Influence of edapho-climatic factors on grape quality in Conca de Barberà vineyards (Catalonia, Spain)

Influence des facteurs édapho-climatiques sur la qualité du raisin des vignes de la Conca de Barberà (Catalogne, Espagne)

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Abstract: Soil and climate of 3 vineyards have been characterised in order to determine their influence on grape quality. These vineyards are located in Conca de Barberà (Catalonia, NE Spain) and belong to Cabernet sauvignon and Grenache noir cultivars. All 3 plots are very close, so only interannual climatic data of the nearest meteorological station have been considered. Different climatic indexes have been calculated from climatic data. The studied vineyard soils present very different textural classes and rock fragment contents, causing very distinct soil water regimes. Besides determining chemical and physical properties of soils, the soil water availability has been characterised using capacitance sensors at different depths for the period from 2003 to 2005. Data of quality of grapes were available. Statistical techniques, concretely Principal Component Analysis and Multiple Regression Analysis, have been used to relate edapho-climatic factors to grape quality. The results show that edapho-climatic data have a high power of estimation on grape quality (generally, R^2 higher than 0.75). Climate appeared to be the most influencing factor, followed by water availability. Soil had also influence on grape yield and some must data.

Key words: vineyard soil, Mediterranean climate, terroir, soil moisture, grape quality

Introduction

Nowadays, modern oenology is based on quality criteria. This quality is often associated to very especial conditions of soil, climate, management and others, which form the concept of terroir (Falcetti, 1994; Vaudour, 2003). This terroir generally is defined as an interaction between the environmental potentialities and technical aspects of winemakers (Seguin, 1986). There are few studies that consider all the factors of the ecosystem as a whole (van Leeuwen *et al*., 2004), however some investigators have worked with units of terroir considering different factors (Carey, 2001; Morlat, 2001). Probably, climate is the factor that determines with more intensity the suitability of the environment for vineyard growing (Hidalgo, 1999). Soil has an important weight, but often it is studied together with climate, because its effects on wine quality are only consistent under the same climatic conditions (Saayman, 1977; Conradie, 1998). The soil properties which have the most influence on grape quality are the physical ones, namely the properties that control the soil water content (Seguin, 1986), due to its direct effect on equilibrium between vegetative vigour and grape production (van Leeuwen and Seguin, 1994).

In this study, the main environmental factors of terroir, soil and climate, were characterised in 3 vineyard plots, Cabernet sauvignon and Grenache noir cultivars. These plots are situated in 3 different soil types but the same climate, so only interannual climatic data were considered for the period from 2003 to 2005. For the same period, soil water content was measured in continuum and at different depths by capacitance sensors. Data of grape quality were available from Miguel Torres Winery. The aim of this study was to establish the influence of edapho-climatic parameters on grape quality.

Materials and methods

This study was developed from 2003 to 2005 in three vineyards (Milmanda, Riu Sec and Muralles) situated in Conca de Barberà region (NE Spain), near the Mediterranean Range System. The sites are situated between 41º 22’ 7’’ and 41º 24’ 8’’ of N latitude and between 1º 3’ 53’’ and 1º 5’’ 24’’ of E longitude. The altitude varies from 440 to 575 m. All three plots have a very distinct soil, but they have a homogeneous climate, since they are located less than 2 km apart. The climate type is Mediterranean with a continental

