Scientific Notes

Climatic water indices for viticulture

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Abstract – The objective of this work was to evaluate the performance of vineyard water indices in different grape-growing regions. The climate data used come from the historical series of weather stations located in 18 countries. The evaluated indices were the following: dryness, Zuluaga, humidity, aridity, moisture, and the grapevine water index. The grapevine water index and the indices of drought, moisture, and aridity exhibit similar performances, which makes them suitable to be used equivalently in climatological studies of grapevine regions.

Index terms: *Vitis vinifera*, climatology, evapotranspiration, viticulture.

Índices hídricos climáticos para a viticultura

Resumo – O objetivo deste trabalho foi avaliar o desempenho de índices hídricos da videira em diversas regiões vitícolas. Os dados climáticos utilizados são provenientes das séries históricas de estações meteorológicas localizadas em 18 países. Avaliaram-se os seguintes índices: de seca, o de Zuluaga, o de excedente hídrico, de aridez, de umidade e o índice hídrico da videira. O índice hídrico da videira e os índices de seca, umidade e aridez apresentam desempenhos semelhantes, o que os torna passíveis de serem utilizados de forma equivalente em estudos climatológicos de regiões vitivinícolas.

Termos para indexação: *Vitis vinifera*, climatologia, evapotranspiração, viticultura.

Climatic variables directly affect grape and wine production and quality. Several methodologies have been used to climatically characterize wine regions in the world. This characterization is often based on indices that only use air temperature (Martínez de Toda & Balda, 2015; Muniz et al., 2015). However, other criteria have also been adopted, including those involving information on water conditions during the grapevine development period (Westphalen & Maluf, 2000; Teixeira et al., 2012; Maluf et al., 2014; Ricce et al., 2014). These criteria may indicate crop restrictions or need for irrigation due to water scarcity, as well as phytosanitary risks caused by excess rainfall.

However, despite the various water indices used in viticulture, the relationships between them are still unknown, as well as whether or not one index can replace the others in climatological studies, such as the evaluation of future agricultural scenarios based on global climate change and on climate-risk viticultural zoning.

The objective of this work was to evaluate the performance of different grapevine water indices in several wine regions around the world.

Climate data were obtained from the Geoviticulture Multicriteria Climatic Classification System (Geoviticulture MCC System) global database (Embrapa Uva e Vinho, 2018), from historical series of 30 years (1961–1990), corresponding to 82 wine-growing regions located in 18 countries: Argentina, South Africa, Australia, Brazil, Canada, Chile, Slovakia, Slovenia, Israel, Spain, France, New Zealand, Peru, Portugal, Switzerland, Tunisia, Turkey, and Uruguay. According to the Geoviticulture MCC System, these regions have climatic classes ranging from humid to very dry conditions (Conceição et al., 2012), making it possible to obtain a high variability of water indices.

The methodology described by Tonietto & Carbonneau (2004) was used in order to calculate the dryness index (DI) values by the following equation:

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$$DI = \Sigma_{Mi}^{Mf} Wo + Pm - Tv - Es$$

in which: Σ is the mathematical summation symbol; Wo is the initial soil-water storage, in mm; Pm is the monthly rainfall, in mm; Tv is the monthly potential vineyard transpiration, in mm; Es is the monthly soil evaporation, in mm; and Mi and Mf are the initial and final months of the grapevine cycle, corresponding respectively to the months of April and September in the Northern Hemisphere, and to October and March in the Southern Hemisphere. Tv was calculated using the expression $Tv = ETPm \times k$, in which: ETPm is the potential monthly evapotranspiration (mm), estimated by the standard Penman-Monteith method (Conceição et al., 2012); and k is the coefficient of radiation absorption by the vines. The Es was estimated by the expression $Es = (ETPm/Nm) \times (1- k) \times JPm$, in which: Nm is the number of days of the month; and JPm is the number of days per month of actual soil evaporation. JPm is estimated by dividing P by 5, and it should be equal to or less than Nm. The DI may be negative to express the potential water deficit, but cannot be higher than Wo, set at 200 mm for this index calculation.

The Zuluaga index (IZ) was calculated using the expression (Westphalen & Maluf, 2000) below:

$$IZ = \Sigma_{Mi}^{Mf} [Tm \times Pm]/Np$$

in which: Tm is the average monthly temperature (ºC); and Np is the number of days of the period, which is 183 days in the Northern Hemisphere (April to September), and 182 days in the Southern Hemisphere (October to March).

