Article

Climatology and evapotranspiration in wine valleys of Baja California

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Abstract

Bioclimatic indices, including evapotranspiration, have been used together to characterize the climate in a region and correlate its influence on the physiological processes of the vine and on the quality of the fruit and wine, as well as to characterize and define growing areas. However, few studies have been conducted to characterize the wine regions in Mexico. Therefore, the objective of this study was to characterize the wine regions of Baja California according to climatic variables. Ambient temperature, irradiance, relative humidity, wind speed and direction were evaluated in the Guadalupe Valley (VG), San Antonio de las Minas (SAM), San Vicente (SV) and Santo Tomás (ST) in Baja California from 2013 to 2018. The relationship between the bioclimatic indices of GDD and HI was significantly high, indicating that these two indices capture the same climate information. Using the GDDs, the SAM and SV valleys were classified as region IV (temperate-warm) while VG and ST were classified as region V (warm and very warm zones). Similarly, evapotranspiration in SAM and SV was 15% lower than that observed in VG and ST. These results help establish the most suitable areas for viticulture as well as for water management in Baja California.

Keywords: bioclimatic indices, climate, evapotranspiration, viticulture.

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Introduction

Temperature, solar radiation, soil type and rainfall have a critical impact on the development of the vine and the ripening of the grape (Hidalgo, 1980). The development of the vine and the ripening of its fruits, for example, require sufficient lighting to ensure photosynthetic saturation. The ideal average temperature range for the development of grapes for wine generally ranges between 11º and 18 ºC, without being less than 10 ºC or greater than 40 ºC (Hidalgo, 1980). Derived from these climatic characteristics, the vine is cultivated in the Mediterranean climates, which correspond to the areas between the parallels of 30º and 50º of north latitude and the 30º and 40º of south latitude.

Temperature and irradiance control many physiological processes in plants, including the vine. It has been determined, for instance, that the buds of the vine open at 4 °C and the leaves appear when the average temperature is 7 °C. The growth is maintained at temperatures no higher than 25 °C; however, after 30 °C, the increase in photorespiration and stomatal closure causes photosynthesis to decrease rapidly (Carbonneau *et al*., 1992). On the other hand, low temperatures (0-6 °C) promote that net photosynthesis ceases and growth stops. Temperature also plays a critical role during ripening.

Ripening at high temperatures, for example, raises sugar concentrations and decreases the concentration of organic acids in berries (Zarrouk *et al*., 2016). In contrast, ripening at low temperatures tends to accumulate low concentrations of sugars and berries end up with high levels of organic acids. Therefore, each wine region has climatic characteristics that impact the physiological characteristics of the vine and the ripening of the berries (Jackson and Lombard, 1993). However, in Mexico there are few studies that contrast the climatic characteristics of wine valleys (Valenzuela Solano *et al*., 2014).

The texture and composition of the soil also play an important role in the physiology of the vine. As for other agricultural crops, the soil for vine cultivation requires to be permeable, usually with a sandy loam soil structure (Conradie *et al*., 2002). Studies agree that the different characteristics of the soil, even under the same climate conditions, induce differences in the final characteristics of wines (Tramontini *et al*., 2013). However, other researchers confirm that the final characteristics of the grape are defined mainly by the local climate and water availability, and secondarily by the type of soil (Conradie *et al*., 2002).

Due to the importance of climate in the development of the vine, indices linked to the cultivation of the vine have been developed (Fraga *et al*., 2013). These indices are usually used together to classify the climate in a region or to determine the influence of climate on physiological processes, production and fruit quality (Jones *et al*., 2010). Both the index of growing degree days (GDD) and the Huglin heliothermal index (HI) are used in order to establish the suitability of the region for the cultivation of the vine (Huglin, 1978).

These climatic indices allow to characterize growing areas in order to define and differentiate the grape-producing regions, as well as to carry out zoning studies of wine regions at different scales (Fraga *et al*., 2013). In addition, climatic parameters are used to estimate evapotranspiration in vineyards and to make an adequate management of water. Despite the importance of climate on the physiology and ripening of the vine, in Mexico there is no detailed characterization of the microclimate and evapotranspiration of the different wine valleys.

Because grape physiology and grape ripening depend on the climate and it is the factor that geographically limits the expansion of viticulture, the objective of this study to evaluate the climatic differences and evapotranspiration between the wine regions of Baja California.

Materials and methods

Study area

The climatic characteristics of four commercial vineyards from different wine valleys of Baja California were evaluated. The Guadalupe Valley (VG) is located 25 km northeast of Ensenada. It is a valley of fluvial origin through which the Guadalupe stream runs and is flanked by hills with average altitudes of 400 m. The San Antonio de las Minas Valley (SAM) is located 10 km from the coast of the Pacific Ocean and west of VG. The Santo Tomás Valley (ST) is located 50 km south of Ensenada and is characterized by mountains that reach 1 000 masl. The topography of this valley presents an elongated shape, which is delimited by the glens that have preferential orientation NW-SE. Finally, San Vicente (SV) is a coastal valley that is located 70 km south of the city of Ensenada and 10 km from the coast of the Pacific Ocean.

Soil analysis

Soil samples (four per vineyard) were taken in the four areas studied (n= 16). Approximately one kg of sample was collected between plant and plant at a depth of 0 to 30 cm. The percentage of water saturation, electrical conductivity by conductometry, pH by potentiometry and total dissolved solids by conductometry were determined. In addition, the concentration of calcium, sodium, magnesium, carbonates, chlorides and sulfates was determined by titrations. Sodium adsorption ratio (RAS) and exchangeable sodium percentage (PSI) were calculated using the concentration of these ions. Soil textural parameters were determined by sieving and pipette analysis for the fine fraction (silts and clays) (USDA, 2006).

