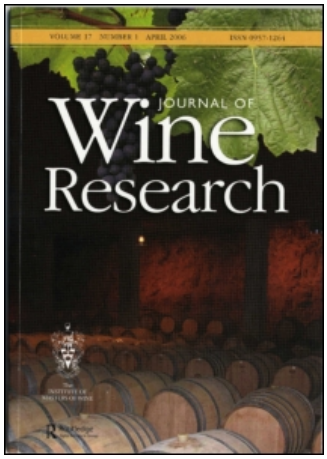

Journal of Wine Research
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713436778

The concept of terroir in viticulture

Cornelis Van Leeuwen; Gerard Seguin

Online Publication Date: 01 April 2006
To cite this Article: Van Leeuwen, Cornelis and Seguin, Gerard (2006) 'The concept of terroir in viticulture', Journal of Wine Research, 17:1, 1 - 10
To link to this article: DOI: 10.1080/09571260600633135
URL: http://dx.doi.org/10.1080/09571260600633135

Journal of Wine Research, 2006, Vol. 17, No. 1, pp. 1–10

Routledge
Taylor & Francis Group

The Concept of Terroir in Viticulture

CORNELIS VAN LEEUWEN and GERARD SEGUIN

Original manuscript received, June 2005

Revised manuscript received, January 2006

ABSTRACT *Terroir is a highly important concept in viticulture because it relates the sensory attributes of wine to the environmental conditions in which the grapes are grown. Quality hierarchy and wine style may, to a considerable extent, be explained by terroir. However, terroir is difficult to study on a scientific basis because many factors are involved, including climate, soil, cultivar and human practices, and these factors interact. The best expression of terroir is achieved when the precocity of the grapevine variety is suited to the local climatic conditions in such a way that full ripeness is reached by the end of the growing season. For the production of high quality red wines, environmental conditions should induce moderate vine vigour, either through moderate water deficit stress or through low nitrogen supply. These conditions are most frequently met on shallow or stony soils, in moderately dry climates. Regular but not excessive vine water and nitrogen supplies are needed to produce high quality white wines. However, great terroir emerges only when socio-economic conditions are favourable to the establishment of quality-orientated wine production.*

Introduction

Terroir is concerned with the relationship between the characteristics of an agricultural product (quality, taste, style) and its geographic origin, which might influence these characteristics. The concept of terroir is frequently used to explain the hierarchy of high-quality wines. It can be defined as an interactive ecosystem, in a given place, including climate, soil and the vine (Seguin, 1988). To understand the way terroir functions, it is essential to take into account the interactions among the factors that contribute to terroir. While very high quality wines are grown in various climates, it is impossible to define the ideal climate for fine wines in terms of temperature, rainfall (amount and distribution), or solar radiation. Nor can one define the best possible soil for growing high-quality wines in terms of pebble, clay or lime content, soil depth or mineral content. These factors of the natural environment have to be considered in terms of their interaction with the vine. Human factors, such as history, socio-economics, as well as viticultural and oenological techniques, are also part of terroir (Seguin, 1986). Viticulture is a human activity. The history of the socio-economic

Cornelis van Leeuwen, Unité de Viticulture, ENITA de Bordeaux, 1, Cours du Général de Gaulle, BP 201, 33175 Gradignan-cedex, France (E-mail: k-van-leeuwen@enitab.fr).

ISSN 0957-1264 print/ISSN 1469-9672 online/06/010001–10
DOI: 10.1080/09571260600633135

environment may be important in understanding why a given vineyard has emerged in a given site and why it has prospered. Mastery of viticultural and oenological practices is necessary in order to optimise in the wine the potential of the natural environmental factors. This last point, which is extensively treated by Jackson and Lombard (1983), is not within the scope of this paper.

Human Factors

It is important to consider the human factor in terroir because no vineyard exists without the intervention of mankind. Wine is an essential element in eating and drinking, especially in Mediterranean regions. Because vines (like olive trees) have low agronomic needs in terms of mineral and water supply, farmers used to reserve richer soils for cereals and grazing and planted vines on poor soils, either because they were shallow or stony, or because they were located on steep slopes. Mankind also played an essential role in the evolution through selection of grapevine varieties to increase their ability to produce high-quality wines, because none of the currently cultivated varieties of *Vitis vinifera* existed in nature.

