Agro-Climatic Suitability Delimitation for Table and Wine Grape Crops under Irrigation Conditions in Northeastern Brazil

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Abstract

Long term weather data were used together with specific regression models involving crop coefficient (K_c), reference evapotranspiration (ET_0), accumulated degree days (DD_{ac}) and precipitation (P), to develop a vineyard water indicator (VWI) for seedless table and wine grapes under different pruning periods in the Brazilian Northeast. The VWI thermo-hydrological indicator was applied together with average values of air temperature (T) for a growing season (GS) to classify the vineyard agro-climatic suitability. For table grapes, the seedless cv. 'Sugraone' used as a reference, it was observed that the region has no thermal limitation for commercial grape production. However, higher sugar contents in berries and yield would be obtained in the areas and pruning periods with higher T_{GS}. In relation to wine grape, cv. 'Syrah' taking as a reference, it was shown that there are some thermal limitations for the tropical wine quality. This is depending on pruning dates, lower acidity and higher potential alcohol and pH. In wines analyzed under conditions of larger T_{GS} values, wines became unbalanced in terms of phenolic and aromatic composition. Considering the whole Brazilian Northeast region, for table grapes the best pruning periods is from July to September, while for wine grapes they are between April and June. The spatially presented analyses can subsidize vineyard water allocation criterions, when aiming at improvements of grape and wine water productivity in conditions of climate and land use changes.

INTRODUCTION

The distribution of vineyards in the world depends on solar radiation, air temperature, atmospheric humidity and soil moisture, which all influence the photosynthetic activity and evapotranspiration (ET). Grapevine phenology, grape yield and wine quality are very dependent on these climatic parameters Vineyard water management is very important for potential adaptations to extreme climate conditions (Gladstones et al., 2004; Teixeira, 2009). The optimum air temperature (T) range for plant development is considered to be between 25 and 30°C (Costacurta and Roselli, 1980). Above 30°C the weight and size of the grapes are reduced and the metabolic processes are decreased under conditions of T values near 45°C. When they are lower than 20°C, photosynthesis is reduced (Coombe, 1987). High T values increase the sugar concentration in berries while low T reduces the acid content (Keller, 2010). Wines produced under warmer conditions present high alcohol content, lower acidity and high pH values, affecting negatively the intensity and quality of aroma, colour and wine longevity (Orduña, 2010).

From the thermo-hydrological point of view, hot conditions directly affect vineyard water requirements (Teixeira, 2009). On the other hand, T values above 30°C increase the concentration of soluble solids. However, large brix values may be correlated with high ET rates (Keller, 2010). T influences ET because the hot air near the vine canopies transfers energy increasing water fluxes (Teixeira et al., 2007). Climates with low rainfall amounts are the most suitable for commercial irrigated vine crops since rain causes direct damage on grapes and the consequent high air moisture increases the risk of disease infection. However, the low soil moisture in dry climates brings the need for irrigation based on vineyard water requirements, with table grapes being more sensitive to excess of precipitation than wine grapes. (Teixeira, 2009).

Vineyard ET has been quantified in the Brazilian semi-arid conditions by point measurements (Teixeira et al., 2007; Azevedo et al., 2008). To upscale these punctual results, tools like remote sensing and Geographic Information System (GIS) can be used (Teixeira, 2010). For the vineyard climatic suitability delimitation, aiming at good productions of grapes and elaboration of tropical wine, one can apply bioclimatic indices considering the thermo-hydrological conditions by using a SIG and long term weather data. In the current research ET under optimum soil moisture conditions (ET_p) is considered as the vineyard water requirements (VWR). From the thermal side, the average values of the mean air temperature for a growing season (T_{GS}) are used for qualification of grapes and wine produced in the Brazilian Northeast, varying the pruning dates. The objective was the development and application of bioclimatic indices on a large scale, to subsidize criteria for the rational expansion of commercial irrigated table and wine grapes lowering the risks of environmental injuries while increasing the possibilities of success.

MATERIAL AND METHODS

Figure 1 shows the location of the Northeast region in Brazil with the states division and the agrometeorological stations used for the interpolation processes. The monthly total precipitation data available from rain gauge measurements were from SUDENE (Northeast Development Superintendence) referred to 1455 locations, while the monthly mean air temperature data were taken from INMET (National Meteorological Institute) recorded in 75 conventional agrometeorological stations. Both meteorological parameters were long term values for the period from 1961 to 1990.