influence, with a mean annual precipitation of 550 mm and a mean annual temperature of 13.6 ºC. The Milmanda soil, classified as Typic Xerofluvent, fine-loamy, carbonatic, mesic (SSS, 2003), is a very deep soil, rich in silt (56.5 %) and carbonates (45.8 %), without stones, moderately well drained and with a high water holding capacity (1,541 $m^3 \cdot ha^{-1}$). The Riu Sec soil, classified as Typic Haploxerept, sandy-skeletal, mixed, mesic (SSS, 2003), is a moderately deep soil, rich in sand (89.4 %) and gravels (60 %) in deep horizons, somewhat excessively drained and with a low water holding capacity (384 $m^3 \cdot ha^{-1}$). The Muralles soil, classified as Fluventic Haploxerept, loamy-skeletal, mixed, active, mesic (SSS, 2003), is a deep loam soil, stony, well drained and with a high water holding capacity (1,522 $m^3 \cdot ha^{-1}$).
Climatic data were recorded in an automatic weather station (Espluga de Francolí) of the Meteorological Service of Catalonia, located at 41º 23' 39'' of N latitude and 1º 6' 1'' of E longitude. Data of rainfall, temperature, solar radiation, wind, relative humidity, atmospheric pressure and ETo were available.
The chosen plots belong to three representative soil mapping units of the region determined in a very detailed (1:5000) soil map made by Miguel Torres Winery. The soil cartography followed the criteria of the Soil Inventory of Catalonia and the Soil Survey Manual. The soil water content was determined by capacitance sensors (ECHO, Decagon Devices Inc.), in continuum (every 30 min) and at different depths (15, 30, 60 and 90 cm). In order to minimise the effect of the internal variability of the cartographic unit, 3 sensors at 20 m of distance were installed for each depth. To make sensors comparable in different soils, without calibration, a water availability index (WA) was calculated. This WA takes the 100 value when the soil moisture content is at field capacity and the 0 value at the minimum soil moisture observed during the study. Field capacity was determined with the capacitance sensors following heavy rainfall periods. Similar methods were used in different previous studies (Lebon *et al*., 2003).
The Milmanda and Riu sec plots are formed of 20-year-old vines of Cabernet sauvignon cultivar, grafted onto 140RUG (Milmanda) and SO4 (Riu Sec) rootstock. The Muralles plot is formed of 13-year-old vines of Grenache noir cultivar, grafted onto R110 rootstock. Vine density is 2,800 (Milmanda) and 3,700 (Riu Sec and Muralles) vines per hectare with vines at 1.2 x 2.8 m (Milmanda) and 1 x 2.2 m (Riu Sec and Muralles) (vine x row spacing). All plots followed similar management: vines were trained to an espalier-type canopy system and were double cordon Royat pruned, vineyards were dry-land farmed, weeds were controlled by ploughing and yield was not limited by pruning.
Data of grape quality were measured directly from containers at the winery entrance, between 25th September and 5th October, with the Maselli SM-03 Winery Grape Must Analyzer. The available variables were yield ($kg \cdot vine^{-1}$), alcoholic degree, pH and total acidity (g tartaric acid/L). Both anthocyanins (extracted at pH 3.2, in mg/L) and grape seed ripening were measured in laboratory, for Cabernet sauvignon plots, following the method of Saint-Cricq de Gaulejac *et al.* (1998).
Data analysis was done by multiple regression, considering data of quality of grapes as dependent variables (DV) and considering edapho-climatic data as independent variables (IV). Correlation matrices and Principal Components Analysis were performed to explore data and make a first selection of variables. The procedure « All possible regressions » was used to select the most representative models (higher R^2) with selected variables. Then, assumptions of multiple regression were checked. Independent variables were changed until most of the assumptions were accomplished and, if possible, model was significant (confidence level of 0.05 %). The software used was NCSS (Hintze, 2004).

Results and discussion

During the study period, a great interannual variability of rain (from 366 mm to 756 mm) and mean temperature (from 13.2 ºC to 14.9 ºC) is remarkable (table 1). The wettest year was 2003 (756 $mm \cdot year^{-1}$), with rains concentrated in the beginning and at the end of the vegetative cycle. This year was the warmest (annual mean of 14.9 ºC), so thermal indexes were the highest too (Huglin Index = 2672) (table 2). In 2004, rainfall was lower (495 mm) than in 2003, but during the growing season was higher, so rainfall april-august was the highest of the period (211 mm). Temperatures were the lowest of the period (annual mean of 13.2 ºC), except for maturation period, as reflected in a high cool-night index (14.6 ºC). In 2005, rain was low for all year and very low for the growing season (rainfall april-august = 76.8 mm). Temperatures were intermediate, except for maturation period, where temperatures were the lowest (cool-night index = 13 ºC). In 2003, solar radiation was notably higher than other years, and in 2004 was slightly higher than in 2005.

Table 1 - Monthly and annual meteorological data from 2003 to 2005 of Espluga de Francolí automatic weather station.

