Agroclimatic zoning for winemaking grape production in the State of Paraná

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ABSTRACT

Paraná is the fourth largest grape producing state in Brazil and the cultivation of *Vitis vinifera* L. cultivars for winemaking is expanding is several regions of the state. The objective of this work was to characterize the potential of wine grape production based on the Géoviticulture Multicriteria Climatic Classification System for Paraná. A 30-year database constituted of 21 IAPAR (Agronomic Institute of Paraná) meteorological stations and 455 rainfall stations from Instituto das Águas do Paraná (Paraná State Water Institute) generated the following climatic indexes: dryness index (DI), heliothermal index (HI) and cool night index (CI) for the periods of October to March and April to September. According to the results, the viticultural climate of some regions in the state of Paraná belongs to the climatic groups where are found several traditional wine-producing regions in the world, showing potential for the expansion of winemaking in the state. Viticultural climate, associated with latitude in Paraná and with thermal conditions for vine growing cycle all over the year, make production displacement possible in the West, North and Northeastern regions and the production of the best quality grapes for winemaking in the fall and winter period, due to the most favorable cold night index and the lowest rainfall volume. In the coldest regions of the state (Center, South and East), it is only possible to have one production cycle, since the risk of frosts prevents the exploration of grapes in different periods.

Key words: Climatic zoning, *Vitis vinifera* L., quality, fine wine, Géoviticulture MCC system.

INTRODUCTION

Winemaking is an economically important activity in the world. Global area, production and productivity of grapes in 2014 were 7.894,6 million of ha, 87.127,9 million t and 11 t/ha, respectively, with a production of 30.8 million t of wine (FAO 2017). In Brazil, grape growing total area in 2014 was 78.75 thousand ha with production of 1.453 thousand t and an average yield of 18.46 t/ha (IBGE 2016). Brazilian viticulture is concentrated in the Southern, Southeastern and Northeastern regions, and the main producers are the states of Rio Grande do Sul, Pernambuco, São Paulo, Paraná, Bahia, Santa Catarina and Minas Gerais, in a descending order.

Grape growing in Paraná started in 1872, when the first Italian immigrants arrived in the Curitiba Plateau, and is currently connected to the culture and traditions of several ethnic groups that live in the state. Grape growing total area in 2014 was 4746 ha, with production of 80.44 thousand t, average yield of 16.95 t/ha and production gross value of R$ 252.6 million. Table grape for winemaking involves 2.9 thousand growers, being 1.4 thousand fine grape growers and 1.5 thousand grow rustic grapes, in an average area of 1.3 ha. From the state's total area, 59.5% is of table grapes, which represents 75.4% of the total production. The varieties produced in the state are mostly fine grapes and rustic grapes, for both table as well as processing. Wine production in the state is based on rustic grapes and the participation of winemaking grapes is expanding (SEAB 2016).

Weather and climate have great influence on vine culture, delimiting its stability in different regions of the world. Vine is grown between latitudes 34ºS and 49ºN, and the *Vitis vinifera* species adapts better to areas with long and dry summers and mild winters. However, this species is grown under several climate types in the world, due to its easy adaptation to different conditions (Thomé et al., 1999). Each location has its uniqueness in regards to soil, climate and production technology, leading to specific products, which hardly ever bring the same results as those from other regions. Ricce et al. (2014) concluded that the state of Paraná has regions with low climate risk for vine culture, recommending cultivation of winemaking grapes in great part of the state, with the exception of the coast and Eastern region.

The Géoviticulture Multicriteria Climatic Classification System (MCC System) was developed to better characterize the viticultural climate of wine production regions around the world. Considering the specificity of wine production, geoviticulture applied to climate helps identify and compare the regions' viticultural climate, characterize its global variability and establish climatic groups of producing regions with some climate potential similarity (Marin et al., 2008). The MCC System has become a valuable tool for using the region's climate data and interpretation, allowing a comparison with other regions (Pommer et al., 2009).

The objective of this work was to characterize the production potential of winemaking grapes based on the MCC System for the state of Paraná, Brazil.

