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Research article

Effects of soil erosion on agro-ecosystem services and soil functions: A multidisciplinary study in nineteen organically farmed European and Turkish vineyards

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ABSTRACT

This multidisciplinary research work evaluated the effects of soil erosion on grape yield and quality and on different soil functions, namely water and nutrient supply, carbon sequestration, organic matter recycling, and soil biodiversity, with the aim to understand the causes of soil malfunctioning and work out a proper strategy of soil remediation.

Degraded areas in nineteen organically farmed European and Turkish vineyards resulted in producing significantly lower amounts of grapes and excessive concentrations of sugar. Plants suffered from decreased water nutrition, due to shallower rooting depth, compaction, and reduced available water capacity, lower chemical fertility, as total nitrogen and cation exchange capacity, and higher concentration of carbonates. Carbon storage and organic matter recycling were also depressed. The general trend of soil enzyme activity mainly followed organic matter stock. Specific enzymatic activities suggested that in degraded soils, alongside a general slowdown in organic matter cycling, there was a greater reduction in decomposition capacity of the most recalcitrant forms. The abundance of Acari Oribatida and Collembola resulted the most sensitive indicator of soil degradation among the considered microarthropods. No clear difference in overall microbial richness and evenness were observed. All indices were relatively high and indicative of rich occurrence of many and rare microbial species. Dice cluster analyses indicated slight qualitative differences in Eubacterial and fungal community compositions in rhizosphere soil and roots in degraded soils.

This multidisciplinary study indicates that the loss of soil fertility caused by excessive earth movement before planting, or accelerated erosion, mainly affects water nutrition and chemical fertility. Biological soil fertility is also reduced, in particular the ability of biota to decompose organic matter, while biodiversity is less affected, probably because of the organic management. Therefore, the restoration of the eroded soils requires site-specific and intensive treatments, including accurately chosen organic matrices for fertilization, privileging the most

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easily decomposable. Restoring soil fertility in depth, however, remain an open question, which needs further investigation.

1. Introduction

Intensive management of vineyards and other permanent tree crops has replaced the traditional mixed cultivation model in Europe (Bignal and McCracken, 2000). Most of intensive management models are applied without taking into account the nature of local soils and thus might originate severe impairment of soil functions (Costantini, 1992; Vaudour et al., 2015; Costantini et al., 2015). Mediterranean woody crops, in particular, are usually cultivated in soils low in organic matter, with limited water availability and on medium to steep slopes, where the occurrence of severely eroded areas, characterized by excessive low yield, is rather frequent (Le Bissonnais et al., 2002; Costantini and Barbetti, 2008). In addition to reduced yield, the accelerated soil water erosion can be responsible for soil compaction, reduced C sequestration and increased greenhouse gas emissions, loss of nutrients, and dispersion of heavy metals, especially copper (Battany, and Grismer, 2000; Cerdan et al., 2010; Prosdocimi et al., 2016; Fernández-Calviño et al., 2008). Climate change is deemed to exacerbate the sustainability of rainfed tree crops in Mediterranean, since a reduced and more erratic rainfall regime is foreseen (Schultz, 2000). The consequence would be an increased water need for irrigation and a resulting harsher competition for freshwater with other utilization types (Van Leeuwen et al., 2013).

In previous studies, much attention has been given to soil degradation occurring after plantation and to the consequent agronomic, environmental and economic damages (Martínez-Casasnovas and Ramos, 2006; Novara et al., 2011). Some studies have also focused on the impact of improper land preparation activities before planting, such as intense levelling and deep ploughing, which may cause destruction, truncation and burial of soil horizons (Cots-Folch et al., 2006; Bazzoffi et al., 2006; Martínez-Casasnovas and Ramos, 2009). The excessive earthworks may result in the disturbance of the natural contour of slopes and significant modifications of soil chemical, physical, biological, and hydrological balances, in turn affecting soil suitability for grapevine (Brye et al., 2003; Costantini et al., 2006; Ramos and Martínez-Casasnovas, 2007; Stanchi et al., 2012). Furthermore, they can be responsible for reduction of soil fertility, enrichment of calcium carbonate and soluble salts, affecting the development and health of grapevines (Costantini et al., 2010; Sharp-Heward et al., 2014). Low water retention capacity, in particular, can lead to increased water stress during dry season, decreased water permeability and circulation of oxygen in the soil, increased runoff volume, surface erosion and landslide risk, reduced soil biodiversity, and limitation of biochemical processes, such as organic matter mineralization and bioavailability of nutrients (Ramos, 2017).

