CHARACTERIZING A VINE TERROIR BY COMBINING A PEDOLOGICAL FIELD MODEL AND A SURVEY OF THE VINE GROWERS IN THE ANJOU REGION (FRANCE)

CARACTÉRISATION DES TERROIRS VITICOLES, À L'AIDE D'UN MODÈLE DE TERRAIN ET D'UNE ENQUÊTE AUPRÈS DES VIGNERONS, EN ANJOU (FRANCE)

F. BODIN* and R. MORLAT

Unité Vigne et Vin, Centre INRA d'Angers, 42 rue Georges Morel, B.P. 57
49071 Beaucouzé cedex, France

Summary : The aim of this research was to develop an operational method of characterization of «terroirs» in response to the request from wine professionals. A study based on both a survey of vine growers and a characterization of the natural factors of «terroir» (geological, pedological and mesoclimatic components) using the concept of Basic Terroir Unit (B.T.U) was made in 18 communes of the Anjou region. The natural factors of "terroir" were characterized by (1) a geological component (stage and nature of the parent rock) and (2) an agro-pedological component studied according to a field model allowing to distinguish three kinds of soil environments named : Rock, Alteration and Altérite. Each of them represent a functioning unit in wich an homogenous response in terms of vine behaviour can be expected. The approach based on the survey of vine growers was developed in order to replace the network of experimental plots of land formerly used to integrate the plant behaviour in its environment. These networks required considerable investment in time and money. Our study showed that vine growers perceived correctly the behaviour of the vine through different variables relative to the soil, the climate and the plant. They distinguished particularly well between two of the environments (Rock and Alterite) generated by the model. There was good agreement between the results obtained with the two approaches (survey and characterization of natural factors of «terroirs»).

Résumé : Le but de ce travail a été d'élaborer une méthode opérationnelle de caractérisation des terroirs pour répondre à une demande croissante de la filière viticole. Une étude basée sur une enquête agroviticole et une caractérisation des facteurs naturels du terroir (composantes géologique, pédologique et mésoclimatique) utilisant le concept d'Unité de Terroir de Base (U.T.B.) a été conduite sur 18 communes du vignoble de l'Anjou. La caractérisation des facteurs naturels du terroir utilise d'une part une composante géologique (étage et nature de la roche mère) et d'autre part une composante agro-pédologique étudiée grâce à un modèle de terrain permettant de distinguer trois milieux sol différents (roche, altération et altérite). Chacun représente une unité de fonctionnement de la vigne. L'approche par enquête viticole parcellaire a été développée de manière a se substituer aux réseaux de parcelles expérimentales, lourds et coûteux, pour appréhender le fonctionnement de la plante dans son milieu. Il ressort de cette étude que les vignerons perçoivent correctement le comportement de la vigne à travers différentes variables relatives au sol, au climat et à la plante. Ils discriminent particulièrement bien deux des milieux générés par le modèle de terrain. On constate aussi une bonne concordance des résultats obtenus avec les deux types d'approche (enquête et caractérisation des facteurs naturels).

Key words: viticultural terroir, survey, vine growers, terrain model, soil depth, water supply, vigor, budburst earliness.

Mots clefs : terroir viticole, enquête, vignerons, modèle de terrain, profondeur de sol, régime hydrique, vigueur, précocité.

INTRODUCTION

In viticulture, the concept of terroir is of growing interest, not only in countries of wine tradition, but in the new production countries. The notion of «terroir» based on natural and human factors (SALETTE *et al.*, 1998) is presented by the French National Institute of Origin as the foundation of the AOC. But today, the controlled origin system starts in the New World countries. The understanding of terroir effect on plant behavior will lead to an adaptation of the cultural practices and so to an increase of the quality of wine. Using the «terroir» factor requires to conduct researches in order to get a better knowledge of this complex system by combining a scientific method of characterization of the natural factors of the «terroir» with the study of the empirical knowledge of vine growers. It is in this spi-

*Corresponding author: bodin@angers.inra.fr

J. Int. Sci. Vigne Vin, 2003, **37**, n°4, 199-211

©Vigne et Vin Publications Internationales (Bordeaux, France)

rit, that the program on «Terroirs d'Anjou» was initiated (MORLAT, 2001) in 1994. It is based on the concept of Basic Terroir Unit (BTU) which was used as framework to develop a pedological field model for soil study (MORLAT, 1989 , 2001, RIOU *et al.*, 1995), to improve and to generalize the characterization of the soil component of the terroir.

In parallel with the characterization of BTU in the field, a survey of the vine growers was conducted at the plot scale. It focused on the following objectives :

- Study of the «terroir» effect on the vine and wine ;

- Study of the empirical perception of the terroir by the vine grower ;

- Adaptation of vine-growing and enological practices to the terroir ;

- Valorization of terroirs.

In this paper, we only present the main results obtained regarding the first two objectives. The other two will be the dealt with in a second paper.

MATERIALS AND METHODS

I -STUDY OF THE NATURAL FACTORS OF THE TERROIR : IDENTIFICATION AND CARTOGRAPHY OF BASIC TERROIR UNITS

In the approach proposed by MORLAT (1989), a vine-producing region is considered as a set of natural environments, each defined by three major components: a geologic component, an agro-pedological component and a landscape component. By definition, the BTU corresponds to a territory that results in homogenous behaviour with respect to the terroir/vine/wine functioning chain. Moreover, its area is sufficient to be managed as an agronomically and commercially viable unit.

The geological component is considered to be the first primary key of identification and cartography of the BTU, by using, the type of parent rock and the geologic stage it belongs to.

