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Original paper

Geographic databases used to monitor vineyards. A case study

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Abstract

Geographic information systems (GIS) are increasingly being applied on a large scale. In the last decade, the technologies of processing the GIS have been successfully used worldwide in vineyards. GIS applications have as a final result the improvement of the wine production, improving not only the quantity but also the quality of wine. The purpose of the article is to provide a current overview of the role of geospatial technologies associated with viticulture. We analyzed Dealu Mare vineyard: six locations of the site, adequacy analysis and identification of vineyard land use. The research was carried out using the digital model (DEM) with a resolution of 30 m. The research focused on obtaining within the studied wine area the following maps: hypsometric, slopes, geology, land use and soils maps, with the program ArcMap 10.5. Geospatial techniques allow the study of natural spatial variability and winegrowers and enologists should also understand why these vineyards are unique in the studied geographical area thanks to the close link between altitude, slope and the soil type.

Keywords

Geographical Information Systems (GIS), viticulture, geomorphological mapping, hypsometric map, slope.

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Introduction

The application of Precision Agriculture (PA) techniques in viticulture is relatively recent (BRAMLEY & PROFFITT [1]; WAMPLE & al [2]). After 1999, the concept of Precision Viticulture (PV) began to have an impact on the wine – growing sector. The objectives of (PV) coincide with those of PA: crop management, an increase in economic benefits and at the same time reduction of environmental impact (ARNÓ & RIBES-DASI [3]).

A large number of factors influence the quality and quantity of the grapes in the vineyard, so it is difficult to assess the winemaking potential and the delimitation of natural *terroir* units. In Romania, more than 40 environmental parameters can be identified by the viticultural literature that correlates with vine growth and fruiting (IRIMIA & al [4], OSLOBEANU & al [5] DAVIDESCU & al [6]). The GIS can be seen as a useful tool in agriculture as some goals can be reached more easily by monitoring input and output data. Thus, it can also reduce the negative effects on the environment (IRIMIA & ROTARU [7] BLACKMORE [8]; SUDDUTH [9]).

Precision Agriculture (COOK BRAMLEY [10], PIERCE & NOVAK [11]) involves the collection and use of large amounts of data on crop performance and attributes of individual production areas (fields, swamps, blocks, etc.). A series of generating technologies are critical to this new approach to agriculture. These include the Global Positioning System (GPS), Geographic Information Systems (GIS), performance monitors, and a range of remote and proximity detection technologies that, together with GPS, enable the collection of georeferential records of mid-season crop performance and, also “on the move” during harvest. Thus, producers have the ability to better observe and develop understanding of variability in their production systems and to use this to better match inputs to desired or expected outputs.

Another important tool is satellite remote sensing which has applications in various fields, including monitoring of different areas of vineyards. Remote sensing offers to PV a wide range of observations to describe the vineyards spatial variability with high-resolution and offer suggestions for improving management efficiency in terms of quality, production and sustainability. The most common index that analysts use in remote sensing is NDVI (Normalized Difference Vegetation Index) quantifies vegetation by measuring the difference between near infrared (which vegetation strongly reflects) and red light (which vegetation absorbs) (ZARCO-TEJADA & al [12]).

Today, technological developments have allowed useful tools to be elaborated that help in the monitoring and control of many aspects of vine growth (MATESE & Di GENNARO [13], COSTE & al [14]). PLANT ([15]) recommended mapping the sampled variables to the site, using geostatistical methods and a reference grid (raster map or surface map) using the spatial variability structure of the sampled data (variogram) and an interpolation method (kriging). Maps constructed at parcel level usually display clear spatial variability (BRAMLEY & HAMILTON [16]). On the line of *terroir* (French idea) these areas normally differ between them in terms of soil properties, slope and microclimate. Through an iterative process this procedure enables the clustering of values interpolated from the maps into homogenous groups (classes) in relation to the variables chosen for the analysis.

The objective of this research has been to realize the hypsometric, slopes and geology maps for the cultivation of the vine in the Dealu Mare vineyard using the information stored in the GIS and treated with software application (digital elevation model (DEM) and ArcGIS 10.5 Program), that make data interpretation and appropriate management.