MATERIALS AND METHODS

The Géoviticulture Multicriteria Climatic Classification System was used to characterize zones for the production of winemaking grapes (Tonietto and Carbonneau 2004). Using a 30-year database for Paraná state, including 21 climate stations from the Agronomic Institute of Paraná and 455 rainfall stations from Instituto das Águas do Paraná (Paraná State Water Institute), the following MCC System climatic indexes were generated for production periods from October-March (classical viticultural cycle of grape production) and April-September (inverted potential cycle of grape production):

- Heliothermal Index (HI) = $\sum_{IC}^{FC} \frac{[(T-10)+(Tx-10)]}{2}.d$

where: T is the mean air temperature (ºC), Tx is the maximum air temperature (ºC), d is the coefficient related to the photoperiod, of value equal to 1.0 for latitudes below 40º. IC and FC are, respectively, the beginning and ending dates for the production period under consideration;

- Cool Night Index (CI) = Tn_{mf}

where: Tn_{mf} is the minimum air temperature (minimum mean) (ºC) of the last month of the period under consideration;

- Dryness Index (DI) = Wo + P - Tv - Es

where: Wo is the soil's initial useful hydric reserve (200 mm), P is the rainfall index (mm), Tv is the vine potential transpiration (mm) and Es is the direct evaporation from the soil (mm).

- Vine potential transpiration (Tv): = ETP*k

where: k is the coefficient that expresses the radiation absorbed by the vines (k = 0.1 for the first month, 0.3 for the second month, and 0.5 for the remaining months of the period under consideration) (Tonietto e Carbonneau 2004) and ETP is the reference evapotranspiration estimated according to Penman (1948). This work used the ETP estimated by Camargo et al. (1999).

- Soil direct evaporation (Es) = $\frac{ETP}{N}(1-k).JPm$

where: N is the number of days in a month and JPm is the number of days in the month of effective soil evaporation, estimated by dividing the monthly rainfall value by 5, which must be below or equal to N.

For the classification of the MCC System of Paraná, each index was classified according to Table 1, and compared to other fine wine producing regions, using Embrapa's database (2016).

Table 1. Classes of viticultural climate for the heliothermal index, cool night index and dryness index of the grape-growing regions (Tonietto and Carbonneau 2004).

Index	Class of viticultural climate	Acronym	Class interval
Heliothermal index, HI	Very warm	HI+3	>3000
	Warm	HI+2	>2400 ≤ 3000
	Temperate warm	HI+1	>2100 ≤ 2400
	Temperate	HI-1	>1800 ≤ 2100
	Cool	HI-2	>1500 ≤ 1800
	Very cool	HI-3	≤ 1500
Cool night index, CI (°C)	Very cool nights	CI+2	≤ 12
	Cool nights	CI+1	>12 ≤ 14
	Temperate nights	CI-1	>14 ≤ 18
	Warm nights	CI-2	> 18
Dryness index, DI (mm)	Very dry	DI+2	≤ -100
	Moderately dry	DI+1	≤ -50 > -100
	Sub-humid	DI-1	≤ 150 > 50
	Humid	DI-2	> 150

The average temperature for the growth periods of October to March and April to September for the IAPAR meteorological stations was calculated and the maturation classification proposed by Jones (2006) was used to compare to regions that produce wine of excellent quality. The average temperatures for the growth periods are: cold, from13 to 15°C; intermediate, from15 to 17°C; warm, from 17 to 19°C and very hot, from 19 to 24°C.

Regression equations were adjusted and the HI, CI and average temperature during the growth period were mapped in function of latitude, longitude and altitude across Paraná, with resolution of 90 m, using the SRTM - Shuttle Radar Topography Mission database (Miranda 2005). For DI, an interpolation by ordinary kriging was

performed. Using maps algebra, the HI, CI and DI classes were grouped in a final map, including all processing and results generation in the Arcgis 10.1 software.

RESULTS AND DISCUSSION

Based on the dryness index (DI), the period of October-March and April-September were classified as "humid". Indeed, rainfall pattern in the state of Paraná does not have a defined dry season (Pereira et al., 2008). According to Tonietto and Carbonneau (2004), this class is characterized by the absence of drought, high hydric availability (sometimes considered excessive), with the best harvest occurring in less humid areas.

