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Runoff, sediment and nutrient exports from a Mediterranean vineyard under integrated production: An experiment at plot scale

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ABSTRACT

Conventional management of Mediterranean vineyards strongly contributes to land degradation. In Portugal, the use of integrated production has been encouraged by governmental subsidies because it is assumed to be a farm management system that protects the environment and favours agriculture sustainability. The purpose of this study is to assess the impact of minimum tillage and regulated fertilization practices, driven by integrated production, on runoff and associated sediment and nutrient exports (total phosphorous – TP, total nitrogen – TN and nitrates – NO_3). A vineyard in the Bairrada wine region was instrumented with six runoff plots (80–122 m^2). Plots were monitored on a weekly to bi-weekly basis (depending on the rainfall pattern), over two hydrological years (from October 2012 to September 2014). Results indicated that annual runoff coefficients ranged from 10% to 20%, sediment losses from 1.1 to 29.0 Mg ha^{-1} yr^{-1}, TP exports from 0.4 to 6.5 kg ha^{-1} yr^{-1}, TN exports from 0.2 to 20.0 kg ha^{-1} yr^{-1} and NO_3 exports from 0.1 to 0.8 kg ha^{-1} yr^{-1}. These results highlight the susceptibility of vineyards to land degradation and their role as a diffuse source of pollution. Rainfall strongly influenced runoff as well as sediment and nutrient concentrations, leading to relevant inter-annual and seasonal differences. Over the study period, about 60% of runoff and > 85% of sediments and nutrients exported by runoff were recorded during winter. Management practices, namely inter-row tillage deeply influenced sediment exports, whereas fertilization, had a strong effect on nitrate exports. Although integrated production lead to lower runoff and nutrient exports than conventional viticulture, additional measures are needed to effectively prevent soil erosion and nutrient losses in Mediterranean vineyards.

1. Introduction

Vineyards are one of the most important fruit crops in the world, covering 7.5 million ha and producing 267 million hl of wine (OIV, 2017). The European Union embraces 39% of the world grape production, with Portugal being its fourth largest wine producer, comprising 190 000 ha of vineyards (OIV, 2017), which represents 27% of the area occupied by permanent crops (INE, 2017). Wine production is one of the most important economic sectors in Portugal, assuring 52% of drinking industry sales (INE, 2017). Besides the unquestionable relevance for the Portuguese economy, some wine regions are also cultural landscapes and were recognized by UNESCO as World Heritage (e.g. the Douro region), thereby having great impact on tourism.

Despite its economical relevance, vineyard sustainability may be endangered due to land degradation, linked with soil erosion and nutrient losses, which hinders the growth of plants and agricultural yield potential (Issaka and Ashraf, 2017; Novara et al., 2017). In the Mediterranean region, vineyards are reported as one of the land uses with highest erosion rates (Prosdocimi et al., 2016; García-Ruiz et al., 2017; Rodrigo-Comino et al., 2018) and identified as one of the major threats to long-term agricultural sustainability (Casalí et al., 2009; Biddoccu et al., 2016). Reports of erosion rates in Mediterranean vineyards are widely variable but attain 2.7–4.7 Mg ha^{-1} yr^{-1} in NW Italy (Biddoccu et al., 2017), 11.51 Mg ha^{-1} yr^{-1} in Anoia–Alt Penedès region, NE Spain (Ramos and Martínez-Casasnovas, 2006) and 16 Mg ha^{-1} y^{-1} in Sicily (Novara et al., 2017). These rates are higher than soil erosion under natural, non-cropped conditions, even for steep slopes (1.6 Mg ha^{-1} yr^{-1} in 63% slopes; Nearing et al., 2017), and above the tolerable/acceptable soil losses that assure land sustainability (1 Mg ha^{-1} yr^{-1}; Verheijen et al., 2009).

The main reasons for the high erosion rates in Mediterranean vineyards include: (i) a reduced soil cover over the year (particularly

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during the rainy season), which leaves the soil surface exposed to rainfall, thereby favouring water and sediment losses (e.g. Casalí et al., 2009); (ii) climate conditions, namely the occurrence of high intensity rainfall events in spring and autumn (e.g. Martínez-Casasnovas et al., 2005); and (iii) high soil erodibility, since vineyards are usually planted on steep-slopes (García-Ruiz, 2010), so the soils have low nutrient and organic matter contents (Novara et al., 2011; García-Díaz et al., 2017b), and therefore low structural stability and aggregation (Ruiz-Colmenero et al., 2013).

Land management practices are also an important driver of land degradation. Conventional vineyards, focused on maximizing commercial production, use high inputs of fertilizers and several phytopharmaceutical products, such as herbicides, and use intensive tillage for soil decompaction and weed control (mechanical weeding) (Novara et al., 2011; Chevigny et al., 2014; Prosdocimi et al., 2016). The use of mechanisation may locally influence soil compaction and decrease infiltration, favouring runoff and soil erosion (Chevigny et al., 2014), which trigger problems to the drainage network and reservoirs siltation (e.g. Martínez-Casasnovas and Ramos, 2006). Diffuse contamination from agriculture has been considered one of the major threats to water resources, namely due to nutrient and pesticide losses from vineyards (e.g. Cerqueira et al., 2005; Ferreira et al., 2010).

Water and soil protection are mandatory for European countries, through the Water Framework Directive (EC, 2006) and the Soil Thematic Strategy (CEC, 2006). To achieve these goals, the governments provide economic incentives to farmers, in order to adopt sustainable management practices. In Portugal, for example, 75% of financial support to implement Agro-Environmental Measures for integrated protection was assigned to vineyards (Amaro, 2003). Integrated production is regulated by the principles of soil preservation and fertility improvement, which imposes the existence of a soil protection cover during the wet season and maximum allowable fertilization rates (Mailly et al., 2017).