Few studies documented the impact of soil erosion and loss of organic matter and organisms on soil functions and biodiversity (Tsiafouli et al., 2014). Generally, soil microorganisms and meso- and macrofauna suffer from management systems involving the use of synthetic pesticides and intensive tillage (Gagnarli et al., 2015; Holland, 2004; Schreck et al., 2012), which impair their activity and ecosystem services, such as organic matter decomposition and humification, regulation of nutrient cycles and beneficial antagonisms against pests and diseases (Lavelle et al., 2006). Most of small invertebrates, such as nematodes, pot worms, springtails, and mites, called ‘biological regulators’ (European Comminssion, 2010) are important components of soil functions in regulating the population of other soil organisms, including pests and diseases, through grazing, predation or parasitism. The composition and abundance of springtails and mites, which are the largest biological regulators, are often used as “early-warning“ bioindicator of environmental changes (Cole, 2002). Fromm et al., 1993, for example, registered that the distribution of springtails in agricultural landscape can follow large-scale soil carbon gradients and type of land cultivation.

Soil enzyme activity is another proximal driver of soil functioning, contributing to biogeochemical cycling, organic matter transformations and nutrient availability. Soil enzyme activities also are widely accepted as sensitive indicators of soil health and candidate “sensors” of changes in soil management, soil health, microbial activity patterns, soil ecological stress and soil fertility (Aon et al., 2001; Badiane et al., 2001; Vepsäläinen et al., 2001). Furthermore, being synthesized by microorganisms, roots and soil micro- and meso-fauna (e.g., earthworms, nematodes), enzymatic activity encapsulates complex information in a simple and informative manner.

Restoring degraded areas is rather problematic and still much debated, since the complex network of interactions between hydrological, chemical, biochemical, and biological processes that impair soil functions is site specific and difficult to disentangle (Nunes et al., 2016; Costantini et al., 2016). A promising option is the implementation of recommended management practices, which include plant cover in the inter-row area, minimum or no tillage and off- and on-farm organic matter amendments (Vicente-Vicente et al., 2016). Organic viticulture is considered another sustainable cultivation method, which may reduce the environmental impacts of conventional grape growing (Merot and Wery, 2017; Costantini et al., 2013).

The first aim of this research work was to understand the causes of reduced soil functionality in the degraded areas of nineteen organically farmed European and Turkish vineyards. Selected methodologies involving soil physics and hydrology, chemistry and biochemistry, micro- and mesobiology, and soil genesis and classification, were tested and related to the viticultural and oenological result.

Our contribution is finally intended to support the definition of a set monitoring methods able to assess soil functionality in vineyards. This is fundamental to work out a proper strategy of soil remediation and to recommend agricultural practices that could be successfully adopted to recover soil fertility in the degraded areas of vineyards and other tree crops.

2. Materials and methods

2.1. Study areas

Commercial organic farms from important viticultural areas of five European countries were selected (Fig. 1 and Table 1). Being placed in well-known and affirmed territories of grape production, they

Fig. 1. Locations of experimental farm and vineyards for wine (rectangles) or table grape (circles) production. LOG: Bodegas Puelles, Abalos, Logroño; MB: Château Maison Blanche, Saint Emillion; PR: Château Pech Redon, La Clape; FON: Fontodi, Greve in Chianti; SD: Sand Disdagio, Civitella Marittima; VS: Brajiniki, Bonini; VL: Brajiniki, Prade; CC: Celebi, Ceyhan; ET: Evran, Tarsus.