Climatological data

Climate data were collected from 2013 to 2018 every 15 min using meteorological stations (Hobo U30, USA) located in each of the vineyards. Temperature and relative humidity were assessed with a Hobo-SJ BM002 mixed sensor. Rainfall was measured with a Hobo RG3M sensor with capacity of 12.7 mm h^{-1}. Photosynthetically active radiation (PAR) was determined from a Hobo Slim 003 sensor. Wind speed and direction were measured with a Hobo Swsetb sensor. The sensors were placed 2.5 m above the ground.

Two bioclimatic indices were calculated from the temperature data to assess the spatial and temporal variation of temperature in the different vineyards. The Winkler index or growing degree days (GDD) was determined as the sum of the temperature above 10 °C (GDD= Σ (Tprom-10)), which was calculated from April 1 to October 31 (Winkler *et al*., 1974). The heliothermal or Huglin index (HI) was calculated using the average daily temperature and the maximum day temperature from April 1 to September 30 (HI= Σ (Tprom-10 + Tmax-10) / 2 × k). The coefficient k expresses the length of the day with respect to latitude (Ensenada k= 1) (Huglin, 1978).

The reference evapotranspiration (ETo) for each of the wine valleys was determined using the Penman-Monteith equation according to Snyder and Eching (2002). $ET_o= \frac{0.408\ \Delta(R_n-G+\gamma\left(\frac{900}{T+273}\right)u_2\ (e_s-e_a)}{\Delta+\ \gamma(1+0.34u_2)}$. Where: Rn= is the net radiation on the surface of the vineyard (MJ m^{-2} d^{-1}); G= soil heat flow (MJ m^{-2} d^{-1}); T= average air temperature at 2 m height (°C); u_2= wind speed at 2 m height (m s^{-1}); e_s= saturation vapor pressure (kPa); e_a= the actual vapor pressure (kPa); e_s - e_a= vapor pressure deficit (kPa); Δ= is the slope of the vapour pressure curve vs. temperature (kPa $°C^{-1}$); and γ a psychrometric constant (kPa $°C^{-1}$).

The net radiation (Rn) was calculated from the equation proposed by Samani (2000). $Rn= Ro * KT * (T_{max} - T_{min})^{0.5}$. Where: Ro= is extraterrestrial radiation (mm d^{-1}); KT= is an empirical coefficient calculated for coastal regions (0.19); T_{max}= is the maximum daily temperature; and T_{min}= is the minimum daily temperature.

Statistical analysis

Statistical differences of bioclimatic indices and soil characteristics were determined with an analysis of variance (Andeva) after testing the normality and homoscedasticity of the data. All multiple comparisons of means were performed with the Shapiro-Wilk test ($p< 0.05$). Contour plots were made from a geostatistical method of interpolation (Kriging) (Burgess and Webster, 1980).

This method provides, from a sample of points, either regularly or irregularly distributed, estimated values of those sites where there is no information, without bias and with a known minimum variance. This analysis was performed to evaluate the relationship between the data obtained from each variable and for each sampling area in the three harvest periods (2016-2018).

Results and discussion

The textural characteristics of the soils of the wine valleys of Baja California showed significant differences (Table 1, $p< 0.05$); however, the soil texture of the vineyards of Baja California was consistent with that observed in the vineyards of California, USA (Knipper *et al*., 2020). The mechanical composition of the soil for VG and SAM was greater than 65% of sands and less than 12% of silts and clays. The textural characteristics of VG are typical of sandy-loamy soils, while those of SAM represent a loamy-sandy soil. On the contrary, the SV and VT valleys presented concentrations of sand less than 60% and between 20 and 30% of silts and clays. In the vineyards of SV and ST, loamy and clay-loam soil predominate, which tend to present greater retention of water and nutrients (White, 2009).

Table 1. **Physicochemical characteristics of soil samples from the Guadalupe Valley (VG), San Antonio de las Minas (SAM), San Vicente (SV) and Santo Tomás (ST).**

Locality	Texture class	Saturation (%)	Conductivity (dS m^{-1})	pH	CA (ppm)	Mg (ppm)	Na (ppm)	HCO_3 (ppm)	CI (ppm)	SO_4 (ppm)	RAS	PSI (%)	MO (%)
VG	Loam	31	0.8	7.98	79.4	39.4	16.7	298.9	56.6	21.1	0.22	0.1	1.61
std	Sandy	1.4	0.23	0.16	19.3	17.7	12.6	40.1	11.1	6.9	0.05	0.1	0.6
SAM	Loam	30.1	0.59	7.47	137.1	113	45.9	244.4	54.7	29.5	1.2	0.99	1.9
std	Sandy	1.9	0.2	0.4	19.2	4.2	31.2	66.2	17.1	28.9	0.52	0.29	0.45
SV	Loam-	29.8	1.52	7.93	102	87	65	204	310.1	235.2	1.4	1.39	1.78
std	loam Clay	4.2	0.44	0.3	30.9	16.9	52	20	28.7	59.3	0.7	0.16	0.5
ST	Loam	32.2	2.97	7.57	273.1	155.4	70.5	355	351.2	232.8	1.6	1.21	2.66
std		0.56	2.04	0.6	66.6	63.25	63	71	306.4	78.2	0.13	0.2	0.62

Water saturation, conductivity, pH, concentration of calcium, magnesium, sodium, carbonates, chlorides, sulfates, total dissolved solids, sodium adsorption ratio, exchangeable sodium percentage and organic matter were determined.

It has been shown that the type of soil can impact grape physiology and ripening (Jackson and Lombard, 1993). It has been shown that a greater amount of water available in the root zone invariably causes overgrowth of vine shoots, promoting the decrease in fruit yields and increasing the possibility of fungal diseases (Jackson and Coombe, 1988).

