A WORLDWIDE PERSPECTIVE ON VITICULTURAL ZONING
UNE PERSPECTIVE MONDIALE DU ZONAGE VITICOLE

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Acknowledgments: The author wishes to express her gratitude to the Committee of the joint SASEV/Terroir Zoning/GESCO Conference, held in Cape Town, South Africa, for encouraging this work.

Keywords: terroir, viticultural zoning, worldwide perspective, scale

Abstract
This article reviews viticultural zoning concerns and issues in a worldwide perspective. In every vineyard in the world, zoning is needed and corresponds to varied applications, definitions and approachs. Zoning aims have been changing together with the needs of the ever-expanding international wine market. There are more and more wine-producing regions and countries involved in zoning studies, and although many of the corresponding works were initiated in Europe, zoning needs go far beyond the countries endowed with centuries-old viticultural history. Demarcating registered designations of origin or protected geographical indications is one of the most obvious of all zoning aims, which originates from the XIXth century in Europe, and now addresses most recent wine-growing countries. Other important zoning aims, not necessarily related to demarcating operations, consist in segmentating a vineyard territory into homogeneous units that are likely to be consistent with either pest management, reparcelation, vineyard restructuring operations, grape harvest quality management, or site selection for new vineyards.
The homogeneous units obtained through viticultural zoning are frequently referred to as '*terroirs*'; however their scale, characteristics, materials and methods may greatly vary depending on authors and vine-growing regions, making international zoning comparisons uneasy. Viticultural zoning can actually be separated into 2 main groups: on the one hand, that insisting on the geographical differentiation of wines, grapes, or plant characteristics; on the other hand, that focused on the geographical differentiation of land capabilities or vineyard suitabilities, for which soil and climate are mostly referred to as key variables, but with varied significations and the use of distinct soil classifications.
Viticultural zoning is not always synonymous with mapping and spatial analysis: this is changing through the enhanced use of geomatics. Digital mapping methods and remote sensing techniques are renewing viticultural zoning at all scales, from plot to region. Suitabilities approaches at the field scale or local level, including precision viticulture, are mostly directed towards the understanding of plant ecophysiological functioning. At the global or regional scale, encompassing wider areas, suitabilities approaches are oriented towards the characterization of land geographical patterns and face the problem of relating these patterns to sample sites described at the field scale. Spatial analysis criteria, including spatial extent, resolution, map scale, sampling design, all together with duration criteria, tools, validation, plant varieties and training systems are likely to enable zoning comparisons at the international level. Some examples are given in this paper.

Résumé:
Cet article répertorie les intérêts et problèmes du zonage viticole dans une perspective mondiale. Le zonage est un besoin pour chacun des vignobles mondiaux où il correspond à des applications, définitions et approches variées. Les objectifs du zonage changent de concert avec les besoins du marché mondial du vin, qui ne cesse de croître. De plus en plus de régions et de pays viticoles sont impliqués dans les études de zonage, et bien qu'un grand nombre des travaux correspondants aient été initiés en Europe, les besoins en zonage vont bien au delà des pays dotés d'une longue histoire

viticole. La délimitation des Appellations d'Origine Contrôlée ou des indications géographiques protégées est l'un des objectifs, parmi tous ceux du zonage, le plus patent, qui remonte à la fin du XIX^{e} siècle en Europe, et concerne à présent les pays les plus récemment viticoles. D'autres objectifs importants, non nécessairement reliés aux opérations de délimitation, consistent en la segmentation d'un territoire viticole en portions homogènes susceptibles de coïncider avec la gestion des maladies, le remembrement, la restructuration du vignoble, la gestion de la qualité des vendanges, ou encore le choix de sites nouveaux pour l'implantation de vignobles.
Les unités homogènes obtenues à travers le zonage viticole sont fréquemment désignées sous le nom de « terroirs », néanmoins leurs échelon spatial, caractéristiques, matériels et méthodes d'obtention diffèrent notablement selon les auteurs et les régions viticoles, ce qui rend les comparaisons inaisées entre les zonages au niveau mondial. Le zonage viticole peut en réalité être dissocié en 2 principaux groupes : d'un côté, celui insistant sur la différenciation géographique des vins, des raisins ou de caractéristiques de la plante ; de l'autre, celui focalisé sur la différenciation géographique des aptitudes des terres ou des potentialités viticoles, pour lesquelles le sol et le climat sont le plus souvent invoqués en tant que variables clés, mais avec des significations variées et différents référentiels taxonomiques de sols.
Le zonage viticole n'est pas toujours synonyme de cartographie et d'analyse spatiale : cela est en train de changer à travers l'essor de la géomatique. Les méthodes de cartographie numérique et les techniques de télédétection renouvellent le zonage viticole à tous les échelons, de la parcelle à la région. Les approches de potentialités à l'échelon parcellaire ou local, y compris la viticulture de précision, sont pour la plupart dirigées vers le fonctionnement écophysiologique de la plante. A l'échelon global ou régional, qui recouvre des surfaces plus étendues, ces approches sont surtout focalisées vers la caractérisation des motifs d'organisation spatiale et se heurtent au problème de la mise en relation de ces motifs avec les sites échantillonnés à l'échelon de la parcelle. Les critères d'analyse spatiale, incluant le champ spatial, la résolution, l'échelle, le schéma d'échantillonnage, de même que les critères de durée, d'outils, de validation, de cépages et de modes de conduite, sont à même de permettre les comparaisons de zonages à l'échelon mondial. Quelques exemples sont donnés dans l'article.

