A VITICULTURAL PERSPECTIVE OF MESO-SCALE ATMOSPHERIC MODELLING IN THE STELLENBOSCH WINE GROWING AREA, SOUTH AFRICA

UNE PERSPECTIVE VITICOLE DE LA MODELISATION ATMOSPHERIQUE MESO-ECHELLE DANS LA REGION VITICOLE DE STELLENBOSCH, AFRIQUE DU SUD

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Mots clés : Modélisation Atmosphérique, brise de mer, humidité relative, température, Sauvignon blanc

ABSTRACT

The sea breeze and induced climatic patterns (increase in wind velocity in the afternoon with a concomitant increase in relative humidity and reduction in temperature) are of particular interest for viticulture. The climatic patterns of the area, including the sea breeze effect, along with soil, viticultural and oenological data were studied in order determine the implications for vine growth and functioning, and, potentially, berry composition and wine character and to fully understand the terroir/vine/wine interactions.

The Regional Atmospheric Modelling System (RAMS) was used to study the degree of penetration by the sea breeze and the resulting climatic characteristics (temperature, relative humidity and wind) along with surface data recorded at agroclimatic stations situated in the vineyards. Associated with the automatic weather stations are experimental plots of Sauvignon blanc within commercial vineyards. The measured viticultural and oenological attributes of these plots were used as a basis to assess the impact of the sea breeze penetration and topoclimate, in conjunction with other terroir components, on viticulture in the study area. Results of statistical analyses emphasized the importance of the climate, especially sea breeze related characteristics.

RESUME

La brise de mer et les facteurs climatiques qu'elle entraîne (accélération de la vitesse du vent au cours de l'après midi, augmentation de l'humidité et baisse de la temperature) sont d'un intérêt particulier pour la viticulture. La configuration climatique de la région, comprenant l'effect de la brise de mer, en parallèle avec des donnés pédologiques, viticoles et

oenologiques sont étudiés afin de determiner les implications sur la croissance et le fonctionnement de la vigne et potentiellement sur la composition du raisin et le caractère du vin et de bien comprendre les interactions terroir/vigne/vin.

Le modèle atmosphérique RAMS (Regional Atmospheric Modelling System) a été utilisé afin d'étudier le degré de pénétration de la brise de mer et les caractéristiques climatiques (température, humidité relative et vent) qui en résultent, en parallèle avec des données en surface enregistrées par des stations agroclimatiques situées dans le vignoble. Des parcelles expérimentales de Sauvignon blanc situées dans les vignes commerciales sont associées à chaque station météorologique automatique. Les mesures viticoles et oenologiques de ces parcelles sont utilisées comme base pour étudier l'impact de la pénétration de la brise de mer et du topoclimat, en conjonction avec d'autres composantes du terroir, sur la viticulture de la région d'étude. Les résultats des analyses statistiques soulignent l'importance du climat, particulièrement les caractéristiques liées à la brise de mer.

INTRODUCTION

The wine growing area in the Stellenbosch surrounds is characterised by a high degree of spatial variability in climatic parameters due to its complex topography and proximity to the Atlantic Ocean (Carey, 2001). The sea breeze is a common phenomenon in this wine producing area due to significant differences between sea and land temperatures during the summer months and it is subject to the combined effects of the sea breezes originating from Table Bay to the west and False Bay to the south. This phenomenon is associated with an increase in wind velocity in the afternoon, and holds important consequences for temperature and relative humidity values in the vineyards (BONNARDOT, 2002). The significant effects of temperature on berry composition and the importance of temperature and relative humidity values for vine functioning have been widely reported and the occurrence of the sea breeze and its associated climatic effects may, therefore, hold important implications for wine quality and character. Because of this the sea breeze studies play a significant role in the terroir studies of this coastal region. The use of an atmospheric modelling system increases understanding of the significance of the associated climatic components within the cultivar x environment interaction and will improve the mapping of terroir units for viticulture. A preliminary study is investigating these relationships in Stellenbosch and surrounds.