Variable	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rain (mm)	2003	9.2	130	38.4	21.4	92.2	11.2	4.0	53	48.8	190	114	43.4	756
	2004	2.0	68.8	68.2	88.6	60.4	10.4	50.8	1.2	34.2	37.6	1.4	71.8	495
	2005	0.0	27.2	12.4	2.6	46.6	7.2	1.4	19	54.2	61.2	130	3.6	366
Mean temperatures (ºC)	2003	6.8	6.3	11.0	13.2	17.3	24.3	25.1	26.2	19.7	13.9	9.5	5.9	14.9
	2004	7.4	4.8	7.3	10.3	13.8	20.2	20.6	23.5	20.1	16.0	7.9	6.6	13.2
	2005	3.5	4.0	8.3	12.7	17.4	22.4	24.1	22.0	18.8	15.3	9.1	4.0	13.5
Solar radiation ($KJ \cdot m^{-2} \cdot day^{-1}$)	2003	7.0	7.7	15.1	17.7	22.3	24.4	24.3	21.5	15.5	9.7	6.6	5.6	14.8
	2004	7.1	9.5	13.2	16.9	20.6	23.7	17.6	19.2	15.4	11.1	7.6	4.8	13.9
	2005	7.6	9.6	14.1	17.1	20.3	21.0	21.8	19.0	13.1	8.7	6.0	5.8	13.7

Table 2 - Viticulture climatic indexes from 2003 to 2005

Index	2003	2004	2005
Sum of degree-day during period of vegetative activity	4612	3809	4060
Thermal index of Winkler	2162	1669	1920
Rainfall april-august	182	211	76.8
Dryness index - DI (Geoviticulture CCM System)	-21	71.8	56.5
Huglin index - HI (Geoviticulture CCM System)	2672	2088	2413
Cool night index - CI (Geoviticulture CCM System)	14.2	14.6	13