Introduction

In 1996 in Angers (France), occured one of the earliest international events focused on identification and study of 'terroirs' and enabling to evaluate the importance of 'terroir' worldwide: it was the first international conference entitled 'Viticultural terroirs. Concept, product, valorization' and organized by the INRA agricultural research centers of both Angers and Montpellier. Such event was renewed in Siena (Italy) in 1998, in Tenerife (Spain) in 2000, then in Avignon (France) in 2002, where it revealed the preeminence of European studies on the subject, while varied studies were coming out from recent viticultural countries. In 2004, in Cape Town, such international conference takes place out of European countries. As in both Tenerife and Avignon, it is specifically aimed at viticultural zoning. Viticultural zoning mainly refers to 'terroir', which can be defined as a spatial and temporal entity that is characterized by homogeneous or dominant features for grape and/or wine, soil landscape and climate, at a given scale-duration level, within a territory founded on social, historical experience and crop technical choices (Vaudour, 2003). Terroir has many human/environmental facets, not always met in every vineyard in the world (as for human facets). However, viticultural zoning is needed everywhere and thus corresponds to varied applications, definitions and approaches.
Zoning aims have been changing together with the needs of the ever-expanding international wine market. There are more and more wine-producing regions and countries involved in zoning studies, and although many of the corresponding works were initiated in Europe, zoning needs go far beyond the countries endowed with centuries-old viticultural history.
This paper first introduces viticultural zoning and its varied aims. Then, it inventories the main wine-producing regions and countries involved in zoning studies. The third part of this paper attempts to describe zoning materials and methods worldwide. Finally, special attention is paid to the actual trends of zoning methods.

Viticultural zoning and its varied aims

Viticultural zoning definition

What is zoning ? basically, it is a term referring to administrative planning, and depicting the operation organizing the distribution of a given territory into zones, for which land use conditions are specified. For wine producers or wine professional organizations, viticultural zoning consists in the spatial characterization of zones that are likely to give birth to grape or wines of similar compositions, while enabling operational decisions at the varied production steps (Vaudour, 2003). Such zones are often named 'terroirs' or 'terroir units'. Be it refferrible to a secular viticulture or a pioneer viticulture, every winegrowing space is individualized by boundaries. Some demarcations are preestablished, whereas others need to be worked out. Zoning doesn't always require to lay down geographical boundaries, when the latter are already defined (such as administrative boundaries, plot boundaries), but at least implies to define conceptual boundaries, so as to characterize a phenomenon. Zoning is associated to output documents, including maps. Provided boundaries are already available, spatial characterization is thus made at a basic level: for example, using or merging plot boundaries. However, in order that the zones defined better meet the winemaker or technical adviser's requirements, cartographic methods and spatial modelling (Burrough, 1986; Legros, 1996; Girard and Girard, 2003) are preferable for viticultural zoning.

Zones versus 'Terroir'

Before discussing viticultural zoning in a worldwide perspective, it is necessary to emphazise a lexical competition resulting from the history of zoning or terroir-related studies, that has emerged between both terms 'zones' and 'terroir'. In centuries-old viticultural countries, marked attention has always been paid to the influence of vineyard conditions on the quality of grapes and their distinctiveness, an influence that is embodied in the French notions of 'terroir' (Falcetti, 1994; Bohmrich, 1996; Salette et al., 1998; Wilson, 1998; Hancock, 1999; Vaudour, 2002). 'Terroir' can be defined as a spatial and temporal entity that is characterized by homogeneous or dominant features for grape and/or wine, soil landscape and climate, at a given scale-duration level, within a territory founded on social, historical experience and crop technical choices (Vaudour, 2003). European viticulture shares the conviction of the importance of human/historical aspects: know-how memory, historical and social heritages. Because of its cultural inheritance, French viticulture was confronted with the difficult and paradoxical reconciliation of terroir myth with terroir rationalization. In addition to the cultural (subjective) linkage existing between terroir and human aspects, objective terroir criteria are not so easy to select and manage. In order to avoid any lexical ambiguity, 'viticultural potentialities', 'viticultural zones', 'soil', 'viticultural environment', are often prefered to that of 'viticultural terroirs'. Employing the term 'viticultural zones', New World viticulture avoids such dilemma. The comprehensive human facets of terroir are not always met in every vineyard in the world, particularly in the young producing countries. While the term 'viticultural zones' enable a minimalist vineyard characterization, that of 'terroir' is likely to require more features and, in any case, more caution. From a New World perspective, much emphasis has been placed on climate and rather scant attention paid to soil and its complex interaction with wine grapes (White, 2003), yet 'terroir' is sometimes (wrongly) assimilated with soil only and opposed to climate. Actually, there exist distinct scientific concepts of 'terroir'. From the simpler to the more complex, those concepts of 'terroir' encompass either vineyard soil, substrate lithology, the 'soil×climate' interaction, the viticultural agroecosystem (interaction 'soil×climate×plant genotypes×training system×grape composition'), the winegrowing agroecosystem (interaction 'soil×climate×plant genotypes×training system×grape composition×winemaking skills'), the historical and sociological winegrowing agroecosystem (Vaudour, 2003). The latter is closer to the familiar acceptance of 'terroir', which rely on secular both collective memory and experience of grape/wine typicality (Letablier and Nicolas, 1994).