In the locations with only precipitation data available, monthly air temperature (T_{month}) values were estimated from the geographic coordinates. As the air temperature data is easier to be obtained for the whole Brazilian Northeast than the others meteorological parameters involved in the water vapour transfer, the Thornthwaite method, which need only monthly values of T_{month} as an meteorological input parameter, was first applied to retrieve the monthly reference evapotranspiration ($ET0_{TH}$) by using the available or estimated T_{month} data from conventional agrometeorological stations (Thornthwaite, 1948).

Field measurements of ET_p in seedless table grape, cv. 'Sugraone', and wine grape, cv. 'Syrah', together with reference evapotranspiration for a grassed surface by the Penman-Monteith method – ET_{0PM} (Allen et al., 1998) allowed the acquirement of the crop coefficient values (K_c) over the growing seasons (Teixeira et al., 2007). Daily data of solar radiation, air temperature, relative humidity and wind speed were used to calculate the daily ET_{0PM} and summed up to obtain the monthly values. A model based on the relation of Kc and the accumulated degree days (DD_{ac}) was then developed in the current study and used to retrieve ET_p after applying regression equations for calibrating $ET0_{TH}$ into $ET0_{PM}$ throughout regression equations. Seven automatic agrometeorological stations in the semiarid conditions of Brazil were used for this calibration.

The ET_p for one growing season (GS) was considered as the vineyard water requirements considering an average GS of three and four months for table and wine grapes, respectively (VWR_{GS}). Taking four and five modelled values of K_c, according to the type of grape, from DD_{ac} and a base air temperature (T_b) of 10°C, being the initial values for DD_{ac} zero and considering the monthly accumulated values during a GS, the average crop coefficients (Kc_{GS}) were multiplied by the $ET0_{GS}$ values:

$$VWR_{GS} = Kc_{GS} ET0_{GS} \quad (1)$$

A vineyard water indicator (VWI_{GS}) was then developed and applied for the table and wine grapes climatic suitability delimitation in the Brazilian Northeast, varying the pruning dates along the year:

$$VWI_{GS} = \frac{P_{GS}}{VWI_{GS}} \quad (2)$$

Air temperature and precipitation data were interpolated in a Geographic Information System (GIS) environment and the models were applied to their grids. Four classes of climatic suitability were considered for both kind of grape crops, according to the VWI_{GS} values with the first two being subdivided according to the mean T_{GS} values.

The indicator represented by Eq. 2 enables the characterization of the water component of the climate, taking into account vineyard water demand and rainfall. It indicates the potential moisture availability in the soil. VWI_{GS} values much higher than 1.00 indicate unsuitable conditions, due to problems of moisture excess, while low ones are related to natural water deficiencies and the degree of irrigation needs according to the grape crop stages.

Base criteria for dividing the Northeastern region into four classes (C1, C2, C3 and C4) of vineyard thermo-hydrological conditions were used. First, the VWI_{GS} values were considered the most important factor, as the excessive moisture are not suitable for both, table and wine grape crop. As warmer conditions affect the berries and wine quality, the most suitable areas in relation to moisture conditions, were classified according to a T_{GS} threshold value.

RESULTS AND DISCUSSION

As the agro-climatic suitability delimitation considers thermal and moisture conditions, first some analyses were done with the average values of T_{GS} and VWI_{GS} for both, table and wine grapes, in the Northeastern Brazilian states. Different GS durations and pruning dates along the year were considered.

Table 1 shows the average T_{GS} values. Considering the entire Brazilian Northeast region, pruning dates from September to October presented higher values for both table (TG) and wine grapes (WG) with GS of three to four months duration (T_{GS} around 25.8°C). These pruning periods should be better for table grapes because of the higher sugar content in the berries. They are not well suited when aiming at increased quality of tropical wines since the intensity and quality of aroma, colour and wine longevity is adversely affected. From the thermal point of view, the states of Maranhão-MA, Alagoas-AL and Bahia-BA, with a mean T_{GS} bellow 24°C, are the best ones for wine, while the other states seems to be better for table grape production. It was observed that growing seasons in the Brazilian Northeast region with T_{GS} values around this threshold value have several situations with thermal conditions above 30°C which contribute to reductions in weight and size of the grapes and decreases of the metabolic processes.

