OENO One
VINE AND WINE OPEN ACCESS JOURNAL
Volume 52 > Number 2 > 2018

Benefit of ancillary data acquired at the cooperative level to study soil type and climatic zone influence on berry composition: a case study in Rioja appellation

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Abstract

Aim: The main objective of this study was to evaluate the influence of soil type and climate on must qualitative parameters in a winegrower's cooperative at Rioja appellation.

Methods and results: The study was conducted from 2009 to 2011 with data collected routinely before harvest by the technician of a cooperative with a total surface area of 525 ha. Soils were classified using an existing soil map (1:50.000 scale) according to their water-holding capacity (WHC), and two climatic zones were differentiated based on the Huglin index. Effects of soil and climate on berry composition were evaluated using HJ-Biplot statistical analysis. High WHC soils produced musts with high total acidity, mainly due to malic acid. Must K concentrations were lower in soils with lower K and clay content. Soils with lower WHC were the only ones able to produce musts with high anthocyanin concentration and higher colour intensity. The climatic zones established only resulted in small differences in grape composition.

Conclusion: It is possible to differentiate berry composition parameters according to soil type considering soil WHC, but less clear differences were observed among climatic zones considering a 50 km^2 area and a difference of approximately 200 m in elevation between the two zones.

Significance and impact of the study: Many wineries have access to soil, climate and grape composition data. Therefore, these data could be used to make a grape composition classification at harvest that could be assessed every year using simple statistical tools.

Keywords: soil water-holding capacity, grape composition, Tempranillo, HJ-Biplot, must acidity

Received : 24 March 2017; Accepted : 5 June 2018; Published : 27 June 2018
doi: 10.20870/oeno-one.2018.52.2.1851

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Introduction

In viticulture, the concept of "terroir" relates the sensory attributes of wines to the environmental conditions of the grapes (Likar *et al.*, 2015). The term terroir dates back to the ancient world, and represents an important descriptor of the connection between wines and their origin (Likar *et al.*, 2015). Some works, as stated by van Leeuwen *et al.* (2004), have determined the effects on grape yield and composition of a single terroir factor, whether climate (Jones and Davis, 2000; Tonietto and Carbonneau, 2004), soil (Tregoat *et al.*, 2002) or others. However, it is less common to find studies that combine different factors. The terroir concept should be considered from a technical-scientific point of view so that, beyond the mystique and marketing, this concept will be based on least debatable realities (Deloire *et al.*, 2005).

Soil is a crucial component in grape and wine production, but its effect is complex, acting on grapevine water and nutrient supply, and on temperature in the root zone (Coipel *et al.*, 2006). Although grapevines can adapt to a wide range of soil properties, grape and wine composition are significantly affected by soil type, which influences the taste of the final product (Wang *et al.*, 2015). Wine quality is often strongly dependent on soil physical properties, such as its texture and depth, due to their relationship with soil water-holding capacity (WHC), since vine behaviour and berry composition are closely related to water uptake conditions (van Leeuwen *et al.*, 2004). In this sense, wine grapes grown on highly permeable soils and under the same environmental conditions with large diurnal temperature differences have faster photosynthetic rates, higher sugar concentrations, and improved chroma and palate (Wang *et al.*, 2015). Sabon *et al.* (2002) also reported the influence of soil on the aromatic composition of Grenache wines, studying representative soils of the Rhone Valley (France) according to their geographical site, climatic conditions, hydrological regulation, and soil profile. Even though there are some studies concerning soil influence on grape quality, van Leeuwen *et al.* (2004) stated that little data have been published related to this subject. Therefore, there is a need to deepen the knowledge of how different types of soil influence grape quality.

Apart from soil, climate is also widely acknowledged as one of the most important factors influencing grapevine development and growth (Fraga *et al.*, 2014). The timing and duration of the grapevine phenological stages are deeply tied to the prevailing atmospheric conditions (Jones and Davis, 2000), which also contribute to variability in grapevine yield (Santos *et al.*, 2011), wine production and quality (Fraga *et al.*, 2014). Sabon et *al.* (2002) observed that wines produced in the areas furthest to the south of the Valley of Rhone, where maturation occurs early, had high aromatic composition, low total acidity and high potential alcohol in their must. All this variability ultimately affects the winemaking process and microbiological, chemical and sensory aspects of wine (Mira de Orduña, 2010). Temperature is widely known to affect vine phenology, vegetative growth and yield and grape quality (Ramos *et al.*, 2015).

In vineyards, spatial variations in topography, climatic conditions, and physical and chemical properties of the soil have been associated with spatial variations in yield and fruit soluble solids (Bramley and Hamilton, 2004). Considering that spatial variability is very high in soil, variation in soil properties appears to be a key driver of vineyard yield and grape composition. To optimally manage vineyard variability, it is critical to identify zones that are likely to produce grapes or wines of similar composition, which will enable operational decisions to be better implemented at the various production stages (Vaudour and Shaw, 2005). Irimia *et al.* (2014) reported that the dominant methods used to delimit zones are based on bioclimatic indices, soil and lithological characteristics, or their combined influence referred to a specific geographical area. Vineyard zoning methodology does not need to always be the same, as individual units are subdivided or grouped into zones differently depending on the purpose of the study.

It is clear then that it is important to take into account the information regarding environmental variability: lithology, topography, soil, climate, etc. There are many wineries having not only this kind of data but also information about yield and berry composition. If the wineries were able to handle this information, it would be possible to start understanding how soil and climate influence vine behaviour, and consequently handle this information in order to assign grapes to different wines or take better decisions regarding the vineyard's management. However, it is difficult to analyse and use these data due to their different origins and scales. Taking all into account, the main objective of this study was to evaluate the influence of soil type and climate on Tempranillo grape composition using data from a winegrower's cooperative in Rioja appellation.

Materials and methods

1. Study area

The study was carried out from 2009 to 2011 in the vineyards of the Bodegas y Viñedos Labastida cooperative winery, situated in DOCa Rioja, Spain. All the vineyards covered 525 ha in a 50 km^2 land area. They were located at altitudes ranging from 450 m to over 650 m, totalling more than 1,000 plots with an average size of less than 0.5 ha. From among all those plots, non-irrigated vineyards and those with the cultivar Tempranillo were selected, covering an area of 60-70% of the whole vineyard. Plant density was 2600-3800 plants ha^{-1}, and training system was mostly gobelet, except for 15-20% that was trellised.

