Deconstructing the soil component of terroir: from controversy to consensus

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Abstract

In the wine sector, the notion of terroir has been very popular; however, it is subject to many interpretations which has often led to an erroneous or misleading use. Especially the relationship between wine properties and soil raises a lot of controversy. As far as the actual soil properties are concerned, the effect of soil physical properties is generally regarded as the most significant (e.g sandy soils being associated with lighter wines while those on clay with colored and tannic ones) mostly through control of water availability which ultimately modifies berry ripening conditions either directly by triggering biosynthetic pathways, or indirectly by altering vigor and yield components. The role of soil chemistry seems to be weakly associated to wine sensory characteristics, although N and K are often considered important in the overall soil effect. However, the actual effect of these factors is also dependent on complex interactions with plant material (variety/clone, rootstock, vine age) and with human factors. Recently, in the light of evidence provided by precision agriculture studies reporting a high variability of vineyard soils, the soil spatial scale is also taken into consideration in terroir evaluation.

Introduction

Wine terroir describes the empirically recognized relation between a geographical area and the distinctive organoleptic characteristics of the wines produced in it. The major abiotic variables (Bodin & Morlat, 2003) that make up the terroir ecosystem are those of climate (temperature, rainfall, radiation, wind etc), and soil (mineralogy, texture, structure, water reserve, depth, color etc). In scientific circles, the role of climate (macro-, meso- and micro-) on grape and wine characteristics is well documented and accepted as the most critical. Agronomic practices are also included in the description of wine terroir as well as plant material. Moreover, there has been increasing interest in recent years about new elements with possible importance in shaping wine terroir like berry/leaf/soil microbiology or even aromatic plants in proximity to the vineyard conferring flavors to the grapes. The contribution of soil, although a fundamental component of terroir and extremely popular among wine enthusiasts, remains a much-debated issue among researchers. This article attempts to breakdown the main soil attributes involved in the terroir effect to suggest an improved understanding about soil's true contribution to terroir.

The role of geology

In wine culture, the link between geology and wine quality is so popular that it often has a confusing and overshadowing effect on the actual role of soil itself. Several authors have suggested that minerals derived by vines from the weathering process of the parent material confer distinctive character to the wines (Wilson, 1998). In agreement, geology is an important part of the methodology used by Bodin & Morlat (2003) for the identification of Basic Terroir Units i.e. the smallest areas with uniform effect on vine biology and wine quality. The example most often cited of a direct connection between the geological origin on wine aroma is "minerality" (earthy smell, or smell of wet stones), seemingly connected to the presence of certain minerals in the soil or underlying rock. According to Maltman (2013), there is no direct connection between wine flavours and geological formations. Although some nutrient mineral elements can participate in a salty taste (Na or K), they lack aroma. Moreover, geological minerals are insoluble, so they cannot be absorbed by vine roots. Instead, it appears that certain volatile compounds, such as benzenemethanethiol, can contribute to the "mineral" aromatic character of certain wines (Tominaga et al., 2003). Certainly, the role of geology might be justified as an indirect one, through its role on soil genesis. The nature of the geological bedrock (hardness, compaction, etc) and its

degree of weathering, greatly influence soil physical properties, which in turn influence soil depth, root penetration and water uptake (Seguin, 1986). Moreover, the bedrock geochemistry affects soil pH and nutrient availability. However, solid scientifically-based data on the exact effects of geology on wine character or "personality" are rare and mostly anecdotal.

Soil physical vs chemical properties

Soil physical properties, such as texture, structure, porosity etc, seem to play a more important role as key factors of terroir than chemical properties (Costantini et al., 2013) as they influence soil temperature, water retention and drainage, and root development. Regarding soil chemical properties, there is a weak or even no relationship reported between the soil nutrient status and wine quality (Seguin, 1986); however, the impact of soil chemical properties with respect to fruit and wine quality should not be overlooked (van Leeuwen et al. 2004) especially that of nitrogen (N), and potassium (K). Potassium is involved in sugar translocation to the ripening fruit and modifies the malic/tartaric acid ratio by forming tartrate salts possibly affecting pH in must and wines. On the other hand, soil nitrogen, apart from defining vine vigor, has a direct effect on certain aromatic grape compounds by enhancing the synthesis of cysteinylated aroma precursors of volatile thiols, which are responsible for the varietal aroma of some white varieties (Peyrot des Gachons et al. 2005).

