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Importance of soil and vineyard management in the determination of grapevine mineral composition

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HIGHLIGHTS

- Mineral compositions of grapevines in production vineyards were determined.
- K, P and Mn explain 67% of total variance of the leaf mineral composition.
- Soil K, Fe, Cu, organic matter and mycorrhiza have the strongest effect on plants.
- Organic versus conventional management is an important factor.

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ABSTRACT

The spatial variability of the mineral composition of grapevines in production vineyards along the east Adriatic coast was determined and compared between conventional and sustainable vineyard management. Cluster analysis shows a high level of spatial variability even within the individual locations. Factor analysis reveals three factors with strong loading for the macronutrients K and P and the micronutrient Mn, which explain 67% of the total variance in the mineral composition. Here, 26% to 34% of the variance of these three elements can be explained by abiotic and biotic soil parameters, with soil concentrations of K, Fe and Cu, organic matter content, and vesicular colonisation showing the strongest effects on the mineral composition of the grapevines. In addition, analysis of the mineral composition data shows significant differences between differently managed vineyards, with increased bioaccumulation of P and K in sustainable vineyards, while Zn bioaccumulation was increased in conventional vineyards. Our data confirm the importance of soil and vineyard management in the concept of terroir, and demonstrate the effects of sustainable management practices on the mineral nutrition of grapevines that result from modified nutrient availability related to changes in the abiotic and biotic characteristics of the soil.

1. Introduction

In viticulture, the concept of terroir relates the sensory attributes of wines to the environmental conditions of the grapes, and it therefore represents an important descriptor of the connection between wines and their origins. It encompasses both the natural factors of soil, climate and topography, and the human role in vineyard management (Van Leeuven and Seguin, 2006).

The soil is one of the most important factors of the terroir, which makes it of special interest for the evaluation of the environmental effects on the mineral composition of grapevines (Van Leeuven and Seguin, 2006). This mineral composition reflects the environment in which the grapevines are cultivated (Bertoldi et al., 2011; Chopin et al., 2008; Marengo and Aceto, 2003; Pessanha et al., 2010). As a consequence, the grapevine products (i.e., grapes, juice, wine) will be influenced by the composition of the soil (Rogiers et al., 2006; Pohl, 2007). The most important soil characteristics that affect the mineral composition of grapevines are the soil pH (Jackson, 2008), the partitioning inside the soil (Chopin et al., 2008), and the Ca content (Gruber and Kosegarten, 2001). In addition, biotic factors such as grapevine variety (Amorós et al., 2011) and rootstock (Bavaresco et al., 2003; Wooldridge et al., 2010), and soil microbiome, can also have profound effects on the availability and uptake of minerals from the soil by the grapevine. Vineyard soils also support indigenous arbuscular mycorrhizal (AM) fungi (Likar et al., 2013; Oehl et al., 2005; Radić et al., 2014) that can have positive effects on grapevine performance (Biricolti et al., 1997; Linderman and Davis, 2001). Furthermore, low root density (Schreiner, 2005) and coarse root texture of grapevines suggest that they are highly dependent on AM fungi (Eissenstat, 1992), making these an important factor in the determination of the mineral composition of the grapevines. This is especially true in organic vineyards that follow low-input

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practices, as these support higher AM fungi spore abundance and diversity (Oehl et al., 2004).

In the ongoing effort to develop techniques for wine monitoring, geochemical fingerprints would greatly improve the traceability of wines to their origins, particularly as the mineral compositions of grapevines and their products are governed by the soil characteristics and the cultural practices. As such, evaluation of the mineral composition of grapevines from conventionally managed vineyards and vineyards with organic practices under different environmental conditions should greatly improve the monitoring system.

The main aim of the present study was to assess the influence of the soil on the mineral composition of grapevine leaves on the east Adriatic coast and to evaluate the effects of conventional and sustainable agricultural practices on grapevine mineral composition. For this, grapevines of the cultivar 'Mali Plavac' (a red wine variety) were sampled in vineyards along a 250-km-long transect, with the evaluation of: (i) the spatial variability in the mineral composition of the grapevines in production vineyards in the east Adriatic Karst region; and (ii) the effects of environment and vineyard management on the mineral composition of the grapevines. Multivariate statistical techniques were applied to evaluate the spatial variations in the mineral compositions of the grapevines. Furthermore, the effects of vineyard management practices (i.e., conventional vs. sustainable) on the grapevine mineral compositions were tested, following the hypothesis that differences in cultivation practices will influence the mineral compositions of the grapevines either directly (due to changes in soil characteristics) or indirectly (as a result of improved microbiota diversity in organically managed vineyards).

2. Materials and methods

2.1. Sampling locations

Eight production vineyards from four distinct localities (two vineyards per wine region) in the Karst region of the east Adriatic area were selected for sampling. The vineyards are located along a transect of 250 km that stretches from north to south. The altitudes of the vineyards range from 50 m to 350 m a.s.l. The climates of all of these localities are of the Mediterranean type, with most of the annual precipitation in autumn and winter (800–1300 mm), and with droughts very often during the late spring and summer periods.

The bedrock is composed mainly of limestone or dolomite, and it is covered with stony carbonate soils. The soil texture ranged from clay loam (Ivan Dolac), to silty clay (Milna) and silt loam (Peljesac). At Zadar conventionally managed vineyard was located on loam soil, whereas soil in sustainable vineyard had sandy loam texture (Table 1). The soils have a pH of 7.9 to 8.2, with the exception of the Zadar location, where the vineyard soil has a pH of 6.0 to 6.1. Organic matter content of the soil ranged around 1.5–3%, but reached above 5% at the locations of Ivan Dolac (both vineyards) and Peljesac (sustainable vineyard).

