y., 2010. A regional-scale study of multi-decennial erosion of vineyard fields using vine-stock unearthing–burying measurements. Catena 82, 159–168. http://dx.doi.org/10.1016/j.catena.2010.06.002.
Paroissien, J.-B., Darboux, F., Couturier, A., Devillers, B., Mouillot, F., Raclot, D., Le Bissonnais, Y., 2015. A method for modeling the effects of climate and land use changes on erosion and sustainability of soil in a Mediterranean watershed (Languedoc, France). J. Environ. Manag. 150, 57–68. http://dx.doi.org/10.1016/j.jenvman.2014.10.034.
Pellegrini, S., Vanino, S., 2006. Impact of land levelling for Vineyard plantation on soil degradation in Italy. Boll. Soc. Geol. Ital. 6, 191–199.
Poeppl, R.E., Keesstra, S.D., Maroulis, J., 2017. A conceptual connectivity framework for understanding geomorphic change in human-impacted fluvial systems. In: Geomorphology, Connectivity in Geomorphology from Binghamton 2016. 277. pp. 237–250. http://dx.doi.org/10.1016/j.geomorph.2016.07.033.
Poesen, J., Ingelmo-Sanchez, F., Mucher, H., 1990. The hydrological response of soil surfaces to rainfall as affected by cover and position of rock fragments in the top layer. Earth Surf. Process. Landf. 15, 653–671. http://dx.doi.org/10.1002/esp.3290150707.
Prosdocimi, M., Cerdà, A., Tarolli, P., 2016a. Soil water erosion on Mediterranean vineyards: a review. Catena 141, 1–21. http://dx.doi.org/10.1016/j.catena.2016.02.010.
Prosdocimi, M., Jordán, A., Tarolli, P., Keesstra, S., Novara, A., Cerdà, A., 2016b. The immediate effectiveness of barley straw mulch in reducing soil erodibility and surface runoff generation in Mediterranean vineyards. Sci. Total Environ. 547, 323–330. http://dx.doi.org/10.1016/j.scitotenv.2015.12.076.
Prosdocimi, M., Burguet, M., Di Prima, S., Sofia, G., Terol, E., Rodrigo-Comino, J., Cerdà, A., Tarolli, P., 2017a. Rainfall simulation and structure-from-motion photogrammetry for the analysis of soil water erosion in Mediterranean vineyards. Sci. Total Environ. 574, 204–215. http://dx.doi.org/10.1016/j.scitotenv.2016.09.036.
Prosdocimi, M., Tarolli, P., Cerdà, A., 2017b. Mulching practices for reducing soil water erosion: a review. Earth-Sci. Rev. 161, 191–203. http://dx.doi.org/10.1016/j.earscirev.2016.08.006.
Quinn, N.W., Morgan, R.P.C., Smith, A.J., 1980. Simulation of soil erosion induced by human trampling. J. Environ. Manag. 10, 155–165.
Quiquerez, A., Brenot, J., Garcia, J.-P., Petit, C., 2008. Soil degradation caused by a high-intensity rainfall event: implications for medium-term soil sustainability in Burgundian vineyards. Catena 73, 89–97. http://dx.doi.org/10.1016/j.catena.2007.09.007.
Quiquerez, A., Chevigny, E., Allemand, P., Curmi, P., Petit, C., Grandjean, P., 2014. Assessing the impact of soil surface characteristics on vineyard erosion from very high spatial resolution aerial images (Côte de Beaune, Burgundy, France). Catena 116, 163–172. http://dx.doi.org/10.1016/j.catena.2013.12.002.
Raclot, D., Le Bissonnais, Y., Louchart, X., Andrieux, P., Moussa, R., Voltz, M., 2009. Soil tillage and scale effects on erosion from fields to catchment in a Mediterranean vineyard area. Agric. Ecosyst. Environ. 134, 201–210. http://dx.doi.org/10.1016/j.agee.2009.06.019.
Ramos, M.C., 2006. Soil water content and yield variability in vineyards of Mediterranean northeastern Spain affected by mechanization and climate variability. Hydrol. Process. 20, 2271–2283. http://dx.doi.org/10.1002/hyp.5990.
Ramos, M.C., 2016. Soil losses in rainfed Mediterranean vineyards under climate change scenarios. The effects of drainage terraces. Agriculture, vol. 1, 124–143. http://dx.doi.org/10.3934/agrfood.2016.2.124.
Ramos, M.C., Martínez-Casasnovas, J.A., 2006. Impact of land levelling on soil moisture and runoff variability in vineyards under different rainfall distributions in a Mediterranean climate and its influence on crop productivity. J. Hydrol. 321, 131–146. http://dx.doi.org/10.1016/j.jhydrol.2005.07.055.
Ramos, M.C., Mulligan, M., 2005. Spatial modelling of the impact of climate variability on the annual soil moisture regime in a mechanized Mediterranean vineyard. J. Hydrol. 306, 287–301. http://dx.doi.org/10.1016/j.jhydrol.2004.09.013.
Ramos, M.C., Nacci, S., Pla, I., 2000. Soil sealing and its influence on erosion rates for some soils in the Mediterranean area. Soil Sci. 165, 398–403.
Ramos, M.C., Benito, C., Martínez-Casasnovas, J.A., 2015. Simulating soil conservation measures to control soil and nutrient losses in a small, vineyard dominated, basin. Agric. Ecosyst. Environ. 213, 194–208. http://dx.doi.org/10.1016/j.agee.2015.08.004.
Richter, G., 1975. Der Aufbau der Forschungsstelle Bodenerosion und die ersten Messungen in Weinbergslagen. Forschungsstelle Bodenerosion d. Univ, Trier, Trier.
Richter, G., 1979. Bodenerosion in Rebanlagen des Moselgebietes. In: Ergebnisse quantitativer Untersuchungen 1974–1977. Universität Trier. ed. Forschungsstelle Bodenerosion d. Univ. Trier, Trier.
Richter, G., 1980. Three years of plot measurements in vineyards of the Moselle-region - some preleminary results. Zf Geomorphol. NF 35, 81–91.
Richter, G., 1983. Bodenerosion und ihre Messungen im Raum Trier. Mitt. Dtsch. Bodenk. Ges, Trier, Germany.
Richter, G., 1989. Erosion control in vineyards of the Mosel Region. In: Soil Erosion Protection Measures in Europe. Soil Techonology Series, Cremlingen, pp. 149–156.
Richter, G., 1991. The soil erosion measurement station and its program. In: Combating Soil Erosion in Vineyards of the Mosel-Region. Forschungsstelle Bodenerosion d. Univ. Trier, Trier, pp. 97–108.