On the other hand, the low water retention by the sandy-loam soil, for example, shown to increase the concentration of sugar in the berries and decrease the growth rate of the vine shoots (Stevens *et al*., 1995). In addition, this decrease in growth rate resulted in a reduction in canopy cover, increasing photosynthetic efficiency and reducing fungal diseases (Dry *et al*., 1998).

The physicochemical characteristics of the soil varied significantly ($p< 0.05$) between the different areas studied (Table 1). The lowest concentration of Ca (79.4 ppm), Mg (39.4 ppm), and Na (16.7 ppm) occurred in the VG soil, while the highest values of Ca (273 ppm), Mg (155 ppm) and Na (70 ppm) were found in ST. The lowest values of HCO_3 (204 ppm) occurred in SV soils and the highest values (355 ppm) in ST soils. The lowest concentration of Cl (56 ppm) was observed in VG soils, while the highest values (351 ppm) occurred in ST. Finally, the lowest concentration of SO_4 (21 ppm) occurred in SAM soils, while the highest values (235 ppm) were observed in SV.

Differences in soil ions are surely the result of differences in origin and texture of the soils of the different valleys. In general, soils are classified as normal, saline, sodic or sodic saline based on their pH values, electrical conductivity (EC), sodium adsorption ratio (RAS) and exchangeable sodium percentage (PSI) (Horneck, 2007). Saline soils can increase osmotic potential, making it difficult for plants to absorb water (Hanson *et al*., 2004). Derived from the concentration of salts in the soil of the wine valleys studied, all are classified as normal soils and potentially do not generate a risk for vine cultivation, which coincides with results of other studies in the area (Salgado-Tránsito *et al*., 2012).

However, it has been found that approximately 10% of the arable area of VG is irrigated with water that contains high levels of salinity (CE> 4 dS m^{-1}, PSI> 15%), which could change the physicochemical characteristics of the soil and affect the physiology of the vine (Salgado-Tránsito *et al*., 2012).

The percentage of soil saturation (30%) was similar in the four areas studied, while the pH values varied significantly (Table 1, $p < 0.05$). However, electrical conductivity (EC), sodium adsorption ratio (RAS), exchangeable sodium percentage (PSI) and organic matter concentration (MO) had the significantly highest values ($p < 0.05$) in ST, while the lowest values were found in VG. Studies suggest that vines require soils with a pH between 6.5 and 7.5 to develop optimally (Conradie, 1983). The pH values of the soil of the four areas studied ranged from 7.5 to 7.9 and are at the upper limit recommended for vine cultivation. In general, nutrient availability increases when the pH of the soil is between 6.5 and 7 and the availability of nitrogen, calcium, magnesium and iron for vines is significantly reduced when the pH of the soil is superior to 8 (Conradie, 1983).

In addition, high pH values (>8.2) and a high concentration of carbonates in the soil promote a deficiency in iron assimilation, causing chlorosis in plants (Saayman, 1982). Therefore, the chlorosis problems presented in some of the vineyards of Baja California could be, partially, the result of high pHs in the soil. This alkalinity effect could occur especially in VG and SV, since the average pH values of the soil are very close to 8 and in some cases, the individual values are superior to 8.2.

The average temperature patterns for the four areas studied were relatively similar (Figure 1). However, the dispersion of daily temperature averages was higher in SAM, ST and VG and was lower in SV. On the other hand, the highest average temperatures during the summer ($p < 0.1$) occurred for VG and ST and the lowest for SV and SAM. However, photosynthesis and vine growth have been shown to be negatively affected when the temperature is above 30 °C (Greer and Weedon, 2012).

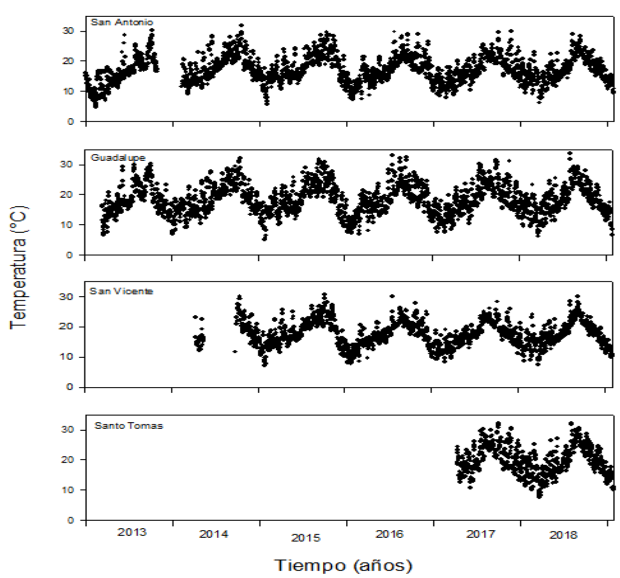

Figure 1. Time series for the average daily temperature in San Antonio de las Minas, Guadalupe Valley, San Vicente and Santo Tomás.

All the wine valleys studied had average daily temperatures greater than 30 °C during the summer. In addition, during some summer days, the maximum temperatures in these valleys reached 40 °C. The high temperatures observed suggest that the climatic conditions of these valleys are not optimal to produce quality wines (Winkler *et al*., 1974).

Climate change models suggest an increase in the accumulation of development degree days and average maximum temperatures in Baja California (Valenzuela-Solano *et al*., 2014). In addition, changes in the rainfall pattern are also likely to be experienced, which could have a negative effect on water availability and the increase in drought seasons in this region (Del-Toro-Guerrero, 2020). Photosynthetically active radiation (PAR) was similar for the study areas (Figure 2). In the four valleys, the highest values of PAR summer (approx 65 mol m^{-2} d^{-1}) and minimum during the winter season (21 mol m^{-2} d^{-1}) were observed.