Materials and Methods

One of the most used notions introduced in the world of wine is that related to “viticultural *terroir*”, that is a French concept embodying all the distinctive features of a particular wine-growing region with effect on the taste and quality of the wine. Generally, this concept describes the characteristics of the region: climate, soil, geography and tradition as they form the typical hallmark of the place that can be recognized in the taste of the wine. With a complex significance, the “*terroir* of a wine” is considered by connoisseurs to be a very important aspect of the “wine identity”. The *terroir* is an umbrella concept that incorporates all the distinctive features of a particular wine-growing region with an effect on the taste and quality of the wine. Generally, it is used to describe how the characteristics of the region – climate, soil, geographical position and tradition – influence the wine produced here (DOUGHERTY [17], LEEUWEN & SEGUIN [18], DEL SANTO & al [19]).

The studied areas were Prahova and Buzau zones as they are representative of the grapes and wine production.

The Prahova area owns 4716 km²; it is located on the southern slopes of the Southern Carpathians, with all the relief forms. According to NIS (National Institute of Statistics) data, the agricultural area is 268,993 hectares. On categories of use, the agricultural area is divided into: arable 142,872 hectares, natural pastures (69,167 hectares), natural meadows (39,464 hectares), vineyards (8,175 hectares) and orchards (9,315 hectares).

The climate depends on the level difference that is more than 2400 meters from the Omu peak. The highest point in the Prahova area, and the lowest point in the plain, as well as the arrangement of the relief in the *amphitheater*, makes the climate elements to vary from region to region. The annual average air temperature varies within the area between less than minus 2°C in the region of the highest heights in Bucegi and above 10°C in the plain region, which results in an increase of about 13°C. Between these extremes, the annual average temperature has intermediate values, depending on the altitude of the relief.

The annual rainfall average is distributed in a varied way on the territory of the area, depending on the overall air circulation and the relief's conformation and altitude. A number of local conditions introduce a variation in rainfall detail distribution, especially the prominent masses; the slopes with western and northern exposure have faced increased rainfall compared to those exposed to the south and east. The most abundant precipitations occur in June, when the humid air of oceanic nature reaches Romania and it is accompanied by powerful convection processes whose consequences are torrential rains. In this case, the values rise from the plain to the mountains as follows: Ploiesti - 588 mm, Campina - 120.6 mm, Sinaia - 126.2 mm, the Omu Peak - 173 mm.

The circulation of air is different in height and on the ground, where the relief is an obstacle to the wind. The vertical variation of all climate elements allows the vertical differentiation of some climate phenomena. The influence in the wine sector is the hill climate, which manifests in the altitude range of 400-1000 m, characterized by annual average temperatures between 6-9°C and precipitations of 600-800 mm year. It also influences the plain area located in the southern part of the studied area with the annual average temperatures of 10°C and precipitations between 550-600 mm/year.

Climatic conditions area an important factor in viticulture, which has a significant impact on the yields, the quality of the grapes and also on the wine quality. Using the climatic data it is possible to correlate the slope exposure with the amount of precipitation and the temperature in order to obtain a higher yield in the vineyards areas.

The Buzau area is located in the eastern part of Romania and covers an area of 6102.6 km² (610,053 ha), out of which 208,260 ha of non-agricultural land, and 401,793 ha of agricultural land, out of which 257,203 ha of arable land (2.7% of the country's arable land, 16th on the area).

Buzau area covers almost all the river basin of the Buzau River, which has the source in the Carpathian Curvature. On the territory of the area there are the three relief forms arranged as follow: in the North the Buzau Mountains, which are part of the Carpathians of Curvature, in the South there is the plain region belonging to the Romanian Plain. Between these two forms of relief there is the hills area, some of these hills descend to the South having the South Mediterranean climate which is favorable for viticulture. The area covered with vineyards is 14,295 ha.

The climate is temperate continental, in general climate specific to the Romanian country. It is characterized by high temperature between the summer and winter season and the humidity are low. In Buzau, the strong winds are from the North East. The wind brings masses of cold air with effects on the temperature in winter. The area is also characterized by extreme phenomena such as long-lasting and abundant torrential rains. The annual average temperature was 10.5°C and 12.5°C at ground level. The average temperature in July was 22°C, while in January drops below minus 3°C. In autumn the temperatures are higher than in spring. Knowing the climate potential of the area helps to take correct measures to eliminate the shortcomings caused by climatic factors during certain periods, for example the crop irrigation.

Climate determines the vineyard management practice. Long-term climate records of a particular vineyard are important in determining the row orientation, variety selection, harvesting period, phytosanitary measures application (CICHI [20]).

