ANALYSIS OF VITICULTURAL POTENTIAL AND DELINEATION OF HOMOGENEOUS VITICULTURAL ZONES IN A TEMPERATE CLIMATE REGION OF ROMANIA

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Abstract

Aims : To characterize the viticultural potential and delineate homogeneous viticultural zones in the Huşi wine growing region (Romania) in order to provide necessary information for viticultural zoning.

Methods and results : The methodology is based on a Geographic Information System (GIS) analysis of 15 ecological parameters, representative of the topography, climate and soils in temperate continental climate vineyards. Three homogeneous viticultural zones were identified : one suitable for quality white wines and red table wines ; one suitable for quality white wines ; and one suitable for white table wines, sparkling wines and wines for distillates.

Conclusion : In order to characterize the viticultural potential, it is necessary to assess the suitability of all ecological factors that influence the quality of the grapes. Omitting one ecological factor may lead to erroneous results in suitability assessment. Climate suitability determines altitudinal differentiation of the viticultural potential, while topographical and pedological suitability determines a horizontal differentiation.

Significance and impact of the study : This study provides the necessary information for viticultural zoning in the Huşi wine growing region in Romania. The methodology allows to evaluate viticultural potential and to delineate homogeneous viticultural zones in wine growing regions with a temperate continental climate.

Key words : Romania, wine growing region, zoning, Geographic Information System, grapevine

Résumé

Objectifs : Caractériser le potentiel viticole et délimiter les zones viticoles homogènes de la région de Huşi (Roumanie) afin d'obtenir les informations nécessaires pour réaliser le zonage viticole.

Méthodes et résultats : La méthodologie est basée sur une analyse SIG (Système d'information géographique) de 15 paramètres environnementaux, représentatifs de la topographie, du climat et des sols des vignobles dans un climat tempéré continental. Trois secteurs viticoles homogènes ont été identifiés : un secteur favorable pour les vins blancs de qualité et les vins de table rouges ; un secteur favorable pour les vins blancs de qualité ; et un secteur favorable pour les vins de table blancs, les vins effervescents et les vins pour distillats.

Conclusion : Pour caractériser le potentiel viticole, il est nécessaire d'évaluer l'adéquation entre tous les facteurs environnementaux qui influent sur la qualité des raisins. L'ensemble des paramètres environnementaux doit donc être pris en compte pour affiner les résultats, notamment la variabilité spatio-temporelle du climat qui est fortement influencée par la topographie (altitude, pente, exposition) et la pédologie.

Importance et impact de l'étude : Ce type de démarche scientifique fournit les informations nécessaires pour le zonage viticole dans la région de Huşi en Roumanie. La méthodologie permet d'évaluer le potentiel viticole et de délimiter les zones viticoles homogènes dans les régions soumises à un climat continental tempéré.

Mots clés : Roumanie, région viticole, zonage, Système d'Information Géographique, vigne

manuscript received 3rd April 2013 - revised manuscript received 16th March 2014

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J. Int. Sci. Vigne Vin, 2014, **48**, 145-167

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INTRODUCTION

Unlike other crops, whose efficiency is mainly determined by yield, the main criterion in viticulture, and particularly in wine grape varieties growing, is the quality of the crop. Another evaluation criterion is the presence of some features that give uniqueness to wines and allow recognition of their geographical origin. All the elements that define the value of the crop for wine varieties are subject to "vineyard viticultural potential". The term has a broader meaning defining both the suitability for vine growth and for high quality crops. Generally, an area is considered to have viticultural potential if it enables the growth of quality grapes for at least one type of viticultural production (e.g., table grapes or table wines, quality wines, sparkling wines, late harvest wines, etc.) (Irimia, 2012). When it comes to wine varieties, an area is considered to be suitable for producing quality wines if it ensures full ripening of grapes, with a consistent quality from year to year (Seguin, 1986).

Viticultural potential is determined by the complex interaction of all the ecological factors that interact in the vineyard : relief, climate, soil and subsoil. All of these factors determine the quality of the crop through the influence that they have on the composition of the grapes : temperature influences sugar, anthocyanin and malic acid content (Kliewer and Lider, 1970 ; Buttrose *et al.*, 1971 ; Coombe, 1987) ; thermal amplitude between day and night influences anthocyanin and aromatic content (Kliewer and Torres, 1972 ; Tomana *et al.*, 1979) ; precipitation can affect grapevine disease incidence/severity and berry maturation (Tregoat *et al.*, 2002) ; solar radiation influences anthocyanin, sugar and malic acid content (Buttrose, 1970 ; Kliewer, 1977 ; Crippen and Morrison, 1986 ; Dokoozlian and Kliewer, 1996) ; soil nitrogen content influences not only vigour, berry weight and sugar, anthocyanin and tannin content (Choné *et al.*, 2001 ; Hilbert *et al.*, 2003) but also the aromatic potential for white wine varieties (Peyrot des Gachons *et al.*, 2005) ; calcareous soil components influence phenolic compound content (Seguin, 1983) ; and clay favours anthocyanin accumulation (van Leeuwen *et al.*, 2004) and volatile compounds (Coelho *et al.*, 2009). Moreover, we can add relief, which, through its influence on climate (Gladstones, 1992 ; Dumas *et al.*, 1997), becomes a major factor in determining the viticultural potential.

Local variation of natural factors generating viticultural potential produces prominent vineyard-scale variability, which is reflected in the quality of grapes and wines. This is why vineyards are composed of numerous microareas with distinctive ecological profiles, which, in turn, produce distinctive wines with identifiable origins. The name given to these microareas is "natural terroir units" (Morlat, 1989). Because the term "terroir" involves "social and historical experiences and technical choices" (Vaudour, 2003), a more general term can be "homogeneous viticultural zones". Their analysis and delineation represent stages of viticultural zoning, where the main purpose is to delimit "designation of origin" areas in order to protect them (Vaudour and Shaw, 2005). This can also be useful for setting the best suited wine grape varieties assortments, selecting new vineyard sites and optimizing technical practices in vineyards.

The methodologies used to characterize and delimit the homogeneous viticultural zones have been documented extensively in previous works (Asselin *et al.*, 2001 ; Deloire *et al.*, 2005 ; Vaudour and Shaw, 2005). In this regard, the dominant methods are based on bioclimatic indices (Huglin, 1978 ; Riou, 1994 ; Tonietto and Carbonneau, 2004), soil and lithological characteristics (Seguin, 1986 ; Morlat and Bodin, 2006 ; van Leeuwen *et al.*, 2010), or their combined influence (Jacquet and Morlat, 1997). Given the multitude of ecological factors that determine viticultural potential and that need to be evaluated (Laville, 1993), in recent decades specific tools and methods of geomatics, particularly Geographic Information Systems (GIS), have been implemented for zoning studies. They allow the combined analysis of a virtually unlimited number of ecological parameters. GIS-based methodologies are especially used in young wine producing regions or countries to identify new areas with viticultural potential (Watkins, 1997 ; Boyer and Wolf, 1998 ; Olsen *et al.*, 2011), to assess the viticultural potential of new vineyards (Jones *et al.*, 2004), and for viticultural zoning (Jones and Duff, 2007, 2011 ; Carey *et al.*, 2008 ; Anderson *et al.*, 2012 ; Tomasi *et al.*, 2013). In established wine producing countries, GIS-based methodologies are used less and mainly for the characterization and delineation of terroirs (Pythoud, 2006 ; Herrera Nuñez *et al.*, 2011). GIS-based methodologies are complex, requiring the determination of the spatial distribution of the ecological factors in the vineyard, the development of an evaluation system for the suitability of ecological factors, and the establishment of an algorithm that allows the quantification of their combined suitability. Besides data accuracy, the results depend on the representativeness of environmental criteria, the scale at which they are represented, and the quality of the digital data layer (van Leeuwen *et al.*, 2010).

Our study presents the results of the evaluation of viticultural potential and the delineation of homogeneous viticultural zones in the Huşi wine growing region in Romania, by using a multi-criteria methodology based on GIS. This is the first study of its kind in Romania, a traditional wine producing country, located between 43°41'-48°26' N latitude and 20°14'-29°49' E longitude (Figure 1), in temperate continental climate Dfb and Dfa in Köppen-Geiger climate classification (Peel *et al.*, 2007). Previous studies (Irimia and Rotaru, 2009 ; Irimia and Patriche, 2010 ; Patriche *et al.*, 2011ab ; Irimia *et al.*, 2012, 2013) have developed the methodology used in the study presented herein. Overall, the aim of this research is to determine the viticultural potential of the Huşi wine growing region, to develop a viticultural zoning that will help identify the optimum location for wine grape varieties, and to optimize the training systems in the vineyard. This study was necessitated by the transition from state property to private property in Romania, which resulted in changes in vineyard management in the region.

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MATERIALS AND METHODS

1. Study area

The study area is the Huşi wine growing region located in the eastern part of Romania, at 46°65'-46°69' N latitudes and 28°02'-28°13' E longitudes (Figure 1). The surface of the wine growing area is 2 139 ha and includes four sub-regions (SR) surrounding the town of Huşi : SR1, 554.3 ha ; SR2, 570.6 ha ; SR3, 264.4 ha ; and SR4, 749.1 ha (Figure 1). The hilly landscape is characterized by a natural amphitheater with an eastern opening and slopes with elevations between 43 and 317 m above sea level (asl). The vineyards of SR1 and SR2 are located in a higher zone between 130-317 m asl, while the vineyards of SR3 and SR4 are located in a lower zone between 43-130 m asl. Traditionally, the Huşi wine growing region produces white wines from *Vitis vinifera* L. Feteasca albă, Tămâioasa românească, Fetească regală and Aligoté wine varieties.

The study covers seven stages : development of the evaluation system ; aquisition and spatial modelling of the ecological data characterizing the study area ; evaluation of the individual suitability of the ecological factors ; evaluation of the suitability of the ecological categories ; setting up the viticultural potential of the assessed area ; delineation of the homogeneous viticultural zones ; and validation. Two different datasets were used : (1) multiannual climate averages and literature data for the development of the evaluation system in the first stage of research and (2) the latest climatic averages and data computed based on digital elevation model (DEM) for the characterization and assessment of the Huşi wine growing region. The rationale of the methodology was to assess the viticultural potential by relating the current vineyard environmental conditions to the environmental profiles that generated the established viticultural specializations of the Romanian wine growing regions.

2. Development of the evaluation system

To set up the evaluation system, 15 ecological factors and bioclimatic indices, representative of the landscape, climate and soils of vineyards in a temperate continental climate (Dfb and Dfa in Köppen-Geiger climate classification), were chosen. They are (Table 1) : slope (S), aspect (A), average annual temperature (AAT), average temperature of the warmest month (TWM), global radiation (GR), actual sunshine duration (ASD), precipitation in the growing season (PP), sum of effective temperatures (Σt_u,°C), length of the growing season (LGS), actual heliothermal index (IHa), bioclimatic index (Ibcv), oenoclimate aptitude index (IAOe), clay content (Cly), humus content (Hum) and gravel content (Gra). The selected ecological factors are already used for viticultural zoning in Romania at macroclimate scale (Oşlobeanu *et al.*, 1991). The bioclimatic indices were selected according to their previous use in viticultural zoning (Constantinescu, 1967 ; Teodorescu *et al.*, 1987), their validation for characterizing wine growing regions with a temperate climate (Riou, 1994 ; Asselin *et al.*, 2001), and their ability to capture local variations, which allows a fine-scale analysis of the topoclimate.