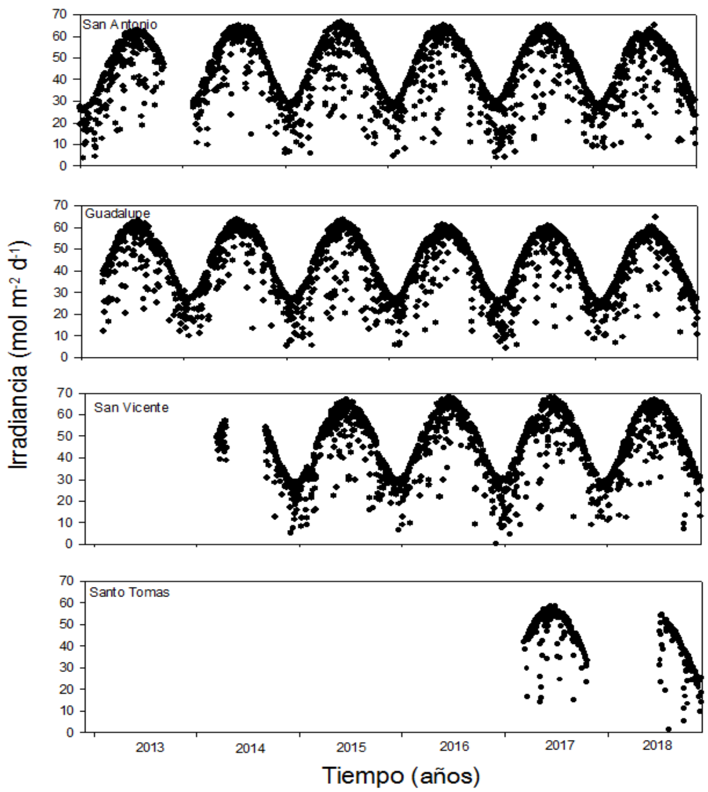

Figure 2. Daily photosynthetically active radiation (PAR) in San Antonio de las Minas, Guadalupe Valley, San Vicente and Santo Tomás.

The lower irradiances were observed in ST and are the result of the mountainous topography and shading of these mountains over the study area. Besides, the slight latitudinal difference in irradiance could also be determined by the frequency of mists. These mists are more intense in southern California, USA and decrease in frequency towards the south of the Baja California Peninsula, Mexico (Lewis *et al*., 2003).

Mists in Baja California occur during the summer and are associated with the increase in upwellings on the coast during the summer (Fischer *et al*., 2009). These upwellings near the coast carry cold water from the seabed and promote the condensation of atmospheric moisture that eventually forms mists. Towards the interior of the coast, SAM is located 10 km from the coast, receiving mists with greater recurrence, while VG, which is further from the coast (25 km) is generally not affected by mists with the same frequency (Johnstone and Dawson, 2010). Despite the differences found, the irradiance observed during the active period of the vine in the wine valleys of Baja California are sufficient to saturate the photosynthesis and ensure an adequate ripening of the fruit (Cabello-Pasini *et al*., 2017).

The rainfall pattern occurred for the same periods of time (winter) in the four wine-growing areas studied (Figure 3). The highest ($p < 0.05$) precipitation during the period 2015-2018 (291 mm) occurred in SAM and the lowest for the valleys of the southern zone (SV and ST). Rainfall for the northern valleys (SAM, VG) was almost double that of the southern valleys (ST, SV) over the study period ($p < 0.05$). A decrease in precipitation from 2014 to 2018 was observed in all areas. During 2018, the amount of rain in the four study areas was very low (<150 mm), while the year with the highest rainfall was 2015 with approximately 300 mm.

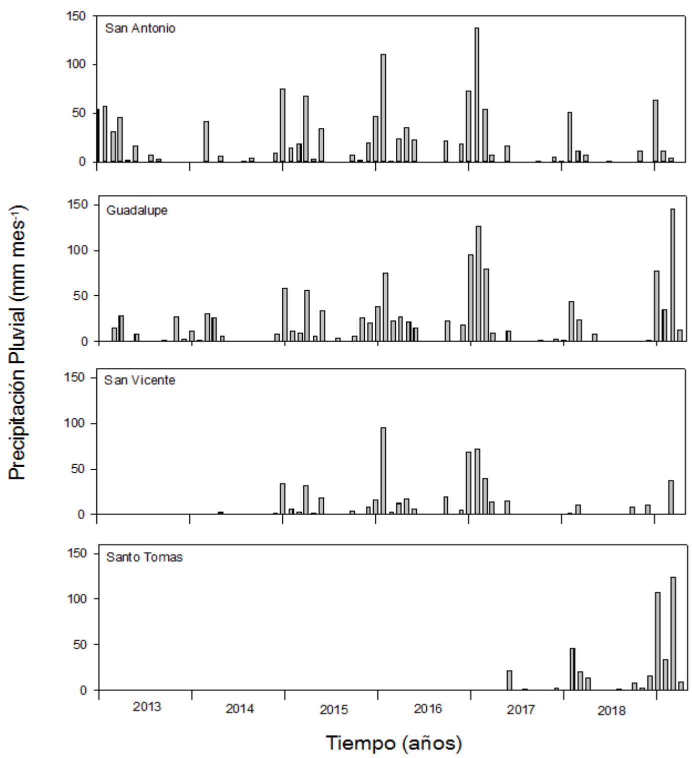

Figure 3. Daily rainfall in San Antonio de las Minas, Guadalupe Valley, San Vicente and Santo Tomás.

The relative humidity (HR) of the air showed variations in the four study areas (Figure 4). The valleys closest to the coast, SAM and SV had daily averages greater than 80% for most of the year, while in VG and ST, daily averages of less than 80% were generally observed throughout the year. The higher HR in SAM and SV are likely to increase the incidence of fungal diseases on the vine in these areas. These data are consistent with the highest amount of moisture observed in the coastal area of California in relation to the central part of the state.