Even though the DI was 200mm for the whole state in the two periods under consideration, it does not mean that there are no important differences in relation to rainfall and soil water balance. Ricce et al. (2013), evaluating climate potential for grape growing under the double pruning system in the state of Paraná, emphasizes that, in relation to soil water balance, normal hydric excess is lower in the Northern and Northwestern regions, when compared to other regions in the state. In these regions (North and Northwest), less excesses were verified in the months of March, April and August, periods in which drier years may present deficiencies. In other regions (Southwest, Center, South and in the Coast), lower surplus was also observed for these same periods; however, the surplus was higher than that of the North and Northwest, where hydric deficiencies are hardly ever observed.

For the state of São Paulo, Marin et al. (2008) observed that the Spring-Summer production period is classified according to the dryness index (DI) as humid (DI-2), affecting the berries and increasing susceptibility to fungal infections. In the fall-winter period, great part of the state of São Paulo gets a more favorable classification for wine production, with "moderate dry" DI in the North, and of "sub-humid" class in the central strip.

In regards to the heliothermal index (HI), in the period of October-March (Figure 1), the Northern, Northwestern and Western regions are classified as"very hot" for wine production. The Southwest, Central, Northern Pioneer, Higher Ribeira valley and the Coast are classified as "hot". In the highest regions of the state, in the South and East, it is classified as "temperate warm" with some regions in the municipalities of Palmas and Clevelândia as "temperate".

From April to September (Figure 1), the "very warm" class was not found in the state. In the Northeast/Southeast direction, a latitude and longitude combination conditions a gradient between the hot classes and the very cold class. However, in this period, the risk of frosts in the coldest regions of the state restricts grape cultivation.

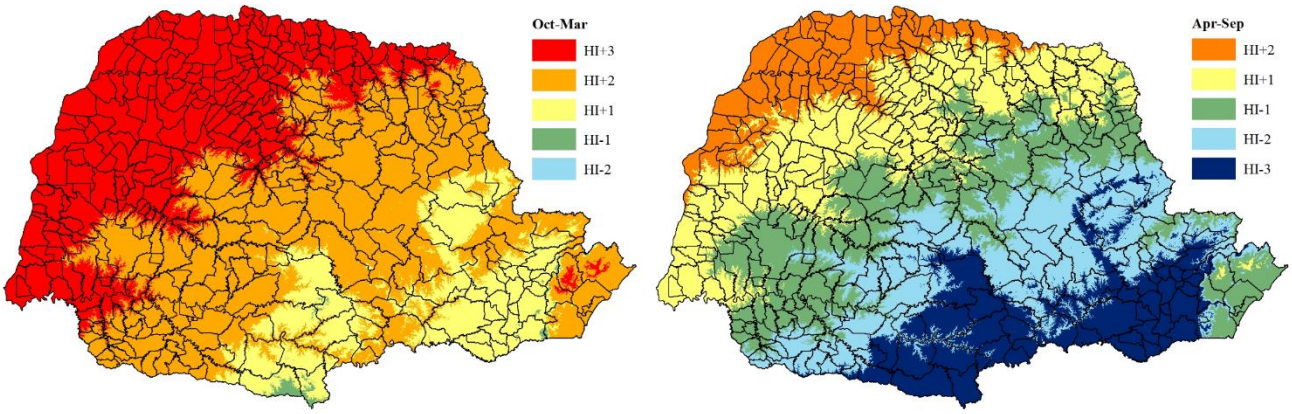

Figure 1. Heliothermal index (HI+3: very warm, HI+2: warm, HI+1: temperate warm, HI-1: temperate, HI-2: cool and HI-3: very cool) from October to March (Oct-Mar) and from April to September (Apr-Set) in Parana state, South of Brazil.

According to Tonietto and Carbonneau (2004), in classical temperate viticultural regions of the world (regions with climate potential for only one vegetative cycle per year), the HI-3 class index includes all regions that are in the inferior thermal limit for vine, where only the very early varieties reach maturity under temperate climates, especially the white varieties (Muller-Thurgau, Pinot Blanc, Gewurztraminer). Class HI-2 enables many grape varieties, whites and reds, to reach maturity, including Riesling, Pinot Noir, Chardonnay, Merlot and Cabernet Franc. The HI-1 class includes the very late varieties such as Cabernet Sauvignon, Syrah and Ugni Blanc, which can equally reach maturation. In zones where the index is classified as HI+1, there is no maturation restriction for all cultivated varieties. The HI+2 is characterized by a heliothermal potential that exceeds what the varieties need to mature and class HI+3 shows no restriction for grapes to mature and, in some regions, more than one harvest per year may occur. Thus, there is great adaptation potential for the state of Paraná, including the two cycles per year variable due to the thermal profile of some regions, typical of the some subtropical and tropical climate for viticulture.