Vineyards emerge in locations where the socio-economic conditions are favourable for wine growing. The difficulty of transporting a liquid beverage in the past should not be overlooked. Many vineyards arose in the vicinity of a concentration of consumers, or near a harbour or a navigable river. Vineyards that were established in locations where the natural environment was favourable for growing quality wines survived, while other, less favourable, locations, disappeared. Because Paris was (and is) an important centre of wine-consumption, a flourishing wine-growing region developed close to the French capital, which produced up to 4.8 million hectolitres of wine on 24,000 ha in 1820 (Logette, 1988). However, climatic conditions in that part of France are not optimum for wine growing since it is difficult to attain ripeness. For this reason, wine growing sharply decreased around Paris after the phylloxera crisis when the opening of the Paris-Lyon-Marseille railway in the second half of the nineteenth century made it possible to transport wine to Paris from the South of France, where climatic conditions were more favourable for wine growing. Around La Rochelle and Bordeaux, two flourishing vineyards developed during the Middle Ages because of the possibility of transporting wine overseas, to England and Holland. The vineyard at La Rochelle, where the soils are not particularly favourable for vine growing, disappeared with the decline of the port; the vineyard at Bordeaux survived, even when its port lost in economic significance, because the environmental conditions (soil and climate) and the cultivars used around Bordeaux were particularly suitable for the production of high-quality wines. Even today, new vineyards develop where the socio-economic context is favourable for the production of wine. The emergence of the Pic Saint Loup area in the Languedoc can largely be explained by the beauty of the countryside, which, combined with the vicinity of Montpellier and the Mediterranean sea, makes it an attractive site for investors. In Australia, wine growing in the Hunter Valley was introduced by early settlers, who brought in vine cuttings via Sydney, although the humid climate is far from ideal for wine growing. Later, wine growing extended to more favourable sites, although vineyards in the Barossa and Yarra Valleys also largely benefited from the vicinity of Adelaide and Melbourne. There are very few examples of famous wine-growing areas developing in inhospitable and remote areas, far from centres of consumption.

It was due to the trade with England that Bordeaux developed the production of wines of origin. Since the Middle Ages, wine was sold in Bordeaux by the name of

the parish. Selling prices varied according to the name of the commune, which means that it was already acknowledged that some origins produced better wines than others. The first estate to sell its wines under its own name was château Haut-Brion, under the ownership of Arnaud de Pontac, in the seventeenth century. He was convinced that the wines of Haut-Brion were superior to other wines of Pessac, justifying higher prices. When Arnaud de Pontac's son opened a tavern in London, Haut-Brion soon became an acclaimed wine in the capital of England. This brought the philosopher John Locke to visit Haut-Brion in 1677. Locke refers to this visit in his complete works (Pijassou, 1980: 358).

> The vine de Pontac, so much esteemed in England, grown on a rising open to the West, in a white sand mixed with a little gravel, which one would think bear nothing; but there is so much a particularity in the soil, that at Mr. Pontac's near Bordeaux the merchants assured me that the wine growing in the very next vineyards, where there was only a ditch between, and the soil, to appearance, perfectly the same, was by no means so good.

This suggests that as early as the second half of the seventeenth century the soil was already thought to be an important factor in wine quality in Bordeaux.

Inspired by the example of Château Haut-Brion, rich Bordeaux merchants created large estates in the Médoc between the end of the seventeenth century and the eighteenth century. Some of today's most famous Médoc estates were among the first to be planted with vines in that region. Apparently, enough empirical knowledge was available at that time for efficient site selection. Qualitative differences among the wines produced led to a sophisticated hierarchy in selling prices, which was the basis for the classification of 1855 (Markham, 1997). Although terroir-related factors such as climate and soil were not directly taken into account in the classification of 1855, the wines from the Médoc châteaux can be considered 'terroir wines'. These châteaux produce their wines exclusively from grapes grown in their own vineyards, where the soil remains invariable over the years.