2. Environmental variables

2.1 Climate

The climate was characterized by being in an area of Oceanic-Mediterranean transition and by presenting a significant altitudinal difference between the Ebro River and the Cantabria mountain range (Barrios, 1994). The climate type could be defined as Temperate Mediterranean following the Papadakis agro-climatic classification (MAGRAMA, 1996).

Heliothermal Index of Huglin (Equation 1; Huglin, 1978) was calculated using 1 km x 1 km daily climatic data modelled from 1971 to 2007, obtained using the methodology of Gutiérrez *et al.* (2010).

$$\text{IndHuglin} = \sum_{1\text{ April}}^{30\text{ September}} \left(\left((T_{mean} - 10) + (T_{max} - 10)\right)/2\right) \text{ x d}$$

(Equation 1)

where T_{mean}=daily mean air temperature (°C), T_{max}=daily maximum air temperature (°C), d=day length coefficient, in our particular case d=1.03 (Tonietto and Carbonneau, 2004).

Afterwards, the vineyards were classified into different climatic zones according to an unsupervised clustering method using the fuzzy k-means algorithm with the program FuzMe v.3.5 (Minasny and McBratney, 2002). Unsupervised clustering aims at grouping data items into homogeneous clusters according to a proximity criterion defined by a distance function (Urretavizcaya *et al.*, 2014). Clustering in three classes did not succeed in highlighting significant differences between classes, and therefore, in order to emphasize differences in climatic parameters between classes, the clustering was finally with two classes (Figure 1). This approach also reduces complexity when handling results, in the opinion of the winery agronomist. The North zone (N) corresponds to a wetter and cooler zone (Huglin Index: 1594-1884), while the South zone (S) holds a drier and warmer zone (Huglin Index: 1885-1983) (Figure 1).

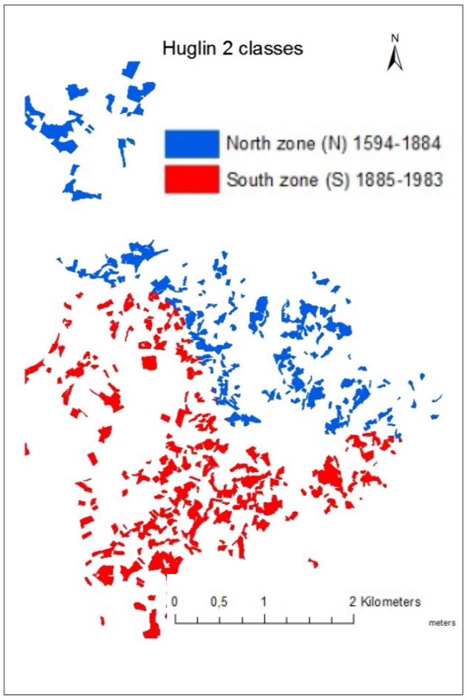

Figure 1. Huglin Heliothermal Index climatic classes for the period 1971-2007 using k-means clustering in the Bodegas y Viñedos Labastida cooperative winery vineyard of Rioja appellation.

2.2 Soils

In the soil map elaborated by Barrios (1994) for Rioja Alavesa (a DOCa Rioja area located in the Basque Country), a total of 21 key mapping units were established according to the USDA's "Keys to Soil Taxonomy" at 1:50.000 scale. These Key units were transformed to the nomenclature used currently (Soil Survey Staff, 2014). The agronomist of the winery classified the 21 soil types into four groups that differed mainly in their soil WHC (Table 1). Soil WHC was calculated for each soil unit according to equation 2 (Unamunzaga *et al.*, 2014), which was obtained in similar vineyards close to the study area. Soil properties necessary to fulfil the equation (plus stoniness) were extracted from the profile description associated with each soil unit on the map where different layers were described and analysed. Depth and carbonate were also extracted from the soil map. In each soil profile the water retention capacity was calculated for each described soil horizon. After calculating the water retention capacity by horizon and taking into account its thickness, the total water retention capacity was calculated as the sum of the water retention capacity of all the layers. Finally, the average WHC was assigned to each soil group.

$$\text{WHC (mm)} = (-98.73+0.09435*\text{clay}+0.1287*\text{silt}+0.09606*\text{sand}-0.26123*\text{organic C})*[1-S] / 100$$
(Equation 2)

where clay, sand and silt are expressed in g kg^{-1}, organic C as SOM/1.72 g kg^{-1} and S as stoniness in g 100 g^{-1}. Each group also corresponds to different vineyard yield and grape composition behaviours observed by the agronomist. Only those plots with more than 70% of the surface assigned to the same soil type were taken into account. The four groups were defined as follows:

- Low WHC group: including *Lithic Xerorthent*, *Lithic Xeric Torriorthent* and *Xeric Torriorthent* soils. These soils had characteristics such as being shallow (25-70 cm), located usually on slopes or high flat uplands, low WHC and high total carbonates (35-50%).

- Medium-low WHC group: corresponding to *Typic Calcixerept* soils that were stony (35-65% of coarse fragments) with high internal drainage and medium-low WHC; *Xeric Haplocalcid* soils on stony medium terraces situated 40-100 m above the Ebro River with a moderate calcic horizon that allows high water infiltration and low retention; and *Typic Calcixerept* soils that were accumulation areas receiving colluvial contributions, an underlying calcic horizon (from 60-70 cm), and moderate depth (100-125 cm). These *Typic Calcixerept* soils could be expected to be found in the Medium-high or High WHC group according to their depth, but the agronomist of the winery observed that their behaviour was similar to other *Typic Calcixerept* and *Xeric Haplocalcid* soils.

- Medium-high WHC group: including mainly *Typic Xerofluvent* and *Xeric Torriorthent* and a few *Typic Calcixerept* soils. These soils were low and medium terraces without stoniness with the exception of *Typic Calcixerepts*. They were generally situated 7-40 m above the Ebro River and were deep (>125 cm) with high WHC.

- High WHC group: corresponding to *Typic Xerofluvent* and *Typic Calcixerept* soils that were deep (>150 cm). *Typic Xerofluvent* soils with high WHC were at valley bottoms. They receive input from sloping areas by erosion processes. *Typic Calcixerept* soils occupied hollows located in concavities or depressed areas in flat landscapes with a calcic horizon between 90 and 100 cm.

Table 1. Physical and chemical soil properties (mean and standard error) of the four soil groups classified from the winery vineyards.

