Science of the Total Environment 622–623 (2018) 474–480

Contents lists available at ScienceDirect

Science of the Total Environment

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

The impact of soil erosion on soil fertility and vine vigor. A multidisciplinary approach based on field, laboratory and remote sensing approaches

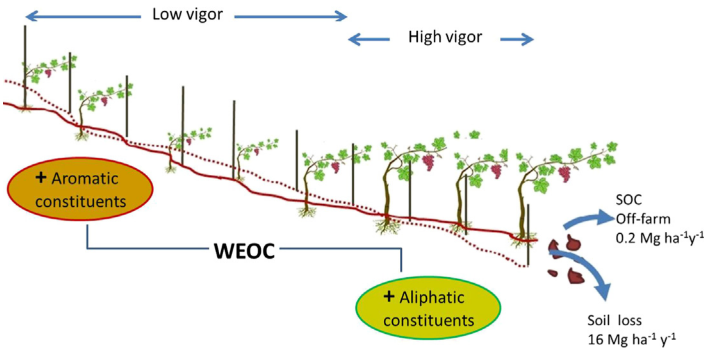
Agata Novara [a,*], Antonino Pisciotta [a], Mario Minacapilli [a], Antonino Maltese [b], Fulvio Capodici [b], Artemi Cerdà [c], Luciano Gristina [a]

[a] *Dept. of Agricultural, Food and Forest Sciences University of Palermo, Palermo, Italy*
[b] *Dept. of Civil, Environmental, Aerospace, Materials Engineering, University of Palermo, Italy*
[c] *Soil Erosion and Degradation Research Group, Department of Geography, University of Valencia, Valencia, Blasco Ibàñez 28, 46010, Valencia, Spain*

HIGHLIGHTS

- Soil erosion in vineyards has a strong effect on soil organic carbon loss and redistribution.
- The interactions among vines vigor, sediment delivery and SOC was analyzed.
- Soil fertility land unit was reduced by 40% and SOC decreased by 0.20 Mg ha^{-1} y^{-1}
- Vine vigor was strongly correlated to WEOC components.
- Soil-plant analyses can detect vineyard fertility, monitoring risk areas in the long term.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 July 2017
Received in revised form 23 November 2017
Accepted 24 November 2017
Available online xxxx

Keywords:
Carbon stock
Viticulture
Erosion
Specific ultraviolet absorbance
NDVI

ABSTRACT

Soil erosion processes in vineyards, beyond surface runoff and sediment transport, have a strong effect on soil organic carbon (SOC) loss and redistribution along the slope. Variation in SOC across the landscape can determine differences in soil fertility and vine vigor. The goal of this research was to analyze the interactions among vines vigor, sediment delivery and SOC in a sloping vineyard located in Sicily. Six pedons were studied along the slope by digging 6 pits up to 60 cm depth. Soil was sampled every 10 cm and SOC, water extractable organic carbon (WEOC) and specific ultraviolet absorbance (SUVA) were analyzed. Erosion rates, detachment and deposition areas were measured by the pole height method which allowed mapping of the soil redistribution. The vigor of vegetation, expressed as Normalized Difference Vegetation Index (NDVI), derived from high-resolution satellite multispectral data, was compared with measured pruning weight. Results confirmed that soil erosion, sediment redistribution and SOC across the slope was strongly affected by topographic features, slope and curvature. The erosion rate was 16 Mg ha^{-1} y^{-1} since the time of planting (6 years). SOC redistribution was strongly correlated with the detachment or deposition areas as highlighted by pole height measurements. The off-farm SOC loss over six years amounted to 1.2 Mg C ha^{-1}. SUVA$_{254}$ values, which indicate hydrophobic material rich in aromatic constituents of WEOC, decreased significantly along the slope, demonstrating that WEOC in the detachment site is more stable in comparison to deposition sites. The plant vigor was strongly correlated with WEOC constituents. Results demonstrated that high resolution passive remote sensing data

---

* Corresponding author.
E-mail address: agata.novara@unipa.it (A. Novara).

https://doi.org/10.1016/j.scitotenv.2017.11.272

combined with soil and plant analyses can survey areas with contrasting SOC, soil fertility, soil erosion and plant vigor. This will allow monitoring of soil erosion and degradation risk areas and support decision-makers in developing measures for friendly environmental management.

