INFLUENCE OF VIGOUR ON VINE PERFORMANCE AND BERRY COMPOSITION OF CV. SANGIOVESE (*VITIS VINIFERA* L.)

Ilaria FILIPPETTI*, Gianluca ALLEGRO, Gabriele VALENTINI,
Chiara PASTORE, Emilia COLUCCI and Cesare INTRIERI

Università di Bologna, Dipartimento di Colture Arboree - Sezione Viticola del Centro Interdipartimentale di Ricerche Viticole ed Enologiche, Viale Giuseppe Fanin 46, 40127, Bologna, Italy

Abstract

Aims: To test the effects of varying degrees of vigour on vine growth, cropping, grape composition and wine quality.

Methods and results: The study was conducted in 2008-2009 in a cv. Sangiovese (*V. vinifera* L.) vineyard (Tuscany). Two uniform zones marked by low (LV) and high (HV) vigour vines were pinpointed using an NDVI (normalized difference vegetation index) map. Soil analysis showed similar texture in both zones, but total soil nutrients were lower in LV than in HV. While only LV vines showed soil water content close to wilting point in 2008, they demonstrated lower leaf area and yield and higher berry sugar and anthocyanin concentrations compared to HV vines. Chemical and wine tasting analysis of the wines made in 2009 showed that the LV wines had better sensory attributes than the HV wines, despite their excessive ethanol content.

Conclusions: The differences in vigour, yield and must and wine quality of LV compared to HV vines were linked to variations in soil fertility and water retention capacity. Precision vineyard management practices like supplementary fertilization and irrigation should be used to increase vigour and yield and to decrease sugar content in LV grapes. Cover crop may be used in HV vines to decrease their vigour and yield.

Significance and impact of the study: The study confirms that the evaluation of within-field variability is crucial for site-specific vineyard management.

Key words: vigour, NDVI, anthocyanins, wine

Résumé

Objectifs: Comprendre les effets de différents niveaux de vigueur sur la croissance des sarments, la production et la qualité des raisins et des vins.

Méthodes et résultats: L'étude a été menée en Toscane (2008-2009) dans un vignoble de Sangiovese (*V. vinifera* L.). À l'aide d'une image NDVI (indice de végétation par différence normalisée), il a été possible d'identifier une parcelle avec souches de faible vigueur (LV) et une parcelle avec souches de forte vigueur (HV). L'analyse du sol a montré que les deux parcelles n'étaient pas différentes pour la granulométrie, mais que dans la parcelle LV la teneur en éléments nutritifs était plus basse que dans la parcelle HV. En 2008, seule la parcelle LV a montré une teneur en eau du sol proche du point de flétrissement. Les souches HV ont montré une surface foliaire et une production plus élevée, associée à des raisins moins riches en sucres et en anthocyanes totales que les souches LV. L'analyse chimique et la dégustation des vins obtenus en 2009 ont montré que le vin des souches LV présentait une meilleure qualité olfactive et gustative, mais un degré alcoolique trop élevé.

Conclusions: Le sol de la parcelle LV a vraisemblablement subi un procédé d'érosion le long de la pente, ce qui a entraîné dans la partie plus basse (HV) une accumulation des éléments principaux de la fertilité et la matière organique plus superficielle ainsi qu'une plus grande capacité de rétention hydrique. Par conséquent, les souches LV ont montré moins de vigueur et de production, mais des raisins plus sucrés et plus riches en anthocyanes. On peut envisager l'utilisation de techniques de précision (fertilisation et irrigation de secours) dans la zone LV pour augmenter la vigueur et la production des souches et diminuer le sucre dans les raisins, sans avoir de conséquences négatives sur la qualité finale. Au contraire, un engazonnement du sol pourrait être utilisé dans la parcelle HV pour maîtriser la vigueur, diminuer la production et améliorer la qualité.

Importance et impact de l'étude: L'étude confirme que la connaissance du comportement végétatif et productif des souches à l'échelle parcellaire est essentiel pour envisager l'application de la viticulture de précision dans le but de maîtriser la variabilité jusqu'à l'obtention de l'uniformité.

Mots clés: vigueur, NDVI, anthocyanes, vin

manuscript received 6th March 2012 - revised manuscript received 15th November 2012

*Corresponding author: ilaria.filippetti@unibo.it

J. Int. Sci. Vigne Vin, 2013, **47**, n°1, 21-33

©Vigne et Vin Publications Internationales (Bordeaux, France)

INTRODUCTION

Spatial variability is a common occurrence in vineyards worldwide, and a number of recent insights have provided tools for better understanding this challenging topic (Bramley and Hamilton, 2004 and 2007 ; Proffitt *et al.*, 2006 ; Tisseyre *et al.*, 2007). Among the most important interacting factors held to be responsible for spatial variations in vine vigour, yield and fruit traits are topography, disease, soil water-holding capacity and soil nutrient content. Vine vigour, defined by Winkler (1962) as « the condition that is expressed in rapid growth of the parts of the vine », usually displays considerable spatial variation within the same vineyard (Johnson *et al.*, 2003). It thus follows that vigorous vines demonstrate a well-developed canopy and total leaf area that have a considerable effect on fruit yield and quality (Dry, 2000 ; Haselgrove *et al.*, 2000 ; Petrie *et al.*, 2000 ; Tisseyre *et al.*, 1999 ; Iland *et al.*, 1994). A literature survey highlights that the application of remote sensing makes it possible to develop a vine vigour index (photosynthetically active biomass, canopy size) that is linked to spatial differences in grape yield (Baldy *et al.*, 1996 ; Lamb and Bramley, 2001 ; Johnson *et al.*, 2001 ; Bramley *et al.*, 2003 ; Bramley, 2005 ; Fiorillo *et al.*, 2012). Note, however, that spatial variability in quality may not be as consistent as yield and not well correlated with yield variability (Bramley and Hamilton, 2004 ; Bramley, 2005). These results are not unexpected as it is known that low cropping does not necessary imply high quality and that grape composition is influenced by more complex factors than yield.

Irrespective of yield variation, vine vigour can affect grape composition. This is shown, for example, by the lower sugar concentration of high vigour vines compared to that of low vigour ones in Pinot noir cv. (Cortell *et al.*, 2008). While seed tannins were not greatly influenced by vine vigour, skin tannins were increased in low vigour vines of Pinot noir (Cortell *et al.*, 2005). Moreover, sensory analysis showed that the wines made from low vigour plants had higher astringency than the wines from high vigour vines (Cortell *et al.*, 2008).

