MAPPING NATURAL TERROIR UNITS USING A MULTIVARIATE APPROACH AND LEGACY DATA

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Abstract

This work aimed at setting up a multivariate and geostatistical methodology to map natural terroir units of the viticultural areas at the province scale (1:125,000).
The methodology was based upon the creation of a GIS storing all the viticultural and oenological legacy data of experimental vineyards (1989-2009), the long term climate data, the digital elevation model, the soilscapes (land systems) and the legacy data of the soil profiles.
The environmental parameters related to viticulture, selected by an explorative PCA, were: elevation, mean annual temperature, mean soil temperature, annual precipitation, clay, sand and gravel content of soils, soil water availability, redoximorphic features and rooting depth.
The selected variables, spatialized by means of geostatistical methods, were used for a k-means clustering aimed to map the Natural Terroir Units (NTU). The vineyard of the province of Siena was subdivided into 9 NTU.
Both the historical DOCG (Chianti Classico, Brunello di Montalcino and Nobile di Montepulciano) and the others DOC were mainly characterized by three or four NTU, whereas the wider Chianti and Chianti Colli senesi DOCG was mainly constituted by seven NTU.

Keywords: GIS, kriging, PCA, clustering, soils, Sangiovese, wine, Tuscany, Italy.

1 INTRODUCTION

Natural Terroir Unit (NTU) is a volume of earth's biosphere that is characterized by a stable set of variables related to the topography, climate, geology and soil (Laville, 1993).
Methods to study the association soil-climate-vines are numerous (Van Leeuwen et al. 2004; Tomasi et al. 2006; Carey et al. 2008; Martínez-Vidaurre et al. 2012), but the main questions are always: which variables are actually important for the quality and the typicality of grapevines, and then wine? How many terroir units can describe a territory?
The environmental functional parameters for grapevine vary according to the territory scale of the evaluation (Vaudour et al. 2002; Van Leeuwen et al. 2010). The choice of the mapping scale depends on environmental and viticultural data availability, but also on the objective pursued. In practice, the scale of the terroir mapping is a compromise between the required precision and the available data.
In this work, we presented a methodology to map Natural Terroir Units (NTU) of the province of Siena, based on a multivariate-geostatistical approach and legacy data. The NTU map, recently published (Priori et al. 2014), wants to show the variability of the environments and soilscapes within the DOC and DOCG territories.

2 MATERIALS AND METHODS

The study area was the Siena province in the Tuscany region (Central Italy). Five DOCG districts are placed in the province: "Vernaccia di San Gimignano" (the only DOCG white wine), "Chianti Classico", "Chianti Colli Senesi", "Vino Nobile di Montepulciano", "Brunello di Montalcino" (Figure 1). Twelve DOC are also situated in the province (Terre di Casole, Grance Senesi and Orcia among others).
The reference grapevine cultivar was "Sangiovese", which is the most important cultivar of the region and represents about 67% of the total vineyards.
The climate, typically Mediterranean, is strongly influenced by the variable topography. The lower mean annual temperature is located around the Mount Amiata (9-12 °C, 1700 m a.s.l.), whereas the higher mean annual temperatures (14-14.5 °C) is localized in the Elsa, Arbia, Ombrone and Orcia river valleys. Long term annual precipitation ranges between 630 (Orcia and Arbia rivers valleys) to 1275 mm (Mount Amiata).
The methodology was based upon the creation of a GIS storing several viticultural and oenological legacy data of 55 experimental vineyards (vintages between 1989-2009), the long term climate data, the digital elevation model, the soil-landscapes (Land Systems) and the soil profiles (724 profiles, 701 augerings and observations) with the soil analysis.
The viticultural data belong to several projects of viticultural zoning at different scales and the vintages span between 1989 and 2009 (Costantini et al. 1996; Costantini et al. 2006; Costantini et al. 2010; Priori et al. 2013), and they had viticultural monitoring for a minimum of 3 vintages. The selected viticultural parameters were: a) *°Brix*; b) *°Brix/day*,