The varied aims of viticultural zoning

Demarcating registered designations of origin, appellations of origin and protected geographical indications is one of the most obvious of all zoning aims, which originates from the XIXth century in Europe, and now addresses most recent wine-growing countries. A registered designation of origin guarantees to the consumer that the product he buys originates from a well identified territory: the demarcated viticultural area. Designations of origin usually admit 100% of harvest from a specifically protected territory, and they include common production rules, such as specified varieties and training modes, maximum yield threshold, minimum sugar content at harvest, minimum planting density, that are likely to favour final products similarity between different winemakers from the same territory. It must be recalled, that 20 countries only, among which France, Italy, Portugal, Hungary, Slovaquia, Bulgaria and the Czech Republic, ratified the Lisbon Agreement on the protection of appellations of origin and their international registration. The appellation of origin concept relies on the existence of terroirs, that is to say, demarcated appellation areas may contain one or more specific terroir units.
In some geographical indications, such as the American Viticultural Areas (AVA) or the Chilean 'Appelation of Origin', guarantee of a unique origin is yet not given for 100% of the harvest used to make the certified wine, and there are no common production rules imposed by the law. Conversely, both the French 'Appellation d'Origine Contrôlée' (AOC) and the Italian 'Denominazione di Origine Controllata e Garantita' (DOCG) might correspond to the strictest designation systems in the world, as they include a sensory control of final products, in addition to viticultural production rules. Under whatever production rules, designations of origin and geographical indications lead to reassure consumers and maintain prices high, hence their geographical demarcation is at stake because it leads to create 'elite' vineyards. So, how to circumscribe protected viticultural areas ? designation demarcation most often rely on preexisting district, commune or plot boundaries, which have to be assigned to a class defined by a unique qualitative variable, with three modalities (the third modality being optional) (Vaudour, 2003): 1) belongs to the defined viticultural area; 2) does not belong to the defined viticultural area; 3) could belong to the defined viticultural area provided certain conditions are satisfied. Assignment criteria for AOC demarcation have often been: historical, based on customs and anteriority; geological; or physiographic, based on the obvious geographical boundaries formed by the hydrological network, topography, or the road network; or even, climatic. Historical assignment criteria may be regarded as empirical, but, paradoxically, those environment-modelled so-called terroirs that lack any anteriority of viticultural use and common production rules cannot wholly fit the familiar acceptance of terroir !
In addition to protecting a production territory from geographical name usurpations, other important zoning aims are not necessarily related to demarcating operations. In the numerous vineyard regions the boundaries of which are already fixed as registered designation of origin or geographical indication areas, those often rough administrative boundaries may not be appropriate for the technical management of the winegrowing space. It is thus necessary to segmentate the geographical indication territory into homogeneous units that are likely to be consistent with either pest management, reparcelation, vineyard restructuring operations, grape harvest quality management, or site selection for new vineyards. For instance, plant material selection may suppose to localize the places where either lime-induced Fe chlorosis, or drought, or excessive wetness occur and are tolerated by resistant vines. In this way, one of the first viticultural zonings was that realized in 1887 by Pierre Viala on behalf of the French Ministry of Agriculture, so as to find native vines resistant to calcareous soils. With the support of the American botanist T. Munson, Viala found lands with high calcium carbonate in middle Texas, and the vigourous native vines growing there: *V. Berlandieri, V. Cinerea, V. Cordifolia*, used since as chlorosis-resistant rootstocks. Reparcelation and vineyard restructuring operations require to characterize sites that are propitious to either variety changes or training mode changes. They rise questions, which are common to most zonings, regarding site suitability and site capability assessment : 1) where are located the best suitable sites for variety selection ? 2) where are located the best suitable sites for obtention of acid and sugar-rich harvest ? 3) which are the best terroirs for making fine wines ? Each of those questions leads to different output maps.
The first question consists in finding which areas correspond to high, moderate, low or no suitability for a given grape variety or a given rootstock. This comes to sort areas by suitability degree, as it was done in Oltrepó Pavese for the Barbera, Croatina, Riesling italico, Pinot noir or Chardonnay cultivars

(Scienza et al., 1990) or in Anjou for the cultivar Cabernet-Franc, based on index of 'precocity' (Barbeau et al., 1998) or, based on varied suitability indexes, for varied rootstocks, such as Riparia, 101-14, 3309C, SO4, Gravesac, 5BB, 1103P, 110R, Rupestris (Morlat, 2001).
The second question consists in chosing, among a viticultural space, the areas that are likely to improve or facilitate grape harvest assemblage. It leads to establish a capability map of vineyards areas. Capability maps are frequent in precision viticulture (some hectares), and rather seldom over wider areas. Fig. 1 gives an example of a capability map for the Southern Côtes-du-Rhône, resulting from the intersection of a potential terroir unit map and the harvest maturity data of 67 plots planted with Grenache noir over a series of 17 years (Vaudour, 2001, 2003).
The third question addresses the hierarchy of vineyard areas, from the best to the worst, regarding the aim of an elite production. The capability classes here come from a complete hierarchy resulting from threshold definitions on varied quantitative environmental/ecophysiological criteria. Such viticultural zoning was seldom carried out. It corresponds, for instance, to that realized in the Ribera del Duero (Spain) by Sotés et al. (1994), from 14 environmental criteria including: soil water content; soil depth; active $CaCO_3$; organic matter content of surface horizon; cation exchange capacity, K content, texture of B horizon; substrate lithology; elevation; slope angle; drainage conditions and waterlogging; the presence of other lithofacies; zones with mixed substrates.
Site selection of new vineyards gathers all zoning aims. As well as an environmental characterization, it requires to chose the best suitable plant material, training modes and viticultural skills, for which no previous experience is available. The lack of empirical viticultural data leads to argue site determination in comparison with the longstanding traditional viticultural regions, the terroirs of which have always been renowned for their fine wines. In Australia, variety and skills choice rely on the knowledge of the European secular vineyards, which are endowed with analogous environmental conditions (homoclimes) : that is the 'homoclime approach' referred to by Dry and Smart (1988).
Another important aim related to viticultural zoning is that of facilitating the management of the varied wine production levels, and scale transfer between them (Fig. 2), which implies to consider both map scale, spatial resolution, and the level of analysis (Girard and Girard, 2003) of the considered levels.
Lastly, viticultural zoning can be aimed at soil conservation, through erosion risk assessment, for example in the Penedès-Anoia vineyard region (Martinez-Casasnovas and Sanchez-Bosch, 2002). This addresses the issue of terroir sustainability.

Main wine-producing regions and countries involved in zoning studies

Viticultural zoning is of international importance. As a matter of fact, resolution VITI 2/93, which proceeds from the General Assembly of the OIV, asks member countries and international organisations: i) to stimulate research on scientific methods by which to characterize and delimit homogenous viticultural zones that, without major human intervention, are capable of yielding original vitivinicultural products of quality; ii) to apply suitable methods of research and interpretation to take into account all the factors of the viticultural ecosystem including the characteristics of the soil, the climate, the interactions between variety and site and the effects of the human factors on the maturation and the quality of the grape. In this way, a terroir zoning group was recently created at the OIV.