The second primary key concerns the soil type. Its high variability is the main problem to solve in the identification of the BTU. In order to overcome this problem, a simple but operational pedological field model (THELIER-HUCHE et MORLAT, 2000) based on the soil depth and its average clay content, often linked to

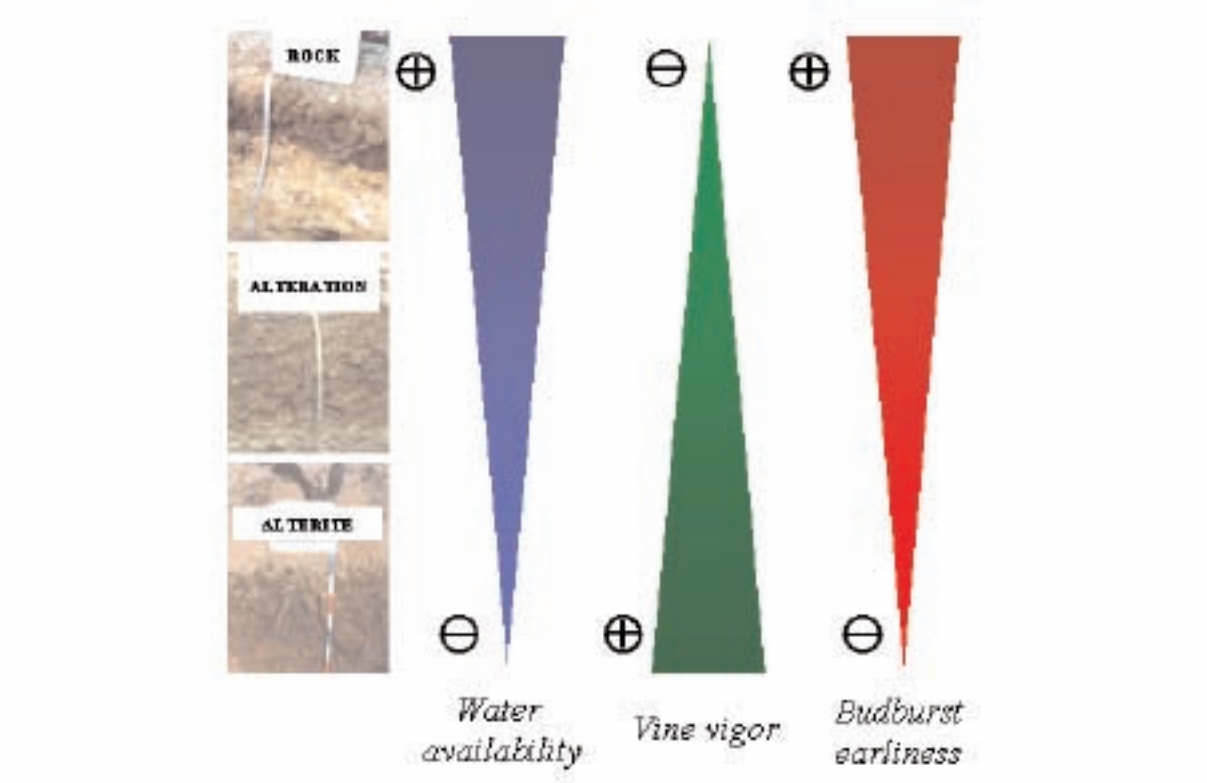

Fig. 1 - Hypothesis on the behavior of the vine in every environment of the pedological field model for soil study.

Hypothèses sur le comportement de la vigne dans chaque milieu du modèle de terrain.

©Vigne et Vin Publications Internationales (Bordeaux, France)

the degree of alteration of the parent rock, was designed. One considers that for every type of rock belonging to a given geological stage, there is a potential series of soils with various levels of evolution. Concerning this series of soils, the field model allows to distinguish between three kinds of environments which are named Rock, Alteration and Alterite with in general a depth and clay content of the profile increasing in the following direction : Rock< Alteration < Alterite. These variables largely affect several physical properties of the soil which are mostly responsible for the terroir effect, (MORLAT, 1998 ; SCHWARZ, 1997), such as water content, global thermal behaviour, and water drainage. We hypothesized that the Rock environment is characterized by a limited water supply, a lower vigour and a higher budbreak earliness of vine (figure 1). The Alterite environment is determined by a non-limited water supply, a higher vigour and a lower budbreak earliness. As for the Alteration environment, its behaviour is intermediate. It is considered that each of these environments can lead to a different behaviour of the vine, liable to modify the physico-chemical composition of the grape and finally the characteristics of the wine (MATTHEWS and ANDERSON, 1988; DREIER *et al.*, 2000; DELOIRE *et al.*, 2001).

The following environments can be distinguished:

The Rock Environment with limited soil depth, in which the soil has the lowest degree of pedological alteration and clay content of the series, covering solid or slightly weathered parent material located on 60 cm in depth or less.

The Alterite environment that represent the deepest soil with the highest clay content of the series and in which the geologic material, even in a weathered state, is only observed from 120 cm in depth or more.

Intermediate situations correspond to the Alteration environment in which the rock in the process of transformation is recognizable between 60 and 120 cm in depth.

Our aim was to verify several hypotheses concerning the behaviour of the vine in each of these three environments, in terms of precocity of the cycle, water supply and vigour (figure 1).

The model proposed is adapted to the soils which are directly issued from the alteration of a parent rock. In Anjou, they represent 65 % of vine-growing surfaces. A BTU will be defined by a soil environment associated with a type of parent rock and a given geologic stage. Concerning the other soils, 35 % of the vine growing surfaces, we distinguished colluvial formations located in thalwegs, some sand-clay-gravel superficial deposits and thick clays from the Cenomanian and also silts to clayed silts from the Quaternary. In total, seven environments could be distinguished which allowed to analyze the totality of the area studied. The large spatial variability of the soil required a land survey (1/12500), essential to map the BTU with accuracy.

Terroir characterization was made by sampling using power augers (on average, 1 sampling/ha) and with the aid of remote sensing by means of digitalized aerial photographs. It also included detailed studies of the soil and of the vine rooting on profiles from representative sites as well as a quantification of the landscape environment of the BTU (altitude, opening of the landscape, intensity and orientation of the slope) according to the method described by MORLAT (2001) and DUMAS *et al.* (1997).

The landscape environment do not generally constitute a major key of zoning because at the scale used, its variations are largely associated with the geologic component and to a lesser extent to the soil component.

The soil effect on vine and wine is translated by differences in the plant physiology which cannot be directly mapped in the field. The most important differences concern the potential of the «terroir» for an early growth cycle of the vine (EPT), the soil water reserve (SWR) and the potential of the «terroir» for the vigour of vine (VPT). In order to overcome the impossibility to map the previous variables that explain the "terroir" effect directly in the field, three expert algorithms, allowing a numerical estimation of these variables, were developed (GUILBAULT *et al.*, 1998). They use and integrate criteria that are directly accessible and mappable on the field in an additive model after weighting of these variables. The choice of criteria and weight were validated on experimental plots.

The study was performed in the Anjou (figure 2) vineyard (France), located in septentrional climatic zone (47°21'N ; 0°40'W) and presenting a large geopedological and vine-growing diversity , within the same regional climate.