In today's wine production, a distinction should be made between 'terroir wines' and 'branded wines'. Terroir wines are produced in a specified location which remains the same over the years. They owe their specific characteristics to the influence of climate and soil on vine behaviour and wine quality. Examples are estate wines or single-vineyard wines. The volume of these wines cannot be increased, which can make some famous terroir wines very prone to speculative investment. Branded wines are produced by blending wine or grapes from larger areas and from a variety of sources, which may vary from year to year. They owe their characteristics to oenological processes and blending. Their volume can be increased to meet demand. Traceability is an important issue in today's agro-business. Terroir wines have always had excellent traceability. Three centuries ago, a consumer who enjoyed a bottle of Lafite could visit the vines which produced the fruit, know when the wine was made and bottled and meet the people involved in its production.

Factors of the Natural Environment

Climate

Macroclimate and vine–climate interaction

The vine is a perennial plant adapted to a wide range of climatic conditions. The main cultivated vine species for quality wine-making is *Vitis vinifera*, which can survive

temperatures as low as −15°C to −20°C (depending on the cultivar) in winter. The heat load needed for grapes to attain full ripeness is highly variable among cultivars. At least 1200 degree days base of 10°C are necessary for the most early ripening cultivars, which is another limitation on vine cultivation at high latitudes. In equatorial regions, vine vegetation is continuous and all the reproductive stages exist simultaneously in the same plot. Although viticulture is possible in equatorial regions, especially for table grape production, fruit grown under these conditions does not have a high oenological potential. Taking into account these limitations, it appears that the zone most suited to growing high-quality grapes is between the 35th and the 50th parallel latitude, on both the northern and southern hemisphere. In some cases, high altitude can compensate for low latitude.

Precociousness for fruit ripening is a genetically determined property that is highly variable from one cultivar to another. Huglin has calculated the heat load requirements for a large range of cultivars (Huglin and Schneider, 1998). In the ampelographic collection of the Ecole Nationale Supérieure d'Agronomie de Montpellier (ENSAM), where several hundred cultivars are grown in the same vineyard, it is common to observe a two-month time lag between the moment of ripeness of the earliest and the latest ripening varieties.

In traditional wine-growing regions in Europe, growers have used this property to adapt the vines to local climatic conditions. At high latitudes, the limiting factor for producing high-quality wines is the level of ripeness of the grapes. Unripe grapes give green, acidic wines, with low alcohol levels, as a result of insufficient sugar accumulation in the fruit. For this reason, early ripening varieties such as pinot noir, chardonnay and gewürztraminer are grown at high latitudes, to optimise the chances of attaining correct ripeness. At lower latitudes, where the climate is warmer, grapes might attain ripeness early in the summer. Quick ripening of the grapes reduces aromatic expression in the wines produced. This was already observed by Ribéreau-Gayon and Peynaud (1960: 122), who wrote that "the best wines are produced with cultivars that just achieve ripeness under the local climatic conditions, as if quick ripening of the grapes burned the essences that makes the finesse of great wines". According to this empirical knowledge, growers have planted late-ripening varieties such as Grenache and Mourvèdre (called Monastrel in Spain) in warmer climates at low latitudes. As a result, in traditional wine-growing regions in Europe, grape picking generally takes place between 10 September and 10 October, despite huge climatic differences between, for example, the Mosel in Germany and Alicante in Spain. This type of viticulture is also called 'cool climate viticulture', not necessarily because the climate is particularly cool, but because the ripening of the grapes occurs in cool conditions, at the end of the summer or in the early autumn.

