CLIMATIC REQUIREMENTS FOR OPTIMAL PHYSIOLOGICAL PROCESSES: A FACTOR IN VITICULTURAL ZONING

BESOINS CLIMATIQUES POUR DES PROCESSUS PHYSIOLOGIQUES OPTIMAUX: UN FACTEUR POUR LE ZONAGE VITICOLE

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ABSTRACT

The suitability of climatic profiles for optimal grapevine photosynthetic activity in different South African regions and in localities within a particular region was determined. Three-year hourly mean ambient temperature, wind speed and relative humidity data from four weather stations in each of three viticultural regions ["hot" (Stellenbosch and Robertson Regions) and "very hot" (Upington Region) classification according to Huglin and Winkler indices] were averaged during the pre- and post-véraison growth periods. A period between 09:00 and 16:00 for maximum photosynthetic activity was used. Temperature (25 – 30 °C), wind speed (< 4 m/s) and relative humidity (60 – 70 %) requirements for optimal photosynthetic activity were superimposed onto the respective regional climatic profiles. Ambient light intensity was accepted as being sufficient. Marked variation in number of hours available for optimal photosynthesis occurred. Based on climatic requirements only, conditions seemed best suited for photosynthesis in the Robertson region. In the other two regions, photosynthesis would be reduced to a higher extent, due to low pre-véraison temperature and strong pre- and post-véraison wind (Stellenbosch) and high pre- and post-véraison temperature and low humidity (Upington). Climatic conditions for growth seemed best in Robertson, followed by Upington and Stellenbosch. Conditions within a particular region may also vary markedly over very short distances, especially in the Western Cape, whereas other locations may be climatically similar in spite of differences in altitude, aspect and distance from the sea. The locations differed markedly regarding their feasibility to support photosynthesis. Evidently, climatic profiles in different regions and locations may have serious implications for proper physiological functioning of grapevines and the impact of potential climatic stress (direct and indirect) on physiological processes would seem to be a factor for consideration in viticultural zoning.

RESUME

Les profils climatiques appropriés pour une activité photosynthétique optimale de la vigne sont déterminés dans différentes régions d'Afrique du Sud et localités à l'intérieur d'une région particulière. La moyenne horaire de température ambiante, vitesse du vent et humidité relative sont calculées pendant les périodes de pré- et post-véraison à partir de données de trois années et de quatre stations météorologiques dans chacune de trois régions viticoles [classées "chaudes" (Stellenbosch et Roberston) et "très chaudes" (Upington) selon les indices d'Huglin et de Winkler]. La période comprise entre 9 et 16 heures pour l'activité photosynthétique maximale est utilisée. La température (25-30°C), vitesse de vent (<4 m/s) et humidité relative (60-70°C) nécessaires à une activité photosynthétique optimale sont surimposés sur les profils climatiques respectifs des différentes régions. L'intensité lumineuse ambiante est acceptée comme étant suffisante. Une variation remarquable du nombre d'heures disponibles pour une photosynthèse optimale apparaît. Basées sur les seuls besoins climatiques, les conditions pour la photosynthèse seraient les meilleures dans la région de Robertson. Dans les deux autres régions, la photosynthèse serait limitée à un plus haut niveau, en raison de basses températures en période de pré-véraison et de vents forts en période de pré- et post-véraison dans la région de Stellenbosch et en raison de températures élevées et faibles humidités pendant les périodes de pré- et post-véraison dans la région d'Upington. Les conditions climatiques pour la croissance seraient meilleures dans la région de Robertson, suivies d'Upington et Stellenbosch. Les conditions climatiques à l'intérieur d'une région particulière peuvent également varier remarquablement sur des distances très courtes, spécialement dans la Province occidentale du Cap, tandis que des régions peuvent être de climats semblables malgré des altitudes, expositions et distances à l'océan différentes. Les localités diffèrent beaucoup selon leurs possibilités à subvenir aux besoins de la photosynthèse. Les profils climatiques des différentes régions et localités peuvent évidemment avoir de sérieuses implications sur le bon fonctionnement physiologique de la vigne et l'impact de ce stress climatique potentiel (direct ou indirect) sur les processus physiologiques semblerait être un facteur à considérer dans le zonage viticole.

