VINE AND WATER
A SHORT REVIEW

LA VIGNE ET L'EAU

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Résumé : L'eau est un facteur important des terroirs viticoles. Elle provient de la pluie, des nappes phréatiques, et quand elle fait défaut à la culture de la vigne, il faut irriguer, ou accepter des contraintes hydriques, qui suivant leur intensité et leur période de survenue, peuvent être favorables à la qualité de la vendange et des vins ou défavorables. L'objet de cet article est de présenter certaines informations sur les relations entre l'eau et la vigne. A cette fin, le climat et le sol, facteurs essentiels mais non exclusifs des terroirs viticoles ne seront qu'évoqués. Nous traiterons de façon non exhaustive, à travers des exemples choisis issus de la bibliographie ou de nos recherches, les aspects suivants : le système racinaire, la croissance végétative, la relation architecture de la plante et état hydrique, le bilan de matière sèche, et la composition biochimique de la baie en relation avec l'état hydrique de la vigne. Nous présentons les techniques actuelles possibles pour mesurer l'état hydrique d'une vigne, et son évolution au cours du cycle végétatif, en relation avec la réserve en eau du sol facilement exploitable par les racines. Enfin des recommandations sur les itinéraires culturaux de la vigne sont données à titre d'exemple, qui se réfèrent à l'évolution de l'état hydrique de la plante au cours de sa croissance, à partir des valeurs seuils du potentiel hydrique foliaire de base.

Summary: Water is an important factor in the terroirs of grape-growing regions. The vine obtains water from rainfall and the water table and when it is in short supply, it is necessary either to irrigate or accept the effects of water stress. Depending on the intensity of the water stress and the period at which it occurs, it may or not be favourable for the harvest and the wine it is used to produce. The objective of this article is to provide some information on the relationship that exists between the vine and water. The climate and the soil, which are essential but not the sole elements of this relationship will only be touched upon, but we will discuss in a non exhaustive way, with information's from the bibliography or from our research, the following aspects: the root system, vegetative growth, the relationship between plant architecture and the water status of the vine, the carbon balance and the biochemical composition of the grape berry in relation to vine water status. We will also present the currently available techniques for measuring vine water status and its evolution during the vegetative cycle as a function of water reserves in the soil easy to use by the roots. Finally examples are presented of possible recommendations for vine cultural practices as a function of the vine water status evolution during the growth, according to the predawn leaf water potential thresholds.

Keywords: grapevine, water, leaf water potential, berry growth, berry biochemistry, sugar, anthocyanins, terroirs.

Mots clefs: vigne, eau, potentiel hydrique foliaire, croissance de la baie, biochimie de la baie, sucre, anthocyanes, terroirs.

CLIMATE

Firstly, it is appropriate to recall the importance of various climatic indices. Heliothermic indices are based on temperature and include:

- Indices that predict whether a given grape variety can arrive at full maturity in a given region, based on the sugar content of the berries (180 to 220 g/l on average). Typical examples are the indices of HUGLIN (1978) and WINKLER (1962).

The «night coolness» index which is based on the minimum air temperature of the month preceding harvest (TONIETTO, 1999). It is often associated with the aromatic characteristics of the grape variety and the colour of a wine. Some authors, in fact demonstrated a relationship between night coolness during ripening, the anthocyanin colour of red wines and the aromatic intensity of both white and red wines (TOMANA *et al.*, 1979 ; KLIEWER and TORRES, 1972).

The drought index permits the type of climate to be defined in relation to the total annual rainfall. Based on

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Table I - The five drought index groups into which wine-growing areas worldwide may be classified (TONIETTO, 1999). The values in mm refer to the hydric balance at the end of the growth cycle.

Les 5 classes de l'indice de sécheresse (IS) permettant de classer les régions viticoles du monde (TONIETTO, 1999). Les valeurs en mm sont celles du bilan hydrique en fin de cycle.

	Drought index -	IS	
Drought	Climate class	Acronym	Class intervals (mm)
Absent	Moist	IS_{00}	>150
	Sub-moist	IS_0	≤150 >50
Present	Moderate drought	IS_1	≤50 >-100
	Severe drought	IS_2	≤-100 >-200
	Very severe drought	IS_3	≤-200

this index the following viticultural zones may be distinguished (after TONIETTO, 1999).

SOIL

The soil is an important element in the constitution of a given terroir (VAUDOUR, 2002 ; MORLAT, 1996 ; SEGUIN, 1983). Notably, it determines how the root system is implanted and the depth of to which the vine rootstock will grow. Variations in the available soil water reserve depend on rainfall, runoff water, plantation density and the training system of the vine which in turn determines surface area of foliage coverage per hectare. Plant transpiration and soil evaporation are responsible for water loss (excluding drainage and cover grass which contribute to water consumption). A formula has been developed to calculate the hydric balance of a given soil type within a single vegetative cycle (CARBONNEAU, 2002 ; RIOU, 1998).

PLANT

I - THE ROOT SYSTEM

Vines have been grafted onto rootstock since the phylloxera invasion. Therefore the root system of a given grape variety is, in fact that of the rootstock. This root system should obviously be resistant to phylloxera but it should also be adapted to the type of soil (for example, limestone) (GALET, 1998). The morphology of the root system is principally determined by the nature of the soil and not by its genotype (SEGUIN in CHAMPAGNOL, 1984). The growth of the root system depends on the water supply to the soil and on the training system which determines the volume of the arial parts of the plant in terms of the total and exposed foliar surface area (HUNTER, 1998 ; CARBONNEAU and CASTERAN, 1987 ; BUTTROSE, 1966). An important factor that determines the volume of the root system and the angle of penetration of the roots in the soil, is the plantation distance between individual vinestocks in a given row. The distance between two rows only gives rise to competition between the root systems of individual plants if the distances are 1.2 metres or less (ARCHER and STRAUSS, 1989 ; 1985). The vine root system becomes established during the 5 to 7 years following plantation (CHAMPAGNOL, 1984). New secondary and tertiary root systems may form each year during the vegetative cycle once the primary root system is established (ARCHER and STRAUSS, 1989 ; 1985). The rootstocks are also classified according to their tolerance to drought (CARBONNEAU, 1985). Recent studies have enabled us to compare the behaviour of Carignan vines grafted onto rootstocks of varying sensitivity to drought. SO4 and 140 Ruggieri rootstocks both grafted with Carignan were planted on the same soil in a given plot, and measurements of the basal leaf water potentials showed significant differences between the two rootstocks in terms of how the water status evolved, notably after veraison. This confirmed the ability of the rootstock to influence the water supply to the plant, all other factors being equal. (SILVA, 2002). This difference in the water status of the Carignan variety particularly affected the biochemistry of the berry, notably anthocyanin biosynthesis. These results confirm that there is a relationship between the water status of the vine and the biosynthesis of phenols, as we will see later (DELOIRE *et al.*, 2001 ; OJEDA *et al.*, 2002).