A very important role in quality determination of black berry grapes is played by skin anthocyanins, which are affected by environmental and management-related factors such as light interception, temperature, nitrogen, and bunch thinning (Winkler *et al.*, 1974 ; Pirie and Mullins, 1980 ; Archer and Strauss, 1989 ; Jackson, 2000 ; Mori *et al.*, 2007 ; Tarara *et al.*, 2008 ; Keller *et al.*, 2005 ; Guidoni *et al.*, 2008 ; Filippetti *et al.*, 2007). The increasing level of canopy vigour status, expressed as NDVI (Normalized Difference Vegetation Index), appears to be negatively related to grape colour in Cabernet Sauvignon grown in cool climate (Lamb *et al.*, 2004). Smart (1985) and Smart *et al.* (1988) see these results as being due to the greater light exposure of the fruiting zone in low vigour vines. Note, too, that the effects of light on berry skin anthocyanin concentration are dependent upon the extent to which berry temperature is raised in response to increased light exposure, as temperatures above 33-35 °C may have a detrimental effect on anthocyanin accumulation (Mori *et al.*, 2007).

Gaining greater insight into the interrelatedness of vine vigour, grape composition and wine analytical and sensory traits represents a crucial issue in vineyard management. Once spatial variability is assessed, different styles of wine may be made from diverse zones of the same vineyard (Bramley and Hamilton, 2007), differential harvests may be performed by mechanical means (Sethuramasamy-raja *et al.*, 2007 and 2010) or site-specific vineyard management may be developed by precision viticulture techniques (Fiorillo *et al.*, 2012). The present trial was performed to assess how different levels of vigour in a commercial vineyard of cv. Sangiovese may influence vine growth response, cropping, grape composition and wine quality and what are the causes of vigour variability.

MATERIALS AND METHODS

1. NDVI preliminary map

The research was conducted in 2008 and 2009 in a non-irrigated hillside vineyard in Pesa Valley, Tuscany (Italy), marked by a steep slope (about 10 %) and rows oriented up and down the slope. The trial block (0.32 ha extent) was selected using a high resolution multispectral image, NDVI map, drawn up by the CNR-IBIMET Institute of Biometeorology (Fiorillo *et al.*, 2012). Multispectral airborne images were acquired using a DFR (Duncan-Flir-Riegl) system installed on a flexible Sky-Arrow 650 TC/TCNS airplane (Papale *et al.*, 2008 ; Matese *et al.*, 2009). The flights were made in 2007 at the end of shoot growth, under clear sky conditions and high solar elevation to reduce shadow effects on the ground. The acquisition of remotely sensed imagery makes it possible to work up a NDVI map (Rouse *et al.*, 1974). Two different homogeneous vigour zones

©Vigne et Vin Publications Internationales (Bordeaux, France)

were thus pinpointed (Figure 1). Vines in the upper part of the trial site were marked by very low vigour (LV), while plants in the lower part of the same site showed high vigour (HV).

2. Plant material

The vineyard was a 6-year-old planting of *Vitis vinifera* L. cv. Sangiovese (clone Janus 20) grafted to stock 161/49 C. The vines were spaced 2.20 m x 0.80 m (inter and intra-row), at a density of 5,680 vines/ha; rows were north-south oriented; and the vineyard was on a south-facing slope, 350 m above sea level. The training system was a vertical shoot-positioned spur-pruned cordon. All the vines in each vigour zone were pruned and left with 5 two-bud spurs per vine. At bloom the shoots were thinned at 10 per vine and light shoot trimming was performed in 2008 and 2009 over the first ten days of July, leaving a canopy height of about 1.3-1.4 m. In each vigour zone 32 vines, distributed in the 4 central rows, were tagged for precise berry sampling and vine measurements. Pest and soil managements were carried out according to local standard practices.

3. Soil and climate description

In 2008, two weeks after a 10-mm rainfall at the end of July, five duplicate soil cores were collected from LV and HV zone in a grid pattern from the root zone, at a depth of 20-80 cm. One replicate was used for measuring soil moisture content and the remaining one for chemical and physical analyses, which were conducted by Sicural Laboratory (Cesena, Italy) using the standard procedures set forth by the Agriculture Ministry (DM 13/09/1999 and DM 25/03/2002). Soil texture, organic matter content, total and active lime, total carbonates, C/N (carbon/nitrogen) ratio, pH and the main nutrient (total nitrogen, phosphorus, P_2O_5, and potassium, K_2O) were assessed. A computer program estimated soil-water characteristics such as wilting point and field capacity after the input of sand, clay and organic matter data (Saxton and Rawls, 2006). Mean daily air temperature and rainfall data were recorded from April to September in 2008 and 2009 at a weather station located close to the trial site.

4. Vine measurements

In 2008 and 2009, 30 berries per tagged plant were collected every two weeks from veraison to harvest and used to determine must soluble solids concentration, with a temperature-compensating refractometer Maselli CR50 (Parma, Italy), and must pH and titratable acidity, with a Crison Titrator (Crison Instruments, Barcelona, Spain). Tagged plants were individually harvested (30th September 2008 and 14th October 2009) and crop weight, bunch number and berry number per bunch recorded.

Final leaf area was estimated in both years after determining the linear relationships between main and lateral shoot length (cm) and the corresponding leaf area (cm^2) for 20 shoots, collected from extra vines in HV and LV zone at the end of shoot growth. The leaf area was measured using a leaf area meter LI-3000A (Li-Cor Biosciences, Lincoln, Nebraska, USA). The four regressions coordinates of the respective equations were calculated in 2008 and in 2009 (data not reported) and were then used to estimate leaf area of tagged vines by measuring the length of all main and lateral shoots after harvest.

Pruning weight per tagged vine was measured in both years during winter. All data related to vine measurements were expressed as per meter of row.

5. Berry anthocyanins : quantification and composition

At harvest 20 berries were sampled from each tagged vine and frozen at -80°C for anthocyanin determination. The analysis was carried out after Mattivi (Mattivi *et al.*, 2006) using a Waters 1525 instruments (Waters, Milford, MA) equipped with a diode array detector (DAD) and a Phenomenex (Castel Maggiore, BO, Italy) reversed-phase column (RP18, 250 mm x 4 mm, 5 µm). Anthocyanins were quantified at 520 nm using an external calibration curve with malvidin-3-

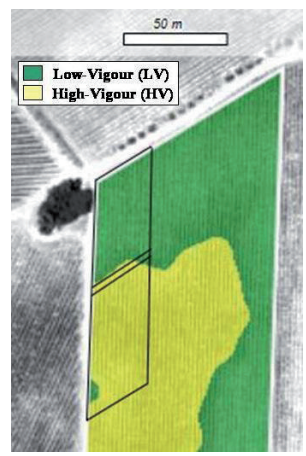


Figure 1 - NDVI image of Sangiovese vineyard where the upper low vigour (LV) and the lower high vigour (HV) block of vines are marked.

J. Int. Sci. Vigne Vin, 2013, **47**, n°1, 21-33
©Vigne et Vin Publications Internationales (Bordeaux, France)

glucoside chloride as the standard (Sigma-Aldrich, St. Louis, MO).

