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Lithology, landscape structure and management practice changes: Key factors patterning vineyard soil erosion at metre-scale spatial resolution

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ABSTRACT

In vineyards, soil erosion is controlled by complex interactions between geomorphological and anthropogenic factors, leading to intra-plot spatial topsoil heterogeneities that are observed at a 1-m scale. This study explores the relative impacts of slope, lithology, historical landscape structure and present-day management practices on soil erosion on vineyard hillslopes. The selected plot is located in the Monthelie vineyard hillslopes (Côte de Beaune, France), where intensive erosion occurs during high-intensity rainfall events. Soil erosion quantification was performed at a square metre scale using dendrogeomorphology. For the same plot, planted in 1972, an initial erosion map was drawn in 2004, with a second map being produced in 2012. These two maps, combined with lithology and slope data, the evolution of landscape structure and the evolution of management practices allow the driving factors of water erosion to be assessed. From the 2004 erosion map, we observed that the spatial distribution of erosion, for the thirty-year period after planting, was mainly controlled by lithology and historical landscape structure, whatever the slope. By subtracting 2004 data from the 2012 data, and thus evaluating erosion over the last decade, we discovered that the erosion rate had increased significantly, that spatial distribution of erosion had changed and is now basically controlled by slope steepness and present-day vineyard management practices. Erosion patterns for the last decade show that the impact of historical landscape structure is gradually declining. This study shows that it is crucial to take into account the pre-plantation history of vineyard plots and management practices to further increase our understanding of the spatial distribution of erosion on vineyard hillslopes.

1. Introduction

Cultivated hillslopes undergo substantial soil loss, specifically in vineyards where erosion rates range from 10 to 1000 t ha^{-1} $year^{-1}$, and where soil thickness decreases considerably (Cerdan et al., 2010; Kosmas et al., 1997; Martínez-Casasnovas et al., 2002; Novara et al., 2011). In this context, soil loss has a major economic impact for winegrowers, since gullies must be filled, uprooted vine stocks must be replanted, and soil deposited at the bottom of the plot must be moved back up to the top (Brenot, 2007; Martínez-Casasnovas and Ramos, 2006; Martínez-Casasnovas et al., 2005).

On sloping surfaces, soil loss is associated to a net redistribution of soil within the plot, controlled by the interaction of factors such as topography, climate, land use and soil management practices (Chartin et al., 2011; Fox and Bryan, 2000; García-Ruiz, 2010; Lagacherie et al., 2006). Erosion preferentially affects the fine soil fraction, leaving behind rock fragments and thus proportionately increasing topsoil stoniness (Poesen et al., 1994). Climate and relief (lithology, slope length and slope steepness) are the main factors involved in soil erosion, which plays an important role in topsoil redistribution down the hillslope (Fox and Bryan, 2000). These factors influence both soil volume and the morphology of water-erosive structures, such as linear rill and gully networks (Quiquerez et al., 2008). As a result, the formation of rill systems through which sediment is exported plays a decisive role in conditioning sediment availability and the spatial distribution of eroded soil at the slope scale.

Past and present-day anthropogenic factors (landscape structure and management practices) may also affect topsoil variability and erosion rates (Blavet et al., 2009; García-Ruiz, 2010). In the vineyard context, the influence of present-day weed management practices on topsoil erosion is recognized. Among them, the effects of the most usual practices *i.e.* no-tillage with chemical weeding (NT) and surface tillage (ST) are still debated. These contradictory results may be explained by the differences existing between the erosion measurement techniques, soil surface condition, climate or topography. Some studies suggests that NT accelerates erosion rate (Raclot et al., 2009) while,

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others studies propose that ST management increases erosion rate (Gómez et al., 2008; Le Bissonnais and Andrieux, 2006). The use of mechanisation may locally influence the soil compaction, by decreasing infiltrability which may lead to the formation of rills (Lagacherie et al., 2006). Tillage erosion contributes to net topsoil redistribution across the landscape, by eroding the upper slope and causing soil accumulation downslope (Van Oost et al., 2000). Historical landscape structure may also affect the spatial distribution and erosion rate (Chartin et al., 2011). Soil redistribution is greatly affected by the presence of existing but also historical landscape structure, where hotspot areas of erosion (on undulations) and deposition (on lynchets) have been identified.

Therefore, it is important not only to estimate sediment budgets, but also to perform detailed analyses of erosion patterns at a high spatial resolution of a few metres to better constrain the factors controlling soil degradation. In the short term, these factors modify soil characteristics (stoniness and available water) which could influence vine vegetative growth, while in the long term, they may affect soil sustainability.

Intra-plot soil erosion at a high spatial resolution can be derived from "surface elevation change-based" methods, but only for very specific temporal scales, e.g. for a single rainstorm event within experimental plots (Martínez-Casasnovas et al., 2005), or for an annual time scale over hillslopes (Sirvent et al., 1997). Spatially distributed soil erosion can also be estimated using geochemical methods, such as radio-nuclide measurements 137Cs which are used to trace sediment movement along cross-sections at a decennial time scale (Krause et al., 2003; Walling and Quine, 1991). Temporally and spatially distributed data can be inferred from the identification of bio-markers, using dendrogeomorphology methods, which have proven very useful to estimate erosion rates (Bodoque et al., 2005; Carrara and Carroll, 1979; Casalí et al., 2009; Vanwalleghem et al., 2010). Aggradation or degradation processes are directly inferred from the position of the root collar, considered as a fixed spatial reference, relatively to the current ground surface. These methods were adapted by Brenot et al. (2008) for vineyard contexts, and have since been used to quantify erosion in a Spanish vineyard (Casalí et al., 2009), in a southern French vineyard (Paroissien et al., 2010) and in a Burgundian vineyard (Quiquerez et al., 2014).