The main characteristics of these 15 ecological parameters, described according to their influence on wine growing in temperate continental climatic conditions of Romanian wine regions, are :

Slope (S). It is defined as the land inclination that influences cold air drainage (Geiger, 1966) and the angle of incidence of solar radiation (Becker, 1985). Optimum slope inclination for grape growing is 8-15 % (Boyer and Wolf,

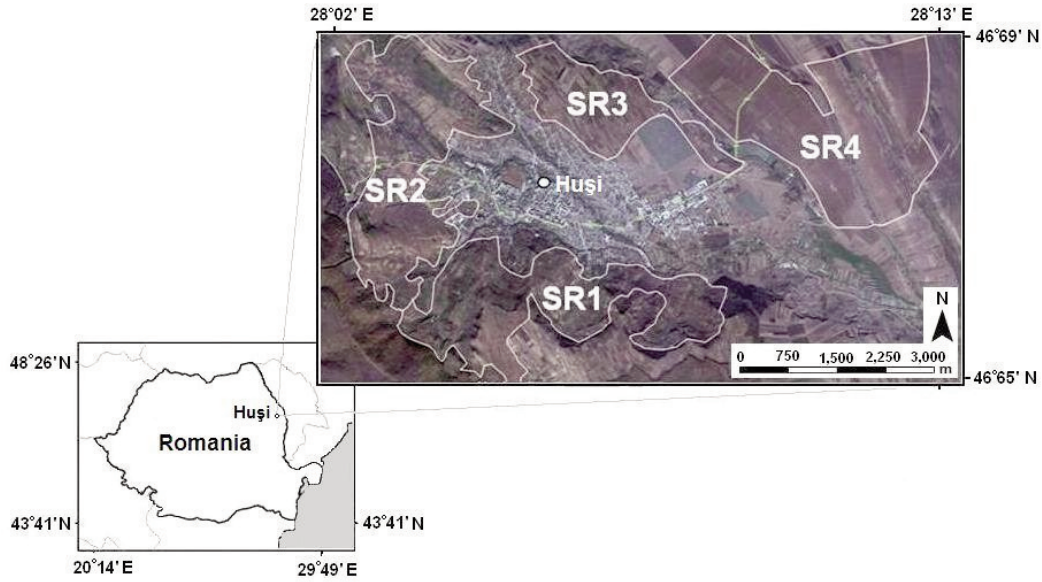


Figure 1. Location and structure of the Huşi wine growing region in Romania, as defined by four sub-regions : SR1 - 554.3 ha ; SR2 - 570.6 ha ; SR3 - 264.4 ha ; and SR4 - 749.1 ha. SR1 and SR2 = the higher zone ; SR3 and SR4 = the lower zone.

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1998 ; Jones *et al.*, 2004). Inclinations smaller than 8 % have poor cold air drainage and retain moisture, providing high but poor quality yields (Ţârdea and Dejeu, 1994) ; those higher than 15 % maintain their ecological suitability and are even more suitable at high latitudes (Becker, 1985), but they are prone to soil erosion and difficult to work (Boyer and Wolf, 1998 ; Jones *et al.*, 2004). By terracing, slopes up to an inclination of 40 % can be planted with vines (Galet, 1988), while those higher than 28 % are considered restrictive for grapevine growing (Jones *et al.*, 2004).

Aspect (A). It is defined as the direction in which the slope faces (Boyer and Wolf, 1998). In temperate continental climates of the Northern Hemisphere, south, southeast and southwest aspects are the most suitable, as they receive the greatest amount of global radiation (Becker, 1985) ; eastern and western aspects have suitable values ; and northern aspects present low levels of heliothermic resources, resulting in low quality potential.

Average annual temperature (AAT ; °C). In Romania, it varies between 11.2 °C in the southern wine growing regions (43°41' N latitude) and 9 °C in the northern ones (48°26' N latitude) (Oşlobeanu *et al.*, 1991), with averages as low as 8.5 °C for vineyards located at elevations exceeding 300 m asl (Irimia and Patriche, 2009). Averages higher than 10.0 °C allow obtaining quality wines, while those lower than 8.5 °C are restrictive for grapevine growing (Ţârdea and Dejeu, 1994).

Average temperature of the warmest month (TWM ; °C). It indicates the climate suitability for different types of wine production (Smart and Dry, 1980). In Romanian wine growing regions, it varies between 18 °C and 22.0 °C (Oşlobeanu *et al.*, 1991), with averages lower than 18 °C being restrictive for grapevine growing. Averages between 18.1 and 19.7 °C indicate the thermal potential for sparkling wine and white table wine production ; averages higher than 19.8 °C reveal climate suitability for quality white wine production, while averages higher than 21 °C indicate suitability for red wine production (Ţârdea and Dejeu, 1994 ; Oşlobeanu *et al.*, 1991).

Global radiation (GR ; kcal/cm^2/April 1st to September 30th). In Romanian wine growing regions, it varies between 80 kcal/cm^2 and 92 kcal/cm^2, with values smaller than 80 kcal/cm^2 being restrictive for grape growing (Oşlobeanu *et al.*, 1991). Values up to 86.9 kcal/cm^2 characterize Romanian regions that produce white wines, while values higher than 87.0 kcal/cm^2 represent regions that produce red wines (Irimia, 2012).

Actual sunshine duration (ASD ; hours/April 1st to September 30th). In Romanian wine growing regions, it varies between 1280 hours and 1700 hours. Values lower than 1280 hours are restrictive for grapevine growing (Oşlobeanu *et al.*, 1991), while values higher than 1502 hours are specific to regions that produce red wines (Irimia, 2012).

Precipitation in the growing season (PP ; April 1st to September 30th). In temperate continental climate of Romanian wine growing regions, it varies between 212 mm and 498 mm (Oşlobeanu *et al.*, 1991). Averages of 250-390 mm characterize quality wine producing areas, while values higher than 390 mm are common in table wine producing areas. Averages smaller than 250 mm correspond to quality wine producing areas frequently affected by drought, with negative impact on grape quality (Guilloux, 1981 ; Becker and Zimmermann, 1984).

Sum of effective temperatures (Σt_u,°C). It represents the sum of fractions of daily temperatures higher than 10 °C during the growing season (April 1st to September 30th) (Branas *et al.*, 1946) :

$$\Sigma t_u, °C = (Tm - 10) \times Nd$$

where : Tm = average daily temperature (°C), 10 = temperature base and Nd = number of days in the growing season (April 1st to September 30th).

In the temperate continental climate of Romanian wine regions, it varies between 1045°C and 1675°C, with values lower than 1045°C being restrictive for grape growing (Oşlobeanu *et al.*, 1991). Values up to 1400°C are specific to the white wine producing areas, while those higher than 1400°C are specific to the red wine producing areas (Irimia, 2012).

Length of the growing season (LGS). It represents the number of days with daily mean temperature ≥ 10 °C, allowing the vines to complete the growing cycle and the grapes to ripen (Irimia, 2012). In the temperate continental climatic conditions of the Northern Hemisphere, the growing season usually takes place from April 1st to September 30th, with a variable duration, depending on latitude and elevation. For Romanian viticulture, the multiannual averages vary between 204 days in southern wine regions and 170 days in northern wine regions and at high elevations (Oşlobeanu *et al.*, 1991). Higher values indicate resources for late-ripening grapevine varieties, anthocyanin accumulation (Teodorescu *et al.*, 1987), and late-harvest wine production.

Actual heliothermal index (IHa). It was derived from the Heliothermal Index of Branas (Branas, 1974) by replacing the sunshine duration in the growing season with the actual sunshine duration (Oşlobeanu *et al.*, 1991). The index is computed for the growing season (April 1st to September 30th) :

$$IHa = \Sigma t_u \times ASD \times 10^{-6}$$

where : Σt_u = sum of effective temperatures (°C) and ASD = actual sunshine duration (hours).

It varies between 1.36 and 2.7, with values lower than 1.36 indicating the lack of heliothermal resources for grape growing and those higher than 1.90 the abundance of heliothermal resources and the suitability for red wine production.

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Bioclimatic index (Ibcv) (Constantinescu, 1967). An index specific to wine growing regions in temperate continental climate areas, where rainfall can be considered an unsuitable factor for grape quality (Hidalgo, 2003). The index is calculated for the growing season (April 1st to September 30th):

$$Ibcv = (ASD \times \Sigma t_a / PP \times Nd) / 10$$

where: ASD = actual sunshine duration (hours), Σt_a = sum of daily average temperatures > 10 °C (°C, April 1st to September 30th), PP = precipitation (mm, April 1st to September 30th) and Nd = number of days in the growing season (April 1st to September 30th).

It varies between 4.0 and 15.0; the lower values indicate a lack of heliothermal resources accompanied by abundant precipitation, while the highest values reveal an abundance of heliothermal resources associated with water stress conditions. Optimum values for grape growing are 10±5 (Constantinescu, 1967); values smaller than 8 are more specific to white wine producing regions and those higher than 8.1 to red wine producing regions (Irimia, 2012).

Oenoclimate aptitude index (IAOe). It indicates the climate suitability for quality red wines (Teodorescu *et al.*, 1987). In Romanian wine growing conditions, this index presented the best correlation with anthocyanin content for the Cabernet Sauvignon variety. It varies between 3700 and 5200, with values smaller than 4300 indicating climate unsuitability for red wines, values from 4300 to 4600 revealing suitability for red table wines, and values higher than 4600 suitability for quality red wine production. It is calculated for the growing season (April 1st to September 30th):

$$IAOe = ASD + \Sigma t_a - (PP - 250)$$

where: ASD = actual sunshine duration (hours), Σt_a = sum of daily average temperatures ≥ 10 °C (April 1st to September 30th), PP = precipitation (mm, April 1st to September 30th) and 250 = minimum precipitation needed for unirrigated vines (mm); for situations where PP < 250 mm, the IAOe is computed as the sum of ASD and Σt_a (Teodorescu *et al.*, 1987).

Clay content (Cly). Clay influences water holding capacity and drainage of the soil (White, 2009). In temperate continental climatic conditions, the optimum clay content (%) for wine varieties is 15-25 %, with values higher than 40 % being restrictive for grapevine growing (Davidescu and Davidescu, 1992). Higher values, up to 40 %, keep the soil moist and cool in autumn (Galet, 1988), delaying grape ripening and preserving a high level of titratable acidity, while values lower than 15 % characterize warmer sandy soils with low water holding capacity. In temperate continental climate, the sandy soils produce flat and poorly coloured wines (Oşlobeanu *et al.*, 1991).

Humus content (Hum). The minimum content needed for vine development is 1.0 % (Seguin, 1986): 1.5-2.0 limits the yields and generates quality wines (Dejeu, 1984), while 2.1-3.0 stimulates vine vigour and increases the yield but delays grape ripening and limits wine quality (Galet, 1988; White, 2009).