In its early stages, New World viticulture did not have the experience of Old World growers with regard to the choice of cultivars in relation to the local climatic conditions. In most cases, early-ripening varieties were planted in relatively warm conditions. These varieties were chosen as much for marketing reasons (chardonnay to produce a white Burgundy-style wine, cabernet sauvignon to produce a red Médoc-style wine) as for technical requirements. Although the grapes easily attain ripeness in these conditions (resulting in high sugar and low organic acid content), they lack specific aromas. To produce aromatic wines, wine-making technology can compensate for the neutrality of the grapes. Good examples are most New World chardonnay wines. Yeasts produce highly aromatic esters (e.g. isoamyl acetate, isobutyl acetate) when the alcoholic fermentation takes place at low temperatures. Lactic bacteria produce aldehydes and carbonyl compounds during malolactic fermentation

(e.g. diacetyl, which smells like butter). Fermentation in new oak gives vanilla aromas. Wines produced from early-ripening varieties in warm climates (especially during grape ripening) can be good when the wine-making technology is controlled, but because the grapes do not contain a high level of aroma compounds, they lack terroir expression. A certain standardisation in taste occurs in this type of wine, which leads many to seek out "anything but chardonnay".

However, although there is more cool-climate viticulture, and, as a result, more wines expressing terroir, in the Old World, this is only due to greater historical experience. Viticulturists in the New World are now finding cooler areas, where wines expressing terroir can be made. In California, good examples are the Carneros region north of San Francisco, where the cool influence of the bay is greater than in the Napa Valley, and the coastal region near Monterrey. In Australia, the relatively cool Yarra Valley (north of Melbourne) and Western Australia are quickly developing regions. New Zealand sauvignon blanc shows how powerfully aromatic this variety can be when grown in cool conditions.

Mesoclimate and topoclimate

Climatic variability within a wine-growing region can be described as mesoclimatic variability. When it is the result of relief (altitude, aspect, slope), it is called topoclimatic variability. Especially in cool regions, where it is difficult to achieve grape ripeness, topoclimate can be a major terroir factor. In the Mosel Valley in Germany, quality wines can only be produced on steep, south-facing slopes. In Burgundy, the best wines are produced in the Côte d'Or, at approximately 300 m above sea level. In the Hautes-Côtes, where the altitude is higher, it is harder for grapes to reach complete ripeness. Picking is delayed by 10 days, and wine quality is generally good, but rarely outstanding, despite the fact that fine soils for vine growing can be found in this part of Burgundy.

Microclimate

Microclimatic variation in the fruit zone can be induced by the soil type and through canopy management. It can have a great impact on the quality performance of a vineyard. Dry soils (for instance stony soils) do warm up more quickly than wet soils and induce early ripening. Night temperatures are cooler close to the ground, but day temperatures are higher. When a cultivar has difficulties in ripening in the given climatic conditions (for instance, cabernet sauvignon in the Bordeaux area), low vine training can contribute to improving quality, although it increases vine susceptibility to spring frost. In warm climates, with early-ripening varieties, high vine training should be preferred, to delay fruit ripening. Soils inducing low vine vigour (for instance, because of low water and/or nitrogen availability for the vines) improve light penetration inside the canopy and on the fruit zone, which is essential for growing high quality fruit. Microclimate can also be improved through specific canopy management (Carbonneau, 1980; Smart and Robinson, 1991), but this subject is not within the scope of this paper.

Soil

Vines can be grown on a huge variety of soils. In deep, rich soils, vines are vigorous and highly productive, but better wines are generally produced when the vines are cultivated on poor soils. The effect of the soil on vine behaviour and grape composition is complex, because the soil influences vine mineral nutrition and water uptake

conditions, but also rooting depth and temperature in the root zone. Soils can be studied from a geological, a pedological or an agronomic perspective.

Geology

Geology deals with rock types and dating of sedimentary strata. Geology indirectly acts on topography. The soil type is also related to the sort of rock on which it has developed. In some regions, there is a rather good correspondence between the geological sediment and the quality of the wines produced on it. The example most often cited is Chablis, where all the famous vineyards are planted on Kimmeridgian limestone and marl, while vineyards on Portlandian limestone produce the less famous petit Chablis (Pomerol, 1989). In this case, the relation is probably based on the influence of the rock type on the geomorphology of the region. South- and east-facing slopes are shaped in the soft Kimmeridgian limestone and marl, providing good exposition and compensating for the cool climate of the Chablis region. The harder Portlandian rock is found on wind-exposed plateaux, located at higher altitudes, where it is harder for chardonnay grapes to attain complete ripeness (Wilson, 1998).