MATERIALS AND METHODS

Numerical simulations were performed over the South Western Cape region with the aid of the Regional Atmospheric Modelling System (RAMS version 4.3) (PIELKE *et al.*, 1992). The methodology was largely described by BONNARDOT *et al.*, 2002). Three synoptic situations were modelled at different resolutions (5 km, 1 km and 200 m): a southerly synoptic flow (onshore) and representative weather conditions at surface level (3&4/02/2000), a northerly synoptic flow (offshore) and very hot conditions (18/02/2000) and a southerly synoptic flow with cool, humid and cloudy conditions due to a cold front (19/02/2000). Climatic variables pertinent to viticulture (wind, relative humidity and temperature) were examined using a vertical cross-section across False Bay and up to 35 km inland in the area to the south and west of Stellenbosch (Fig.1). These data were compared to the real-time data from the synoptic weather station at Cape Town International airport and agroclimatic automatic weather stations of the ARC Nietvoorbij-Infruitec network situated in the Stellenbosch vineyards.

Plots of Sauvignon blanc have been delimited in commercial vineyards in close proximity to agroclimatic automatic weather stations to monitor the site x cultivar interaction (Table 1). These plots are at differing distances from Table and False Bay and, because of the complex topography of the area, are variously exposed to the sea influence. Soil profiles were examined and standard soil analyses performed in October 2000. The vines were spur pruned to 16 buds per meter cordon within a two-week period. Grapes were harvested at similar analyses (soluble solids, total titratable acidity and pH) and microvinified according to standard procedures at ARC Infruitec-Nietvoorbij. Wines were evaluated approximately six months after harvest by a trained panel of 14 judges. An unstructured line scale was used to evaluate the wine aroma based on pertinent categories of the Noble Wine Aroma Wheel (Noble *et al.*, 1987). Maximum, minimum and mean temperature, number of hours with temperature between 20°C and 25°C, number of hours with a wind speed greater than 4 $m.s^{-1}$, mean relative humidity at 15:00 LST and the FREGONI index (FREGONI & PEZZUTO, 2000) were calculated for the month before harvest for each of the plots. In addition, the HUGLIN (HUGLIN, 1986), AMERINE and WINKLER growing degree-day, as adjusted for South Africa by LE ROUX (1974), and RIOU (in TONIETTO, 1999) indices were calculated.

Outliers were removed and normality of the data tested. ANOVAs (GLM procedure) were performed to test the means of variables between years and plots. Discriminant analyses of viticultural and oenological data and stepwise selection (REG procedure) of environmental data for each viticultural and oenological attribute as dependant variables were performed to ascertain the variables having the greatest discriminatory value between plots. Principal Component Analyses (factor procedure, no rotation) were used to examine the relationships between variables that differed significantly between plots based on the ANOVA results. SAS version 8.2 was used for all procedures.

RESULTS AND DISCUSSION

Although the extent of the sea breeze penetration was clearly shown to reach beyond the frame of the study (more than 100 km inland) (BONNARDOT *et al.*, 2001), a steep temperature and relative humidity gradient was noted at the interface between maritime and inland air, causing the effect of the sea breeze on temperature and relative humidity to decrease rapidly with distance from the ocean (BONNARDOT, 2002). Topography and the prevailing wind in the boundary layer have a significant effect on the inland penetration of the sea breeze. The fullest extent of the sea breeze influx was usually noted in the mid-afternoon. It can be assumed that the southerly synoptic airflow and the surface weather conditions of the 3/02/2000 represent the most common climatic conditions during the ripening period (Fig.1). These conditions favoured and strengthened the sea breeze penetration from False Bay causing a corresponding reduction in temperature and increase in relative humidity between 13:00 and 15:00 LST (BONNARDOT, 2002) for stations situated on slopes facing the ocean and exposed to the sea air. The sea breeze penetration from the south (or from the west) increased the temperature differences between south facing and north facing slopes (and west and east facing slopes), but the effect decreased with distance from the sea. Differences of up to 4°C could be noted between the south facing and north facing slopes of the first hill on 3/02/2000 at 14:00 LST (Fig. 1). The dry and hot air carried by the offshore synoptic wind on 18/02/2000 created a greater contrast with the cool and humid maritime air and caused greater temperature decreases (up to 6°C) in the Stellenbosch wine growing area than was recorded with onshore synoptic wind conditions and cooler conditions (BONNARDOT, 2002). The temperature decrease and humidity increase due the sea breeze penetration (up to 2°C and 10%) was noticeable using the surface data recorded in the vineyards (Fig.2). On comparison between the data recorded at agroclimatic weather stations in the study area (Fig.2) and the modelled data (Fig. 1), it is clear that site conditions may prevail over the local circulation. Stations situated close to the ocean may be warmer than predicted due to being situated in a closed position (e.g. T14, T26) or as a result of warm, light coloured sandy soils (e.g. T13) or the presence of granitic outcrops (e.g. T12).