The zone studied has a surface of about 40,000 ha (29 communes), in the South of the Loire river. It is located at the boundary of two geologic regions: in the West, the Armorican Massif (eruptive, metamorphic and sedimentary of the Precambrian and the Primary) and in the East, the Parisian Basin (sedimentary) of the Secondary and Tertiary periods. Four geologic systems prevail here: metamorphic often sandstone schists (métagrauwacke) of the Mauges sequences

©Vigne et Vin Publications Internationales (Bordeaux, France)

(Brioverian), the schists of Angers and Bouchemaine (Ordovician to Silurian), the schist-sandstone and volcanic complex of Saint-Georges-sur-Loire (Ordovician superior to Devonian) and the coal-bearing and volcanic complex (Namurian) of the furrow of the Lower Loire. In the East, Brioverian and Primary rocks are often covered by stony sands and glauconeous clays of the Cenomanian and shell-marl of the Miocene. The region is crossed, according to a N-NW/S-SE axis, by an important fault occupied by the Layon river.

Although under oceanic influence, the region has rather low rainfall (570 mm.year-1), an average annual temperature (12.1 °C) with low temperature variations,

Fig. 2 - The vine growing area studied in the Anjou region (France)

Zone viticole étudiée dans la région de l'Anjou (France)

Table Ia - Modalities and tests values statistically significant obtained by multiple component analysis (MCA) of the natural variables of the terroir associated with each soil environment and obtained by survey of the vine growers.

Modalités et valeurs tests statistiques significatives issues d'une analyse en composantes multiples concernant les variables naturelles du terroir associées à chaque milieu sol et obtenues par enquête auprès des vignerons.

Soil environments obtained by the pedological field model for soil study						
	Rock (2587 plots)		Alteration (2623 plots)		Alterite (1279 plots)	
	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities
Period of sunshine	higher (15.5)	lower (-5.9) to average (- 13.7)	higher (3.0)	average (- 2.5)	average (11.0)	------
Fog frequency	higher (3.0)	lower (-3.5)	higher (3.9)	average (-5.3)	average (4.9)	higher (-7.1)
Wind velocity	higher (9.0)	average (- 9.6)	------	------	average (7.1)	higher (-4.6)
Soil temperature	higher (24.3)	average (- 11.7) to lower (-20.3)	average (2.9)	higher (-3.1)	lower (12.8) to average (6.1)	higher (-15.1)
Air temperature	higher (18.1)	average (-15.3) to lower (-4.9)	------	lower (-3.1)	average (11.9)	higher (-13.8)
Soil moisture content	lower (21.6)	higher (-19.1) to average (-8.2)	average (5.1)	higher (-2.7)	higher (11.8) to average (3.5)	lower (-13.6)
Pebble content	higher (13.3)	lower (-11.4)	average (3.4)	higher (-2.8)	lower (5.3)	higher (-7.0)
Soil depth	50 cm (14.2)	80 cm (-13.0)	50 to 80 cm (3.3)	50 cm (- 2.7)	80 cm (5.4)	50 cm (- 6.6)

©Vigne et Vin Publications Internationales (Bordeaux, France)

Table Ib - Modalities and tests values statistically significant obtained by multiple component analysis (MCA) of the natural variables of the terroir associated with the other environments and obtained by survey of the vine growers.

Modalités et valeurs tests statistiques significatives issues d'une analyse en composantes multiples concernant les variables naturelles du terroir associées aux autres milieux et obtenues par enquête auprès des vignerons.

	Other environments							
	Clays (424 plots)		Superficial deposits (317 plots)		Clayed silts from the Quaternary (470 plots)		Colluvial formations (303 plots)	
	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities
Period of sunshine	------	-------	average (3.5)	higher (-3.3)	lower (3.9) to average (10.7)	higher (-12.2)	lower (5.3)	------
Fog frequency	lower (2.9)	average (-4.7)	-------	-------	average (3.0) to lower (3.3)	higher (- 8.3)	higher (6.1)	lower (-3.3)
Wind velocity	------	------	-------	-------	average (6.4)	lower (-4.5)	lower (6.3)	higher (-6.7)
Soil temperature	lower (4.3) to average (3.7)	higher (-7.5)	higher (3.37)	lower (-3.0)	average (5.2) to lower (11.1)	higher (-13.5)	lower (5.0)	higher (-3.1)
Air temperature	average (4.8)	higher (-6.5)	-------	-------	average (6.4) to lower (6.7)	higher (-11.4)	lower (2.6)	-------
Soil moisture content	higher (3.1)	lower (-4.4)	lower (2.6)	-------	higher (9.9)	lower (-11.1)	higher (6.3)	lower (-3.3)
Pebble content	lower (3.4)	higher (-3.1)	-------	-------	lower (9.2)	average (5.2) to higher (-6.1)	lower (3.6)	-------
Soil depth	80 cm (4.3)	50 cm (- 4.3)	80 cm (2.5)	50 cm (- 4.1)	80 cm (8.4)	50 cm (-4.5)	------	------

dominant Southwest winds and 1318 hours of sunshine between April and September (MORLAT, 1989).

These climatic conditions are favourable to vine-growing and to the production of different types of wines. The main cultivars are: *Vitis vinifera* cv. Chenin which produces dry and dessert style white wines (named Coteaux de l'Aubance, Coteaux du Layon, Coteaux du Layon - villages, Bonnezeaux and Quarts de Chaume), *Vitis vinifera* cv. Cabernet franc and *Vitis vinifera* cv. Cabernet Sauvignon used to produce red and rosé wines, but also *Vitis vinifera* cv. Grolleau used for rosé wines.

II – STUDY OF THE TERROIRS BY MEANS OF A SURVEY OF THE VINE GROWERS

1 - Protocol

A systematic survey (THELIER-HUCHE and MORLAT, 2000) of the vine-growers from 18 vine-producing rural districts of the Anjou region was performed at the plot scale by means of a questionnaire including the following points:

- Direct perception by the vine-grower of the natural factors of the terroir: pedological characteristics (soil depth, texture and colour, pebble content), pedo-climatic (soil moisture content and temperature) and climate (air temperature, wind velocity, risks of frost, fog frequency). For variables such as pebble content and depth of the soil, the survey concerned only 12 rural districts.

- Indirect perception by the vine- grower of the natural factors of the terroir, through the behaviour of the vine: earliness of budbreak, vigor of the vine, vegetative development in dry year and in average year, susceptibility to diseases, and capacity of over ripening of the plot.

The survey included questions with closed answers, generally with three modalities of answer for each variable studied (lower than average, on average, higher than average) and questions with opened answers (characterization of the soil, vine production potential of the plot, sensory characteristics of the wine).