Soil group	Average WHC* (mm)	Depth* (cm)	Carbonates* (%)	Sand** (%)	Silt** (%)	Clay** (%)	OM** (%)	K** (mg kg^{-1})	pH**
Low WHC	77.59	25-75	35-50	51.55 ± 0.86	34.03 ± 0.64	14.75 ± 0.36	0.84 ± 0.01	140.46 ± 2.84	8.76 ± 0.02
Medium-low WHC	106.93	100-125	15-55	55.23 ± 1.07	30.42 ± 0.79	14.62 ± 0.53	0.95 ± 0.02	156.26 ± 5.41	8.75 ± 0.02
Medium-high WHC	135.65	>125	30-50	61.05 ± 2.19	28.16 ± 1.72	10.81 ± 0.78	0.94 ± 0.03	132.61 ± 6.75	8.71 ± 0.06
High WHC	240.49	>150	35-40	49.19 ± 1.43	35.32 ± 0.99	15.53 ± 0.77	0.94 ± 0.02	147.94 ± 5.72	8.72 ± 0.02

WHC=water-holding capacity, OM=organic matter, *data from soil map, **data from the 662 soils analysed.

Soil sampling throughout the winery vineyards was carried out by collecting 662 soil samples from the tilled rows but close to the herbicide-treated undervines to a depth of 10-35 cm, since there were no roots in the top 10 cm. Soil pH was determined in water in a 1:2.5 soil-to-water ratio, and these soils on average had high pH (8.87 ± 0.34). Organic matter content (Walkley and Black method; Hesse, 1971) was also analysed. Texture was measured by the pipette method (MAPA, 1994). Soil potassium content was measured by an extraction with 1N ammonium acetate at pH 7 and subsequently read by flame emission (MAPA, 1994). All these results are presented in Table 1 for each soil group.

It is worth mentioning that different training systems were included in the analysis at the beginning, and they did not provide statistical differences among must parameters. Therefore, this factor was not included in the statistical analysis to avoid making interpretation more difficult.

3. Target variables

3.1.Vegetation index

Normalized Difference Vegetation Index (NDVI) information was obtained at veraison in 2009 (20/08/2009) and 2010 (23/08/2010) from an airborne image with 0.5 m resolution (RS Servicios de Teledetección SL, Lleida, Spain and SpecTerra Services, Leederville, Australia) and was calculated from these individual measurements as follows (Equation 3):

$$NDVI = \frac{(NIR-VIS)}{(NIR+VIS)} \quad \text{(Equation 3)}$$

where VIS and NIR stand for the spectral reflectance measurements acquired in the visible (red) and near-infrared regions, respectively. Images were corrected for camera-induced geometric and radiometric distortions (Lamb *et al.*, 2004). Image rectification (assigning map coordinates to individual image pixels), following the methodology proposed by Acevedo-Opazo *et al.* (2008) was then completed using 16 ground control points. These points were readily identifiable features, of known dGPS coordinates, in the images, consisting of ends of selected vine rows.

3.2 Must qualitative parameters

Grape samples (60-100 berries each) from 185, 141 and 310 plots were taken during 2009, 2010 and 2011, respectively, 15 days before harvest. Sampling was done by taking 20-30 vines per plot and three grapes per vine (one grape from the shoulder, another from the intermediate zone and the other from the head), alternating between grapes exposed to sun and grapes from the inside of the cluster, collecting and making a zigzag within the vine lines all over the vineyards.

The winery collected and carried out an analysis where grapes were weighed and introduced in a chopper for 4 seconds at 800 W, then they were filtered with a 20-25 µm pore filter and afterwards analysed with the FOSS analyser. Probable alcoholic content (degree), total acidity (g L^{-1}), malic acid (g L^{-1}), tartaric acid (g L^{-1}), pH, K concentration (g kg^{-1}), polyphenol total index (PTI), anthocyanins (mg L^{-1}) and colour intensity (CI) were analysed. Anthocyanins (mg L^{-1}) and CI were only measured in 2010 and 2011.

4. Statistical analysis

Statistical analysis was performed using an HJ-Biplot (Galindo, 1986) in order to relate the differences in must parameters with the different soil types and climatic zones. A Biplot analysis (Gabriel, 1971; Gabriel and Odoroff, 1990; Gower and Hand, 1996) allows for the simultaneous representation of individuals (rows) and variables (columns) of a numerical data matrix in a low dimensional space. Gabriel (1971) proposed two different analyses: JK-Biplot and GH-Biplot. In a JK-Biplot only the rows of the data matrix (i.e. the individuals) are well represented whereas in a GH-Biplot only the variables are well represented.

The HJ-biplot is a conjoint representation in a low-dimensional subspace space of rows (grape samples) and columns (target variables) of data matrix X, using markers for its rows and columns. Generally, points are used to represent the rows and vectors to reflect variables.

The HJ-Biplot (Galindo, 1986) has the advantage to perform a simultaneous representation in strict sense, that is, it gets the highest quality of representation both for the samples and for the variables of the data matrix in the same reference system.

The Biplot techniques has been widely applied in many studies; as examples of application of HJ-Biplot to wine data sets: Santos *et al.* (1991); Rivas-Gonzalo *et al.* (1993), and in other fields, for example, Fernández-Gómez *et al.* (1996); Gallego-Álvarez *et al.* (2013); Morillo *et al.* (2014); Hernández *et al.* (2014), among others.