The results of the simulation showed that the sea breeze penetration (on 3/02/2000 at 14:00 LST) resulted in temperatures that were too low for maximum photosynthesis (below 24°C) up to 4 km from the sea (Fig. 1a). The conditions most favourable for photosynthesis, taking temperature and relative humidity into account were found between approximately 4 km and 13 km from False Bay. Relative humidity values were too low (below 60%) further inland (Fig. 1b). The sea breeze penetration also resulted in wind velocities greater than 4 $m.s^{-1}$ (Fig. 1c), with potential to cause stomatal closure and associated reduction in photosynthesis and increase in potassium mobilisation to the grape berries (KLIEWER & GATES, 1987) as well as reducing shoot growth and yield (Dry, Reed & Potter, 1988). The southerly wind flow favoured the strengthening of the sea breeze circulation with a maximum speed of 14 $m.s^{-1}$ over False Bay and 10 $m.s^{-1}$ at coastline. This did not continue beyond a few kilometres inland because of the surface friction and sudden roughness of the land surface generated by dune ridges of 80 m high, parallel to the coast. The simulated surface wind speed was 6 $m.s^{-1}$ at 5 km inland on the southern slope of the first hill and modelled values below 4 $m.s^{-1}$ only beyond 12 km on the northern slopes.

Viticultural and oenological data gathered for the experimental Sauvignon blanc plots in the Stellenbosch wine growing area for the period 1996 to 2001 were analysed in order to determine the importance of sea breeze related factors in the cultivar x site interaction. The site effect appeared to be distinguished by an altered the sink: source ratio as shoot mass and yield were selected as discriminating variables between plots. However, besides shoot mass and yield, phenology, bunch mass, berry size, the yield: pruning mass ratio and must total titratable acidity differed significantly between plots ($p=0.05$) as did the wine quality related factors of total titratable acidity ($p=0.05$), pH ($p<0.0001$) and extract ($p=0.03$) and the wine character related variable of fresh vegetative aromas ($p=0.03$) (Table 2).

Principal component analysis showed a relationship of wine pH with temperature related indices and soil depth and nutrition along factor 1 (32% of total variance), which were contrasted to the date of harvest and bunch mass (Fig. 3). The soil nutrition (P and K), wine pH and extract also appeared to be related along factor 2 (22.6% of total variance), and were contrasted with the number of hours during the month before ripening with a wind speed greater than 4 $m.s^{-1}$ (sea breeze induced pattern), yield, berry size and the yield: pruning mass ratio (Fig. 3). Literature suggests that increased exposure to persistent, moderate winds results in increased wine pH as a result of increased potassium mobilisation to the berries (KLIEWER & GATES, 1987) but an opposite effect has also been noted (Dry *et al.*, 1987), which was ascribed to a predominant canopy density effect on potassium mobilisation and wine pH. It appears that the increased shoot growth in this study also resulted in an overriding canopy effect on wine pH, together with the well-recorded effect of higher temperatures causing higher wine pH values. Soil K values may also have had an effect on wine pH. According to the stepwise selection of environmental variables, wine pH was determined by the mean maximum temperature in the month before harvest (+, $p=0.006$) and soil K (+, $p=0.0001$). Factor 3 (15.7% of the total variance) contrasted the must TTA, shoot mass and soil pH with the yield: pruning mass ratio and FREGONI index. Must TTA (+, $p=0.01$) and fresh vegetative characteristics (+, $p=0.04$) were related to the soil pH in the stepwise selection process. Wine TTA was related to temperature via the HUGLIN index (-, $p=0.0006$). The yield: pruning mass ratio was related to the soil K (-, $p=0.0001$) and pH (-, p=0.02) with shoot mass being most closely related to soil K (+, p=0.001) and yield to soil P (+, p=0.0004). The wine extract increased with increasing soil K (+, p=0.0024).