Traditional wine producing countries

Most traditional wine producing countries of the Old World, such as France, Italy, Spain, and Germany, have been involved in zoning studies long ago. In these countries, viticultural designation areas have been demarcated in all viticultural regions, over varied extents, from less than 1 ha to more than 200 000 ha. In France, the first wine producing, exporting, importing, and consuming country in the world, some of the earliest terroir-related studies actually emerged together with the AOC genesis in the 1930's and they focused on vine and wine, on behalf of the French National Board of Appellations of Origin (*Institut National des Appellations d'Origine*, INAO). Post-phylloxera reconstruction of renowned inherited wine districts needed to justify the influence of geographic origin on quality of wines on some objective basis. Among the varied French regions concerned by zoning studies, many of which have

been initiated since the 1970's, one can quote, quite not exhaustively: Bordeaux (Seguin, 1986; Van Leeuwen et al., 1989), the Languedoc (Bonfils, 1980; Astruc et al., 1980), the Loire Valley (Morlat, 1989; Barbeau et al., 1998; Morlat, 2001), Alsace (Party et al., 1990; Lebon, 1993), Champagne (Dolédec, 1995), the Côtes-du-Rhône (Vaudour et al., 1998; Vaudour, 2001, 2003), Cognac (Cam et al., 2003). Alsace is the only French region the terroirs of which have been entirely mapped over near 14 600 hectares (Party et al., 1990). Since the mid-XIXth century, both the University of Bordeaux (Faculty of Enology) and the Viticulture Department of the Agricultural Engineering Institute of Montpellier (so-called 'Agro-Montpellier' today) have been playing a leading role, in association with open-minded and resolute vinegrowers and wine professionals who financially supported several zoning works. Many facets of the "terroir/vine/wine" system have been examined at the viticultural research center INRA-URVV of Angers, whereas cartographic issues of viticultural zoning have been pointed out at the *Institut National Agronomique Paris-Grignon* ; not mentioning all other implied organisms. In Italy, since the 1990's mainly, the Piedmont, Lombardy, Trentino, Tuscany regions have given rise to several zoning studies focused on the adaptation and functioning of vine varieties (viticultural 'vocations'), owing to either the Viticulture Department of the Catholic University of Piacenza, the University of Milan (*Istituto de Cultivazione Arboree*), the *Istituto Agrario* of San Michele all'Adige (Trentino) or the *Istituto Sperimentale per lo Studio e la Difesa del Suolo* of Florence (Falcetti et al., 1997). In Spain, since the 1990's, the *Escuela Technica Superior de Ingenieros Agronomos* of the Madrid Polytechnic University surveyed the viticultural suitabilities of several regions, including the Ribera del Duero (Sotés et al., 1994), Duero, La Mancha, Rueda, Toro. The Agricultural Chemistry Faculty of the University of Seville drove several studies on Andalusian designations of origin, including Jerez-Xérès-Sherry (Paneque et al., 2002). Geographical differentiation of varied island sites was obtained from sensory analysis in Majorca (Mulet et al.,1992) and the Canary Islands (Gutierrez-Afonso y Yanes-Marrero, 2002). In Germany, since the 1970's, environmental site characterization has been investigated in the Rheingau and Sudbade vineyards (Becker, 1977).
Generally, European terroir-related studies rely on all the available data on both the vine/wine response and the vineyard environment, and they often insist on the soil influence on terroir (Vaudour et al., 2004). Terroir cartography has been developed at all scales, essentially since the 1990's, together with the widespread implementation of geomatics.

Young wine producing countries

In the New World, the Viticulture Department of the California University performed several studies in connection with Californian wine professionals, such as the Californian 'degree-day' climatic zoning carried out by Amerine and Winkler (1944). This prominent study linked the climatic delineation of five viticultural zones ('temperature regions') to grape quality estimation. Deprived from a subtle secular and gradual adaptation of human skills to the environment, the New World viticulture was looking for technical basis for implanting new vineyards. In recent years effectively, viticulture has seen phenomenal growth worldwide, particularly in such countries as Australia, New Zealand, the United States, Chile, and South Africa. Since the 1970's, along with the United States in California (Noble, 1979; Guinard and Cliff, 1987) and the Four Corners Region (Dutt et al., 1981), South Africa has been given rise to the some of the earliest terroir-related studies, specifically in the South Western Cape (Saayman, 1977) in the Stellenbosch District (Carey et al., 2003). Site characterisation and/or zone surveying are now being initiated in most of the young wine producing countries, including New Zealand (Tesic, 2002), Canada (Shaw, 1999), Australia (Bramley and Lamb, 2003), Chile (Parra and Vaudour, 2004), and Brazil, Argentina, Uruguay.
Caricaturally, non-European terroir-related studies rely on the vine/wine response, and/or they often insist on climate (Gladstones, 1992), underestimating or even ignoring the soil influence, despite the South African works (Saayman, 1992) and some Australian ones (Northcote, 1988; White, 2003). Terroir cartography is now often developed in the context of precision viticulture.

VII. Zoning materials and methods worldwide

The homogeneous units obtained through viticultural zoning are frequently referred to as '*terroirs*'; however their scale, characteristics, materials and methods may greatly vary depending on authors and vine-growing regions, making international zoning comparisons uneasy.