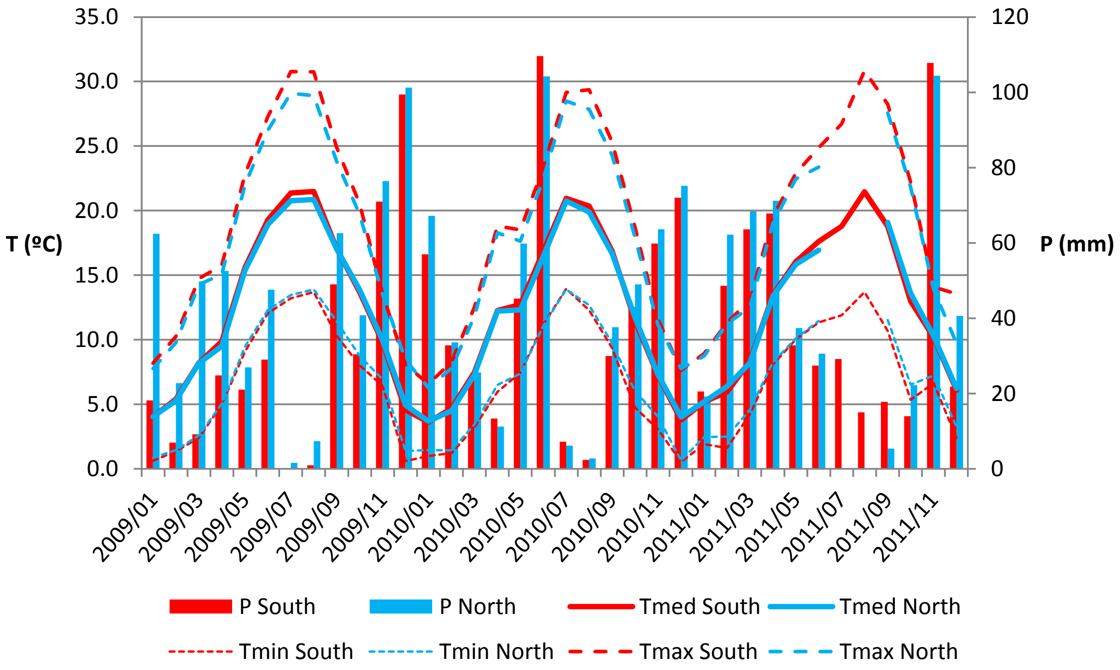

Figure 2. Average, minimum and maximum temperature and monthly precipitation at Hueta (North Zone) and Espirbel (South Zone) weather stations from January 2009 to December 2011.

We used the Classical Biplot software package available free of charge (http://biplot.usal.es/ClassicalBiplot/index.html; Vicente-Villardón, 2014).

In our study, prior to the analysis, the quantitative variables were first centred and standardised because they were measured with different units. Environmental variables are introduced as nominal variables. Climate and soil types were the independent variables (Environmental variables) used in this study. Must qualitative parameters, such as pH, malic acid, tartaric acid, total acidity, K concentration, PTI, CI, anthocyanins and NDVI, were the dependent variables (Target variables) measured.

The rules for the interpretation of the graphical representation obtained from the HJ-Biplot analysis were as follows, as described by Galindo (1986): (1) the distances among samples were interpreted as an inverse function of similarities in such a way that closer markers (centres) were more similar. This property allowed for the identification of clusters of individuals with similar profiles; (2) the lengths of the target variables (vectors) approximate the standard deviations of the variables; (3) the cosines of the angles between the column vectors approximate the correlations among variables in such a way that small acute angles were associated with variables that were strongly positively correlated, obtuse angles close to 180° with variables that were strongly negatively correlated, and right angles with non-correlated variables. Similarly, the cosines of the angles between the variable markers and the axes (the principal components) approximated the correlations between them; (4) the order of the orthogonal projections of the samples (points) onto a target variable (vector) approximated the order of the row elements (values) in that column; the greater the projection of an individual point the higher the value of the variable on that sample. The target variables should be interpreted in the planes where their relative contributions in the corresponding axis are the highest (that is, in those planes where the quality of representation is the highest). There is no cut-off point to decide from what value a high quality representation is considered, but from a value of 400 (out of 1000) it can be considered to be an acceptable value. Those variables are highlighted in bold. If variables are represented in grey, they could not be interpreted in this plane, because they had low relative contribution there. Same soil group in relation to WHC (same colour) were defined by hand in polygons in order to facilitate the reader interpretation.

Results

As the study years were 2009, 2010 and 2011, the temperature and precipitation data for each climatic zone (Hueta weather station for North zone and Espirbel weather station for South zone) are summarized in Figure 2. July and August data for 2011 in Hueta weather station were not available. The climatic differences between the two zones were 0.15°C in average temperature, 0.75°C in maximum temperature and 100 mm in precipitation.

Table 2. Number of samples for each climatic zone, soil type and grape parameters and NDVI mean and standard error in 2009.

2009	N	NDVI	Degree (Brix)	Total acidity (g L^{-1})	pH	Tartaric acid (g L^{-1})	Malic acid (g L^{-1})	PTI	K (g kg^{-1})	CI	Anthocyanin (mg L^{-1})
N	47	0.323 ± 0.015	13.28 ± 0.10	5.15 ± 0.07	3.56 ± 0.02	5.91 ± 0.05	2.70 ± 0.07	81.97 ± 1.00	552.81 ± 35.26	-	-
S	185	0.306 ± 0.007	13.23 ± 0.05	5.30 ± 0.04	3.61 ± 0.02	6.06 ± 0.03	2.37 ± 0.04	79.36 ± 0.64	483.98 ± 21.68	-	-
Low WHC	95	0.269 ± 0.008	13.23 ± 0.07	5.22 ± 0.04	3.62 ± 0.02	6.14 ± 0.04	2.36 ± 0.04	81.30 ± 0.76	521.26 ± 25.17	-	-
Medium-low WHC	36	0.328 ± 0.014	13.46 ± 0.10	5.21 ± 0.09	3.64 ± 0.04	6.07 ± 0.07	2.41 ± 0.07	82.74 ± 1.11	540.64 ± 42.83	-	-
Medium-high WHC	21	0.372 ± 0.015	13.38 ± 0.12	5.49 ± 0.08	3.41 ± 0.01	5.71 ± 0.05	2.34 ± 0.11	73.03 ± 1.40	249.43 ± 41.90	-	-
High WHC	33	0.371 ± 0.012	12.98 ± 0.11	5.30 ± 0.10	3.60 ± 0.04	5.81 ± 0.04	2.86 ± 0.09	77.84 ± 1.00	562.12 ± 37.50	-	-

NDVI = normalized difference vegetation index, PTI = polyphenol total index, CI = colour index

Averaged grape composition results from 2009, 2010 and 2011 are presented in Tables 2, 3 and 4, respectively. In the results of HJ-Biplots, only planes where variables had good representation quality are presented, and Table 5 refers to the variance in the data of each Axis. Thus, planes 1-2 and 1-3 for 2009 (Figure 3, A and B), 1-2 and 2-3 for 2010 (Figure 4, A and B) and 1-2 and 1-3 for 2011 (Figure 5, A and B) were selected to show the results.

Figure 3A presents an acute angle among the K, tartaric acid, pH and PTI variables showing a strong correlation, and the same among the NDVI, total acidity and malic acid variables. In contrast, the total acidity, malic acid and NDVI variables showed right angles with the variables K and tartaric acid, reflecting no relationship.

Plane 1-2 in 2009 (Figure 3A) allowed us to fundamentally differentiate High WHC soils from the rest, and these soils were characterized, in general, by producing musts with the highest malic acid concentration and medium-high total acidity concentration, and they had high NDVI (Table 2). In the opposite quadrant to these three variables (malic acid, total acidity and NDVI), there were mainly Low WHC soils located in the South climate zone. Hence, grape samples from these plots tended to have low acidity and NDVI.