Table 2 shows the mean VWI_{GS} values per state. The highest values of this indicator occur during the rainy periods from January to April, indicating that, in general, pruning dates inside this period are not suitable for commercial vineyards. Considering the moisture conditions, the best pruning dates are during the middle of the year when the lowest VWI_{GS} values occur. The State of Maranhão-MA appears as the most problematic for commercial vineyards, while Rio Grande do Norte-RN presents the best moisture conditions for grapes. Considering all the Northeast region, pruning in January is the worst period with average VWI_{GS} values of 1.23 and 1.65, for TG and WG, respectively. On the other hand, the best conditions are when the pruning is done in July, when they are, in average, respectively, 0.19 and 0.27 for TG and WG. Considering all pruning periods of the year, the average values are 0.61 and 0.86 for TG and WG, respectively. One can conclude from the VWI_{GS} analyses that varieties with shorter GS have more chances of success in the Brazilian Northeast region.

Considering the GS thermo-hydrological conditions under different pruning dates along the year, the classification of areas with different degree of agro-climatic suitability was done. As air temperature and water conditions affect differently table and wine grapes, distinct criteria were used. For TG, high sugar content is desired and this situation happens at high T_{GS} values (Keller, 2010). As in the Brazilian Northeast the thermal conditions are inside of the acceptable limits for vineyards (Table 1), it was concluded that the hottest areas are the most favourable, while water excess in some areas and pruning dates may affect more the quality and productivity of TG than for WG (Teixeira et al., 2007).

Base criteria for dividing the Brazilian Northeast region into four classes (C1, C2, C3 and C4) of vineyard thermo-hydrological conditions were used. First, the VWI_{GS} values were considered the most important factor, as the excessive moisture unsuitable for both, table and wine grape crop. When VWI_{GS} values are lower or equal to 1.50 or 2.00 (classes C1 and C2) according to the variety being respectively TG or WG, the moisture conditions are the best lowering the risk of plant diseases, root respiration problems and direct damage to the fruits promoted by rain. Consequently, they favour better quality of grapes, must and wine. According to yield data from the Brazilian Geographical and Statistical Institute (IBGE), the commercial vineyard growing areas with good yield are concentrated under these moisture conditions in the Brazilian Northeaster region (Teixeira, 2009).

For TG, two classes of climatic suitability (C1 and C2) were considered, with VWI_{GS} values lower or equal to 1.50 and according to the T_{GS} threshold value of 24.0°C. C1 areas were those with T_{GS} above and C2 class were those areas bellow this value. Although both classes have suitable moisture conditions for irrigated table grapes, as long as the T_{GS} increases beyond this threshold value, the sugar content in berries will increase if the ranges of air temperature values in the Brazilian Northeastern region are inside of the suitable thermal conditions for the vineyard photosynthetic processes.

In situations of VWI_{GS} higher than 1.50, an increase of commercial seedless table grape areas are, according to yield data from IBGE, reduced. A class with VWI_{GS} higher than 1.50 and lower or equal to 3.50 was then considered as an intermediary one. If the natural moisture increases, the table grape yield should be affected, independently of the thermal conditions. Areas and pruning dates inside the worst class (VWI_{GS} higher than 3.50) should present the biggest problems for TG yield due to high levels of natural humidity that compromise the berries sanity and direct injuries by rains.

Figure 2 shows the results for the agro-climatic classification for the seedless TG cv. 'Sugraone', representing a vineyard with GS duration of three months. As the GS length is shorter than that for the WG, it is possible to make a pruning schedule with lower damages caused by the rainfall excesses. The best options (classes C1 and C2) are for pruning periods from August to September in the west sides of the states of Bahia-BA, Pernambuco-PE and Paraíba-PB, and almost all areas of Rio Grande do Norte-RN, Ceará-CE, Piauí-PI and Maranhão-MA. The worst class C4 appears only in the Maranhão-MA state. Even though it is influenced by the Amazon climate, some areas classified as C1 are verified for pruning periods from July to September. The areas climatologically more suited for table grape growing present high thermal availability and low natural moisture having then a higher potential for the crop under irrigation conditions.

