Towards a unified terroir zoning methodology in viticulture
Vers une méthodologie de zonage de terroirs viticoles unifiée

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ABSTRACT
In viticulture, terroir is a key concept that refers to an area and thus possesses a geographical dimension. Hence, zoning of viticultural terroir is an important issue. This paper addresses soil and climate related aspects of terroir zoning. The first step of the zoning process is a clear identification of the objectives that are being pursued. Soil zoning and climate zoning methods are presented separately, although both approaches are preferably carried out simultaneously, in order to take into account soil-climate interactions in the terroir effect. Definition of a scale adapted to the objectives is critical, particularly so in soil zoning. For soil zoning, the relevance of geology, geomorphology and pedology (soil science) is discussed. The use of new technologies (e.g. GIS or remote sensing) enables the production of more detailed maps at reduced costs. In climate zoning, climate data and agroclimatic indices must be chosen according to the zoning objectives. High quality climatic data must be selected and validated. Following, homogeneous climatic zones are indentified. Viticultural zoning has to be validated, preferably so by eco-physiological studies. This paper is based on the unified terroir zoning methodology that is currently in preparation by the experts of the International Organisation of Vine and Wine (OIV).

Keywords : viticulture, terroir, zoning, soil, climate.
Mots-clés : viticulture, terroir, zonage, sol, climat.

1 INTRODUCTION
Wine style and quality are subject to environmental factors, particularly soil and climate. Hence, quality and value of wine is related to its origin. This feature is generally referred to as the "terroir" effect. Because terroir has a spatial dimension, zoning is an important issue. Many methods of terroir zoning have been developed during the past decades. They vary according to the objectives and the scientific discipline used for the zoning. The International Organisation of Vine and Wine (OIV) is working on guidelines for an unified zoning methodology. This enables the comparison of terroir zoning studies carried out in various winegrowing regions and countries. The structure of this paper is based on the OIV guidelines. Terroir zoning comprises soil and climate related aspects. Because soil and climate interact in terroir expression, their zoning should be ideally undertaken simultaneously. However, for the sake of clarity to end users, soil and climate zoning are presented separately.

2 OBJECTIVES OF SOIL- AND CLIMATE RELATED TERROIR ZONING STUDIES
Terroir zoning studies may have various objectives. Among these we can identify:
- Delimitation of wine producing areas
- Optimisation of technical vineyard management
- Optimisation of plant material (root stocks and grapevine varieties)
- Territorial management of water resources
- Zoning of crop protection risk
- Zoning of climatic risks
- Landscape protection from urbanisation

It is critical to define precisely the objectives prior to the implementation of the zoning, because scale and methodology may vary according to them. For instance, zoning of climatic risks requires focussingon specific climatic parameters, while landscape protection from urbanisation rather involves soil related zoning aspects. Optimisation of technical vineyard management needs fine scale zoning (e.g. 1/5,000th), while landscape protection from urbanisation may be relevant at a smaller scale (e.g. 1/50,000th).

3 SOIL ZONING
3.1 Soil-based zoning can be bases on one or several scientific disciplines
Geology enables a synthetic approach which is adapted to small scale zoning (≤ 1/ 50,000th). Geological maps are quite cheap to produce and they do exist for most regions worldwide. However, the relation between Geology and the behaviour of the vine (development, yield parameters, grape ripening) is rather loose. Hence, geology can be used as a first approach in terroir zoning, but it needs to be complemented with further, more in-depth studies (determination of soil-types).

Geomorphology describes the forms of land surface (plateau, slope, valley, terrace etc) which are the result of the nature of the rocks (especially the differences in hardness), tectonic phenomena and erosion. This discipline enables a synthetic approach which is adapted to small scale zoning (≤ 1/ 50,000th), as with geology, but does explain vine behaviour only indirectly.

Pedology) is an approach adapted to medium or large scale zoning (≥ 1/25,000th). To create soil maps samples are taken with a hand held auger and soil pits are studied. Pedology enables explaining, to a certain extent, the physiological functioning of the vine. It is recommended that the soil map is based on the "Soil Taxonomy" (American classification; [1]), the "World Reference Base for Soil Resources" (FAO classification; [2]) or the "Référentiel Pédologique" (French classification; [3]).

If only one discipline has to be chosen, pedology should be preferred. However, the combination of geological, geomorphological and pedological approaches allows the implementation of particularly accurate terroir zoning.

3.2 Scale issues

The scale of zoning must be defined beforehand. This scale will depend on the zoning objectives and the scientific discipline chosen as approach. The larger the scale the more precise the zoning is, but the higher the cost. To produce soil maps at a given scale a certain density of observations must be respected to have a resolution corresponding to a proposed scale (table 1).

Table 1. The number of auger probes and soil pits necessary to produce a soil map at a given scale (source: working group OIV).