The survey was conducted in parallel with the characterization and zoning of BTU, between 1995 and 1999. A total of 380 vine growers were surveyed. The survey unit was the plot of land, the cadastral coordinates of which allowed to place it geographically, according to a geographic information system (G.I.S.). Neither the investigator, nor the vine grower, knew at the time of the survey one or several BTU of the plot concerned.

©Vigne et Vin Publications Internationales (Bordeaux, France)

Table IIa - Modalities and test values statistically significant obtained by multiple component analysis (MCA) of the variables relative to the vine behaviour associated with each soil environment of the field model and obtained by survey of the vine growers.

Modalités et valeurs tests statistiques significatives issues d'une analyse en composantes multiples concernant les variables relatives au fonctionnement de la vigne associées à chaque milieu sol du modèle de terrain et obtenues par enquête auprès des vignerons.

	Soil environments obtained by the pedological field model for soil study					
	Rock (2587 plots)		Alteration (2623 plots)		Alterite (1279 plots)	
	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities
Frost risk	higher (9.0)	lower (-7.2)	lower (2.7)	average (- 2.5)	lower (4.4)	higher (-6.1)
Budbreak earliness	higher (17.7)	lower (-12.5)	------	higher (-3.1)	lower (7.1) to average (7.1)	higher (-12.5)
Vine vigour	lower (10.1) in average (3.3)	higher (-11.9)	------	------	higher (7.7)	lower (-7.1) to average (-2.4)
Leaf development in average year	lower (6.1) to average (2.6)	higher (-5.8)	------	lower (-2.8)	higher (3.9)	average (-2.6) to lower (-4.0)
Leaf development in dry year	lower (11.5)	higher (- 8.2) to average (- 4.3)	average (2.8)	lower (-4.8)	average (5.2) to higher (3.3)	lower (-8.2)

Table IIb - Modalities and tests values statistically significant obtained by multiple component analysis (MCA) concerning the variables relative to the vine behaviour associated with the other environments and obtained by survey of the vine growers.

Modalités et valeurs tests statistiques significatives issues d'une analyse en composantes multiples concernant les variables relatives au fonctionnement de la vigne associées aux autres milieux et obtenues par enquête auprès des vignerons.

	Other environments							
	Clays (424 plots)		Superficial deposits (317 plots)		Clayed silts from the Quaternary (470 plots)		Colluvial formations (303 plots)	
	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities
Frost risk	average (4.4)	lower (-2.4)	average (4.8)	higher (-3.3)	lower (8.3)	higher (-8.4)	higher (7.6)	lower (-4.9)
Budbreak earliness	average (5.3)	higher (-5.8)	higher (3.1)	lower (-4.1)	lower (9.6)	higher (-7.6)	lower (4.7)	------
Vine vigour	higher (4.1)	lower (-3.7)	------	higher (-2.8)	higher (7.3)	average (-2.8) to lower (-5.6)	higher (3.5)	average (-3.0)
Leaf development in average year	------	lower (-3.2)	average (2.8) to lower (3.7)	higher (-4.4)	higher (3.6)	lower (-2.3)	higher (3.3)	average (-2.8)
Leaf development in dry year	higher (3.0)	lower (-2.9)	lower (7.2)	average (-3.5) to higher (-3.7)	higher (6.3)	lower (-4.9)	higher (3.8)	average (- 2.6)

2 - Data processing

Several BTU coexisted frequently in the same plot. To analyze precisely the perception and the valorization of the terroir by the vine grower, only the plots were retained (among 8006) in which the dominant BTU occupied at least 50 percent of the surface. Data from the survey were compared to those obtained from the characterization of the natural factors of the BTU.

Data from both the survey and the characterization were processed at the same time using a system of geographic information (G.I.S. Alliance and database ACCESS of Microsoft) (BOLO *et al.*, 1996) and analyzed by one-variable sorting, multivariate breakdown and factorial analysis [Multiple Correspondence Analysis (MCA)] using the SPAD software.

In the MCA, test values (similar to the absolute value of one normal variable centered and reduced) allowed us to isolate the variables significantly (at p £ 0.05) associated (test value > 1.96) or opposed (test value <-1.96) to a given environment or BTU. The higher the association or the opposition of a variable,

©Vigne et Vin Publications Internationales (Bordeaux, France)

Table IIIa - Modalities and test values statistically significant obtained by multiple component analysis (MCA) of the natural variables of the terroir associated with the soil environment and obtained by survey of the vine growers; grouped by direct hierarchical classification.

Modalités et valeurs tests statistiques significatives issues d'une analyse en composantes multiples concernant les variables naturelles du terroir associées aux milieux sol et obtenues par enquête auprès des vignerons ; regroupés par classification hiérarchique directe.

	Categories of soil environments obtained by direct hierarchical classification							
	Rock + superficial deposits (2904 plots)		Alterite + clays + clayed silts from the Quaternary (2173 plots)		Colluvial formations (303 plots)		Alteration (2623 plots)	
	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities
Period of sunshine	higher (13.6)	lower (-5.9) to average (-11.8)	lower (4.3) to average (15.7)	higher (-17.1)	lower (5.3)	------	higher (3.0)	average (-2.5)
Fog frequency	------	lower (-2.7)	lower (2.9) to average (4.3)	higher (-9.9)	higher (6.1)	lower (-3.3)	higher (3.9)	average (-5.3)
Wind velocity	higher (8.5)	average (- 9.7)	average (10.6)	higher (-6.6)	lower (6.3)	higher (-6.7)	------	------
Soil temperature	higher (25.0)	lower (-20.7)	lower (19.3)	higher (-23.0)	lower (5.0)	higher (-3.1)	average (2.9)	higher (-3.1)
Air temperature	higher (17.3)	lower (-4.3) to average (-14.7)	lower (6.5) to average (15.5)	higher (-20.3)	lower (2.6)	------	------	lower (-3.1)
Soil moisture content	lower (22.2)	higher (-18.7)	higher (17.3)	lower (-19.3)	higher (6.3)	lower (-3.3)	average (5.1)	higher (-2.7)

Table IIIb - Modalities and test values statistically significant obtained by multiple component analysis (MCA) of the natural variables of the terroir associated with the soil environment and obtained by survey of the vine growers; grouped by direct hierarchical classification.

Modalités et valeurs tests statistiques significatives issues d'une analyse en composantes multiples concernant les variables relatives au fonctionnement de la vigne associées aux milieux sol et obtenues par enquête auprès des vignerons ; regroupés par classification hiérarchique directe.