INTRODUCTION

The seasonal evolution of bunch morphology and chemical composition of the berry result from the interaction between long term practices (chosen site, establishment technique, soil type, row direction, vine spacing, and trellising and pruning system), short term practices (e.g. seasonal irrigation, fertilisation, and canopy management program and ripeness level at harvest) and variation in environmental conditions (JACKSON & LOMBARD, 1993; HUNTER & ARCHER, 2001a, 2001b; DELOIRE *et al.*, 2002). All of these factors affect the source-sink relationships in the grapevine and thus physiological processes (HUNTER, 2000; CARBONNEAU & DELOIRE, 2001). It also relates to a viticultural "terroir" unit, excluding wine technology, as defined by CARBONNEAU (2001). The determination of the most suitable "terroir" and zoning of the environment for maximum expression of typicity and quality of a cultivar wine had been the subject of many studies (FALCETTI, 1994; FALCETTI & IACONO, 1996; MORLAT, 1997; Carey, 2001; VAUDOUR, 2000; DELOIRE *et al.*, 2002). However, although temperature (KRIEDEMANN, 1968; KLIEWER, 1971, 1977; LAKSO & KLIEWER, 1978; COOMBE, 1987; MARAIS *et al.*, 1999), humidity (Champagnol, 1984) and wind velocity (Freeman *et al.*, 1982; KOBRIGER *et al.*, 1984; HAMILTON, 1989) threshold values for various physiological processes, such as photosynthesis of the leaves as well as color, sugar and organic acid concentration, mineral content and even flavor development of the grapes, exist, such climatic requirements favoring the optimal physiological functioning of the vine were briefly referred to in terms of grape composition (Pirie, 1979; COOMBE, 1987; ILAND, 1989), but are mostly not considered in the context of "terroir" and zoning studies.

For a grapevine subjected to a specific "terroir", the extent to which physiological requirements are met is paramount for optimal functioning and achievement of maximum berry quality. In this paper, the suitability of climatic profiles for optimal grapevine photosynthetic activity in different South African grape growing regions and in localities within a particular region was determined. It is part of a greater study in which the climatic suitability of regions and localities for the requirements of many physiological processes and accumulation of components that are viticulturally and oenologically important is determined. The ultimate goal is to facilitate "terroir" selection and zoning.

MATERIAL AND METHODS

Climatic data from four automatic weather stations of the Agricultural Research Council network in each of three grape growing regions of South Africa, namely the Stellenbosch Region (winter-rainfall coastal area), Robertson Region (semi-arid Breede River Valley area) and Upington (Orange River) Region (semi-arid), were used (Fig. 1). According to climatic indices for viticulture of HUGLIN (1978) and Winkler *et al*. (1974), calculated for three seasons (1998/99, 1999/2000 & 2000/01), Stellenbosch and Robertson Regions are classified as "hot" and the Upington Region as "very hot" (Table 1). Finer climatic aspects within the Stellenbosch Region were also assessed by comparing data from three weather stations in this region.

Hourly mean ambient temperature, wind speed and relative humidity data from three seasons (1998/99, 1999/2000 & 2000/01) were averaged during the pre- and post-véraison growth periods (November-December and January-February, respectively). Hourly min./max. ambient temperature and relative humidity and max. wind speed, i.e. the number of hours with temperature/humidity/wind speed below or above the optimal range for photosynthesis within the allocated diurnal period for maximum photosynthetic activity, were also calculated. The period 09:00 - 16:00 (SAST = Greenwich Meridian Time +2) was taken as optimum for photosynthetic activity. The temperature (25 – 30 °C) (KRIEDEMANN, 1977), wind speed (< 4 m/s) (Freeman *et al*., 1982; Hamilton, 1989) and relative humidity (60 – 70 %) (CHAMPAGNOL, 1984) requirements for optimal grapevine photosynthetic activity were superimposed on the respective climatic profiles of the different regions. Ambient light intensity was accepted as being sufficient. An ANNOVA procedure (Waller grouping) using the hours as replicates was used to determine whether the observed climatic differences were statistically significant.