In regards to the cold night index (CI) (Figure 2), in the October-March period, the largest part of the state shows "hot nights" characteristics. The Central, Southern and Eastern regions present "temperate nights", and the class of "cold nights" is only found in some areas of greater altitude. During the April-September period, the

warmer regions show “temperate nights”. “The “cold nights” class is found in the Southwest, Center and Alto da Ribeira and “very cold nights” in the South and East. Brighenti and Tonietto (2004) found the same “cold nights” condition in São Joaquim, state of Santa Catarina, which constitutes a differential for other producing regions in Brazil.

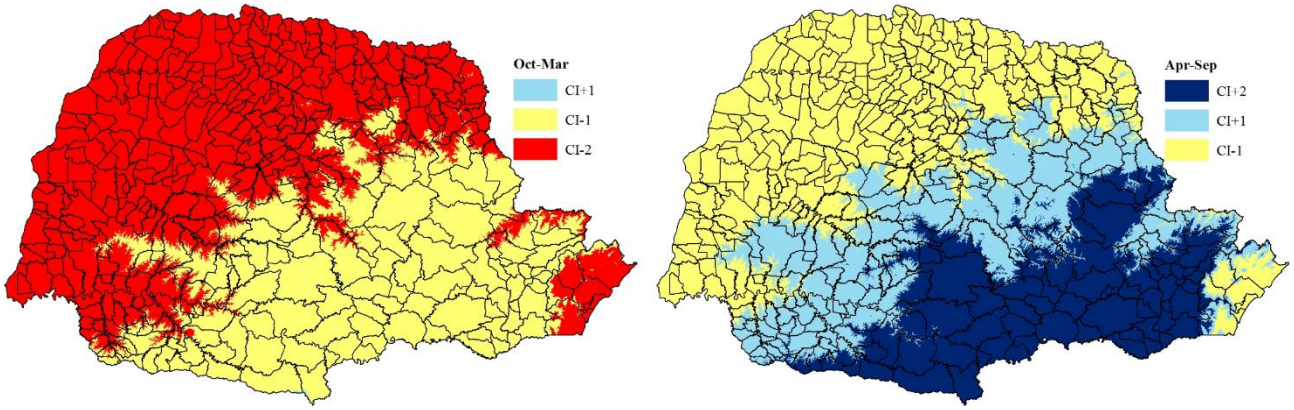

Figura 2. Cool night index (CI+2: very cool nights, CI+1: cool nights, CI-1: temperate nights and CI-2: warm nights) from October to March (Oct-Mar) and from April to September (Apr-Set) in Parana state, South of Brazil.

The CI is a grape growing climate index developed to estimate the nictothermal condition associated to the grapes maturation period (Tonietto and Carbonneau 2004). Through the night minimum temperatures, the index is an indicator of the regions’ potential characteristics in relation to the secondary metabolites (polyphenols, aromas and color) in grapes and wines. According to Tonietto and Carbonneau (2004), in CI-2 regions, all grapes varieties go through a growth period with high night temperatures until maturation, which can affect berry color and aromatic potential. In the CI-1 class, the latest varieties go to mature under lower temperature conditions at night than the early varieties. In CI+1, conditions are colder than in the CI-1class, so that a maximum limit of night with temperatures favorable to maturation will not be surpassed for any variety. In CI+2, night temperature conditions are low and their positive effects depend, above all, on a heliothermal potential that could guarantee good maturation level of grapes of a determined variety.

Winegrowing production cycle in the Paraná regions, as well as in the traditional production areas of Rio Grande do Sul and São Paulo, starts at the end of winter with production pruning, and ends with harvesting from December to February/March/April in regions where winter is more rigorous, characterizing the spring-summer production period.

