EVALUATION OF THE SITE INDEX MODEL FOR VITICULTURAL ZONING

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Abstract
A composite variable termed the Site Index (SI), integrating soil physical properties and mesoclimate, was previously proposed for characterisation of vineyard sites based on a three-year study of Cabernet Sauvignon vineyards in the Hawke's Bay region of New Zealand. In this paper, viticultural data collected from Chenin Blanc and Cabernet Franc vineyard sites in the Loire Valley (France) were analysed. These analyses provided an opportunity for validation and understanding of limitations of the SI model. The relationship between SI and Chenin Blanc fruit composition in Anjou was found to be similar to that determined in the New Zealand study. In this study, a modified SI that included winter rainfall was found to be a better predictor of grapevine vigour than original SI. In cases when the range of SI values between sites was small, no significant correlation between SI and viticultural variables was observed. Factor analysis extracted one factor best related to SI and fruit quality potential, and the second factor related to modified SI that included winter rainfall and vegetative vigour. It was determined that SI has the potential to be included as an additional indicator to the range of attributes available for vineyard site evaluation. It would be particularly useful where input variables (soil depth, texture, rockiness, water influx and air temperature) are considerably different between sites that are being compared.

Evaluation du modèle d'Indice de Site pour le zonage viticole

Résumé
Une variable composite, dénommée Indice de Site (SI), intégrant les propriétés physiques du sol et le mésoclimat, avait été proposée pour caractériser les terroirs dans le cadre d'une étude des vignobles de Cabernet Sauvignon de Hawke's Bay en Nouvelle Zélande. L'objet du présent exposé est l'analyse de bases de données viticoles du Val de Loire (France) constituées à partir de parcelles d'essai « terroirs » de Cabernet franc et de Chenin, sur de plus longues périodes. Dans les cas où les valeurs du SI étaient faibles, aucune corrélations entre le SI et les paramètre viticole n'ont été observés. L'index de site peut être un outil additionel s'ajoutant à la liste des charactéristiques servant à évaluer les vignobles. Le SI serait particulièrement utile lorsque les variables tel que profondeur du sol, texture, présence de cailloux, de même que les conditions hydriques et température ambiante de l'air sont particulièrement différentes au niveau des sites comparés.

Acknowledgements
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Key words: terroir, modelling, phenology, fruit composition, Chenin Blanc, Cabernet Franc

Introduction
Site Index (SI) is a simple formula based on several site mesoclimatic and soil variables that characterised the effect of site on Cabernet Sauvignon fruit and wine quality potential in the wine region of Hawke's Bay, New Zealand (Tesic et al, 2002). In the present paper, data from two groups of

vineyard sites in the Loire Valley (France), planted with cultivars Chenin Blanc and Cabernet Franc, respectively, were analysed to validate SI, as well as to examine potential improvements of this empiric model to address a greater range of environmental conditions present in diverse viticultural growing areas. These two network of sites were originally monitored in a long-term research project investigating the concept of BTU (Base Terroir Unit, Morlat, 2001). The BTU system was developed in France, and is used on a commercial basis to assess the potential of a vineyard site for the production of certain wine styles and quality categories. The main difference between SI and BTU is that the latter is qualitative (descriptive), whereas SI integrates certain site attributes in a singular numeric value. Furthermore, while BTU is based on a detailed description of site geology and edaphic conditions, SI also integrates elements of site mesoclimatic conditions. Both these site evaluation models are empirical. A number of advanced crop models applicable to grapevines have more recently been developed (Brisson et al, 2003; Keating et al, 2003; Stockle et al, 2003 and van Ittersum et al, 2003). These models are based on complex and modular frameworks and they are universally applicable. They are mostly mechanistic and thus robust, and they would appear to have potential for viticultural zoning in the future. This study aims to validate SI as a tool for viticultural zoning and delimitation of sub-regions or areas of particular viticultural merit.