Geographical differentiation of vineyards :zoning materials

Viticultural zoning can actually be separated into 2 main groups, on the basis of their zoning materials: on the one hand, that insisting on the geographical differentiation of wines, grapes, or plant characteristics; on the other hand, that focused on the geographical differentiation of land capabilities or vineyard suitabilities, for which soil and climate are mostly referred to as key factors, but with varied significations and the use of distinct component variables and distinct soil taxonomies (Vaudour, 2002). The geographical differentiation of wines, grapes, or plant characteristics according to experimental plots or commercial wineries, has been widely demonstrated using physico-chemical analysis and/or sensory analysis, in California (e.g., Noble, 1979; Guinard and Cliff, 1987) as well as in Europe (e.g., Mulet et al., 1992; Fischer et al., 1999). However, in many of these studies, sites or wineries are often only roughly spatially referenced and/or environmentally defined, which questions how such geographical differentiation arises, as well as the sample site spatial representativity. More, there might be too few sample sites or wineries, to enable the demarcating of sensory/chemical zones boundaries, along with the grape/wine quality data only. Therefore, most zoning studies that deal with geographical differentiation of grapes and wines either focus on the understanding of plant ecophysiological functioning at the local scale or consider the mapping of land capabilities or vineyard suitabilities, according to varied spatialized environmental data. Sensory/physico-chemical analyses may intervene after representative sites are comprehensively characterized within terroir units, e.g. in the Loire Valley (Brossaud et al., 1998).

The varied scales of viticultural zoning studies

Until now, in spite of the diversity of terroir-related scientific works, very little attention has been paid to the spatial modelling and scale issues of terroir (Vaudour, 2002). For the last three decades mainly, most terroir-related scientific works have been focused on the plant or plot (or subplot/block) level, through a network of experimental sites. These local approaches consider the relationships between the physico-chemical and sensorial monitoring of wine, with the monitoring of grape maturation and a few soil and climate characteristics: e. g. in Bordeaux (Seguin, 1986), California (Noble, 1979), the Loire Valley (Morlat, 1989), Trentino (Falcetti and Scienza, 1991), Alsace (Lebon, 1993), Rheingau (Fisher et al., 1999). Traditionally, such approaches have been performed considering point measurements only, without replacing and validating them within larger areas, except for the Loire Valley (Morlat, 2001) where surveys have been further carried out.
Other approaches have been oriented towards the characterization of land geographical patterns (Bonfils, 1980; Astruc et al, 1989; Party et al., 1990; Dolédec, 1995; Sotés et al, 1997; Vaudour, 1997, 2001; Carey, 2001; Cam et al., 2003). Because of the wide extent of study areas, over more than 10 000 ha, those regional 'spatial' approaches are seldom, or only partially, validated through viticultural data. The widespread implementation of geomatics leads to question the way terroir units have to be spatially characterized. Geomatics, which include Geographic Information Systems (GIS), Global Positioning System (GPS), digital image processing and interpretation of both satellite images and aerial photographs, are needed for the analysis of terroir units through the Earth's geographic space, at scales (or organizational levels) that may range from the field, farm, watershed, to the region, continent or global level. It is important to consider several of these levels together. The field level has to be examined in order to understand some viticultural situations, and this requires to enter further into understanding of the relationship "whole plant-berries" (Deloire et al., 2002) : acting on the intrinsic components of a considered terroir unit, such as light, temperature or moisture-related microclimate in the canopy within the bunch zone, the vintner may influence the quality of the harvest and the wine 'typicality' together with the winemaker. Higher levels, encompassing wider areas, are more adapted to professional managerial needs over a viticultural district (Fig. 2) and their relation to the sample of sites selected at the field level has to be analysed.

Three organizational levels, which stem from climatology, are commonly referred to in grapevine research: ‘macroscale’ for a wide area (usually more than 1000 ha); ‘mesoscale’ for a topographical unit and even block/vineyard (about 10-100 ha); and ‘microscale’ for the canopy (less than 10 ha). These levels may exhibit some ambiguity because their corresponding map scale and spatial resolution are not strictly defined (Vaudour, 2003); microscale is sometimes confused with phytoscale, plant scale. A map scale higher than or equal to 1/25 000 is currently recommended for terroir zoning, so as to enable the monitoring at the scale of the territory under control of a winery or a vine-growing farm.

Main zoning methods

The simplest zoning method is that of registration demarcation. It consists in a simple assignment to preexisting boundaries, according to a single qualitative variable (cf. above text), based on historical/empirical justifications mainly. As for registration demarcation, many local approaches rely on already defined boundaries, and actually, they are based on weather, plant/grape or wine point observations that are roughly interpolated within those existing boundaries. In such cases, discussion is focused on the causal relationships between the varied plant functional parameters of the terroir/grape/wine system (Fig. 3), rather than their spatial validity.
The regional ‘spatial’ approaches are those likely to determine map units, which in the widespread case of a choropleth map, are graphically described by map polygons areas circumscribed by boundaries. Soil survey is the most common basis for most terroir maps, mostly resulting from so-called ‘free survey’ field approaches (Burrough, 1986; Legros, 1996). Many terroir studies in grapevine research are actually based on conventional pedological surveys with free sampling design (e.g., Costantini and Lizio-Bruno, 1996; Paneque et al., 2002) sometimes carried out over a reference soil region supposed to represent a wider area, so as to anticipate the results on it (Cam et al., 2003). The conceptual model of the UTB (*unité terroir de base,* terroir basic unit) defined by Morlat (1989), which was simplified through the “rock, alteration, alterite”indicators trilogy (Morlat, 2001), derives from geological free survey.
Other spatial approaches perform thematic map design (Legros, 1996), from comprehensive geographical databases, including or not soil maps. Thematic map design can be based on a quantitative mechanistic model, such as that performed for the zoning of sugar content over the European Union (Riou et al., 1994), from a comprehensive viticultural database of 108 plots, and a 5 km-resolution network of 333 weather stations with temperature and rainfall data. Thematic map design can also be based on several parametric criteria (Bonfils, 1980; Astruc et al., 1980; Sotés et al, 1994). The problem of parametric criteria complete aggregation is that of criteria comparability, criteria hierarchy, how to set notes and threshold values, and the possible compensation of some criteria with very different other criteria in final notes. Lastly, thematic map design can combine and chain varied GIS-handled spatial models, either without any soil data (Laville, 1990), or integrating available soil maps (Dolédec, 1995; Carey, 2001; Vaudour, 2001, 2003). All GIS-handled spatial approaches of terroir lead to a considerable renewal and updating of it, focused on the needs of vine-growing and wine-making management. However, it sets several problems. The number of output modelled units is infinite, and uneasy to wholly validate by enough viticultural sampling data of sufficient duration. Some output units may not correspond to any physiographic field reality, liable to be experienced by the vine-growers, and therefore they have to be either clustered or segmented. Multi-scale and multi-source data are used: data integration is hardly solved by the computer by itself, and the issue of information synthesis is at the very heart of the spatial modelling of terroir. A three-step method, using satellite remotely-sensed imagery as a prominent tool supporting such a synthesis, was proposed by Vaudour (2001, 2003): (i) a soil landscape conceptual model is built using field knowledge, satellite image processing, stereoscopic photograph examination, along with multiple topographical, geological and pedological maps, each soil landscape unit being described according to several environment variables; (ii) soil landscape units are aggregated into broader-scale potential terroir units using cluster analysis from environment variables, so as to limit the number of output units and enable viticultural validation (iii) potential terroir units are validated into terroir units across serial grape harvest quality clusters, over the course of a long series of vintages (Fig. 4).