Richter, G., Negendank, J.F.W., 1977. Soil erosion processes and their measurement in the German area of the Moselle river. Earth Surf. Process. 2, 261–278. http://dx.doi.org/10.1002/esp.3290020217.

Riding, M.J., Herbert, B.M.J., Ricketts, L., Dodd, I., Ostle, N., Semple, K.T., 2015. Harmonising conflicts between science, regulation, perception and environmental impact: the case of soil conditioners from bioenergy. Environ. Int. 75, 52–67. http://dx.doi.org/10.1016/j.envint.2014.10.025.

Riquelme Chaparro, 1970. Influencia de algunas prácticas de manejo en Viñas plantadas en lomajes de la Costa, sobre el proceso de Erosión Hídrica. Universidad de Concepción, Concepción, Chile.

Riquelme Chaparro, J., Fernández, M., Peña, L., 1972. Influencia de algunas prácticas de manejo en viñas plantas en lomajes de la costa, sobre el proceso de erosión hídrica. Chillán, Chile. Bol. Téc. Esc. Agron. Univ. Concepc. 40 (31 p).

Rodrigo-Comino, J., Cerdà, A., 2018. Improving stock unearthing method to measure soil erosion rates in vineyards. Ecol. Indic. 85, 509–517. http://dx.doi.org/10.1016/j.ecolind.2017.10.042.

Rodrigo-Comino, J., Ruiz Sinoga, J.D., Senciales González, J.M., Guerra-Merchán, A., Seeger, M., Ries, J.B., 2016a. High variability of soil erosion and hydrological processes in Mediterranean hillslope vineyards (Montes de Málaga, Spain). Catena 145, 274–284. http://dx.doi.org/10.1016/j.catena.2016.06.012.

Rodrigo-Comino, J., Iserloh, T., Morvan, X., Malam Issa, O., Naisse, C., Keesstra, S.D., Cerdà, A., Prosdocimi, M., Arnáez, J., Lasanta, T., Ramos, M.C., Marqués, M.J., Ruiz Colmenero, M., Bienes, R., Ruiz Sinoga, J.D., Seeger, M., Ries, J.B., 2016b. Soil erosion processes in European vineyards: a qualitative comparison of rainfall simulation measurements in Germany, Spain and France. Hydrology 3, 6. http://dx.doi.org/10.3390/hydrology3010006.