1. Introduction

Soils are important natural resources for food production. However, they are affected by several soil degradation factors with consequent significant impacts on agricultural productivity and environmental and human health (Brevik et al., 2015; Brevik et al., 2017; Blum, 2013; Steffan et al., 2017). Erosion is considered one of the most widespread human induced causes of land degradation, impacting crop yields and threatening the soil system and sustainability of human societies (Mol and Keesstra, 2012). This is why the importance of soils has been highlighted to achieve the United Nations Goals for Sustainability (Keesstra et al., 2016). Erosion leads to loss of nutrients, lower soil water holding capacity, decrease thickness of the soil layer that is most useful for plant growth, and reduction in soil fertility and biodiversity (García-Díaz et al., 2017; Li et al., 2016). The effect of erosion on loss of productivity for arable land has been widely studied, quantifying the value in economic terms (Williams et al., 1984), which also make it necessary to develop an economic and biophysical approach to management that contributes to soil restoration (Cerdà et al., 2017). den Biggelaar et al. (2003), in a literature review on the effects of erosion on soil productivity, estimate that relative wheat yield losses ranged from 0.04% yr^{-1} in Europe to 0.67% yr^{-1} in Australia. Such loss of productivity undermines food production with several negative economic effects. Loss of productivity due to land degradation has a direct impact on net income, but while the farmers' perception of this reduction and the economic evaluation can be easy in some crops (i.e. cereal yield), it is more difficult for other productions such as grapes. The market for grapes for wine and table production, in fact, is mainly focused on grape quality rather than quantity. Therefore, the effects of erosion in vineyards should be evaluated not only on grape yield, but also on plant fertility and vigor, which are the key indicators of final wine quality (Wezel et al., 2002; Zingore et al., 2007). Erosion is responsible for soil nutrient losses and negative effects on plant nutrition. To restore soils affected by erosion and recover their fertility there is a need to increase external chemical inputs to maintain plant vigor (Zingore et al., 2007). The use of fertilizes and passes by heavy machinery leads to noteworthy reductions in vineyard sustainability due to increases in costs at the farm level, water pollution, soil erosion rates, and higher CO_2 emissions (Cerdà et al., 2017). Under stable conditions, soil erosion by water is a natural process generally in balance with natural soil formation due to weathering, but human activities considerably increase the magnitude of soil erosion over equilibrium levels with several impacts on the environment (Zhang et al., 2017). Most Mediterranean hilly vineyards exceed such equilibrium with erosion rates ranging from few tons of sediment to 100 Mg ha^{-1} y^{-1} (Novara et al., 2011; Rodrigo-Comino et al., 2016a, 2017; Ruiz-Colmenero et al., 2013). Similar high erosion rates have also been found in vineyards under temperate climate conditions (Rodrigo-Comino et al., 2016b). Moreover, the impact of vineyard cultivation on erosion risk is exacerbated by improper management such as soil tillage, low organic matter contents, biomass removal and limited percentage of soil cover (Prosdocimi et al., 2016). The effect of soil erosion on sediment loss has been widely elucidated, but the influence of erosion processes on soil organic carbon (SOC) cycling is still poorly understood and contradictory findings have been reported (Doetterl et al., 2016). Soil erosion could have a negative impact on C sequestration, being a source for atmospheric CO_2 (Novara et al., 2016) due to a decrease in net primary production on eroded soil and a higher SOC decomposition in buried sediments (Jacinthe and Lal, 2001; Lal and Pimentel, 2008). On the other hand, some studies have found that erosion of agricultural soils is a sink for atmospheric CO_2. The eroded sediments buried at deposition sites are protected from quick decomposition, therefore the organic matter turnover rates are reduced (Van Oost et al., 2008). Although soil erosion could be considered a positive process for CO_2 reduction, in agricultural land it has a negative impact on ecosystem services, considering that fertile soils are degraded and the effects of dissolved organic carbon dynamics in the aquatic environment (Whitehead et al., 2006). The reduction of agricultural land fertility and crop productivity as a consequence of soil erosion is widely recognized by researchers but the difficulties in quantification of SOC loss and the specific delineation of C deposition/erosion sites has resulted in a weak perception of the risk by farmers and stakeholders (Moges and Holden, 2008). Estimations of SOC loss in a sloping area have been determined through SOC cycle and erosion models, providing useful information on C balance and total SOC loss off farm, but further knowledge on the redistribution of bulk SOC and SOC pools along the slope are needed for specific agricultural production purposes. Therefore, in agricultural soils, knowledge of C loss should be integrated with evaluation of SOC dynamics to define the stability of the SOC pool in conjunction with measurement of plant vigor to estimate the loss of fertile area. Considering the hypothesis of a strong relationship existing between sediment erosion, carbon losses and plant vigor, the goal of this study was to analyze, in a Mediterranean vineyard: (i) soil erosion rates and SOC losses, and their interaction; (ii) impact of soil erosion and C distribution on plant vigor; and (iii) interaction between indirect (NDVI) and direct (pruning weight) methods of plant vigor estimation with soil erosion rates and SOC distribution.

2. Materials and methods

2.1. Study area and soil analysis

A vineyard (cultivar Viognier) located in Menfi, in southwestern Sicily (37°34′N, 12°59′E), was selected as representative of Mediterranean vineyards: steep slopes, shallow soils, and millennia of ploughing. The area is characterized by a Mediterranean climate (summer drought), with mean annual temperature of 18 °C and mean annual precipitation of 516 mm. The soils are Calcic-gleyic-vertisols according to WRB (2006) (clay = 42.0%, silt = 37.2, sand = 20.8%; pH = 8; $CaCO_3$ = 22%) (unpublished data, Assessorato Regionale Agricoltura, dello Sviluppo Rurale e della Pesca Mediterranea-Ufficio Intercomunale di Menfi). The vineyard has an area of 3 ha and lies on an *E*-NE facing hillside with an average slope of 9.5%. The vineyard is located on a hydraulically disconnected slope, according to field observations. It was planted in 2011 with a 2.40 m distance between rows and 1 m distance intra-row. The vines were cane pruned and a vertical shoot positioning trellis system was used at fruit set. The vineyard was traditionally managed with four or five shallow tillage passes (10 cm depth) during the year to control weeds, water evaporation and avoid the formation of soil cracks. Conventional cultivation practices for the production of healthy grapes were used. Along the slope, in the vineyard intra-row, six pedons were studied by digging six pits (W1 to W6) up to 60 cm depth (Fig. 1) during the summer of 2016. Pit positions along the slope were chosen after vineyard pole height measurements which was helpful to discriminate deposition and detachment areas. In each pit, 3 soil samples were collected every 10 cm depth up to 60 cm depth (total soil samples 84), sieved at 2 mm and stored for soil organic carbon (SOC) analysis. An EA-IRMS (Elemental Analyser Isotope Ratio