In most other regions, the link between geology and wine quality is less obvious. In Bordeaux, very good wines are produced on sediments of a large variety of geological origin: Oligocene heavy clay sediments, Oligocene limestone and Quaternary alluvium (Seguin, 1983). Some of the finest wines are produced on Oligocene Asteries limestone in Saint-Emilion, while lesser wines are made on the same rock type in the Entre-Deux-Mers region.

Pedology

Soil types can be mapped, based on a pedological classification. Some soil types, such as limestone soils, are known for producing generally high quality wines, while others, such as soils subject to water logging, are known for being less suitable for producing quality wines. However, throughout the world, outstanding wines are grown on a huge variety of soils. In the Bordeaux area, top wines are produced on soils as different as alkaline limestone soils (Ausone), acidic gravely soils (Lafite-Rothschild), neutral gravely soils (Cheval Blanc) or heavy clay soils (Petrus, Cheval Blanc). It is generally not possible to equate a soil map of a given region with a map of quality potential for wine-growing (van Leeuwen, 1989).

Agronomic approach

To understand the effect of the soil in viticulture, it is necessary to take into account the interaction between the soil and the vine (agronomic approach). Soil influences vine behaviour and wine quality through the temperature in the root zone, and through mineral and water supplies.

Barbeau *et al.* (1998a, b) showed that vine precocity, especially at budbreak, is related to soil temperature in the root zone. Soil temperature in the root zone is high in dry and shallow soils and low in deep, humid soils. Vine precocity can be an important quality factor in cool climates, as in the Loire Valley, where it is difficult to ripen cabernet franc in cool vintages.

Among the minerals the soil supplies to the vine, nitrogen is obviously the one that most influences vine vigour, yield and grape ripening. Many studies deal with the influence of various levels of nitrogen fertilization on these parameters (Kliewer, 1971; Bell *et al.*, 1979; Delas *et al.*, 1991; Spayd *et al.*, 1993; Spayd *et al.*, 1994). Other papers deal with the depressive effect of cover crops on vine nitrogen supply, which can partly explain the quality-improving effect of this technique in red wine production

(Soyer *et al.*, 1996). Much less documented in scientific literature is the fact that vine nitrogen uptake is likely to vary considerably in relation to soil parameters such as soil organic matter content, C/N ratio of soil organic matter and organic matter turnover, even when no nitrogen fertilization or crop cover is implemented. Soil organic matter turnover depends on soil temperature, soil aeration, soil pH and soil moisture content. It is also very much slowed down by the presence of active limestone. As a result, the level of natural soil nitrogen supply to the vines can be considered as a component of terroir and it is highly variable depending on the soil type (van Leeuwen *et al.*, 2000). Choné *et al.* (2001a) showed that limited nitrogen supply to the vines due to soil parameters increases quality in red wine production because it reduces vine vigour and increases berry and wine phenolic content. This is not true in white wine production, where vine nitrogen supply should be at least moderate to obtain high aroma potential in grapes (Peyrot des Gachons *et al.*, 2005).

The effect of other minerals on vine development and grape quality potential is much less obvious, as long as neither excess nor severe deficiency alters vine physiology (Seguin, 1983). This was confirmed by van Leeuwen *et al.* (2004).

Vine Water Uptake Conditions

Vine water status depends on climate (rainfall and potential evapotranspiration), soil (water holding capacity) and training system (canopy architecture and leaf area). Vine water uptake conditions are a key factor in understanding the effect of the terroir on grape quality potential, because the main terroir factors are involved and interact (climate, soil, grapevine). Vine water uptake was first studied by means of a neutron moisture probe in the soils of the Haut-Médoc (Seguin, 1969). The same author showed that grape quality potential was related to a regular but moderate water supply to the vines (Seguin, 1975). In unirrigated field conditions, berry size is decreased and total phenolics are increased when vines face water deficits, which results in higher grape quality potential for red wine-making but lower yields (Duteau *et al.*, 1981; van Leeuwen and Seguin, 1994; Koundouras *et al.*, 1999; Choné *et al.*, 2001a; Tregoat *et al.*, 2002; van Leeuwen *et al.*, 2004). These effects were confirmed in irrigation trials by Matthews and Anderson (1988) and Ojeda *et al.* (2002). Berry ripening speed is increased when vine water status is low (van Leeuwen *et al.*, 2003). Aroma potential of white grapes might be decreased under severe water deficit stress (Peyrot des Gachons *et al.*, 2005).