	Categories of soil environments generated by direct hierarchical classification							
	Rock + superficial deposits (2904 plots)		Alterite + clays + clayed silts from the Quaternary (2173 plots)		Colluvial formations (303 plots)		Alteration (2623 plots)	
Wind velocity	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities
Frost risk	higher (7.5)	lower (-7.8)	lower (7.7)	higher (-10.5)	higher (7.6)	lower (-4.9)	lower (2.7)	average (- 2.5)
Budbreak earliness	higher (18.6)	lower (-13.7)	lower (12.1)	higher (-16.9)	lower (4.7)	------	------	higher (-3.1)
Vine vigour	lower (10.6)	higher (-12.7)	higher (12.3)	lower (-10.5)	higher (3.5)	average (-3.0)	------	------
Leaf development in average year	lower (7.6)	higher (-7.5)	higher (6.1)	lower (-5.8)	higher (3.3)	average (- 2.8)	------	lower (-2.8)
Leaf development in dry year	lower (14.3)	higher (-9.5)	higher (7.6) to average (4.4)	lower (-10.8)	higher (3.8)	average (- 2.6)	average (2.8)	lower (-4.8)

the higher the absolute value of the test value. In the tables of results the significant modality and its test value are presented in front of each variable and for each environment of the model.

Besides, a classification was made on factors issued from the MCA of Burt's sub-table. A hierarchical classification (SPAD 4.5 software, CISIA) was used, which means that calculations (algorithm of the mutual neighbours) were made on the factorial coordinates of a preliminary analysis and used Ward's aggregation criterion. A criterion of aggregation is a criterion by which one can decide that two individuals will be clustered within the same class or will be separate. The principle of Ward's criterion consists in maximizing the interclass inertia of the partition found (that is to say, maximi-

©Vigne et Vin Publications Internationales (Bordeaux, France)

Table IV – Soil depth in the different environments obtained by survey and cartography.

Profondeur de sol des différents milieux obtenues par enquête et cartographie

Method	Survey	Cartography	
Environments	Soil depth (cm)	Test value	Soil depth (cm)
Clays	More than 80 cm	4.3	120
Alterite	More than 80 cm	5.4	105
Superficials deposits of Cenomanian	More than 80 cm	2.5	100
Silts of the Quaternary	More than 80 cm	8.4	100
Alteration	50 – 80 cm	3.3	80
Rock	Less than 50 cm	14.2	35
Colluvial formations	N C	<1.96	90

Table Va - Modalities and test values statistically significant obtained by multiple component analysis (MCA) of the variables of characterization of the model environments.

Modalités et valeurs tests statistiques significatives issues d'une analyse en composantes multiples concernant les variables de caractérisation des milieux du modèle.

	Soil environments obtained by the pedological field model for soil study					
	Rock		Alteration		Alterite	
	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities
Altitude	[50-70 m] (10.0)	----	[50-70 m] (12.7)	---	[50-70 m] (10.0)	----
Slope	average (4.7)	----	----	----	small to null (6.2)	high (-3.5)
Opening of landscape	averagely open (6.2) to open (3.1)	closed (-5,2)	averagely open (7.3)	----	----	open (-7.9)
Soil depth	< 40 cm (12.2)	70 cm and + (-7.2)	[60-100 cm] (10.4)	----	> 100 cm (11.3)	< 40 cm (-15.9)
Pebble content	average to higher (12.9)	lower (-6.2)	average to lower (5.2)	higher (-6.5)	average to lower (10.6)	higher (-10.2)
Soil drainage	favourable (14.3)	lower (-5.3)	imperfect (6.3)	----	lower (9.2)	favourable (-8.6)
SWR	lower (35.3) to average (6.4)	higher (-5.0)	average (6.2)	----	higher (40.5)	lower (-10.5)
EPT	normal to higher (10.2)	----	----	----	normal (8.5) to lower (5.2)	higher (-10.2)
VPT	average to lower (5.3)	higher (-5.2)	higher (5.2)	----	higher (10.1)	lower (-5.1)

zing the Euclidian distance between two individuals from two different groups) which comes to minimize the distance separating grouped individuals (LEBART *et al.*, 1995). A tree of hierarchical aggregation, or dendogramme, is then produced.

III - THE NETWORK OF EXPERIMENTAL PLOTS

In order to compare the answers of the vine growers to direct measures on the field, a network of experimental plots was installed. Three plots of each of the model environments planted with the Chenin variety were selected among the Anjou vineyard.

The vines were aged between 15 to 25 years. In each plot, on 30 plants of vine, budburst earliness was notated during three years (2000, 2001, 2002).

RESULTS

I - PERCEPTION BY THE VINE GROWERS OF THE CHARACTERISTICS OF THE DIFFERENT TERROIR UNITS

Statistically, the vine growers perceived differently the three environments obtained by the pedological field model which are characterized by several soil variables (tables I and II).

The Rock environment was associated with a pebble content higher than average (tv = 13.3) and a depth lower than 50 cm (tv = 14.2). It was also associated with a soil temperature higher than average (tv = 24.3) opposed to a temperature in the average or lower than average, a soil moisture content lower than average (tv = 21.6) opposed to a moisture content higher than average (tv =-19.1). This environment was associated with

©Vigne et Vin Publications Internationales (Bordeaux, France)

Table Vb - Modalities and tests values statistically significant obtained by multiple component analysis (MCA) of the variables of characterization of the environments different from those of the model.

Modalités et valeurs tests statistiques significatives issues d'une analyse en composantes multiples concernant les variables de caractérisation des milieux autres que ceux du modèle

	Other environments							
	Clays		Superficial deposits		Clayed silts from the Quaternary		Colluvial formations	
	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities	Associated modalities	Opposite modalities
Altitude	[50-70 m] (6.0)	----	[50-70 m] (6.0)	----	[50-70 m] (9.0)	----	[30-50 m] (14.2)	---
Slope	small to null (12.2)	high (-10.5)	average (3.0)	----	small to null (5.3)	----	small to null (4.2)	----
Opening of landscape	----	open (-5.9)	open (5.5)	----	averagely open (5.2)	----	closed (9.9)	----
Soil depth	> 100 cm (16.3)	< 40 cm (-17.0)	60 to 100 cm (8.9)	70 cm and + (-5.1)	60 to 100 cm (10.9)	< 40 cm (-11.1)	60 to 100 cm (6.2)	----
Pebble content	lower (12.8)	+ higher (-15.2)	average to higher (11.1)	lower (-3.8)	average to lower (7.2)	----	average (5.1) to lower (4.2)	higher (-6.5)
Soil drainage	lower (11.2)	favourable (-12.0)	imperfect (10.3)	----	lower (8.4)	Favourable (-10.6)	low (5.3)	----
SWR	higher (51.6)	lower (-18.6)	lower (8.9)	----	lower (5.6)	----	average to higher (5.8)	----
EPT	average (10.2) to lower (6.1)	higher (-11.4)	average to higher (8.1)	----	average (5.2) to lower (3.4)	higher (-7.6)	----average to lower (5.6)	----
VPT	----	----	average to lower (3.1)	----	higher (3.4)	lower (-2.7)	higher (6.3)	----

an air temperature higher than average (tv = 18.1) opposed to an air temperature lower than average, and a higher wind velocity(tv = 9.0). One can also note a risk of fog (tv = 3.0) and a period of sunshine (tv = 15.5) longer than average.