CONCLUSION

The proximity to the ocean causes cooler maximum temperatures and the sea breeze penetration results in additional reductions in temperature and saturation deficit, and thus a longer optimal period for photosynthesis and physiological ripening. RAMS clearly demonstrated these climatic effects. Further simulations at higher resolution will aid in the demonstration of specific site effects.

The significance of temperature for wine quality was once again shown. Higher temperatures resulted in lower must total titratable acidity and increased wine pH for Sauvignon blanc, negative quality factors in a warmer climate. Less wind exposure appeared to result in increased shoot growth and reduced yield: pruning mass ratio, and consequently increased canopy shading could be expected. Contrary to what was expected, therefore, higher wine pH values were associated with fewer hours with a wind speed greater than 4 $m.s^{-1}$. It is also clear that soil related factors have a significant effect on grapevine growth and wine character and quality: a soil with no limits to root growth resulted in increased shoot mass, higher must TTA and increased fresh vegetative characteristics for Sauvignon blanc.

It must be stressed that these results are preliminary and from non-homogenous plots but these particular cultivar responses to climatic factors closely linked with the sea breeze phenomenon suggest that the RAMS simulations will be invaluable, in conjunction with soil maps and analysis of the degree of exposure of sites, as a tool for delimitation of geographical indications on a regional level, once the cultivar X environment interaction is better understood.

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Table 1. Topographic, climatic and soil attributes of plots in the Stellenbosch wine producing area.

	T04	T05	T06	T08	T10	T12	T13	T14	T15	T26
Aspect	NW	NW	ESE	NW	SW	W	Flat	SE	SSW	SW
Altitude (m)	160	200	220	185	142	303	32	16	128	247
Distance to False Bay (km)	18	20	13	18	13	10	5	8	16	9
Distance to Table Bay (km)	33	32	24	25	23	36	32	28	27	36
Soil	Medium textured yellow neo-cutanic	Medium textured yellow neo-cutanic	Light textured neo-cutanic	Medium textured yellow neo-cutanic	Shallow wet medium sand duplex	.	Wet alluvial	Alluvial	Red neo-cutanic	Medium deep wet duplex
Soil pH[1]	*5.0*	*5.3*	*4.6*	5.6	5.7	.	4.8	4.1	4.9	.
Soil K[2]	*196*	*125*	*102*	113	90	.	55	137	188	78
Soil P[3]	*16*	*34*	*39*	66	51	.	49	96	62	36
MaxT[4]	29.3	28.0	26.5	26.6	25.9	26	27.7	27.7	27.9	30.2
MinT[5]	15.4	15.5	15.2	16.3	15.4	15	16.0	16.4	16.9	19.0
RH 1500[6]	53	58	58	56	58	63	60	58	59	47
WS>4m/s[7]	14	106	101	311	226	63	273	136	184	44

[1]pH(KCl) for the B horizon [2, 3] $mg.kg^{-1}$ in the A Horizon [1,2 & 3] Figures in italics denote weighted means for 0-1000mm (Conradie *et al.*, 2002) [4, 5]Mean maximum, minimum temperatures for month before harvest [6]Mean relative humidity at 15:00 for month before harvest [7] mean number of hours with wind speed higher than 4 $m.s^{-1}$ for month before harvest . denotes missing value.