ARCHITECTURE

The water status of the vine will affect vegetative growth in conjunction with the sum of temperatures over a given period. Nonetheless, where the vigour is equal, other elements which influence the growth of primary and secondary shoots should be taken into account:

- The training system (CARBONNEAU *et al.*, 2001 ; MARAIS *et al.*, 1999).

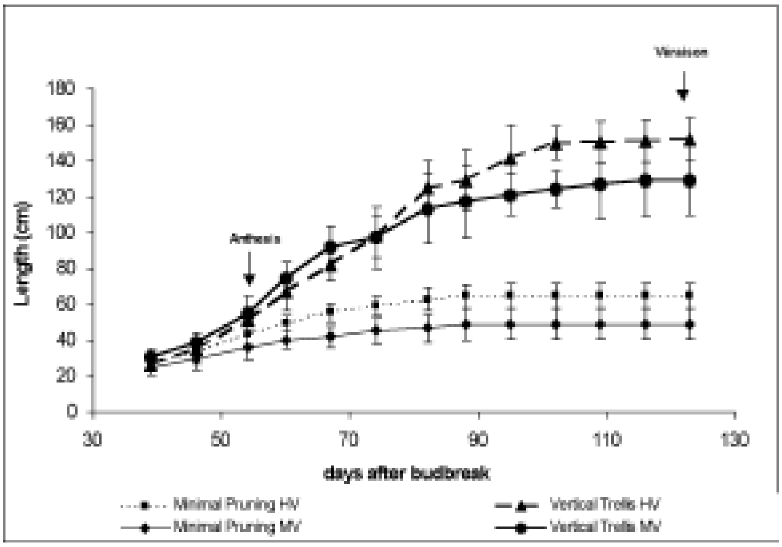


Figure 1 - Croissance des rameaux principaux du cépage Merlot, du débourrement à véraison, conduit en espalier et en taille minimale en interaction avec la vigueur.

On observe dans cet exemple que le système de conduite influe de façon prédominante sur la croissance des rameaux primaires. HV : vigueur forte ; MV : vigueur moyenne.

Growth of the principal shoots of Merlot vines from budbreak to veraison: effect of minimal pruning training and vertical trellising on the vigor of the grapevine.

It may be observed in this example that the training system predominantly influences stem growth . HV: Highly Vigorous; MV: Moderately Vigorous.

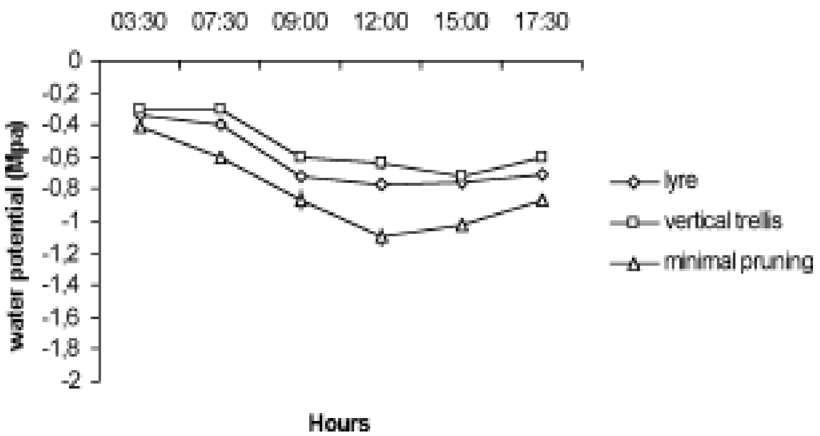


Figure 2 - Evolution journalière du potentiel hydrique foliaire de feuilles « ensachées » du cépage Merlot (23/07/02). Comparaison de trois systèmes de conduite en situation de vigueur moyenne : lyre, espalier et taille minimale.

On observe que les potentiels hydriques foliaires de base ne sont pas significativement différents (environ –0,3/-0,4 Mpa à H.3 :30). L'évolution journalière du potentiel foliaire montre des valeurs toujours plus élevées pour la taille minimale, de H7 :30 à H17 :30. On observe aussi un comportement hydrique différent entre la lyre et l'espalier. La Lyre semble induire une consommation en eau légèrement supérieure au cours de la journée, mettant ainsi la vigne en situation de contrainte hydrique moyenne favorable au métabolisme de la baie et donc à la qualité de la vendange.

Daily evolution of the « bagged » leaf water potential of Merlot vines (23/07/02). Comparison of three training systems in a moderate vigor situation: vines trained on lyre, vertical trellising and minimal pruning.

It may be observed that the predawn leaf water potentials are not significantly different (about –0,3/-0,4 Mpa at 3 :30 AM). Evolution of the daily leaf water potential shows that values are always higher from 7 am to 5.30 pm for the minimally pruned vines. It may also be seen that the vines behave differently with respect to their water consumption depending on whether they are trained in the lyre system or on a vertical trellis. The lyre seems to induce slightly greater consumption of water during the day, which creates moderate water deficiency that encourages berry metabolism and enhances the quality of the harvest.

- The growing period (i.e. the various phenological stages : budburst, flowering, flowering-veraison, veraison-maturity (LORENZ *et al.*, 1995 ; FOURNIOUX, 2001).

- The relationship between the exposed (SFE) or total (SFt) foliar surface area and grape production (per m^2 or per hectare) (CARBONNEAU *et al.*, 1998 ; CARBONNEAU, 1995 ; MURISIER, 1996).