The survey showed that climatic conditions actually result in a budbreak earliness higher than average (tv = 17.7), a higher risk of frost (tv = 9.1) and a vigour lower than average (tv = 10.1). In this environment, vines can be subject to water deficit, because leaf development in average year, as in dry year, was scored lower than average (respectively tv = 6.1 and 11.5).

The Alteration environment was the most difficult to characterize, because of its intermediate position. It is characterized by an average pebble content (tv = 3.3) and a soil depth ranging between 50 and 80 cm (tv = 3.3). It is associated with a soil moisture content (tv = 5.1) and temperature in the average (tv = 3.0) opposed to a higher moisture content of the soil (tv =-2.7) and to a lower soil temperature (tv= -3.1). There is a fog frequency (tv = 4.0) and a period of sunshine (tv= 3.1) higher than average. It can be noticed that test values of the various variables, although significant, are less high, which underlines the less good characterization of the Alteration environment.

The Alterite environment is perceived much more clearly by the vine-growers. It is associated with a lower pebble content than average (tv = 5.3) and a soil depth of more than 80 cm (tv = 5.4). It is defined by a soil temperature lower than average (tv = 12.8), a soil moisture content higher than average (tv = 11.8) and an air temperature in the average (tv = 11.8). To these modalities are opposed a soil temperature higher than average (tv =-15.1), a soil moisture content lower than average (tv= -13.6) and an air temperature higher than average (tv=- 13.8).

The survey showed that climatic conditions have an effect at the plant level as shown by a lower budbreak earliness than average (tv = 7.1), in the average (tv = 7.1) and a lower risk of frost (tv = 4.4), opposed to a higher precocity (tv =-12.5) and a high risk of frost (tv= -6.1). While the Rock environment is associated with a wind velocity higher than average, the Alterite environment is opposed to it (tv=- 4.6). Vigour is higher than average in the Alterite environment (tv= 7.7). Moreover, water availability should not be limited, since leaf development was scored higher than ave-

©Vigne et Vin Publications Internationales (Bordeaux, France)

rage in average year (tv= 3.9) and in the average (tv= 5.2) in dry year.

Clays are associated with a pebble content lower than average (tv = 3.4) and a soil depth of more than 80 cm (tv = 4.3). They are characterized by a soil temperature lower than average (tv = 4.3) opposed to a higher soil temperature (tv =-7.5), a soil moisture content higher than average (tv = 3.1) opposed to a lower soil moisture content (tv = -4.4), and an air temperature higher than average (tv = - 6.5).

Consequences at for the plant are an average risk of frost (tv = 4.4), an opposition to an early budbreak higher than average (tv =-5.8) and a higher vigour (tv = 4.1). Leaf development in dry year is higher than average (tv = 3.0), and there seems to be no problem of water supply to the vine.

Superficial deposits of Cenomanian are poorly defined by the variables of the survey. They are only associated with a soil water content lower than average (tv = 2.6), and a soil temperature higher than average (tv = 3.4).

A vine planted on these soils will present an average risk of frost (tv = 4.8) and a budburst precocity higher than average (tv = 3.1), in opposition to a high risk of frost (tv =-3.3) and a budbreak earliness lower than average (tv= -4.1). We will also note a development in dry year lower than average (tv= 7.2) and average to lower in average year (tv= 2.8 and 3.7, respectively).

The silts of the Quaternary are characterized by a pebble content lower than average (tv = 9.2) and a soil depth of more than 80 cm (tv = 8.4). They are also associated with a soil temperature in the average (tv = 5.3) to lower than average (tv = 11.1) in opposition to a higher soil temperature (tv =-13.6). Their soil moisture content seems to be higher (tv= 9.9) in opposition to a soil moisture content lower than average (tv= -11.1), an air temperature in the average (tv= 6.4) to lower (tv= 6.7) in opposition to a higher air temperature (tv=- 11.4) and a wind velocity in the average(tv= 6 .4) in opposition to a wind velocity lower than average (tv=-4.5).

Consequences for the plant are a risk of frost lower than average (tv = 8.3) and a budbreak earliness lower than average (tv = 9.6). We can also note a vigour higher than average (tv= 7.3). Leaf development in dry year as well as in average year is higher than average (tv= 3.6 and 6.3, respectively) which indicates that water supply is not limited.

The colluvial formations are defined by a soil moisture content higher than average (tv = 6.3), a wind velocity lower than average (tv = 6.3) in opposition to a wind velocity higher than average (tv =-6.7), and they are associated with a soil temperature lower than average (tv= 5.0).

Consequences for the plant are a high risk of frost (tv = 7.6), a precocity lower than average (tv = 4.7) and a vigour higher than average (tv = 3.5). Vines growing on these soils do not seem to face water deficit, leaf development in average year as in dry year, being higher than average (tv = 3.3 and 3.8, respectively).

II - APPROACH OF THE ENVIRONMENTAL PERCEPTION USING A GROUPING (CLUSTERING) BY HIERARCHICAL CLASSIFICATION METHOD

The hierarchical classification made using the SPAD 4.5 software was applied to the previous seven environments. It allows to study the characters common to different environments and to generate automatically homogeneous groups associated with very significant variables of characterization.