Material and Methods

Viticultural data for this study were collected from three groups of vineyard sites located in the Loire Valley (France). The first group comprised five Chenin Blanc sites that were observed over 10 years, the second consisted of 12 Cabernet Franc sites observed over a four-year period and the third group of sites consisted of 14 Cabernet Franc sites in the Saumur area observed over 2002. All these vineyards are unirrigated, hand pruned and harvested. The experimental vines were grown using the same training and pruning system (simple Guyot for Cabernet Franc and double short Guyot for Chenin) and same spacing (2 x 1 m), across all investigated sites. All viticultural practices were standardised in order to minimise the effect of human factors; chemical weed control on all plots, same pruning date (mid-February), same suckers removal date. The thinning of the bunches was performed at the end of July, in order to meet the A.O.C. regulations (60 hL/ha). The decision when to harvest was based on the average maturity: all plots of each variety were harvested the same day, except on rare and extreme situations. The harvesting date for Chenin referred to the production of dry white wines, not dessert wines.

Studied variables:

a) precocity of the phenological stages: 50% bud break, 50% flowering and harvest date for Chenin Blanc (in Julian days);
b) berry quality at harvest: berry weight in g, Total Soluble Solids (TSS in °Brix), titratable acidity (TA in g H_2SO_4/L), pH, anthocyanin content (mg/kg of berries) for Cabernet Franc sites in Anjou;
c) vigour (pruning weight in kg/vine) and yield in kg/vine;
d) two ratios were calculated for the needs of the study : the Ravaz index (yield to pruning ratio) and the sugar to acid ratio;
e) wine score was available for the Cabernet Franc sites in Anjou

Long-term climatic data for the Anjou area in the Loire Valley are according to Morlat, 1989. Climatic data for Chenin Blanc sites were adjusted according to available site information. The effect of site altitude on air temperature was accounted for by subtracting 0.6 ºC for each 100 m of increase in altitude. The effect of aspect was approximated by increasing average air temperature by an 0.2 ºC on all sites that faced South, according to G. Barbeau (personal communication). For the Cabernet Franc group of sites, such adjustment was not done due to lack of relevant site information. Instead, climatic records of the Montreuil-Bellay weather station (INRA) were used as estimates of site mesoclimatic conditions.

A lack of actual on-site weather records was a limitation to this study. For this reason, it was necessary to estimate certain climatic variables for investigated vineyard sites. It is likely that access to actual climatic records, instead of using estimated data, would have enabled a more precise subsequent analysis of the relationship between site environmental conditions and vine behaviour.

Site Index (SI) and Site Index based on winter rainfall (SI_w)
In addition to the published SI calculation (Tesic et al, 2002) an attempt was made to provide a better fit between SI and vine vegetative growth data by changing one of the variables used to calculate SI. This was achieved by changing the seasonal rainfall figure (originally in the SI formula) to include winter rainfall (total rainfall for months November through to March). This index, calculated using winter instead of seasonal rainfall is labelled SI_w.

Results and Discussion
Chenin Blanc sites
Environmental conditions across five Chenin Blanc sites in the Anjou area of the Loire Valley, over the period of 10 years resulted in a considerable range in SI and SI_w (Table 1). Ten-year averages for pruning weights at different sites varied almost twofold between individual sites. Yield and berry weight was less variable. There was little difference between sites in phenology, while there was a pronounced variability in juice attributes.

When annual data for these sites were analysed, there was a negative correlation between SI and berry weight at harvest (r=–0.35), however there was no relationship between SI and yield or pruning weight. The main berry constituents (TTS and TA) were significantly correlated with SI (r=0.62 and r=–0.52, respectively). The relationship between SI and TSS (Figure 1) is similar to that found in previous studies on Cabernet Sauvignon in New Zealand (Tesic et al. 2002), thereby appearing to validate SI as a tool to differentiate Chenin Blanc sites in Anjou based on their sugar ripening capacity.

When SI_w was used instead of SI there was a negative correlation with pruning weight (r=–0.58, Figure 2), which was similar to the relationship between SI_w and pruning weight (r=–0.59) in Cabernet Sauvignon from the Hawke's Bay region of New Zealand (unpublished results). SI_w was correlated with yield to pruning weight ratio (r=–0.75), a considerably stronger correlation than between the same viticultural variable and winter rainfall (r=–0.50), which would appear to indicate an advantage of using SI_w instead of the plain figure for total winter rainfall.

From these results it would appear that SI_w has an advantage over SI in terms of stronger relationship with vine vegetative growth (as expressed by pruning weight). This is supported by the results of the PCA analysis, as discussed later in this text.