Soil chemical and physical soil properties are also interrelated; for example, clay content determines both texture but also the soil cation exchange capacity and thus soil fertility; some elements like calcium (Ca) that occur in calcareous soils act as determinants of both soil pH but also improve soil structure creating favourable conditions for root development, especially on heavy soils, which in turn affects both water and nutrient uptake. On the whole, there is ample evidence of soil effects on grape composition but these effects are far from determining specific flavour characteristics in a decisive and systematic manner in the produced wines.

Soil-Rootstock interaction

Rootstock genotype has a major influence on root density (Southey and Archer, 1988) even though the distribution of grapevine roots is significantly dependent also on edaphic conditions and vine spacing. Moreover, grapevine root growth depends on the interaction of a given rootstock genotype with environment, i.e. its adaptation to soil factors such as soil texture, fertility, pH and calcium carbonate. For semiarid environments, adaptation to drought conditions is a key factor for rootstock selection and could provide an alternative means to control grapevine response to water deficits. Classification of commercial rootstocks with regard to their drought tolerance have been previously conducted (Carbonneau, 1985). As a result, the scion variety adaptation to soil conditions, especially water deficits, is greatly affected by the choice of rootstock variety.

Role of grape-grower: which is the limit?

According to Laville (1993), the abiotic environmental factors are expressed in the wine through the choice of plant material and various management decisions, resulting in wines with a distinctive and identifiable character. However, the magnitude of the contribution of human-related factors (irrigation, fertilization, soil management) to the soil effect still remains ambiguous. Vineyard management interferes with the effects of local soil features, mainly by adapting nutrient and water supply to the vines through fertilization and irrigation. Deep ploughing before planting as a means to increase root penetration and also management of soil surface by either cover crops or cultivation, all interfere with the natural soil properties. Especially the role of irrigation modifies the most important of the functions of terroir which is the determination of vine water status. In an attempt to clarify the concept of "terroir", Laville (1993) mentioned that, although the terroir cannot be viewed in isolation from management and cultivation practices, the latter do not form part of the intrinsic definition a terroir and introduced the notion of the "natural terroir unit (NTU)" as a unit of the earth's surface that is characterised by relatively homogenous patterns of topography, climate, geology and soil alone, without including the biotic and human-related factors.

Spatial soil variability: is it part of the notion of "Terroir"?

A new approach to assess and manage soil spatial variability in vineyards is the delineation of homogeneous management zones using proximal and remote sensing mapping (Bramley et al., 2011). Precision Viticulture aims at managing vineyards at a sub-field scale according to the real needs of each part of the field. Inherent soil variability can be very important, especially in vineyards on sloppy terrain. Moreover, this variability is associated with similar spatial changes in vine and grape attributes. In a study conducted in a Greek vineyard with the red grape cultivar 'Agiorgitiko' showed that grapes situated on the upper slopes had berries with the

highest phenolic content and were the ones best suited for the production of premium red wines (figure 1). Grapes from the shallower soils and the lowest water reserves were associated with low vine vigor (estimated as winter pruning wood weight) and yield (Koundouras 2018). To relate within-field variability to the concept of terroir, some authors refer to management zones as the "Basic Terroir Units" (Deloire et al., 2005). However, Terroir Units should have a broader sense, therefore incorporating a greater number of soil-based management zones. A possible solution to overcome the effect spatial soil variability on terroir definition is to adopt a similar to climate description, i.e. a macro-, meso- and micro-soil approach.