Gravel content (Gra). Gravels improve water drainage and exert a favourable influence on soil temperature in cool climate vineyards (Seguin, 1983); gravelly soils are considered to produce the best wines, no matter the climate (Gladstones, 1992), while calcareous gravels correspond to great terroirs (White, 2009). In temperate continental climate, the optimum gravel content for wine varieties is about 20-30 %, with values higher than 40 % considered as being restrictive (Davidescu and Davidescu, 1992). High contents favour spring frost (Galet, 1988), delay budburst, and make the soil excessively permeable, exposing the vines to drought; lower contents characterize common soils, without any distinctive viticultural potential.

The evaluation system was designed as a table comprising all the 15 ecological parameters grouped into three categories (topography, climate, soil) and ranked according to their relationship with the types of wine production (Table 1). Each ecological parameter is represented by a suitability interval encompassing three suitability classes - class I, class II, class III - to which class IV was added for restrictive values.

The climatic component of the evaluation system was developed by using multiannual averages characterizing the baseline climate (Jones *et al.*, 2005) of Romanian wine growing regions, as follows: for AAT and PP, averages of 85 years (1900-1985); for TWM, Σt_u and LGS, averages of 52 years (1933-1985); for IHa, Ibcv and IAOe, averages of 34 years (1951-1985); and for GR and ASD, averages of 24 years (1961-1985). These climatic data characterize the wine growing regions' climate best fitted with traditional assortments (Jackson and Lombard, 1993) and less affected by climate change (Menzel and Fabian, 1999; Jones *et al.*, 2005). Thus, they can be used as reference for the development of the climatic component of the evaluation system. The climatic data were obtained from the database of the Valea Călugărească National Institute for Viticulture and Winemaking, which manages the national weather station network for viticulture in Romania. This network covers 48 wine growing regions, totalling about 200,000 ha spread between 20°14'-29°49' E longitude and 43°41'-48°26' N latitude.

The topographical and pedological components of the evaluation system were developed by using literature data on grapevine growing in temperate continental climate (Oşlobeanu *et al.*, 1991; Davidescu and Davidescu, 1992).

The suitability interval for each climatic parameter (Table 1) encompasses the range of values recorded in the temperate continental climatic conditions of Romanian wine growing regions. It is bounded by the smallest and the largest multiannual averages: the smallest average generally characterizes the least suitable wine region (producing white table wines and wines for distillates), while the highest characterizes the most suitable wine region (producing quality red wines). For the topographical

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Table 1. Ecological factors and bioclimatic indices ranking according to their suitability for different types of wine production in temperate continental climatic conditions of Romanian wine growing regions

Ecological category	Ecological factors and bioclimatic indices (abbreviation, units)	Suitability interval	Unsuitable	Suitability classes/ranking points[a]		
			IV/0	III/5	II/8	I/10
				Type of wine production		
			restrictive for grapevine growing	white table wines, sparkling wines, wines for distillates	quality white wines, red table wines	quality red and white wines
Topographical factors	Slope (S, %)	0-28	-	< 8	> 15	8-15
	Aspect (A)	-	-	NW, N, NE	E, W	SE, S, SW
Climatic factors and bioclimatic indices	Average annual temperature (AAT, °C)	8.5-11.2	< 8.5	8.5-9.3	9.4-10.0	10.1-11.2
	Average temperature of the warmest month (TWM, °C)	18.0-22.0	< 18.0	18.1-19.7	19.8-21.0	21.1-22.0
	Global radiation (GR, kcal/cm^2)	80.0-92.0	< 80.0	80-83.9	84.0-86.9	87.0-92.0
	Actual sunshine duration (ASD, hours)	1280-1610	< 1280	1280-1450	1451-1550	1551-1610
	Precipitation in the growing season (PP, mm)	250-390	-	> 390	< 250	251-390
	Sum of effective temperatures (Σt_u, °C)	1045-1675	< 1045	1045-1200	1201-1400	1401-1675
	Length of the growing season (LGS, days)	160-210	< 160	160-175	176-190	> 190
	Actual heliothermal index (IHa)	1.36-2.66	< 1.36	1.36-1.70	1.71-2.20	2.21-2.66
	Bioclimatic index (Ibcv)	3.9-13.0	< 3.9	3.9-5.0	5.1-8.0	8.1-13.0
	Oenoclimate aptitude index (IAOe)	3793-4600	< 3793	3793-4300	4301-4600	> 4600
Pedological factors	Clay content (Cly, %)	6-40	> 40.0	< 15	25-40	15-25
	Humus content (Hum, %)	1.5-4.0	-	3.1-4.0	2.1-3.0	1.5-2.0
	Gravel content (Gra, %)	0-40	> 40.0	< 10	30-40	10-30

[a]Suitability classes of ecological factors for different wine type productions. Values were graded using a 10-point scale, as follows: 10, 8 and 5 points for class I, II and III, respectively; unsuitable values (class IV) were given 0 points.

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and pedological factors, the suitability interval was set up according to literature data (Oşlobeanu *et al.*, 1991 ; Davidescu and Davidescu, 1992).

The suitability classes of the evaluation system are (Table 1) : class I, characteristic values of the wine regions specialized in quality red wine and, secondarily, in quality white wine production ; class II, characteristic values of the wine regions specialized in quality white wine and, secondarily, in red table wine production ; and class III, characteristic values of the wine regions specialized in white table wines, sparkling wines and wines for distillates. For the climatic parameters, the suitability classes were established by delimiting the ranges of averages common to Romanian wine growing regions with similar types of wine production in the suitability intervals. For the topographical and pedological parameters, literature data were used (Becker, 1985 ; Galet, 1988 ; Oşlobeanu *et al.*, 1991 ; Davidescu and Davidescu, 1992 ; Boyer and Wolf, 1998 ; Jones *et al.*, 2004).

Class IV classifies the values restrictive for grapevine growing in temperate continental climatic conditions. The values under the lower limit of the suitability interval of AAT, TWM, GR, ASD, Σt_u, LGS, IHa, Ibcv and IAOe as well as the values exceeding the upper limit of the suitability interval of both Cly and Gra were the only ones that were considered restrictive (Table 1). The values outside of the suitability interval for S, A, PP and Hum were classified as suitable. This is due to the fact that their restrictiveness can be diminished by technical measures and farming practices (terracing, use of early ripening varieties, canopy division, irrigation, fertilization, etc.). Taking into consideration the ongoing climate warming (Menzel and Fabian, 1999 ; Jones *et al.*, 2005) and the predictions regarding its effect on vineyard climate (Santos *et al.*, 2012), the values exceeding the upper limit of the suitability interval of AAT, TWM, GR, ASD, Σt_u, LGS, IHa, Ibcv and IAOe were classified as class I as well. In this case, the upper limit indicates only the value up to which the factor influence fits the type of viticultural production. The reasons why this upper limit cannot be restrictive are : (1) high quality wines are produced in warmer climates ; (2) it is impossible to define a climate profile for fine high quality wine production (Seguin, 1986) ; and (3) the ongoing climate warming causes an increase in the multiannual averages characterizing the vineyards (Jones *et al.*, 2005 ; Santos *et al.*, 2012).

In order to quantify the ecological suitability, the values from class I were given 10 points, the values in class II 8 points, the values in class III 5 points and the values in class IV (unsuitable) 0 points (Table 1).

3. Aquisition and spatial modelling of the ecological data characterizing the study area

The evaluation of the Huşi wine growing region was carried out by using the latest data characterizing the area, as follows :

- topographical variables were modelled by using a digital elevation model (DEM), developed in raster format with a resolution of 30 x 30 m, based on the elevation information extracted from topographical maps at a scale of 1:25,000 (Patriche *et al.*, 2011a) ;

- GR was computed in two stages (Patriche, 2007) : first, the potential (clear-sky) radiation was derived on the basis of DEM, by using the Incoming Solar Radiation module from SAGA-GIS 2.0.4 software (Olaya, 2004) ; then the potential radiation was multiplied by the N factor (1 - 0.65 x N^2), where N is the cloud cover fraction (Entekhabi, 1997) ;

- the maximum possible sunshine duration was derived from DEM by using the same SAGA-GIS 2.0.4 module ; this DEM-based computation has the advantage of taking into account the landscape topography. Consequently, higher sunshine values are experienced on hilltops because of the larger horizon, while lower values are observed along valley bottoms. By multiplying the maximum possible sunshine duration by the sunshine fraction, the spatial distribution of ASD was obtained ;

- vertical temperature gradients were used to model the spatial distribution of temperature variables and bioclimatic indices. These gradients were computed from the available meteorological station data from eastern Romania, for the 1960-2000 period, implemented in NewLocClim software and belonging to the FAO Agromet database (FAO, 2003). By using the average temperature data from the Huşi meteorological station (1961-2000), the temperature gradients and DEM, temperature maps were achieved in GIS environment ;

- the spatial distribution of PP was extracted from a regression-kriging model, computed for the larger area of the Moldavian Plateau (Patriche *et al.*, 2011a) ;

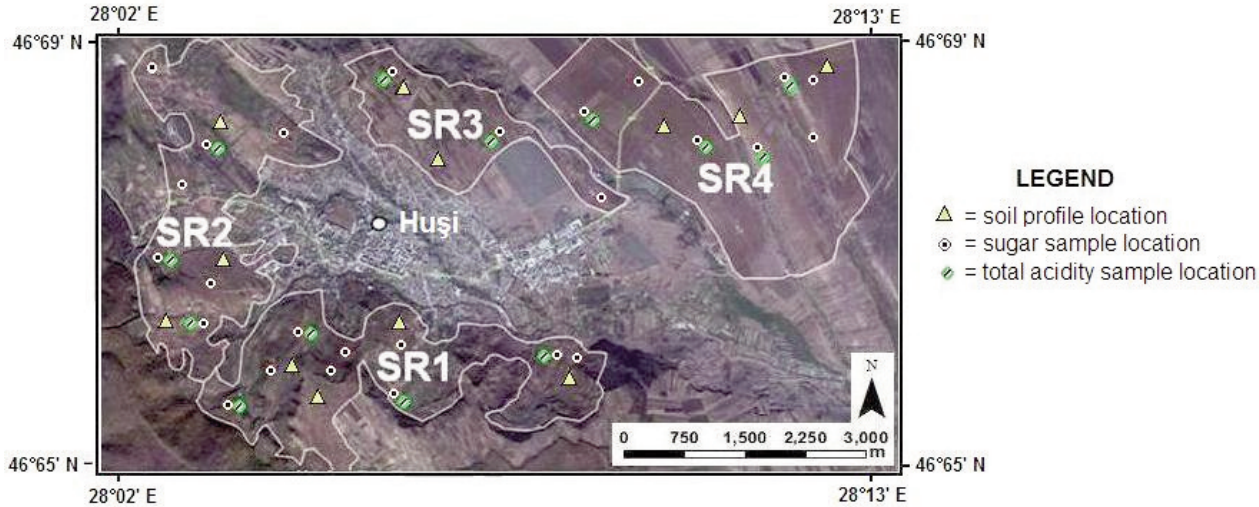
- the characterization of pedological factors was based on the analysis of 12 soil profiles obtained from the Vaslui County Laboratory of Pedological and Agrochemical Studies (OJSPA) through pedological studies at a 1:10,000 scale. These profiles are spread over the entire Huşi wine growing region and represent the different soil units (Figure 2). Spatialization of Cly was achieved by simple interpolation (inverse distance weighting, IDW), while Hum was modelled by regression-kriging with elevation as predictor.