RESULTS AND DISCUSSION

The seasonal climatic indices (Winkler and Huglin) for three grape growing regions of South Africa varied between Regions IV and V, with Stellenbosch and Robertson Regions being "hot" and Upington Region being "very hot" (Table 1). The Stellenbosch Region has previously been classified as "warm temperate climate" (Region III), but temperatures of the three seasons that were studied were higher than normal, especially during the 1999/2000 season (data not shown). Considering the optimum temperature range within the allocated diurnal time period, marked variation in number of hours available for optimal photosynthesis occurred between the three regions (Fig. 2). During pre-véraison (November – December), the Upington Region had two hours suitable for optimal photosynthesis in the morning, the Robertson Region four hours in the afternoon and the Stellenbosch Region three hours at the lower temperature limit in the afternoon. A similar situation occurred during ripening (January – February), except for the Stellenbosch Region where temperatures were well within the optimum temperature range.

Based on climatic requirements only, conditions seemed best suited for photosynthesis in the Robertson Region. In the other two regions, photosynthesis would be reduced to a higher extent, due to low pre-véraison temperature (Fig. 2) and strong pre- and post-véraison wind in the Stellenbosch Region (Fig. 3) and high pre- and post-véraison temperature (Fig. 2) and very low humidity in the Upington Region (Fig. 3). Higher and more favorable temperatures in the Stellenbosch Region post-véraison may result in a continuation/re-start of vegetative growth during this period, which is not feasible for obtaining high grape quality. The Stellenbosch Region experiences a cooler climate due to a moderating effect of the sea along the coast compared to the interior (SAWB, 1996). The occurrence of the sea breeze in the Stellenbosch Region (BONNARDOT *et al.*, 2002), with its associated increase in wind velocity in the afternoon and concomitant increase in relative humidity and reduction in temperature, explains the lower temperature and higher humidity and frequency of wind velocity in this region compared to the other two regions. The wind speed and relative humidity values are significantly different (Table 2). The arrival of the sea breeze also explains the earlier and lower maximum temperature (Fig. 2) and earlier and stronger winds in the Stellenbosch Region (Fig. 3). The sea breeze therefore seems to be a restrictive factor for optimal photosynthesis.

Although the climatic requirements employed in this study for optimum photosynthesis would seem to indicate that conditions are best suited in Robertson, followed by Upington and Stellenbosch, vines in the winter-rainfall Stellenbosch region (Schulze, 1997) are moderately vigorous and trained onto smaller trellises, whereas those in the semi-arid inland regions such as Robertson and Upington are more vigorous and trained onto larger trellises for growth accommodation (Hunter & Archer, 2001a). Vines in coastal regions are also mostly low intensity irrigated or grown under dry land conditions, whereas those in the inland regions are intensively irrigated. In addition to climatic differences, application of the aforementioned regional viticultural practices (as well as soil type, plant spacing and row direction), at meso- and microclimate levels, may also have a significant bearing on conditions that are experienced by the grapevine, and thus canopy photosynthesis (and eventual grape and wine quality). Moreover, the extent and timing of seasonal canopy management are critical for interior-canopy photosynthetically active radiation, temperature, humidity, wind velocity and eventual photosynthetic efficiency of the leaves situated in this position (HUNTER & VISSER, 1988; HUNTER *et al.*, 1995; RIOU, 1998; HUNTER & ARCHER, 2001a, 2001b). A lack of preventative measures in the Robertson and Upington regions will therefore result in vigorous growth and most probably dense canopies with only a small portion of photosynthetic efficient leaf area. This would largely nullify the potentially favorable effects of the climatic profiles for photosynthetic activity and growth in these regions.