In Paraná, the annual double pruning is not used with grapes for winemaking production, being adopted only for fine table grapes (Kishino et al., 2007). Nevertheless, in Southern Minas Gerais state, double pruning has been adopted for the off-season production displacement only, including one formation pruning in the winter and one production pruning in the summer (Favero et al., 2008). However, to characterize and compare winemaking regions, the MCC System climatic indexes were generated in this work for the production periods of October-March and April-September. Thus, according to the climate conditions, there is the possibility of adopting double pruning in some regions of the state of Paraná, such as the North and Northwest part (Jubileu et al., 2010), which may become the best period for winemaking grape production.

Ricce et al. (2013) concluded that the state of Paraná offers the necessary conditions for two grape growing vegetative cycles in the same year. In warmer regions, in the North and Northwest, it is possible to grow genotypes with greater thermal need, while in the coldest regions, in the South and Center-South, only genotypes with less thermal need allow for annual double harvest, since, in these regions, the occurrence of frosts limits the cultivation period.

For the October-March period (Figure 3), considered a regular harvest period, no hydric deficiency was observed, considering that the climate for the whole state is characterized as humid (DI-2). For HI, the classification was Cold (HI-2) for the highest regions in the South up to Very Hot (HI+3) for the lowest regions in the North, Northwest, West and in the Coast. For CI, the classification was Cold Nights (CI+1) for the highest regions in the South up to Hot Nights (CI- 2) for most part of the state.

The comparative analysis based on the MCC System (Embrapa 2016), allows the identification, for the period from October to March, in the state of Paraná, of the following regions that belong to the same climatic groups:

- DI-2 HI+1 CI-1: Serra do Sudeste, RS / Encruzilhada do Sul, RS and Serra Gaúcha, RS / Vale dos Vinhedos, RS;
- DI-2 HI+2 CI-1: wine growing region for this climate group was not identified by the database of the CCM system;
- DI-2 HI+2 CI-2: wine growing region for this climate group was not identified by the database of the CCM system;

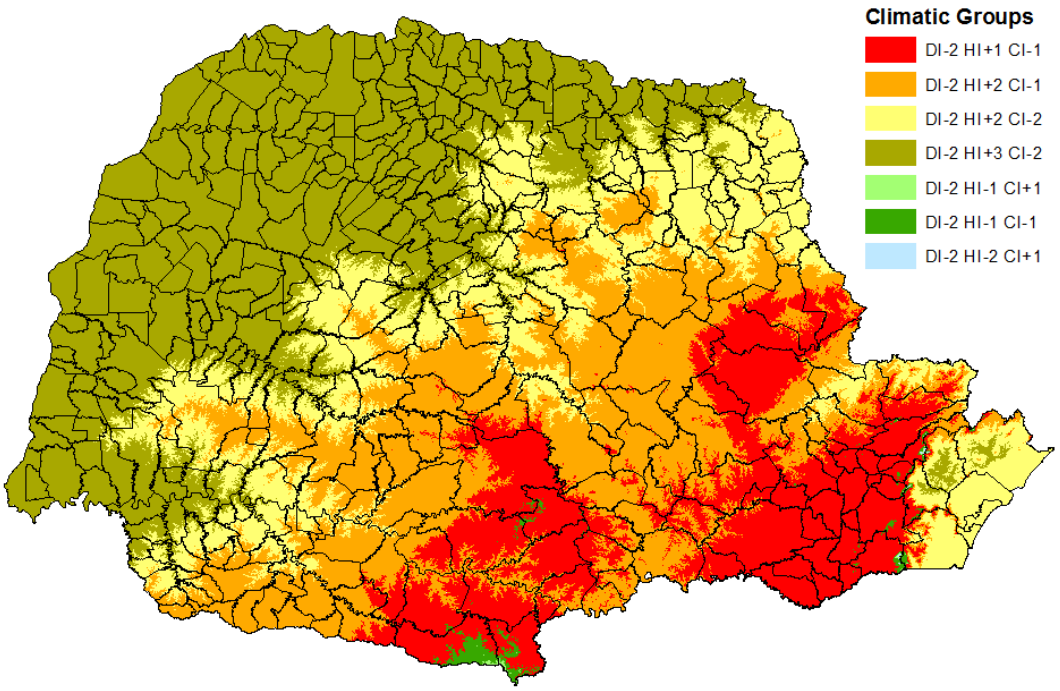

Figure 3. Geoviticulture MCC System classification of the viticultural climate in Parana state, South of Brazil, from October to March.