Scale	Number of ha per auger sample	Number of auger samples per ha	Number of ha per soil pit	Total number of observations per ha (auger samples soil pits)
1/2,500	0.06 - 0.13	8 – 16	2 - 4	8 - 16
1/10,000	1 - 2	0.5 – 1.0	20 - 50	0.5 – 1
1/25,000	7 - 14	…	70 - 140	0.08 – 0.16
1/100,000	120 - 240	…	600 - 1200	0.005 – 0.01
1/250,000	750 - 1500	…	4000 - 8000	0.0008 – 0.0016

This table is based on the following rules:
0.5 to 1 observations per cm^2 of soil map, and :
- for the scale 1/2,500 = 30 auger samples/soil pit
- for the scale 1/10,000 = 20 auger samples/soil pit
- for the scale 1/25,000 = 10 auger samples/soil pit
- for the scale 1/100,000 = 5 auger samples/soil pit
- for the scale 1/250,000 = 5 auger samples/soil pit.

If the distribution is locally complex, it may be necessary to increase the density auger samples and / or soil pits, especially for the scales 1/25.000 and 1/100,000. For the scale 1/250,000 it is recommended to map one or more "reference areas" in a larger scale to highlight the distribution of soils according to the geology and the geomorphology.

3.3 The use of new technologies

New technologies can be implemented to increase the precision of zoning or to reduce the cost. Some of these new technologies have been developed in the framework of precision agriculture. Although very useful, they cannot completely replace field work (auger samples, soil pits).

- Geographic Information Systems (GIS) are computer based technologies designed to manage spatial information. They are particularly useful to design maps and combine several layers of spatial information.
- Digital Elevation Models (DEM) can provide highly accurate geomorphological maps at reduced cost.
- The implementation of geophysical surveys prior to soil mapping (Electrical Resistivity Tomography (ERT) or Electro Magnetic Induction (EMI)) enables the production of very precise soil maps while limiting the number of auger sampling points. This approach is particularly adapted to large scale zoning studies (≥ 1/5,000th).
- Airborne remote sensing can help to analyse soil surface differences when no vegetation is present.
- Point based information can be transformed into spatial information by means of Geostatistics.

4 CLIMATE ZONING

4.1 Select appropriate climatic indicators

Climate zoning is based on the use of agro-climatic indicators. Appropriate indicators have to be selected at relevant time scale, according to the zoning objectives (table 2).

4.2 Select high quality climate data

Three possible sources of climate data can be identified: weather stations, remote sensing and dynamic circulation models. For data sourced from weather stations, a serious quality control is critical because invalid data from poorly located weather stations, or due to either sensor malfunctioning or database construction mistakes has to be identified and rejected. Optionally, such data can be replaced by estimates obtained from surrounding weather stations.

Weather stations provide point-located data. Spatialisation of point-data can be implemented either by geostatistic based interpolation or by subjective demarcation. An estimation of the uncertainty of the

interpolation has to be carried out with an independent data set (e.g. leave-one-out cross validation).
Remote sensing provides climate data over large areas and over continuous timescale. This data has to be pre-processed to eliminate artefacts.
Dynamic circulation models produce very large quantities of climate data, covering large areas. However, the spatial resolution is, most of the time, very low (grid between 50 and several hundreds of kilometres).

Purpose of zoning	Relevant climate data and agroclimatic indices	Timescale required
Precocity of phenology	GDD, AvGST	Month, day, hour
Potential of a territory to produce wines of a certain style	WB, RR (flowering-harvest), ET_0, AMP., Min, GDD, AvGST	Month, day, hour
Water management	WB, RR (vegetative period), ET_0	Month, day, hour
Crop protection	TM, RH, DH, Crop protection models	Day, hour
Frost threat	TN, TS, GDD	Day, hour
Extreme heat threat	TX	Day, hour

Table 2. Climate data and agroclimatic indices relevant for climate-based vitiviniculture zoning according to objectives and desired scale. ACRONYMS USED: AvGST: Average growing season temperature; WB: water balance; DH: Duration of humidification; ET0: Reference (potential) evapotranspiration; GDD: Growing degree days and its derivatives (Winkler's index, Huglin's index,...); AMP: Indices based on the temperature range in the ripening period; MIN: Indices based on temperature minimums in the ripening period; RH: Relative humidity; RR: Cumulative rainfall; TM : Average air temperature; TN: Minimum temperature; TS: Surface temperature; TX: Maximum temperature (source: working group OIV).

Climatic zoning can be based on a selection of several relevant indices. For instance, the Multicriteria Climate Classification of Tonietto and Carbonneau [4] combines the use of the the Huglin's Index, a Water Balance and a Cool Night Index.

4.3 Identify climatically homogeneous zones

While soil zoning is mainly based on qualitative data (soil types), climate zoning is based on quantitative data. Spatial variability among the climatically homogeneous zones must be greater than the mapping error. Zoning should be based on criteria that are relevant for viticulture.
Climate varies from year to year (vintage effect). Hence, zoning should be based on a sufficient number of years. For some climatic parameters which are highly variable from year-to-year and which show little redundant spatial structures, like rainfall, a great number of years is necessary (ideally 30). Other climatic parameters, like temperature, show greater spatial stability. Zoning based on a limited number of years can be acceptable for these parameters when the objective is the identification of climatically homogeneous zones inside the area (5 years). However, when the zoning aims at comparing the climate of the study area with other winegrowing regions, it should be based on 30-years averages.

