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Effectiveness of carbon isotopic signature for estimating soil erosion and deposition rates in Sicilian vineyards

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ABSTRACT

Traditional methods for measurement of soil erosion provide information on erosion rates and mechanisms but fail to determine the spatial distribution of sediment redistribution. Recent studies have used carbon (C) stable isotopes to trace sediment and to monitor soil organic carbon (SOC) redistribution. The difference in δ^{13}C values in a slope-transect or in a watershed provides information about the source of suspended organic matter and sediment removal and deposition, but miss enough information to quantify sediment loss. The objective of this research was to develop a method to estimate soil erosion using the natural discrimination of δ^{13}C-SOC with soil depth, comparing δ^{13}C variation in different profiles sampled along a slope. The method was developed in a Sicilian vineyard, where soil losses were previously measured by means of Gerlach collectors and by pole methods. δ^{13}C was measured in different soil profiles in the top, middle and bottom of the slope. The variation of δ^{13}C with soil depth in the profiles along the slope was compared to the δ^{13}C values of the near flat area, in order to reconstruct the original topography of slope transect. δ^{13}C increased with depth and decreased from the top to the bottom of the slope in all pedons. The soil δ^{13}C signature ranged from −26.7‰ to −25.7‰, from −26.2‰ to −25.3‰, and from −27.0‰ to −24.8‰ in the profiles at the top, middle, and bottom of the slope, respectively. The rates of δ^{13}C enrichment along the slope could be explained as different rates of detachment and deposition. The erosion value estimated with δ^{13}C method was 77 Mg ha^{-1} y^{-1}. The comparison of different methods (102 Mg ha^{-1} y^{-1} with the pole method and 89.6 Mg ha^{-1} y^{-1} with the Gerlach method) indicate that carbon isotopic signature is a reliable indicator of short- and long-term soil erosion processes.

1. Introduction

Soil erosion has attracted worldwide attention because of its adverse impacts on soil quality (Wiaux et al., 2014), land productivity (Yitbarek et al., 2012), and environmental sustainability (Prokop and Poręba, 2012; Zhao et al., 2013). Vineyards are often susceptible to soil erosion because of the presence of bare soil during much of the year, the lack of a crop cover during the winter and intensive ploughing. Moreover, vineyards are frequently located on slopes and on soils with low organic matter content and high erodibility (Arnáez et al., 2007; Marques et al., 2010; Novara et al., 2012; Ramos and Martínez-Casasnovas, 2004; Ruiz-Colmenero et al., 2013). By reducing the risk of soil degradation, controlling soil erosion will increase the sustainability of wine production.

Soil erosion rates have been traditionally estimated by watershed monitoring, slope measurements, and rainfall simulation experiments. (Desprats et al., 2013; Iserloh et al., 2013; Haregeweyn et al., 2013; Mahmoodabadi and Cerdà, 2013). Estimates by means of plots and watershed monitoring are also expensive and require decades of measurement. The development of effective erosion control methods requires a deep understanding of erosion processes (Mandal and Sharda, 2013), which in turn will require new methods to measure the temporal and spatial dynamics of both erosion and sedimentation.

Tracers have been previously used to monitor the temporal and spatial variation of erosion in order to understand sediment removal and redistribution on slopes and in watersheds (Mekuria et al., 2012). Most of these methods use rare earth elements (Liu et al., 2004) (REEs) or radionuclides including ^{137}Cs, ^{7}Be, and ^{210}Pb from deposited atmospheric dust (Wallbrink and

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Murray, 1996; Walling and Quine, 1991; Zhang et al., 1999). These methods have several disadvantages, such as a relatively long measurement time and a high cost of laboratory analysis.

Researchers have recently developed the necessary techniques to use carbon (C) stable isotopes to trace the movements of sediments and soil organic carbon (SOC) (Alewell et al., 2009; Buck and Monger, 1999; Fox and Papanicolaou, 2007; Jacinthe et al., 2009; Papanicolaou et al., 2003; Schaub and Alewell, 2009; Turnbull et al., 2008). The difference in $\delta^{13}C$ values in a soil transect or in a watershed can provide information about the source area of suspended organic matter or soil sediment. Because of the difference in photosynthetic pathways, tissues of C_3 plants ($\delta^{13}C$: −35 to −20‰) and C_4 plants ($\delta^{13}C$: −19 to −9‰) have distinct ^{13}C isotopic compositions (Farquhar et al., 1989). This difference in ^{13}C signature has been extensively used in assessing C storage and dynamics at sites where shifts in C_3–C_4 vegetation can be documented (Balesdent and Balabane, 1996; Bernoux et al., 1998; Novara et al., 2013a; Puget et al., 1995). Jacinthe et al. (2009) determined the amount and source of eroded C retained in C_3 grass filters receiving runoff for several years from sites supporting C_4 vegetation. Other authors qualitatively assessed soil erosion in transects with only C_3 plants by using additional information like C/N ratios (Papanicolau et al., 2003), fatty acids contents (Hancock and Revill, 2013), or the gradient from oxic upland to anoxic wetlands (Schaub and Alewell, 2009).