- DI-2 HI+3 CI-2: wine growing region for this climate group was not identified by the database of the CCM system;

- DI-2 HI-1 CI+1: Campos de Cima da Serra, RS / Vacaria, RS and Pau, France;

- DI-2 HI-1 CI-1: Beli Kriz, Slovenia; and

- DI-2 HI-2 CI+1: Catarinense Plateau/ São Joaquim, SC.

There was no hydric deficit in Paraná during the April to September period (Figure 4), even though this is a period with less rainfall, being the whole state characterized as humid (DI-2). For HI, the classification was Very Cold (HI-3) for the highest regions in the South and Hot (HI+2) for the lowest regions in the North and Northwest of the state. CI was classified as very cold nights (CI+2) for the highest regions in the South up to temperate nights (CI-1) in great part of the state. Before recommending cultivation in this period, it is necessary to conduct a frost risk analysis, since the incidence of such events in the South may affect the production.

The comparative analysis based on the MCC System (Embrapa 2016), allows the identification, for the period from Abril to September, in the state of Paraná, of the following regions from the same climatic groups:

- DI- 2 HI+1 CI-1: Serra do Sudeste, RS / Encruzilhada do Sul, RS and Serra Gaúcha, RS / Vale dos Vinhedos, RS;

- DI-2 HI+2 CI-1: wine growing region for this climate group was not identified by the database of the CCM system;

- DI-2 HI-1 CI+1: Campos de Cima da Serra, RS / Vacaria, RS and Pau, France;

- DI-2 HI-1 CI-1: Beli Kriz, Slovenia;

- DI-2 HI-2 CI+1: Catarinense Plateau / São Joaquim, SC;

- DI-2 HI-2 CI+2: Freiburg, Geiseinheim and Neustadt in Germany; Bizeljsko, Murska Sobota and Novo Mesto in Slovenia; Besançon, France; Genève, Switzerland; and

- DI-2 HI-3 CI+2: Stuttgart, Trier and Würzburg in Germany; Quebec, Canada; Maidstone, UK.

The MCC System has been used in several Brazilian regions. For Minas Gerais, Conceição and Tonietto (2005),

using the same methodology, concluded that the Northern region of the State has great climate potential to become a winemaking grape growing regions, especially for the off-season production, in the period of Fall and Winter. They found regions belonging to the same climatic group of Bordeaux and Cognac in France and Murcia in Spain.