6. Small lot vinification and wine analysis

In 2009, grapes from all vines in each vigour zone were harvested manually and kept separated for the micro-scale vinification (four replications for HV and four replications for LV) performed at an experimental winery at Bolgheri (Tuscany). For each replication, 50 kg of grape were mechanically destemmed, crushed and transferred to stainless-steel fermentation tanks. The musts were sulphated with 30 mg/L of SO_2 and inoculated with a selected yeast strain. During alcoholic fermentation, mass temperature was maintained at 28 °C and the skins were punched down twice a day. After 10 days of fermentation the liquid part was separated, marc was pressed to a maximum of 1.5 bars and the resulting wine was inoculated with *Oenococcus oeni*. After completion of malolactic fermentation, the wines were 20 mg/L SO_2 added, cold stabilized, stored into 750 mL bottles closed with cork stoppers and stored horizontally at room temperature.

The wines were analysed for alcohol, total acidity and pH one year after crushing (Iland *et al.*, 1993). Wine colour intensity (OD_{420}+OD_{520}), colour hue (OD_{420}/OD_{520}) and total phenol and anthocyanin counts were determined by spectrometry. Total phenols were quantified at 280 nm using a calibration curve with catechin. Total anthocyanins were quantified at 520 nm using a calibration curve with malvidin-3-glucoside chloride.

Table 1 - Soil analysis for low vigour (LV) and high vigour (HV) zones measured in summer 2008.

Parameter	LV	HV
Sand (%)	38 a	44 a
Silt (%)	34 a	30 a
Clay (%)	28 a	26 a
Total carbonates (g/kg)	84 a	63 a
Active lime (g/kg)	21 a	19 a
pH in H_2O	8.4 a	8.3 a
N (g/kg)	0.9 b	1.5 a
P (mg/kg P_2O_5)	4 b	13 a
K (mg/kg K_2O)	63.4 a	79.3 a
Organic matter (g/kg)	7 b	13 a
C/N ratio	< 5.8	< 5.8
Field capacity (% vol)	31 a	30 a
Wilting point (% vol)	18.5 a	18.3 a
Water content (% vol)	18.22 b	24.33 a

Means within rows designated by different letters are significantly different by the Tukey test at $P < 0.05$.

7. Wine sensory evaluation

The sensory evaluation of wines was conducted a few days after chemical analysis. The wine replication of HV and LV were served at 18 °C and poured about 30 minutes before testing by quantitative descriptive analysis (QDA). The panel was composed of 9 judges with experience in wine scoring and trained to express their judgement per sample and per attribute based on an appropriate list of descriptors. The list of key attributes for wine ratings was developed during three training sessions in which judges were provided with a draft scorecard to describe the Sangiovese profile. Ten descriptors were included: colour intensity (by sight), red fruits and olfactory elegance (finesse) (by nose), and mouth-feel attributes including spicy, vegetal, full body, acidity, astringency, bitterness and a further wine parameter, "global assessment". The intensity of the 10 descriptors was rated on a 10-cm-long unstructured scale, from "imperceptible" to "pronounced". In one rating session the 8 wine samples were evaluated independently in individual booths in a completely random order.

8. Statistical analysis

A combined analysis of variance over years after Gomez and Gomez (1984) was performed using the mixed procedure of the SAS statistical package (SAS Institute, Cary, North Carolina, USA). The experimental design had two fixed effects (the two vigour zones) and the random errors were year and plots nested in the vigour zone. Means separation between vigour zones was performed with the Tukey test. Percentage of di-substituted and tri-substituted anthocyanins was subjected to arc sine and square root transformation, respectively, prior to statistical analysis. Non-parametric analysis of variance (ANOVA) was performed using a mixed model with judges as random effects on wine sensory data.

RESULTS AND DISCUSSION

1. Climatic and soil condition

Rain and temperature trends of both years from April to October are reported in Figure 2. The

©Vigne et Vin Publications Internationales (Bordeaux, France)

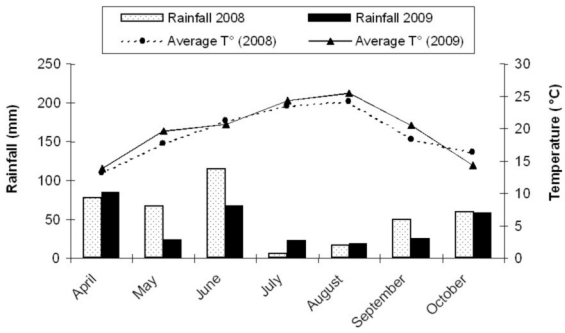


Figure 2 - Monthly average temperature and rainfall recorded for the growth period (April-October) in 2008 and 2009 at a weather station close to the trial site.

vegetative period was wetter in 2008 than in 2009 as total rainfall was respectively 392 mm vs. 299 mm; the average temperature in July, August and September was higher in 2009 than in 2008.

While the soils of the two vigour zones showed similar texture, total nitrogen content was higher in HV than LV (Table 1). Organic matter, phosphorus and potassium content showed values below the optimal range (which is considered 1.5-2 % for organic matter, 50-100 ppm for P_2O_5 and 100-150 ppm for K_2O, respectively) in both soils, although LV soil scored the lowest values (Table 1). Visual assessment showed soil erosion from the top of the slope (which corresponds to the LV zone) to the bottom (HV zone). This phenomenon may explain the differences observed in chemical soil composition.

Wilting point and field capacity appeared very similar between the two soils (Table 1). Water content as measured gravimetrically in July 2008 was lower in LV (18.22 %) than in HV soil (24.33 %), the former being very close to wilting point, equal to 18.5 % (Table 1).

2. Yield

Since shoot number was normalized at bloom, the harvest data showed that the number of bunches per tagged vine was similar between the two zones. Therefore, no differences in shoot fertility, measured as bunches per shoot, were registered between zones. Nonetheless, a significant difference was registered between years due to a higher bunch number in 2009, mainly in HV vines (Table 2). Yield per meter of cordon was significantly reduced (4-fold) in LV compared to HV vines in both years despite the fact that bunch number was similar between the two zones. Consequently, the yield reduction in LV vines was mainly due to poorer bunch weight following lower berry number per bunch and berry weight. Among the different well-known environmental factors that may affect each step of the flowering process (i.e., induction, anthesis, berry set and berry growth), vine water status may play a determinant role. Several papers showed that early-season water stress affects both cell division and cell enlargement in the developing berry, thus decreasing berry size, yield and, when the stress is repeated over several consecutive years, even berry number (Hardie and Considine, 1976; Matthews and Anderson, 1989; Myburgh, 2003; Vasconcelos *et al.*, 2009). Based on water content in LV soil before veraison in 2008, it may be assumed that LV vines were subjected to severe water stress that

Table 2 - Yield components of Sangiovese vines in low (LV) and high vigour (HV) zones, 2008 and 2009.