Despite a global climatic classification, climatic indices of locations within a particular region, e.g. Stellenbosch Region, may vary markedly over very short distances due to proximity to the sea and complexity of topography (Carey, 2001; BONNARDOT *et al.*, 2002). In order to assess this variation, data from three weather stations in the Stellenbosch Region were compared (Table 3). From this it is evident that, in spite of differences in altitude, aspect and distance from the sea, locations may also be climatically similar on the basis of averaged seasonal data. When monthly data are calculated, differences are significant (Table 4). The three weather station locations, two classified as "cool" and one classified as "hot" according to the Winkler index (Regions III & V, respectively), were therefore also compared for their feasibility to support photosynthesis. In the "Cool A" location, temperatures were lower than the minimum range for photosynthesis pre-véraison, whereas during the post-véraison period temperatures were only approximately 60 % within the optimal range (Fig. 4). Furthermore, the latter occurred mainly during the afternoon and were at the lower level of the temperature range. In the "Hot" location, temperatures were mostly inside the optimal range for photosynthesis and varied from the minimum to the maximum range; here, the location on an eastern facing bottom mountain slope heated up faster in the morning and, sheltered from the cool sea breeze by the mountains, stayed warmer for a longer period of time. Within the allocated diurnal period for maximum photosynthesis, the wind speed in the "Cool A" location was approximately 40 % within the preferred wind speed pre- and post-véraison (Fig. 4). In the "Hot" location, seasonal wind speeds were mostly lower than the theoretical threshold above which photosynthesis is inhibited. Relative humidity of only the "Cool A" location pre-véraison was inside the preferred range for photosynthesis (Fig. 4). The rest was less than the required minimum. Although mean climatic profiles of the "cool" and "hot" locations seemed not suitable for optimum photosynthesis, the frequency of temperature, wind speed and relative humidity occurrence falling inside the preferred range for every climatic parameter from 09:00 to 16:00 pre- and post-véraison, indicates large weather fluctuations which often meet the requirements (Fig. 4). Comparing locations "Cool A" and "Cool B" with seemingly similar humidity and temperature profiles (Fig. 5) (although significantly different during the ripening period - Table 4) and thus climatic classification within a region (Table 3), variation in wind speed occurred, which may further impact on photosynthesis (Fig. 5). The location "Cool B" receives sea breezes originating from both Table Bay (colder ocean temperature) and False Bay (warmer ocean temperature) and is well situated (100 m higher in altitude on the hill crest compared to "Cool A") to experience stronger up-slope breezes than "Cool A" (BONNARDOT *et al.*, 2002).

On a macro-scale, climatic indices used to classify different "terroirs" and which are applied for zoning, seem to be only an indication of what in reality is experienced between vine rows and by the root system and canopy in particular. The more macro-, meso-, micro- and even nano-(e.g. inside the bunches and at soil-root interface level)climatic conditions in a particular region and at a particular site favor physiological requirements of the grapevine cultivar-rootstock combination and the more cultivating conditions can complement meso-climatic conditions to the benefit of grapevine functioning and grape development, the better expression of "terroir" potential in grape and wine quality will be achieved. Conversely, failure to successfully marry these concepts will result in an under-exploitation of the real potential of the chosen grapevine cultivar and "terroir" and will only result in an apparent zoning. In order to understand the behaviour of the grapevine within a particular "terroir" and to facilitate future "terroir" selection and zoning, these concepts must be studied in concert.

CONCLUSION

The results showed that climatic profiles in different regions might have serious implications for the physiological functioning of grapevines. Mean climatic data are seemingly not sufficient to properly understand variation in weather conditions and consequently to quantify grapevine physiological behavior at a particular location. This may lead to the zoning of only apparently homogeneous environments, resulting in heterogeneous grapevine response. In this regard, minimum/maximum data and the frequency of occurrence would seem to be more suitable parameters for climatic profile quantification aimed at grapevine physiological requirements. The impact of potential climatic stress (direct and indirect) on grapevine physiological processes should be further quantified and would seem to be a factor to be considered in the selection of a "terroir" and in zoning for grapevine growing.