Cabernet Franc sites (Anjou)
Environmental conditions across 12 Cabernet Franc sites in the Anjou area of the Loire Valley, over the period of 4 years resulted in a moderate variability in SI and SI_w (Table 2). Four-year averages for pruning weights at different sites varied up to four times between individual sites. A considerable degree of variability in berry weight is also noted, as well as in berry juice attributes. Overall wine sensory scores, however, varied only slightly between sites.

SI_w values were smaller than SI as the winter rainfall across this range of years was higher than during season (while the opposite was true over 10 years observed in the Chenin Blanc study, which is the reason average SI_w values for this cultivar's vineyard sites were higher in this study).

Overall statistical analysis of the relationship between SI/SI_w and viticultural variables at Cabernet Franc sites has shown a limited number of significant correlation coefficients. When this was investigated into more detail, it was concluded that in these relationships there was one obvious outlier and this was the POY site. This site has exhibited a fairly poor vegetative potential compared to relatively favourable site conditions. Further investigations had shown that this site had a recent change of management and that there was evidence of a significant disease incidence and other vineyard management issues. Because of these reasons it was considered that a removal of this outlier from statistical analysis would be justified.

With the outlier removed, a number of significant correlations between site indices and viticultural attributes were noted. TSS, as the main indicator of fruit ripeness, was related to SI and date of harvest. This multiple regression (TSS=-4.26-0.04*SI+0.19*harvest date, R^2=0.26, p=0.012) shows an interaction between site conditions and the decision when to harvest (harvest date varied from year to year). A negative relationship between SI and pH (r=–0.38), was not expected, as it meant that in conditions of warmer and drier environment juice pH was lower, ie. more acidic. On the basis of existing information it is not clear why this had occurred, but it can be assumed that the decision when to harvest influenced this compositional attribute.

Pruning weight was also related with SI although the correlation was moderate (r=–0.48). However, when SI_w was used as the indicator, this correlation was stronger (r=–0.62). Again, it would appear that a site indicator that includes total winter rainfall aligns better with the vine vegetative vigour as expressed by pruning weight.

Cabernet Franc sites (Saumur)
Environmental conditions across 14 Cabernet Franc sites in the Saumur area of the Loire Valley, over the 2002 season resulted in a relatively small range of SI (and SI_w) values (Table 3). It should be noted that actual on-site weather data were unavailable and this might have contributed to the apparent uniformity of site conditions across sites as per these indices.

On the other hand, measured viticultural attributes have exhibited a considerable degree of variability between sites. Pruning weights, for example, varied 0.32-1.08 kg/vine. There were also some differences in fruit composition, TSS ranging 18.4-21 ºBrix, with some differences also observed in organic acid concentration in berries (there was a notable variation in malic acid content ranging 2.8-4.5 g/L).

Considering the above results, it is not surprising that there were no significant correlations between SI (and SI_w) and most observed viticultural attributes. Correlation between SI and fruit maturity index (GA) was r=-0.55, which was significant, but opposite to that noted in other groups of sites that were analysed in this and other studies (Tesic et al, 2002 and Tesic, 2004). One possible explanation for this apparent anomaly is the small range of SI values (1.2-2), which is less than in the Cabernet Franc – Anjou group of sites (2.3-4.3) and Chenin Blanc group of sites (2.7-4.2). It is possible that SI cannot explain the variability in viticultural performance when the overall input range of data used for its calculation is low.

Principal Component Analysis (PCA) of site environmental and vine behaviour data
PCA of vineyard site environmental and vine growth, phenology, yield and quality data was conducted for two groups of sites investigated in the present paper (Table 4). The first analysis involved 20 variables derived from five Chenin Blanc vineyards over 10 years. The second one comprised 15 variables from 11 Cabernet Franc Anjou vineyards over a four-year period (the POY site was once again removed from the analysis as an outlier).

These analyses indicated that one principal component was best represented by SI, while the second was best correlated with SI_w. Further interpretation shows that the first principal component can be termed a ‘quality’ factor. It was strongly correlated with TSS, harvest date and TSS/TA ratio, and juice pH in the case of Cabernet Franc. Within this factor, environmental conditions of observed vineyards sites were well represented by SI, and also seasonal rainfall (which was negatively correlated with this ‘quality’ factor). In addition, the ‘quality’ factor in the Cabernet Franc data analysis was strongly correlated with air temperature and winter rainfall.