- Fertilisation (SCHALLER, 1999 ; CONRADIE, 1980).

Figure 1 shows the relationship between primary shoot growth and vigour of Merlot vines trained in Espalier with Minimal Pruning. These two opposing training systems strongly influence primary and secondary shoot growth in relation to the vigour, in terms of different variations in available soil water. In this example vegetative and berry growth are principally dependant on the architecture of the vine. Comparison between pruned and non-pruned vines (Minimal Pruning) clearly show that competition between the different organs determines their growth. The biochemical composition of the berry is closely linked to the water status of the vine and to the microclimate of the leaves and the grape bunches (CARBONNEAU and DELOIRE, 2001 ; SMART 1995 ; CARBONNEAU *et al.*, 1978).

Any given vine architecture will change throughout the development cycle of the plant, especially the water status of Merlot vines after veraison, as is demonstrated by the daily evolution of leaf water potentials (figure 2). A relationship exists between the training system, the root system and total foliar surface area which causes the plant to dry out the soil and its tissue water reserves more rapidly both during the day (measured by the leaf water potential, ψf), and over the course of the development cycle (measured by the predawn leaf water potential, ψb). How may the effect of vine water status and nitrogen fertilisers on vegetative growth and yield be evaluated ? One possibility is to carry out a study of the plant's carbon balance.

A study carried out on Syrah shoots at different growth stages showed the carbon balance between the different organs (primary shoot, secondary shoots, grape bunches) in the absence of water deficit (Espalier training system). It was observed that the primary shoot, excluding its organs, represents, at maturity, approximately 30 % of he carbon balance; the leaves, 25 %, the secondary shoots 10 % (in this example) and the grape bunches, 25 %. This type of study allows us to identify the growing parts (apart

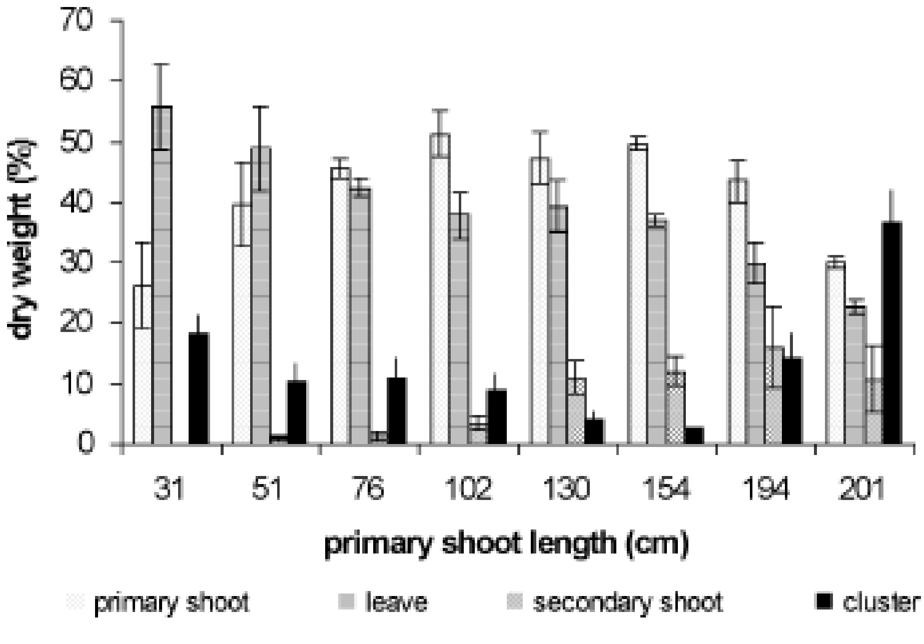


Figure 3 - Exemple du bilan de matière sèche (poids sec) d'un rameau de Syrah à différents stades de sa croissance (système de conduite espalier ; situation sans contrainte hydrique).

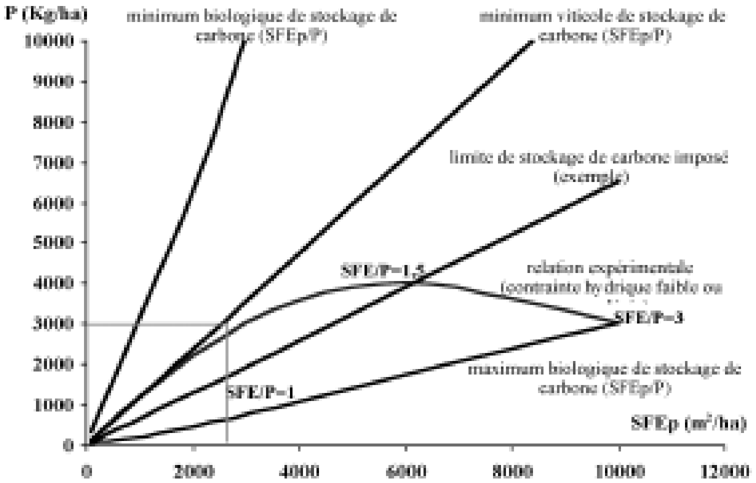
Le poids sec relatif des différentes parties du rameau est représenté : la tige, ses feuilles, les entre-cœurs et les grappes. A maturité, la proportion (en % des poids secs) des différentes parties du rameau (201 cm de long), est : tige seule : 30% ; feuilles : 25% ; entre-cœurs complets : 10% ; grappes : 35%.

Example of the relative dry weight of the principal organs of a Syrah primary shoot during its growth phase (vertical training system, without water stress).

The relative dry weights of the different parts of the shoot presented are: the primary shoot alone, its leaves, inter-nodes with leaves and the clusters. At maturity, the proportions (in % of dry weight) of the different organs of a 201 cm primary shoot are: primary shoot alone, 30%; its leaves 25%; inter-nodes, 10% and clusters, 35%.