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Table 1. Winkler and Huglin climatic indices for the Stellenbosch Region (winter-rainfall coastal area), Robertson Region (semi-arid Breede River Valley area) and Upington (Orange River) Region (semi-arid). Av. for three seasons (1998/99 - 2000/01).

Region	Winkler (classification)	Huglin (classification)
Stellenbosch	1959 (4) (usually region 3)	2465 (hot climate)
Robertson	1992 (4)	2582 (hot climate)
Upington	2896 (5)	3323 (very hot climate)

Table 2. Mean Temperature (°C), Wind speed ($m.s^{-1}$) and Relative humidity (%) Pre- and Post-véraison for Stellenbosch, Robertson and Upington Regions. Av. for three seasons (1998/99 - 2000/01). Means followed by the same letter are not significantly different.

Region	Temperature (°C)		Wind speed ($m.s^{-1}$)		Relative humidity (%)	
	Pre-véraison	Post-véraison	Pre-véraison	Post-véraison	Pre-véraison	Post-véraison
Stellenbosch	20.3 b	22.1 b	3.6 a	3.9 a	71.2 a	69.1 a
Robertson	20.4 b	22.4 b	2.3 b	2.6 b	64.0 b	64.5 b
Upington	25.8 a	27.4 a	1.9 c	1.7 c	27.6 c	34.4 c

Table 3. Description of three locations within the Stellenbosch Region.

Location	Season	Winkler	Huglin	Mean Winkler classif.	Alt. (m)	Aspect	Distance from cold ocean (km)	Distance from warm ocean (km)
Cool A	1998/99	1828	2250	3	130	SW	24	12
	1999/00	1898	2339					
	2000/01	1568	2063					
Cool B	1998/99	1852	2243	3	235	N	27	20
	1999/00	1993	2396					
	2000/01	1719	2071					
Hot	1998/99	2246	2677	5	160	E	43	32
	1999/00	2354	2825					
	2000/01	2160	2630					

Table 4. Mean Temperature (°C), Wind speed ($m.s^{-1}$) and Relative humidity (%) during November, December, January and February for three locations in the Stellenbosch Region. Av. for three seasons (1998/99 - 2000/01). Means followed by the same letter are not significantly different.

Region	Temperature (°C)				Wind speed ($m.s^{-1}$)				Relative humidity (%)			
	Nov	Dec	Jan	Feb	Nov	Dec	Jan	Feb	Nov	Dec	Jan	Feb
"Cool A"	18.0 b	20.4 b	20.7 c	21.0 a	3.2 b	3.3 b	3.3 b	3.3 b	75.0 a	74.3 a	73.2 a	72.0 a
"Cool B"	18.0 b	20.5 b	21.1 b	21.6 b	3.7 a	3.8 a	3.8 a	3.6 a	74.1 b	73.3 b	71.9 b	72.2 a
"Hot"	19.8 a	22.9 a	23.5 a	23.9 a	2.8 c	2.3 c	3.1 c	3.4 b	64.2 c	61.1 c	61.2 c	60.9 b