The second principal component could be termed a ‘vigour’ factor, as it was correlated well with pruning weight and yield to pruning ratio. Vineyard site environmental conditions associated with this factor pointed to soil water reserves at the beginning of the season (correlation with soil depth and SI_w).

Conclusions

SI is an empirical model derived from relationships observed in Cabernet Sauvignon vineyards over two seasons in a New Zealand wine region and it has a number of assumptions that might not be equally valid when this model is applied elsewhere. The New Zealand study of SI (Tesic et al, 2002) indicated that there was a strong effect of SI on pruning weight, and this had presumably occurred through a vast range of available water Cabernet Sauvignon vines were experiencing in that study. It is quite possible that, where such a wide range of available water is not experienced, that there is no associated effect on vine vigour and subsequent effects associated with fruit composition. This would explain a lack of correlation between SI and vine growth observed in part in this and other (Tesic 2004) studies.

The analysis of vineyard environmental conditions and viticultural attributes of two varieties, Chenin Blanc and Cabernet Franc, when grown on different sites in the Loire Valley, confirms the validity of SI as a general concept of considering both above- and below-ground environmental conditions of a vineyard site. However, what this, as well as previous studies (Tesic 2004), have shown is that different viticultural areas will have different site attributes as major drivers for vine performance.

SI has the potential to be included as an additional indicator to the range of attributes available for site evaluation. It would be especially useful if input variables (soil depth, texture, rockiness, water influx and temperature) are all very varied between sites that are being compared.

Research on the SI concept had brought to attention a lack of weather data gathered on vineyard sites and within sub-regions in wine regions around the world. The advent of affordable weather stations should increase the availability of such data in the future and in turn enable more precise modelling, or wider practical use of existing models. Analysis of the on-site collected vineyard weather data is increasing being the focus of research efforts (Considine et al, 2004; Heazlewood et al, 2004).

This research had also contributed towards the formulation of a “minimal list” of soil attributes that are useful for characterising vineyard site conditions pertinent to vine performance.

The SI_w index, as a modified SI, had shown the importance of winter rainfall for vineyard water budget and vine performance in the subsequent season. More research should be done to assess the contribution of winter rainfall and possibly the water use of over-wintering weeds on subsequent vine performance, particularly in areas with mild winters (such as many areas of Australia). In such areas vines frequently do not begin the new growing season with soil water reserves at field water capacity across the rooting zone depth.

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List of Tables and Figures

Table 1. Summary of averages for 1992-2001 for Chenin Blanc in Anjou

Site	SI	SI_W	Pruning Weight	Yield	Berry Weight	Budb.	Flow.	Harv.	TSS	TA	pH
1BLO	3.1	4.2	0.67	2.35	1.74	96	168	289	20.6	5.91	3.29
1BON	3.5	4.8	0.45	1.92	1.49	94	165	290	24.3	4.89	3.30
1BOR	2.7	3.6	0.85	2.02	1.79	97	167	290	21.7	5.89	3.36
1SAU	3.4	4.6	0.50	1.85	1.44	94	167	290	22.2	4.94	3.43
1VAL	4.2	5.8	0.45	1.98	1.50	94	166	290	24.4	4.71	3.38
Average	3.4	4.6	0.58	2.02	1.59	95	167	290	22.6	5.27	3.35

Table 2. Summary of averages for 1995-1998 for Cabernet Franc in Anjou

Site	SI	SI_W	Pruning Weight (kg/vine)	Berry Weight (g)	TSS (ºBrix)	TA (g/L)	pH	Anthocyanins (mg/kg)	Wine Score
1ALT	2.8	2.3	1.03	1.13	19.6	5.2	3.31	1391	2.6
1DAM	3.0	2.5	0.77	1.52	20.9	4.9	3.31	1462	3.4
2ALT	3.2	2.6	0.63	1.08	21.4	4.8	3.44	1760	3.0
2EL	3.1	2.5	0.81	1.51	19.6	5.2	3.27	1340	2.9
3EL	3.4	2.8	0.70	1.54	19.4	4.7	3.29	1472	2.9
4EL	3.1	2.6	0.98	1.46	20.2	5.1	3.34	1322	3.0
CHA	3.8	3.2	0.51	1.34	19.8	4.0	3.40	1664	2.8
FAL	3.7	3.1	0.27	1.12	18.5	4.0	3.40	1689	2.5
PER	3.3	2.7	0.94	1.65	20.0	5.3	3.27	1371	2.8
POY	2.3	1.9	0.58	1.44	20.4	4.8	3.38	1885	3.1
SCI	4.3	3.5	0.62	1.15	21.6	4.7	3.27	1525	2.9
TUR	3.5	2.9	0.70	1.33	18.8	5.6	3.35	1370	2.9