Scales of "Terroir": is macro-, meso- and micro-soil concept relevant?

While it is accepted that soil effects become more significant than climate on a local level, it is not clear whether these micro-variations of vineyard soils are determining in the terroir effect. At a "regional scale", soil characteristics are less likely to be important, although geology could be similar, thereby the notion of a macro-soil component in the terroir effect is somehow difficult to establish. However, at a "within-region" scale, interaction between topography and geology can affect soil characteristics in a similar way that general climate (macroclimate) and topography determine mesoclimate, which is in the centre of the terroir definition. Lastly, the micro-variations of soil within a field, often described as management zones, could be considered as the equivalent of the vine microclimate which actually is the result of soil variability reflected on the vigor of the vine as it is often proved by the application of vegetation indices (i.e. NDVI). Thus, the concept of terroir embodies a soil classification at a large scale, similarly to climate, with the meso-soil being the most relevant for the delineation of natural terroir units and the micro-soil best representing the management zones associated with the within-field soil variability.

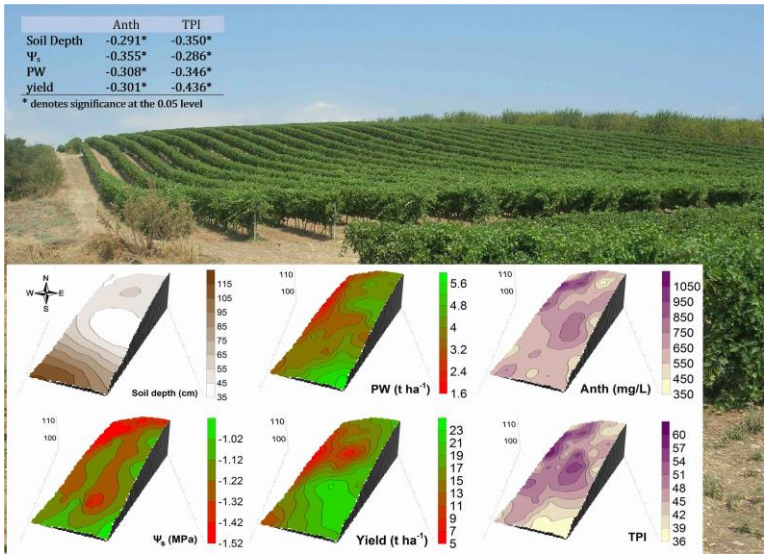

Figure 1. Six maps relating the spatial variability of the phenolic composition of grapes, to topography, soil, water status and biomass production in an Agiorgitiko vineyard in 2010 in central Greece.
Abbreviations: Ψs = midday stem water potential; PW = winter pruning weight; Anth = total anthocyanins in the juice; TPI =total grape phenolics index. Pearson correlation coeffcients for the inter-relationships of
soil and vine parameters with grape phenolic potential correspond to the mean values per 10×20 m cell. (Koundouras 2018)

Soil influence on terroir: is there a direct effect?

The exact effects of soil on wine character and style are probably one of the most widely debated topics in viticulture. Soil composition does not seem to have an independent effect on grape aroma quality: mostly, it is an indirect one, related to soil water and nutrient availability. As a general rule, fruity wine aromas are usually enhanced under conditions of moderate soil fertility and water (stony or sandy soils with good drainage, water deficit to no irrigation) while the more vegetative and spicy aromas are more expressed in wines from soils that are deep, clay-rich and have higher nitrogen and water reserves. Conditions of limited-to-moderate water and nutrient supply (dry farmed vineyards, dry areas or light-textured soils) are more suitable for the aromatic quality of red grapes and wines, whereas for white cultivars (especially early ripening ones), higher aroma expression