FIGURES

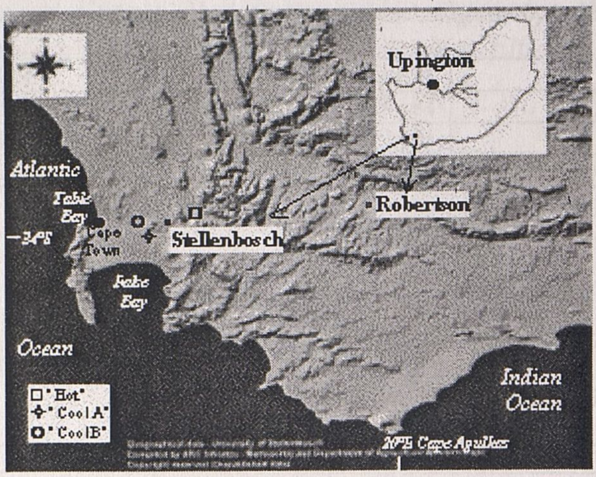

Fig. 1. Location of the three grape growing regions of South Africa, namely the Stellenbosch Region (winter-rainfall coastal area), Robertson Region (semi-arid Breede River Valley area) and Upington (Orange River) Region (semi-arid), used in the study.

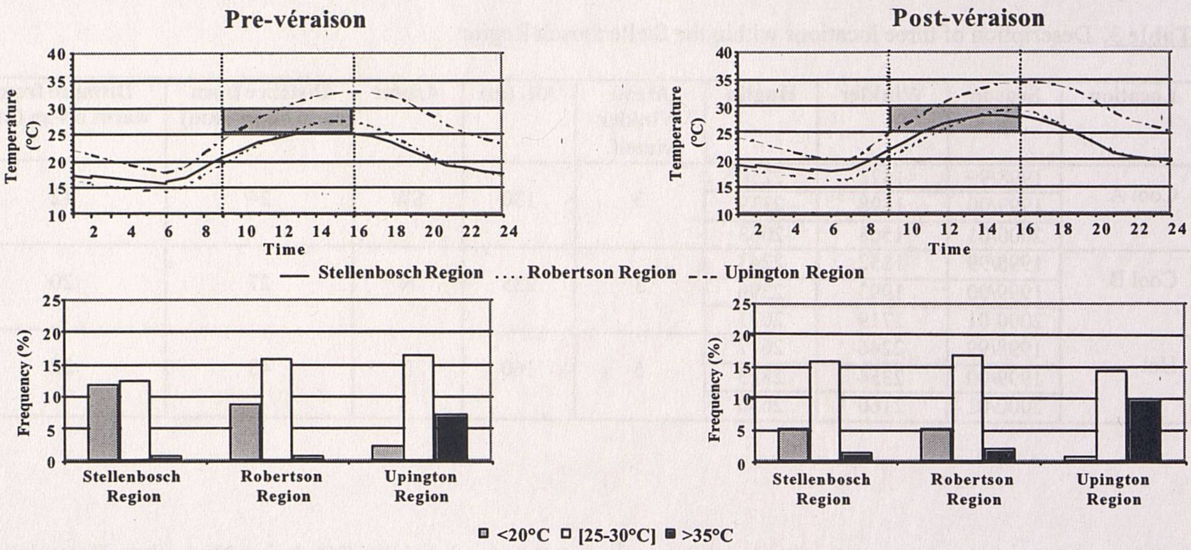

Fig. 2. Hourly mean temperature (top) and temperature thresholds (bottom) for photosynthesis (av. 1998/99 – 2000/01) Pre- and Post-véraison for the Stellenbosch, Robertson and Upington Regions (av. of 4 weather stations). Window for optimum photosynthesis indicated in grey.