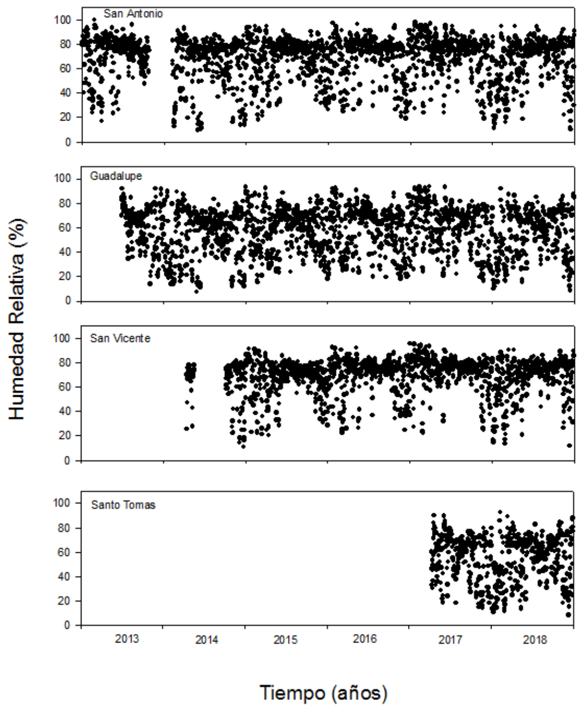

Figure 4. Daily average of relative humidity in San Antonio de las Minas, Guadalupe Valley, San Vicente and Santo Tomás.

This pattern is mainly controlled by the annual temporality, where cold and rainy winters and hot and dry summers occur. In summer, cloud and mist coverage is very common along the coast of California and Baja California, decreasing in frequency and intensity as it moves away from the coast. Altogether, the high level of relative humidity of the air in areas near the coast is the result of the evaporation of seawater and sea breezes towards the coast (Maderey, 1975). Therefore, in ST and VG, the lowest humidity percentages occurred mainly due to their topography, their remoteness from the coast and the high temperatures in these valleys.

Wind speed fluctuated significantly ($p< 0.05$) throughout the year and between the areas studied (Figure 5). Wind speed was significantly higher ($p< 0.05$) in summer and lower in autumn-winter. The speeds in summer for SAM and VG were approximately 2 m s^{-1}, while in winter, occasional maximum speeds of up to 3.2 m s^{-1} occurred. In the southern valleys, ST and SV, the wind speed in summer exceeded 2.5 m s^{-1} and in winter there were wind speed events greater than 3 m s^{-1}. In general, the subtropical high-pressure cell of the Pacific governs the climate of the northwest region of the country.

This cell has a seasonal displacement, which moves northward in summer, while in winter it moves southwards. This oscillation promotes dry and warm summers dominated by the trade winds that cross the north of the country. On the contrary, in winter, the system of westerly winds and cold fronts carry the humidity of the sea, generating winter rains and low temperatures. However, the lowest layers of wind circulation (between 4 and 10 m) are determined by the series of mountain ranges that extend from north to south along Baja California (García *et al*., 1983).

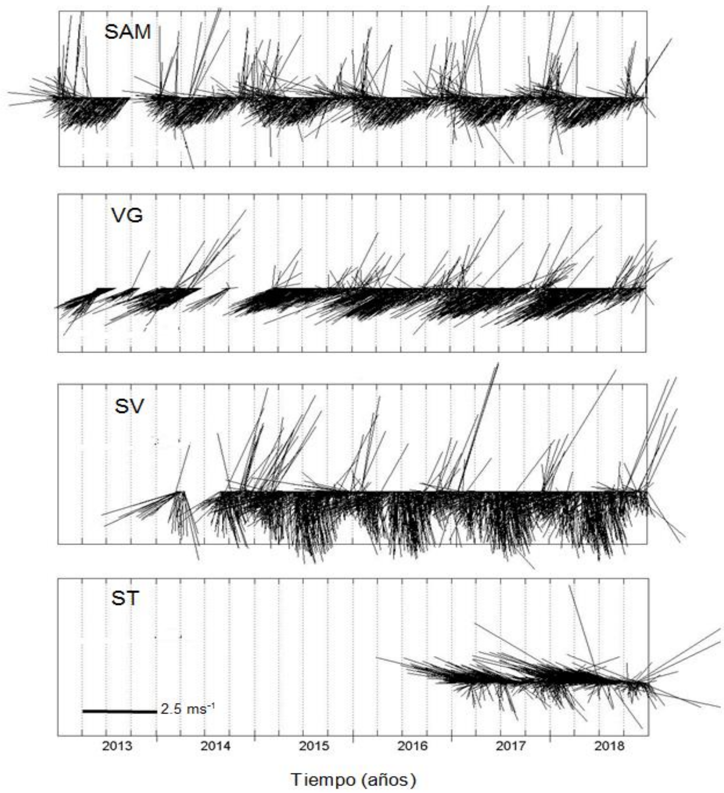

Figure 5. Wind direction and speed (m s^{-1}) in San Antonio de las Minas, Guadalupe Valley, San Vicente and Santo Tomás.

The prevailing winds in SAM and VG have a southwest orientation, while in the winter, the westerly winds have their origin in the anticyclonic cell of the Pacific. The orientation of the wind is directed towards the lower part of the mountain range that surrounds the valleys, promoting a stream of air that moves in the same direction. In SV, the prevailing wind comes from the east (Pérez-Villegas, 1988), but since it cannot cross the mountain barrier, it deviates and flows into the lower part of the valley and is guided by a canyon heading south. In ST, the winds present a northwest orientation following the direction of the valley that is surrounded by mountains that exceed 500 m in height.

