HOW MUCH DOES THE SOIL, CLIMATE AND VITICULTURAL PRACTICES CONTRIBUTE TO THE VARIABILITY OF THE TERROIR EXPRESSION?

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Abstract:

Context and purpose of the study - When considering the application of a systemic approach to assess the intrinsic complexity of agricultural production, the following question immediately arises: how is this synthesis made? In this sense, characterizing the joint effects of environmental factors and viticultural practices on vine functioning represents a key challenge for the correct management of Terroir. In order to provide a response to this challenge, this work assesses the relative importance of the main factors comprised into the Terroir concept: climate (or "Year" effect), "Soil" and the "Source-sink" relation, on the vegetative development, yield, berry composition and plant sanitary status

Material and methods - The study was carried out between 2011 and 2014 on six viticultural regions in the south of Uruguay, involving nine vineyards. The cultivar studied was Tannat, which was vertically trellised and north-south oriented in all vineyards. The year effect refers to climate, which was characterized using solar irradiation and three bioclimatic indices calculated according to the Multicriteria Climatic Classification System. The soil was characterized by digging pits and determining physicochemical properties, in order to determine three textural categories and to define soil depth and water availability. The source-sink relationship factor referred to the ratio between leaf surface and yield, and included four categories that simulated different vine balances. This factor has been assimilated to a management that winegrowers may potentially achieve through a set of technical operations, such as pruning, shoot thinning, leaf and lateral removal and cluster thinning.
Statistical analyses included a Mixed Model with random effects to determine the relative importance of each factor on the total variability within the dataset.

Results - Our results showed that vegetative growth depends mainly on the "soil" factor followed by the "Year". Total yield per vine was explained by the "Source-sink" relationship and the "Year*Source-sink" interaction, both linked to the rainfall amount occurred during the maturation period. Berry weight was explained by "Year". Rot incidence was more dependent on the "Year*Source-sink" interaction, and then on the "Year*Soil" interaction, and on the "Soil" factor.
The synthesis of primary compounds in the berries depended mainly on the "Year" factor and the interaction of "Year*Source-Sink". The pH value was explained by the "Year*Soil" interaction. Secondary metabolite concentrations in the berry depended mainly on the "Source-sink" relationship and the "Year" factor.
This investigation enables the adjustment of technical itineraries for managing this given terroir according to the characteristics of its physical environment and the production target to be achieved.

Keywords:vineyard soils, viticultural zoning, source-sink relationships, vine balance, berry composition, mixed model.

1. Introduction

Terroir is considered as the interaction amongst the elements that constitute a given ecosystem: climate, soil and grapevine within a given geographical location, and human factors, expressed as the viticultural practices (Seguin, 1988). Knowledge about the real functioning of the vineyard and designing technical schedules stand out among the advantages of the methodological approach that implies studying terroirs.

Due to the complexity of systematic studies, research on viticulture tends to use reductionist approaches and to the analysis of cause-effect relationships. In contrast, the joint study of terroir key factors, such as climate, soil and cultivar, is more complex to deal with and, hence, the amount of these studies is lower.

For instance, several authors worked on defining climatic indices to describe the suitability of a given region for producing wine (Jones 2006, Ferrer et al., 2007, Tonietto et al., 2013). In addition, other researchers got deep into climate effects on vine functioning (Hunter and Bonnardot, 2011), wine and vintage quality (Soar et al., 2008), or on characterizing vine performance (Ferrer et al., 2014).

Soil factor and its influence on vine performance have been comprehensively studied (Bodin and Morlat, 2006, Trought et al., 2008, Van Leeuwen 2010, Echeverría et al., 2017). Several authors proved the huge influence of water availability on vintage quality (Ojeda et al., 2002). Source-sink modulation through cultural practices is a key factor since it affects vine vigour, yield and berry quality (Poni et al., 2013, Bobeica et al., 2015, Verdenal et al., 2016). In this sense, the operations performed by the vine grower represent an adaptation mechanism for rearranging vine components and directing the vineyard system in order to achieve a pre-defined goal.

The studies including more than one determinant factor are scarce. Nevertheless, some authors proved the significant effect of climate, soil and genetic factors on grapevine response (Van Leeuwen et al., 2004). In particular, soil and climate had a greater incidence than cultivar on the variability of the system, likely due to their influence on grapevine water status.

From the results of partial studies, it is possible to build models that allow for identifying the relative importance of each factor on the final response and, thus, generate tools that growers and technicians can use for a suitable management of the vineyard and improve its efficiency.