To date, C isotopes have been used to investigate the origin of sediments (Alewell et al., 2009; Bellanger et al., 2004) but have not been used to estimate the amount of sediment lost or gained. The objectives of this study were (i) to quantify soil losses using the changes in $\delta^{13}C$ in space and time in a vineyard located on a slope through studying the changes in soil depth and $\delta^{13}C$ values along a slope in order to determine the soil deposition and detachment areas; and, (ii) to reconstruct the spatial and temporal variation of the original soil profiles and to thereby estimate the rate of soil erosion/sedimentation.

2. Materials and methods

2.1. Study area

The study area was a drip-irrigated vineyard in a typical, hilly landscape nearby *Sambuca di Sicilia* in southwestern Sicily, Italy (37°39′17″N and 13°00′53″E) (Fig. 1). The vineyard was planted in 2001, after 80 cm deep ploughing. To fit the aims of the survey, we chose an E-NE facing slope between 350 and 373 m a.s.l., with a plant density of 5000 vines ha^{-1}, and a row width of 2.2 m. The vineyard was traditionally managed, and the soil was harrowed 4–5 times each year with a shallow tillage (5 cm depth) to preserve water evaporation and to control weeds.

The climate is semiarid Mediterranean with a dry period of 4–5 months (mean annual temperature: 17.4 °C; mean annual rainfall: 648 mm). The soil udometric regime is xeric, and the thermometric regime is thermic (Soil Survey Staff, 2010).

2.2. Soil sampling and analysis

In the study area two soil surveys were carried out in the same pedon: the first one according to genetic horizons for soil description and the second one every 10 cm for isotopic erosion method. In detail, along the selected slope (Fig. 1), three soil pedons (P1-top, P2-mid, and P3-bottom, with respect to position on the slope) were described and sampled in July 2013 according to the sequence of the genetic horizons (Schoeneberger et al., 2012). Each pedon was also sampled three times every 10–60 cm depth using a core sampler (Ø8 cm). Three additional soil samples (M1, M2, and M3) were collected at 10 cm depth along the slope (three times replicated). Moreover, in the flat area of the vineyard, where neither deposition nor detachment was evident, 10 random samples of top soil were collected for $\delta^{13}C$ determination. All soil samples were air-dried and passed through a 2 mm sieve for laboratory analysis. Particle-size distribution was determined by

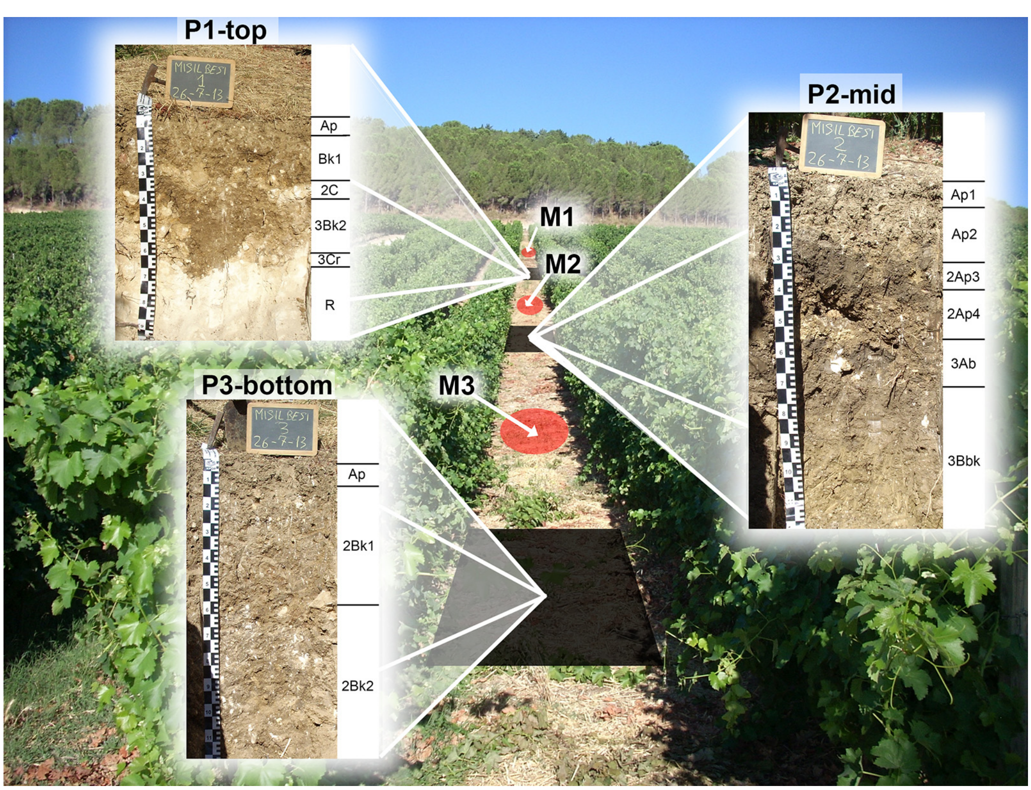

Fig. 1. Location of sampling points and soil profiles along the slope of the study site (a vineyard in Sicily).