Low WHC soils could be found throughout the entire figure, although there were fewer near malic acid, total acidity and NDVI (Figure 3A), reflecting low acidity and low vigour. Next to the variables PTI and tartaric acid, there were mainly Low and Medium-low WHC soils (Figure 3A), indicating that only these soils were able to produce musts containing the highest PTI and tartaric acid concentrations (Table 2).

On the other hand, in the lower and middle right side there were samples representing Medium-high WHC soils (Figure 3A). These soils produced musts containing the lowest K concentration, pH, tartaric acid concentration and PTI rate (Table 2).

Plane 1-3 in 2009 (Figure 3B) shows that only Low and Medium-low WHC soils produced musts with high probable alcoholic degree. By contrast, High WHC soils produced musts with the lowest probable alcohol content (Table 2) since they were on the opposite side of the variable. Medium-high WHC soils were not related to probable alcoholic degree

Table 3. Number of samples for each climatic zone, soil type and grape parameters and NDVI mean and standard error in 2010.

2010	N	NDVI	Degree (Brix)	Total acidity (g L^{-1})	pH	Tartaric acid (g L^{-1})	Malic acid (g L^{-1})	PTI	K (g kg^{-1})	CI	Anthocyanin (mg L^{-1})
N	53	0.615 ± 0.009	13.52 ± 0.08	6.20 ± 0.10	3.70 ± 0.01	5.54 ± 0.05	2.65 ± 0.08	81.13 ± 0.85	689.72 ± 33.29	3.95 ± 0.18	123.19 ± 6.60
S	88	0.567 ± 0.007	13.39 ± 0.07	5.62 ± 0.05	3.71 ± 0.01	5.62 ± 0.03	2.02 ± 0.05	79.67 ± 0.72	606.72 ± 25.13	3.62 ± 0.10	121.99 ± 3.44
Low WHC	75	0.558 ± 0.007	13.37 ± 0.07	5.71 ± 0.06	3.72 ± 0.01	5.63 ± 0.04	2.11 ± 0.06	79.95 ± 0.69	611.69 ± 29.34	3.71 ± 0.12	122.17 ± 4.08
Medium-low WHC	45	0.616 ± 0.010	13.62 ± 0.11	5.86 ± 0.11	3.72 ± 0.02	5.58 ± 0.05	2.32 ± 0.09	82.95 ± 1.00	686.24 ± 35.63	4.01 ± 0.18	135.98 ± 5.62
Medium-high WHC	2	0.647 ± 0.033	12.85 ± 0.45	6.31 ± 0.74	3.65 ± 0.05	5.45 ± 0.05	2.85 ± 0.55	69.80 ± 2.10	667.50 ± 18.50	2.65 ± 0.75	76.00 ± 41.00
High WHC	19	0.616 ± 0.012	13.34 ± 0.08	6.23 ± 0.15	3.66 ± 0.02	5.45 ± 0.05	2.61 ± 0.15	75.91 ± 1.21	623.84 ± 44.05	3.39 ± 0.22	96.32 ±8.85

NDVI = normalized difference vegetation index, PTI = polyphenol total index, CI = colour index

Table 4. Number of samples for each climatic zone, soil type and grape parameters and NDVI mean and standard error in 2011.

2011	N	NDVI	Degree (Brix)	Total acidity (g L^{-1})	pH	Tartaric acid (g L^{-1})	Malic acid (g L^{-1})	PTI	K (g kg^{-1})	CI	Anthocyanin (mg L^{-1})
N	118	-	13.53 ± 0.07	4.64 ± 0.04	3.69 ± 0.01	6.27 ± 0.03	2.72 ± 0.04	91.94 ± 0.62	843.72 ± 20.59	6.84 ± 0.12	227.27 ± 4.37
S	192	-	13.59 ± 0.05	4.36 ± 0.04	3.73 ± 0.02	6.34 ± 0.05	2.41 ± 0.05	93.39 ± 0.90	866.76 ± 31.49	6.55 ± 0.15	232.71 ± 4.58
Low WHC	155	-	13.61 ± 0.06	4.41 ± 0.03	3.74 ± 0.01	6.39 ± 0.03	2.47 ± 0.04	94.43 ± 0.56	902.79 ± 19.81	6.86 ± 0.11	238.22 ± 3.27
Medium-low WHC	73	-	13.67 ± 0.08	4.43 ± 0.06	3.71 ± 0.01	6.23 ± 0.04	2.55 ± 0.06	92.55 ± 0.85	825.25 ± 29.04	6.68 ± 0.14	229.26 ± 5.81
Medium-high WHC	29	-	13.59 ± 0.15	4.37 ± 0.05	3.68 ± 0.03	6.21 ± 0.07	2.36 ± 0.08	90.41 ± 1.80	728.34 ± 60.66	5.86 ± 0.17	216.14 ± 5.82
High WHC	53	-	13.29 ± 0.11	4.73 ± 0.07	3.69 ± 0.02	6.25 ± 0.04	2.76 ± 0.06	89.92 ± 1.10	843.02 ± 37.53	6.49 ± 0.23	218.30 ± 7.59

NDVI = normalized difference vegetation index, PTI = polyphenol total index, CI = colour index

(Figure 3B). According to climatic zones, there were no clear patterns among must parameters.

Figure 4A shows again a positive correlation among the K, pH and PTI variables. Total acidity and malic acid also remained correlated, as did anthocyanins and CI. A nearly 90º angle was observed between the total acidity and malic acid variables and those of anthocyanin and CI, which indicates no direct relationship between these variables.

Taking into account the distribution of samples in Figure 4A, next to the variables that provide high grape quality, such as anthocyanins and colour (CI), there were mostly Low and Medium-low WHC soils, indicating that these soils produce musts with the highest colour (Table 3). Moreover, there were many Low and Medium-low WHC soils near the pH, K and PTI variables.

High WHC soils located in the North produced musts with high total acidity and malic acid (Table 3) but low anthocyanin concentration and colour index (Table 3 and Figure 4A).

For 2010, plane 2-3 (Figure 4B) highlights that soils located in the North were placed mainly near the NDVI index (Table 3), especially High WHC soils. Low WHC soils and almost all soils in the South were in the left top position, so these soils had low NDVI values. Tartaric acid did not show any clear differences among soil groups or climatic zones.

A positive correlation between pH and PTI was again observed as well as between total acid and malic acid concentration (Figure 5A) in 2011. Medium-high WHC soils were located mainly in the opposite quadrant from the K variable, as also occurred in 2009, showing lower K values than other soil groups (Table 4). High WHC soils from the North produced musts with high acidity since they were closer to total acid and malic acid (Table 4). In Figure 5A, Low and Medium-low WHC soils were located throughout the figure, indicating that these soils did not produce musts with specific characteristics. Regarding climatic zones, there were no clear differences among must parameters.