4. Evaluation of the individual suitability of the ecological factors

Individual suitabilities were derived in GIS environment using ArcGIS 9.3 software (ESRI). For this purpose, the spatial distributions of ecological factors and bioclimatic indices achieved in the previous stage were classified according to the limits specified in Table 1. The ranking points of classes were then recorded in the attribute tables, after which they were converted to raster format (grids), resulting in the spatial distributions of suitability classes for each factor.

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Figure 2. Soil, sugar and total acidity sample locations in the study area.



5. Evaluation of the suitability of the ecological categories

This was achieved by the computation of the ranking point average at the pixel level, for each of the three categories of ecological factors, by using ArcGIS 9.3 software (ESRI). It resulted in an interval of averages from 5.0 to 10 points, according to the suitability of factors associated to a pixel. The decimal suitability computed for a pixel was rounded up to the nearest integer suitability value. Therefore, suitability values falling within the 5.0-5.49 interval were assigned to an average suitability of 5, values within the 5.5-6.49 interval were assigned to an average suitability of 6, and so on. The integer suitability averages were further aggregated into three suitability classes as follows: averages of 5 and 6 were grouped in class III, comprising floating values from 5.0 to 6.49; averages of 7 and 8 were grouped in class II, comprising floating values from 6.5 to 8.49; and averages of 9 and 10 were grouped in class I, comprising floating values from 8.5 to 10.

The three suitability classes characterize broader viticultural specializations (class I - quality red wines; class II - quality white wines; and class III - white table wines, sparkling wines, and wines for distillates), while the average of ranking points indicate more specific specializations (Table 2). The law of minimum is used to define class IV: if one factor is restrictive (0 ranking points) for grapevine growing in a certain area, then the respective area is considered unsuitable for grape growing, regardless of the suitability of the other factors.

6. Setting up the viticultural potential of the assessed area

The viticultural potential was determined by integrating the three suitability maps (topographical, climatic and pedological) and by calculating the average for each pixel. It resulted in averages between 5.0 and 10 points, which were classified, as in the case of ecological category suitability, into three classes (class I, class II, and class III). Keeping the initial logic of the evaluation system, every class represents the type(s) of viticultural production defined by the suitability of its factors (Table 2). Again, the pixels that were previously scored in class IV, in any of the three ecological categories, were also mapped as restrictive for grapevine growing. Expressing the suitability and the viticultural potential as an average of ranking points was a mean of improving the delineation of homogeneous viticultural zones in the assessed area. In an early stage of this research (Irimia and Patriche, 2010), we found out that expressing suitability by the sum of ranking points at the pixel level generates an scattered distribution of the viticultural potential and gives a dominant share to the category represented by a larger number of factors, in our case the climate category.

7. Delineation of homogeneous viticultural zones

The homogeneity of the zones with distinct viticultural potential was established by statistical analysis of the variability of ranking points, which reveals the suitability of the factors from the respective areas. To assess the homogeneity, descriptors were calculated (maximum, minimum, range, variance, standard deviation and coefficient of variation) for topographical, climatic, pedological and final composite suitability of each homogeneous zone with distinct viticultural potential.

8. Validation

As a means of validation, the values characterizing topographical, climatic and pedological suitabilities were correlated with two grape quality parameters: sugar content (g/L) and total acidity (g/L, H_2SO_4). Because of the unavailability of the multiannual data regarding the two grape quality parameters, samples representing only one vintage (year 2011) were used. In order to have comparable

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Table 2. Characterizing viticultural potential according to the average of ranking points.

Class	Average of ranking points	Viticultural potential of the area
I	10	Viticultural potential for quality red wines.
	9	Viticultural potential primarily for quality red wines and secondarily for quality white wines.
II	8	Viticultural potential primarily for quality white wines and secondarily for red table wines.
	7	Viticultural potential for quality white wines.
III	6	Viticultural potential for white table wines, sparkling wines, and wines for distillates, as well as for quality white wines in very suitable years, in terms of climate.
	5	Viticultural potential for white table wines, sparkling wines, and wines for distillates.
IV	0	Unsuitable for grape growing.

samples, they were taken in a single day, during grape ripening. There were 26 different locations representing the entire Huşi wine growing region (Figure 2). The coordinates were determined by GPS. For each location, 13 determinations of sugars were performed for each of the Fetească albă, Fetească regală, Aligoté and Tămâioasă românească grapevine varieties. Total acidity was analyzed for 13 locations (Figure 2). The ranking points were correlated with sugar content and total acidity, the results being evaluated according to the statistical significance of the linear regression model parameters (Pearson coefficient, regression coefficient) for a significance level of 0.05.

RESULTS

1. Spatial distribution of ecological factors and bioclimatic indices

The spatial distribution of ecological factors and bioclimatic indices was analyzed separately for each of the four sub-regions grouped in the lower zone (SR3 and SR4) and the higher zone (SR1 and SR2) of the region.

Topographical factors. The spatial distribution of slopes clearly differentiate the two zones (Figure 3a and Table 3): while in the higher zone (SR1 and SR2) slope inclination is more pronounced, with averages of 12.8-15.6 % and maxima up to 31.9-37.9 %, in the lower zone (SR3 and SR4) the slopes are gentle, with averages of 5.3-6.0 % and maxima of 23.4-25.5 %. Aspect is quite variable in SR1 and SR2 and relatively uniform in SR3 and SR4 (Figure 3b), although the variety reveals the presence of all aspects (8) in all the four sub-regions (Table 3). The dominant aspect in SR1 and SR2 is NE, which is less suitable for grapevine growing. In SR3 and SR4, the majority is represented by SW aspect, while the least represented are NW and N.

Climatic factors. The spatial distribution of AAT reveals a warmer climate in the lower zone compared to the higher zone (Figure 4a). AAT falls from averages of 9.7-10.0 °C in the lower zone (SR3 and SR4) to averages of 9.4-9.5 °C in the higher zone (SR1 and SR2) (Table 4); a larger difference is found in the minima, ranging from 9.5-9.8 °C in the lower zone and 8.5-8.8 °C in the higher zone. The other thermal variables have a similar distribution (Table 4): TWM decreases from averages of 21.2-21.7 °C in the lower zone to 20.9-21.0 °C in the higher zone (Figure 4b) and Σt_u from averages of 1352.1-1430.4 °C in the lower zone to 1289.6-1316.0 °C in the higher zone (Figure 4c). The temperatures from the lower zone are specific to the wine growing regions producing quality red wines, while those from the higher zone are specific to the wine growing regions producing white table wines and sparkling wines. The spatial distribution of GR indicates higher solar radiation resources in the lower zone (Figure 4d). The average values vary between 89.9-90.1 kcal/cm^2 in SR3 and SR4 and between 83.7-88.8 kcal/cm^2 in SR1 and SR2 (Table 4). Moreover, in SR1, values as low as 72.2 kcal/cm^2 are registered, being restrictive for grape growing. ASD varies between averages of 1365.4 hours in SR2 and 1401.1 hours in SR3 (Table 4), with a very irregular spatial distribution in the region (Figure 4e), resulting in maximum values for the eastern part of SR1 and SR3. The spatial distribution of LGS reveals better condition for grape maturation in the lower zone (Figure 4f); the averages vary from 185-188 days in SR3 and SR4 to 179-182 days in SR1 and SR2 (Table 4). Also, in the lower zone, LGS has a uniform distribution, with differences of only 4-5 days between maximum and minimum, while in the higher zone these differences are of 12 days. The maximum values of 190 days in SR4 allow overmaturation of grapes, whereas the minimum values of 173-176 days in SR1 and SR2 just satisfy the minimum requirement for grape maturation. The spatial distribution of PP is quite uniform in the region (Figure 4g), with average values varying from 344.0 mm in SR4 to 358.3 mm in SR2 (Table 4).

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The spatial distribution of the bioclimatic indices is comparable to that of the thermal variables. Representative of these indices is the IAOe index distribution (Figure 4h): in SR4, the highest average in the region (4621.0), characteristic to red wine producing areas; at the bottom of the slopes and in SR3, values of 4300-4500, which are more specific to quality white wine producing areas; and at the upper third of the slopes from the higher zone, the minimum values, down to 4004, which characterize white table wine producing areas (Table 4).

Pedological factors. The percentage and spatial distribution of Cly and Hum (Figure 5 and Table 5) reveal that the lower zone has soils with higher clay content and higher fertility, while the higher zone has lower clay content and less fertile soils. The averages of Hum of 1.5-1.7 % from SR1 and SR2 are specific to the quality wine producing areas, while those of 2.8-2.9 % from SR3 and SR4 are specific to the areas specialized in table wines. The soils from the Huşi wine growing region do not contain Gra to increase their suitability for wine varieties.

Table 3. Statistics for the topographical factors characterizing the Huşi wine growing region.

Topographical factor	Statistical parameters	Higher zone		Lower zone	
		Sub-regions			
		SR1	SR2	SR3	SR4
Slope (%)	Min	0.2	0.3	0.1	0.0
	Max	31.9	37.9	25.5	23.4
	Range	31.6	37.6	25.4	23.3
	Median	15.6	12.8	5.3	6.0
Aspect	Variety	8	8	8	8
	Majority	NE	NE	SW	SW
	Minority	SW	NW	NW	N
	Mean	NE	E	S	S

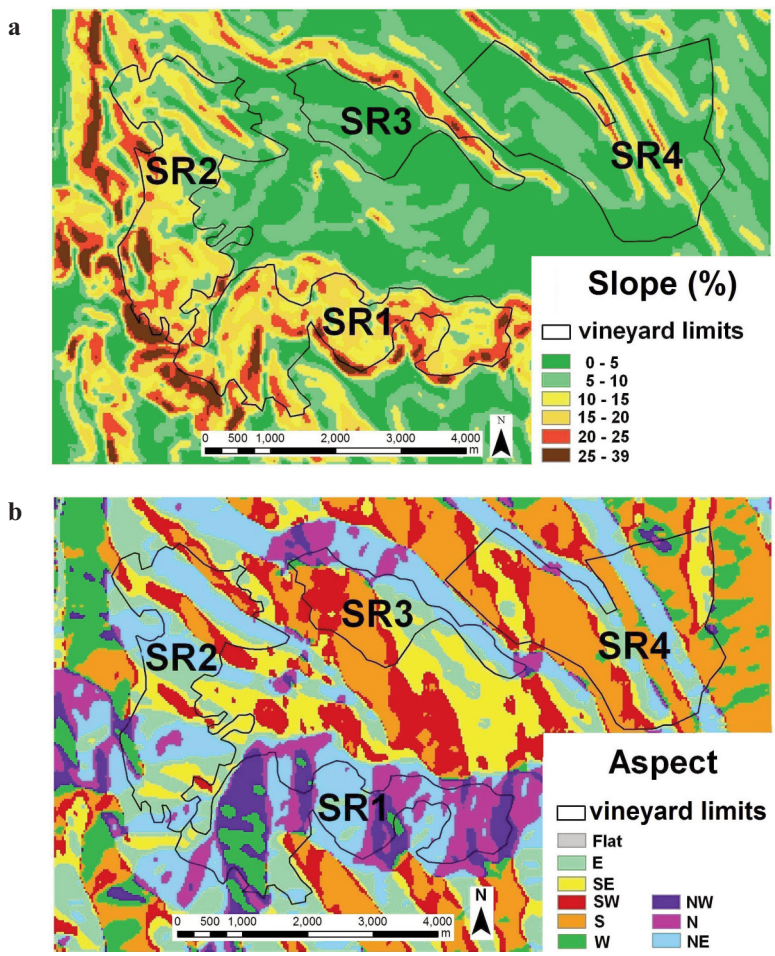


Figure 3. Maps of topographical factors in the study area: a. slope; b. aspect.