Like the speed, the wind direction varied significantly throughout the year in the different valleys (Figure 6). In SAM and VG, the predominant direction throughout the year was southwesterly (SO), except for the period from November to January, where the winds were westerly (O), with short periods of northerly (N) direction and more intense speeds. The wind pattern in SV was southward during the whole year, with short periods of winds coming from the north (N) and moderate to strong speeds.

The prevailing wind direction observed in ST was from the northwest (NO); however, during the months of November to February, the direction of the prevailing wind was from the southeast (SE). The winds coming from the north in all study areas during the autumn and winters are derived from the winds of Santa Ana (Guzman-Morales and Gershunov, 2019). These winds are characterized by being warm and dry with magnitudes greater than 5 m s^{-1}, coming from desert regions, with high temperatures and low humidity.

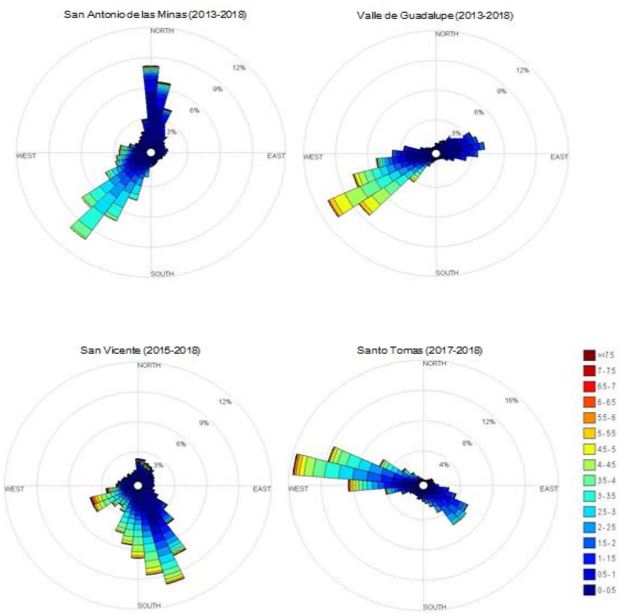

Figure 6. Wind roses, frequency (%) and speed (m s^{-1}) for San Antonio de las Minas and the Guadalupe Valley, San Vicente and Santo Tomás.

The bioclimatic indices showed significant differences between the sampling areas (Figure 7, $p< 0.05$). The least warm areas in terms of heat accumulation (GDD, HI) were SAM and SV. The mean GDD value for SAM was 2165 and for SV it was 2065, while VG and ST had values of 2 411 and 2 774, respectively. During 2016 and 2018, the distribution of GDDs behaved similarly, while for 2017, a westward shift of isolines was observed, being more evident for SAM and VG.

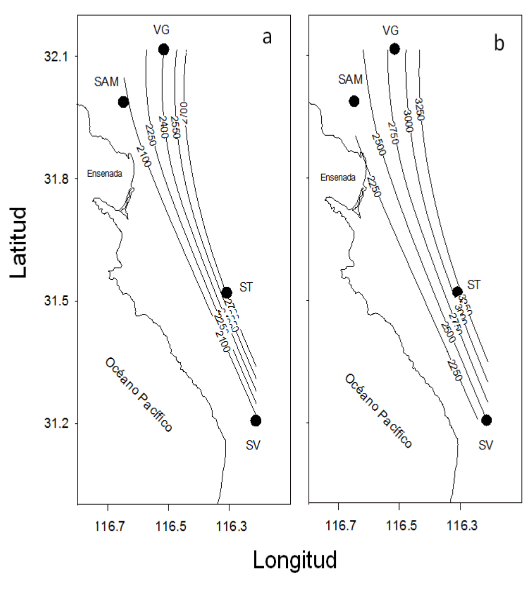

Figure 7. Isoline graphs for the growing degree days (GDD) and Huglin index for the Guadalupe Valley (VG), San Antonio de las Minas (SAM), San Vicente (SV) and Santo Tomás (ST), during 2018.

The Huglin index showed a difference between the localities that followed the same trend as the GDDs. In general, the isolines to the southern region are closer to each other, so the distribution of the growing areas is reduced, while the dispersion that was observed to the north suggests a wider distribution for vine cultivation. The correlation between the bioclimatic indices of GDD and HI is high (r> 0.94), suggesting that these two indices capture the same climatic information (Jones *et al*., 2010). Therefore, the characteristics reflected in the HI index in this study are very similar to that defined by the GDD index.

According to the GDD index, SAM and SV are classified as region IV (Temperate-warm), which is consistent with what was observed in other studies (Valenzuela-Solano *et al*., 2014). The HI index classifies SAM and SV as temperate regions, suggesting that both zones are more suitable for vine cultivation (Jones *et al*., 2010). On the other hand, VG and ST are classified as region V, so they are considered the least suitable to produce quality wines.

This is the first study on evapotranspiration in wine valleys of Baja California and demonstrates a significant variation between these. A seasonal variation of ETo was observed in the valleys studied, with maximum values in summer and minimum values in winter (Figure 8). Summer ETo values in VG and ST (approx. 9 mm d^{-1}) were 15% higher than in SAM and SV (7.5 mm d^{-1}, $p<$ 0.05) and are consistent with those reported for agricultural areas of the south of California, USA (Knipper *et al*., 2019). The highest ETo values for VG and ST are mainly the result of higher temperatures and lower HR with respect to the other wine valleys.