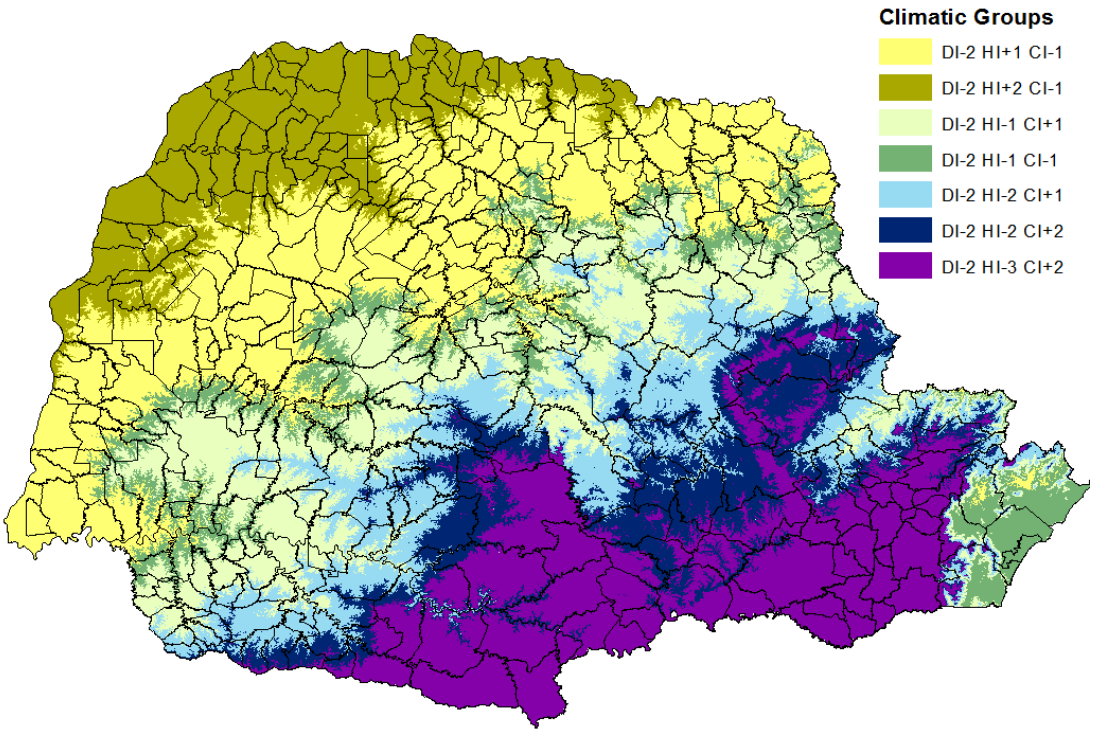

Figure 4. Geoviticulture MCC System classification of the viticultural climate of Parana state, South of Brazil, from April to September.

For the county of Campos dos Goytacazes in Northern Rio de Janeiro state, Pommer et al. (2009) also using this methodology for several cultivation periods, concluded that the best periods for vine exploration, from pruning to harvesting, are those that coincide with lower temperatures (HI+2), with the presence of moderate drought (DI+1) and temperate nights (CI-1). The authors found classifications in the same climatic groups of the Pirapora, Montes Claros, table grapes producing regions in Minas Gerais and of Murcia, Spain.

Brighenti and Tonietto (2004) verified that the São Joaquim valley, SC, has a wine growing climate different from other fine wine producing regions in Brazil, mainly in relation to cycle thermal and nictothermal of maturity criteria. Such climate, at the global level, is also different from other wine growing regions from the same climate group of São Joaquim, as a result, specially, of its geographical location, in a lower latitude, when compared to traditional wine cultivation regions with the same wine growing climate.

In São Paulo state, Marin et al. (2008) found climate similarities among the wine producing regions of Bento Gonçalves in Rio Grande do Sul, Beli Kriz in Slovenia, Tarragona in Spain, Ajjacio, Bastia, Braga, Bordeaux, Carcassone, Pau and Toulouse in France, Pune, in India, Ravenna in Italy, Kofu in Japan, Napier in New Zealand, Bangkok and Chiangmai in Thailand and Las Brujas in Uruguai. Bardin-Camparotto et al. (2014), by using the CCM system to characterize climate potential for grape production in the São Paulo - Circuito das Frutas region, concluded that wine producing climate of the HI class for the summer harvest were “warm”, “temperate warm”, “temperate”; CI “warm nights” or “temperate nights”, and DI “humid”. For the winter cycle, however, the DI values were kept high, with the following climate classes: “warm”, “temperate warm” and “temperate” for the HI and “very cold nights” for CI.

Indicators related to the framing of the Paraná regions into climatic regions, where other wine production regions in the world are also found, must be analyzed carefully. The lower latitude conditions in the state of Paraná affects the thermal dynamics along the year, generating a unique climate profile in relation to the classical temperate climate regions around the world. Similarly, the state of Paraná regions with wine producing climate with intra annual variability, typical of tropical viticulture, in which more than one wine producing cycle per year is possible, creating opportunities for unique wine producing climate in relation to those found in classic vitiviniculture around the world.

The use of the Géoviticulture Multicriteria Climatic Classification System for the state of Paraná can become an important tool to evaluate the production potential of fine grapes for winemaking. Despite its little tradition in grape production, the state has regions with potential for the production of quality grapes, even when compared with regions of great importance in the global scenario. Even though the Paraná regions show similar conditions, the local climate variation may lead to the production of the same varieties of grapes with distinct quality.

