Science of the Total Environment 574 (2017) 204–215

Contents lists available at ScienceDirect

Science of the Total Environment

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

Rainfall simulation and Structure-from-Motion photogrammetry for the analysis of soil water erosion in Mediterranean vineyards

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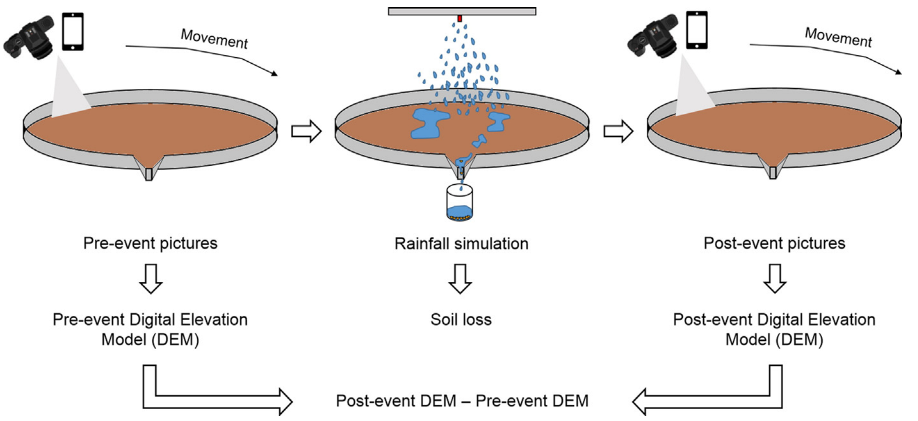
HIGHLIGHTS

- Structure-from-Motion is able to detect topographic changes at very fine scales.
- Smartphones can be used to obtain reliable image datasets for Structure-from-Motion.
- Sediment connectivity plays a key role in estimating eroded materials.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 20 June 2016
Received in revised form 5 September 2016
Accepted 5 September 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Soil water erosion
Mediterranean vineyards
Rainfall simulation
Structure from motion
Sediment connectivity

ABSTRACT

Soil water erosion is a serious problem, especially in agricultural lands. Among these, vineyards deserve attention, because they constitute for the Mediterranean areas a type of land use affected by high soil losses. A significant problem related to the study of soil water erosion in these areas consists in the lack of a standardized procedure of collecting data and reporting results, mainly due to a variability among the measurement methods applied. Given this issue and the seriousness of soil water erosion in Mediterranean vineyards, this works aims to quantify the soil losses caused by simulated rainstorms, and compare them with each other depending on two different methodologies: (i) rainfall simulation and (ii) surface elevation change-based, relying on high-resolution Digital Elevation Models (DEMs) derived from a photogrammetric technique (Structure-from-Motion or SfM). The experiments were carried out in a typical Mediterranean vineyard, located in eastern Spain, at very fine scales. SfM data were obtained from one reflex camera and a smartphone built-in camera. An index of sediment connectivity was also applied to evaluate the potential effect of connectivity within the plots. DEMs derived from the smartphone and the reflex camera were comparable with each other in terms of accuracy and capability of estimating soil loss. Furthermore, soil loss estimated with the surface elevation change-based method resulted to be

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http://dx.doi.org/10.1016/j.scitotenv.2016.09.036

of the same order of magnitude of that one obtained with rainfall simulation, as long as the sediment connectivity within the plot was considered. High-resolution topography derived from SfM revealed to be essential in the sediment connectivity analysis and, therefore, in the estimation of eroded materials, when comparing them to those derived from the rainfall simulation methodology. The fact that smartphones built-in cameras could produce as much satisfying results as those derived from reflex cameras is a high value added for using SfM.

1. Introduction

Throughout the world, soil erosion by water is a serious problem, especially in semi-arid and semi-humid areas (Cerdà et al., 2009, 2015; Cerdan et al., 2010; Garcìa-Ruiz, 2010; Ligonja and Shrestha, 2015; Novara et al., 2016;Taguas et al., 2015; Rodrigo Comino et al., 2016a). Although soil erosion by water consists of physical processes that vary significantly in severity and frequency according to when and where they occur, they are also strongly influenced by anthropic factors such as land-use changes on large scales and unsustainable farming practices (Cerdà, 2000; León et al., 2015; López-Vicente et al., 2015; Ochoa-Cueva et al., 2015; Montgomery, 2007; Mwango et al., 2016; Nanko et al., 2015; Tarolli et al., 2014). This has led to the definition of 'accelerated' soil erosion as being the result of human impact on the landscape (Tarolli and Sofia, 2016) and this is found in all the continents (Borrelli et al., 2015; Cao et al., 2015; Gessesse et al., 2015; Rodrigo Comino et al., 2016b).