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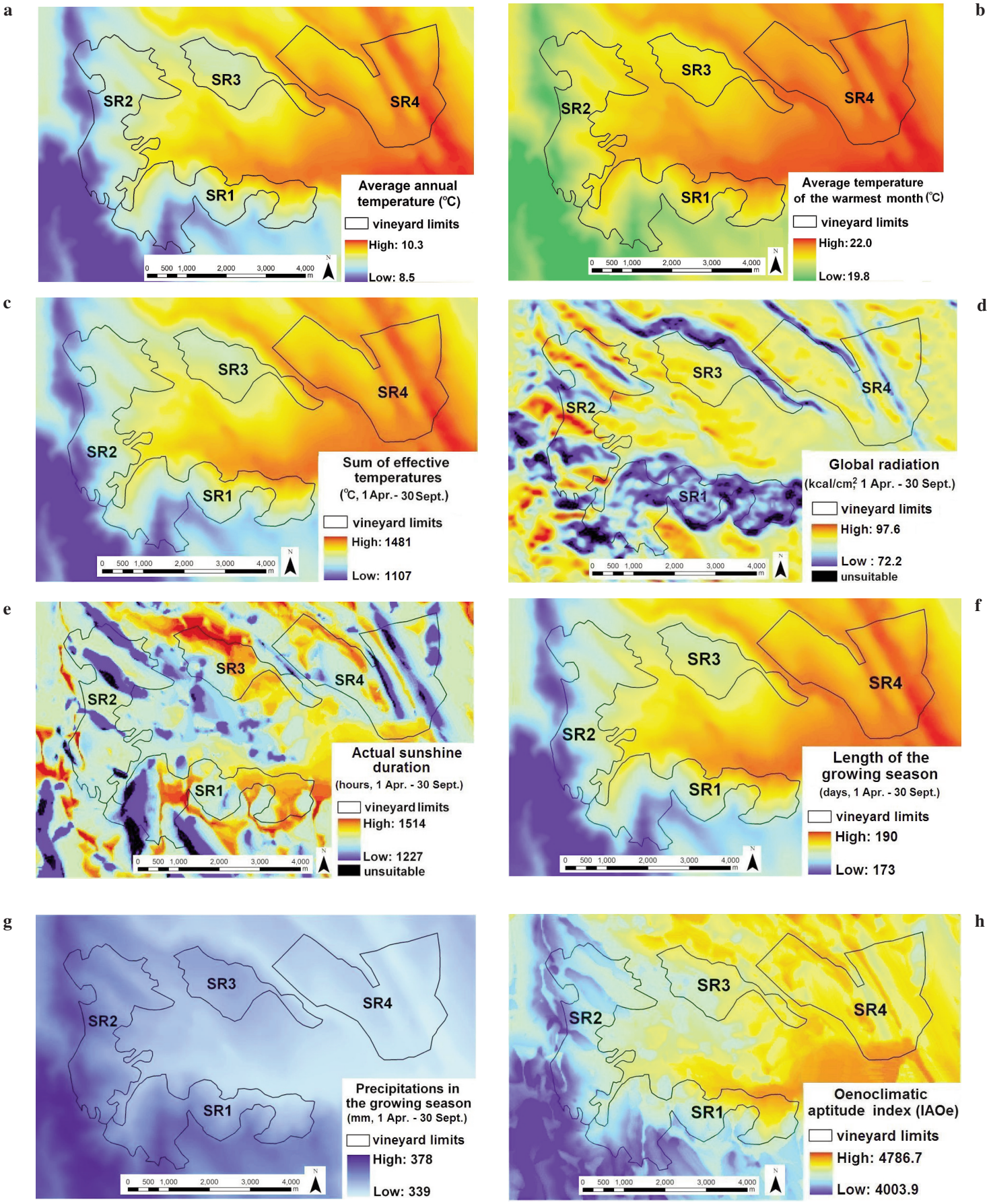


Figure 4. Spatial distribution of some climatic factors and bioclimatic indices in the study area : a. AAT ; b. TWM ; c. Σt_u ; d. GR ; e. ASD ; f. LGS ; g. PP ; h. IAOe.

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Table 4. Statistics for the climatic factors and bioclimatic indices characterizing the Huşi wine growing region

Climatic factor/ bioclimatic index[a]	Statistical parameters	Higher zone		Lower zone	
		Sub-regions			
		SR1	SR2	SR3	SR4
AAT (°C)	Min	8.8	8.5	9.5	9.8
	Max	10.1	9.9	10.1	10.3
	Range	1.2	1.4	0.5	0.4
	Mean	9.5	9.4	9.7	10.0
TWM (°C)	Min	20.2	19.8	21.1	21.4
	Max	21.8	21.5	21.7	22.0
	Range	1.6	1.6	0.6	0.5
	Mean	21.0	20.9	21.2	21.7
Σt_u (°C)	Min	1176.6	1107.1	1324.5	1386.2
	Max	1450.3	1390.3	1439.8	1481.0
	Range	273.7	233.2	115.2	94.7
	Mean	1316.0	1289.6	1352.1	1430.4
GR (kcal/cm^2)	Min	72.2	75.7	80.1	82.0
	Max	95.3	97.6	92.7	94.4
	Range	23.1	21.0	12.6	12.4
	Mean	83.7	88.8	89.9	90.1
ASD (hours)	Min	1227.1	1252.8	1287.6	1261.5
	Max	1513.8	1513.8	1514.6	1505.1
	Range	286.7	261.0	227.0	243.6
	Mean	1370.4	1365.4	1401.1	1386.4
LGS (days)	Min	176	173	183	185
	Max	188	185	188	190
	Range	12	12	4	5
	Mean	182	179	185	188
PP (mm)	Min	342.0	348.0	343.1	339.5
	Max	370.1	373.1	354.7	348.5
	Range	28.0	25.1	11.6	8.9
	Mean	355.6	358.3	351.9	344.0
Ibcv	Min	5.7	5.5	6.3	6.6
	Max	7.7	7.0	7.5	7.8
	Range	2.0	1.5	1.1	1.2
	Mean	6.7	6.4	7.0	7.2
IHa	Min	1.5	1.4	1.7	1.8
	Max	2.1	1.9	2.0	2.1
	Range	0.5	0.4	0.3	0.3
	Mean	1.8	1.7	1.9	1.9
IAOe	Min	4177.3	4003.9	4371.5	4455.3
	Max	4704.9	4534.3	4647.7	4786.7
	Range	527.6	530.3	276.2	331.3
	Mean	4430.8	4269.1	4521.0	4621.0

aAAT, average annual temperature; TWM, average temperature of the warmest month; tu, sum of effective temperatures; GR, global radiation; ASD, actual sunshine duration; LGS, length of the growing season; PP, precipitation in the growing season; Ibcv, bioclimatic index; IHa, actual heliothermal index; IAOe, oenoclimate aptitude index.

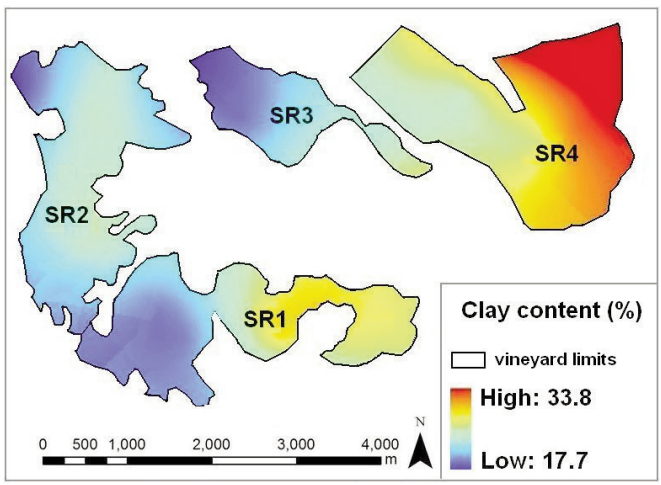
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Table 5. Statistics for the pedological factors characterizing the Huşi wine growing region.

Pedological factor[a]	Statistical parameters	Higher zone		Lower zone	
		Sub-regions			
		SR1	SR2	SR3	SR4
Cly (%)	Min	17.7	18.2	20.2	22.9
	Max	22.0	21.1	24.9	33.8
	Range	3.3	2.9	6.7	10.8
	Median	19.8	19.7	22.6	27.0
Hum (%)	Min	1.3	1.2	2.0	2.0
	Max	2.5	2.0	3.9	3.8
	Range	1.2	0.8	1.9	1.8
	Median	1.7	1.5	2.9	2.8
Gra (%)	Median	0	0	0	0

[a]Cly, clay content; Hum, humus content; Gra, gravel content.

a



b

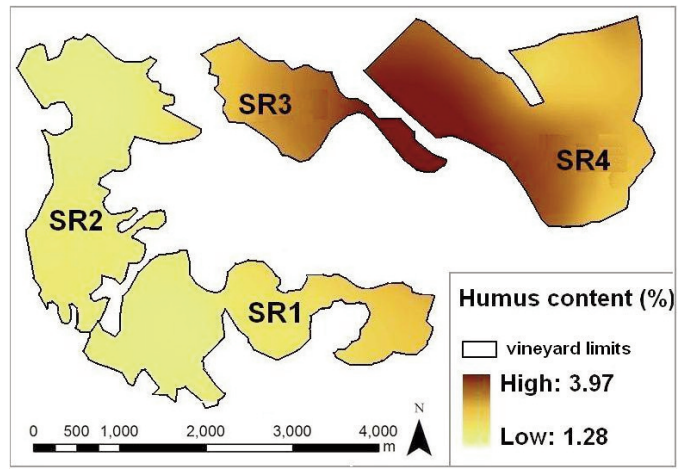


Figure5. Spatial distribution of pedological factors in the study area: a. Cly; b. Hum.

2. Suitability of ecological factors and bioclimatic indices

The suitability of ecological factors and bioclimatic indices is expressed by the suitability classes in which their values are encompassed and ranked.

Topographical factors suitability. The data presented in Table 6 show that 27.2 % of slopes are ranked in class I, 27 % in class II and 45.6 % in class III. For 42.2 % of the region, the aspect is ranked in class I, 19.6 % in class II and 38.0 % in class III.

Climatic factors suitability. The data presented in Table 6 show that the values of climatic parameters fall mainly in class II, indicating the suitability for quality white wine and red table wine production. Exceptions are ASD, represented mainly by class III (77.2 %), TWM and GR, represented mainly by class I (73.8 % and 66.9 %, respectively), and PP, characterized by class I over the entire region. The spatial distribution of climatic factors suitability is very irregular over the region: in the lower zone, classes I and II are more prevalent, while in the higher zone, classes II and III are more common (Table 6).