Vine water uptake conditions can be monitored either by measuring or modelling variations in soil water content or by means of physiological indicators. Physiological indicators use the vine as an indicator of its own water status. Among physiological indicators, stem water potential (Choné *et al.*, 2001b) and carbon isotope discrimination measured on grape sugar (van Leeuwen *et al.*, 2001; Gaudillère *et al.*, 2002), have proved to be particularly efficient to indicate vine water status in terroir studies (Tregoat *et al.*, 2002).

Vine water uptake conditions can be modified by means of irrigation. Irrigation increases not only the production of sugar and skin phenolics per vine, but also yield (Matthews and Anderson, 1988). Yield is generally more rapidly increased than sugar and skin phenolics on a per vine basis, which might result in dilution. Only deficit irrigation can result in economically acceptable yields with high quality potential grapes in very dry regions. Irrigation is likely to modify terroir expression. The ideal water status with regard to grape quality potential is highly dependent on yield. In dry farmed vineyards in dry areas, excellent red wines can be made from

fruit grown on severely water stressed vines, as long as the yield is very low. For higher yield, the best results in terms of quality are obtained when water deficit is mild, which might be obtained through deficit irrigation in dry areas.

Conclusions

The highest expression of terroir is obtained in cool-climate viticulture, when the precociousness of the grapevine variety allows it to ripen its fruit at the end of the growing season (at the end of September in the northern hemisphere). Early-ripening varieties should be chosen in cool climates, in order to obtain full ripeness, and late-ripening varieties should be chosen in warmer climates, so that grape ripening does not take place in the warmest part of the summer. High grape quality for red wine production is obtained when a limiting factor reduces vine vigour and berry size and increases grape skin phenolics. In most terroirs known for their high quality performance, this limiting factor is mild water deficit, either because the climate is dry (high ET_0 and/or moderately low rainfall) or because the soil water holding capacity is low. Soil water holding capacity can be low because of high pebble content or because of reduced soil depth. Hence, high quality potential viticultural soils are either stony or shallow. Low nitrogen supply as a result of soil parameters can also be a quality factor in red wine production. For white wine production, water and nitrogen supply to the vines should be at least moderate, because severe stress can negatively affect grape aroma potential.

Acknowledgements

We thank Julia Harding for proofreading.

References

Barbeau, G., Morlat, R., Asselin, C. and Jacquet, A. (1998a) Relations entre la précocité de la vigne et composition des baies de divers cépages du Val de Loire, *Progrès Agricole et Viticole*, 6, 127–130.

Barbeau, G., Asselin, C. and Morlat, R. (1998b) Estimation du potentiel viticole des terroirs en Val de Loire selon un indice de précocité du cycle de la vigne, *Bulletin de l'O.I.V.*, 805–806, 247–262.

Bell, A., Ough, C. and Kliewer, W. (1979) Effects on must and wine composition, rates of fermentation, and wine quality of nitrogen fertilization on *Vitis vinifera* var. Thompson seedless grapevines, *American Journal of Enology and Viticulture*, 30, 124–129.

Carbonneau, A. (1980) Recherche sur les systèmes de conduite de la vigne. Essai de la maîtrise du microclimat et de la plante entière pour produire économiquement du raisin de qualité, *Thèse Docteur-Ingénieur, Université Bordeaux II*.

Choné, X., van Leeuwen, C., Chéry, P. and Ribéreau-Gayon, P. (2001a) Terroir influence on water status and nitrogen status of non irrigated Cabernet Sauvignon (*Vitis vinifera*): vegetative development, must and wine composition, *South African Journal of Enololgy and Viticulture*, 22, 8–15.

Choné, X., van Leeuwen, C., Dubourdieu, D. and Gaudillère, J.-P. (2001b) Stem water potential is a sensitive indicator for grapevine water status, *Annals of Botany*, 87, 477–483.