The climatic classification of Thornthwaite (1948) is based on the humidity index (Ih), the aridity index (Ia), and the moisture index (Im), expressed as $Ih = 100 \times (EXC/ETP)$, $Ia = 100 \times (DEF/ETP)$, and $Im = Ih – 0,6 \times Ia$, in which EXC is the water surplus (mm); and DEF is the water deficit (mm). Although the water balance at each station was performed for annual periods, the water indices were calculated considering the sums of DEF and EXC values from April to September in the Northern Hemisphere, and from October to March in the Southern Hemisphere. Soil-water storage capacity (SWC) was considered to be equal to 200 mm, which is the same value as Wo used for DI.

The grapevine water index (GWI), proposed by Teixeira et al. (2012), represents the relationship between rainfall and potential crop evapotranspiration (ETc) during the grapevine phenological cycle (mm), as follows:

$$GWI = \sum_{Mi}^{Mf} Pm / \sum_{Mi}^{Mf} ETcm$$

in which: ETcm is the monthly potential crop evapotranspiration (mm), that varies according to the vineyard management. In the present work, the ETcm was considered to be equal to the ETPm, in order to allow of comparisons between the different regions.

The evaluations were performed using linear correlations, classified with basis on the criterion adopted by Vanzela et al. (2010) as: very high, to $1.00 \geq | r | > 0.90$; high, to $0.90 \geq | r | > 0.70$; moderate, to $0.70 \geq | r | > 0.50$; low, to $0.50 \geq | r | > 0.30$; and very low, to $0.30 \geq | r | > 0.00$. The F test was used at 1% probability level for significance analysis.

All correlations were significant according to the F test. The grapevine water index (GWI) showed very high correlations with all the other indices (Table 1), except for the humidity index (Ih). The correlation between GWI and the moisture index (Im) showed a low-dispersion level, both in dry and wet regions (Figure 1 A). However, the correlation between GWI and the aridity index (Ia) was lower than the one obtained using Im because when the GWI values are higher than 0.95, the Ia values equal zero (Figure 1 B). The same performance of GWI was observed in relation to the dryness index (DI), which showed values equal to 200 for GWI higher than 0.93 (Figure 1 C). For the Zuluaga index (IZ), the wetter regions showed a greater data dispersion in relation to the GWI (Figure 1 D). The high correlation between GWI and IZ shows, in turn, that GWI can also be used to evaluate the risk of grapevine fungal disease (Teixeira et al., 2012; Conceição et al., 2013).

The DI also showed a very high correlation with Ia and Im (Table 1). For Im values higher than 6.3, DI assumes values equal to 200 (Figure 1 F), which leads to a reduction of the correlation between these two indices when compared to Ia. It is also observed that the highest Ia values showed a greater data dispersion (Figure 1 E), which indicates that the differences between the two indices are higher in drier regions. The reason why it happens is that the water balance methodology employed for Ia calculation uses an exponential function to determine the soil-water storage (Dourado-Neto et al., 2010), whereas DI

Table 1. Correlation coefficients (r) between the following indices: dryness (DI), Zuluaga (IZ), humidity (Ih), aridity (Ia), moisture (Im), and grapevine water index (GWI).

Index	DI	IZ	GWI	Ih	Ia	Im
DI	-	0.7811	0.9134*	0.3659	-0.9578*	0.9322*
IZ	0.7811	-	0.9046*	0.4958	-0.8088	0.8334
GWI	0.9134*	0.9046*	-	0.6050	-0.9282*	0.9654*
Ih	0.3659	0.4958	0.6050	-	-0.3831	0.5841
Ia	-0.9578*	-0.8088	-0.9282*	-0.3831	-	-0.9735*
Im	0.9322*	0.8334	0.9654*	0.5841	-0.9735*	-

* Values whose correlation was classified as very high (| r | >0.90).

