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Scale effect of terroir under three contrasting vintages in the Chianti Classico area (Tuscany, Italy)

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ABSTRACT

In viticulture, terroir is a concept used to explain the specific combination and interaction of natural and human factors that provides distinctive characteristics to the wine. The role of soil and geology on wine characteristics is debated and sometimes considered less important than either climate or the human component.

The present study, performed on one of the largest farms of the "Chianti Classico" wine district (Tuscany, Italy), focused on the effect of terroir on wine characteristics using two different zoning scales. At a broader scale, called macro-terroir (MT), the experimental vineyards were selected based on lithology, soilscape, morphology, and mesoclimate. Each vineyard was then subdivided at a detailed scale into two homogeneous zones for soil features, the Basic Terroir Units or Unité Terroir de Base (UTB). The study was conducted during three different vintages (2012, '13 and '14), in vineyards located in four different MT, which are representative of large parts of the Chianti Classico wine district. The vineyards were surveyed by proximal sensors, namely electromagnetic induction sensor (EMI) and gamma-ray spectroscopy to characterize soil spatial variability and to define two homogeneous areas (UTB) of about 2 ha in each MT. The UTB differed for some soil features, mainly texture, gravel content, soil depth, available water capacity, and internal drainage. The weather for the three vintages was very different e during the growing season, which was very dry and hot in 2012, moderately wet and warm in 2013 and chilly and very wet in 2014. Grape harvest, wine-making and six-month ageing were carried out separately for the different UTB, using the same methodology. Mixed-design analysis of the variance of several must and wine features demonstrated that MT played the major role on must pH, as well as total acidity, glycerine content and colour intensity of the wine. The climate of the vintage played a stronger role than MT on the content of must malic acid, as well as polyphenols, anthocyanins and dry extract of the wine. Blind wine sensory analysis performed for all vintages showed significant differences between wines from the different UTB, in particular for colour intensity and wine aroma, but the differences between UTB within each MT were not stable over the three contrasting vintages, being less pronounced in the most humid vintage (summer 2014).

This study demonstrates that characteristics of pedo-geological landscapes can be used for a wine district zoning, while a more detailed soil mapping, leading to UTB identification, is needed for differentiating particular wine characteristics.

1. Introduction

The concept of "terroir" has long been used in viticulture to describe the relationships between the sensory attributes of wine and the geographical territory from which it is derived (Vaudour, 2002; Deloire et al., 2005). The terroir distinction has progressively gained relevance in wine marketing as a tool to endorse the quality of wines and improve their competitiveness and profitability on the international markets. Probably more than many other foods and beverages, wine has a strong identity and a tight connection with its place of origin (Salette et al., 1998; Bucelli et al., 2011; Costantini et al., 2016).

To date, the terroir concept is not easily understood and remains one of the most debated issues in the world of wine, because of the large variety of interacting natural and human factors, on which there is not always agreement. These factors include climate, soil, topography, grapevine cultivar, viticultural and oenological practices, which together create unique and distinctive characteristics in the wine from a given place that is perceived and recognizable by consumers and

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experts (Fischer et al., 2016; Costantini et al., 2016; Barham, 2003; Vaudour et al., 2015; Wilson, 1998). According to the definition adopted by the International Organization of Vine and Wine (OIV), the viti-vinicultural terroir refers to "an area in which collective knowledge of the interactions between the identifiable physical and biological environment and applied viti-vinicultural practices develops, providing distinctive characteristics for the products originating from this area" (OIV, 2010).

Beside the human factor, which plays the most important role through viticultural and oenological practices, the natural factors that are most important in the expression of terroir may vary depending on the spatial scale. At a "regional scale", macroclimate in interaction with the grapevine cultivar is likely to be most important (Jones et al., 2005). At a "within-region" and "wine district" scale, the interaction between mesoclimate, topography and geology might be the dominant factors driving grapevine performance and grape peculiarities (Nicholas et al., 2011; Priori et al., 2014b; Ramos et al., 2015). Topography greatly affects mesoclimate by altitude, proximity to large water bodies, aspect, and slope. It is well known that during grape ripening, the spatial variability of day and night temperatures plays a very important role in separating wine producing areas characterized by different grape maturation, aroma, and colouration (Tonietto and Carbonneau, 2004). The role of geology on wine peculiarities is much more debated. While many authors (Vaudour, 2002; Van Leeuwen and Seguin, 2006; Costantini et al., 2012; Bonfante et al., 2015) assert that vineyard geology contributes significantly to wine peculiarities, other authors consider the effects of soil and bedrock on grape and wine negligible (Matthews, 2016).

Although vineyard geology is widely hypothesized to contribute significantly to wine typicity, there is still little scientifically-based knowledge on how this connection is established and which specific geological parameters are involved. Some significant examples are the relationship of Chablis wines with Kimmeridgian limestone, or that of Beaujolais wines with granite, which along with many others are taken as a crucial for the expression of wine typicality (Van Leeuwen and Seguin, 2006).