In relation to wine grape, taking the cv. 'Syrah' as a reference, the same indicators but with different criteria for the agro-climatic classification were used. From the thermal point of view, high air temperatures will increase alcohol levels and pH, while reducing the acidity, what is undesired for commercial tropical wine production (Orduna, 2010). From the moisture point of view excess rainfall is less problematic than it is for TG, being so considered IHV_{GS} limits slightly higher for WG based on field observations (Teixeira et al., 2007).

As for TG, four classes of agro-climatic suitability were also considered. They are presented in Figure 3 considering the elaboration of commercial typical tropical wines. C1 areas are those with T_{GS} below 24°C and C2 areas are those with values above this limit. The latter class has suitable moisture conditions for irrigated grapes as long as the air temperature increases above this threshold value. However, wine quality should be affected by high levels of alcohol, low acidity and large pH values, becoming unbalanced with instability of the phenolic and aromatic composition. A class with VWI_{GS} higher than 2.00 and lower or equal to 4.00 was considered as an intermediary one. If the natural moisture increases, the wine quality should be affected, independently of the thermal conditions. Areas and pruning dates inside the worst class, those having VWI_{GS} higher than 4.00, should present the biggest problems for tropical wine quality due to high levels of natural humidity that compromise the grape sanity and the enological potential (Teixeira, 2009).

For wine grapes with four months GS duration, the best options for typical wine commercial elaboration are for pruning dates between May and June in the states of Bahia-BA, Pernambuco-PE, Alagoas-AL and Sergipe-SE, and the west side of Maranhão-MA, while the classes C3 and C4 only occur when the pruning is done from December to February and January to March, respectively.

CONCLUSIONS

Regression models, based on the crop coefficient, reference evapotranspiration and accumulated degree days, together with long-term precipitation and air temperature data, allowed the development of bioclimatic indices for agro-climatic suitability classification of table and wine grapes in the Brazilian Northeast region. Different criteria between table and wine grape had to be considered for the classification of vineyard agro-climatic suitability. The best options of commercial production of table grapes are the west side of the states of Bahia-BA, Pernambuco-PE and Paraíba-PB, and almost all areas of Rio Grande do Norte-RN, Ceará-CE, Piauí-PI and Maranhão-MA, when the pruning is done from July to September. The best options for typical commercial wine production are the states of Bahia-BA, Pernambuco-PE, Alagoas-AL and Sergipe-SE, and the west side of Maranhão-MA with pruning dates between May and June. Finding the limits of vineyard agro-climatic suitability delimitation is together with other ecological characteristics important in situations of climate and land use changes to ensure improvements in vineyard water productivities.

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Tables

Table 1. Monthly averages of the growing season air temperatures (T_{GS}) for wine (WG) and table (TG) grape, respectively, in the Brazilian Northeastern states of Maranhão (MA), Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Alagoas (AL), Sergipe (SE) and Bahia (BA), for different pruning dates.