The state of Paraná has regions with potential for two fine table grapes vegetative cycles (*Vitis vinifera*) (Ricce et al., 2013). However, for winemaking grapes, production displacement for the most favorable climate period is more important than having two harvests annually, mainly to reduce the risk of mildew, the most severe fungal disease in areas of warm and humid climate (Genta et al., 2010). Jubileu et al. (2010) concluded that the grapes 'Cabernet Sauvignon' and 'Alicante', grown during the off-season in Northern Paraná, show late cycle and high yield, and grape bunches occurs under favorable climate conditions, between May and June, resulting in adequate grapes for red wine production. Sato et al. (2011) concluded that during the off-season production of the 'Alicante' and 'Syrah' vines, bunches have an excellent phytosanitary aspect, with good potential to produce fine wines.

According to Figure 5, from October to March, the average temperature class during the growth period is considered very warm in some Southern regions and part of the East of the state, also considered warm regions. From April to September, the central, Southern and Eastern parts of the state are classified as intermediate and cold; however, in these regions, the risk of frosts prevents cultivation.

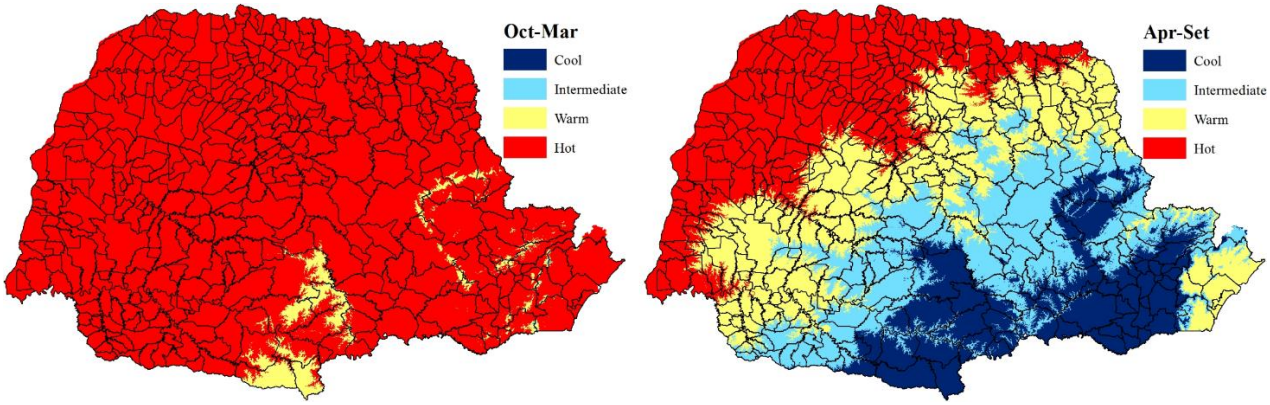

Figure 5. Climatic classification for grapevine cultivars according to Jones (2006), from October to March and from April to September in Parana state, South of Brazil.

According to Jones (2006) there is, for each class, a group of winemaking grapes that best expresses their qualities. For the cold class, there are the grapes Muller-Thurgau, Pinot Gris, Gewurztraminer and Riesling. For the intermediated class the grapes Riesling, Pinot Noir, Chardonnay, Sauvignon Blanc, Sémillon, Cabernet Franc, for the warm class the grapes Cabernet Franc, Tempranillo, Dolcetto, Merlot, Malbec, Viognier, Syrah, Cabernet Sauvignon, Grenache, Carignane, Zinfandel, Nebbiolo, and for the very hot class, the fine table grapes and raisins.

The classification generated by this work, associated to the MCC System of the viticultural climate of Paraná State, makes the determination of regions and periods with greater potential for winemaking grapes possible and points out to the most adequate varieties, promoting the diversification of the current grape production system in the state of Paraná. However, it is important to consider that only the coldest regions in the state, the Center, South and East, it is possible to obtain a productive cycle, since the risk of frosts prevents the exploration of grapes in different periods.

CONCLUSIONS

Paraná has regions similar to the climatic groups of several traditional fine wine producing regions in the world, showing its potential for winemaking expansion in the state.

Climatic groups, associated to latitude, create the possibility of dislocating production in the West, East, North and Northeast regions, making the production of better quality grapes for winemaking possible in the fall- winter period, due to the more favorable heliothermic and cool night indexes and low rainfall.

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