STATEWIDE RELATIONSHIPS BETWEEN WATER POTENTIALS, GAS EXCHANGE AND $\Delta^{13}C$ OF GRAPE MUSTS IN CALIFORNIA. IMPLICATIONS FOR USE IN PRECISION VITICULTURE

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Abstract:

Context and purpose of the study– The measurement of carbon isotopic discrimination of musts ($\delta^{13}C$) at harvest is an integrated assessment of water status during ripening of grapevine. It is an alternative to traditional measurements of water status in the field, which is crucial for understanding spatial variability of plant physiology at the vineyard scale, proven useful for delineation of management zones in precision viticulture. The aim of this work was to attune the method for the first time to California conditions across a range of areas and cultivars with different hydric behavior, and to evaluate its efficiency in delineating management zones for selective harvest in commercial vineyards.

Material and methods – The experiment was performed in 91 experimental units located at four different locations across the State, planted to three different table and wine grape cultivars (Crimson Seedless, Cabernet Sauvignon, Merlot) whose hydric behavior ranged from isohydric to anisohydric, and in between. Leaf gas-exchanges and stem water potentials (Ψ) were measured routinely in each experimental unit, and the $\delta^{13}C$ at harvest. At one of the locations, $\delta^{13}C$ and water potentials were measured on an equi-distant grid, spatialized and clustered to compare their efficiency in the differentiated the vineyard block into two distinct zones having grapes with different flavonoid composition.

Results - A significant and direct relationship was evident between $\delta^{13}C$ and average stem water potential (R^2 = 0.72), stomatal conductance (R^2 = 0.66) and net carbon assimilation (R^2 = 0.62) measured throughout the season. Differences between the cultivars were small, independently from their reported hydric behavior and it was possible to pool all of them together. This was also true in crossed relationships between stem water potential, stomatal conductance, and net carbon assimilation that were not able to clearly discriminate between the reported hydric behaviors. A unique state-wide calibration was therefore developed between $\delta^{13}C$ and plant water status. Simulation exercise demonstrated that variability in slope and R^2 of the $\delta^{13}C \sim \Psi$ regression can be caused by comparison of discrete measurements (Ψ) of water status to a continuous measurement ($\delta^{13}C$), and that apparent variability decreased with increasing sampling points of the discrete measurement (Ψ).The use of $\delta^{13}C$ was then tested in a precision viticulture context. The management zones obtained by $\delta^{13}C$ and stem water potentials were similar at 72% and allowed to separate the harvest in two pools, having statistically different grape composition (soluble solids, organic acids and anthocyanin profiles). Our results provided evidence that $\delta^{13}C$ discrimination was a reliable and repeatable assessor of plant water status in vineyard ecosystems useful for delineation of management zones in precision viticulture.

Keywords: Grapevine, $\delta^{13}C$, carbon stable isotopes, water status, leaf gas-exchange, precision agriculture, selective harvest

1. Introduction.

State wide relationships between water potentials, gas exchange and δ13C of grape musts in California. Implications for use in precision viticulture.

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Abstract

Carbon isotope discrimination of musts at harvest ($\delta^{13}C$) is an integrated assessment of water status during grape ripening. It is an alternative to traditional measurements of water status, which is crucial for understanding spatial variability of plant physiology at the vineyard scale. This work was performed in 91 experimental units located at four different locations across California, more than 400km apart, planted to three different table and wine grape cultivars (Cabernet-Sauvignon, Merlot, Crimson-Seedless) whose behavior ranged from isohydric to anisohydric and in between, as reported by recent scientific literature. Leaf gas-exchange and stem water potentials were routinely measured in each experimental unit. The $\delta^{13}C$ was measured at harvest and a direct relationship was evident between stem water potential (R^2 = 0.65), stomatal conductance (R^2 = 0.71) and net carbon assimilation (R^2 = 0.62) measured throughout the season. All cultivars were pooled together and behaved the same independently from their reported hydric behavior. This was confirmed by crossed relationships between stem water potential and gas exchange that were not able to discriminate between the reported hydric behaviors. A unique state-wide calibration was therefore developed between $\delta^{13}C$ and plant water status. The use of $\delta^{13}C$ was therefore tested in a precision viticulture context, to develop management zones for separating anthocyanins composition in selective harvest and compared to the use of stem water potentials for this purpose.

