CLIMATE VARIABILITY AND ITS EFFECTS IN THE PENEDÈS VINEYARD REGION (NE SPAIN)

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ABSTRACT
This study present a detailed analysis of the rainfall and temperature changes in the Penedès region in the period 1995/96 -2008/09, in comparison with the trends observed during the last 50 years, and its implications on phenology and yield. Temperature increases are higher than in previous time periods, which together with the irregular rainfall distribution throughout the year give rise to significant water deficits for vine development. Water deficits are being exacerbated during the last years by the increase of temperatures which imply an increase of evapotranspiration. The dates at which each phenological stage starts and the length of the different phenological stages are affected by temperature (accumulated degree-days and daily air temperature difference), precipitation and water accumulated into the soil. Winegrape yield was also influenced by soil water availability.

KEYWORDS
Evapotraspiration- Mediterranean climate- NE Spain- phenology- trends-yield

INTRODUCTION
Climate change and its potential impacts on viticulture and viniculture have become increasingly important as a consequence of changes in earth surface characteristics associated with the increase in greenhouse gases and changes in global temperatures, radiation budget and hydrological cycles. Vines, one of the most extensive crops in some parts of the Mediterranean Spanish area, which are cultivated under rainfed conditions, may therefore be one of the crops that suffer the consequences of climate change. According to Olesen and Bindi (2002), in the current production areas the yield variability (fruit production and quality) may be higher in the future than it is at present. However, some areas may suffer negative effects such as water stress due to a reduction in water availability and shortening of the ripening period, with harvest occurring during time with high temperatures, which may have negative impacts on wine quality (Duchêne and Schneider, 2005). Examples of impacts of temperature changes, frost occurrence and growing season lengths on grape productivity are found in the literature (Jones et al., 2005).

The Mediterranean climate is characterized by dry and warm summers and two wet seasons (spring and autumn), in which most rainfall is recorded, but there is high variability from year to year. Some authors indicate decreasing precipitation trends for the Mediterranean (Karl, 1998) and significant changes in extreme events concentrated in a small number of events such as more frequent and extreme droughts, increases in cool season precipitation, and warm season drying (Easterling et al. 2000). This study presents an analysis of temperature and precipitation and their possible impacts on grape development in the Alt Penedès (NE Spain), which is dry farming area with a long tradition on vine cultivation but with significant changes during the last decades.

MATERIALS AND METHODS

The study area: The Alt Penedès region, located in the northeast Spain, is part of the Penedès Tertiary Depression**.** The main soil types in the area are *Calcixerepts petrocalcics, Typic Haploxeralfs, Palexeralfs petrocalcics, Typic Haploxerepts, Typic Xerofluvents, Typic Haploxerepts, Typic Xerorthents and Typic Calcixerepts* (Martínez-Casasnovas and Ramos, 2009). Calcilutites (marls) are the main lithological material, with occasional sandstones and conglomerates and due to labours carried out in the field to facilitate labour mechanization, soil profiles have been disturbed, leaving on top of the surface materials which are poor in organic matter and very week soil structure. This affects water intake and further redistribution, with an important limitation of water availability for the vine.

The climate is Mediterranean, with a mean annual temperature of 15ºC and a mean annual rainfall of 550 mm, mainly concentrated in spring (April to June) and autumn (September to November). High-intensity rainstorms are particularly frequent in autumn.

The Alt Penedès area has a long tradition of vineyard cultivation under the Penedès and Cava Designation of Origins (DO). Vineyards are the main land use, representing 80% of the cultivated area, about 17500 ha (CRDOP, 2008), (about 67% of the DO surface) 82% of them planted with white varieties, being the most representative: Xarelo (31%), Macabeo (25.7%), Parellada (18.6%) and Chardonnay (5%). Among the red varieties Cabernet Sauvignon (4.3%) and Merlot (7.3%) are the most extended (CRDOP, 2008). At present, about 50% of vineyards have been transformed into new vineyards, in which almost all labours are mechanised. For this study four observatories distributed in the area and two vineyards close to them are considered to asses the effects of climate trends on production and phenology.