Tartaric acid was placed on the top of Figure 5B, while anthocyanins and CI were down at a right angle; therefore they were almost independent. Medium-high WHC soils were opposite for CI and anthocyanin, indicating low values for these variables (Table 4). In plane 1-3 again (Figure 5B), the variability in the berry composition produced by Low and Medium-low WHC soils was evidenced by the large dispersion that can be seen in the figure. Next to

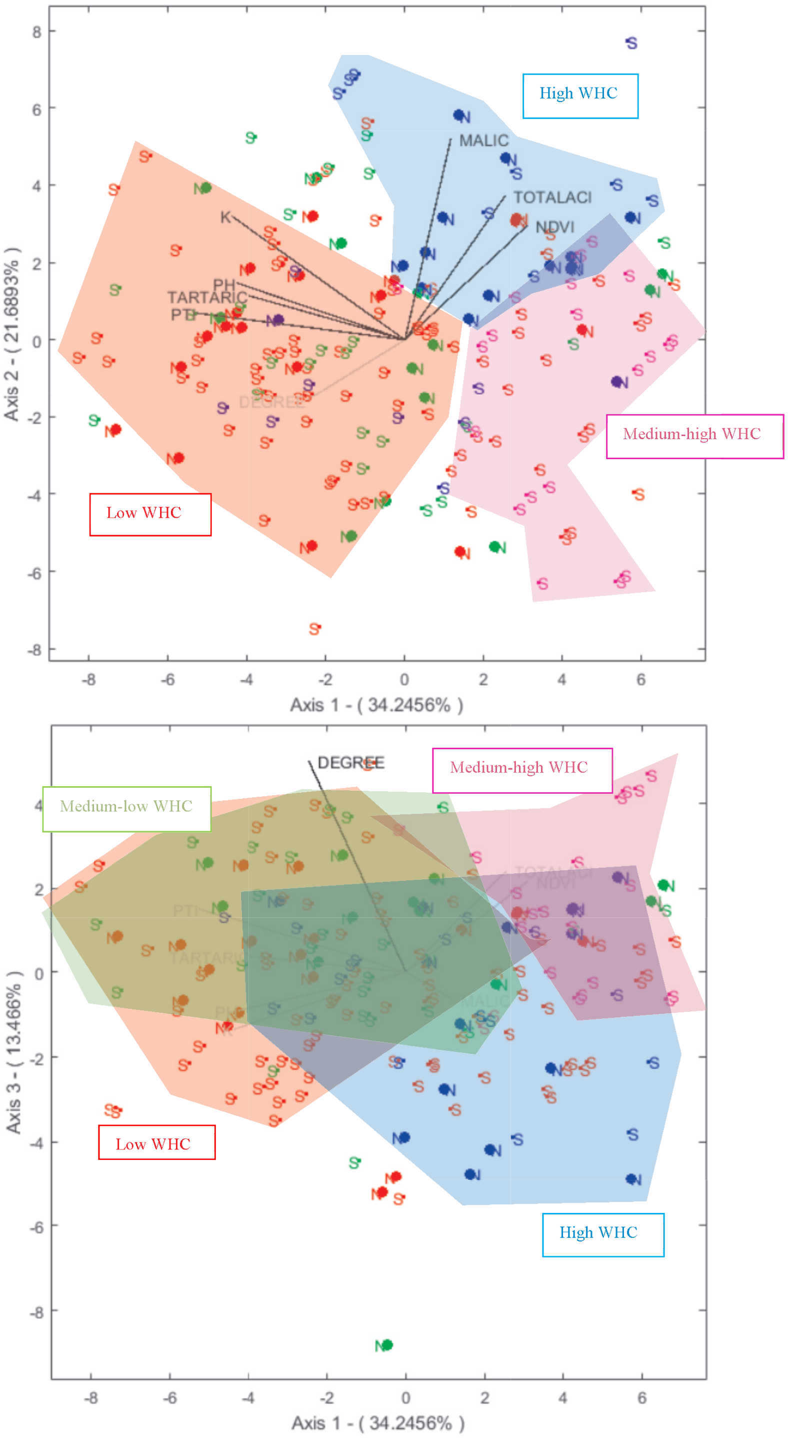

Figure 3. (A) HJ-biplot representation of quantitative must parameters (pH, malic acid, tartaric acid, total acidity, K, PTI) and NDVI in 2009 for plane 1-2 and (B) probable alcoholic degree in 2009 for plane 1-3. Low WHC soil samples are shown in red (● *), Medium-low WHC in green (● *), Medium-high WHC in pink (● *) and High WHC in blue (● *). Plots situated in the North climatic zone are shown with the letter N and symbol ● and those from the South with the letter S and symbol *. Only black variables could be interpreted in each figure.