Actual trends of zoning methods

Both influences of water regime and soil temperature regime on grape/wine quality are currently admitted (Seguin, 1986; Van Leeuwen et al., 1989; Morlat, 2001; White, 2003; Vaudour et al., 2004). However, knowledge on environmental determinism is still fragmentary. The vine root system is uneasy to explore owing to vine considerable depth and life duration. In this way, the thorough characterization, according to common criteria, of the varied viticultural terroirs in the world, is to develop. The issue of the spatial worldwide generalisation of viticultural data is still unsolved: how are the distinct vine environment conditions comparable worldwide ? the multicriteria climatic classification system for world viticulture suggested by Tonietto (1999) is a step toward answering such question, reffered to as 'geoviticulture' by Carbonneau and Tonietto (1998); soil data could also be described with the world FAO system (ISSS, 1998), and training systems have been given a recent reference system by Carbonneau and Cargnello (2003).

Another related issue is that of rationalizing both criteria and zoning methods worldwide. This is all the more difficult, than all zoning approaches partly depend on available geographical data, which are not obtained from the same methods in every place. Spatial data availability is a limitation for whatever zoning, especially climatic and viticultural data, over sufficient series of vintages. It is also a limitation for the mapping of soil properties, rather than soil types, through the performing of pedotransfer models.

More, the spatial approaches of viticultural zoning are being now challenged by the implementation of high resolution-mapping. Since vintage 1999, when the first commercially available grape yield monitor came onto the market, it has been possible for grapegrowers and winemakers to acquire detailed geo-referenced information about vineyard performance (Bramley and Lamb, 2003). Precision viticulture uses high resolution data (from some decimetres to a few metres) and, performing geostatistics, leads to define quality zones at a very detailed map scale (more than 1/10000), so as to enable selective harvesting according to different yield/quality criteria. It is thus necessary to know (Bramley and Lamb, 2003): wether the patterns of within-vineyard variation are constant from year to year; wether patterns in variation in yield are matched by patterns of variation in quality; what the key drivers of vineyard variation are and wether these may be managed; finally, wether targeting management delivers an economic benefit over conventional uniform management. Answering those questions requires to deliver powerful improvements to vineyard soil survey (increase in soil map polygon purity), for instance through the use of soil electric resistivity measurements, elevation modelling, targeted ground sampling, and remote sensing techniques.

Recent research on detailed block zoning using aerial or satellite remote sensing focuses on the visible and near infrared spectral bands of the electromagnetic spectrum. Vineyard canopies have been monitored generally on the basis of the NDVI index (*Normalised Difference Vegetation Index*), which was put into relation with the LAI (*Leaf Area Index*), so as to estimate vine *vigour*, e.g. from 4 m-resolution IKONOS satellite images (Johnson, 2003; Johnson et al., 2003) and 25 cm-resolution aerial images (Hall et al., 2003). Vineyard soil surface variability was also investigated, e.g. from aerial photographs (Wassenaar et al., 2001) and from both 4 m-resolution IKONOS and 2,5 m-resolution supermode SPOT satellite images through varied classifications (Parra and Vaudour, 2004). With further research, hyperspectral remote sensing collecting data from other parts of the spectrum may also prove useful.

Conclusions

All viticultural zonings converge towards the improvement in either grape/wine quality, environment sustainability, or financial gain worldwide or them all, whenever it be possible. The diversity of zoning aims stems from the varied territorial directives, economic stakes, and potential users at the varied wine production levels. It is important to consider several of these levels together. Thematic maps, that lead to vineyards geographical divisions supporting decision-making, may actually derive from terroir maps, but not only. Viticultural zoning is not always synonymous with terroir zoning, with all the facets implicated by the familiar acceptance of terroir. In addition to their materials, study scales, methods, zoning approaches may differ in their spirit: either demonstrating the specificity and typicality of long tradition wines from small family wineries, or managing industrial chameleon wines so as to satisfy the average world consumer at the present moment. If viticultural zoning may prove useful to both spirits, precision zoning implies elevated costs that still make it reachable for industrial wines only.

