Catena 141 (2016) 1–21

Contents lists available at ScienceDirect

Catena

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

Soil water erosion on Mediterranean vineyards: A review

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ARTICLE INFO

Article history:
Received 9 January 2015
Received in revised form 8 February 2016
Accepted 9 February 2016
Available online 24 February 2016

Keywords:
Agriculture
Erosion rates
Topography
Soil properties
Rainfall
Soil conservation techniques

ABSTRACT

Soil water erosion on cultivated lands represents a severe threat to soil resources in the world, and especially in Mediterranean areas, due to their topographic, edaphic and climatic conditions. Among the cultivated lands, vineyards deserve a particular attention because, aside representing one of the most important crops in terms of income and employment, they also have proven to be the form of agricultural use that causes one of the highest soil losses. Although the topic of soil water erosion on vineyards has been studied, it still raises uncertainties, due to the high variability of procedures for data acquisition, which consists into different scales of analysis and measurement methods. There is still a great gap in knowledge about the effect of triggering factors on soil water erosion and, so far, an effort to quantify this effect on the Mediterranean viticulture has not been made yet. Therefore, this paper review aims to (i) develop a documented database on splash, sheet and rill erosion rates in Mediterranean vineyards, (ii) identify and, if possible, quantify the effect of triggering factors such as topography, soil properties, rainfall characteristics and soil conservation techniques on soil water erosion, and (iii) provide suggestions for a more sustainable viticulture. Although the large variability of data, some general trends between erosion rates and triggering factors could be found, as long as data were categorized according to the same measurement method. However, no general rule upon which to consider one triggering factor always predominant over the others came out. This paper review supports the importance of monitoring soil water erosion by field measurements to better understand the relationship between the factors. However, protocols should be established for standardizing the procedure of collecting data and reporting results to enable data comparison among different study areas.

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http://dx.doi.org/10.1016/j.catena.2016.02.010
0341-8162/

1. Introduction

Throughout the world, the topic of soil water erosion on cultivated lands has received much concern, due to both the increase of problems caused by the erosion itself and the significant environmental and economic consequences (Cerdà et al., 2007, 2009; Fernández-Calviño et al., 2012; Galati et al., 2015; Gunatilake and Vieth, 2000; Leh et al., 2013; Lieskovský and Kenderessy, 2014; Mandal and Sharda, 2013; Martínez-Casasnovas and Ramos, 2006; Quinton and Catt, 2007; Ramos and Martínez-Casasnovas, 2004; Verstraeten et al., 2003; Zhao et al., 2013; Tarolli and Sofia, 2016). In Europe, 12% of the emerged lands are estimated to be subject to erosion by water (CEC, 2006), which is considered to be one of the most critical forms of soil degradation (FAO, 2000), capable of causing both on-site and off-site (Antoni et al., 2006; Corell et al., 1999; Douglas et al., 1998; Fernández-Calviño et al., 2012, 2013; Pieri et al., 2007; Pimentel et al., 1995; Ramos and Martínez-Casasnovas, 2004; Steegen et al., 2001; Verstraten and Poesen, 2002; Verstraeten et al., 2003). Fig. 1 shows some typical erosion processes caused by water affecting agricultural lands.

In terms of economic consequences, soil erosion by water on cultivated lands may cause annual costs that have been estimated to be £205 million in England and Wales in 2009 (Verheijen et al., 2009) and $44 billion in the U.S.A. in 1995 (Pimentel et al., 1995). The strong impact of soil erosion on society has raised the need for severe threshold values against which to assess the soil monitoring data. At this regard, Verheijen et al. (2009) proposed a modified definition of tolerable soil erosion as 'any actual erosion rate at which a deterioration or loss of one or more soil functions does not occur'. For Europe, they estimated the upper limit of tolerable soil erosion, as equal to soil formation, to be ca. 1.4 Mg ha^{-1} yr^{-1} while the lower limit to be ca. 0.3 Mg ha^{-1} yr^{-1}. Having said that, actual soil erosion rates for tilled, cultivated lands in Europe resulted to be, on average, 3 to 40 times greater than the upper limit of tolerable soil erosion (Verheijen et al., 2009). Montgomery (2007) adopted and updated the approach of Bennett and Lowdermilk (1938) against which to evaluate sustainable and tolerable soil erosion rates. His results quantitatively confirmed the contention that erosion rates from conventionally plowed agricultural fields averaged 1–2 orders of magnitude greater than rates of soil production, erosion under native vegetation and long-term geological erosion. This indicated that conventional plow-based agriculture increased erosion rates enough to prove unsustainable (Montgomery, 2007).