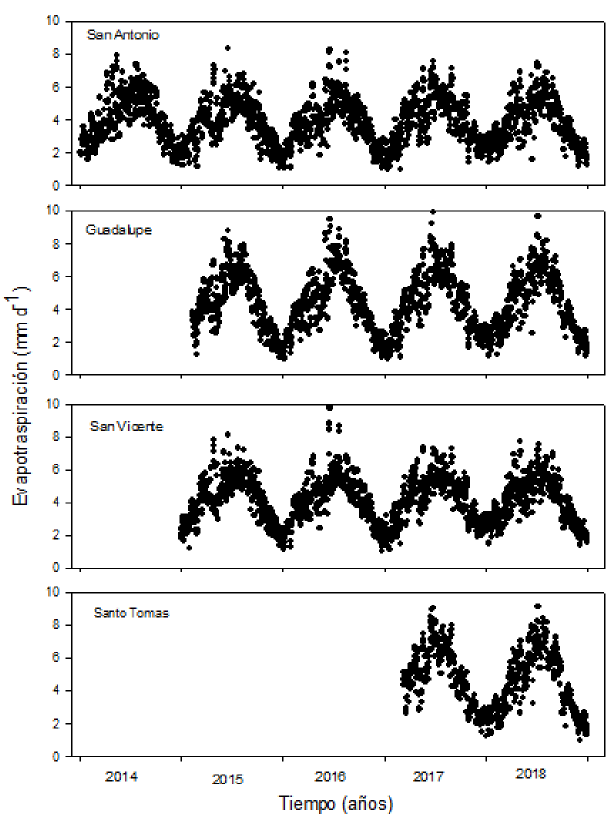

Figure 8. Evapotranspiration (mm d^{-1}) for San Antonio de las Minas, Guadalupe Valley, San Vicente and Santo Tomás.

The results suggest a higher water requirement for viticulture in VG and ST, in relation to the more coastal wine valleys. Establishing appropriate irrigation programs is critical to develop successful wine cultivations, and this can only be achieved by knowing in detail the variations in ETo throughout the year. Furthermore, it has been shown that moderate water stress programs can improve the composition or quality of grapes used for wine production (Williams *et al*., 1994).

Conclusions

The climate and soil characteristics are the two most important parameters that define the development of the vine and the ripening process of the grape. The wine valleys of Baja California presented climatic differences that critically impact on their suitability to produce quality grapes for wine production and on their demand for water resources. These differences are mainly defined by their proximity to the coast, the altitude and the orography of the place.

These climatic differences and differences in ETo surely affect the phenology, ripening and chemical characteristics of the grape. According to the classification of the climatic indices established in this research, SAM and SV had a temperate to warm climate, which suggests that both areas are more suitable for the cultivation of the vine. On the other hand, VG and ST are classified with a warm to hot climate, so they are considered as the least suitable to produce grapes and quality wines.

The meteorological data described in this paper contribute to the calculation of climatic indices and ETo differences that describe the wine regions of Baja California. The good correlation between bioclimatic indices (GDD and HI) suggests that both capture the same climate information (Jones *et al*., 2010). The results showed the climatic variability within the wine regions and will be decisive in defining the best areas for new grape cultivations in Baja California.

Cited literature

Burgess, T. M. and Webster, R. 1980. Optimal interpolation and isarithmic mapping of soil properties: The semi-variogram and punctual kriging. J. Soil Sci. 31(2):15-331.

Cabello-Pasini, A.; Macias-Carranza, V. and Mejia-Trejo, A. 2017. The effect of mesoclimate on the rippening of Nebbiolo grapes (*Vitis vinifera*) in Valle de Guadalupe, Baja California, Mexico. Agrociencia. 51(6):617-633.

Carbonneau, A.; Riou, C.; Guyon, D.; Riom, J. and Scheineider, C. 1992. Agrométéorologie de la vigne en France. Luxembourg, office des publlications officielles des communautés européennes. 169 p.

Conradie, W. J. 1983. Liming and choice of rootstock as cultural techniques for vines in acid soils. S. Afr. J. Enol. Vitic. 4(2):39-44.

Conradie, W. J.; Carey, V. A.; Bonnardot, V.; Saayman, D. and Van-Schoor, L. H. 2002. Effect of different environmental factors on the performance of sauvignon Blanc grapevines in the stellenbosch/Durbanville districts of South Africa. I. Geology, soil, climate, phenology and grape composition. S. Afr. J. Enol. Vitic. 23(2):78-91.

Del-Toro-Guerrero, F. J. and Kretzschmar, T. 2020. Precipitation-temperature variability and drought episodes in northwest Baja California, México. J. Hydrol. Regional Studies 27:100653.

Dry, P. R.; Loveys, B.; Johnstone, A. and Saddler, L. 1998. Grapevine response to root pruning. The australian grapegrower and winemaker. Annual Technical Issue. 414(1):73-78.

Fischer, D. T.; Still, C. H. y Williams, P. A. 2009. Significance of summer fog and overcast for drought stress and ecological functioning of coastal California endemic plant species. J. Biogeogr. 36(4):783-799.

Fraga, H.; Malheiro, A. C. and Santos, J. A. 2013. Future scenarios for viticultural zoning in Europe: ensemble projections and uncertainties. Int. J. Biometeor. 57(6):909-925.

García, E.; Vidal, R.; Cardoso, M. y Hernández, M. E. 1983. Las regiones climáticas de México. Memoria de IX congreso nacional de geografía. Sociedad Mexicana de Geografía y Estadística. Guadalajara, México. 123-130 pp.

Greer, D. H. and Weedon, M. M. 2012. Modelling photosynthetic responses to temperature of grapevine (*Vitis vinifera* cv. Semillon) leaves on vines grown in a hot climate. Plant Cell Environ. 35(6):1050-1064.

Guzman-Morales, J. and Gershunov, A. 2019. Climate change suppresses Santa Ana winds of Southern California and sharpens their seasonality. Geophysical Res. Letters. 46(5):2772-2780.

Hanson, B. S.; Grattan, S. R. and Fulton, A. 2004. Agricultural salinity and drainage. Water management handbook series. publication 3375. University of California. Davis, California. 157 p.