Average	3.3	2.7	0.71	1.38	20.1	4.8	3.33	1524	2.9

Table 3. Site conditions and Cabernet Franc performance in the Saumur area in 2002

Site	SI	SI_w	Pruning weight (kg/vine)	Berry weight (g)	TSS (ºBrix)	TA (g/L)	pH	Tartaric acid (g/L)	Malic acid (g/L)
CHI2	1.8	4.1	0.86	1.48	20.1	5.5	3.40	4.4	4.1
CHI3	2.0	4.7	0.68	1.66	19.7	5.5	3.50	5.1	3.6
RES1	2.0	4.6	0.55	1.57	19.5	5.0	3.45	4.3	4.0
SNB1	1.9	4.3	0.84	1.34	20.0	5.8	3.40	5.4	4.5
SAV1	1.6	3.6	0.32	1.51	19.4	4.6	3.40	4.7	2.8
LAR1	1.8	4.2	1.08	1.42	19.2	5.6	3.30	4.5	4.2
LAR2	1.7	3.9	0.63	1.31	21.0	5.3	3.37	5.4	3.3
CHI1	1.3	3.1	0.61	1.29	20.2	5.4	3.30	4.4	3.8
SOU2	1.7	3.9	0.88	1.57	19.1	5.1	3.40	5.2	3.2
PAR1	1.7	3.9	0.75	1.58	19.4	4.9	3.30	4.8	3.1
SNB2	1.7	4.0	0.78	1.54	19.2	4.9	3.40	4.8	3.1
CYR1	1.7	3.9	0.85	1.51	18.4	5.5	3.30	4.9	3.9
SOU1	1.2	2.9	0.53	1.53	19.9	4.5	3.36	4.6	2.8
RES2	1.7	3.9	0.59	1.45	19.2	5.3	3.30	5.2	3.3
Average	1.7	3.9	0.7	1.5	19.6	5.2	3.4	4.8	3.6

Table 4. Factors (or principal components, PC) extracted by PCA for the Chenin Blanc sites (1992-2001) and Cabernet Franc Anjou sites (1995-98). Marked coefficients > ±0.700.

	Chenin Blanc		Cabernet Franc	
	PC 1	PC 2	PC 1	PC 2
Clay to silt ratio	0.188	0.369	-	-
Gravel percentage	0.212	0.643	0.010	-0.524
Rooting zone depth	-0.205	**-0.777**	-0.199	**0.715**
Mean temperature - April	0.333	0.326	**-0.955**	-0.189
Mean temperature - July	0.212	0.268	**-0.955**	-0.189
Seasonal rainfall (Apr-Oct)	**-0.786**	0.083	**0.955**	0.189
SI	**0.793**	0.209	**-0.746**	-0.624
SI_W	-0.442	**0.713**	-0.423	**-0.808**
Winter rainfall (Nov-Mar)	0.594	-0.359	**0.955**	0.189
Pruning weight	0.255	**-0.807**	-0.005	**0.819**
Yield	-0.482	0.056	-	-
Yield to pruning ratio	-0.546	**0.711**	-	-
Berry weight	-0.347	-0.562	-	-
Budburst date	0.024	-0.298	-	-
Flowering date	0.045	-0.459	-	-
Harvest date	**0.734**	-0.242	-	-
TSS	**0.887**	0.196	0.629	0.148
TA	-0.642	-0.525	**-0.911**	0.259
Sugar : acid ratio	**0.777**	0.440	**0.908**	-0.250
pH	0.233	0.059	**0.918**	-0.107
Anthocyanins in berry skins	-	-	-0.180	-0.681
Wine sensory score	-	-	0.126	0.088
Explained Variance	5.189	4.366	7.362	3.273
Proportion of Total Variance Explained	0.259	0.218	0.491	0.218