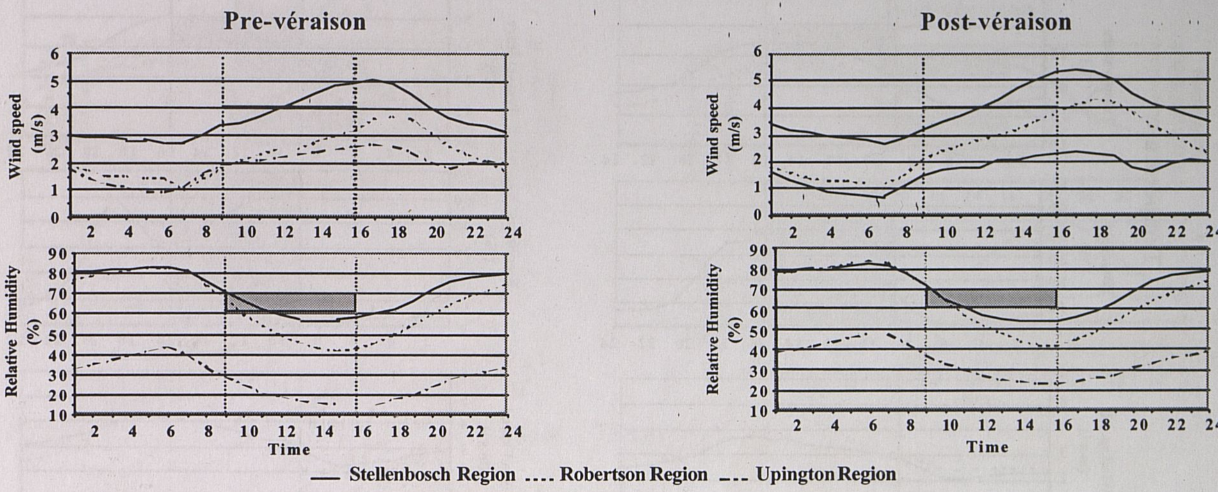

Fig. 3. Hourly wind speed (top) and relative humidity (bottom) (av. 1998/99 – 2000/01) Pre- and Post-véraison for the Stellenbosch, Robertson and Upington Regions (av. of 4 weather stations). Wind speed threshold indicated with a bold line and window for optimum photosynthesis indicated in grey.