Table II - Predawn leaf water potential and grapevine water status (CARBONNEAU, 1998).
Les seuils du potentiel hydrique foliaire de base et l'état hydrique de la vigne (CARBONNEAU, 1998)

phfb (Ψb)	Water status of the vine
0 Mpa ≥ Ψb ≥ -0,2 Mpa	Water stress mild or absent
-0,2 Mpa > Ψb ≥ -0,4 Mpa	Mild to moderate water stress
-0,4 Mpa > Ψb ≥ -0,6 Mpa	Moderate severe water stress
-0,6 Mpa > Ψb	Severe water stress



équation simplifiée de la relation expérimentale : P = 4/3 (SFEp/P) -

Figure 4 - Modélisation de la relation Puissance (P) – Surface Foliaire Exposée potentielle (SFEp) à partir de points de repère expérimentaux (P (Kg/ha) = 0,5 x poids des bois de taille + 0,2 poids de la récoltes).

Modeling of the relation between « Puissance, (P) » and potential exposed leaf area (SFEp) (P (Kg/ha) = 0,5 x pruned shoots weight + 0,2 x yield weight).

from perennial structures) that are primarily affected by either water stress or surplus under different conditions of water status, and indeed the effect of other factors (fertilisation, presence of cover grass, etc.) A study of the carbon balance also allows us to calculate the water consumed by the plant during its growth cycle. Excessive vigour due to an excess of water or nitrogen fertilisers leads to crowding of the leaves which is unfavourable to bunch microclimate, berry ripening (dilution of the berry contents in relation to volume) and favours the penetration of pesticides into the berry. In addition, the berries are rendered more sensitive to attack by *Botrytis cinerea* (DELAS, 2002).

Once the characteristics of the «grape variety-terroir» relationship have been defined, evaluation of the potential quality of a vineyard should be based simultaneously on the vegetative cycle and the «puissance», (P) which comprises all available sources of carbon. An adjustment curve between the two has been experimentally derived (figure 4). In all cases, this curve is based on the average response in a situation of zero-to-moderate drought.

BERRY GROWTH AND BIOCHEMISTRY. THE CONCEPT OF BERRY QUALITY

Berry growth occurs primarily in two stages. The first is the herbaceous growth stage which begins after fertilisation of the flowers and which ends before veraison;. the second stage begins at veraison (following a short pause in growth) and continues until the fruit is ripe. The first growth stage involves cell multiplication and enlargement, whereas the second stage consists solely of cell enlargement (OLLAT *et al.*, 2002 ; OJEDA *et al.*, 1999 ; MCCARTHY, 1997 ; COOMBE, 1992). We have recently shown that the berry growth from veraison to ripeness could also be divided onto three phases (WANG *et al*, 2003a et b). The water status of the vines has a significant influence on berry growth, both at the herbaceous growth stage and during the period veraison to maturity (OJEDA *et al*, 2001). Therefore, it is possible to influence the yield in vineyards where irrigation is necessary from the time of flowering (DRY and LOVEYS, 1998) or even later.

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Table III - Relationship between type of terroir and water status of the vine (i.e. evolution of the soil water reserve accessible by the roots).

Examples are presented of possible recommendations for cultural practices for the majority of the vines planted on terroirs whose natural water levels are measured in terms of predawn leaf water potential (plwp, Ψb). The situations presented below are common to Mediterranean regions. It is assumed that the rootstock is adapted to the type of soil. The recommendations should also be interpreted in terms of the type of wine it is sought to produce. The ideal situations are presented in bold print. The information presented in this table may be used for the principal grape varieties, with some adjustment.

Relation «terroirs» et état hydrique de la vigne (en relation avec la réserve utile du sol exploitable par les racines).

Exemple de recommandations possibles pour les itinéraires culturaux de la vigne, planté sur des terroirs dont le comportement hydrique naturelle est lu à travers la mesure des potentiels hydriques foliaires de base. Les situations présentées ci-dessous sont fréquentes en région méditerranéenne. On suppose ici que le porte-greffe est adapté au type de sol. L'ensemble se raisonne aussi en fonction de la gamme de vin à réaliser. La situation idéale est présentée en caractère gras. Les informations de ce tableau sont utilisables pour les principaux cépages, avec des ajustements.

Water status of the vine (plwp, Ψb, Mpa)	Phenological stages	Degree of water stress	Expected consequences	Comments	Recommendations for cultural practices
0 to -0,2 Mpa	Bud-burst to maturity	Absent-to-very mild	Excessive vigour and dilution of berry metabolites	Unfavourable	Draining a possibility, vertical trellis training system ; single or double cordon pruning. Balance the load during pruning ; training wires at minimum two different levels; row spacing ≤ 1,2m. ; cover grass to compete with the vine may be envisaged. Reduce nitrogen fertilisers to a minimum. Favour practices that reduce the vigour of the plant (but give preference to yield-control operations that are not labour-intensive and therefore costly). SFEp/load (m2/Kg) ≥ 1 ; de-budding a possibility, leaf removal around the immediate area of the grapes should be considered from berry set and/or bunch closure
0 to -0,2 Mpa	Bud-burst to flowering	Absent-to-very mild	Normal growth	favorable	Adjust the load according to the SFEp. Cover grass may be envisaged (but not to compete with vines, therefore leguminous plants recommended), to minimize erosion or to facilitate machine access.
-0,2 to -0,4 Mpa	Flowering to bunch closure/veraison	Moderate and progressive	Controlled vigour (slowed vegetative and fruit growth); no disruption of biochemistry	Favorable	Adjust the load according to the SFEp
-0,4 to - 0,6 Mpa	Flowering to bunch closure/veraison	Moderate to severe	Vegetative growth reduced or inhibited and uneven surface foliage : berry growth is inhibited ; possible disruption of tannin biosynthesis.	Unfavourable	Sowing of cover grass not recommended ; use suitable soil practices (e.g., scraping) SFEp/load ≥ 1,25 (e.g.. 1 m^2 exposed foliage surface for 0.8 Kg of grapes per m2 or per plant) ; manual de-budding or green harvesting (green bunch removal) to reduce the load on the vine; consider supplying a reasonable amount of water to raise the water potentials of the foliage to –0,4 Mpa.
-0,4 to ≤ - 0,6 Mpa	Veraison to maturity	Moderate-to -severe and progressive	plant : vegetative growth slows and/or stops ; reduction of photosynthesis ; possible yellowing of the leaves at the base berries : growth reduction ; reduced loading of sugar in the berries, but final potential alcoholic strength is favourable ; possible stimulation of anthocyanin biosynthesis; slow ripening without major inhibition; concentration of metabolites in fine ; increase of the skin/flesh ratio	favorable	Cover grass should be used advisedly (or use inter-row species that are dry at this time of the year in order to facilitate machine access); SFEp/load ≥ 1,25
< -0,6 Mpa	Veraison to maturity	Severe and drastic	plant : vegetative growth stops; the leaves at the base yellow and fall; significant reduction in photosynthesis. berries: severe growth reduction; possible inhibition of ripening: significant reduction in sugar loading; disruption of anthocyanin biosynthesis; over-concentration of metabolites; increase in the skin/flesh ratio.	Unfavourable on terroirs where the water stress is intense during ripening	Cover grass not recommended ; SFEp/load > 1,25 ; green harvest should be considered; working of the soil should be adapted: supply a reasonable quantity of water before veraison so that the vines remain at –0,6 Mpa at the start of ripening