Parameter	2008		2009		Year	Year x treatment interaction
	LV	HV	LV	HV		
Shoots/m of row (n.)	12.3 a	12.5 a	12.2 a	12.4 a	ns	ns
Bunches/m of row (n.)	10.7 a	10.3 a	11.1 a	13.3 a	**	**
Bunches/shoot (n.)	0.87 a	0.83 a	0.91 a	1.07 a	**	**
Bunch weight (g)	87.9 b	367.9 a	107.4 b	380.5 a	ns	ns
Berry weight (g)	1.00 b	1.53 a	1.53 b	2.33 a	**	ns
Berries/bunch (n.)	83.9 b	228.7 a	66.6 b	155.1 a	ns	ns
Yield/m of row (kg)	0.93 b	3.76 a	1.26 b	5.10 a	**	*

Means within rows designated by different letters are significantly different by the Tukey test. * = significant at $p < 0.05$; ** significant at $p < 0.01$; ns = not significant

©Vigne et Vin Publications Internationales (Bordeaux, France)

Table 3 - Shoot growth and vine balance indices of Sangiovese vines, in low (LV) and high vigour (HV) zones, 2008 and 2009.

Parameter	2008		2009		Year	Year x treatment interaction
	LV	HV	LV	HV		
Main leaf area/m of cordon (m^2)	2.09 a	3.22 a	1.92 a	2.92 a	ns	ns
Lateral leaf area/m of cordon (m^2)	0.11 b	1.25 a	0.35 b	1.95 a	*	ns
Total leaf area/m of cordon (m^2)	2.20 b	4.47 a	2.27 b	4.87 a	ns	ns
Average main leaf area (cm^2)	137.6 b	199.0 a	132.4 b	166.9 a	ns	ns
Average lateral leaf area (cm^2)	89.8 b	98.5 a	72.7 b	86.6 a	ns	ns
Leaf-to-fruit ratio (m^2/kg)	2.72 a	1.24 b	2.61 a	1.09 b	ns	ns
Pruning weight/m of cordon (kg)	0.48 b	1.17 a	0.42 b	1.25 a	ns	ns
Yield-to-pruning weight ratio (kg/kg)	1.98 b	3.29 a	2.83 b	5.28 a	**	ns

Means within rows designated by different letters are significantly different by the Tukey test. * = significant at $p < 0.05$; ** significant at $p < 0.01$; ns = not significant

Table 4 - Berry composition of cv. Sangiovese in low (LV) and high vigour (HV) zones, 2008 and 2009.

Parameter	2008		2009		Year	Year x treatment interaction
	LV	HV	LV	HV		
Must soluble solids (°Brix)	26.2 a	22.2 b	26.1 a	23.4 b	ns	*
pH	3.47 a	3.46 a	3.66 a	3.61 a	**	ns
Titratable acidity (g/L)	6.68 a	6.30 a	5.74 a	5.69 a	**	ns
Total anthocyanins (mg/kg)	1155 a	842 b	946 a	686 b	**	ns

Means within rows designated by different letters are significantly different by the Tukey test. * = significant at $p < 0.05$; ** significant at $p < 0.01$; ns = not significant

may be partially responsible for yield losses compared to HV.

Thus, given the greater bunch number and weight registered in 2009, yield was also higher in the second year. Berry weight followed the same trend as that for crop parameters, being greater in 2009 than in 2008 (Table 2).

3. Vine growth

Total leaf area per meter of cordon was higher in HV than in LV tagged vines in both years (Table 3). The effect was mainly due to the stronger growth of laterals in HV vines (Table 3) as trimming in mid-July in all the vines stopped the growth of main shoots. Moreover, the average leaf size of both main and lateral shoots was lower in LV vines in both years (Table 3). On these bases, the reduction in main leaf area is mainly attributable to a reduction in leaf size, while the reduction in lateral leaf area is due to the lower number of lateral growth in LV vines after trimming compared to HV vines. HV vines also showed a higher pruning weight (Table 3). In both years leaf-to-fruit ratio exceeded 2 m^2 per kg of grape in LV vines while HV vines showed values around 1 m^2 per kg. Kliewer and Dokoozlian (2005) consider both values as sufficient for assuring a good level of sugar accumulation in hedgerow systems. In our conditions the higher leaf-to-fruit ratio values in LV vines was mainly due to their very low yield level. In fact, the yield of LV vines was 25 % of that of HV vines (Table 2), while the leaf area was 50 % of that of HV vines. This is also verified in the yield-to-pruning weight ratio, which was significantly higher in HV vines in both years. The differences between years are probably due to the greater yield registered in 2009 (Table 2). Indeed,

©Vigne et Vin Publications Internationales (Bordeaux, France)

both HV and LV vines showed correct pruning weight and leaf area in a hedgerow cordon system (Dokoozlian *et al.*, 2010).

4. Grape composition

In both years the accumulation of soluble solids was faster in LV vines, where remarkable improvement in berry sugar content was achieved at harvest compared to HV vines, scoring values over 26°Brix (Figure 3). No differences between HV and LV vines were found for pH and titratable acidity evolutions (data not presented). Sugar concentration at harvest did not differ between years, despite that harvest in 2009 was performed two weeks later, but pH and titratable acidity were respectively higher and lower in 2009 (Table 4). These results may be linked to the higher yield registered in 2009, which delayed ripening, while the higher air temperature (Figure 3) may have affected malic acid degradation (Kliewer and Lider, 1968 ; Kliewer, 1971) and caused total acidity to decrease with respect to 2008.

The optimal source-to-sink ratio of LV vines fits with grape composition improvement but seems contradictory with the lower number of berries per cluster found in these vines, which is dependent on the number of differentiated flowers and on the fraction of flowers that set fruit. As previously reported, we may suppose that the reduction of flower number is linked to the water stress occurring each year even before veraison in the LV zone (Matthews *et al.*, 1989).

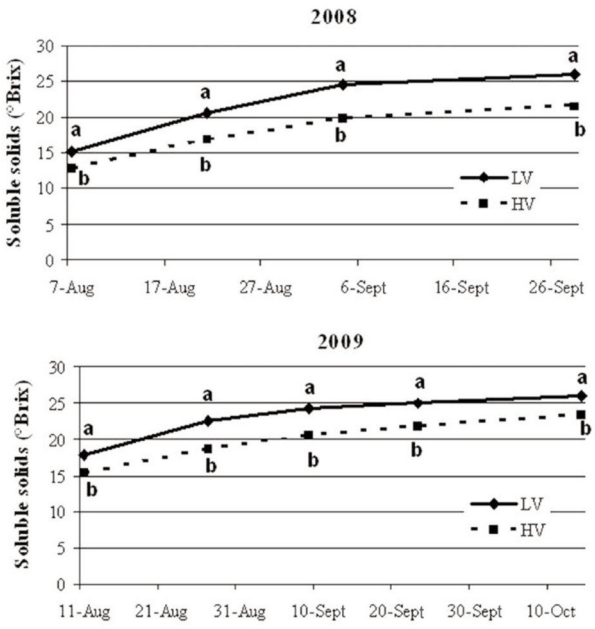


Figure 3 - Soluble solids accumulation during ripening in LV and HV berries in 2008 and 2009. Different letters indicate significant differences between the treatments by Tukey test (P < 0.05).