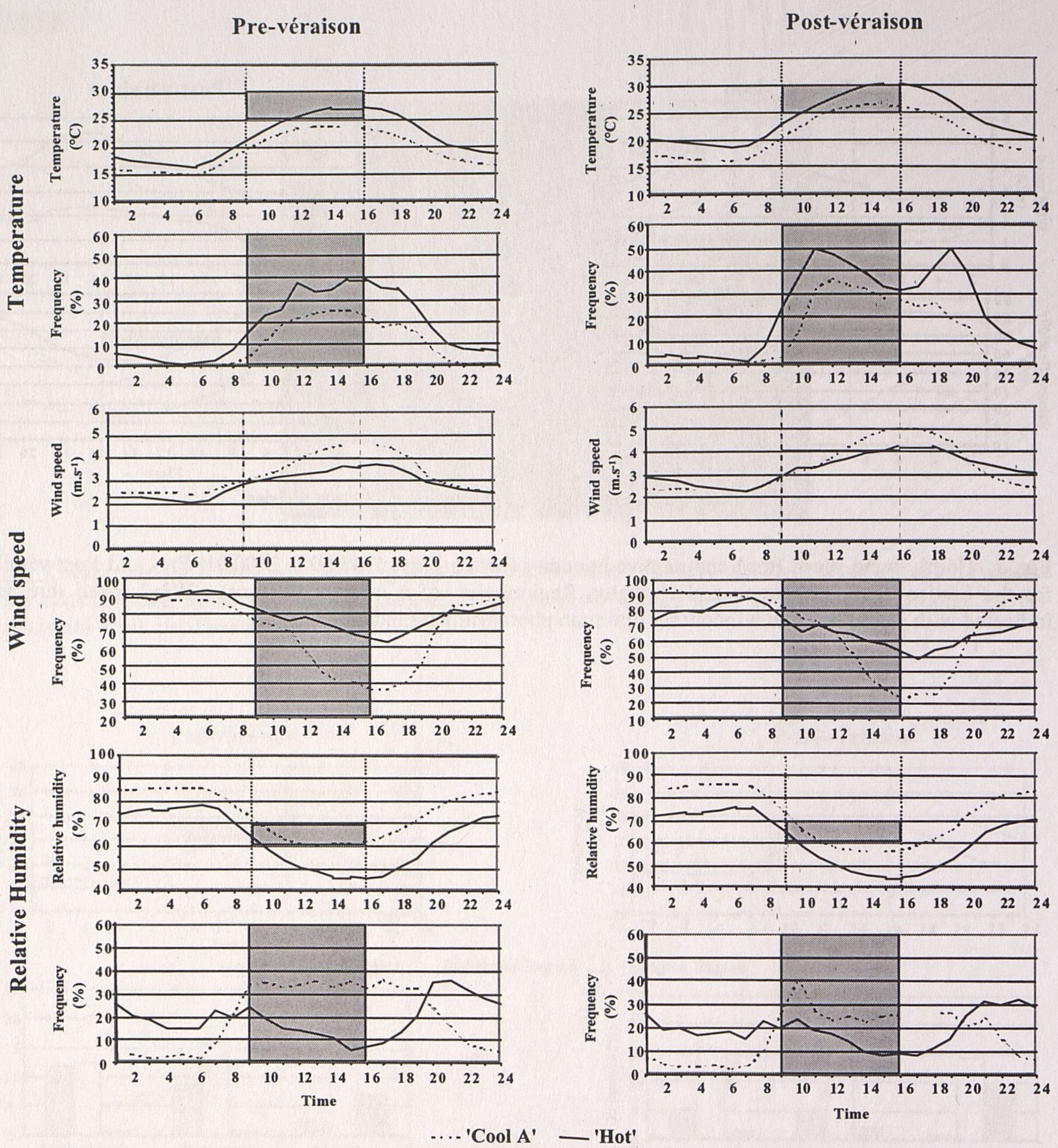

Fig. 4. Hourly mean temperature, wind speed and relative humidity (av. 1998/99 - 2000/01) (top) and % of time with temperature 25 - 30°C, wind speed below 4 $m.s^{-1}$ and relative humidity 60 - 70% (bottom) Pre- and Post-véraison at a cool and hot location (Stellenbosch Region). Window for optimum photosynthesis indicated in grey.

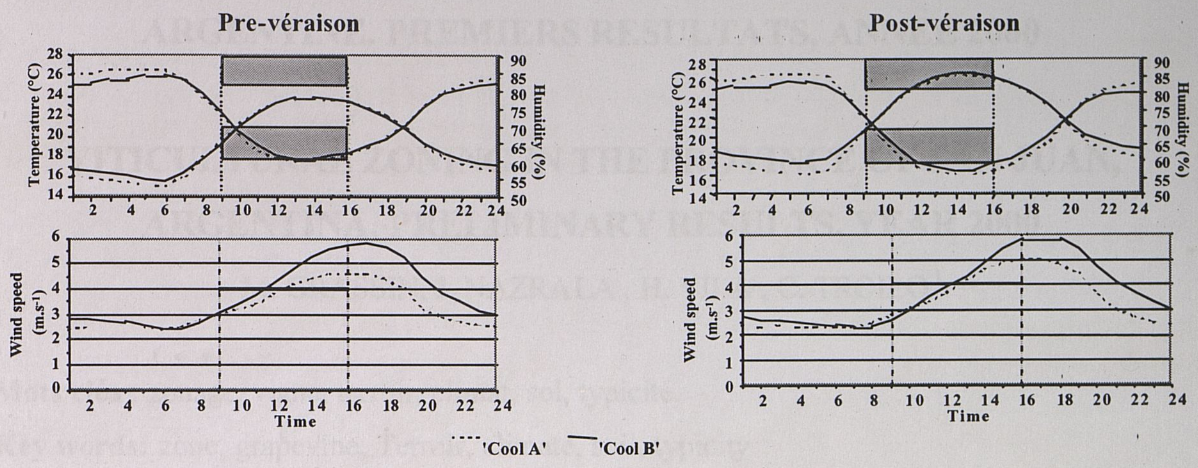

Fig. 5. Hourly mean temperature, relative humidity and wind speed (av. 1998/99 - 2000/01) at two cool locations in the Stellenbosch Region Pre- and Post-véraison. Window for optimum photosynthesis indicated in grey.