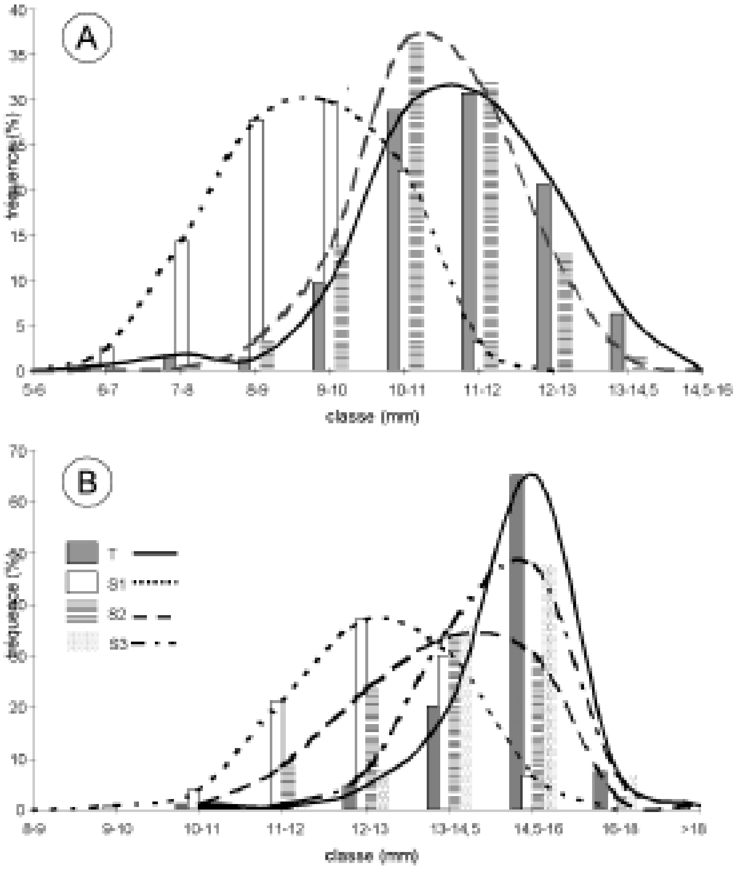


Figure 5 - Distribution des baies, selon leur diamètre, de plants de Syrah soumis à différents traitements hydriques
T (témoin), S1 (contrainte forte entre nouaison et véraison), S2 (contrainte moyenne entre nouaison et véraison), S3 (contrainte forte entre véraison et maturité). Les histogrammes correspondent à deux dates de prélèvement : début véraison (48 jours après anthèse, A) et maturité (110 jours après anthèse, B). Aux deux stades de prélèvement il est observé entre 7 et 8 classes de baies. Le niveau de la contrainte hydrique, sa durée et sa période de survenue ont influé sur le volume des baies et leur répartition par classes de diamètre. La différence de croissance des baies est notable entre véraison (A) et maturité (B) pour (S2), (S3) et (T) plus que pour (S1). La contrainte hydrique avant la véraison modifie de façon durable la croissance des baies.

Distribution of Syrah berries according diameter from vines subjected to different hydric treatments
T (control), S1 (severe hydric stress from setting to veraison), S2 (moderate hydric stress between setting and veraison), S3 (severe hydric stress between veraison and maturity). The histograms correspond to two different developmental stages, the beginning of veraison (d48 after anthesis, A) and maturity (d110 after anthesis, B). For each of the stages, 7-8 classes of berry size are observed. The severity of the water stress, its duration and the stage at which it was applied influence the volume of the berries and their distribution by diameter class. The difference in berry growth is significant between verasion (A) and maturity (B); this difference is greater for (S2), (S3) and (T) than for (S1). Hydric stress applied before veraison was found to have a long-lasting effect on berry growth.

OJEDA *et al.* (2001) showed that moderate-to-severe water deficit from flowering to veraison irreversibly modified the size of Syrah berries, even if the vines received a normal supply of water from veraison to maturity. Water deficit modified the diameter and therefore the volume of the berry (figure 5) which affected the ratio of skin surface to juice content and as a consequence, the composition of must and wines.

As regards the biochemical composition of the berry, a clear distinction should be made between that which relates to concentration (which is related to the volume and the number of cells in the berry) and that which relates to biosynthesis, which is dependant on environmental parameters (water, temperature and light).

The quality of the berry may be defined in terms of its biochemistry.

The composition of the berry, notably in terms of sugars, titratable acidity (tartaric and malic acids) phenolic compounds (tannins; proanthocyanidols, flavonols, anthocyanins etc.) is strongly dependant on the water status of the vine associated with the microclimate of the grape bunches and the architecture of the vegetation. (OJEDA *et al*, 2002 ; PRICE *et al*, 1995 ; NAOR *et al.*,

Table IV - Biochemical, physiological and morphological indicators of grapevine water content.

This non-exhaustive list of indicators shows different degrees of facility of use in the vineyard and laboratory in terms of equipment cost and the level of technical expertise required. Their suitability for the measurement of grapevine water content is discussed.

Indicateurs morphologiques, physiologiques ou biochimiques de l'état hydrique d'une vigne ou d'un vignoble.