Pruning date/ Grape	T_{GS_MA} (ºC)		T_{GS_PI} (ºC)		T_{GS_CE} (ºC)		T_{GS_RN} (ºC)		T_{GS_PB} (ºC)		T_{GS_PE} (ºC)		T_{GS_AL} (ºC)		T_{GS_SE} (ºC)		T_{GS_BA} (ºC)	
	WG	TG	WG	TG	WG	TG	G	TG	WG	TG	WG	TG	WG	TG	WG	TG	WG	TG
Jan	22.5	22.7	24.9	25.1	25.7	25.9	25.9	26.2	24.8	25.3	24.7	25.2	24.5	25.1	25.4	25.8	24.2	24.6
Feb	22.4	22.2	24.5	24.7	25.2	25.2	25.3	25.6	24.2	24.5	23.9	24.3	23.8	24.2	24.6	25.1	23.4	23.9
Mar	22.2	22.2	24.0	24.2	25.1	25.1	24.8	25.1	23.5	23.8	23.1	23.5	22.8	23.2	23.5	24.1	22.5	22.9
Apr	22.7	22.4	24.0	23.7	25.2	25.0	24.6	24.5	23.2	23.2	22.7	22.6	22.1	22.2	22.8	22.9	22.1	21.9
May	23.5	23.1	24.6	23.9	25.7	25.4	24.8	24.5	23.4	23.1	23.0	22.6	22.0	21.7	22.5	22.4	22.3	21.9
Jun	24.4	23.6	25.6	24.8	26.2	25.9	25.1	24.8	23.9	23.5	23.6	23.0	22.5	21.9	23.0	22.5	23.2	22.5
Jul	25.3	25.1	26.6	26.4	26.7	26.5	25.7	25.5	24.7	24.3	24.6	24.1	23.4	22.8	23.9	23.3	24.0	23.9
Aug	25.2	25.8	26.9	27.2	27.0	26.9	26.2	26.0	25.3	25.1	25.3	25.1	24.3	23.9	24.7	24.3	24.4	24.4
Sep	25.0	25.4	26.7	27.0	27.1	27.1	26.5	26.4	25.7	25.6	25.7	25.7	24.9	24.8	25.4	25.3	24.6	24.6
Oct	24.0	24.3	26.1	26.3	27.0	27.1	26.7	26.6	25.9	25.8	25.8	25.8	25.2	25.1	25.8	25.7	24.5	24.4
Nov	23.4	23.5	25.6	25.8	26.6	27.0	26.6	26.7	25.7	25.9	25.6	25.8	25.3	25.3	25.9	25.8	24.6	24.5
Dec	23.0	23.3	25.3	25.5	26.2	26.5	26.3	26.5	25.4	25.6	25.3	25.6	25.1	25.3	25.8	26.0	24.6	24.7
Mean	23.6		25.4		26.1		25.7		24.6		24.4		23.8		24.4		23.7	

Table 2. Monthly averages of the vineyard water indicator (VWI_{GS}) for wine (WG) and table (TG) grape, respectively, in the Brazilian Northeastern states of Maranhão (MA), Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Alagoas (AL), Sergipe (SE) and Bahia (BA), for different pruning dates.

Prune date/ Grape	IH_{GS_MA} (ºC)		IH_{GS_PI} (ºC)		IH_{GS_CE} (ºC)		IH_{GS_RN} (ºC)		IH_{GS_PB} (ºC)		IH_{GS_PE} (ºC)		IH_{GS_AL} (ºC)		IH_{GS_SE} (ºC)		IH_{GS_BA} (ºC)	
	WG	TG	WG	TG	WG	TG	WG	TG	WG	TG	WG	TG	WG	TG	WG	TG	WG	TG
Jan	3.26	2.65	1.85	1.55	1.86	1.39	1.43	1.02	1.47	1.07	1.28	0.94	1.25	0.77	1.30	0.71	1.15	0.94
Feb	2.68	2.35	1.42	1.20	1.78	1.44	1.52	1.13	1.57	1.16	1.32	0.96	1.58	1.01	1.69	1.04	0.91	0.69
Mar	1.75	1.52	0.79	0.66	1.16	0.95	1.18	0.88	1.28	0.94	1.10	0.79	1.73	1.15	1.96	1.28	0.67	0.49
Apr	0.82	0.77	0.25	0.24	0.51	0.47	0.68	0.60	0.81	0.71	0.75	0.66	1.49	1.28	1.75	1.44	0.44	0.37
May	0.41	0.31	0.11	0.07	0.20	0.17	0.38	0.34	0.52	0.46	0.52	0.46	1.11	0.97	1.31	1.11	0.36	0.28
Jun	0.31	0.21	0.15	0.06	0.08	0.07	0.17	0.18	0.27	0.28	0.29	0.29	0.61	0.65	0.75	0.77	0.34	0.23
Jul	0.37	0.22	0.28	0.12	0.05	0.03	0.08	0.07	0.15	0.13	0.19	0.15	0.35	0.33	0.47	0.43	0.49	0.26
Aug	0.57	0.34	0.49	0.28	0.10	0.04	0.08	0.04	0.14	0.09	0.22	0.14	0.26	0.21	0.35	0.30	0.67	0.46
Sep	0.77	0.55	0.69	0.48	0.15	0.09	0.10	0.06	0.16	0.11	0.27	0.19	0.24	0.19	0.31	0.25	0.86	0.67
Oct	1.48	0.75	1.21	0.65	0.38	0.14	0.23	0.09	0.33	0.15	0.48	0.25	0.36	0.21	0.41	0.26	1.28	0.83
Nov	2.23	1.19	1.63	0.88	0.94	0.30	0.65	0.18	0.74	0.26	0.81	0.36	0.59	0.27	0.55	0.27	1.34	0.88
Dec	2.84	1.78	1.86	1.18	1.48	0.75	1.09	0.52	1.15	0.59	1.07	0.61	0.86	0.44	0.84	0.39	1.30	0.92
Mean	1.46	1.05	0.89	0.61	0.72	0.49	0.63	0.43	0.72	0.50	0.69	0.48	0.87	0.62	0.97	0.69	0.82	0.59

