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Mapping suitability for Sangiovese wine by means of δ^{13}C and geophysical sensors in soils with moderate salinity

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ABSTRACT

A three year experiment was carried out to test the possibility of using the carbon isotope ratio (δ^{13}C) measured in wine, combined with data of proximal and remote soil sensors, to assess viticultural and oenological suitability for Sangiovese. Two specialized vineyards on similar geomorphological conditions were investigated. Twelve plots were positioned differently along slopes. The soils were similar, except for structure, porosity and related hydrological characteristics, and salinity of the deeper horizons.

Soil electrical conductivity and resistivity were measured at three different depths, as well as cumulative soil moisture down to the root-limiting layer. Satellite images were analyzed to obtain the NDVI. Soil water content in the plots was monitored at different depths. Yield, phenological phases, and chemical analysis of grapes were determined. Stem water potential was measured during summer. Grapes of each plot were collected for wine making in small barrels. The wines obtained were analyzed and submitted to a blind organoleptic testing. The wine was also analyzed for its δ^{13}C isotopic ratio.

Almost all plots had rather high amounts of transpirable water, even during the driest time of the year. However, only yield components of Sangiovese were influenced by water availability. Wine quality was instead significantly improved by the moderate salinity of the deeper horizons, which increased plant water stress during berry ripening and reduced production. The moderate physiological stress affecting vines was reflected in stem water potentials and δ^{13}C values. δ^{13}C was correlated with several viticultural and oenological parameters, and also with panel test evaluations of wine quality. The threshold between good and bad scores corresponded to a δ^{13}C value of -26.7 ± 1.2‰.

Soil salinity affected the geophysical survey and its relationship with the viticultural and oenological result. In particular, the electromagnetic conductivity measured at the beginning of the experiment was functional in distinguishing the two vineyards, but it was not useful for a more detailed prediction of Sangiovese performance. However, electromagnetic resistivity in the first 0.5 m was not influenced by salinity of the deep soil horizons, but only by clay content, and permitted a significant estimation of the Sangiovese anthocyanins content, colour intensity, and must acidity.

The outcomes of this study recommend the use of δ^{13}C in combination with electromagnetic resistivity to map soil suitability for Sangiovese. The favourable performance of Sangiovese in moderately saline soils may encourage diffusion of the cultivar outside its traditional areas of cultivation.

1. Introduction

Physiology and production potential of the vine, as well as wine quality, are significantly determined by summer water stress (Van Leeuwen and Seguin, 1994; Deloire et al., 2004). Plant water stress is primarily conditioned by total rainfall and crop management, particularly irrigation, but also by rooting depth and soil water holding capacity. This in turn is regulated by soil particle size and structure, as well as by topography, which can convey rain water and subsurface flows to different areas of the vineyard. Soil salinity can also lower water potential, limit root uptake, and has significant influence on vine performance and wine quality (Lanyon et al., 2004). Recently, in addition to the more commonly used viticultural and oenological indicators – namely yield components, leaf and stem water potential, oenological parameters and sensorial appraisal – a new physiologic marker has been used for a synthetic evaluation of the overall vine water uptake conditions during the ripening period, i.e., the ratio between the two stable carbon isotopes $^{13}C/^{12}C$, called δ^{13}C, measured in the must sugars upon

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harvesting or in the alcohol of the wine produced (Van Leeuwen et al., 2001, 2003; Tregoat et al., 2002). Being correlated with important components of must quality (e.g., sugar content and titratable acidity) δ^{13}C can be used to map terroirs at different scales (Van Leeuwen et al., 2001; Zufferey and Murisier, 2006; Guix-Hébrard et al., 2007). Reported δ^{13}C values range from −21.0 and −28.0‰, and −25.5 or −26.0‰ were considered threshold values between water stress and non-limiting water nutrition (Van Leeuwen et al., 2003; Deschepper et al., 2006). According to the same authors (Van Leeuwen et al., 2003; Tregoat et al., 2002) values of about −23‰ should correspond to a minimum stem water potential close to −1.2 MPa, a value that matched an optimal correlation with the berry sugar accumulation rate. However, other authors pointed out a lack of correspondence between δ^{13}C and other proxies for soil water conditions, in particular soil electric resistivity, which would be correlated instead with other components of quality, namely phenols and anthocyanins (Deschepper et al., 2006). In addition, a genetic variability of δ^{13}C performance has been observed among cultivars, pointing to the need for a calibration according to variety (Gaudillère et al., 2002). So far, no information is available about carbon isotope discrimination in grapevines cultivated on moderately saline soils.

The use of proximal and remote sensors for precision viticulture and mapping terroirs has been introduced for some years and is increasing (Tisseyre et al., 2007; Acevedo-Opazo et al., 2008). Geophysical sensors, measuring soil electrical conductivity and resistivity, as well as satellite images, can provide information about the spatial variability of edaphic properties influencing crop yield, in particular particle size and water content (Corwin and Plant, 2005). This information was complemented with vine and wine performance indicators, among others δ^{13}C, and used to delineate site-specific management units and terroirs (Deschepper et al., 2006). Nevertheless, there are limitations in using geophysical sensors where others factors affect the measurements, particularly soil type and salinity (Dabas et al., 1989; Corwin and Lesch, 2005; Samouëlian et al., 2005). Managing this variability could constitute a significant challenge for vine growers. On the other hand, it has been shown that some parameters, such as yield and canopy vigour, can present significant temporal as well as spatial stability. If one could demonstrate the stability of soil differences detected by means of sensors, then it would be possible to map the soil of the vineyard by means of a single survey using a combination of sensors, thus reducing the cost of their application. However, temporal stability was not observed in grape quality in non-irrigated vineyards. Therefore, the potential use of maps from previous years as a decision-making tool for quality management in the years to come was not feasible (Tisseyre et al., 2007).