Ces indicateurs (non exhaustifs) présentent des niveaux différents de facilité d'utilisation sur le terrain ou en laboratoire, en fonction de la technicité requise et du coût des équipements à mobiliser. Leur adéquation avec l'état hydrique de la vigne est discutée.

Vine drought indicators	Suitability for the determination of grapevine water status	Level of technical ability required
	physiological and biochemical indicators	
Leaf water potential	Sufficient for the definition of threshold values	**
Photosynthesis and stomatal conductance	Use in conjunction with other indicators	***
Total (SFt) and exposed (SFE) foliar surfaces	Use in conjunction with other indicators	*
Measurement of abscissic acid	Under investigation	***
Carbon 13 (_13C) isotopic ratio	Under development	***
Berry biochemistry (sugar, titratable acidity, anthocyanins, flavonols, etc.)	Use in conjunction with other indicators	** / ***
Surface temperature	Useful in arial imagery	** / ***
	morphological and physical indicators	
Growth of primary and secondary shoots	Use in conjunction with other indicators	*
Berry growth and weight	Use in conjunction with other indicators	* / **
Dry matter Bilan	Use in conjunction with other indicators	**
Vigour, vegetative expression	Use in conjunction with other indicators	*
Trunk circumference	Under investigation	*
« puissance »	Use in conjunction with other indicators	*
Micrometric variation of the organs	Under investigation	***

*** : high level of technical ability ; ** : reasonable level of technical ability ; * : readily executed

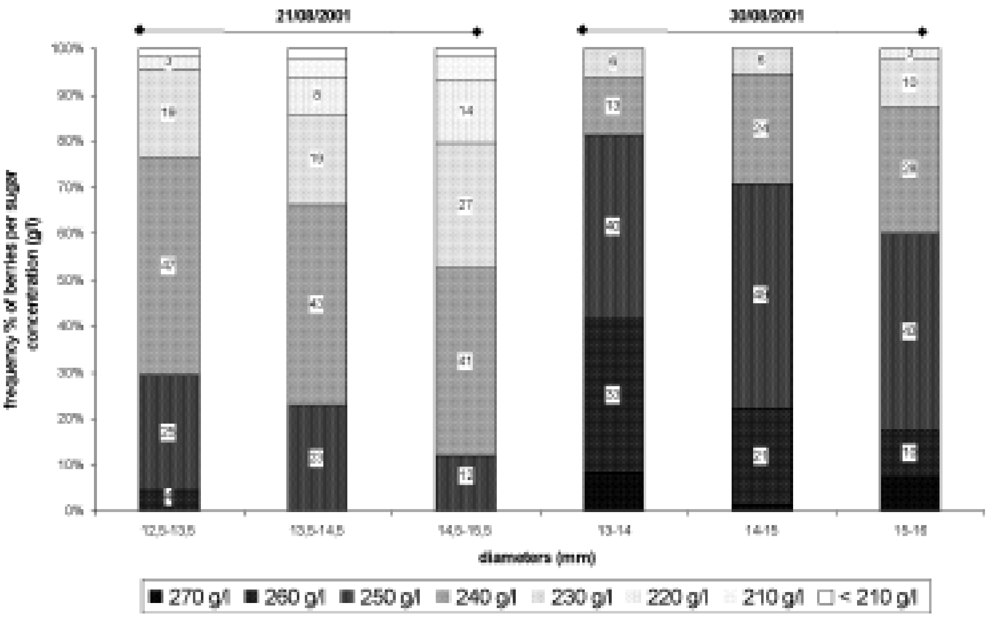


Figure 6 - Tri de baies de Merlot par diamètre en premier (pas de 1 mm) puis par concentration de sucre en second.

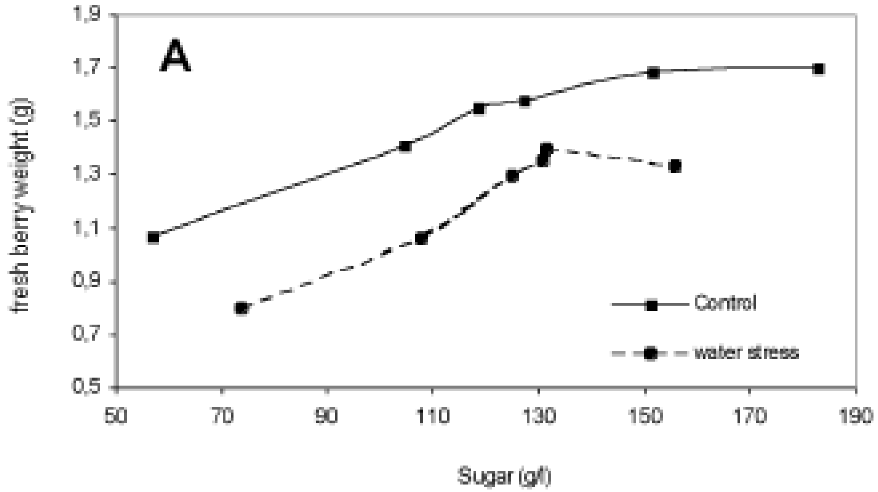
Cette expérimentation permet de montrer qu'une classe de diamètre a des baies de concentrations en sucre différentes. A l'inverse des baies de même concentration en sucre ont des diamètres (donc des volumes) différents. La classe majoritaire en concentration de sucre, parmi les classes de diamètre, évolue au cours de la maturation (240 g/l pour le 21/08/01 et 250 g/l pour le 30/08/01).

Merlot berry classification according to their diameter first and to their sugar concentration in second.

This allows to shows that a diameter class has berries with different sucrose contents. A class of sucrose concentration has berries with different diameters. The most predominant class (240 g/l for the 21/08/01 and 250 g/l for the 30/08/01).