Rodrigo-Comino, J., Iserloh, T., Lassu, T., Cerdà, A., Keestra, S.D., Prosdocimi, M., Brings, C., Marzen, M., Ramos, M.C., Senciales, J.M., Ruiz Sinoga, J.D., Seeger, M., Ries, J.B., 2016c. Quantitative comparison of initial soil erosion processes and runoff generation in Spanish and German vineyards. Sci. Total Environ. 565, 1165–1174. http://dx.doi.org/10.1016/j.scitotenv.2016.05.163.

Rodrigo-Comino, J., Quiquerez, A., Follain, S., Raclot, D., Le Bissonnais, Y., Casalí, J., Giménez, R., Cerdà, A., Keesstra, S.D., Brevik, E.C., Pereira, P., Senciales, J.M., Seeger, M., Ruiz Sinoga, J.D., Ries, J.B., 2016d. Soil erosion in sloping vineyards assessed by using botanical indicators and sediment collectors in the Ruwer-Mosel valley. Agric. Ecosyst. Environ. 233, 158–170. http://dx.doi.org/10.1016/j.agee.2016.09.009.

Rodrigo-Comino, J., Senciales González, J.M., Ramos, M.C., Martínez-Casasnovas, J.A., Lasanta Martínez, T., Brevik, E.C., Ries, J.B., Ruiz-Sinoga, J.D., 2017a. Understanding soil erosion processes in Mediterranean sloping vineyards (Montes de Málaga, Spain). Geoderma 296, 47–59. http://dx.doi.org/10.1016/j.geoderma.2017.02.021.

Rodrigo-Comino, Brings, C., Iserloh, T., Casper, M.C., González, Senciales, Seeger, M., Brevik, E.C., Ruiz-Sinoga, J.D., Ries, J.B., 2017b. Temporal changes in soil water erosion on sloping vineyards in the Ruwer-Mosel Valley. The impact of age and plantation works in young and old vines. J. Hydrol. Hydromech. 6 (4), 4002–4409. http://dx.doi.org/10.1515/johh-2017-0022.

Rodrigo-Comino, J., Wirtz, S., Brevik, E.C., Ruiz-Sinoga, J.D., Ries, J.B., 2017c. Assessment of agri-spillways as a soil erosion protection measure in Mediterranean sloping vineyards. J. Mt. Sci. 14, 1009–1022. http://dx.doi.org/10.1007/s11629-016-4269-8.

Rodrigo-Comino, J., García-Díaz, A., Brevik, E.C., Keestra, S.D., Pereira, P., Novara, A., Jordán, A., Cerdà, A., 2017d. Role of rock fragment cover on runoff generation and sediment yield in tilled vineyards: role of rock fragments on erosion in vineyards. Eur. J. Soil Sci. http://dx.doi.org/10.1111/ejss.12483.

Rodrigo-Comino, J., Senciales, J.M., Cerdà, A., Brevik, E.C., 2018a. The multidisciplinary origin of soil geography: a review. Earth-Sci. Rev. 177, 114–123. http://dx.doi.org/10.1016/j.earscirev.2017.11.008.

Rodrigo-Comino, J., Brevik, E.C., Cerdà, A., 2018b. The age of vines as a controlling factor of soil erosion processes in Mediterranean vineyards. Sci. Total Environ. 616–617, 1163–1173. http://dx.doi.org/10.1016/j.scitotenv.2017.10.204.

Rodrigo-Comino, J., Davis, J., Keesstra, S.D., Cerdà, A., 2018c. Updated measurements in vineyards improves accuracy of soil erosion rates. Agron. J. 110, 411–417. http://dx.doi.org/10.2134/agronj2017.07.0414.

Ruiz Colmenero, M., 2012. Influencia del empleo de cubiertas vegetales en viñedos en pendiente sobre el control de la erosión Thesis.

Ruiz Sinoga, J.D., 1987. Influencia del medio físico sobre el viñedo en las Cordilleras Béticas litorales. An. Geogr. Univ. Complut. 7. pp. 315–323.

Ruiz-Colmenero, M., Bienes, R., Marques, M.J., 2011. Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. Soil Tillage Res. 117, 211–223. http://dx.doi.org/10.1016/j.still.2011.10.004.

Ruiz-Colmenero, M., Bienes, R., Eldridge, D.J., Marques, M.J., 2013. Vegetation cover reduces erosion and enhances soil organic carbon in a vineyard in the central Spain. Catena 104, 153–160. http://dx.doi.org/10.1016/j.catena.2012.11.007.