Among the cultivated lands, vineyards merit a particular attention, because, aside from representing one of the most important crops in terms of income and employment (Anderson and Nelgen, 2011), they also constitute, for the Mediterranean areas, a form of agricultural land use that causes the highest soil losses (Cerdà and Doerr, 2007; Cerdan et al., 2002, 2010; García-Ruiz, 2010; García-Ruiz et al., 2010; Kosmas et al., 1997; Martínez-Casasnovas and Sánchez-Bosch, 2000; Martínez-Casasnovas and Ramos, 2006; Raclot et al., 2009; Tropeano, 1983).

This can be explained by a combination of natural and anthropogenic factors. First, Mediterranean vineyards are usually located on steep slopes (Arnáez et al., 2007; Wichereck, 1993) and, therefore, they are more susceptible to soil water erosion (Corti et al., 2011). In fact, topography is recognized to be one of the most significant factors affecting soil water erosion (i.e. Cerdan et al., 2010; Koulouri and Giourga, 2007; Musgrave, 1947) and the transport of sediments. Then, Mediterranean vineyards are usually characterized by poor nutrient and organic matter contents (Cerdà, 1996; Ibáñez et al., 1996; Muñoz-Rojas et al., 2013; Novara et al., 2011). This is mainly due to the climatic conditions of the Mediterranean but also as a consequence of erodible soils and parent materials. At this regard, the Plio-Pleistocene politic marine sediments are recognized to be very susceptible to soil water erosion (Corti et al., 2011). Soils evolved from these fine-textured marine sediments are characterized by low stability of aggregates and low organic matter. Consequently, these weak soil aggregate collapse under the impact of raindrops, leading to the formation of soil sealing and crusts that reduce permeability and, in turns, favor runoff and the formation of rills (Robinson and Phillips, 2001). Furthermore, Mediterranean vineyards have to bear high intensity rainfall events, mainly concentrated in spring and autumn that are recognized to have an influence on soil water erosion and runoff processes (Borga et al., 2011; Tarolli et al., 2012). In addition, in Mediterranean vineyards the soil under the vines is usually artificially maintained without plant cover, leaving large areas exposed to the rainfall (Arnáez et al., 2007; García-Ruiz, 2010; Novara et al., 2011; Tropeano, 1984). In fact, the two most common soil conservation techniques (SCTs) are considered to be tillage (mechanical weeding) and no-tillage (chemical weeding) (Raclot et al., 2009; Novara et al., 2011), and both of them generally turn out in bare soil management during the whole year (Lasanta and Sobrón, 1988). Fig. 2 shows two examples of Mediterranean vineyards affected by soil water erosion. Fig. 2a was taken in a terraced vineyard located in the Marche region, central Italy. Here, the wrong positioning of the drainage system facilitated the formation of surface wash that eroded the terrace risers, exposing in this way the roots of vines (black arrow). On the other hand, Fig. 2b was taken in an almost flat vineyard located in the province of Valencia, Spain. Here, a severe rainstorm caused sheet erosion processes, as pointed out by the black arrow, that were enhanced even by the absence of grass cover in the inter-rows and by the early stage of the vineyard implant.

Alternative systems to chemical weed control in the vine inter-rows are straw and prunings mulching (Blavet et al., 2009; Carsoulle et al., 1986; Cerdà et al., in press. Gril et al., 1989; Keesstra et al., 2016; Louw and Bennie, 1991; Morvan et al., 2014; Prosdocimi et al., 2016; Sadeghi et al., 2015; Tejada and Benítez, 2014), natural or permanent grassing (Gril et al., 1989; Messer, 1980; Morvan et al., 2014; Novara et al., 2011; Raclot et al., 2009; Schwing, 1978) and covering the soil with rock fragments (Blavet et al., 2009; Nachtergaele et al., 1998). Fig. 3 shows an example of three alternative systems to chemical weed control and reduction of soil erosion in the vine inter-rows: chopped prunings mulching (3a), permanent grassing (catch crops) (3b) and straw mulch cover (3c).

Furthermore, the abandonment of land, land use changes and farming techniques have accelerated erosion processes in vineyards too (Ballif, 1990; Blavet et al., 2009; Cerdà, 1994; Dunjó et al., 2003; Ferrero et al., 2005; García-Ruiz, 2010; Martínez-Casasnovas, 1998; Novara et al., 2011; Porta et al., 1994; Tarolli et al., 2014; Tarolli et al., 2015; Usòn, 1998). At this regard, García-Ruiz (2010), focusing on the effects of land uses on soil erosion in Spain, highlighted how vineyards expanded to steep slopes, sometimes on new unstable bench terraces,