Scope

Plant water status is a main driver of plant physiology, berry composition and the yield. $\delta^{13}C$ of musts is a bio-datalogger of leaf physiology and plant water status during the ripening period, but values can very across regions or varieties, and experiences in California are still lacking in the scientific literature. This work answered the question:

IS IT POSSIBLE TO DEVELOP A SINGLE MULTIVARIETY CALIBRATION OF $\delta^{13}C \sim \Psi_{stem}$ AND $\delta^{13}C \sim$ GAS EXCHANGE IN CALIFORNIA CONDITIONS?

Once this calibration was developed, the next step was to apply $\delta^{13}C$ in a practical context, such as for selective harvest in precision viticulture.

Methods

VINEYARDS

- Cabernet-Sauvignon/110 R, high-quadrilateral, Healdsburg, Sonoma County
- Cabernet-Sauvignon/1103P, high-quadrilateral, Galt, Sacramento County
- Merlot/1103P, vertical shoot positioned, Paso Robles, S. Luis Obispo County
- Crimson-Seedless/Freedom, open gable, Earlimart, Tulare County

GRAPEVINE PHYSIOLOGY & BERRY COMPOSITION

- Solar-noon stem water potential (Ψ_{stem}).
- Leaf gas exchanges: net carbon assimilation, A_N ; stomatal conductance, g_s ; intrinsic water use efficiency, WUEi, leaf internal [CO2], Ci, ambient [CO2] Ca
- Carbon isotope discrimination of musts, $\delta^{13}C$ respect to VPDB standard
- Low molecular weight phenolics (anthocyanins)
- Leaf nitrogen (%N dry weight).
- Pruning weights

SENSING

- Ground-sensed Normalized Difference Vegetation Index (NDVI)
- Electrical resistivity, EM38
- Digital Elevation Model Analysis

STATISTICAL ANALYSIS

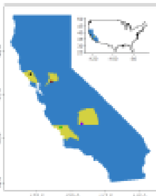

Figure 1. Geographical locations of the experimental vineyards (black dots) in the study. See text (Methods – Vineyards) for color reference. Coordinate system: WGS84

Results

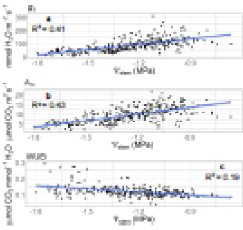

Figure 2. Relationship between stem water potential (Ψ_{stem}) and leaf gas exchange in grapevine across 3 different vineyards in different viticulture areas and 2 different varieties (Merlot and Cabernet-Sauvignon). a) relationship with stomatal conductance (g_s), b) relationship with net assimilation, A_N, c) relationship with intrinsic water use efficiency (WUEi); n = 294. Blue line is a linear regression line; in grey is the confidence interval.

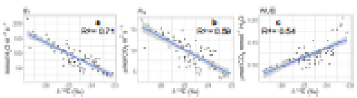

Figure 3. Relationship between the carbon isotopic discrimination of musts at harvest expressed as $\delta^{13}C$ (‰) and seasonal integrals of leaf gas exchange across 3 different vineyards in 3 different viticulture areas and 2 different varieties (Merlot and Cabernet-Sauvignon). a) relationship with stomatal conductance (g_s), b) relationship with A_N, c) relationship with intrinsic water use efficiency (WUEi); n = 71. Blue line is a linear regression line; in grey is the confidence interval.

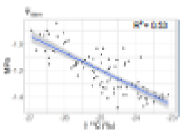

Figure 4. Relationship between the carbon isotopic discrimination of musts at harvest expressed as $\delta^{13}C$ (‰) and seasonal integrals of stem water potentials across 4 different vineyards in 4 different viticulture areas and three different varieties (Merlot, Cabernet-Sauvignon, Crimson-Seedless); n = 91. Blue line is a linear regression line; in grey is the confidence interval.

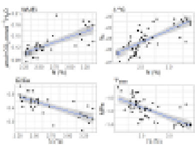

Figure 5. Relationship between Nitrogen content measured in leaf blades, and seasonal integrals of WUEi, Ci/Ca (df = 32), carbon isotopic discrimination of musts at harvest, and stem water potential (df = 50). Blue line is a linear regression line; in grey is the confidence interval (R^2 WUEi = 0.50, Ci/Ca = 0.52, 13C = 0.56, Ψ_{stem} = 0.46)

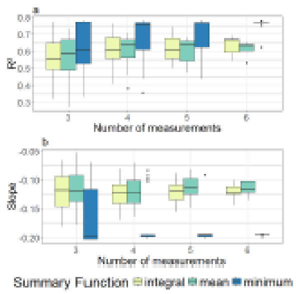

Figure 6 – Evolution of the linear regression estimates between stem water potential Ψ_{stem} and the carbon isotopic discrimination of musts at harvest expressed as $\delta^{13}C$ (‰) according to the number of measurement time points throughout the season. Experiment from the Sonoma vineyard were a larger number of measurement time points was available for resampling. Number of examples = 100

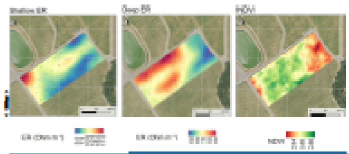

Figure 7. Maps of shallow (0.375 m) and deep (0.75 m) electrical conductivity and ground sensed NDVI in the field of study. Black dots indicate the locations of the experimental units composed by 5 grapevine on the same row.