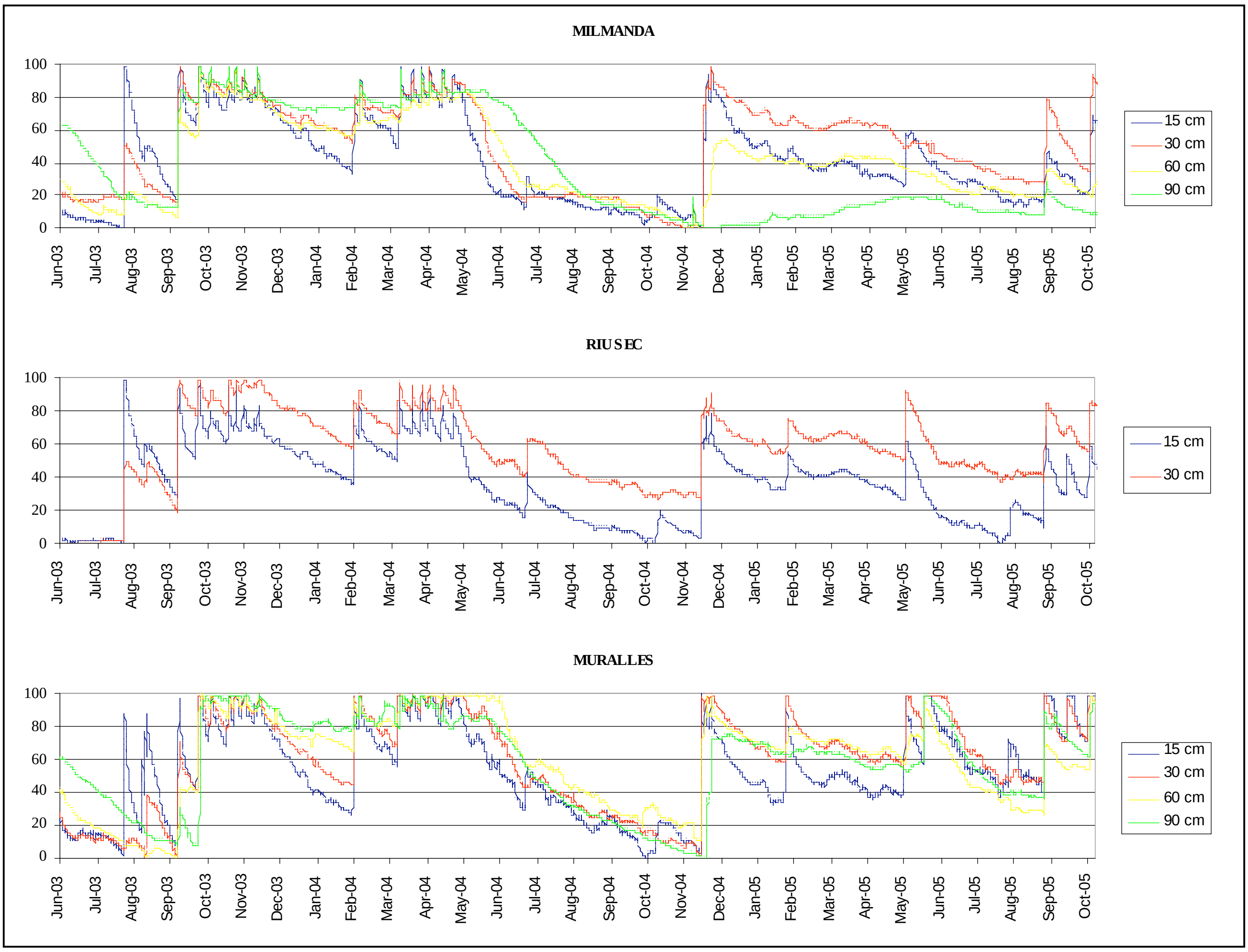

Figure 1 - Water availability index, in continuum and at different depths, for Milmanda, Riu Sec and Muralles plots

Figure 1 shows water availability (WA) evolution from June 2003 to October 2005. Generally, summer WA seems inversely proportional to annual rainfall, and spring WA too. The lowest summer WA (< 20 %)

occured in 2003 (Riu Sec) and 2004 (Milmanda and Muralles), when rain and spring WA were the highest (generally, higher than 80 %). The high rain and WA could have favoured vegetative development, and vines would be most water demanding in summer. On the contrary, WA values during 2005 were low (< 60 %) in the first months of the growing season, and summer WA were high (> 20 % in Milmanda and > 40 % in Muralles). Some differences between soil types can be observed. In Riu Sec soil, WA usually is lower than in other soils, probably due to quick drainage and low water holding capacity. In Muralles, WA is slightly higher than in Milmanda. Between these soils, important differences occur at different depths. During 2005, the horizon at 90 cm depth recovered the WA in Muralles, but not in Milmanda: the rain in Milmanda was not enough to reach field capacity in superficial horizon, so deep horizons did not increase their WA. In Muralles, where water holding capacity is lower, the WA increases at all depths.
The most productive vintage was 2003 in Milmanda and Riu Sec, except for Muralles which suffered an abnormal yield in 2004 (table 3). The vintage least productive was 2005 except for Milmanda (2004): the great development of vegetation could have broken the equilibrium between vegetative activity and fruit production. The highest grape alcoholic degree was in 2004, except for Muralles (2003). The highest pH of must took place in 2003. The highest total acidity took place in 2004. Grape seed ripening had the highest value in 2003, but the minimum value was in 2005 for Milmanda and 2004 for Riu Sec. Anthocyanins had the highest value in 2004, but the minimum value was in 2005 for Milmanda and 2003 for Riu Sec.

Table 3 - Data of grape quality.

Plot	Milmanda			Riu Sec			Muralles		
Year	2003	2004	2005	2003	2004	2005	2003	2004	2005
Yield ($kg \cdot vine^{-1}$)	1.78	1.34	1.65	1.42	1.07	1.01	2.15	3.91	1.60
Alcoholic degree	15.3	16.1	13.3	14.5	15.5	14.4	15.8	13.7	15.6
pH	3.64	3.26	3.57	3.58	3.30	3.47	3.45	3.4	3.27
Total acidity (g/L)	8.81	10.67	7.13	6.21	11.1	7.26	6.02	6.55	6.38
Grape seed ripening	10.13	8.56	7.20	17.03	3.57	7.71	-	-	-
Anthocyanins (mg/L)	387	424	318	442	666	540	-	-	-