Hidalgo, L. 1980. Caracterización microfísica del ecosistema medio-planta en los viñedos españoles. Comunicaciones INIA. Serie producción vegetal, Nº 29. (Ed). Instituto Nacional de Investigaciones Agrarias. Madrid. 255 p.

Horneck, D. S.; Ellsworth, J. W.; Hopkins, B. G.; Sullivan, D. M. and Stevens, R. G. 2007. Managing salt-affected soils for crop production. Oregon state university, Washington State University. Pacific Northwest Extension Publication PNW. 601(E):12-15.

Huglin, P. 1978. Nouveau mode d'évaluation des possibilités héliothermiques d'un milieu viticole. Comptes rendus de l'académie d'agriculture de France. 64:1117-1126.

Jackson, D. I. and Coombe, B. G. 1988. Early bunch stem necrosis a cause of poor set. Proceeding's 2nd International Symposium of cool climate viticulture and oenology, January, 1988. Auckland, New Zealand, NZ Society for Viticulture and Oenology. 72-75 pp.

Jackson, D. I. and Lombard, P. B. 1993. Environmental and management practices affecting grape composition and wine quality-a review. Am. J. Enol. Viti. 44(4):409-430.

Johnstone, J. A. and Dawson, T. E. 2010. Climatic context and eco-logical implications of summer fog decline in the coast redwood region. Proc. Nat. Acad. Sci. 107(10):4533-4538.

Jones, G.; Duff, A. A.; Hall, A. and Myers, J. W. 2010. Spatial analysis of climate in winegrape growing regions in the western United States. Am. J. Enol. Viti. 61(3):313-326.

Knipper, K. R.; Kustas, W. P.; Anderson, M. C.; Alfieri, J. G.; Prueger, J. H.; Hain, C. R.; Gao, F.; Yang, Y.; McKee, L. G.; Nieto, H. and Hipps, L. E. 2019. Evapotranspiration estimates derived using thermal-based satellite remote sensing and data fusion for irrigation management in California vineyards. Irri. Sci. 37(3):431-449.

Knipper, K. R.; Kustas, W. P.; Anderson, M. C.; Nieto, H.; Alfieri, J. G.; Prueger, J. H.; Hain, C. R.; Gao, F.; McKee, L. G.; Alsina, M. M. and Sanchez, L. 2020. Using high-spatiotemporal thermal satellite ET retrievals to monitor water use over California vineyards of different climate, vine variety and trellis design. Agricult. Water Manag. 241:106361.

Lewis, J.; Koracin, D.; Rabin, R. and Businger, J. 2003. Sea fog off the California coast: viewed in the context of transient weather systems. J. Geophy. Res.: Atmos. 108(6):1-17.

Maderey, L. E. 1975. La humedad y la vegetación en la península de Baja California. Invest. Geog. 6:73-85.

Pérez-Villegas, G. 1988. El viento superficial en el noroeste de México. Inves. Geográ. 18:31-49.

Saayman, D. 1982. Soil preparation studies: II. The effect of depth and method of soil preparation and of organic material on the performance of *Vitis vinifera* (var. Colombar) on Clovelly/Hutton soil. S. Afr. J. Enol. Vitic. 3(2):61-74.

Salgado-Tránsito, S.; Vélez, O. P.; Spínola, A. G.; Gavi, F. y Mejía, E. 2012. Efecto de la calidad de agua del acuífero Valle de Guadalupe en la salinidad de suelos agrícolas. Rev. Mex. Cienc. Agríc. 3(1):79-95.

Samani, Z. 2000. Estimating solar radiation and evapotranspiration using minimum climatological Data. J. Irrig. Drain. Eng. 126(4):265-267.

Snyder, R. L. and Eching, S. 2002. Penman-Monteith daily (24-hour) reference evapotranspiration equations for estimating ETo, ETr and HS ETo with daily data. Regents of the University of California. 1-5 pp.

Stevens, R. M.; Harvey, G. and Aspinall, D. 1995. Grapevine growth of shoots and fruit linearly correlate with water stress indices based on root-weighted soil matric potential. Aust. J. Grape Wine Res. 1(2):58-66.

Tramontini, S.; Leeuwen, C.; Domec, J. C.; Destrac-Irvine, A.; Basteau, C.; Vitali, M.; Mosbach-Schulz, O. and Lovisolo, M. 2013. Impact of soil texture and water availability on the hydraulic control of plant and grape-berry development. Plant and Soil. 368(1):215-230.

USDA. 2006. United States Department of Agriculture, Soil Mechanics Level 1. Module 3-USDA, Textural Soil Classification Study Guide.

Valenzuela-Solano, C.; Ruiz-Corral, J. A.; Ramírez-Ojeda, G. y Hernández-Martínez, R. 2014. Efectos del cambio climático sobre el potencial vitícola de Baja California, México. Rev. Mex. Cienc. Agríc. 5(10):2047-2059.

White, R. E. 2009. Understanding vineyard soils. Oxford University Press, Oxford, UK. 267 p.

Williams, L. E.; Dokoozlian, N. K. and Wample, R. L. 1994. Grape. *In*: Shaffer, B. and Anderson, P. C. (Ed.) handbook of environmental physiological of fruit crops. Temperate crops, CRC Press, Orlando. 1:83-133.

Winkler, A. J.; Cook, J. A.; Kliewer, W. M. and Lider, L. A. 1974. General viticulture. Berkley, University of California Press. 710 p.

Zarrouk, O.; Brunetti, C.; Egipto, R.; Pinheiro, C.; Genebra, T.; Gori, A.; Lopes, C. M.; Tattini, M. and Chaves, M. M. 2016. Grape ripening is regulated by deficit irrigation/elevated temperatures according to cluster position in the canopy. Front. Plant Sci. 7:1640.