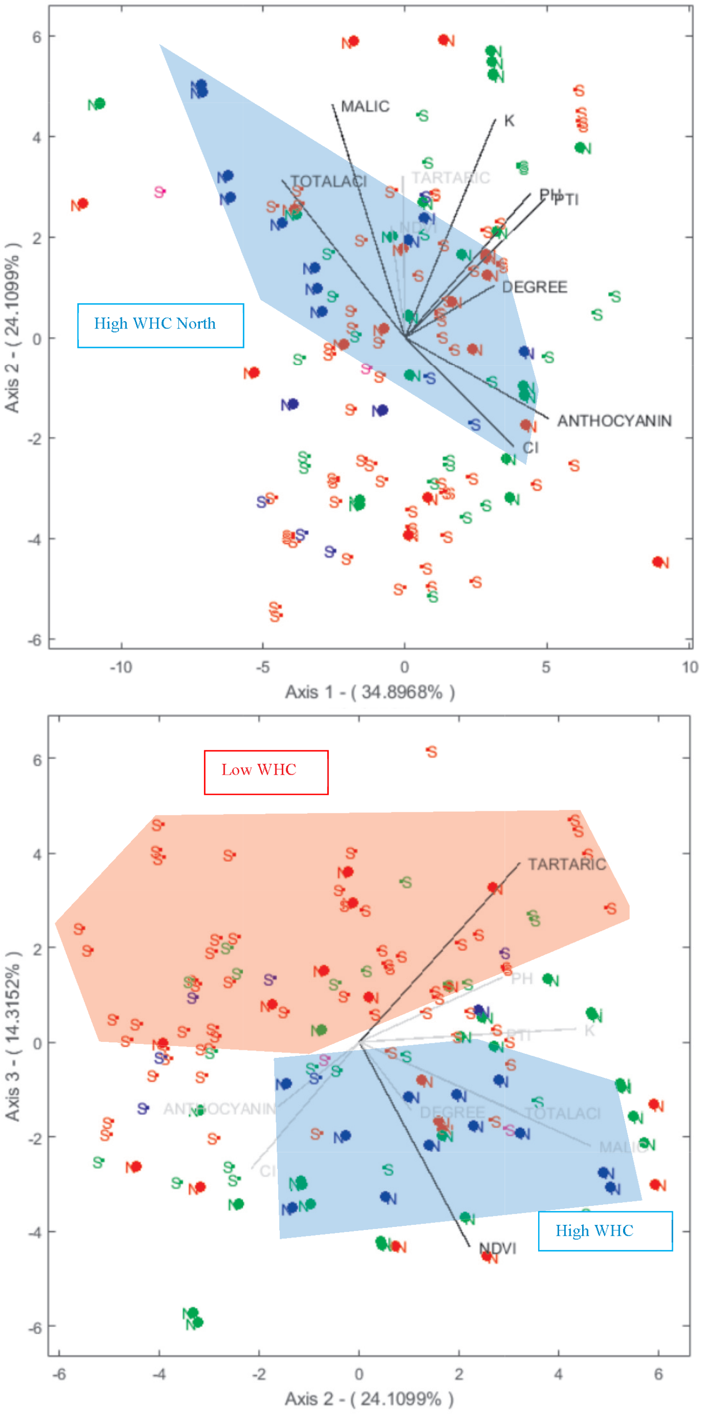

Figure 4. (A) HJ-biplot representation of quantitative must parameters (degree, pH, malic acid, total acidity, K, PTI, CI, anthocyanins) in 2010 for plane 1-2 and (B) NDVI and tartaric acid in 2010 for plane 2-3. Low WHC soil samples are shown in red (● *), Medium-low WHC in green (● *), Medium-high WHC in pink (● *) and High WHC in blue (● *). Plots situated in the North climatic zone are shown with the letter N and symbol ● and those from the South with the letter S and symbol *. Only black variables could be interpreted in each figure.

Table 5. Results of the variance for each axis for the 2009, 2010 and 2011 years.

	2009	2010	2011
Axis 1	34.25%	34.90%	44.76%
Axis 2	21.69%	24.11%	18.96%
Axis 3	13.47%	14.32%	13.44%

the variables that add colour (anthocyanins and CI), there were no Medium-high or High WHC soils (Figure 5B), indicating that these soils produced musts with lower colour, although it could not be appreciated as clearly as in 2009.

Discussion

There are factors that were not taken into account, such as age of the vines and row orientation, making it more difficult to observe the influence of the study factors (soil and climatic classification). Moreover, different plots were analysed every year, but even if the experimental error due to these reasons is high, there were some effects that could be highlighted. Thus, in the three years of the study, the influence of soil variability on berry composition was greater than that of climate classification. Ubalde *et al.* (2011) reported that soil is one of the most important factors in viticultural zoning due to its direct effect on vine development and wine quality, especially soil properties related to soil moisture regime and available water capacity. These authors stated that climate or geology alone cannot be used for viticultural zoning at detailed scale unless soil properties are taken into account.

The HJ-Biplot statistical analysis showed that there was a differentiating pattern among different soil groups that was repeated through the three years of study. In this regard, Leone *et al.* (2010) stated that the structure of the relationships between soil and grape variables was highly comparable and consistent from one year to another, although some variables vary from year to year. Wang *et al.* (2015) reported that different soil types can significantly affect the composition of wine grapes and the final wine product. In our case, soils with higher water retention capacity (**High WHC soils**) produced musts with higher total acidity during the three years of study, mainly due to higher malic acid content, since these variables were correlated in all the Figures. These results are in accordance with those of van Leeuwen *et al.* (2004), Acevedo-Opazo *et al.* (2008), Intrigliolo and Castel (2010) and Ramos *et al.* (2015), which showed high malic acid concentrations in soil resulting in higher vine vigour, where clusters were more shaded because of excessive leaf surface. This caused a lower bunch temperature, thus temperatures higher than 30°C were less frequent, and consequently malic acid was not eliminated by combustion. In this sense, a higher NDVI was achieved in High WHC soils, especially in 2009. This higher NDVI in 2009 was reflected in a lower probable alcoholic degree, which is in line with Coipel *et al.* (2006), who related high sugar content to limited vine growth and yield from shallow soils.

Medium-high WHC soils (low and medium terraces) generally produced musts with lower K concentration, which is caused by lower soil K and clay content in the horizon between 10 and 35 cm (Table 1). These K differences among soils were not so high as to increase total acidity in Medium-high WHC soils. Clay particles can hold nutrients due to their high cation exchange capacity, CEC (Pal and Marschner, 2016); thus, soil with low clay and K content (such as Medium-high WHC soils) could be expected to produce must with lower K concentration, as was observed in this study. A greenhouse study using the same cultivar (Leibar *et al.*, 2017) in different soils but with similar fertilization showed that the initial soil K content directly influenced the must K concentration. In turn, K content raises the pH due to precipitation of tartaric acid to potassium bitartrate (Mpelasoka *et al.*, 2003), adversely affecting wine stability; thus, in musts with a lower K concentration, it is expected that the pH would also be lower, as was reflected mainly in 2009 and in 2011 in this work.

Low and Medium-low WHC soils were in general the only ones that produced musts with high phenolic content. This higher colour has been shown to be inversely related to vigour (NDVI), as seen in 2009 and 2010 for our conditions, being in line with Lamb *et al.* (2004), who reported soils with higher vigour produced musts with lower grape colour. Filippetti *et al.* (2013) observed similar results. These results are caused by higher light exposure of the fruiting zone in low vigour vines. In our case, PTI, K and pH showed a consistent correlation throughout the study. Coipel *et al.* (2006), comparing five different soil types under dry Mediterranean conditions, also observed that soils with the lowest WHC had the highest potential for making quality red wines. In deep rich soil, vines are vigorous and highly productive, but better wines are generally produced when the vines are cultivated on poor soil (van Leeuwen and Seguin, 2006). Thus, grape quality could be high on soils that induce water deficit, reducing shoot growth, berry size and yield. These factors generally enhance grape quality for the