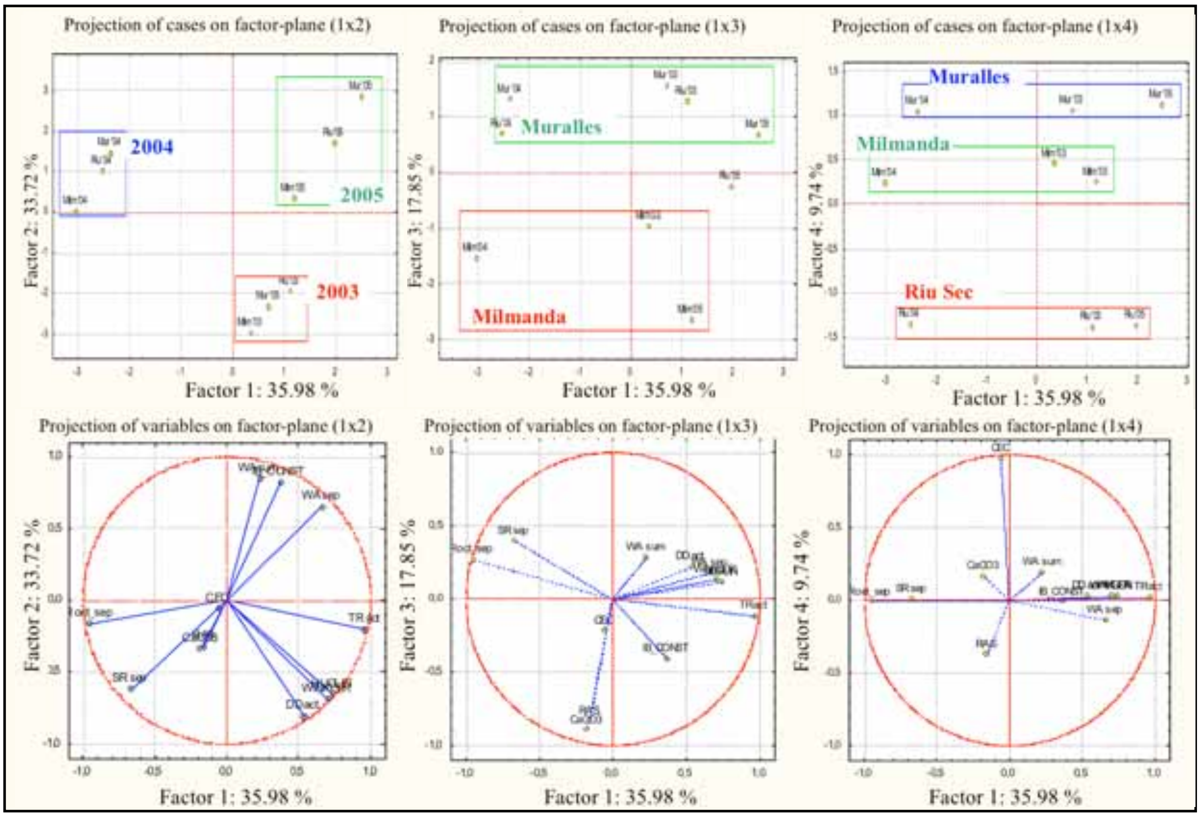

Figure 2 - Projection of cases and variables on the factor-planes of the PCA performed with selected variables.
(WA sum: mean WA in summer, WA sep: mean WA in September, CEC: Cation Exchange Capacity, RAS: ratio absorption sodium, SR set: mean daily solar radiation in September, TR act: mean daily temperature range for vineyard growing season, DD act: sum of degree-day for vineyard growing season, R oct-sep: Rain during October-September, Winkler: Winkler index, Huglin: Huglin index, Const: Constantinescu index)