Sangiovese is one of the most important Italian wine cultivars, especially widespread in central Italy (Caldano and Rossi, 2008) where climatic conditions during the crop season are intermediate between the very hot and dry summers of southern Italy and the milder climates of northern Italy. Nevertheless, Sangiovese is becoming appreciated in other viticultural areas over the world for its capacity to express local peculiarities (Paoletti, 1995). Local suitability for Sangiovese might be assessed through using both δ^{13}C and proximal/remote sensors in the attempt to measure water stress, since this cultivar needs a moderate deficit during summer to produce high quality wine (Costantini et al., 1996; Storchi et al., 2005; Palliotti et al., 2008). However, the role played by soil salinity should be carefully considered. In fact, vineyards planted with Sangiovese on moderately saline soils are not infrequent, as it has been reported in some important viticultural areas such as Montalcino and Chianti (Brancadoro et al., 2006; Costantini et al., 2006). This could contrast with the assumption that considers salinity a limitation for viticulture (White, 2003; Lanyon et al., 2004). Thus, the use of new technologies for mapping terroirs must be properly calibrated when the cultivar is Sangiovese and soils are moderately saline. The goal of this work was to test the use of δ^{13}C combined with multiple proximal and remote sensors in zoning vineyards for the Sangiovese vine in environmental conditions characterized by moderate soil water and salinity stresses.

2. Materials and methods

Two experimental vineyards (2 ha each) were selected at Cetona (Chianti area, central Italy, 42°57′N, 11°54′E). They had the same climate, lithology, and geomorphological setting, but different soils. Long term mean air temperature was 12.7 °C, annual rainfall 644 mm, and Winkler's index 1800. Both vineyards were planted on soils covering slopes with similar steepness (from 2 to 13 or 18%) and aspect (E and NE), and formed from fine silty marine sediments of the Pliocene era. The vine variety was Sangiovese, plant density 3500 per ha, the rootstock 420A (Vitis Berlandieri × Riparia), which is considered to be resistant to drought and active lime (Fregoni et al., 1978), but not to salinity (Lambert et al., 2008). Both vineyards were planted in 1991, after slope reshaping by bulldozing and deep ploughing down to about 0.8–1.0 m. Viticultural husbandry was similar and the soil surface was periodically cultivated to limit weed growth, interrupt capillarity and reduce evaporation.

The benchmark soil profiles of the two vineyards had a cambic horizon and were strongly calcareous. Profile 1 hosted a perched water table during rainy seasons, as a consequence of the massive structure of the Cr horizon, and was then classified Stagnic Cambisol (Calcaric, Hyposodic, Hyposalic) according to WRB (F.A.O. et al., 2006) and Aquic Haplustept, fine silty, mixed, mesic, active, following Soil Taxonomy (Soil Survey Staff, 1998). Profile 2 was a Haplic Cambisol (Calcaric) and a Typic Haplustept, fine silty, mixed, mesic, superactive.

Agricultural practices, especially land levelling before vine planting, led to soil scalping, so that the unweathered substratum could be found at a shallow depth. That was especially the case of the vineyard 1 profile (Table 1). Chemical fertility of that soil was influenced by the presence of substratum at shallow depth, which was the reason for the relatively higher active lime, lower organic carbon and micronutrient content. However, the most striking differences between the two soils were related to salinity, namely the presence of sodium and magnesium salts. In fact, soil 1 showed rather high electrical conductivity in the lower horizons, as well as high exchangeable sodium and magnesium (more than 7% and 50% of CEC, respectively).

Moisture content at −33 kPa and −1500 kPa of disturbed samples of the benchmark profiles were analyzed in laboratory by the ceramic-plate system (Kassel and Nielsen, 1986) and bulk density with the core method on replicated samples. Soil description and routine analysis of the air-dried <2 mm fraction followed the official Italian methods (Costantini, 2007; MiPAF, 2000). In particular, soil texture was tested in the laboratory by the sieve and pipette method; mean geometric diameter was calculated according to Gee and Or (2002). $CaCO_3$ content was measured gas-volumetrically, by addition of HCl in a Dietrich-Frühling calcimeter; active $CaCO_3$ was analyzed with a solution of ammonium acetate. This is the more active fraction of $CaCO_3$, which easily dissolves and precipitates. Soil electrical conductivity of the plots was tested every 0.2 m; organic carbon content was determined by using the Walkley-Black procedure; pH and electrical conductivity were measured in a 1:2.5 (w w^{-1}) water suspension; cation exchange capacity (CEC) was measured by use of 1 M Na-acetate solution at pH 7.0; exchangeable bases were extracted with 1 M NH_4^+ acetate solution at pH 7.0 and measured by flame photometry (Na, K and Ca) and atomic absorption spectrometry (Mg).

Twelve experimental plots, about 300 m^2 each, were located along the slope in correspondence with the three basic morpholog-