from veraison to harvest; c) *Tacid*, Must titratable acidity as tartaric acid g L^{-1}; d) *GYV*, Grape yield per vine in kg; e) *nBV*, number of bunches for vine; f) *MBW*, mean bunch weight in g; g) *100bW*, mean weight of 100 berries in g.
The land units of the "Land Systems" are polygons delineated by the photo-interpretation and represents a particular association of land elements, the smallest landscape components classified according to lithology, geomorphology and land use.
To investigate the relationships between soil, morphology, climate, pedoclimate and viticultural features, a multivariate approach was chosen. Two exploratory Principal Component Analysis (PCA) were performed: i) relating climate, pedoclimate and morphological features with the viticultural data; ii) relating the main soil features and viticultural data. The factors chosen for the data elaboration were the factors that explained more than 10% of the total variance. The variables with a factor loading higher than 0.5 (in absolute value) were selected as explanatory variables of the terroirs mapping model.
The environmental parameters related to viticulture were: elevation, mean annual temperature, mean soil temperature, annual precipitation, clay, sand and gravel content of soils, soil water availability, redoximorphic features and rooting depth.
The selected variables were interpolated by means of geostatistical methods, using land systems polygons (1:100,000), the information of the soil observations database (1,425 observations) and of the Topographic Wetness Index (TWI), derived from Digital Elevation Model. Three geostatistical methods were tested for the interpolation of the selected pedological parameters: regression kriging (RK) using TWI as predictive variable (Hengl et al. 2004), simple kriging with varying local means (SKLM) using the mean values of the land systems as secondary variable (Castrignanò et al. 2009) and multicollocated simple cokriging with varying local mean (MSCLM), using both TWI and the mean values of land systems (Rivoiraid 2001).
The geostatistical methods, chosen on the basis of the lower mean error (ME), were:

- RK to interpolate the rooting depth;
- SKLM, to interpolate coarse fragments and redoximorphic mottles depth;
- MSCLM, to interpolate AWC, clay and sand content;

The map of the viticultural areas within the province was extracted from the Corine Land Cover 2006.
A k-means cluster analysis was performed in the viticultural areas, using the selected variables maps standardized from 0 to 1. The right number of clusters was set after a V-fold cross-validation by means of Statistica 10 software (StatSoft Inc., USA), using the smallest percentage decrease of cost function in the scree plot > 2%.

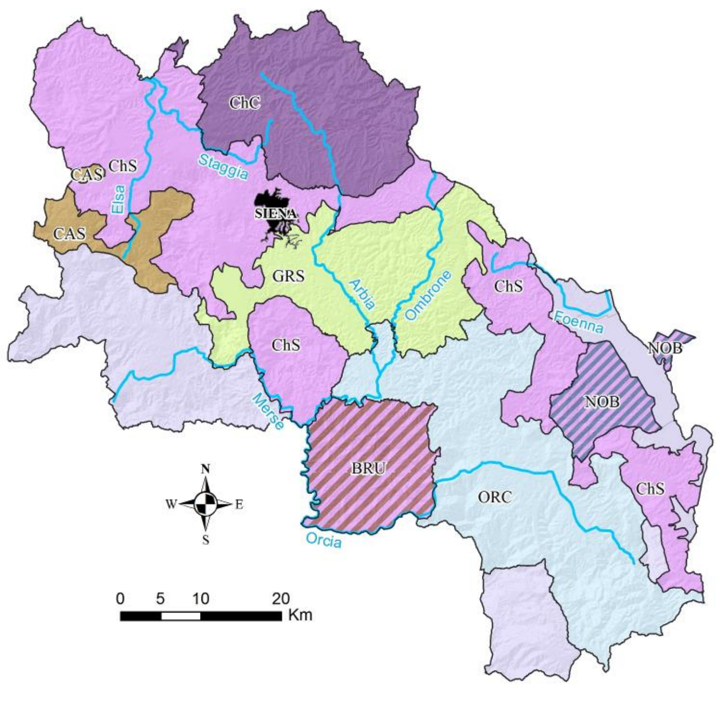

Figure 1: Topographic sketch of the province of Siena, with the red wines DOC (ORC- Orcia, GRS- Grance senesi, CAS- Terre di Casole) and DOCG areas (BRU- Brunello di Montalcino, NOB- Nobile di Montepulciano, ChS- Chianti and Chianti Colli Senesi, ChC- Chianti Classico). The area of Chianti Colli Senesi DOCG included the areas of Brunello di Montalcino DOCG and great part of the Nobile di Montepulciano DOCG.

3 RESULTS AND DISCUSSION

The two exploratory PCA (Tab.1) demonstrated that, using a multivariate approach, the variables more correlated with the mean viticultural parameters were sand, clay, gravel content, AWC, rooting depth and redoximorphic mottles depth for the soil, and elevation (H), annual precipitation (AP), mean annual temperature (MAT), mean annual soil temperature (MST) and Winkler index (WI) for the climate, pedoclimate and morphology. These last two variables (MAT and WI) were very strongly correlated (r = 0.96), therefore we decided to select just the mean annual temperature.
In particular, °Brix and °Brix/day are mainly correlated to sand, gravel content, and annual precipitation; must acidity (TAcid) is mainly correlated to AWC, mottles depth and elevation (H); mean bunch weight (MBW) mainly to AWC and mean soil temperature (MST); berry weight (100bW) to soil depth.