The impact of soil erosion on modern society has required to set threshold values against which to assess the monitoring of soil data, especially in agriculture (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, 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., 2010; Martínez-Casasnovas and Sánchez-Bosch, 2000; Prosdocimi et al., 2016a; Raclot et al., 2009; Rodrigo Comino et al., 2015; Rodrigo Comino et al., 2016c). One of the main reasons for this is the bare soil under the vines that is exposed to high intensity rainfall events, mainly concentrated in spring, autumn and winter, which characterize the Mediterranean climate (Arnáez et al., 2007; Borga et al., 2011; Garcìa-Ruiz, 2010; Prosdocimi et al., 2016a). For this cultivation, the two most common soil management techniques are considered to be tillage, where the weeds are usually removed mechanically, and no-tillage, where the weeds are usually removed chemically (Novara et al., 2011; Raclot et al., 2009), and both of them generally turn out in bare soil management during the whole year. Extreme rainfall events that occur in the Mediterranean area are able to cause significant soil water erosion processes, especially when no protective material covers the soil (Fig. 1) (Bisantino et al., 2015; Keesstra et al., 2016; Novara et al., 2016; Prosdocimi et al., 2016c). However, to reduce the high soil erosion rates, more conservation-minded soil management practices have also been used such as mulching (Cerdà et al., 2015; Costantini et al., 2015; Jordán et al., 2011; Prosdocimi et al., 2016b, 2016c), cover crops (Novara et al., 2011), rock fragments (Blavet et al., 2009), natural grassing (Grimaldi et al., 2015; Mekonnen et al., 2015a; Mekuria et al., 2016; Raclot et al., 2009) and geotextiles (Giménez Morera et al., 2010; Mekonnen et al., 2015b; Mengistu et al., 2016). Furthermore, new approaches to evaluate incentives for the adoption of agri-environment measures in degraded and eroded vineyards have been implemented (Galati et al., 2015) and mulching is one of those successful strategies (Prosdocimi et al., 2016c).

Another issue related to soil water erosion in Mediterranean vineyards is the lack of a standardized procedure of collecting data and reporting results, mainly due to a great variability among the measurement methods applied to quantify it (Prosdocimi et al., 2016a; García-Ruiz et al., 2015). This induces difficulties in comparing data coming from different studies and obtained with different methodologies. Based on the paper review of Prosdocimi et al. (2016a), six different methodologies to assess soil water erosion in vineyards have been identified: (i) experimental plot stations under simulated or natural rainfalls, (ii) erosion markers, (iii) models, (iv) the surface elevation change-based methods, (v) geochemical methods, and (vi) carbon stable isotopes. This works focuses on the use of plot stations under simulated rainfall and on the surface elevation change-based method. Rainfall simulation has become a very effective technique for assessing soil erosion, particle detachment and overland flow at very fine scales (Arnáez et al., 2007; Cerdà et al., 1997; Iserloh et al., 2013; Rodrigo Comino et al., 2016b). Several types and designs of rainfall simulators have been realized to meet the objectives of researchers (Iserloh et al., 2013; Lassu et al., 2015). In particular, the advantages of using a portable rainfall simulator are: i) its versatility, ii) low cost and easy operation, and iii) capability of obtaining data under controlled conditions and over relatively short periods of time. The surface elevation change-based method is able to detect the topographic changes over time. It relies on Digital Elevation Models (DEMs) that can be used as basic topographic information to derive morphometric attributes and quantify soil erosion and deposition rates (Martínez-Casasnovas and Sánchez-Bosch, 2000; Martínez-Casasnovas et al., 2002; Prosdocimi et al., 2015). Remote-sensing technologies have proven to facilitate significantly the

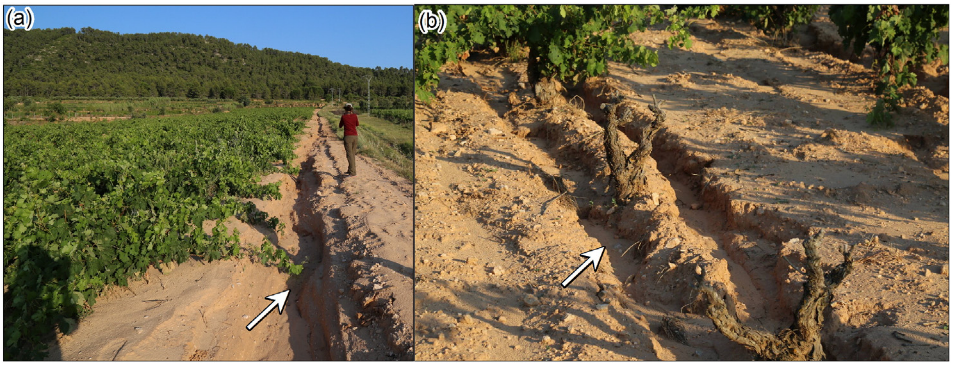

Fig. 1. Examples of soil water erosion processes caused by a 40 mm in 30 min thunderstorm occurred in mid-June 2015 in the study area. The white arrows point out a gully (a) and a rill (b).