Matthews (2016) asserts that the word "terroir", interpreted as geology and soil associated, is often abused and not preceded by scientific discoveries of soil- and rocks-derived flavours or characteristics of the wine. He also writes that "grapevines have next to no interaction with rocks" (Matthews, 2016) which supports Maltman (2008), who wrote that a direct rock geochemical influence on wine is undemonstrated and scientifically impossible. The author disapproves of the use of direct connection between wine flavours and rocks, like "minerality, rocky flavour", "quartz taste", and "smell of graphite", the latter for wines produced in schists with graphite in Priorat (Maltman, 2008). On the other hand, he also affirms that rock and soil features can indirectly influence the bio-chemical pathway of elements during grape growing and vinification, and then wine peculiarities. Characteristic isotopic speciation and transfer can been followed from bedrock to soil, vine, grape, and wine, thus allowing wine origin to be traced at a very detailed scale (Braschi et al., 2018).

Certainly, the role of geology might be expressed indirectly. The bedrock geology determines the relief and the landforms of an area, and is a key factor in soil genesis. The nature of the bedrock, along with its physical status (colour, hardness, compaction, presence of planes of weakness) and degree of weathering, greatly influence soil physical and hydrological properties, which influence root development and water uptake. Moreover, the bedrock geochemistry affects soil pH, nutrient supply, and balance, which are crucial for vine growth and grape composition (Kodur, 2011; Retallack and Burns, 2016).

However, the relationship between soil properties and the underlying bedrock may not always be so clear. For instance, soils can develop from allochthonous parent material, such as aeolian sediments, colluvial depositions, or human transported materials (Dazzi et al., 2009). In other cases, the relationship can be broken by erosion (Martínez-Casasnovas and Concepción Ramos, 2009) or land preparation activities for vineyard planting, including levelling, bedrock crashing, and deep ploughing. These activities can reduce soil depth, disturb the natural soil profile, and can increase the short-range spatial variability of the soil across a vineyard (Costantini et al., 2015). Therefore, at the farm or "within-vineyard" scale, soil characteristics are credited as major terroir components (Bramley et al., 2011a, 2011b; Tardaguila et al., 2011; Priori et al., 2013a, 2013b). Soil physical properties, such as texture, structure, internal drainage, and soil depth, influence soil temperature, soil/water relationships, and root development, which subsequently influences water and chemical nutrition of the vine (Morlat and Bodin, 2006). Chemical nutrition is critical for grapevine development and berry production, but there is often a weak or no relationship between the soil nutrient status and wine quality, due to factors regulating plant nutrient uptake, including soil nutrient dynamics and availability, soil water content, vine rooting patterns and antagonism between nutrients (Garcia et al., 2001; Mackenzie and Christ, 2005). More attention is given to soil water status and water uptake conditions, which are confirmed as key factors of terroir (Costantini et al., 2013; Marciniak et al., 2013; Bonfante et al., 2015). High grape quality, especially for red wine, is often associated with mild water deficit, which in rainfed vineyards is related to a complex interaction between climate (rainfall, evapotranspiration), soil hydrology (water holding capacity, internal drainage) and the density and distribution of vine roots (Bonfante et al., 2011; Costantini et al., 2013; Deloire et al., 2005; Dry, 2016; Marciniak et al., 2013; Brillante et al., 2016).

A recent approach to investigate and manage soil spatial variability in vineyards consists of mapping homogeneous management zones using proximal and remote sensing methods, which provide increased resolution and accuracy of soil spatial characterization, while reducing the sampling costs, and improving management of wine quality in relation to soil features (Acevedo-Opazo et al., 2008; Taylor et al., 2009; Bramley et al., 2011a, 2011b; Bonfante et al., 2015; Vaudour et al., 2017; Tardaguila et al., 2017). Some authors refer to homogeneous management zones as the "Basic Terroir Units" or "Unité Terroir de Base" (UTB), to underline the concept that each of them represent the smallest useful area for vineyard management, in which the natural factors (soil, geology, climate) are homogeneous and have uniform effect on vine biology and wine quality (Deloire et al., 2005). Key questions in this approach, also reported by Bramley (2016a, 2016b), include: does variation in soil properties have a functional impact on grape and wine composition? At what scale are these effects expressed? How stable are these effects across vintages characterized by contrasting climatic conditions?

The present study was conducted in one of the largest and most renowned wineries in the "Chianti Classico" district (Tuscany, Italy), the Barone Ricasoli farm. The objective of the research is to evaluate the effect of terroir on wine quality at two different zoning scales: i) the "macro-terroir" (MT) level, as defined according to geology, soilscapes, morphology and climate, and ii) the UTB level, based on the division of each MT into homogeneous sub-zones according to soil proximal sensing survey and soil physical-hydrological properties (texture, gravel content, depth, available water capacity).

2. Materials and methods

2.1. Study variety and area

The grapevine cultivar studied was *Sangiovese*, the most important for "Chianti Classico" and other high quality wines of Central Italy, such as "Brunello di Montalcino", "Vino Nobile di Montepulciano" and "Morellino di Scansano". The *Sangiovese cv.* can express a wide variety of wine peculiarities, due to its high responsiveness to the environmental factors (Bucelli et al., 2004; Dalla Marta et al., 2010; Ducci, 2013; Mattii et al., 2005; Scalabrelli et al., 2001). Moreover, it is very