1993 ; CARBONNEAU *et al*, 1978). Sugar loading in the berry depends on environmental conditions and the grape variety associated with efficiently the vine uses its water and carbon supplies (WANG *et al.*, 2003b; ZUFFEREY *et al.*, 2000 ; CARBONNEAU, 1996 ; KATERJI *et al.*, 1994 ; SCHULTZ, 1993)

Amongst the questions on the relationships between berry and sugar, there is the one on the relation between the berry volume and the sugar loading. We have down berry classification on Merlot, first according to their diameter and second to their sugar concentration (according to a method developed by C. ROMIEU, INRA Montpellier). The results show figure 6 allow to conclude that there is no direct relation between the berry volume and the sugar concentration for a single berry (i.e. berries with the same diameter from a population which has different sucrose contents). The active berry sugar loading depends mainly on the vine water status and photosynthesis. To demonstrate this point, a method called the « berry-cup » has been developed to study the sugar berry loading (i.e. phloem berry unloading) as a function of the vine water status and light interception (WANG *et al.*, 2003a).



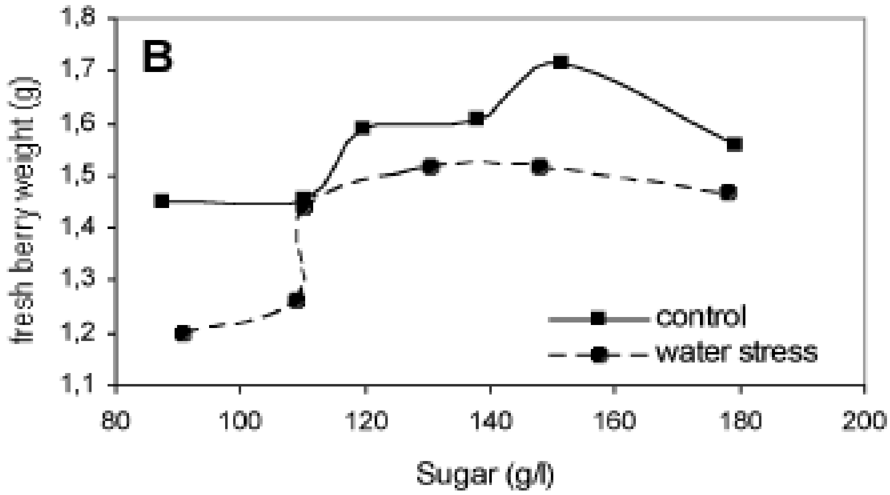


Figure 7A et B Relation entre la concentration en sucre (g/l) et le poids moyen d'une baie: comparaison de vignes de Syrah sous contrainte hydrique et témoin.

(A): la contrainte hydrique durant la maturation est < -0,6 Mpa (mesurée par le potentiel hydrique foliaire de base). La croissance de la baie et son chargement en sucre sont perturbés. (B): la contrainte hydrique durant la maturation est ≅ -0,4 Mpa (mesurée par le potentiel hydrique foliaire de base). Seule la croissance de la baie est perturbée et pas le chargement en sucre.

Relationship between sugar concentration (g/l) and the average fresh berry weight during maturation: comparison between control and water stress of Syrah vines.

(A): the water stress during ripeness is < -0,6 Mpa (according to the predawn leaf water potential). We observe that the berry growth and the sugar loading of the water stressed vines are reduced (dotted line). (B) the water stress during ripeness is ≅ -0,4 Mpa (according to the predawn leaf water potential). We observe that the berry growth of the water stress vines is reduced, but not the sugar berry concentration (dotted line).

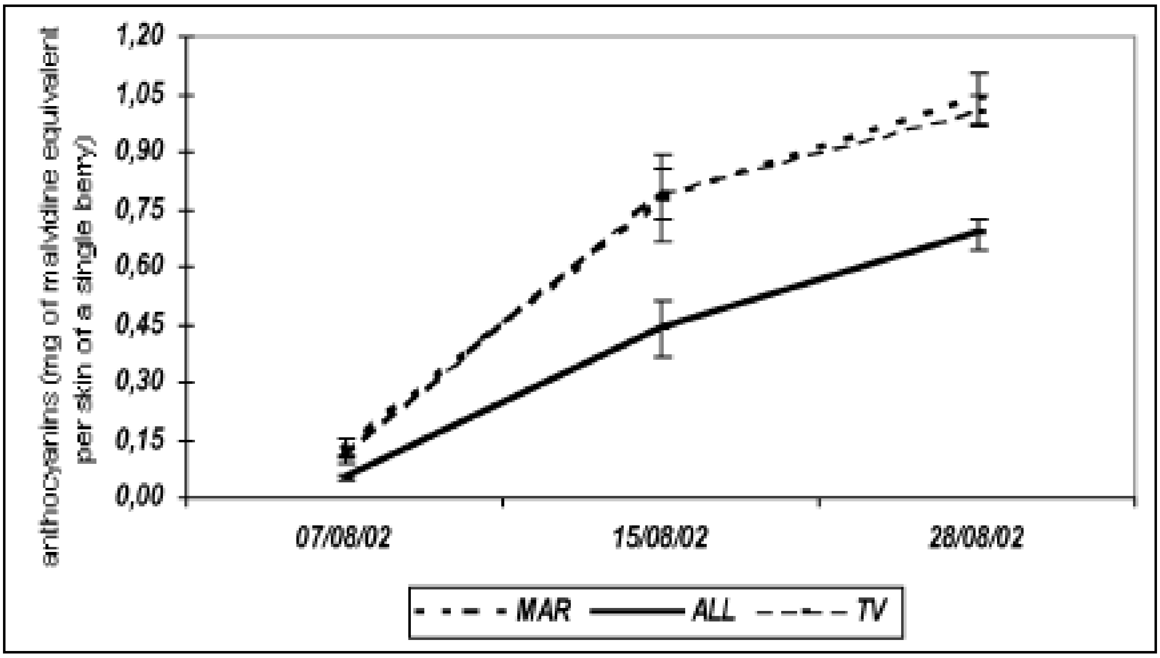


Figure 8 - Evolution de la biosynthèse des anthocyanes du Grenache noir planté sur trois types de sol : Mar (marnes) ; ALL (alluvions) ; TV (terrasses villafranchiennes).

L'état hydrique de la vigne durant la maturation – en relation avec l'évolution de la réserve utile du sol – va influencer la biosynthèse des anthocyanes. Une contrainte hydrique moyenne à forte (entre –0.4 and –0.6 Mpa, potentiel hydrique foliaire de base) et progressive durant la maturation, est favorable à la biosynthèse des anthocyanes (exprimée ici en équivalent malvidine). C'est la situation rencontrée pour MAR et TV.