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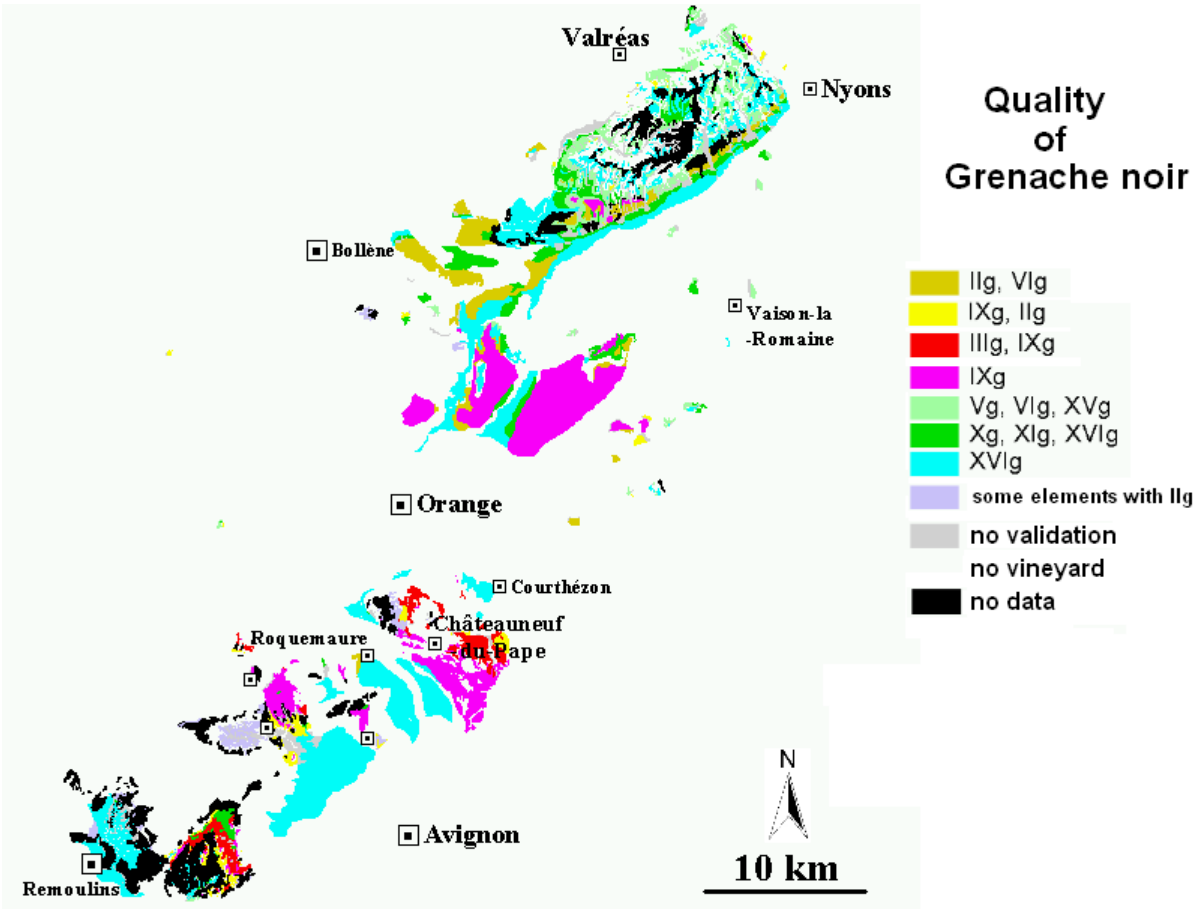
List of tables and figures (do not include in the text body)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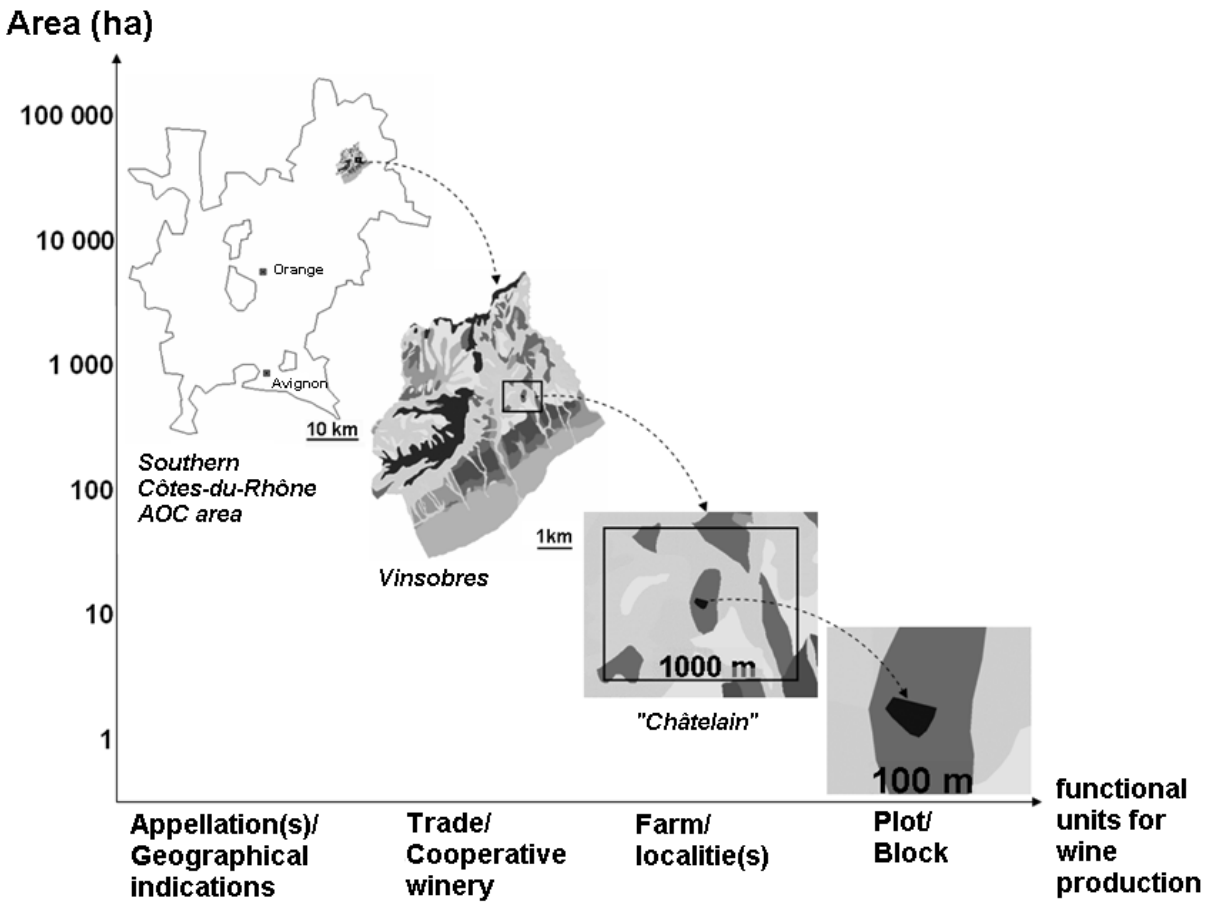
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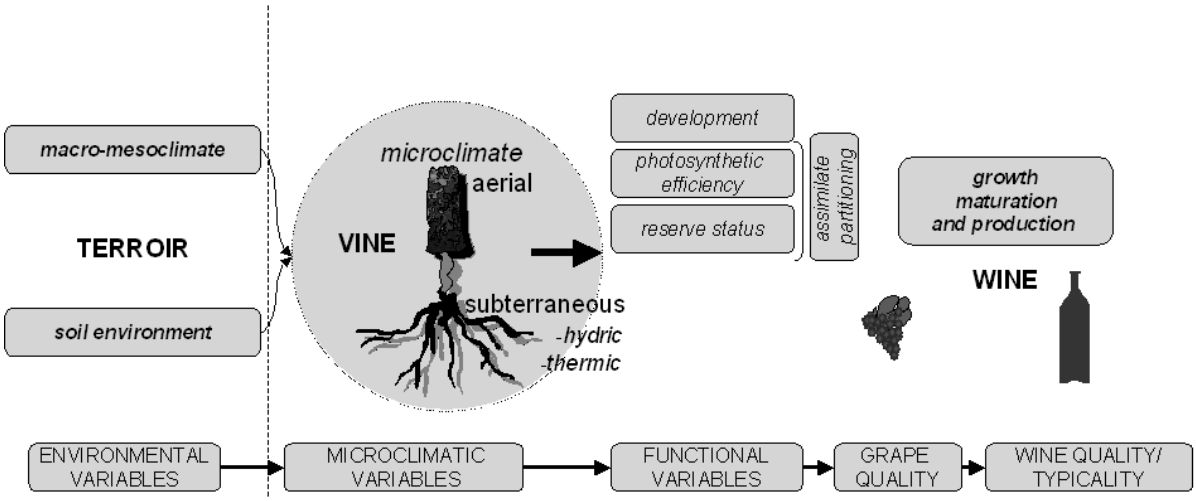