The tree obtained by hierarchical classification is shown in figure 3. Division of the tree into an optimal number shows 4 different clusters (table III):

- The first cluster includes the Rock and superficial deposit of Cenomanian environments. It is associa-

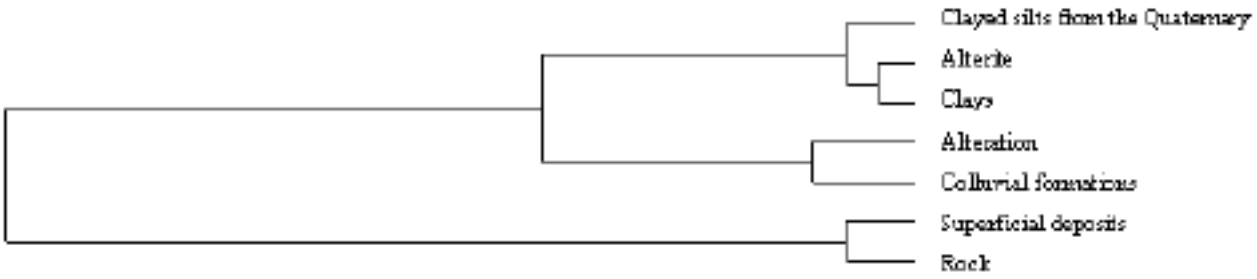

Fig. 3 - Tree of partitions

Arbre des partitions

©Vigne et Vin Publications Internationales (Bordeaux, France)

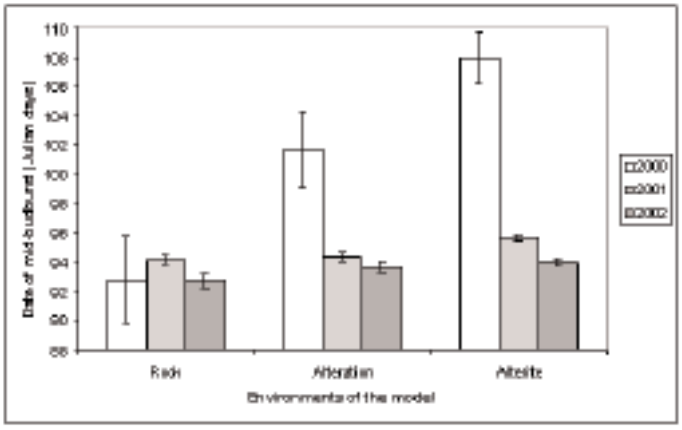

Fig. 4 - Date of mid-budburst of the vine in the three environments (rock, alteration, alterite)

Date de mi-débourement dans les trois milieux (roche, altération, altérite)

ted with a period of sunshine higher than average (tv = 13.7), opposed to a lower to average period of sunshine (tv =-5.9 and 11.8, respectively), also associated with a wind speed higher than average (tv = 8.5), a higher soil temperature (tv= 25.0), a higher air temperature (tv= 17.3) and a soil moisture content lower than average (tv= 22.2). Consequences for the plant are a risk of frost higher than average (tv= 7.5), a budbreak earliness higher than average (tv= 18.6), and a lower vigour (tv= 10.6). In this type of environment, the vine can face water deficit as shown by a leaf development lower than average in average year (tv= 7.6) as in dry year (tv= 14.3).

- The second cluster represents the Alteration environment.

- The third cluster represents the colluvial formations.

- The fourth cluster represents the Alterite, Clays, and silts of the Quaternary environments. This cluster is characterized by a lower to average period of sunshine (tv = 4.3 and 15.7, respectively), a wind speed in the average (tv = 10.6), a soil temperature lower than average (tv = 19.2), an air temperature from lower (tv = 6.5) to average (tv = 15.5) and a soil moisture content higher than average (tv = 17.3).

For the plant, the risk of frost is lower (tv = 7.7), the budbreak earliness is lower than average (tv = 12.1), and the vigour higher than average (tv = 12.3). The vine seems to have a non limited water supply, since this group of environments is associated with a leaf development modality in dry year higher than average (tv = 7.6).

III – DIRECT VALIDATION OF THE VINE GROWERS' ANSWERS, COMPARING TO MEASURES IN THE FIELD

To verify the viability of such an approach, we have compared data obtained in the field by cartography and the answers of the vine growers.

The adequation between values of soil depth obtained by each of the methods are very good (table IV).

The Rock environment is perceived with a soil depth of less than 50 cm and the average soil depth measured is 35 cm. It is the same for the alteration environment (50 to 80 cm ; 80 cm). The other environments (Alterite, clays, superficials deposits of Cenomanian, silts of the Quaternary and colluvial formations) are described by the vine grower with a soil depth of more then 80 cm, which correspond to the depth measured in the field.

The behavior of the vine observed with the network of experimental plots is the same that the one described by the vine growers (table II). The budburst earliness is higher in the rock environment than in the altérite one (figure 4). The vine in the alteration environment had an intermediate behavior.

DISCUSSION - CONCLUSION

Results presented above show the relevance of a survey of the vine-growers at the plot scale to characterize vine behaviour in various «terroirs». Indeed, results from the survey were consistent with those obtained by the characterization in the field (table V).

Thus, in the case of the Rock environment, the «terroir» characterization showed an association between an average slope, a soil depth lower than 50 cm and a high pebble content. These characteristics result in a favorable drainage, a low field water capacity (52 mm on average), a score of earliness potential of the «terroir» (EPT) normal to high and a score of vigour potential of the «terroir» (VPT) average to low. Results from the survey also showed that the Rock environment was associated with a budbreak earliness higher than average, a vigour potential lower than average and a leaf development of vine in dry or average year lower than average (associated with limited water supply to the vines).

This was confirmed by already known relations between the budbreak earliness and vigour potential variables, and certain soil factors (CARBONNEAU *et al.*, 1992). So, vine precocity appears to be related to the air and soil temperature. It is thus dependent on the climatic conditions of the year, through the sum

©Vigne et Vin Publications Internationales (Bordeaux, France)

of temperatures of the air but also of the soil, in connection with the mesoclimate and the thermal pedoclimate of the plot (De KOCHKO and CURMI, 1985 ; MORLAT, 1989). The two major constituents of the pedoclimate are the temperature and moisture content of the soil. The soil warming largely depends on its moisture content. Likewise, water and mineral supply, highly affect the vigour of the vine (GALET, 1993; Van LEEUWEN et SEGUIN, 1994). We noticed that the Rock environment, was related to a budbreak earliness higher than average, as well as to a vigour lower than average. The Alterite environment with opposite characteristics was characterized by a lower earliness and a vigour higher than average.

The consistency between the results of the survey and the hypotheses underlying the model seems to be confirmed for the budbreak earliness variable: an earliness higher than average corresponds to a warmer and drier soil and to a higher air temperature, whereas a lower earliness is associated with a colder and wetter soil and an air temperature lower than average. An environment with a lesser soil depth lead to a warmer pedoclimate.