Evolution of the biosynthesis anthocyanins in Grenache noir grapes on three different types of soil : marl (Mar.) ; alluvium (All) ; villafranchien terraces (TV).`

The water status of the vine during berry ripening - which is related to reserves of water in the soil (terroir effect) - influences the biosynthesis of anthocyanins. Moderate-to-moderately severe water stress, between –0.4 and –0.6 Mpa, (which is, however, progressive during ripening) is favourable for the biosynthesis of anthocyanins (expressed here as malvidin equivalent); here this corresponds to marls and villafranchien terraces.

The principal results relating to Syrah berry sugar loading as a function of vine water status and light interception are presented in WANG *et al.*, 2003b.

Water deficit (according to the predawn leaf water potential thresholds) reduces photosynthetic activity which in turn lowers berry sugar unloading. The latter is not related to berry volume, however, after a certain point during ripening the berries become more concentrated due to continued sugar unloading and size reduction due to direct water loss (figure 7 A).

Depending on the severity of water stress level and the point in time at which it is applied or occurs naturally (terroir effect), a reduction in vegetative growth (i.e. the plant's vigor) can compensate for the observed reduction in photosynthetic activity without affecting berry sugar unloading (figure 7 B).

The berries were classified according to their diameter which enabled us to demonstrate that berry sugar loading appears to be independent of the berry volume but is closely related to the water status of the vine and its photosynthetic capacity. This clearly confirms that it is extremely useful to determine precisely for a given parcel:

- The relationship between SFE/P (see figure 4);

- How the water status of the plant evolves (and not only its level at the time of harvest).

Anthocyanins metabolism may be disrupted by severe water stress before veraison, or conversely, it may be stimulated by moderate-to-severe water stress after veraison (OJEDA *et al.*, 2002). The effect of water stress on the metabolism of phenols depends on the degree of water stress, the point in time at which it is applied and its duration. Grenache noir seems to have a different response threshold from Syrah, particularly in relation to the metabolism of anthocyanins. Figure 8 shows the relation between Grenache noir berry anthocyanins biosynthesis and the type of soil (i.e. the terroirs). The vine water status and evolution was measured by the predawn leaf water potential which allows to establish relation with the soil water content during the period of veraison to ripeness. Other families of phenols were analysed and results showed a variation in their metabolism according to the water status of the vines; the compounds in question were derivatives of hydroxycinnamic acid, flavonols and flavane-3-ols (OJEDA *et al*, 2002 ; DELOIRE *et al*, 2002 ; CARBONNEAU et DELOIRE, 2001). Taking these factors into consideration, to understand the influence of water status of the vine on the phenolic composition of the grapes, it is important to analyse the different compounds separately and to make the distinction between biosynthesis (amount per entire berry which varies from cell to cell) and concentration (amount per berry weight).

MAJOR METHODS USED TO MEASURE VINE WATER STATUS

I - TECHNIQUES

Plant water status: This information is obtained by measuring the leaf water potential using the pressure chamber technique (SCHOLANDER *et al.*, 1965). This method involves applying an inert gas to the leaf in order to determine its ability to retain water. The greater the pressure required to force water out of the leaf, the less water it contains. The result is expressed in Bars or Mpa and always has a negative value. The current reference method is the measurement of the basal (predawn) leaf water potential (phfb ; ψb) which is carried out before sunrise when the leaves' stomata are still closed, and the plant has had the opportunity to re-equilibrate its water level in relation to that of the soil. Thus there is a good relationship between the plant's water status, measured in terms of the pfhb, and the available water reserves in the soil area occupied by the roots. Threshold values of pfhb, based on a number of observations in Bordeaux and the Languedoc have been proposed by CARBONNEAU (1998), and the degree of water stress to which a plant was subjected may be estimated from these values. Approximate threshold values based on 20 years' observations in several vineyards of several grape varieties are presented in table II.

Based on values of predawn leaf water potential, it is possible to understand how the vine uses its available water supply during vegetative growth and development, the biochemical evolution of the grapes (primary and secondary metabolites). It is thus possible to characterise the relationship between a grape variety and terroir and to design an irrigation regime which permits yield control (in terms of berry volume). As regards grape metabolism, (which also determines the harvest date) decisions are made based on the grape variety, berry biochemistry on a given date (subject to the availability of analytical techniques, including sensorial analysis of the grape berries) and, in conjunction with oenological techniques, the type of wine required.

Nonetheless, others method of measuring leaf water potential may be used: measurement of leaf potential or «stem» potential (WILLIAMS and ARANJO., 2002; CHONÉ *et al.*, 2001), which in reality is the particular potential of a «bagged» non-transpiring leaf (CARBONNEAU *et al.*, 2003). These measurements are carried out during the day. All of these methods are based on the pressure chamber technique; they differ only at the level of the stomata. The phfb is measured in plants where all the stomata are closed and whose water level is re-equilibrated with that of the soil area occupied by the roots. The leaf potential during the day involves leaves whose transpiration is regulated by the opening and closing of stomata, and thus this test provides information on the water status of an entire plant in full activity (engaged in transpiration, photosynthesis, etc.). In the measurement of the « bagged » leaf potential, the leaf is placed in a small bag in darkness and in many cases, particularly in Mediterranean climates, it is actually disconnected from the vascular supply of the shoot (CARBONNEAU *et al.*, 2003). Other techniques have been tested as indicators of vine water stress (table IV), such as morphological, physiological or biochemical indicators involving the fruit or the vegetative parts of the plant.

Carbon 13 (δ13C) isotopic discrimination by photosynthesis (GAUDILLÈRE *et al.*, 2002) is a technique by which analysis of the berries at harvest is used to classify different parcels in terms of grapevine water status. Nonetheless, in order to understand properly how the biochemistry of the berry evolves, and thus the potential quality of the harvest, it may necessary to carry out kinetic measurements on the evolution of vine water status and berry biochemistry, sometimes as early as during vegetative growth. The basic idea is to understand the relationships between the vine and the grape during the course of its development cycle in order to apply the most appropriate cultural practices and oenological techniques. (DELOIRE *et al.*, 2003).

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