Anthocyanin concentration, expressed as mg per kg of grape and evaluated to verify the potential amount that can be extracted into wine, showed a significantly higher count in LV than in HV vines in both years (Table 4). Anthocyanin synthesis, expressed as concentration in mg per g of skin, was not affected by vine vigour conditions in both years and no differences were recorded in skin weight per berry between LV and HV despite significant year x treatment interaction (Table 5). The relative skin-to-berry weight ratio was significantly higher for LV in both years (Table 5). In this regard, Roby and Matthews (2004) reported that water deficits may increase the skin-to-berry weight ratio. This may have occurred in LV vines, at least in 2008, when soil moisture content measured at the end of July indicated a probable water stress that was not foreseeable in HV vines (Table 1). However, despite the fact that a number of studies (Castellarin *et al.*, 2007 ; Bucchetti *et al.*, 2011) reported a positive impact of moderate water deficit stress on anthocyanin synthesis, this did not occur in our conditions, where anthocyanin concentration expressed in mg per g of skin fresh weight was similar between the two vigour zones (Table 5).

Overall, although our results indicate that the increase in total anthocyanins per kg of grape in LV vines is mainly due to the smaller size of LV berries compared to the HV ones, we have to take in account the lack of difference in the skin weight per berry, which suggests a higher number of epidermal cell layers on the smaller LV berries compared to HV.

5. Anthocyanin composition

The anthocyanin profile was affected by vine vigour (Table 5). Concentration in mg per g of skin of malvidin-3G was significantly higher in HV than in LV grapes in both years. An opposite trend was detected for cyanidin-3G in 2008. Consequently, the anthocyanin count (Figure 4) at harvest differed by year : in 2008 LV vines showed a higher count of 3',4'-OH anthocyanins (cyanidin-3G and peonidin-3G) and a lower one of 3',4',5'-OH (malvidin-3G, delphinidin-3G and petunidin-3G) compared to HV vines ; the same trend was found in 2009 only for cyanidin-3G and malvidin-3G.

J. Int. Sci. Vigne Vin, 2013, **47**, n°1, 21-33
©Vigne et Vin Publications Internationales (Bordeaux, France)

Table 5 - Anthocyanin concentration and composition (mg/g of skin) and berry traits of cv. Sangiovese vines in low (LV) and high vigour (HV) zones, 2008 and 2009.

Parameter	2008		2009		Year	Year x treatment interaction
	LV	HV	LV	HV		
Total anthocyanins (mg/g of skin)	4.836 a	4.823 a	4.834 a	5.409 a	ns	ns
Skin weight (g/berry)	0.253 a	0.289 a	0.316 a	0.297 a	**	**
Skin-to-berry weight ratio	0.25 a	0.18 b	0.21a	0.13 b	**	ns
Delphinidin-3G (mg/g of skin)	0.624 a	0.686 a	0.720 a	0.662 a	ns	*
Cyanidin-3G (mg/g of skin)	1.538 a	0.989 b	1.213 a	1.128 a	*	**
Petunidin-3G (mg/g of skin)	0.643 a	0.758 a	0.756 a	0.767 a	*	ns
Peonidin-3G (mg/g of skin)	0.893 a	0.663 a	0.763 a	0.856 a	ns	**
Malvidin-3G (mg/of skin)	1.138 b	1.727 a	1.381 b	1.996 a	*	ns

Means within rows designated by different letters are significantly different by the Tukey test. * = significant at $p < 0.05$; ** significant at $p < 0.01$; ns = not significant

Despite that anthocyanin profile is considered closely related to genetic traits and has been used to differentiate grape cultivars, a large number of studies demonstrated that the accumulation of a single anthocyanin in a given cultivar may be influenced by several agro-ecological factors acting through different mechanisms (Esteban *et al.*, 2001; Guidoni *et al.*, 2002; Spayd *et al.*, 2002; Downey *et al.*, 2004). Our results agree with findings by other researchers who found that, in some cultivars, the increase in leaf area-to-yield ratio gained by bunch thinning induces a higher concentration of berry sugar and 3',4'-OH anthocyanins in berries at harvest (Filippetti *et al.*, 2007; Guidoni *et al.*, 2008). Recently, Pastore *et al.* (2011) also found an increase in 3',4'-OH anthocyanins in bunches of thinned vines, suggesting that it might reflect the specific up regulation of F3'Hb found during all stages of ripening. Nevertheless our results differ from what Fournand *et al.* (2006) reported on Shiraz, since in our trial the sugar accumulation in pulp was not associated with an increase in the methoxylated forms peonidin and malvidin.

Moreover, although bunch light exposure was not measured in either vigour zone, we may assume more bunch shading in HV since its total leaf area was twice that of LV (Table 3) and that high vigour resulting from non-limiting soil moisture conditions and high levels of available nitrogen can modify the vine microclimate and increase bunch shading (Smart, 1985). In these conditions, the changes in the anthocyanin profiles of HV vines agree with findings reported by others, where berries from shaded vines showed an increase in malvidin-3G and a decrease in 3',4'-OH anthocyanins under similar temperature conditions (Chorti *et al.*, 2010; Tarara *et al.*, 2008).

Our results seem to support the hypothesis that the pattern of berry skin anthocyanin evolution during ripening is more related to the complex interaction between genetic, agronomical and seasonal conditions in respect to berry sugar concentration, as reported in Cabernet-Sauvignon and Tempranillo (Ryan and Revilla, 2003).

Table 6 - Chemical analysis on wines from cv. Sangiovese berries in low (LV) and high vigour (HV) zones, 2009.

Parameter	LV	HV
Ethanol (% v/v)	15.7 a	14.0 b
pH	3.38 a	3.43 a
Titratable acidity (g/L)	5.29 a	5.05 a
Hue	0.82 b	1.00 a
Colour intensity	5.63 a	1.9 b
Anthocyanins (mg/L)	262.7 a	80.3 b
Phenols (mg/L)	1826 a	1123 b

Means within rows designated by different letters are significantly different by the Tukey test. * = significant at $p < 0.05$; ** significant at $p < 0.01$; ns = not significant

6. Wine chemical and sensory analyses

The main chemical results of 2009 wines (Table 6) reflect berry composition. Coherently with must

©Vigne et Vin Publications Internationales (Bordeaux, France)

sugar content, alcohol concentration was significantly higher in LV than in HV wines (15.7 and 14 %, respectively) ; no differences were recorded in titratable acidity and pH. As expected, wine anthocyanins, total phenols and colour intensity were higher in LV than in HV wines (Table 6). The anthocyanin count followed the berry trend, most likely contributing to the superior colour intensity of LV wines (Table 6).

Sensory evaluation detected differences between the aroma of wine from LV and HV zones (Figure 5), showing a tendency for quality to decrease with increasing yield.

Particularly important are the higher content of polyphenols, anthocyanins and alcohol characterizing the LV wines. These substances, as well-know, strongly influence different aspects of wine traits such as bitterness, warmth and astringency, wine colour, body and some flavour nuances.

Sensations perceived in tasting LV wines showed finely textured astringency and high flavour concentration with an attractive fruity aroma, confirming the increasing level of solid compounds such as phenols (Table 6).