Delas, J., Molot, C. and Soyer, J.-P. (1991) Effects of nitrogen fertilization and grafting on the yield and quality of the crop of *Vitis vinifera* cv. Merlot, in: Rantz, J. (ed) *Proceedings of the International Symposium on Nitrogen in Grapes and Wines*, Davis: American Society of Enology and Viticulture.

DUTEAU, J., GUILLOUX, M. and SEGUIN, G. (1981) Influence des facteurs naturels sur la maturation du raisin, en 1979, à Pomerol et Saint-Emilion, *Connaissances de la Vigne et du Vin*, 15, 1–27.

GAUDILLÈRE, J.-P., VAN LEEUWEN, C. and OLLAT, N. (2002) Carbon isotope composition of sugars in grapevine, an integrative indicator of vineyard water status, *Journal of Experimental Botany*, 53, 757–763.

HUGLIN, P. and SCHNEIDER, Ch. (1998) *Biologie et écologie de la vigne*. Paris: Lavoisier Tec et Doc.

JACKSON, D. and LOMBARD, P. (1993) Environmental and management practices affecting grape composition and wine quality—a review, *American Journal of Enology and Viticulture*, 44, 409–430.

KLIEWER, W. (1971) Effect of nitrogen on growth and composition of fruits from 'Thompson seedless' grapevines, *American Journal of Horticultural Sciences*, 96, 816–819.

KLIEWER, W. (1991) Methods for determing the nitrogen status of vineyards, in: *Proceedings of the International Symposium on Nitrogen in Grapes and Wines*, in: RANTZ, J. (ed) *Proceedings of the International Symposium on Nitrogen in Grapes and Wines*, Davis: American Society of Enology and Viticulture.

KOUNDOURAS, S., VAN LEEUWEN, C., SEGUIN, G. and GLORIES, Y. (1999) Influence de l'alimentation en eau sur la croissance de la vigne, la maturation des raisins et les caractéristiques des vins en zone méditerranéenne (exemple de Némée, Grèce, cépage Saint-Georges, 1997), *Journal International des Sciences de la Vigne et du Vin*, 33, 149–160.

LOGETTE, L. (1988) *La vigne et le vin*. Lyon: La Manufacture.

MARKHAM, D. (1997) 1855, *A history of the Bordeaux classification*. London: Wiley.

MATTHEWS, M. and ANDERSON, M. (1988) Fruit ripening in *Vitis vinifera* L.: responses to seasonal water deficits, *American Journal of Enology and Viticulture*, 39, 313–320.

OJEDA, H., ANDARA, C., KRAEVA, E., CARBONNEAU, A. and DELOIRE, A. (2002) Influence of pre- and postveraison water deficit on synthesis and concentration of skin phenolic compounds during berry growth of *Vitis vinifera* cv. Syrah, *American Journal of Enology and Viticulture*, 53, 261–267.

PEYROT DES GACHONS, C., VAN LEEUWEN, C., TOMINAGA, T., SOYER, J.-P., GAUDILLÈRE, J.-P. and DUBOURDIEU, D. (2005) The influence of water and nitrogen deficit on fruit ripening and aroma potential of Vitis vinifera L. cv Sauvignon blanc in field conditions, *Journal of the Science of Food and Agriculture*, 85, 73–85.

PIJASSOU, R. (1980) *Un grand vignoble de qualité: le Médoc*. Paris: Tallandier.

POMEROL, C. (1989) *The Wines and Winelands of France. Geological Journeys*. London: Robertson McCarta.

RIBÉREAU-GAYON, J. and PEYNAUD, E. (1960) *Traité d'œnologie*. Tome premier. Paris: Librairie Polytechnique Ch. Beranger, Paris et Liège.

SEGUIN, G. (1969) Alimentation en eau de la vigne dans des sols du Haut-Médoc, *Connaissance de la Vigne et du Vin*, 2, 93–141.

SEGUIN, G. (1975) Alimentation en eau de la vigne et composition chimique des moûts dans les Grands Crus du Médoc. Phénomènes de régulation, *Conaissance de la Vigne et du Vin*, 9, 23–34.