Our hypotheses concerning the ecophysiological behaviour of the vine in the different environments generated by the pedological field (figure 1) model were confirmed by the survey. For example, the Rock environment, for which limited water supply, lower vigor and higher precocity of vine had been hypothesized was characterized in the survey by a warmer climate, a soil drier and warmer than the average, an earliness of the vine higher, a higher risk of frost and a wind velocity higher than average. The same consistency was obtained with the Alterite environment. As for the Alteration environment, because of its intermediate position, it remained very difficult to characterize.

The direct hierarchical classification allowed to distribute the various environments into four groups of «terroirs», as regards the variables relative to natural factors (temperature, moisture content…) instead of seven. This grouping allows to refine the characterization of the environment obtained by the survey. We obtained higher test values and new modalities of variables appeared. Characterization in the field led to the same categories for these variables. Grouping the «terroirs» according to the variable, showed that the partition of the various environments according to the modalities of the variables cannot be performed in the same way with all the variables (table V).

Some of them can be grouped such as the Opening of landscape and the altitude, but colluvial formations are totally different from the other environments. This could indicate that the Opening of Landscape is not very discriminant. This partition was not observed for the behavioural variables which suggests that, in our case, the range of variation of the Opening of landscape and the altitude variables was not sufficient to influence the plant behaviour.

Our results show that an approach combining a survey and a field study to characterize viticultural «terroirs» and their effects on vine can replace an experimental network of plots, provided that an approach based on qualitative instead of quantitative variables is sufficient. The hypotheses concerning the vine behaviour in the various environments of the model are confirmed; this behaviour was also studied in the other environments. Soil depth is a major component of terroir. When soil depth is limited (rock environment), the water availability is reduced, the vigor of vine is decreased and the quality of the product is enhanced. When the soil depth is higher (altérite), water supply is better and vigor too, which induced lesser quality of berries.

After grouping, the three main environments (Rock, Alteration and Alterite) are in different groups, associated with other environments whose modalities of characteristic variables are close to them. It can be concluded that grouping the environments is possible in case of direct use of the method by the vine grower. This grouping could constitute a means of alleviating the method.

The adaptation of vine-growing and enological practices and the valorization of the “terroirs” will be the dealt with in a second paper.

Acknowledgements : The authors gratefully thank the Fédération des Syndicats viticoles de l’Anjou, the MNRT and Interloire for their financial support.

BIBLIOGRAPHY

BOLO P., MORLAT R. et RIOUX D., 1996. Un système d'informations à références spatiales sur le vignoble. Un outil performant d'aide aux recherches sur la caractérisation des terroirs viticoles. Actes du 1er coll. int. sur les terroirs viticoles. Angers, 113-121.

CARBONNEAU A., RIOU C., GUYON D ., RIOM J. et SCHNEIDER C. 1992. Agrométéorologie de la vigne en France. INRA. Office des publications officielles des communautés européennes.

DELOIRE A., CARBONNEAU A., OJEDA H., SILVA P., KRAEVA E., JACQUET O. et ANDARY C. 2001.Relations entre l’état hydrique de la vigne et les composés phénoliques de la baie de raisin des cépages Syrah et Grenache Noir. Proposition de principes de ges-

©Vigne et Vin Publications Internationales (Bordeaux, France)

tion de la végétation. 12e journées GESCO, Montpellier, 3-7 juillet 2001. Vol 1 : 253-258.

DE KOCHKO P. et CURMI P., 1985. Porosité et comportement thermique des sols d'un vignoble d'anjou. *Science du Sol*, **3**, 169-174.

DREIER L.P., STOLL G.S. et RUFFNER H.P. 2000. Berry ripening and evapotranspiration in *Vitis vinifera* L. *Am. J. Enol. Vitic.*, **51**, 4, 340-346.

DUMAS V. LEBON E. et MORLAT R., 1997. Différenciation mésoclimatique au sein du vignoble alsacien. *J. Int. Sci. Vigne Vin*, **31**, 1, 1-9.

GALET P. 1983. *Précis de viticulture* (4e edition). Montpellier : Déhan, 584 pp.

GUILBAULT P., MORLAT R. et RIOUX D., 1998. Elaboration de cartes-conseil pour une gestion du terroir à l'échelle parcellaire. Utilisation d'algorithmes basés sur des paramètres physiques du milieu naturel. *Actes du 2e coll. int. sur les terroirs viticoles*, Sienne, Italie, 19-24 mai. 741-751.

LEBART L., MORINEAU A. et PIRON M., 1995. *Statistique exploratoire multidimensionnelle*. Paris : Dunod, 439 p.

MATTHEWS M.A. and ANDERSON M.W. 1988. Fruit ripening in *Vitis vinifera* L. : response to seasonal water deficits. *Am. J. Enol. Vitic.*, **39**, 313-20.

MORLAT R., 1989. Le terroir viticole : contribution à l'étude de sa caractérisation et de son influence sur les vins. Application aux vignobles rouges de la moyenne vallée de la Loire. *Thèse* Doc. Etat, Université de Bordeaux II.

MORLAT R., 2001. *Terroirs viticoles : étude et valorisation*. Chaintré : Oenoplurimédia (2001)b, 118 p.

MORLAT R., 1998. Les relations entre le terroir, la vigne et le vin. *C.R. Acad. Agric. Fr*., **2**, 19-32.

RIOU C., MORLAT R. et ASSELIN C., 1995. Une approche intégrée des terroirs viticoles. Discussions sur les critères de caractérisation accessibles. *Bull. O.I.V.*, **767**/**768**, 94-106.

SALETTE J., 1997. La typicité : une notion nouvelle au service du produit, de ceux qui l'élaborent et de ceux qui le consomment en l'appréciant. *Rev. Œnol*., **85**, 11-13.

SALETTE J., ASSELIN C., & MORLAT R., 1998. Le lien du terroir au produit : analyse du système terroir-vigne-vin ; possibilité d'application à d'autres produits. *Sci. aliments*, **18**, 251-265.

SCHWARZ R.,1997. Predicting wine quality from terrain characteristics by regression trees. *Cybergeo*, n° 35, 9 p.

THELIER-HUCHE L et MORLAT R.2000. Perception et valorisation de facteurs naturels du terroir par les vignerons d'Anjou. *J. Int. Vigne. Vin*, **34**, 1, 1-13.

VAN LEEUWEN C. et SEGUIN G. 1994. Influences 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-Émilion 1990). *J. Int. Sci. Vigne Vin*, **28**, 2, 81-110.

Manuscrit reçu le 25 juillet 2003 ; accepté pour publication le 6 octobre 2003

 ©Vigne et Vin Publications Internationales (Bordeaux, France)