Pedological factors suitability. Cly falls in class I and II suitability (Table 6). Hum is represented by all three suitability classes, with 40.1 % in class I, 24.0 % in class II and 35.8 % in class III; classes I and II, characteristic to areas specialized in quality wines, predominate in the higher zone, while class III, specific to white table wine producing areas, represents the whole lower zone (81.8 % of SR3 and 72.5 % of SR4).

3. Suitability of ecological categories

The suitability is expressed by the average of ranking points given to the factors in each category for each suitability class.

Topographical suitability. Topographical suitability, generated by the composite of aspect and slope, shows that 51.3 % of the surface is represented by class II, 32.1 % by class III, and only 16.6 % by class I (Table 7). Class I

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Table 6. Structure of ecological factors and bioclimatic indices suitability in the study area according to the ranking system given in Table 1.

Ecological category	Environmental parameters[a]	Suitability		Higher zone / Lower zone % of sub-region surface				Total	
		ranges	classes	SR1	SR2	SR3	SR4	ha	%
Topographical factors	S (%)	< 8	III	8.3	23.1	86.2	76.1	977.2	45.6
		> 15	II	56.6	35.4	4.9	6.5	578.4	27.0
		8-15	I	35.0	41.4	8.8	17.2	583.4	27.2
	A	NW, N, NE	III	77.7	37.7	19.3	14.1	814.3	38.0
		E, W	II	19.3	27.4	16.1	15.2	420.9	19.6
		SW, S, SE	I	2.8	34.3	62.1	70.2	902.8	42.2
Climatic factors	AAT (°C)	< 8.5	IV	0	0	0	0	0	0
		8.5-9.3	III	29.4	38.3	0	0	382.2	17.8
		9.4-10	II	63.5	61.6	93.6	20.9	1108.2	51.8
		10.1-11.2	I	7.0	0	6.3	79.0	648.6	30.3
	TWM (°C)	< 18.0	IV	0	0	0	0	0	0
		18.1-19.0	III	0	0	0	0	0	0
		19.8-21	II	43.1	56.2	0	0	560.1	26.1
		21-22	I	56.8	43.7	100	100	1578.9	73.8
	Σt_u (°C)	< 1045	IV	0	0	0	0	0	0
		1045-1200	III	3.0	6.1	0	0	51.5	2.4
		1201-1400	II	86.7	93.8	90.7	6.1	1303.0	60.9
		1401-1675	I	10.2	0	9.2	93.8	784.5	36.6
	GR (kcal/cm^2)	< 80	IV	6.1	1.3	0	0	41.5	1.9
		80-83.9	III	35.7	11.9	4.6	1.1	287.7	13.4
		84-86.9	II	36.9	18.3	5.4	7.1	377.8	17.6
		87-92	I	21.1	68.2	89.8	91.6	1143.9	66.9
	ASD (hours)	< 1280	IV	4.8	2.5	0	2.6	60.6	2.8
		1280-1450	III	66.0	96.1	57.6	78.0	1652.3	77.2
		1451-1550	II	29.1	1.3	42.3	19.3	426.1	19.9
		1551-1610	I	0	0	0	0	0	0
	LGS (days)	< 160	IV	0	0	0	0	0	0
		160-175	III	0	0	0	0	0	0
		176-190	II	100	100	100	100	2139.1	100
		> 190	I	0	0	0	0	0	0
	PP (mm)	> 390	III	0	0	0	0	0	0
		< 250	II	0	0	0	0	0	0
		251-390	I	100	100	100	100	2139.1	100
	Ibcv	< 3.9	IV	0	0	0	0	0	0
		3.9-5.0	III	3.9	3.8	0	0	44.3	2.0
		5.1-8.0	II	96.0	96.1	100	100	2094.7	97.9
		8.1-13.0	I	0	0	0	0	0	0
	IHa	< 1.36	IV	0	0	0	0	0	0
		1.36-1.70	III	22.0	23.7	0	0	257.6	12.0
		1.71-2.20	II	77.9	76.2	100	100	1881.4	87.9
		2.21-2.66	I	0	0	0	0	0	0
	IAOe	< 3793	IV	0	0	0	0	0	0
		3793-4300	III	19.0	21.0	0	0	225.9	10.5
		4301-4600	II	66.5	78.9	95.5	51.1	1454.9	68.0
		> 4600	I	14.4	0	4.4	48.8	458.1	21.4
Pedological factors	Cly (%)	> 40	IV	0	0	0	0	0	0
		< 15	III	0	0	0	0	0	0
		25-40	II	31.1	0	0	67.6	679.1	31.7
		15-25	I	68.8	100	100	32.3	1459.1	68.2
	Hum (%)	3.1-4.0	III	1.1	0	81.8	72.5	766.5	35.8
		2.1-3.0	II	43.3	47.9	0	0	513.4	24.0
		1.5-2.0	I	55.5	52.0	18.1	27.4	858.4	40.1
	Gra (%)	> 40	IV	0	0	0	0	0	0
		< 10	III	100	100	100	100	2139.1	100
		30-40	II	0	0	0	0	0	0
		10-30	I	0	0	0	0	0	0

[a]S, slope; A, aspect; AAT, average annual temperature; TWM, average temperature of the warmest month; tu, sum of effective temperatures; GR, global radiation; ASD, actual sunshine duration; LGS, length of the growing season; PP, precipitation in the growing season; Ibcv, bioclimatic index; IHa, actual heliothermal index; IAOe, oenoclimate aptitude index; Cly, clay content; Hum, humus content; Gra, gravel content.

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corresponds to southern facing slopes from SR2 and SR4 (Figure 6a); class II characterizes most of SR3 and SR4 (65.9 % and 63.4 %, respectively); and class III most of SR1 (51.1 %).

Climate suitability. The most representative climate for the study area is class II, which characterizes 76.3 % of the area (Table 8). Class I climate, suitable for quality red wines, characterizes 16.9 % of the wine growing area, while class III climate, which is less suitable, encompasses only 2.0 % of the area. Class I climate predominates in SR4 and at the bottom of the slopes of the eastern border of SR1 (Figure 6b); class II climate characterizes the lower third of the slopes of the higher zone, the entire SR3 and half of SR4; and class III climate characterizes the upper third of the slopes in the higher zone. In the valley bottoms of SR4 and in some parts of SR1, the climate is restrictive for grapevine growing.

Pedological suitability. Pedological suitability, expressed as the average of Hum, Cly and Gra suitability, presents the narrowest local variability. As shown in Table 9, 64.0 % of the area contains class II soils (medium suitability) and 35.8 % class III soils (low suitability). Class II soils predominate in the higher zone and in the eastern part of SR4 (Figure 6c); class III soils characterize most of the lower zone. In the region, there are neither class I soils nor restrictive soils for grape growing.

4. Structure and spatial distribution of viticultural potential

The combination of suitability of topographical, climatic and pedological factors generated a composite map of

Table 7. Structure of topographical suitability.

Suitability	Average of ranking points	Share								Total		
		SR1		SR2		SR3		SR4				
		ha	%	ha	%	ha	%	ha	%	ha	%	
Class I	10	0.8	0.1	73.3	12.8	5.4	2.0	81.8	10.9	161.3	7.5	16.6
	9	40.8	7.3	120.2	21.0	2.4	0.9	30.1	4.0	193.6	9.0	
Class II	8	61.4	11.0	51.7	9.0	0	0	13.0	1.7	126.2	5.9	51.3
	7	167.5	30.2	165.6	29.0	174.3	65.9	462.7	61.7	970.2	45.3	
Class III	6	257.2	46.4	135.7	23.7	53.3	20.1	107.1	14.2	553.4	25.8	32.1
	5	26.3	4.7	24.0	4.2	28.8	10.9	54.8	7.3	134.1	6.2	
Class IV	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	-	554.3	100	570.6	100	264.4	100	749.7	100	2139.1	100	100

Table 8. Structure of climate suitability.

Suitability	Average of ranking points	Share								Total		
		SR1		SR2		SR3		SR4				
		ha	%	ha	%	ha	%	ha	%	ha	%	
Class I	10	0	0	0	0	0	0	0	0	0	0	16.9
	9	17.7	3.1	0	0	3.1	1.1	342.1	45.6	362.7	16.9	
Class II	8	329.7	59.4	390.6	68.4	261.3	98.8	388.0	51.7	1369.8	64.0	76.3
	7	129.4	23.3	132.8	23.2	0	0	0	0	262.2	12.2	
Class III	6	18.3	3.3	25.2	4.3	0	0	0	0	43.4	2.0	2.0
	5	0	0	0	0	0	0	0	0	0	0	
Class IV	0	59.0	10.6	22.1	3.8	0	0	19.6	2.6	100.8	4.7	4.7
TOTAL	-	554.3	100	570.6	100	264.4	100	749.7	100	2139.1	100	100

Table 9. Structure of pedological suitability.

Suitability	Average of ranking points	Share								Total		
		SR1		SR2		SR3		SR4				
		ha	%	ha	%	ha	%	ha	%	ha	%	
Class I	10	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0	
Class II	8	141.7	25.5	297.2	52.0	47.8	18.1	0	0	486.4	22.7	64.0
	7	405.7	73.3	273.4	47.9	0	0	205.9	27.4	885.9	41.3	
Class III	6	6.7	1.12	0	0	216.3	81.8	543.9	72.5	766.7	35.8	35.8
	5	0	0	0	0	0	0	0	0	0	0	
Class IV	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	-	554.3	100	570.6	100	264.2	100	749.7	100	2139.1	100	100