The current study aimed to establish the importance of each of the abovementioned factors on vineyard performance.

2. Material and methods

In the current analysis, data from four vintages (2011 to 2014), collected on nine vineyards (Plot) located over the Uruguayan coast of Río de la Plata have been used (Table 1). This region contains most of the vineyard surface in the country.

The study was conducted in commercial non-irrigated vineyards. On each location, 30 vines (*Vitis vinifera* L. cv. Tannat) were randomly chosen; they were distributed on three rows with 10 vines each. Grapevines were vertically trellised on a Guyot system. Rows were north-south oriented in all vineyards

Weather variables were recorded in six stations located close to the vineyards. The Multicriteria Climate Classification (MCC) was applied and the following indices were estimated: Heliothermal index (HI), Dryness index (DI) and Cool Night index (CI) as per Tonietto and Carboneau (2004).

Soil from each plot was described according to FAO (2006) and classified using USDA Soil Taxonomy. Textural classification from volume of soil explored by active roots was defined as TCra. Available water capacity (AWC) was determined and considered as the initial volume of water in the soil (Wo) for estimating the soil water balance.

Potential exposed leaf surface (SFEp) was estimated at veraison (Carbonneau, 1995). At harvest, a shoot bearing a cluster was collected from the middle of the branch in ten vines. Length (LP) of these shoots was measured

At harvest, yield (Y) and cluster number per vine were recorded. Those clusters that showed, at least, 5% of the berries affected by diseases (mainly *Botrytis sp*) were counted and separately weighed (Yenf). Berry weight (Pb) was obtained from three samples of 250 berries each

The leaf/fruit ratio (source/sink factor) was established as a factor in order to analyse its influence on vine performance. Through the quotient (SFEp)/(Y) four classes of (Source-sink) were defined: < 0.40; 0.40-0.60; >0.60-0.80; >0.80 (m^2*kg $grape^{-1}$).

Harvest was carried out at "technological maturity" for each plot, considering pH values, the ratio between sugar content and titratable acidity of the grapes and berry weight. These parameters were determined periodically using the OIV (2007) procedures.

In the berry samples, we also determined total anthocyanins (ApH1), extractable anthocyanins (ApH 3.2), phenolic richness (A280) and the cell maturity index (EA) according to Glories and Augustin (1993). These indices were calculated considering the respective dilution of the grape extracts according to González-Neves et al. (2004).

In order to determine the relative importance of the different factors (and their interactions) on the total variability of vine performance, the following levels were defined:

Year (weather effect): four levels = 2011; 2012; 2013;2014 -

Soil (TCra): three levels = Clay loam; Silty clay; Silty clay loam -

Source-sink: four levels= <0.40; 0.40-0.60; >0.60-0.80; >0.80 - (m^2*kg grape^{-1})

A Mixed Model with random effects was considered:

y = Year, Soil, Source-sink effect, interactions and residuals, except the intercept.

The model was run for each dependent variable and the variance was estimated by the Restricted Estimation by Maximum Likelihood (REML). The relative percentage of each one over the total sum was determined. Mixed Models were constructed using R (R Development Core Team www.r-project.org).In addition,ANOVA was used for assessing the effect of Source-sink factor on vine performance. Fisher LSD test was used for mean separation (p<0.10). ANOVA was performed using the InfoStat software.

3. Results and discussion

Table 2 shows the relative importance of each factor ("year", "soil" and "source-sink") and their interactions on the variance of the studied dataset. Source-sink ratio was used as a factor because the determination of its magnitude is not dependent on the two variables from which it consists of (SFEp/Y).

Most of the factors, either individually or their partial interactions, did not explain the variability in the obtained results. In many cases, the percentages were zero or their values were not significant. In general, the percentages accumulated as "residual" surpassed those from the studied factors and interactions. The greatest variability assigned to "residual" corresponded to the group of variables associated with vegetative vigour.

Source-sink relation explains 82% of the yield variability in the dataset, while the interaction "year*soil" explained 14% of the rot incidence and 36% of the pH value in the juice. The interaction "year*Source-Sink" affected significantly the variability of yield (13%), rot incidence (43%) and titratable acidity (27%).

Variables associated to vegetative development were influenced by soil and year, primarily, and for source-sink to a lesser extent. In contrast, yield variables were influenced mostly by year, source-sink and their interaction. Berry composition was affected by year, source-sink, the interactions year*source-sink and year*soil.