is achieved under less stressful water and nitrogen soil conditions (Peyrot des Gachons et al. 2005). In an experiment conducted in nonirrigated vineyards in Nemea (Southern Greece) with the red cultivar 'Agiorgitiko' (Koundouras et al. 2006), the grape content of precursors of the main aromatic compounds were higher on soils that induced a limited water availability and moderate vine vigor. Moreover, the wines produced from grapes harvested on shallow soil consistently received a higher note in wine tasting trials (figure 2). Water deficit are reported to activate the carotenoid and isoprenoid metabolic pathways resulting in increased concentrations of terpenols and C13-norisoprenoids (Deluc et al. 2009).
Moreover, soil effect on the quality of wines is dependent on climatic conditions, indicating an inter-relationship between soil and climate. Deep soils without chemical or physical restraints for root development will promote a well-developed root system which would allow avoiding extreme water deficits under semi-arid conditions, whereas smaller soil depth would be more suitable under cooler and more humid conditions. Similarly, soil suitability is also related to the desired wine style: deeper soils with higher water and nitrogen content would be favourable for some white cultivars producing "green" aromas (like Sauvignon blanc) to increase aroma potential (Peyrot des Gachons et al. 2005), whereas red varieties cultivated for the production of premium red ones require some level of water and nitrogen restriction to achieve highest quality.

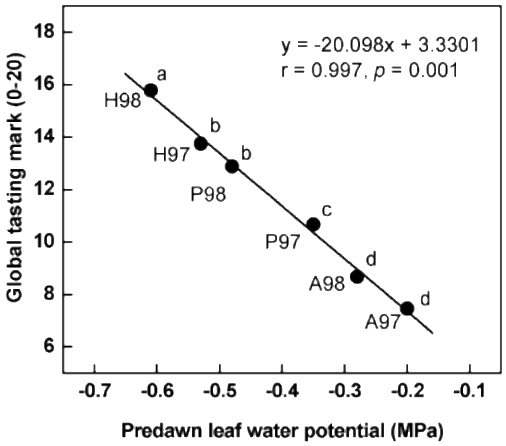

Figure 2. Relationship between average predawn leaf water potential between fruit set and harvest and wine sensory evaluation. Experiment conducted on nonirrigated vineyards in Nemea (Greece) of the red cultivar 'Agiorgitiko'.
Data labels refer to three sites with signifcantly different characteristics: P is uniform, calcareous silty loam situated on a flood plain; H is a shallow soil developed on a soft limestone bedrock; A is clay loam, with a hardpan of nearly 70% clay at 140 cm of depth, leading to permanent water logging due to poor drainage. Data was collected over the two seasons of 1997 and 1998. Data points labeled with different letters (a, b, c, d) differ signifcantly in their overall tasting mark ($p<0.05$). Adapted from Koundouras et al. (2006).

The vine: the ultimate factor

Although it is widely believed that soil has a direct effect on grapes and wines, soil only provides anchorage to the vine, minerals and water which in turn affect the vine's biosynthetic pathways leading to the production of specific metabolites in ripening berries. Thus, a major shortcoming of the majority of works about soil effects on wine characteristics is the absence of connection with actual vine physiological processes since all soil effects on grape and wine chemistry and sensorial properties are ultimately mediated through vine responses. Therefore, to explain the effect of terroir on wine composition, interactions between the soil and the vine need to be considered, through their impact on vine physiology. The understanding of effect of soil factors (geology, soil type, effective soil depth, water supply to the vine) on vine growth, phenology and grape ripening dynamics over a period of time is crucial and provides a measurable way to evaluate soil effect on wine terroir.

Conclusion

A good soil for the production of richly flavored wines with identifiable character is commonly considered one that enhances complete ripening of the appropriately chosen grape cultivar, by adjusting nutrient and water availability to moderate levels. It is proposed that soil parameters per se are not as significant determining factors in the terroir effect but rather their mutual interactions as well as with other natural and human factors included

in the terroir concept. Consequently, similarly to bioclimatic indices, composite soil indices (i.e. soil depth, water holding capacity, fertility, temperature etc), incorporating multiple soil parameters, might provide a more accurate and quantifiable means to assess the relative weight of the soil component in the terroir effect.

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