The low testing score for the HV wine well represents the negative effect of both excessive vigour and yield on the wine's mouth-feel and flavour properties, as also reported by Reynolds *et al.* (1994 a ; 1994b ; 1994c).

As a whole, soil properties are the most important factors to consider when investigating the relationship between the biophysical environment of vine growth and the vine's response (Seguin, 1986 ; van Leeuwen *et al.*, 2004). While soil properties like texture, field water capacity and wilting point were very similar between the two zones, LV had lower fertility elements, especially nitrogen and organic matter, confirming the role played by soil chemical properties in controlling wine composition (Bramley *et al.*, 2011).

One of the factors that enabled the HV zone to grow more vigorous vines with higher yield was thus attributed to the better soil fertility recorded in the lower part of the vineyard, probably linked to the observed soil erosion phenomena. Notable, too, is the LV soil water content in 2008, which, unlike HV, was close to wilting point. HV's greater water supply should be considered as one more factor affecting the different response of these vines and their relative wine traits.

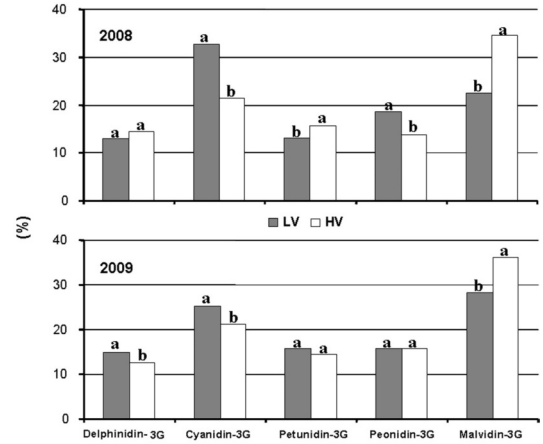


Figure 4 - Anthocyanin percentage composition at harvest in LV and HV grape in 2008 and 2009. For each year and each compound different letters indicate significant differences between the treatments by Tukey test (P < 0.05).

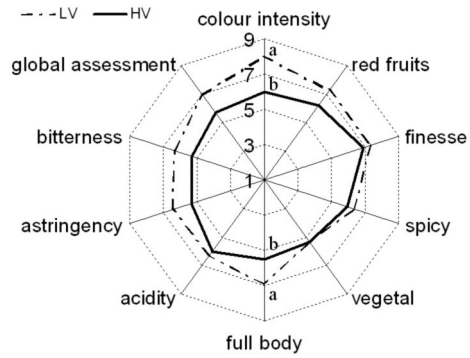


Figure 5 - Sensory profiles of LV and HV 2009 wines defined after Quantitative Descriptive Analysis. Different letters indicate significant differences between the treatments using non parametric Anova.

The higher vigour of HV vis à vis LV vines showed up as a greater number of laterals, whereas the higher cropping of the former compared to the latter was attributable to heavier bunches bearing bigger and far more numerous berries.

It is quite interesting to note that these factors induced in HV a yield reduction that was more than proportional to the vegetative vigour one. The same type of effects was detected while comparing the vine behaviour associated with cover crop between the rows with tillage (Intrieri *et al.*, 2004)

In effect, neither the response of HV nor that of LV vines can be taken as optimal. The former cropped too much and, despite having rather high berry sugar content, demonstrated relatively low

J. Int. Sci. Vigne Vin, 2013, **47**, n°1, 21-33
©Vigne et Vin Publications Internationales (Bordeaux, France)

anthocyanin count in their wine, which had a good alcohol level but was more astringent and of poor colour. It has to be noted that harvest date could not be delayed in HV vines due to bad weather conditions.

The latter, on the other hand, had a cropping that was too low and a must sugar content that was too high, yielding wine with excessive alcohol content but less astringent and rich in colour. Clearly then, as no wines from such specific vineyard sites can be sold at premium wine prices, it is advisable to apply site-specific vineyard management techniques in the LV zone, like supplementary localized inputs of fertilizers, especially of organic matter, and irrigation to provide emergency support before soil water content reaches the wilting point. Such targeted management practices should be able to improve the vigour and yield of vines in the LV zone without excessive detrimental effects on grape quality traits. Moreover, a cover crop and bunch thinning can be adopted in HV vines to reduce their vigour and yield and to balance vineyard spatial variability.

CONCLUSIONS

The present trial showed that different levels of vigour in a commercial vineyard of cv. Sangiovese may influence vine growth response, cropping, grape composition and wine quality. High vigour vines demonstrated higher leaf area and yield associated with berry quality traits marked by lower sugar and anthocyanin concentration compared to the low vigour vines. Sensory test and chemical analysis of the wines made from the berries of these zones in 2009 demonstrated the higher quality of LV wines. The causes of vigour variability were linked to variations in soil fertility and water retention capacity. Precision vineyard management practices may be adopted to balance vineyard spatial variability.

Acknowledgements : The authors would like to thank Dr Stefano Di Blasi from Consorzio Tuscania, Florence (Italy) for providing NDVI map and Dr Enrico Muzzi from University of Bologna (Italy) for his useful advice and assistance on statistical analysis.

REFERENCES

Archer E. and Strauss H.C., 1989. Effect of shading on the performance of *Vitis vinifera* L. cv. Cabernet Sauvignon. *S. Afr. J. Enol. Vitic.*, **10**, 74-77.

Baldy R., De Benedictis J., Johnson L., Weber E., Baldy M., Osborn B. and Burleigh J., 1996. Leaf color and vine size are related to yield in a phylloxera-infested vineyard. *Vitis*, **35**, 201-205.

Bramley R., Pearse B. and Chamberlain P., 2003. Being profitable precisely - A case study of precision viticulture from Margaret River. *Aust. N.Z. Grapegrow. Winemak.*, **473**a, 84-87.

Bramley R.G.V. and Hamilton R.P., 2004. Understanding variability in winegrape production systems 1. Within vineyard variation in yield over several vintages. *Aust. J. Grape Wine Res.*, **10**, 32-45.

Bramley R.G.V., 2005. Understanding variability in winegrape production systems 2. Within vineyard variation in quality over several vintages. *Aust. J. Grape Wine Res.*, **11**, 33-42.

Bramley R.G.V. and Hamilton R.P., 2007. Terroir and precision viticulture : are they compatible ? *J. Int. Sci. Vigne Vin*, **41**, 1-8.

Bramley R.G.V., Ouzman J. and Boss P.K., 2011. Variation in vine vigour, grape yield and vineyard soils and topography as indicators of variation in the chemical composition of grapes, wine and wine sensory attributes. *Aust. J. Grape Wine Res.*, **17**, 217-229.

Bucchetti B., Matthews M.A., Falginella L., Peterlunger E. and Castellarin S.D., 2011. Effect of water deficit on Merlot grape tannins and anthocyanins across four seasons. *Sci. Hortic.*, **128**, 297-305.