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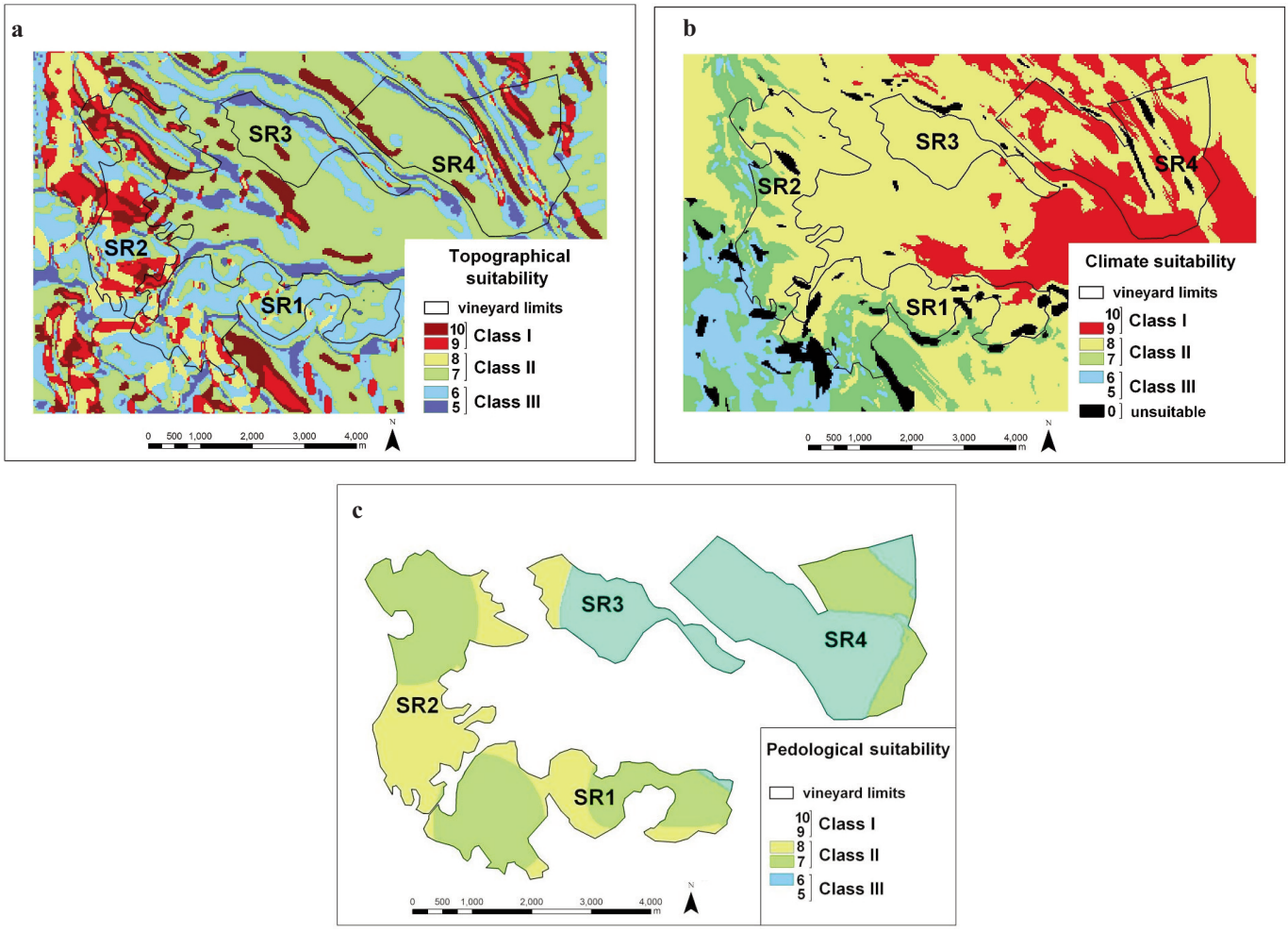


Figure 6. Maps of ecological categories suitability in the study area : a. topographical suitability ; b. climate suitability ; c. pedological suitability. The suitability is mapped according to the classes given in Table 6.

viticultural potential, expressed through suitability classes and averages of ranking points (Figure 7).

As shown in Table 10, 83.9 % of the area is characterized by class II suitability, which expresses potential for quality white wine production and red table wine production ; 11.3 % by class III, which indicates lower potential usually dedicated to the production of white table wines, sparkling wines and wines for distillates ; and 4.7 % by class IV, indicating a lack of viticultural potential. In the study area, there are no class I areas with viticultural potential for quality red wine production. The analysis of the study area in relation to the average of ranking points (Table 10) shows that it contains three zones with distinct viticultural potential : an area characterized by an average of 8 ranking points, with viticultural potential for quality white wine and red table wine production, representing 15.0 % of the wine growing region ; an area characterized by an average of 7 ranking points, with viticultural potential for quality white wine production, representing 68.9 % of the wine growing region ; and an area characterized by an average of 6 ranking points, which can produce white table wines, sparkling wines and wines for distillates, representing 11.3 % of the wine growing region.

The three zones with distinctive viticultural potential are spread across the region (Figure 7) : areas characterized by an average of 8 ranking points mostly correspond to slopes with southern aspects, less fertile soils and moderate inclination from SR2 and SR4, with a smaller proportion found in SR1 and SR3 (4.6 % and 2.0 %, respectively) ; areas characterized by an average of 7 ranking points constitute the largest part of the wine growing region ; and areas characterized by an average of 6 ranking points correspond to slopes with NE-NW aspect and fertile soils from SR3 and SR4 and to slopes with E and W aspect, moderate inclination and less fertile soils from SR1 and SR2. The lands that are restrictive for grapevine growing are situated mostly in slopes with northern aspects and more than 15 % inclination from SR1 and SR2, and in the valleys from SR3 and SR4.

5. Homogeneity

The homogeneity of the zones was analyzed in relation to their viticultural potential, expressed by the average of

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ranking points. The values close to 0 of the coefficient of variation (CV) show that all three viticultural zones are characterized by a high homogeneity of ecological factors generating their viticultural potential (Table 11). The most homogeneous zone (CV = 12.4) is that characterized by an average of 7 ranking points, followed by the zone with an average of 8 ranking points (CV = 13.4) and finally the zone with an average of 6 ranking points (CV = 16.2).

When analyzed in relation to topography, soils and climate characteristics, the most homogeneous zone is that characterized by an average of 8 ranking points, represented by terrains with 8-15 % inclination, less fertile soils and southern aspects. The zones characterized by an average of 6 and 7 points include factors with contrasting suitability: in SR1, the very suitable soils and slopes correspond to northern aspects, while in SR4, the very suitable climate corresponds to flat terrains with clay soils.

6. Validation.

The analysis of the quality parameters for the grape samples taken from the 26 locations (Figure 2) generated 975 values for sugar content (g/L) and 104 values for total acidity (g/L, H_2SO_4). The average sugar content ranged between 173.04 and 231.8 g/L, with minimum in SR1 and maximum in SR3; total acidity ranged between 5.04 and 8.82 g/L H_2SO_4, with minimum in SR1 and maximum in SR3 (data not shown). The statistical analysis of the data show that sugar content depends on climate suitability, which explains 47.0 % of variance with a root mean square error (RMSE) of 10.95 g/L (Table 12). At the variety level,

Table 10. Structure of viticultural potential of the study area.

Suitability class	Ranking points/class	Share								Total		
		SR1		SR2		SR3		SR4				
		ha	%	ha	%	ha	%	ha	%	ha	%	
Class I	10	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0	
Class II	8	25.2	4.6	193.3	33.94	5.4	2.0	96.9	12.9	322.5	15.0	83.9
	7	408.9	73.9	318.2	55.7	191.5	72.3	555.5	74.1	1473.4	68.9	
Class III	6	60.8	10.9	36.9	6.47	67.4	25.5	77.6	10.2	243.2	11.3	11.3
	5	0	0	0	0	0	0	0	0	0	0	
Class IV	0	58.0	10.4	22.1	3.87	0.0	0.0	19.6	2.6	99.9	4.7	4.7
TOTAL		554.3	100	570.6	100	264.4	100	749.1	100	2139.1	100	100

Values in bold represent the total area (%) associated to each suitability class.

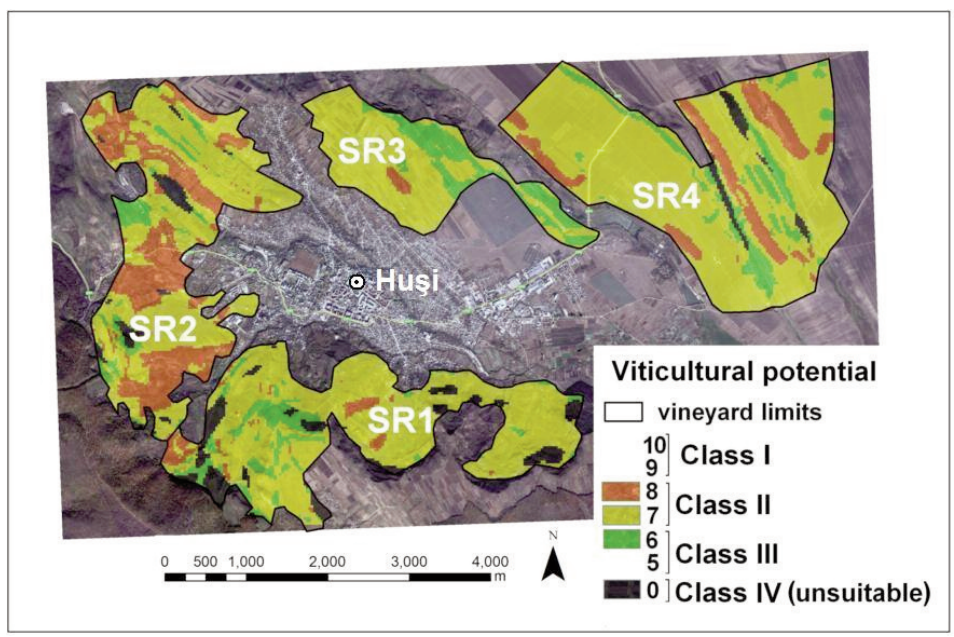


Figure 7. Map of viticultural potential of the study area, as defined by the combination of topographical, climatic and pedological suitabilities.
For the list of wine types associated to each class, see Table2.

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Table 11. Summary of statistical analysis of homogeneity of the zones with distinct viticultural potential from the Huşi wine growing region.

Indices of variation	Unsuitable	Class III		Class II		Class I	
	0	5	6	7	8	9	10
Mean	4.5	-	6.6	7.2	8.2	-	-
Mode	0	-	6	7	8	-	-
Min	0	-	5	5	6	-	-
Max	10	-	9	9	10	-	-
Range	10	-	4	4	4	-	-
Variance	10.9	-	1.1	0.8	1.2	-	-
Standard deviation (SD)	3.3	-	1.0	0.8	1.1	-	-
Coefficient of variation (CV)	72.7	-	16.2	12.4	13.4	-	-

Table 12. Statistical relations between the suitability of ecological categories and grape composition.

No.	Relationships	Regression parameters	Coefficients	N	R	R^2	RMSE
1.	Climate suitability / Sugar content	Intercept	84.1	26	0.68	0.47	10.95
		Climate suitability	15.1				
2.	Climate suitability / Sugar content for Fetească regală	Intercept	105.2	15	0.64	0.41	10.84
		Climate suitability	11.4				
3.	Climate suitability / Sugar content for Fetească albă	Intercept	116.6	18	0.66	0.44	9.06
		Climate suitability	11.5				
4.	Climate suitability / Sugar content for Aligoté	Intercept	62.9	18	0.69	0.48	12.57
		Climate suitability	16.9				
5.	Climate suitability / Sugar content for Tămâioasă românească	Intercept	38.4	9	0.83	0.69	11.59
		Climate suitability	21.1				
6.	Climate + Pedological suitability / Sugar content	Intercept	-47.6	26	0.76	0.59	9.82
		Climate suitability	23.5				
		Pedological suitability	8.2				
7.	Topographical suitability / Total acidity	Intercept	10.0	13	-0.54	0.30	0.89
		Topographical suitabilit	-0.4				

N, sample size; R, Pearson's coefficient of correlation; R^2 , coefficient of determination; RMSE, root mean square error.

the situation is different, with R^2 values ranging from 0.41 for Fetească regală to 0.69 for Tămâioasă românească. Simple linear regressions indicate that when the climatic suitability increases by one point, the sugar content values increase on average by 15.1 g/L, ranging between 11.4 for Fetească regală and 21.1 g/L for Tămâioasă românească. The multiple linear regressions further indicate that pedological suitability plays a secondary role in sugar accumulation, increasing the explained variance to 59.0 % and decreasing the RMSE to 9.82 g/L.