Table 1: Exploratory PCA factor loadings and explained variance (n=55). Climatic-pedoclimatic-morphological data: WI-Winkler Index, AP-Annual Precipitation, MAT-Mean Annual Temperature, MST-Mean Soil Temperature, SAI-Soil Aridity Index, H-Elevation, SL-Slope, TWI- Topographic Wetness Index. Soil features: AWC- Soil Available Water Capacity, CSC-Cation Exchange Capacity, OC-Organic Carbon. Viticultural parameters: °Brix- must sugar content (°Brix), °Brix/day- grape sugar accumulation (°Brix day-1), TAcid -must titratable acidity (g L-1), GYV-Grape yield per vine (Kg), nBV- number of bunches per vine, MBW- mean bunches weight (g), 100bW- mean weight of 100 berries (g).The factor loadings positive and > 0.5 are highlighted in dark grey, the negative < -0.5 in pale grey.

Factor loadings (soil parameters)			
	Factor 1	Factor 2	Factor 3
Sand	0.623	0.745	-0.076
Clay	-0.485	-0.626	0.306
Gravel	0.557	0.082	-0.358
AWC	-0.566	-0.717	-0.069
Soil depth	-0.020	0.179	0.827
Mottles depth	0.411	0.617	0.067
Ca	-0.149	-0.301	-0.394
CSC	0.126	-0.473	0.293
°Brix	0.725	-0.338	0.056
°Brix/day	0.721	-0.508	-0.051
Tacid	-0.500	0.557	0.045
GYV	-0.742	0.387	-0.064
nBV	-0.454	0.275	-0.404
MBW	-0.671	0.289	0.150
100bW	0.229	0.228	0.633
Explained variance	26.9%	21.7%	11.7%
Cumulated variance	26.9%	48.6%	60.3%

Factor loadings (climate-morph.-pedoclimate)		
	Factor 1	Factor 2
WI	-0.107	0.954
AP	0.621	-0.259
MAT	-0.136	0.961
MST	-0.510	0.477
SAI	-0.197	0.438
H	0.024	-0.953
SL	0.172	0.139
TWI	-0.210	0.010
°Brix	0.785	0.227
°Brix/day	0.818	0.286
Tacid	-0.602	-0.590
GYV	-0.843	0.016
nBV	-0.585	-0.057
MBW	-0.710	0.058
100bW	0.218	-0.108
Explained variance	28.5%	26.8%
Cumulated variance	28.5%	55.3%

The pedological variables selected by the PCA were physical and hydrological soil features. Clay, sand and gravel content constitute the physical characteristics of the soil, AWC the maximum available water for the plant and rooting depth the volume of the soil that is explorable by the roots. Redoximorphic mottles depth is inversely related to drainage, since, in general, shallower mottles leads to slower drainage and more frequent water-logging. All the interpolated maps show high precision and low mean square standard errors, which span between 0.93 and 1.12% for sand, clay and gravel content, 1.1 mm/m for AWC, and between 0.89 and 1.13 cm for redoximorphic mottles and rooting depth.
The six maps of soil features (clay, sand, gravel content, AWC, redoximorphic mottles and rooting depths) and the four maps of climatic, pedoclimatic and morphological data (MAT, MST, AP and H), masked for the viticultural areas, were used for the k-means clustering, (Figure 2). According to the V-fold cross validation, the maximum number of cluster groups significantly differentiated was 9.
NTU numbers are related to elevation, with NTU 1 and 2 the lowest terroirs, with NTU 8 and 9 at a higher altitude (fig. 3). Clearly, the MAT and MST reflected the altitude trend, therefore NTU 1 and 2 are the warmest and 8 and 9 the coldest. NTU 3, 6 and 9 show the highest annual precipitation (> 800 mm), whereas the others have an AP of about 700-750 mm. From a pedological perspective, NTU 2 and 7 have the highest clay content and the lowest internal drainage (redoximorphic mottles depth of about 90 cm). The most sandy soils are in NTU 8 and 9, whereas the more gravelly are in NTU 6, 7 and 9. The highest soil AWC are NTU 1, 2, 3 and 4, the lowest in NTU 6 and 9. NTU 9 also has the shallowest soils (rooting depth < 75 cm) and the highest internal drainage.