Methodology: the topographical map of Romania at 1: 25000 scales was scanned and geo-referenced into the stereographic projection system used in Romania. The Soil Map of Romania at 1: 200000 was presented in digital format including analytical data and digital elevation model (DEM) with a resolution of 30 m; the maps presented were created using the ArcGIS 10.5 Program. The DEM was downloaded free from ([www://geo-spatial.org](http://www.geo-spatial.org) [21]) and all the used vectors were downloaded free from (<http://www.opengis.org> [22]).

The use of land map was obtained from Corine Land Cover 2000 (<https://land.copernicus.eu/pan-european/corine-land-cover/clc-2000> [23]). CLC 2000 is the European reference data set which covers the land and it has 44 distinct classes grouped into three hierarchical layers. The Satellite database for achieving CLC 2000, known as IMAGE 2000, was LANDSAT ETM+images (BALTEANU & SERBAN [24]).

Results and Discussions

The evolution of GIS offers enormous potential for the development of different solution for distributed information by PV.

The studied area "DEALU MARE"/"THE BIG HILL", it is a part of the wine-growing zone CII, according to the Order 645/2005 regarding the approval of the Romanian wine-growing regions in the wine-growing areas of the European Union. The wines produced in this area have specific characteristics and a reputation which is attributable only to this area (MATEI-RADOI & al [25]). The grapes come in 100% from this geographical area. The oenological practices and treatments are carried out according to the legislation in force. The wine produced in the studied area has an actual alcohol content of at least 11% vol, depending on the quality of the grapes in the ripening phenophase as it is given by the sugar content (TOTI, & al [26]).

From a geographic point of view, Dealu Mare vineyard is part of wine sectors located between 44°59'-45°32' northern latitude and 26°02'-27°00' eastern longitude (Figure 1).

Figure 1. Geographical positions of six locations (yellow pins) in Dealu Mare vineyard area from Google Maps.

In relation with the hills orientation and the slopes exposure suitability we analyzed six different areas in Dealu Mare vineyard (Table 1).

Table 1. Geographical location in Dealu Mare area of six studied vineyard

Vineyard area	Surface (ha)	Geographical location
Sahateni winery	76 (60.3 ha fructification)	Muntenia hills
Dealu Mare vineyard	61 ha in property 29 ha in lease	Bucovelul Hills
Blaga domains	43	Ceptura Hills
Divine Area	64	Big Hill - Breaza
Halewood wine cellars	145	Big Hill
Ceptura wine cellar	200	Ceptura Hills

The following maps were elaborated for the Dealu Mare vineyard: hypsometric, slopes, geology, land use and soils maps. This unique vineyard in the studied geographical area exists thanks to the close link between the altitude, slope and the soil type.

The hypsometric map was the first elaborated map (Figure 2). The role of this map is to show how altitude varies across the studied area. In Prahova and Buzău countries the altitude is between 19-2498 m.

The area is divided into ten altitudinal classes. And the most part of the Dealu Mare vineyard area, which is situated in the middle part of the two countries, the altitude is between 150-500 m.

Figure 2. The hypsometric map of the Dealu Mare vineyard (six locations - black points)

The region where the wineries are situated creates favorable conditions for the development of vineyard plantations.

Analysing the hypsometric map can be observed that the predominant colour of the area is green which corresponds to an altitude between 19-500 m located in the south-east. This area occupies the plain and part of the hilly area. In the central area, the yellow colour predominates, having an altitude of 500-1000 m. In the north it is the mountain area with the red colour.

The slope map. A slope represents the morphometric characteristic which expresses the degree of inclination of the surfaces that come into the structure of the relief forms. The degree of inclination of a territory together with petrographic and structural characteristics is one of the most important requirements in the geomorphological assessment of the analyzed area, they also condition the intensity and types of processes are modeling the substrate.

From a geomorphological point of view, the Dealu Mare vineyard is part of the Curb Subcarpathians (Figure 3). In this area the vineyards are situated on the slopes of the hills and their depressions (TOTI & al [26]).

The study area has five slope classes: the green with values from 0-10 degrees, in the south. The yellow area (10-15 degrees) intersects with the red (25-59.7 degrees) occupying almost half of the surface.

Slopes are an important aspect of morphological analysis of the point of view of the influence of solar radiation and the temperatures of the area and progression geomorphological processes and will also affect the plant growth and development.