Castellarin S.D., Matthews M.A., Di Gaspero G. and Gambetta G.A., 2007. Water deficits accelerate ripening and induce changes in gene expression regulating flavonoid biosynthesis in grape berries. *Planta*, **227**, 101-112.

Chorti E., Guidoni S., Ferrandino A. and Novello V., 2010. Effect of different cluster sunlight exposure levels on ripening and anthocyanin accumulation in Nebbiolo grapes. *Am. J. Enol. Vitic.*, **61**, 23-30.

Cortell J.M., Halbleib M., Gallagher A.V., Righetti T.L. and Kennedy J.A., 2005. Influence of vine vigor on grape (*Vitis vinifera* L. cv. Pinot noir) and wine proanthocyanidins. *J. Agric. Food Chem.*, **53**, 5798-5808.

Cortell J.M., Sivertsen H.K., Kennedy J.A. and Heymann H., 2008. Influence of vine vigor on Pinot noir fruit composition, wine chemical analysis, and wine sensory attributes. *Am. J. Enol. Vitic.*, **59**, 1-10.

Dokoozlian N., Ebisuda N. and Cleary M., 2010. Some new perspectives on the impact of vine balance on grape and wine flavor development. In : *Proceedings of the 17th International GiESCO Symposium*, Asti-Alba, Italy, pp. 407-409.

Downey M.O., Harvey J.S. and Robinson S.P., 2004. The effect of bunch shading on berry development and flavonoid accumulation in Shiraz grapes. *Aust. J. Grape Wine Res.*, **10**, 55-73.

©Vigne et Vin Publications Internationales (Bordeaux, France)

Dry P.R., 2000. Canopy management for fruitfulness. *Aust. J. Grape Wine Res.*, **6**, 109-115.

Esteban M.A., Villanueva M.J. and Lissarrague J.R., 2001. Effect of irrigation on changes in the anthocyanin composition of the skin of cv Tempranillo (*Vitis vinifera* L) grape berries during ripening. *J. Sci. Food Agric.*, **81**, 409-420.

Filippetti I., Ramazzotti S., Centinari M., Bucchetti B. and Intrieri C., 2007. Esperienze triennali sugli effetti del diradamento dei grappoli sulla qualità delle uve della cultivar Sangiovese. *Italus Hortus*, **14**, 412-416.

Fiorillo E., Crisci A., De Filippis T., Di Gennaro S.F., Di Blasi S., Matese A., Primicerio J., Vaccari F.P. and Genesio L., 2012. Airborne high-resolution images for grape classification : changes in correlation between technological and late maturity in a Sangiovese vineyard in Central Italy. *Aust. J. Grape Wine Res.*, **18**, 80-90.

Fournand D., Vicens A., Sidhoum L., Souquet J.-M., Moutounet M. and Cheynier V., 2006. Accumulation and extractability of grape skin tannins and anthocyanins at different advanced physiological stages. *J. Agric. Food Chem.*, **54**, 7331-7338.

Gomez K.A. and Gomez A.A., 1984. *Statistical Procedures for Agricultural Research*. Wiley & Sons, Singapore.

Guidoni S., Allara P. and Schubert A., 2002. Effect of cluster thinning on berry skin anthocyanin composition of *Vitis vinifera* cv. Nebbiolo. *Am. J. Enol. Vitic.*, **53**, 224-226.

Guidoni S., Ferrandino A. and Novello V., 2008. Effects of seasonal and agronomical practices on skin anthocyanin profile of Nebbiolo grapes. *Am. J. Enol. Vitic.*, **59**, 22-29.

Hardie W.J. and Considine J.A., 1976. Response of grapes to water-deficit stress in particular stages of development. *Am. J. Enol. Vitic.*, **27**, 55-61.

Haselgrove L., Botting D., Van Heeswijck R., Hoj P.B., Dry P.R., Ford C. and Iland P.G., 2000. Canopy microclimate and berry composition : the effect of bunch exposure on the phenolic composition of *Vitis vinifera* L. cv. Shiraz grape berries. *Aust. J. Grape Wine Res.*, **6**, 141-149.

Iland P.G., Ewart A.J.W. and Sitters J.H., 1993. *Techniques for Chemical Analysis and Stability Tests of Grape Juice and Wine*. Kitchener Press, Adelaide.

Iland P.G., Botting D.G., Dry P.R., Giddings J. and Gawel R., 1994. Grapevine canopy performance. In : *Proceedings of the ASVO Viticulture Seminar : Canopy Management*, Mildura, Australia. Hayes P. (Ed.), Hyde Park Press, Adelaide, pp.18-21.

Intrieri C., Filippetti I., Lia G., Ramazzotti S., Colucci E. and Poni S., 2004. Intra-row vineyard spacing and soil management : long-term field trial results with cv Pignoletto. In : *Proceedings of the 7th International Symposium on Technology Application in Horticulture & Viticulture - Quality Management in Horticulture and in Viticulture*, Stuttgart, Germany, pp.192-202.

Jackson R.S., 2000. *Wine Science : Principles, Practice, Perception*. Academic Press, San Diego, CA.

Johnson L.F., Roczen D. and Youkhana S., 2001. Vineyard canopy density mapping with IKONOS satellite imagery. In : *Proceedings of the 3rd International Conference on Geospatial Information in Agriculture and Forestry*, Denver, Colorado (CD-ROM). Veridian, Ann Arbor, MI, USA, p. 10.

Johnson L.F., Roczen D.E., Youkhana S.K., Nemani R.R. and Bosch D.F., 2003. Mapping vineyard leaf area with multispectral satellite imagery. *Comput. Electron. Agric.*, **38**, 33-44.

Keller M., Mills L.J., Wample R.L. and Spayd S.E., 2005. Cluster thinning effects on three deficit-irrigated *Vitis vinifera* cultivars. *Am. J. Enol. Vitic.*, **56**, 91-103.

Kliewer W.M. and Lider L.A., 1968. Influence of cluster exposure to the sun on the composition of Thompson Seedless fruit. *Am. J. Enol. Vitic.*, **19**, 175-184.

Kliewer W.M., 1971. Effect of day temperature and light intensity on concentration of malic and tartaric acids in *Vitis vinifera* L. grapes. *J. Amer. Soc. Hortic. Sci.*, **96**, 372-377.

Kliewer W.M. and Dokoozlian N.K., 2005. Leaf area/crop weight ratios of grapevine : influence on fruit composition and wine quality. *Am. J. Enol. Vitic.*, **56**, 170-181.

Lamb D.W. and Bramley R.G.V., 2001. Managing and monitoring spatial variability in vineyard productivity. *Nat. Resour. Manag.*, **4**, 25-30.

Lamb D.W., Weedon M.M. and Bramley R.G.V., 2004. Using remote sensing to predict grape phenolics and colour at harvest in a Cabernet Sauvignon vineyard : timing observations against vine phenology and optimising image resolution. *Aust. J. Grape Wine Res.*, **10**, 46-54.