Matrix correlations and PCA were done in order to explore data and select the best explicative factors. Figure 2 shows a PCA considering only the selected variables, which is more understandable. Factor 1, which explains 35.98 % of variability, separates 2004 vintage from 2003 and 2005 vintages. 2004 vintage has higher quantities of rain during October-September (R oct-sep), meanwhile 2003 and 2005 vintages are both characterized by a higher mean daily temperature range for vineyard growing season (TR act). Factor 2, which explains 33.72 % of variability, distinguishes between 2003 and 2005 vintages. 2003 vintage is situated in an area with high thermal indexes (sum of degree-day for vineyard growing season (DD act), Winkler index, Huglin index). 2005, for the other side, is characterised by a high water availability index (WA); 2004 shows the same tendency than 2005. Factor 3, which explains 17.85 % of variability, clearly separates Muralles soil from Milmanda soil, mainly by $CaCO_3$ content and ratio absorption sodium (RAS). Factor 4, explaining 9.74 % of variability, separates each vineyard by its Cation Exchange Capacity (CEC), having Muralles the highest CEC and Riu Sec the lowest one. In conclusion, climatic data and water availabity explain 70 % of variability (factors 1 and 2). For this reason, climate and water availability are the main factors which allow differentiate vintages, with climate having probably more influence than water availability. Finally, soil data explain 28 % of variability (factors 3 and 4).
Models for estimation of grape quality were performed by Multiple Regression Analysis (Table 4). These models have a high estimation capacity, with R^2 higher than 0.75 (except for pH and grape seed ripening). The models are significant ($p < 0.05$) for yield, total acidity and anthocyanins; and slightly nonsignificant ($0.05 < p < 0.07$) for alcoholic degree, pH and grape seed ripening. Yield is highly correlated with edapho-climatic data ($R^2 = 0.88$). The chosen independent variables are CEC and Winkler Index, with a similar importance (similar standardized regression coefficient). The properties of must can be highly estimated, except for pH and grape seed ripening ($R^2 = 0.63$). Anthocyanins is the most correlated variable ($R^2 = 0.9$). In models for must properties, a climatic index (SR september, R oct-sep, Huglin index and DD act) and a water availability index (WA summer) is always present, except for grape seed ripening, where there is only a climatic index (DD act). Climatic indexes have higher influence than WA indexes, except for anthocyanins, where WA summer has the greatest weight. Soil data appear in alcoholic degree model, having few importance (CEC); and total acidity model, having high importance (RAS).

Table 4 - Results of Multiple Regression Analysis for grape quality variables.

Dependent variable	Independent variables	Regression coefficient (b)	Model quality	
Yield	CEC	0.6795 **	R^2	0.8795
	Winkler index	0.5566 *	n	8
			Significance (p level)	0.005
Alcoholic degree	CEC	0.3619 ns	R^2	0.8128
	SR september	1.1050 *	n	8
	WA summer	0.8318 *	Significance (p level)	0.062
Total acidity	R oct-sep	0.6736 *	R^2	0.7663
	RAS	0.8190 *	n	9
	WA summer	0.4280 ns	Significance (p level)	0.049
pH	Huglin index	0.6092 ns	R^2	0.6256
	WA summer	-0.3406 ns	n	9
			Significance (p level)	0.052
Anthocyanins	R oct-sep	0.5594 *	R^2	0.9040
	WA summer	0.8623 *	n	6
			Significance (p level)	0.030
Grape seed ripening	DD act	0.791 ns	R^2	0.6257
			n	6
			Significance (p level)	0.061

*, **, ns indicate significance at $p < 0.05$, $p < 0.01$ and nonsignificant, respectively.

Showed by the PCA, climatic data have the highest influence on regression models, particularly the climatic indexes which estimate must data. Water availability is the second important predictor, as it is shown in must data. Soil data are important variables to predict yield and total acidity. These results agree with the conclusions obtained in previous studies (Van Leeuwen, 2004), where climate appears as the most influencing factor on must quality.

Conclusion

The effect of both soil and interannual climate parameters on grape quality were studied, without considering cultivar effect and considering the same climate for all plots. A water availability index was calculated from soil moisture data measured by capacitance sensors. The water availability index resulted a useful tool to predict grape must quality. According to the performed PCA, climatic data and water availability explained 70 % of vintage variability and soil data explained 28 % of vintage variability. Climatic data seemed slightly more explicative than water availability. The Multiple Regression Analysis showed that edapho-climatic factors had generally a high power of estimation of yield and quality of grapes, with R^2 higher than 0.75. Models were significant ($p<0.05$) or slightly nonsignificant ($0.05 < p < 0.07$). Climate appeared to be the most influencing factor, followed by water availability, concretely in models referring to must data. Climatic data used in models were climatic indexes, as Huglin index or Winkler index. The selected water availability index was mean water availability in summer. Generally, soil data had influence on yield and some must data.

Acknowledgements: We would like to thank Núria Llop from the University of Lleida and Alicia Zayas, Anna Mata and other people from Miguel Torres Winery, for their collaboration in data acquisition and statistical analysis.

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