Figure 3. The slope map of the of the Dealu Mare vineyard (six locations - black points)

Table 2 shows the influence of the altitude and slope on wine production. It can be observed that if the altitude and slope have low values the wine quality and production is high.

Table 2. Wine production (hl) depending on the altitude (m) and slope (degrees) of Dealu Mare vineyard areas

Vineyard area	Altitude (m)	Slope (degrees)	Wine production (hl) (BOBOC & al [25])
Săhăteni winery	125	5-10	4000 (3000 hl are bottled)
Dealu Mare vineyard	134	5-10	4000 (2000 hl are bottled)
Blaga domains	150	10	2000 (700-1000 hl are bottled)
Divine Area	300	15	1500 – 2000 (1000 hl are bottled)
Halewood wine cellars	150	5-10	4000 (3500 are bottled)
Ceptura wine cellar	160	5-10	2000 (1500-1800 hl are bottled)

The direction a slope face is in relation with the sun and has a profound influence on the vegetation, as well as the exposure to the wind. And create condition for a microclimate of the valley. In other words, these are mini-climate zones different from the area around it. If you compare this to the opposite site, the north-facing slopes receive less direct sunlight because of its orientation.

The relief map. According to the map of the relief units shown in the figure 4 the studied wine-growing area is between the following relief units: Podeni Depression, Ceptura Hills, Valea Calugareasca Glacis, Ciortea Hill, Dealu Mare Hill, Pietroasele Glacis.

Figure 4. The relief map of the Dealu Mare vineyard (six locations - green points)

The geological map. From the geological point of view the Dealu Mare vineyard area is located on alluvial-proluvial and coluvial deposit (Figure 5).

Figure 5. The geological map of the Dealu Mare vineyard (six locations - black points)

The Dealu Mare vineyard area is crossed by southeast-oriented valleys, which delineate a series of nearly parallel hills, with an altitude of 134-170 m at the plain border and 460-550 m in the higher hills.

The general direction of the valleys in the N-S direction creates very favorable conditions for the vineyard cultivation, which occupies both sides of the hills. In this area most of the slopes have southern, south-eastern and south-western exposures.

The soil map. The pedological characterization demonstrated in the Dealu Mare vineyard there are a great varieties of soils, due to the active erosion processes that take place in this region (Figure 6).

Figure 6. The soil map of the Dealu Mare vineyard (six locations - black points)

The wines with controlled designation origin Dealu Mare owe their quality characteristics to the geographical environment, with its natural and human factors. The wines from Dealu Mare vineyard are mostly varietal wines; they have also different assembly formulas based on 2-3 wines.

In the table 3 are presented vineyard structure with the link between geological and pedological composition, and also the brands from this area.

The white wines from Dealul Mare vineyard are characterized by extractivity, balanced structure, good acidity, due to the south-eastern exposure of the slopes as well as the viticultural practices that maintain the productions at a moderate level. Red wines are characterized by fineness, light tannins, strong colour. These characteristics are influenced by the ecological and pedological conditions of the Dealu Mare area through the brown - red soils, rich in ferric salts.

Another important characteristic that determines the planting varieties according to adaptability are specific soil type to the vineyard and slopes exhibition.

In the western side of the Dealu Mare vineyard are soils formed on red clays, marl and on fine sands. Those soils have high iron oxides content. In this area are obtained red wines (Cabernet Sauvignon, Merlot, Feteasca neagra and Syrah), and also white wines varieties (Feteasca albă, Feteasca regală, Sauvignon blanc and Chardonnay).

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The eastern part of Dealu Mare vineyards presents sarmatic limestone, clays, sandstone and fine sands deposits are alternating with gravel. The area is favorable for red wines Pinot noir, Merlot and for white wines Riesling italian and Pinot gris. In the areas with skeletal soils that have high calcium carbonate are obtained the aromatic wines Tamaioasa romaneasca and Muscat Ottonel. The white grapes varieties and Pinot noir are planted in the Dealul Mare vineyard at the slopes base on eastern exhibitions where in August they are protected from solar burns.

The red varieties (Cabernet Sauvignon, Merlot and Feteasca neagra) are planted towards on slopes top because they love heat.

The land use map. The figure 7 shows the land use map of the studied area. The Geographic area Dealu Mare according to the map shows important areas of vineyards.

Figure 7. The CLC map of the Dealu Mare vineyard (six locations -black points)

Vineyards area according to CLC map has brown colour. In the southern part vineyards are bordered with fruit trees and berry plantations (pink colour). Near the vineyards there is a pasture area, in the north part.