Figures

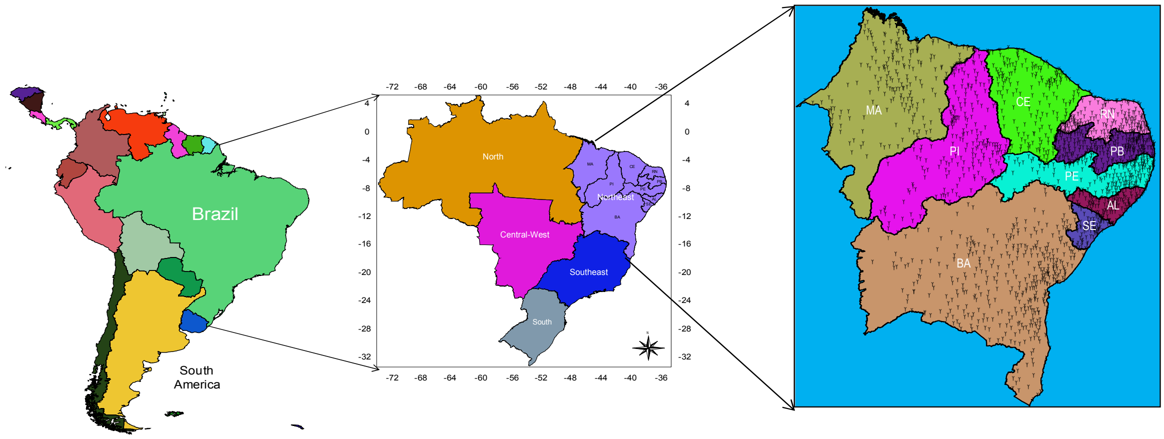

Fig. 1. Brazilian regions and the Northeastern states of Maranhão-MA; Piauí-PI; Ceará-CE; Rio Grande do Norte-RN; Paraíba-PB; Pernambuco-PE; Alagoas-AL; Sergipe-SE; and Bahia-BA, together with the location of the rain gauges and agro-meteorological stations.