Table 2. Viticultural attributes of Sauvignon blanc plots in the Stellenbosch wine growing area. Means followed by the same letter do not differ significantly ($p \leq 0.05$).

	T04	T05	T06	T08	T10	T12	T13	T14	T15	T26
Shoot mass (kg/vine)	0.7def	0.9cd	0.8de	0.4f	1.3ab	0.6def	0.5ef	0.5ef	1.5a	1.1bc
Yield (kg/vine)	1.7bc	1.8bc	2.0bc	2.3b	3.7a	1.2c	3.5a	1.9bc	2.1bc	1.3bc
Date of Harvest	15/2de	13/2e	15/2de	26/2bc	24/2cd	11/3a	17/2de	17/2de	20/2cde	29/2b
Mass 100 berries (g)	184abc	158bc	189ab	185abc	209a	66d	178abc	204a	155c	195a
Yield: pruning mass ratio	2.3bc	1.8c	2.7bc	2.4bc	2.9bc	2.1c	6.6a	4.3b	1.4c	1.2c

Table 3. Oenological attributes of Sauvignon blanc plots in the Stellenbosch wine growing area. Means followed by the same letter do not differ significantly ($p \leq 0.05$).

	T04	T05	T06	T08	T10	T12	T13	T14	T15	T26
Must acidity (g/l tartaric acid)	8.3ab	8.6a	8.8a	7.8ab	8.2ab	7.8ab	7.1b	7.8ab	7.1b	8.4ab
Wine acidity (g/l tartaric acid)	6.1ab	6.2ab	6.2ab	5.6bc	6.1ab	6.7a	5.4bc	5.6bc	5.0c	6.1ab
Wine pH	3.7b	3.6bcd	3.6bc	3.7b	3.6bcd	3.3e	3.5cd	3.4de	4.1a	3.7b
Wine extract	24.7ab	22.1bc	23.7abc	22.3bc	22.9abc	20.3c	22.2bc	22.0bc	26.5a	25.3ab
Fresh vegetative aroma (10)	3.3bc	4.2ab	4.4ab	3.7abc	5.1a	3.2bc	3.6abc	3.0bc	2.5c	3.7abc

FIGURES

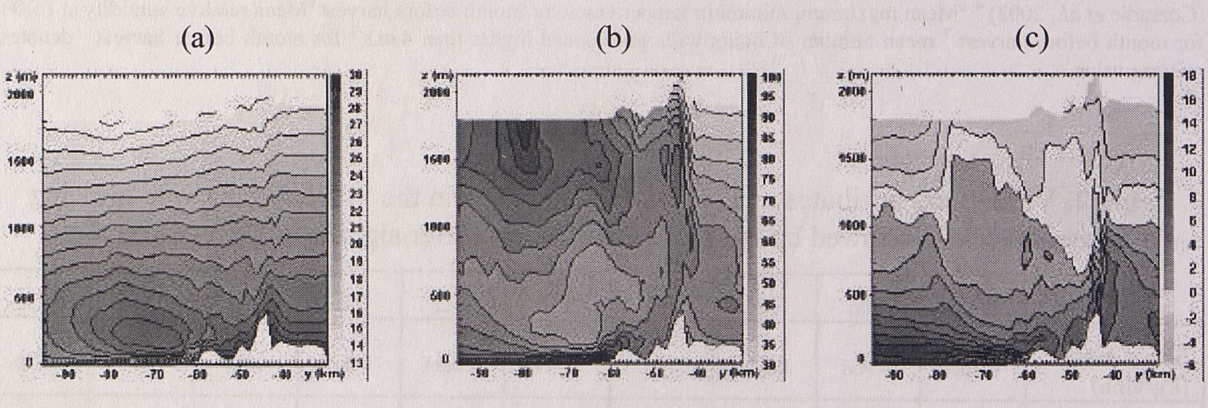

Figure 1. North-south vertical cross sections (ca.18°47' E) for (a) temperature in °C, (b) relative humidity in % and (c) wind speed in $m.s^{-1}$ (positive values represent southerly wind and negative values northerly wind) generated by the Regional Atmospheric Modelling System for 03/02/2000 at 14:00 LST across the Stellenbosch wine growing area. The y values represent the distance from the centre of Grid 1 (initial plot).