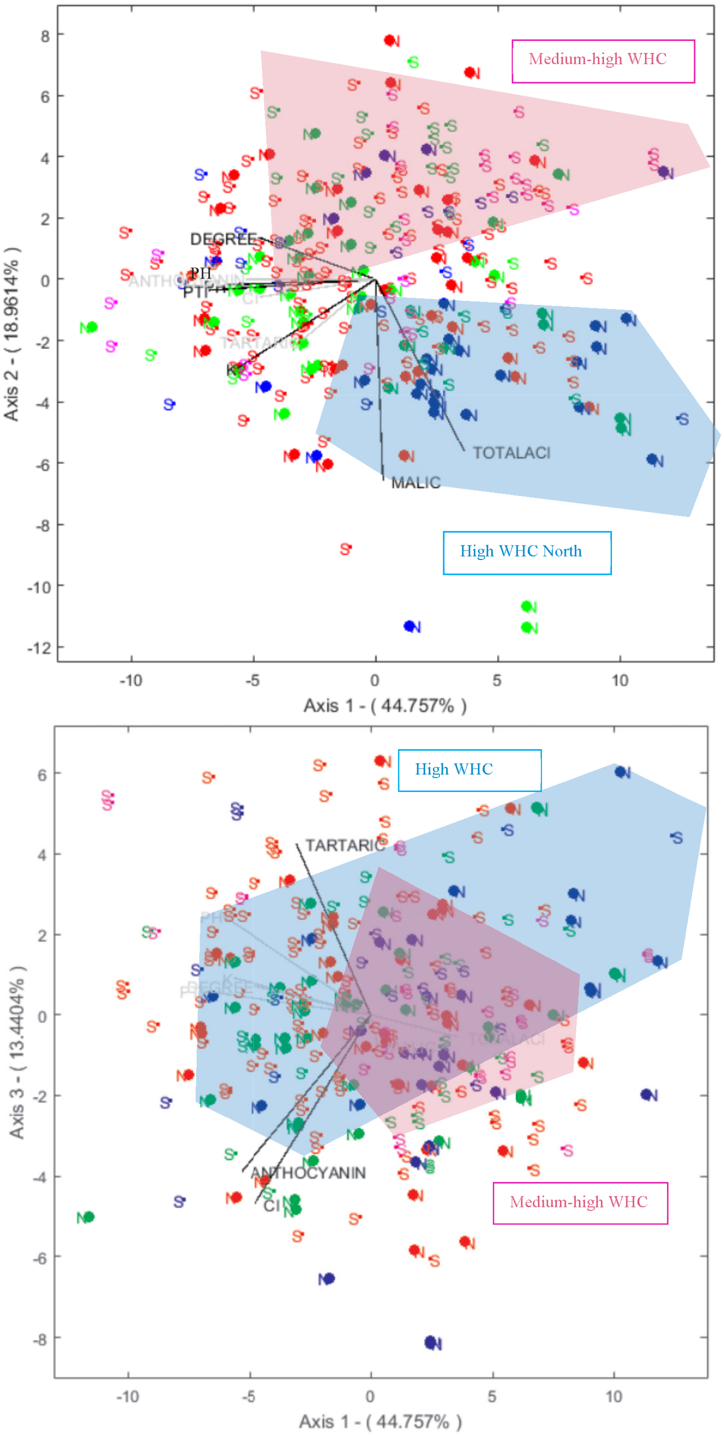

Figure 5. (A) HJ-biplot representation of quantitative must parameters (degree, pH, malic acid, total acidity, K, PTI) in 2011 for plane 1-2 and (B) CI, anthocyanins and tartaric acid in 2011 for plane 1-3. Low WHC soil samples are shown in red (● *), Medium-low WHC in green (● *), Medium-high WHC in pink (● *) and High WHC in blue (● *). Plots situated in the North climatic zone are shown with the letter N and symbol ● and those from the South with the letter S and symbol *. Only black variables could be interpreted in each figure.

production of red table wines. However, in our study, these Low and Medium-low WHC soils were also able to produce musts with low colour parameters. These results are not unexpected, as it is known that low WHC does not necessary imply high quality and that grape composition is influenced by more complex factors (Filippetti *et al.*, 2013). Skin anthocyanins, which among other parameters play an important role in the quality determination of grapes, are affected by environmental and management-related factors such as light interception, temperature, nitrogen, and bunch thinning (Filippetti *et al.*, 2013). In our case, since there were many variables that we did not control, it was difficult to establish accurate conclusions.

According to climatic zones, few distinctions among berry composition were detected, although some small differences could be observed, mainly with High WHC soils located in the North that showed high NDVI in 2009 and 2010, high total acidity in 2010 and 2011, high malic acid in 2010 and low CI and anthocyanins in 2010. In our study, grape composition differences produced by soils located in the North and South were not clear. The temperature differences between the two zones were not sufficient to identify differences in grape composition over the three years of study. Moreover, in the Ribera del Duero, 115 km along the Duero River and 300000 ha, Ramos *et al.* (2015) studied the phenology and grape ripening characteristics of cv. Tempranillo, and they found high variability related to site soil and landscape characteristics. These authors observed phenological differences between the western and eastern parts of the area where the average temperature differed by 0.23°C, with the western locations generally being earlier as driven by warmer climatic conditions, producing musts with higher pH values, sugar content and anthocyanins.

Conclusion

Some general tendencies have been observed referring to soil influence on grape composition, even using a soil map that does not provide a very high level of accuracy. Soil type and soil water-holding capacity in particular differentiated grape parameters in a winegrower's cooperative. Soils with higher water-holding capacity (High WCH soils) produced must with higher total acidity, mainly due to a higher malic acid concentration. Medium-high WHC soils, low and medium terraces from the Ebro River, had lower must K concentration caused by a lower K soil content. Some of the soils with lower water-holding capacity (Low and Medium-low WHC soils) were the only ones that could produce must with higher colour, probably due to better exposure of the clusters. On the other hand, climatic zones established for the winery vineyards showed small differences among must parameters.

This work could be useful for many wineries that currently have detailed soil, climate and grape composition data. Thus, using these data together with simple statistical analysis, a grape composition classification could be made and evaluated afterwards.

Acknowledgements

We thank the Department of Economic Development and Competitiveness of the Basque Government for their financial support. Urtzi Leibar was the recipient of a grant from "Fundación Cándido Iturriaga y María Doñabeitia". The authors thank Bodegas y Viñedos Labastida for their collaboration and Oscar del Hierro (Neiker-Tecnalia) and Maialen Iturbide (Instituto de Física de Cantabria) for their excellent technical assistance obtaining 1 km x 1 km climatic data.

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