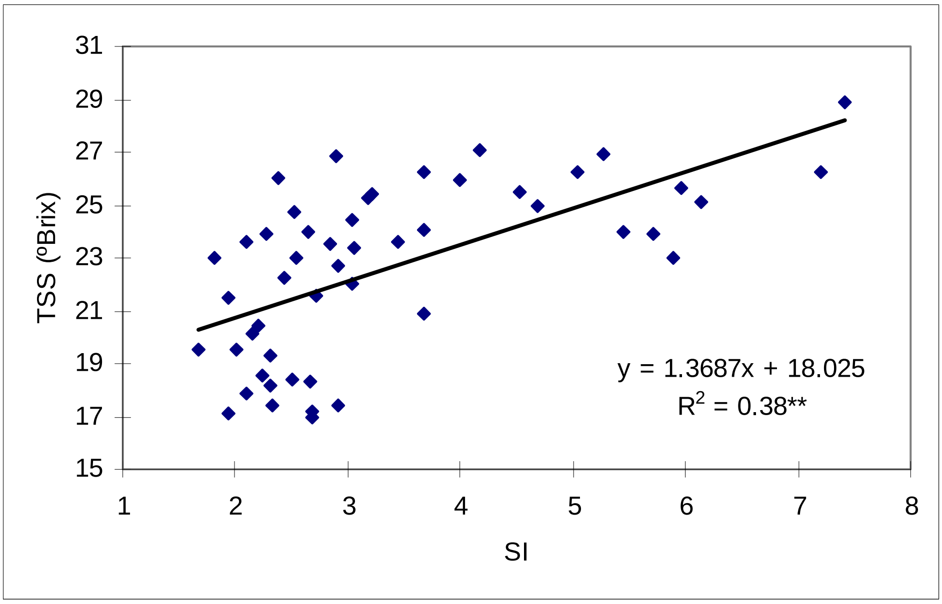

Figure 1. Regression of SI on TSS (ºBrix) in Chenin Blanc grown on five sites in Anjou (1992-2001)

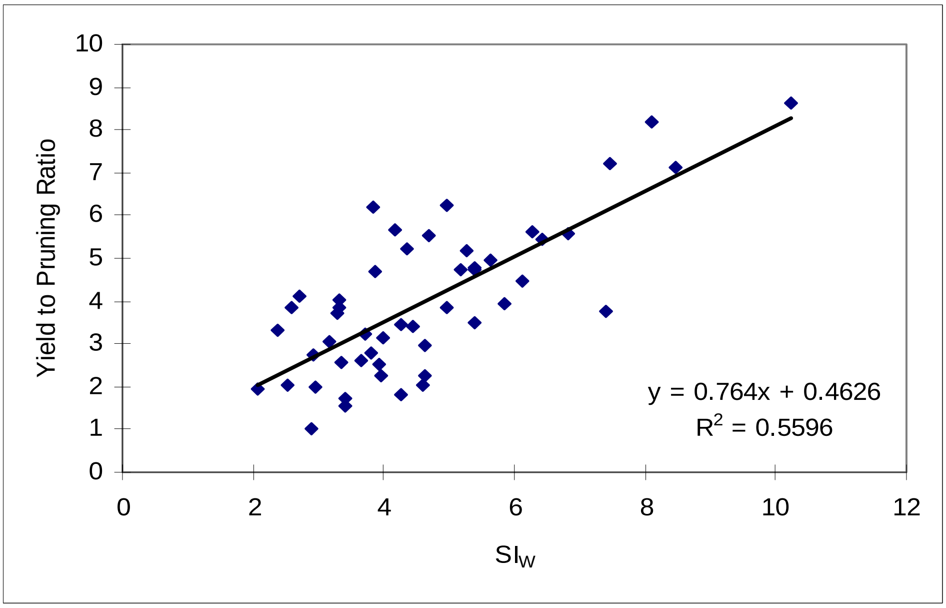

Figure 2. Regression of SI_w on yield to pruning ratio in Chenin Blanc when grown on five sites in Anjou (1992-2001)