5 VALIDATION OF TERROIR ZONING

The relevance of terroir zoning can be validated by various methods
- By eco-physiological studies. These aim at studying the behaviour of the vines (precocity of phenological events, vigour, grape ripening) in relation to environmental factors (soil and climate). Many aspects of vine behaviour can be explained by its water and mineral status (particularly nitrogen) and by air temperatures. Eco-physiological studies can be either punctual (network of reference plots) or spatialized (maps of vine vigour, vine water status, vine nitrogen status, berry compounds at ripeness);
- By sensory analyses of wines produced in the various demarcated zones;

6 CONCLUSION

Clear objectives have to be defined prior to choosing a terroir zoning methodology and the appropriate scale at which the study will be implemented. A scale of 1/5,000th is appropriate for zoning at the estate level, while 1/10,000th or 1/25,000th is appropriate for zoning at an appellation level. Highly relevant zoning at the soil level can be obtained by combining geology, geomorphology and pedology (soil science). However, when only one of these disciplines is chosen for the implementation of the study, pedology should be preferred. In climate zoning, relevant agro-climatic indicators must be selected and averaged over an appropriate number of years. Quality of source data is a critical issue. Differences among identified homogeneous zones must be greater than intra-zone uncertainty.

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Geostatistical analysis of the vineyards in the canton of Geneva in relation to soil and climate

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ABSTRACT
Soil and climate maps at the 1:10000 scales exist for more than 12'000 ha of Swiss vineyards. The use of these maps as consulting tools for growers remains difficult due to the complexity of the relationship between terroir and the large number of grape varieties planted. The current distribution of varieties and rootstocks is the result of a long optimization process. This study aims at analyzing the relationships between grape varieties, soil characteristics and climatic conditions.
The study was performed on the 1365 ha of Geneva's vineyards with 3885 digitalized parcels. The 19 grape varieties planted on at least 5 ha were matched with the soil and potential radiation maps. The surface of each variety-soil combination and the mean radiation were calculated for each parcel.
The analysis showed that grape varieties were primarily planted according to meso-climatic conditions. Late ripening varieties, like Syrah or Merlot, were always planted on parcels receiving higher amounts of radiation than those planted with Pinot noir or Gamaret. Minimum radiation was calculated for each variety. Traditional grape varieties (e.g. Gamay or Chasselas) were planted in all meso-climates, indicating that the warmest plots were not judged to be too warm for early varieties. Regarding soil characteristics, early varieties were more present on BRUNISOL, which mainly represented flatter areas of the vineyards (10% mean slope) and late varieties on steeper areas (mainly CALCOSOL with 16 % mean slope).
The present study revealed actual practices and criterions used by growers to make planting decisions. It might indicate minimum climatic and soil requirements for a given variety in the canton of Geneva. Continued monitoring may show the adjustments made by the growers to correct unsuccessful planting decisions. The analysis of these adjustments provides useful information for vineyard consultants.

Keywords: grape varieties, soil, climate, terroir, SIG, geostatistic, Geneva.

1 INTRODUCTION

Climatic conditions, soil type, ecological and cultural objectives possibly lead to a diversification of planted grape varieties, if permitted by law. Of the many terroir surveys conducted, some focused on mapping soils or geological factors (1, 2, 3) others on the grapevine's reaction to different climatic conditions or soil characteristics (4, 5). Recently, terroir studies using Geographic Information Systems were performed in order to visualize spatial patterns of climate and soil properties (6, 7, 8). However, none of the studies used detailed partitioning of the varieties in the landscape in an extended area. The possibilities of performing experiments to test all soil-variety combinations are limited. Despite the large amount of information available, choosing the right grape variety remains a main concern to the producers.
The vineyards in the canton of Geneva were mapped with high precision (9). In addition, the planting partitioning of the grape varieties was digitalized and covers almost 95% of the surface for official purposes.
The aim of this study was using the considerable amount of information in order to gain knowledge on the adaptation potential of a grape variety within a region. This analysis may add information to the minimum requirements necessary for sufficient fruit quality and the best variety-rootstock combination for the climatic conditions and soils of the region. Two main questions were assessed: (i) do the parcels planted with the same grape varieties and/or rootstocks have something in common regarding climatic conditions or soils? (ii) Is this proposed analysis method helpful in the decision making process concerning variety-rootstock combination for a given parcel?

2. MATERIALS AND METHODS

Soil maps (1:10000, soil type and geology) and digitalized maps of the 3885 parcels in the canton of Geneva (showing variety, rootstock, and planting year) were used. A digital elevation model (DEM) with 1m resolution was extrapolated to a 5m resolution map to simplify the calculations.
The surface planted each year and the partitioning by variety was calculated from the parcel vector file. Mean potential radiation for April and June, integrating