The grapevine coverage of the vineyards is 5% to 10%, with total plant cover reaching 5–87% (according to averages of Braun-Blanquet classes).

2.2. Sample collection and analysis

Root samples of five randomly chosen grapevines and their rhizosphere soil were collected to a depth of 20 cm to 30 cm at each of the vineyards, in the Summer of 2010. The element compositions of the grapevines were assessed according to the European criteria for assessment of grapevine elements, which are based on whole-leaf analysis, in contrast to the American criteria where only the leaf petiole is analysed (Čoga et al., 2008).

The soil samples were air dried, sieved to 2 mm, and ground to a fine powder in an agate mortar. Total organic matter was measured by wet combustion, according to Kandeler (1995). The plant-available phosphorous was extracted using 0.5 M NaHCO$_3$, and determined photometrically according to Olsen and Sommers (1982). The soil pH was measured in soil:water (1:2, v/v) extracts, using deionised water. The soil mineral composition was measured by energy dispersive X-ray fluorescence spectrometry in soil pellets pressed from 0.5 g powdered soil material, which were prepared using a pellet die and a hydraulic press. For fluorescence excitation, a [^{109}]-Cd annular radioisotope source was used (300 MBq, 22.1 keV; Isotope Products Laboratories, USA). An X-ray spectrometer was used that was based on a Si (Li) detector (EG and G ORTEC, USA), with a 25-mm-thick Be window. The energy resolution of the spectrometer at count rates below 1000 c/s was 175 eV at 5.9 keV. X-ray fluorescence measurements were performed in air, and each sample was irradiated for 3000 s. The analysis of the X-ray spectra was performed using AXIL programme (Van Espen and Jansen, 1993), as included in the QAES software package (Vekemans et al., 1994; Kump et al., 2007). Quality assurance for the element analysis was performed using standard reference materials: NIST SRM 1573a (tomato leaves, homogenised powder); CRM 129 (hay powder); and OU-10 (geological sample of longmyndian greywacke, GeoPT24).

The mineral compositions of the leaves were determined by total reflection X-ray spectrometry. For TXRF about 0.1 g of the powdered material was digested in 3 mL HNO$_3$ in Teflon vessels, using the CEM microwave sample digestion system (MarsX Press). The cooled digests were diluted to 10 mL with Milli-Q water, and spiked with standard solution of Ga as an internal standard to a final concentration of 10 μg/L (Golob et al., 2005; Kump et al., 1996; Vogel-Mikuš et al., 2006). Two aliquots of 10 μL of the resulting sample solutions were deposited onto quartz sample carrier plates and dried in a dessicator overnight. For excitation, a focused X-ray beam from a fine-focus X-ray tube

Table 1
Soil physico-chemical characteristics for selected vineyards from four locations under different agricultural practice (conventional, sustainable), with altitude and plant cover (according to Braun-Blanquet 1964).

	Ivan Dolac		Milna		Peljesac		Zadar	
	Conventional	Sustainable	Conventional	Sustainable	Conventional	Sustainable	Conventional	Sustainable
Plant available P[a] (mg/g)	13.3 ± 3.09	3.77 ± 1.67	1.94 ± 0.2	1.77 ± 0.42	4.58 ± 0.62	0.28 ± 0.11	5.77 ± 0.62	0.37 ± 0.08
K[a] (mg/g)	18.4 ± 1.96	21.5 ± 1.39	17.0 ± 2.03	17.1 ± 1.64	8.28 ± 2.10	9.00 ± 2.47	12.8 ± 2.66	10.2 ± 2.44
Ca[a] (mg/g)	69.5 ± 9.08	42.4 ± 10.1	121 ± 10.1	15.0 ± 17.1	160 ± 15.1	123 ± 41.2	105 ± 12.5	44.1 ± 1.62
Mn[a] (mg/g)	1090 ± 140	1173 ± 121	872 ± 179	657 ± 48	569 ± 71	511 ± 31	487 ± 54	379 ± 41
Fe[a] (mg/g)	41.3 ± 0.85	43.9 ± 1.85	37.8 ± 1.82	35.9 ± 2.27	13.3 ± 2.68	20.5 ± 5.78	18.8 ± 3.36	22.8 ± 3.19
Zn[a] (mg/g)	103 ± 25	111 ± 19	89 ± 9	87 ± 16	73 ± 27	63 ± 20	51 ± 11	41 ± 9
Cu[a] (mg/g)	170 ± 28	124 ± 6	117 ± 33	132 ± 17	480 ± 119	83 ± 28	131 ± 7	51 ± 2
OM[b]	5.76 ± 0.33	4.09 ± 0.48	1.62 ± 0.18	2.03 ± 0.25	2.81 ± 0.17	9.39 ± 2.54	1.44 ± 0.21	1.73 ± 0.21
pH	8.02 ± 0.06	8.15 ± 0.05	8.18 ± 0.07	8.05 ± 0.08	8.05 ± 0.14	7.87 ± 0.05	6.00 ± 0.16	6.10 ± 0.08
Soil texture	Clay loam	Clay loam	Silty clay	Silty clay	Silt loam	Silt loam	Loam	Sandy loam
Altitude (m a.s.l.)	45	60	100	100	90	100	300	300
Plant cover (%)	5	5	87	87	5	5	5	5

[a] Concentration of the element per soil dry weight.

[b] OM, organic matter content (%).