Data analysis: Precipitation and temperature data were recorded in Vilafranca del Penedès (VP) (41.434º; 1.419E; 230 m) from 1952 to 2009 and in Sant Sadurní d'Anoia (SSA) (41,208º; 1.791E; 164 m), La Granada (LG) (41.367º; 1.724E; 238 m) and Els Hostalets de Pierola (EHP) (41.526º; 1.805E; 312 m) from 1996 to 2009. Daily rainfall, maximum and minimum temperatures and evapotranspiration were analysed for the growing season (April-September) and for each phenological stage (budbreak-bloom [BB], bloom-veraison [BV] and ripening [R]). Additionally, several bioclimatic indexes such as accumulated effective temperature [Tef=Σ(Tm-10ºC)] and Huglin [HI] and Winkler [WI] indexes were analyzed.

Dates at which each phenology stage started was examined in two vineyards planted with Xarelo: beginning of budbreak, early bloom (beginning of flowering, grapes colour change and grapes ripe for harvesting. In the text, the different stages are identified as: dormant period (D): time between 1srt November-budbreak start; budbreak-bloom (BB); bloom-veraison (BV); ripening (veraison-harvest: R), post harvest (PH): time between harvest and 31st October. The length of each phenological period was evaluated for each year.

Crop yield was also evaluated in the same vineyards. The ratio between precipitation and crop evapotranspiration, estimated using the crop coefficients proposed by the FAO (Allen et al., 1998), was evaluated as well as the relationship between temperature and the related indexes and the date at which the different phenological events took place. Results related to Xarelo variety are presented. In addition, the relationship between grape production and temperature and water availability was analysed. For these analysis, a step multiple regression analysis (forward variable selection) was performed using the Statgrapics 5.1 software.

RESULTS AND DISCUSSION

Temperature and bioclimatic indexes along the crop growing season: Table 1 shows the mean values of climate parameters related to the growing season (GS) recorded in four observatories in the area during the period (1996-2009). The mean temperature (TGSM) ranged between 18.7 and 22.2ºC, with mean maximum temperature (TGSMax) ranging between 23.8 and 25.9 and mean minimum temperatures (TGSMin) ranging between 12.4 and 13.7ºC. During the last decades, increasing mean, maximum and minimum temperature trends were observed in the growing season in this study area (Ramos et al., 2008). Growing season mean temperatures increased in about 0.04ºC/year in VP, during the last 50 years, which implies and increase of about 2.2 ºC in the period (1952-2006). If we focus on the last 14 years (1996-2009), the trend of the mean temperature is similar (0.038 ºC/year), but the minimum temperature seems to increase much more than in previous decades (ranging between 0.105 and 0.149ºC/year depending on the observatory). Other bioclimatic indices which also showed significant increasing trends during the past decades such as the Winkler index (trend=7.81GDD/year) or the Huglin index (7.24GDD/year), show now higher values in VP (20.9 and 22.2 DDD/year), although lower values are found in other observatories (e.g. (8.23 and 11.2 GDD/year, respectively in EHP and 6.5 GDD/year in LG). While the mean WI index value during the past decades (1860 GDD) places this region in Winkler region III (Ramos et al., 2008), it is observed that at present the mean values are clearly in region IV. This means the need of adapting some varieties to this new situation. Particularly, some of the most extended varieties in the region could be affected (Parellada or Chardonnay).

One of the direct consequences of the temperature increase is the higher evapotranspiration rates. During the last 14 years evapotraspiration rates showed a significant positive trend in all observatories. However, those ratios were on average 9.3 mm/year in SSA, 11.1 mm/year in and EHP and about 3 mm/year in VP and LG, observatory where the average evapotranspiration was already higher. This increase means an annual evapotraspiration increase ranging between 1 and 2.3%.