Matese A., Di Gennaro F.S., Genesio L., Vaccari F.P., Crisci A., Zaldei A., Toscano P., Gioli B., Fiorillo E., De Filippis T. and Di Blasi S., 2009. An integrated multi-scale monitoring approach to understand the relationships between climate, agricultural practices on grapes quality. In : *Proceedings of the 16th International GiESCO Symposium*, University of California, Davis, pp. 437-441.

Matthews M.A. and Anderson M.M., 1989. Reproductive development in grape (*Vitis vinifera*

©Vigne et Vin Publications Internationales (Bordeaux, France)

L.) : responses to seasonal water deficits. *Am. J. Enol. Vitic.*, **40**, 52-60.

Mattivi F., Guzzon R., Vrhovsek U., Stefanini M. and Velasco R., 2006. Metabolite profiling of grape : flavonols and anthocyanins. *J. Agric. Food Chem.*, **54**, 7692-7702.

Mori K., Goto-Yamamoto N., Kitayama M. and Hashizume K., 2007. Loss of anthocyanins in red-wine grape under high temperature. *J. Exp. Bot.*, **58**, 1935-1945.

Myburgh P.A., 2003. Responses of *Vitis vinifera* L. cv. Sultanina to water deficits during various pre- and post-harvest phases under semi-arid conditions. *S. Afr. J. Enol. Vitic.*, **24**, 25-33.

Papale D., Belli C., Gioli B., Miglietta F., Ronchi C., Vaccari F.P. and Valentini R., 2008. ASPIS, a flexible multispectral system for airborne remote sensing environmental applications. *Sensors*, **8**, 3240-3256.

Pastore C., Zenoni S., Tornielli G.B., Allegro G., Dal Santo S., Valentini G., Intrieri C., Pezzotti M. and Filippetti I., 2011. Increasing the source/sink ratio in *Vitis vinifera* (cv Sangiovese) induces extensive transcriptome reprogramming and modifies berry ripening. *BMC Genomics*, **12**, 631.

Petrie P.R., Trought M.C.T. and Howell G.S., 2000. Fruit composition and ripening of Pinot Noir (*Vitis vinifera* L.) in relation to leaf area. *Aust. J. Grape Wine Res.*, **6**, 46-51.

Pirie A.J.G. and Mullins M.G., 1980. Concentration of phenolics in the skin of grape berries during fruit development and ripening. *Am. J. Enol. Vitic.*, **31**, 34-36.

Proffitt T., Bramley R., Lamb D. and Winter E., 2006. *Precision Viticulture - A New Era in Vineyard Management and Wine Production*. Winetitles, Adelaide.

Reynolds A.G., Edwards C.G., Wardle D.A., Webster D.R. and Dever M., 1994a. Shoot density affects "Riesling" grapevines. I. Vine performance. *J. Amer. Soc. Hort. Sci.*, **119**, 874-880.

Reynolds A.G., Edwards C.G., Wardle D.A., Webster D. and Dever M., 1994b. Shoot density affects "Riesling" grapevines. II. Wine composition and sensory response. *J. Amer. Soc. Hort. Sci.*, **119**, 881-892.

Reynolds A.G., Wardle D.A. and Dever M., 1994c. Shoot density effects on Riesling grapevines : interactions with cordon age. *Am. J. Enol. Vitic.*, **45**, 435-443.

Roby G. and Matthews M.A., 2004. Relative proportions of seed, skin and flesh, in ripe berries from Cabernet Sauvignon grapevines grown in a vineyard either well irrigated or under water deficit. *Aust. J. Grape Wine Res.*, **10**, 74-82.

Rouse J.W. Jr., Haas R.H., Schell J.A. and Deering D.W., 1974. Monitoring vegetation systems in the Great Plains with ERTS. In : *The 3rd ERTS Symposium*, NASA SP-351, **1**, pp. 309-317.

Ryan J.M. and Revilla E., 2003. Anthocyanin composition of Cabernet Sauvignon and Tempranillo grapes at different stages of ripening. *J. Agric. Food Chem.*, **51**, 3372-3378.

Saxton K.E. and Rawls W.J., 2006. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. *Soil Sci. Soc. Am. J.*, **70**, 1569-1578.

Seguin G., 1986. "Terroirs" and pedology of wine growing. *Experientia*, **42**, 861-873.

Sethuramasamyraja B., Sachidhanantham S., Wample R.L. and Yen M., 2007. Interpolation of wine grape quality indicators (anthocyanin and Brix) and development of differential harvest attachment. *ASABE* (*Am. Soc. Agric. Biol. Engineers*, St. Joseph, Michigan), Paper No. 071097.

Sethuramasamyraja B., Singh H. and Mazhuvancheriparambath G.M., 2010. Geospatial modeling of wine grape quality (anthocyanin) for optimum sampling strategy in mechanized on-the-go differential harvesting programs. *Int. J. Eng. Sci. Technol.*, **2**, 6058-6073.

Smart R.E., 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. A review. *Am. J. Enol. Vitic.*, **36**, 230-239.

Smart R.E., Smith S.M. and Winchester R.V., 1988. Light quality and quantity effects on fruit ripening for Cabernet Sauvignon. *Am. J. Enol. Vitic.*, **39**, 250-258.

Spayd S.E., Tarara J.M., Mee D.L. and Ferguson J.-C., 2002. Separation of sunlight and temperature effects on the composition of *Vitis vinifera* cv. Merlot berries. *Am. J. Enol. Vitic.*, **53**,171-182.

Tarara J.M., Lee J., Spayd S.E. and Scagel C.F., 2008. Berry temperature and solar radiation alter acylation, proportion, and concentration of anthocyanin in Merlot grapes. *Am. J. Enol. Vitic.*, **59**, 235-247.

Tisseyre B., Ardoin N. and Sevila F., 1999. Precision viticulture : precise location and vigour mapping aspects. In : *Proceedings of the 2nd European Conference on Precision Agriculture*, Odense, Denmark. Stafford J.V. (Ed.), Sheffield Academic Press, Sheffield, UK, pp. 319-330.

Tisseyre B., Ojeda H. and Taylor J., 2007. New technologies and methodologies for site-specific viticulture. *J. Int. Sci. Vigne Vin*, **41**, 63-76.

Van Leeuwen C., Friant P., Choné X., Tregoat O., Koundouras S. and Dubourdieu D., 2004. Influence of climate, soil, and cultivar on terroir. *Am. J. Enol. Vitic.*, **55,** 207-217.

©Vigne et Vin Publications Internationales (Bordeaux, France)

Vasconcelos M.C., Greven M., Winefield C.S., Trought M.C.T. and Raw V., 2009. The flowering process of *Vitis vinifera*: a review. *Am. J. Enol. Vitic.*, **60**, 411-434.

Winkler A.J., 1962. *General Viticulture*. University of California Press, Berkeley.

Winkler A.J., Cook J.A., Kliewer W.M. and Lider L.A., 1974. *General Viticulture*. 2d ed. University of California Press, Berkeley.

©Vigne et Vin Publications Internationales (Bordeaux, France)