The analysis of the relative importance of factors (and their interactions) to the variance allows interpreting a complex effect determining plant performance, which cannot be attributed only to the selected elements or to their partial interactions. The high percentages accumulated in "residual" might reveal the effect of other factors and interactions that have not been considered; for instance, soil fertility, in-row weed management, vine reserve accumulation or the occurrence of extreme climate events.

Vegetative development variables were not influenced by the studied factors and their interactions. However, studies such as Van Leeuwen et al., (2004), show that "year" and "soil" factors exerted a significant influence on some vegetative development variables. A strong correlation between soil available water capacity and canopy development, yield, berry size and must quality has been detected, as observed by other authors (Ojeda et al., 2002, Trought et al., 2008, Van Leeuwen et al., 2010, and Echeverría et al. 2017). High rainfall amounts in the summer promoted a greater biomass development. This situation was more marked in those vineyards located on soils with high AWC.

The influence of the three studied factors and their interactions on the determination of yield components was evident. Yield per plant was correlated positively with rainfall amount over the maturation period (data not shown). According to our results, the greatest weight in the determination of yield components corresponded to the "Source-sink" and "Year" factors, but also to their interaction. Moreover, the driver of the "Source-sink" factor was yield and not leaf surface, since differences on SFEp have not been detected.

Even though AWC affects to the vegetative and reproductive development, it induces a differential variability between both dimensions, benefiting yield. In the current study, soils with favourable conditions for higher vegetative development and yield were associated to a greater incidence of diseases (especially bunch rot). Sanitary status was affected by the "Year" factor and the interactions "Year*Source-sink" and "Source-sink*Soil". The greater categories of source-sink ratio (potentially regulated by the grower) could be associated to a lower cluster volume and to a canopy microclimate with less risk of disease incidence. However, this ratio is not enough for explaining yield losses in years characterized by high rainfall amounts.

Berry composition variables were affected by the three studied factors to different extents. The seasonal variation in berry primary components depended less on the source-sink ratio than on vine water status (Etchebarne et al., 2010), which is mainly associated with the "Year" factor and its interaction with "Soil", but also with "Source-sink". The main factor determining pH values was the interaction "Year*Soil". The "Year" acted through its influence on organic acid synthesis (malic and tartaric acids) at pre-veraison and on their degradation rate during maturation. This process is highly dependent on solar radiation, temperature and vine water status. Soil had and indirect influence through modulating water availability, thus conditioning the energy balance and vine response. Water stress limits the concentration of cations in the berries, particularly K^+, affecting titratable acidity and pH (Etchebarne et al., 2010).

Regarding the synthesis of secondary components, such as anthocyanins and tannins, the Clay Loam soils, with a lower water storage ability than Silty clay and Silty clay loam soils, generated moderate water stress conditions during maturation, favouring phenolic compounds synthesis (data not shown).

"Source-sink" factor was determinant for phenolic concentrations, especially those of anthocyanins, but it did not show a linear relationship with the synthesis of these compounds, which increased till the ">0.60-0.80" class and then decreased (Table 3).

When carbon availability is lower, as in the case of leaf/fruit ratio "<0.40", soluble solids (SS) concentration was reduced by 10%, whereas ApH1 was reduced by 47% (Table 3). These results are in accordance with the report by Parker et al. (2016), who indicated that reducing canopy size would decrease the SS/AT ratio and delay maturation.

According to Zamboni et al. (1995), different pruning intensities may lead to similar leaf/fruit ratios but different preferences for the resultant wines. Similarly, leaf removal practices that lead to a given leaf/fruit ratio might cause different effects on the vines depending on the time of application and the position of the removed leaves.

4. Conclusions

The combined analysis of "year", "soil", "source-sink" and their partial interactions on vine performance proved to be useful for understanding viticulture terroir functioning. In the studied terroirs, vegetative development variables depended on climate and soil, but also on other factors and interactions not included in the current study, leading to the need for research including new explaining factors and their interactions. Yield per vine was explained by the "source-sink" ratio, the "year" effect and their interaction; both were linked to rainfall amount during maturation. Crop load carried by vines was determinant of this "source-sink" ratio, surpassing the leaf surface influence. Berry primary components synthesis depended on year and the interactions of year with soil and source-sink ratio. Concentrations of secondary metabolites in the berry depended on the "source-sink" ratio and weather.

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