Rainfall distribution along the crop growing season: The rainfall characteristics of the Mediterranean climate, with high variability from year to year and within the year, makes difficult to confirm precipitation trends. At annual scale no significant trends may be confirmed, but higher variability may be observed: rainfall increases in winter and autumn and decreases in spring, mainly affecting the bloom-veraison stage. A significant decrease ranging between 4.6 and 5.9 mm/year was observed in that period, which represent about 10% of the rainfall recorded during that crop stage. The irregular distribution of the rainfall and its decrease during the growing period makes, that very often, the vines suffer deficits which may not be covered by the water reserves accumulated into the soil profile.

Using the data belonging to one of the observatories included in this analysis (EHP) an analysis of the water availability for the crop during the last years was done. In this analysis the relationship between rainfall and evapotranspiration in each crop stage as well as the accumulated water from the previous stage was considered.

Figure 1a shows the water available (P- ETc) from the dormant period to the end of crop cycle. In only five (1996, 1997, 2002, 2004 and 2007) of the 14 years included in the analysis, precipitation exceed evapotranspiration needs during the whole growing cycle. In four years more (1999, 2000, 2004 and 2008) precipitation recorded during the dormant period helped to cover water needs during the budbreak-bloom stage, but during the rest of the year, the plant suffer significant water deficits. However, there were some years, dry years or years with very irregular distribution, in which the accumulated precipitation was not enough to cover evapotraspiration in any stage of the whole growing season (2001 and 2005).

Even more, taking into account the rainfall intensity and the limited soil infiltration capacity in many cases, water restrictions are even higher. A specific study carried out in two vineyards planted with Xarelo, one of the varieties most commonly extended in the area, shows how water deficits recorded, not only during the ripening period but in earlier stages, are even higher. We can see how water deficits during the bloom to veraison and during the ripening period were significantly increased in almost all years (Fig. 1b). These water deficits are affected for both irregular distribution and higher temperatures, which gave rise to higher evapotranspiration rates. Under these results we could understand the difficulty of extracting general conclusions. Even in the case that total precipitation does not change so much, it is clear that a decrease of precipitation during some stages of the crop have additional effects.

Table 1: Mean temperature and precipitation indices and trends covering the growing period in four observatories of the study area (1996-2009)

	Vilafranca del Penedès	Trend/ year	La Granada	Trend /year	Sant Sadurní D'Anoia	Trend/ year	Els Hostalets de Pierola	Trend/ year
TGSM	19.8±0.9	0.102*	19.4±0.5		22.2±3.3		18.7±0.9	0.038
TGSMax	24.0±1.3	0.105*	25.9±0.8		25.2±0.9	0.106	23.8±0.8	0.149*
TGSMin	13.5±0.9	0.108*	13.7±0.4	0.072*	12.4±0.7	0.084	12.9±0.9	0.068
WI	2104±140	20.9*	2119+180	6.5 *	2120+180	35.2	2066+160	11.9*
HI	2813±150	22.2*	2573±170	12.8	2575±170	27.5	2385±130	8.23*
PGS	336±110		322±100		322±120		350±150	
ETcGS	414±18	2.7 *	482±20	3.8 *	322±120	9.32 *	366±100	11.1 *
P-BB	68±50		81±60		87±60		79±60	
P-BV	47±30	-5.34*	34.2±30	-4.84 *	36±30	-4.6 *	76±70	-5.9 *
P-R	103±38		125±20		96±45		90.6±70	

* means significant differences at 95% level

Climate parameters impacts on vineyards: According to the Consell Regulador de la Denominació d'Origen Penedès, the ranks of the vintage from the region are given as good, very good and excellent for both white and red wines. In 12 out of the last 15 years the vintage qualification was very good plus one more excellent (CRDOP, 2010). From this point we could think that there is not a serious impact of climate or water availability on the sector despite different authors having already pointed out the impacts that climate change could have on wine quality (Duchêne and Schneider, 2005; White et al., 2006; Makra et al., 2009).