The project's Land Use and Land Cover. Land use and land cover change have been among the most important perceptible changes taking place around us. Although perceptible, the magnitude, variety and the spatial variability of the changes taking place has made the quantification and assessment of land use and land cover changes (ROY & ROY [28]).

The spatial analysis using the geographic information systems of the studied area is based on six presented maps; these maps can be used to evaluate the viticulture potential of the studied area.

Table 3. Vineyard structure depending on the geological and pedological composition of Dealu Mare vineyard areas

Vineyard area	Geological composition	Pedological composition	Vineyard structure (BOBOC & al. [25])		
			Vine variety	Surface (ha)	Brands
Săhăteni winery	Coluvial deposit	Clays, sandy – clays with calcareous substrate	<i>Red varieties:</i> Feteasca neagra Cabernet Sauvignon Syrah Merlot Pinot noir Cabernet Franc	29.9	Domeniile Săhăteni Aurelia Vişinescu Nomad Artisan
			<i>White varieties:</i> Tamaioasa romaneasca Feteasca alba Feteasca Regala Riesling italian Chardonnay Sauvignon blanc Pinot gris	29.4	Karakter Anima Signum Arbora
Dealu Mare vineyard	Coluvial deposit	Reddish brown soils, neutral slightly pH to alkaline	<i>Red varieties:</i> Feteasca neagra Cabernet Sauvignon Merlot	49	Incantation Paganus
			<i>White varieties:</i> Muscat Ottonel Riesling italian Sauvignon blanc	38	Trei Pesti
Blaga domains	Coluvial deposit	Molic soil, clay soil	<i>Red varieties:</i> Cabernet Sauvignon Merlot Cabernet Franc	30.3	Domeniile Blaga
			<i>White varieties:</i> Feteasca alba Feteasca regala	5.1	
			<i>Mixture varieties</i>	7.6	
Divine Area	Aluvial – proluvial deposit	Reddish – brown, podzolic brown soils, slightly eroded on slopes	<i>Red varieties:</i> Feteasca neagra Cabernet Sauvignon Syrah Merlot Pinot noir Cabernet Franc	44.8	1000 de Chipuri Divine Area
			<i>White varieties:</i> Tamaioasa romaneasca Feteasca alba Riesling italian Chardonnay Sauvignon blanc	19.2	
Halewood wine cellars	Aluvial proluvial deposit	Brown eumezic soil	<i>Red varieties:</i> Feteasca neagra Cabernet Sauvignon Syrah Merlot Pinot noir Cabernet Franc	111.3	Prahova Valley Floarea Soarelui
			<i>White varieties:</i> Tamaioasa romaneasca Feteasca regala Riesling italian Chardonnay Pinot gris Sauvignon blanc Viognier	33.9	Floarea de Luna Rhea
Ceptura wine cellar	Aluvial proluvial deposits	Brown eumezic soil, brown luvic soil, regosol	<i>Red varieties:</i> Cabernet Sauvignon Feteasca neagra Syrah	140	Magnus Monte Cervus Cepturum Astrum Şoapta Călugărului Sângele Ursului
			<i>White varieties:</i> Feteasca regala Fetească albă Sauvignon blanc Chardonnay	60	

Conclusion

The aim of the research is to inform the state of the art of technologies in the field of precision viticulture. One of the advantages in the application of these innovative solutions is a cost reduction in crop management, by improving crop quality, the environmental sustainability with a rational use of the chemical inputs.

The area delimited for the study "DEALU MARE" / "THE BIG HILL" was represented for the first time on the hypsometric map. It shows how the altitude varies in the study area (150-500) demonstrating the typicality of this wine growing area.

The morphometric characteristic was represented by the slope, which is the most important requirement in the geomorphological evaluation of the analyzed area. It can be observed that if the altitude and slope have low values the wine quality and production is high.

The Dealu Mare vineyard is part of the Curb Subcarpathian and from the geological point of view this area is located on alluvial-proluvial deposit and colluvial deposit. The pedological characterization showed that in the western part of the map, the Dealu Mare massif has high iron oxide content which is indicated for the red wine variety cultivation. The erosion processes was demonstrated in the eastern zone of the map that is why only organic and mineral fertilizers are used in this area. The skeletal soil, with a high content of calcium carbonate favors the production of aromatic wines.

The geographical representation of the Dealu Mare shows important areas of vineyards.

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