(a)

(b)

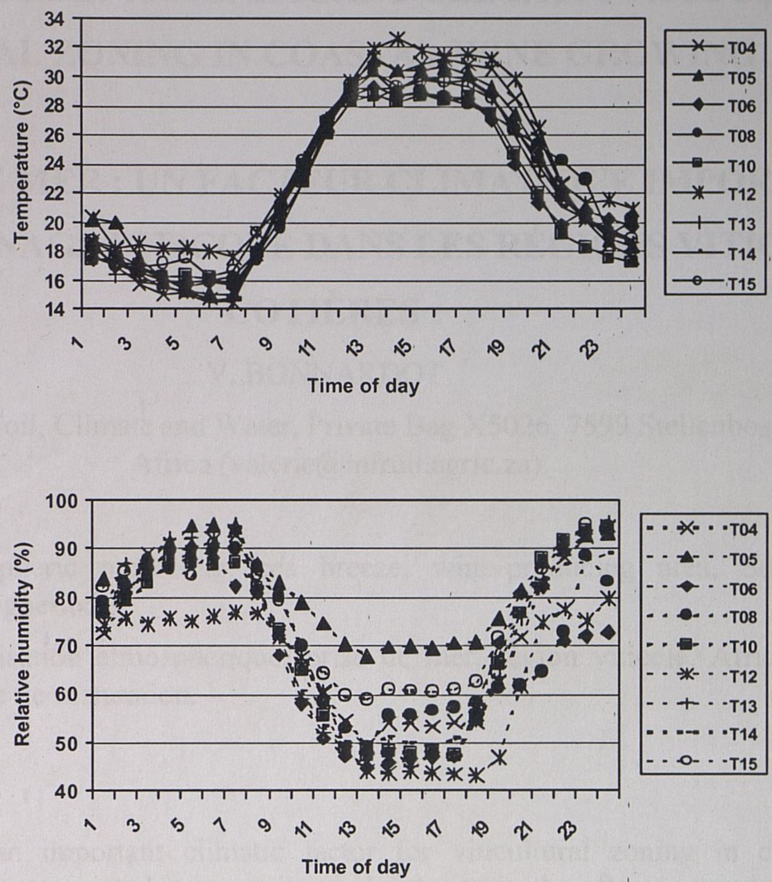

Figure 2. Hourly temperature in °C (a) and relative humidity values in % (b) on 03/02/2000 for automatic agroclimatic weather stations in the Stellenbosch wine growing region.

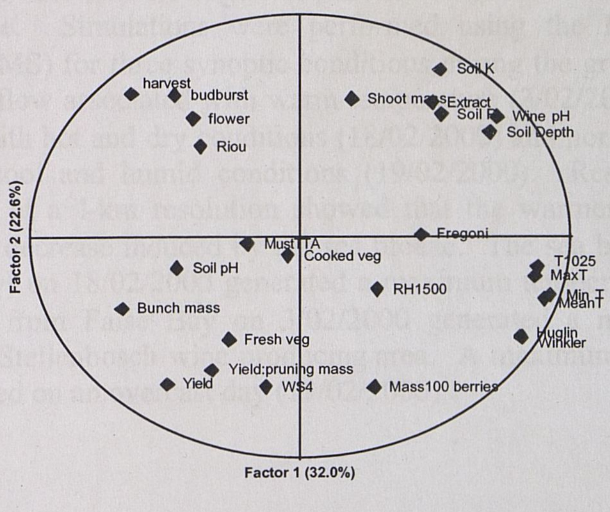

Figure 3. First two principal components for a combined analysis of viticultural, oenological and environmental data from Sauvignon blanc plots in the Stellenbosch wine growing area (1996-2001).