SEGUIN, G. (1983) Influence des terroirs viticoles sur la constitution et la qualité des vendanges, *Bull. De l'O.I.V.*, 56, 3–18.

SEGUIN, G. (1986) 'Terroirs' and pedology of vinegrowing, *Experientia*, 42, 861–873.

SEGUIN, G. (1988) Ecosystems of the great red wines produced in the maritime climate of Bordeaux, in: L. FULLER-PERRINE (ed.) *Proceedings of the Symposium on Maritime Climate Winegrowing*. Geneva, NY: Department of Horticultural Sciences, Cornell University.

SMART, R. and ROBINSON, M. (1991) *Sunlight into Wine. A Handbook for Winegrape Canopy Management*. Adelaide: Winetitles.

SOYER, J.-P., MOLOT, C., BERTRAND, A., GAZEAU, O., LOVELLE, B. and DELAS, J. (1996) Influence de l'enherbement sur l'alimentation azotée de la vigne et sur la composition des moûts et des vins, in: A. LONVAUD-FUNEL (coordonnateur) *OENOLOGIE 95*. Paris: Lavoisier Tec et Doc.

SPAYD, S., WAMPLE, R., STEVENS, R., EVANS, R. and KAWAKAMI, A. (1993) Nitrogen fertilization of white Riesling grapes is Washington. Effects on petiole nutrient concentration, yield, yield components, and vegetative growth, *American Journal of Enology and Viticulture*, 44, 378–386.

SPAYD, S., WAMPLE, R., EVANS, R., STEVENS, R., SEYMOUR, B. and NAGEL, C. (1994) Nitrogen fertilization of white Riesling grapes in Washington. Must and wine composition, *American Journal of Enology and Viticulture*, 45, 34–41.

TRÉGOAT, O., GAUDILLÈRE, J.-P., CHONÉ, X. and VAN LEEUWEN, C. (2002) Etude du régime hydrique et de la nutrition azotée de la vigne par des indicateurs physiologiques. Influence sur le comportement de la vigne et la maturation du raisin (*Vitis vinifera* L. cv Merlot, 2000, Bordeaux), *Journal International des Sciences de la Vigne et du Vin*, 36, 133–142.

VAN LEEUWEN, C. (1989) *Carte des sols du vignoble de Saint-Emilion et sa notice explicative* Bordeaux: La Nef.

VAN LEEUWEN, C. and SEGUIN, G. (1994) Incidences de l'alimentation en eau de la vigne, appréciée par l'état hydrique du feuillage, sur le développement de l'appareil végétatif et la maturation du raisin (Vitis vinifera variété Cabernet franc, Saint-Emilion, 1990), *Journal International des Sciences de la Vigne et du Vin*, 28, 81–110.

VAN LEEUWEN, C., FRIANT, Ph., SOYER, J.-P., MOLOT, C., CHONÉ, X. and DUBOURDIEU, D. (2000) L'intérêt du dosage de l'azote total et l'azote assimilable dans le moût comme indicateur de la nutrition azotée de la vigne, *Journal International des Sciences de la Vigne et du Vin*, 34, 75–82.

VAN LEEUWEN, C., GAUDILLÈRE, J.-P. and TRÉGOAT, O. (2001) Evaluation du régime hydrique de la vigne à partir du rapport isotopique $^{13}C/^{12}C$, *Journal International des Sciences de la Vigne et du Vin*, 35, 195–205.

VAN LEEUWEN, C., TRÉGOAT, O., CHONÉ, X., JAECK, M.-E., RABUSSEAU, S. and GAUDILLÈRE, J.-P. (2003) Le suivi du régime hydrique de la vigne et son incidence sur la maturation du raisin, *Bulletin de l'O.I.V*, 76, 367–379.

VAN LEEUWEN, C., FRIANT, Ph., CHONÉ, X., TRÉGOAT, O., KOUNDOURAS, S. and DUBOURDIEU, D. (2004) The influence of climate, soil and cultivar on terroir, *American Journal of Enology and Viticulture*, 55, 207–217.

WILSON, J. (1998) *Terroir, the role of geology, climate and culture in the making of French wines*. San Francisco: University Press of California.