	Slope	Elevation	SAGA WI	Shallow EC	Deep EC	NDVI	Wood (kg)	SWP int	$\delta^{13}C$	gs int	An int	WUEi int
NDVI	0.06	0.43	0.36	0.03	0.09		0.60 *	-0.29	0.03	0.04	-0.12	0.05
Ψ_{stem} int	-0.27	-0.78 *	-0.87 *	-0.70 ***	-0.63 *	-0.28	0.23		0.82 ***	-0.83 ***	-0.86 ***	-0.79 ***
$\delta^{13}C$	-0.07	0.48	0.37	0.84 *	0.43	-0.03	-0.52 *	0.82 ***		-0.80 ***	-0.80 ***	0.82 ***
gs int	-0.06	-0.52	-0.40	-0.82 ***	-0.38	-0.04	-0.61 *	0.83 ***	-0.80 ***		0.87 ***	-0.83 ***
An int	-0.06	-0.87 *	-0.43	-0.81 ***	-0.38	-0.13	0.39	0.88 ***	-0.88 ***	0.87 ***		-0.85 ***
WUEi int	0.06	0.53	0.44	0.87 *	0.48	0.05	-0.61 *	-0.78 ***	0.83 ***	-0.80 ***	-0.86 ***	

Table 1. Spatial correlations (modified t-test) between terrain characteristics, soil electrical conductivity, ground sensed NDVI and integrals of physiological measurement of plant water status and photosynthesis. Column level Bonferroni significance threshold for alpha = 0.05 is 0.005. Stars indicate p-values, *: 0.05; **: 0.01; ***: 0.001.

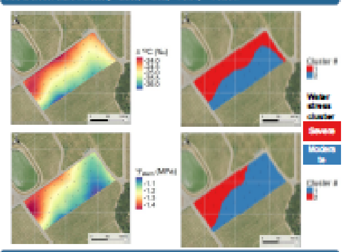

Figure 8. Mapping plant water status and delineating management zones through carbon 13 isotopic discrimination (upper panels) or stem water potential (lower panels). Maps were interpolated using a linear interpolation with x, y and z as auxiliary variables. Root mean squared error in the bootstrap validation analysis is 0.63‰ with R^2 = 0.54 for interpolation of $\delta^{13}C$ and 0.1 MPa with R^2 = 0.58 for interpolation of Ψ_{stem}. Similarity between the two clusters as expressed by Rand index is 0.87.

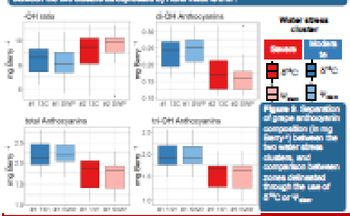

Figure 9. Separation of grape anthocyanin composition (in mg berry-1) between the two water stress clusters, and comparison between zones delineated through the use of $\delta^{13}C$ or Ψ_{stem}

Conclusions

In this study the $\delta^{13}C$ of musts was effectively related to Ψ_{stem} and leaf gas-exchange. Independently from the reported hydric behavior of the varieties in the study a single relationship was obtained, suggesting continuity and non dichotomy between the isohydric and anisohydric response.

Methodology questions were assessed, showing the variability in regression estimates between $\delta^{13}C$ and Ψ_{stem} because of the comparison of a continuous estimator of plant physiology, the $\delta^{13}C$, against a discrete measurement obtained in peculiar days and conditions, the Ψ_{stem}. Nevertheless, in California the steady weather during ripening allowed to obtain good regression estimates with relatively few measurement points.

Finally, $\delta^{13}C$ was related to the environmental variability in soil and topography and compared to the use of routine Ψ_{stem} measurements for separating grape anthocyanin composition at harvest in precision viticulture. It revealed to be effective, but cannot be used over fishnet grids for production purposes. However, if $\delta^{13}C$ is used to monitor few smart locations in contrasting environments, it could provide plant physiology significance to spatial maps obtained through sensing approaches.