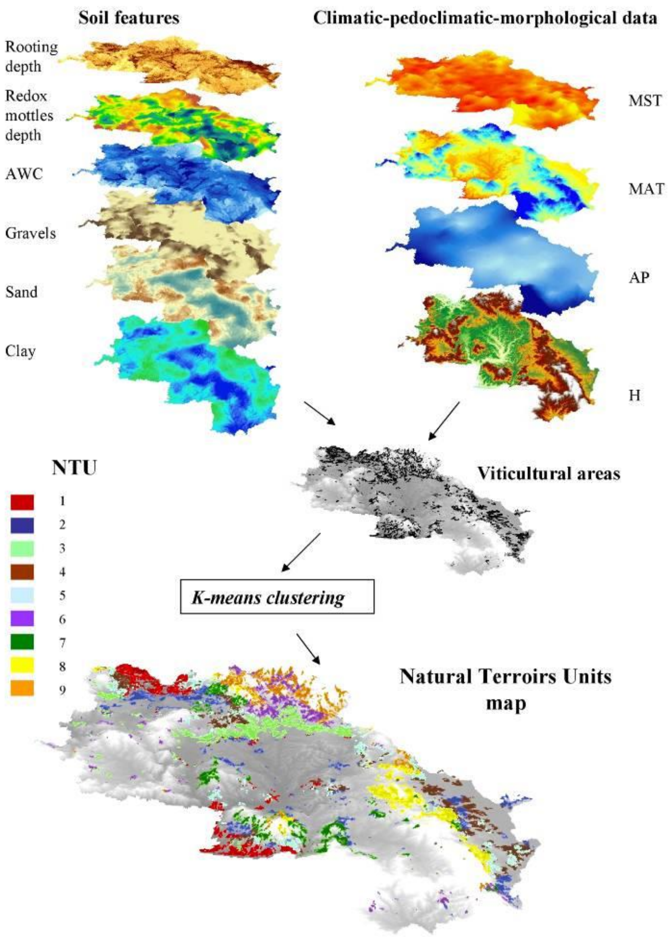

Figure 2: Maps used for the k-means clustering to obtain the Natural Terroirs Units (NTU) map (Priori et al., 2014).

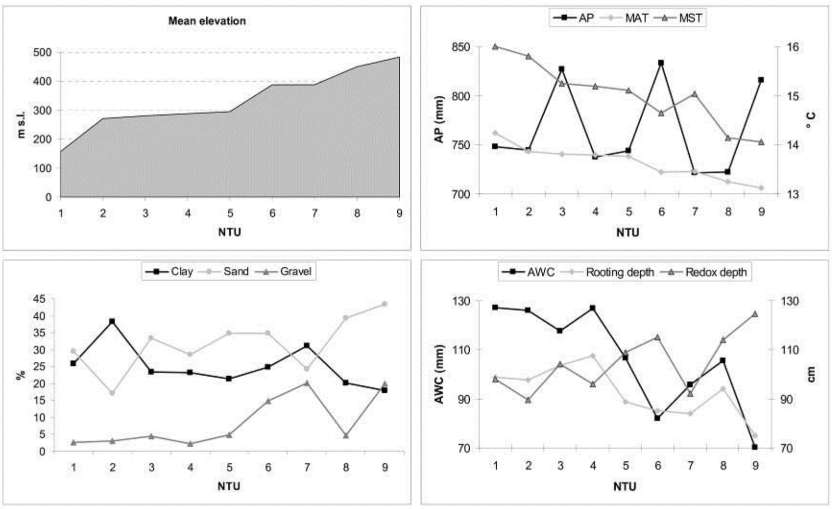

Figure 3: Mean values of the variables used for the clustering in each NTU.

4 CONCLUSION

The vineyard areas of Siena province was subdivided into 9 NTU, statistically differentiated for variables: elevation, mean annual temperature, mean soil temperature, annual precipitation, clay, sand and gravels content, soil water availability, soil internal drainage (redoximorphic mottles depth) and rooting depth.

The study demonstrated the strength of a multivariate approach for NTU mapping at province scale (1:125,000), using viticultural legacy data.

Principal component analysis is a good statistical approach to observe the statistical multivariate relationships between viticultural data and environmental variables, and to remove the not-significant variables.
K-means clustering with V-fold cross validation allow to calculate the right number of groups statistically discriminated, and then to group the variables in Natural Terroir Units.
Identification and mapping of terroir diversity within the DOC and DOCG at the province scale suggest the adoption of viticultural subzones. The subzones, based on the NTU, could bring to the fruition of different wine-production systems that enhanced the peculiarities of the terroir.

Aknowledgements

The authors are grateful to the "Province of Siena" for funding the project of viticultural suitability at provincial scale, performed in 2004-2006. The authors want also thank the wineries "Barone Ricasoli", "Il Poggione", "Fattoria dei Barbi", "Le Fonti", "Trecciano", "Castello di Modanella", "Colle di Trequanda", and "Campriano", the Cetona cooperative and all the other farms that collaborated in this work.

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