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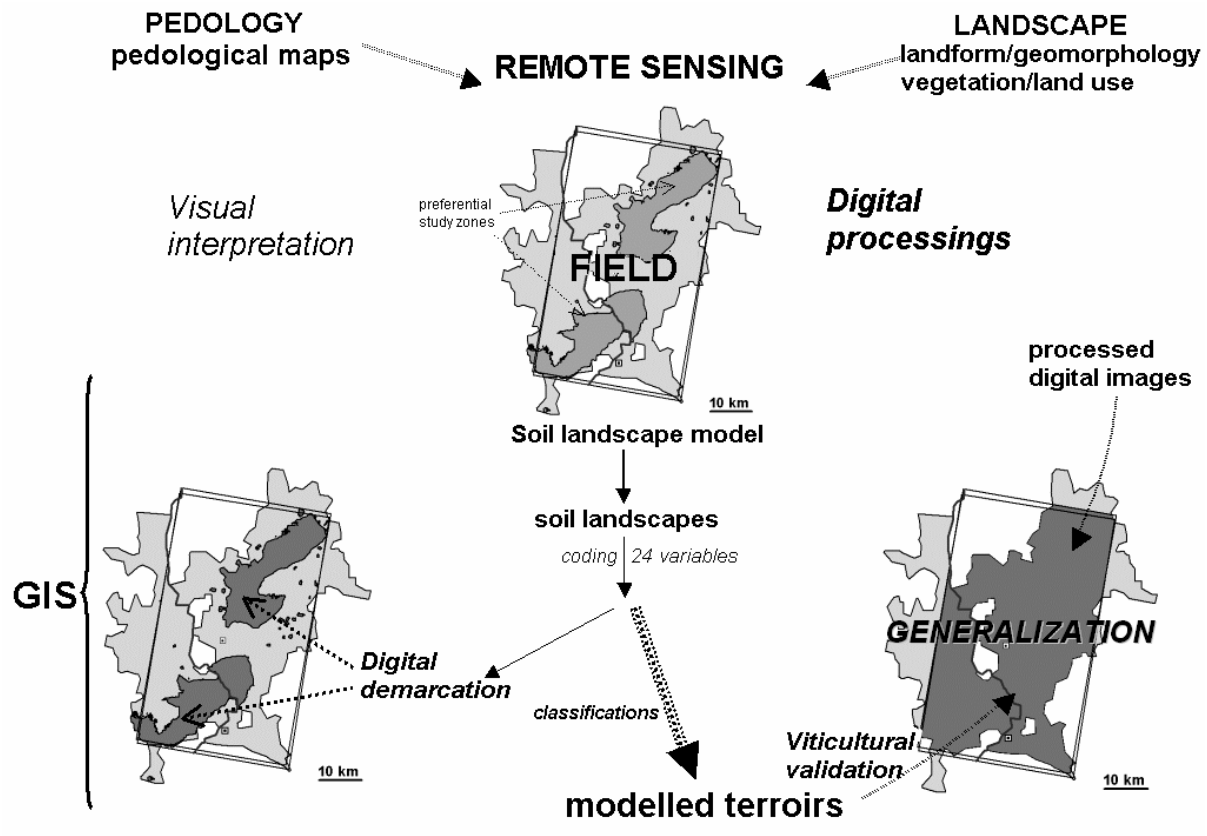
WINE QUALITY/ TYPICALITY


PEDOLOGY
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REMOTE SENSING
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GIS
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GENERALIZATION
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