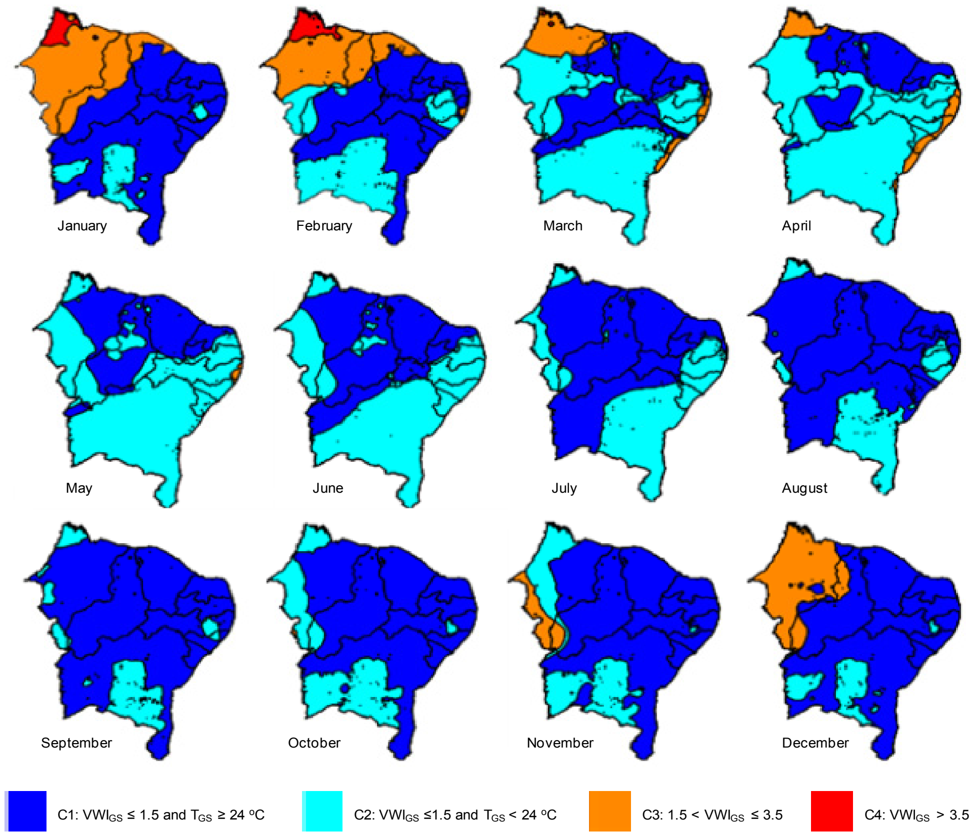

Fig. 2. Maps of the table grape climatic suitability, cv. 'Sugraone', for different pruning dates, and an average growing season of three months, in the Brazilian North-eastern producer states.

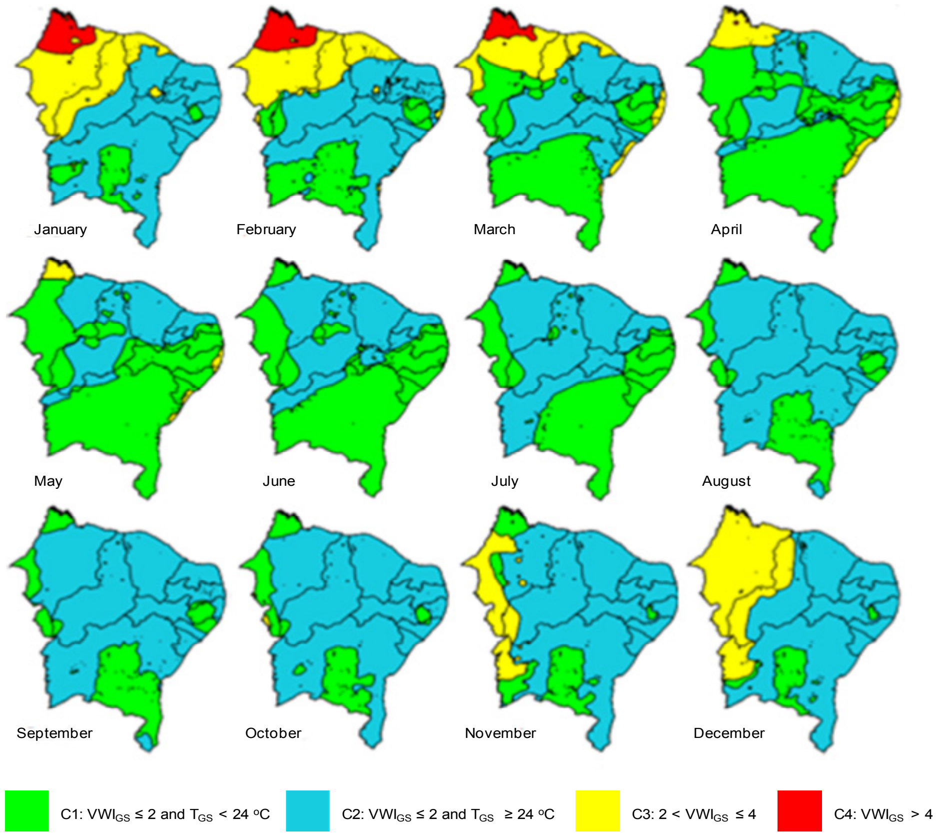

Fig. 3. Maps of the wine grape climatic suitability, cv. 'Syrah', for different pruning dates, and an average growing season of four months, in the Brazilian Northeastern producer states.