Schmitt, A., Dotterweich, M., Schmidtchen, G., Bork, H.-R., 2003. Vineyards, hopgardens and recent afforestation: effects of late Holocene land use change on soil erosion in northern Bavaria, Germany. In: CATENA, Geomorphic Responses to Land Use Changes. 51. pp. 241–254. http://dx.doi.org/10.1016/S0341-8162(02)00171-6.

Schweizer, S.A., Fischer, H., Häring, V., Stahr, K., 2017. Soil structure breakdown following land use change from forest to maize in Northwest Vietnam. Soil Tillage Res. 166, 10–17. http://dx.doi.org/10.1016/j.still.2016.09.010.

Serpa, D., Nunes, J.P., Keizer, J.J., Abrantes, N., 2017. Impacts of climate and land use changes on the water quality of a small Mediterranean catchment with intensive viticulture. In: Environ. Pollut. Barking Essex 1987, http://dx.doi.org/10.1016/j.envpol.2017.02.026. (In press).

Shi, Z.H., Fang, N.F., Wu, F.Z., Wang, L., Yue, B.J., Wu, G.L., 2012. Soil erosion processes and sediment sorting associated with transport mechanisms on steep slopes. J. Hydrol. 454–455, 123–130. http://dx.doi.org/10.1016/j.jhydrol.2012.06.004.

Sofia, G., Tarolli, P., 2017. Hydrological response to ~30 years of agricultural surface water management. Land 6, 3. http://dx.doi.org/10.3390/land6010003.

Steffan, J.J., Brevik, E.C., Burgess, L., Cerdà, A., 2018. The effect of soil on human health: an overview. Eur. J. Soil Sci. 69, 159–171. http://dx.doi.org/10.1111/ejss.12451.

Taguas, E.V., Guzmán, E., Guzmán, G., Vanwalleghem, T., Gómez, J.A., 2015. Characteristics and importance of rill and gully erosion: a case study in a small catchment of a marginal olive grove. Cuad. Investig. Geográfica 41, 107–126. http://dx.doi.org/10.18172/cig.2644.

Tarolli, P., Sofia, G., Calligaro, S., Prosdocimi, M., Preti, F., Dalla Fontana, G., 2015. Vineyards in terraced landscapes: new opportunities from Lidar data. Land Degrad. Dev. 26, 92–102. http://dx.doi.org/10.1002/ldr.2311.

Tetzlaff, B., Wendland, F., 2012. Modelling sediment input to surface waters for German states with MEPhos: methodology, sensitivity and uncertainty. Water Resour. Manag. 26, 165–184. http://dx.doi.org/10.1007/s11269-011-9911-1.

Tropeano, D., 1984. Rate of soil erosion processes on vineyards in central Piedmont (NW Italy). Earth Surf. Process. Landf. 9, 253–266. http://dx.doi.org/10.1002/esp.3290090305.

Vaudour, E., 2002. The quality of grapes and wine in relation to geography: notions of terroir at various scales. J. Wine Res. 13, 117–141. http://dx.doi.org/10.1080/0957126022000017981.

Vaudour, E., Leclercq, L., Gilliot, J.M., Chaignon, B., 2017. Retrospective 70 y-spatial analysis of repeated vine mortality patterns using ancient aerial time series, Pléiades images and multi-source spatial and field data. Int. J. Appl. Earth Obs. Geoinf. 58, 234–248. http://dx.doi.org/10.1016/j.jag.2017.02.015.

Verheijen, F.G.A., Jones, R.J.A., Rickson, R.J., Smith, C.J., 2009. Tolerable versus actual soil erosion rates in Europe. Earth-Sci. Rev. 94, 23–38. http://dx.doi.org/10.1016/j.earscirev.2009.02.003.

Vršič, S., 2011. Soil erosion and earthworm population responses to soil management systems in steep-slope vineyards. Plant Soil Environ. 57, 258–263.

Vrsic, S., Ivancic, A., Pulko, B., Valdhuber, J., 2011. Effect of soil management systems on erosion and nutrition loss in vineyards on steep slopes. J. Environ. Biol. 32, 289–294.

Zdruli, P., Karydas, C.G., Dedaj, K., Salillari, I., Cela, F., Lushaj, S., Panagos, P., 2016. High resolution spatiotemporal analysis of erosion risk per land cover category in Korçe region, Albania. Earth Sci. Inf. 9, 481–495. http://dx.doi.org/10.1007/s12145-016-0269-z.