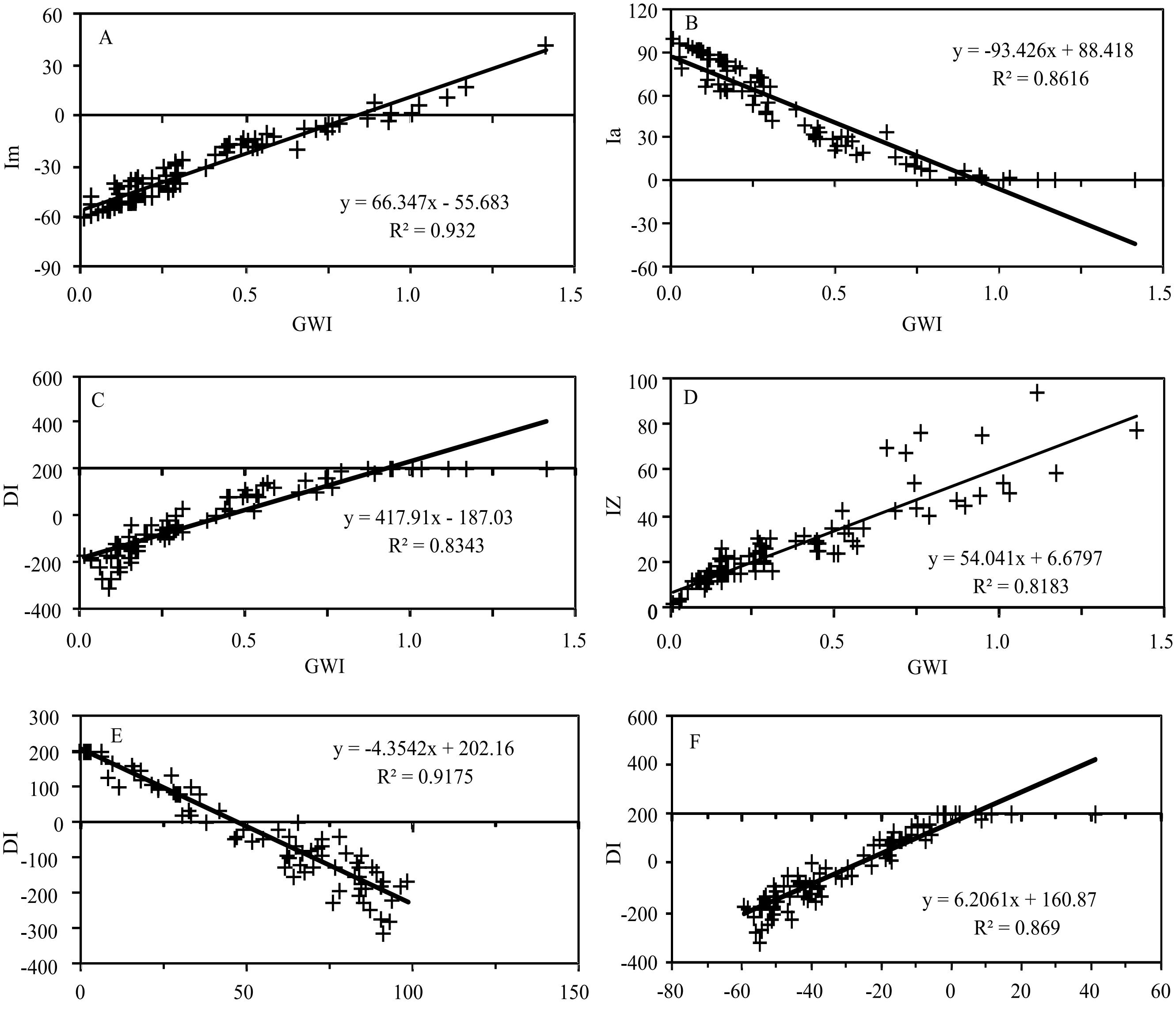

Figure 1. Comparison of the following indices: A, the grapevine water index (GWI) and moisture (Im); B, GWI and aridity (Ia); C, GWI and dryness (DI); D, GWI and Zuluaga (IZ); E, Ia and DI; F, Im and DI.

calculation uses a linear relation for the same purpose (Tonietto & Carbonneau, 2004). Thus, the reduction of soil-water storage in drier regions increases the differences between Ia and DI values.

The Ih showed a moderate correlation with GWI and low correlations with the other indices. This occurred because most of the wine-growing regions did not show water surplus (Ih=0) during the grapevine development period, although there are three regions in Brazil (São Joaquim, Bento Gonçalves, and Vacaria) that showed Ih greater than zero. This was the reason why this index had been used before in wine-growing climatic characterization areas of the country (Westphalen & Maluf, 2000). However, in more recent studies conducted in these regions, Ih was no longer used for this purpose (Maluf et al., 2014; Ricce et al., 2014).

The grapevine water index (GWI), the dryness index (DI), the moisture index (Im) and the aridity index (Ia) show similar behavior, within the limits previously presented, and they can be used in an equivalent way for climatological studies in grapevine regions.

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