Our work investigates the impact of geomorphological (lithology and slope) and anthropogenic (historical landscape structure and management practices) factors controlling topsoil erosion at metre-scale in a vineyard plot. For this purpose, we studied a one-hectare hillslope vineyard plot planted in 1972, and still cultivated by the same wine-grower, for which historical land use data were available for the last two centuries. Lithology, slope, and erosion were mapped at a metre-scale to assess the influence of geomorphological factors on erosion. Two erosion maps were measured in 2004 and in 2012, allowing spatial quantification of erosion over two periods, *i.e.* respectively period. The 1972–2004 and 2004–2012 periods differ by their weed control management practices. These maps were compared to historical landscape structure to analyse erosion patterns and rates over time. This study reveals the complex and changing interactions between geology, slope, present-day vineyard management practices and the remaining effects of historical landscape structure.

2. Material and methods

2.1. Study area

The study area is located on the hillslopes of Monthelie (Fig. 1A), in the Côte de Beaune area (Burgundy, France). This 1.1 ha vineyard plot lies on the western side of a north-oriented valley, cross-cutting the Jurassic formations of the Burgundian plateau (Rémond, 1985) (Fig. 1B and C). According to the WRB classification (IUSS Working Group WRB, 2006), the soil is a stony silty clay Calcaric Cambisol which developed on Jurassic marls. Topsoil contents 35% calcareous gravel and stones, 7.1% mean organic matter, 48% calcium carbonate content, and pH is 8.1. Topsoil bulk density ranges from 1.25 to 1.5 g cm^{-3} depending on row or inter-row position (Brenot et al., 2008). Since the last plantation in 1972, the plot has always been cultivated by the same wine-grower.

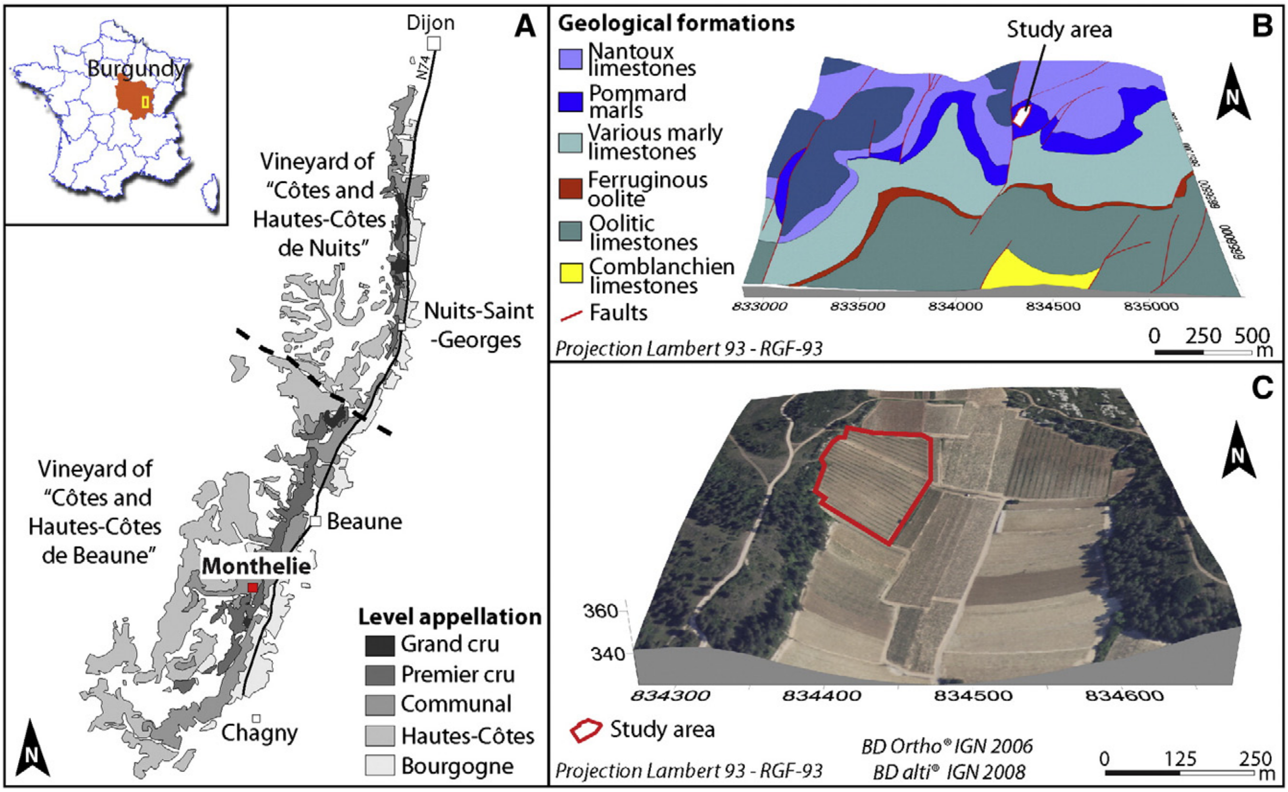

Fig. 1. Location map (A) and geological map (B) of the study area. Ortho-photograph overlain on the 25-m DEM (IGN, 2006) highlighting the study area (C).