Although some researchers have investigated the impact of sustainable viticulture practices, such as minimum tillage (e.g. Ramos and Martínez-Casasnovas, 2006), the use of catch crops (Bonfante et al., 2015) or the application of straw mulches (e.g. Prosdocimi et al., 2016), the contribution of integrated production to minimize land degradation have been overlooked. Furthermore, most of these studies focus on runoff and erosion, without considering the associated nutrient losses. Hence, the main objectives of this study were to: (i) quantify surface runoff, sediment and nutrient (total P, N and NO_3) losses in a Portuguese vineyard under integrated production; and (ii) relate these losses with environmental variables and management practices (tillage and fertilization practices used in integrated production). Assessing the sustainability of vineyards under integrated production is important not only to guaranty crop productivity but also to evaluate the effectiveness of management practices receiving financial support from governmental agencies.

2. Methodology

2.1. Study site

This research was carried out in a commercial vineyard in São Lourenço (40° 25′ 58″N; 8° 30′ 6″W), a small catchment (6.2 km^2) in North-Central Portugal (Fig. 1). This vineyard is included in the specialized wine region of Bairrada, which accounts for 3.6% of the Portuguese wine production (INE, 2017) and includes some top-quality wines that have been distinguished in national and international contests. The São Lourenço stream transports a considerable load of sediments (attaining occasionally 60 t day^{-1}; Serpa et al., 2015). It is a tributary of Cértima River, where pollution problems have been documented in a few sections of ińs main course, mostly regarding biochemical oxygen demand, Kjeldahl nitrogen and total phosphorus (Cerqueira et al., 2005; Ferreira et al., 2010). Eutrophication is visible in some of the river stretches, with large amounts of vegetation developing periodically. The Cértima River is the principal source of water flowing into the Pateira de Fermentelos, the largest natural lake of the Iberian Peninsula.

The studied vineyard was planted in 2012, according to slope orientation. It has a plant density of 3460 vines ha^{-1}, with plants 1.3 m apart in straight rows and inter-rows distance of 2 m. This vineyard has been following integrated production since 2007, with minimum tillage and regulated application of fertilizers and phytosanitary treatments (in terms of products and maximum application rates). Tillage is performed twice a year (usually in spring and autumn), using a chisel with 5–7 nozzles, which rips the soil at 10 cm depth (non-inversion of soil layers). Tillage is performed only between some inter-rows, to maintain partial vegetation cover. Tilled inter-rows change every time, so that soil is not mobilized more than once per year. Weeds in the vine rows are controlled chemically once or twice per year, through herbicide (glyphosate) application, between March and July. Pre-emergent fungicides are applied about eight times per year, between March and August. Foliar fertilizers are applied twice per year, between May and July. Tractors with dispersers are used in pesticide and foliar fertilizer application. Fertilization may be complemented with manure application during tillage. Pruning and harvesting are performed manually in January and October, respectively. The vineyard is exclusively rain fed, so there is no irrigation even during the dry season.

The climate in the region is Mediterranean but there is a strong influence of the Atlantic Ocean. Between 1971 and 2000, the average annual rainfall was 1077 mm in Oliveira do Bairro, ~8 km from São Lourenço, with the following seasonal distribution: 7.5%, 29.7%, 38.0% and 24.7% respectively in summer (June–August), spring (March–May), autumn (September–November) and winter (December–February) (SNIRH, 2014). During the same period, the average annual temperature was 15.7 °C (SNIRH, 2014). The slopes in the catchment are gentle (< 10%) and the soils are typically Calcaric Cambisols with a clay texture (Serpa et al., 2015).

2.2. Experimental design and sampling

Six plots (P1–P6) were established in a commercial vineyard under integrated production to monitor runoff, total suspended solids (TSS) as well as nutrients concentrations and exports (total phosphorus: TP, total nitrogen: TN and nitrates: NO_3). The plots were installed in the inter-row zone and were naturally bounded by a path on the top and by vine strips on the sides (elevated soil surface). At the outlet of each plot, a collector grid was buried beneath the soil surface. The collector grid was connected to a tipping-bucket device, which in turn was connected by a garden hose to an 80-L tank that collected runoff (Fig. 2). Plot design had to be simple to avoid disturbance of vineyard management practices, particularly tractor traffic. Plot installation was completed on mid-September 2012. Frequent runoff leakages, derived from construction problems, were observed in plots P3 and P6 over the study period. Since data quality was not assured, both plots were excluded from the study. The drainage area of the four plots included in the study ranged from 79.9 m^2 to 122.0 m^2 (Table 1).

Data collection started in October, about two weeks after the installation in order to mitigate soil disturbance with plot outlet installation. Plots monitoring was performed over two hydrological years (until September 2014). Runoff accumulated in the tanks was measured and collected on a weekly or by-weekly basis, depending on rainfall occurrence. Under warm settings runoff samples were collected immediately after the storm, in order to avoid water quality changes. Homogeneous samples (after stirring) for TSS analyses were collected in 1500-mL plastic bottles, whereas those for nutrient analyses were stored in acid-washed 250-mL polyethylene bottles. Samples were taken to the laboratory in a cooler (~4 °C).

Due to tipping-bucket's malfunction only cumulative runoff data was recorded. An automatic rainfall gauge was installed a few meters

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