However, water availability may have a direct impact on yield with a significant economic impact for the sector. In order to evaluate the relationship between grape production and temperature and water stored into the soil, a step multiple regression analysis (forward variable selection) was performed. Although several variables related to temperature and soil water have influence on yield when they are tested isolated (negative effect: effective temperature corresponding to D+BB period [(Tef_D+BB), to BV period (Tef_BV) or to the whole growing season (Tef_WGS); positive effect: accumulated water during D+BB period (WA_D+BB)], if all these variables are combined in a multiple regression analysis, the only significant value was the accumulated water during the budbreak-bloom stage, which represents about 47% of total variance (Tab. 2).

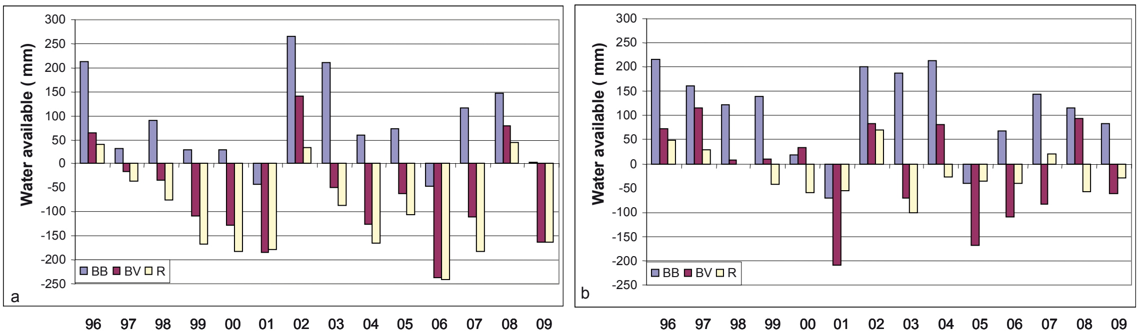

Fig. 1. Water availability during each stage of the growing period (BB: budbreak-bloom; BV: bloom-veraison; R: ripening) of a vineyard planted with Xarelo): a) precipitation – evapotranspiration in each stage: b) precipitation-runoff- evapotranspiration in each stage

On the other hand, variables related to phenology such as the dates at which different phenological stages start are also influenced by water availability as well as by temperature. In particular, a significant correlation was found for this variety between the data at which veraison starts and the effective temperature during the bloom-veraison period (negative correlation, which represents about 29% of total variance), and between that variable and the water available during the same period (positive correlation, representing about 38% of the variance) (Tab. 2)

Tab. 2. Fit parameters for Xarelo grapevine yield and some phenological dates in relation to effective temperature during the bloom-veraison period (Tef_BV)) and soil water available during budbreak-bloom (WA_BB) and during bloom-veraison (WW_BV) periods

Variety		variable	parameter	R^2 (%)	F-Ratio	P-Value
Xarelo	Yield (kg/ha)	Constant				
		WA_BB	17.97	43.47	6.92	0.04
	Veraison data	Tef_BV	-0.106	28.78	4.04	0.07
		WA_ BV	0.081	37.95	6.11	0.02

CONCLUSIONS

The high variability of the Mediterranean climate together with the high intensity rainfall and the increasing temperature trends give rise to significant water deficits for vine development in the Penedès region, in which vineyards have been cultivated for centuries without irrigation. Significant water deficits have been observed not only in dry years but also in years with total rainfall above the mean value in the area. Water deficits during the growing season may be in part supplemented by water accumulated during the dormant period, but in most years water balance is negative for the whole growing period. Water deficits are being exacerbated during the last years by the increase of temperatures, which results in an increase of evapotranspiration.

Winegrape yield and the dates at which each phenological stage starts are affected by temperature (accumulated degree-days) and by soil water availability.

The lack of water resources in the area makes very difficult or excessively expensive to implement irrigation systems in the fields, and because of that vineyards may be seriously affected if temperature continues increasing. Water deficits, driven by the irregularly rainfall distribution and the increase of evapotranspiration in the stages in which vine water needs should not be restricted, may challenged the sustainability of some vineyards in the area. On the other hand, yield may be reduced due to higher water stress under a scenario of climate change.

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