Total acidity (g/L H_2SO_4) correlates with topographical suitability (p-value = 0.053). This value, although not statistically significant, mainly because of the smaller sample size (13 values), demonstrates the presence of a strong correlation tendency between the two variables. The relation has a moderate degree of explanation (30.0 %), indicating a decrease in acidity values by 0.4 g/L H_2SO_4 (on average) when topographical suitability increases by one ranking point.

DISCUSSION

The combined analysis of topographical, climatic and pedological factors suitability allowed the characterization of the viticultural potential of the Huşi wine growing region in Romania and the delineation of homogeneous viticultural zones.

The methodology used topographical parameters besides the established viticultural zoning criteria (bioclimatic indices, soil and lithological characteristics and their combined influence). The influence of topography on vineyard climate (Becker, 1985) and consequently on grape quality (Nadal *et al.*, 2008) is well-known, with numerous

authors considering it as a major factor in determining the viticultural potential (Gladstones, 1992 ; Dumas *et al.*, 1997). There are some similarities between the present methodology and other GIS-based zoning methodologies (Watkins, 1997 ; Jones *et al.*, 2004). Still, what makes it original is that (1) it evaluates viticultural potential by relating the current environmental conditions of the assessed area to the environmental profile generating traditional types of viticultural production, (2) it is designed for viticultural zoning in temperate continental climatic conditions and (3) it expresses the viticultural potential of the assessed areas as the types of wine they can provide.

The use of this methodology in other climate types is constrained by the configuration of the suitability intervals of the ecological parameters, which is based on their influence on grapevine growing in temperate continental climate conditions. However, when comparing our data with literature data on grapevine requirements in other climate types (Galet, 1988 ; Gladstones, 1992 ; Huglin and Schneider, 1998 ; Hidalgo, 2003 ; Eynard and Dalmasso, 2004), it can be noticed that the restrictivity is mainly due to the upper thresholds established for Cly and Gra. In their case, the restrictivity threshold is 40 % (Oşlobeanu *et al.*, 1991), while in other climate types (e.g., oceanic climate), high quality wines are produced on soils with up to 50 % Cly and up to 60 % Gra (Seguin, 1986). The lack of restrictive thresholds in the case of S, A, PP and Hum as well as of upper restrictive thresholds in the case of AAT, TWM, GR, ASD, Σt_u, LGS, IHa, Ibcv and IAOe allows the adaptation of this methodology to viticultural zoning in other climate types.

The spatial distribution of ecological factors and bioclimatic indices across the Huşi wine growing region shows a hilly and fragmented relief, with important elevation differences and apparently less variable soil types. The data in Figure 4 show that climate variability is manifested by (1) altitudinal differentiation of temperatures and bioclimatic indices in three value groups characterizing three different types of viticultural production, (2) high amplitude of GR and ASD, each varying from restrictive for grape growing (72.2 kcal/cm^2 and 1227.1 hours, respectively) to highly suitable for quality red wine production (97.6 kcal/cm^2 and 1514.6 hours, respectively) and (3) high amplitude of LGS, from 173 days, very close to the minimum of 170 days needed for grape maturation (Shaulis and Dethier, 1970), to 190 days, with potential for grape overmaturation.

The bioclimatic indices examined in this study are quite similar to those previously calculated for the Huşi wine growing region : here the IAOe values ranged from 4004 to 4787, compared to 4666 used in previous studies (Teodorescu *et al.*, 1987), and the IHa and Ibcv values (1.5-2.1 and 5.5-7.8, respectively) correspond to those used for viticultural zoning in Romania (1.8-2.3 and 5.5-10.8, respectively) (Oşlobeanu *et al.*, 1991).

The pedological factor values and spatial distribution reveal a low variability in soil types, less specific to vineyard areas (van Leeuwen *et al.*, 2008 ; White, 2009). This is manifested by the predominance of chernozems in the lower zone and sandy-clay of Sarmatian lithological origins in the higher zone (Condorachi, 2006). This narrow variability in soils allowed the characterization of the spatial distribution of the pedological factors based on a lower resolution of soil data than generally required in vineyard soil assessment (Resolution OIV VITI 423-2012).

The individual suitability of ecological factors and bioclimatic indices revealed the contrasting ecological specificities of the Huşi wine growing region. In the lower zone (SR3 and SR4), there is a strong contrast between the high suitability of climatic factors and the lack of suitability of topographical and pedological factors ; in the higher zone (SR1 and SR2), the contrast between the suitability of slopes and soils and the lack of suitability of aspect and temperatures was highlighted. Table 6 shows that some parameters (AAT, GR, ASD, IAOe and Σt_u) have high amplitude, marking all three suitability classes, a feature that revealed their usefulness for fine-scale characterization of vineyard topoclimates. Less representative are the environmental parameters that, under the presented methodology, fall into one or two suitability classes (PP, LGS, Gra, IHa and Ibcv). This means reduced representativeness for topoclimate, an opinion that was also expressed by other authors (Asselin *et al.*, 2001).

The suitability of ecological categories was determined to obtain the average value of each category for the calculation of viticultural potential. It is a computation method used in GIS analysis of terroir (Jones *et al.*, 2004).

In the structure of relief suitability, which was shown in Table 6, the slope appears as a factor that diminishes the viticultural potential, as its suitability interval (8-15 %) is narrower than that of the aspect (SE-S-SW). For this reason, class I is restricted to landscapes with very suitable slopes of 8-15 %. The high aspect suitability of the lower zone (SR3 and SR4) partially lost its advantage due to flat and gradually sloping landscape, while in the case of the higher zone (SR1 and SR2) it was due to steeper slopes, which are technically limiting for grapevine growing.

The structure of climate suitability confirms that the topoclimate characteristics change along with slope inclination (Lebon, 1993). In the Huşi wine growing region, the climate is divided into three topoclimate units with different suitability for wine varieties. According to this climate suitability structure, the lower zone (SR3 and SR4) meets the conditions for producing quality red wines. If the viticultural potential of the Huşi region were to be evaluated only on the basis of climate characteristics, this would be an argument to introduce quality red wine varieties in the region.

The suitability of the soils, less variable than that of the climate and relief, occurs in the Huşi wine growing region as a factor that diminishes the viticultural potential. The low suitability is largely due to the absence of Gra, whose favourable influence on viticultural soil characteristics was

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widely shown in previous studies (Seguin, 1983 ; Morlat and Jacquet, 1993). In the methodology used here, Gra was used as an identifier of the ecological potential to produce high quality wines.

Viticultural potential. The structure of viticultural potential reveals the compensatory or corrective influence of the ecological factors that interact in the study area. The advantage of high climate suitability diminished under the influence of limited pedological and topographical suitability, and only the final averages of ranking points showed the real viticultural potential of the region. Unlike climate suitability, which varies mainly according to elevation, the viticultural potential, expressed as an average of topographical, climatic and pedological suitabilities, varies horizontally. These results show that the influence of soil and topographical parameters on viticultural potential is significant, and that these parameters must be integrated into the evaluation. When these parameters are poorly represented or not even included in the evaluation, the viticultural potential shows an altitudinal differentiation.

Compared to the Bucium wine growing region, located to the north (47°15' N latitude), in a cooler climate and producing white wines (Patriche *et al.*, 2011b), the Huşi wine growing region (46°69' N latitude) has a higher viticultural potential. This is highlighted by its potential to produce red table wines. In contrast, compared to the Urlați wine growing region, located to the south (44°98' N latitude) and producing quality red wines (Irimia *et al.*, 2013), the Huşi wine growing region has a lower viticultural potential. This confirms the specificity of the Huşi wine growing region as a transition zone from white wine producing areas in the northern part of Moldova to red wine producing areas in the southern part (Oşlobeanu *et al.*, 1991) and supports the accuracy of the results.

Viticultural zone homogeneity. The analysis showed that due to the multitude of factors that generate viticultural potential, the homogeneous zones are difficult to delimit. Previous research (Carey *et al.*, 2008) concluded that by using the topographical, climatic and geopedological similarities of wine regions as zoning criteria, a myriad of homogeneous viticultural zones can be identified, requiring regrouping in larger, more viable areas. In our study, the assessment of homogeneity, based on suitability of the factors generating viticultural potential, revealed the specificity of the delineated homogeneous viticultural zones. Some differences in topography, climate and pedology may exist between different locations within a homogeneous viticultural zone, but the composite of their ecological suitabilities generates a similar viticultural potential.

Validation of results by correlating the viticultural potential with quality parameters of the grapes is one of the methods suggested by the OIV (Resolution OIV VITI 423-2012). The variability in the age and status of vineyards made the selection of representative samples difficult. However, statistical analysis of the relationships between categories of ecological suitability, sugar content and total acidity allowed identifying some correlations that support the accuracy of the methodology. The statistically significant correlation between sugar content and climate suitability ($R^2 = 0.47$) validates the usefulness of the approach. Also, the positive correlation between sugar content and the combined influence of climate and pedological suitability ($R^2 = 0.59$) as well as the negative correlation between topographical suitability and total acidity ($R^2 = 0.30$) support the choices of pedological and topographical parameters for characterizing the viticultural potential of the area. However, the lack of multiannual data regarding the sugar content and total acidity, which are representative of many vintages, prevents us from considering the validation results as unchangeable.

CONCLUSION

This study shows that viticultural potential is the result of a complex interaction of ecological factors influencing the expression of the biological potential of grapevine varieties. Leaving out one ecological category from the evaluation, or even one ecological factor influencing the composition of the grapes, such as soil fertility or aspect, affects the accuracy of the results. The fine-scale analysis of wine growing regions with temperate continental climate and hilly relief, characterized by a large amplitude of variation in ecological factors, requires the use of geomatic tools such as GIS, which allows the emphasis of the complex spatial distribution of the ecological factors.

The study provided a composite analysis of the ecological structure of the Huşi wine growing region and revealed the individual and combined suitability of ecological factors for different types of viticultural production. Spatial analysis of the ecological factors revealed their specific distribution. It highlighted the altitudinal differentiation of climate suitability, with maximum values characteristic to quality red wine growing regions in the lower zone and minimum values characteristic to white table wine growing regions in the higher zone of the region. The composite effect of the ecological factors determined the existence of three zones with different viticultural potential : a zone suitable for quality white wine and red table wine production ; a zone suitable for quality white wine production ; and a zone with low viticultural potential, which can be developed for producing white table wines, sparkling wines and wines for distillates. The analysis of variation characterized these zones as homogeneous from an "ecological suitability" point of view : CV = 13.4 for the zones with an average of 8 ranking points ; CV = 12.4 for the zones with an average of 7 ranking points ; and CV = 16.2 for the zones with an average of 6 ranking points.

The results of this study provide the necessary information for viticultural zoning in the Huşi wine growing region in Romania, for selecting the types of wine varieties to be grown, and for establishing the optimum vineyard management practices for the region. The methodology, developed on multiannual averages specific to temperate continental climate and on environmental parameters that can be easily determined, can be used for viticultural

zoning in any temperate continental wine growing region. Furthermore, data on the spatial distribution and the composite suitability of climatic factors can constitute benchmarks for future studies on the influence of climate change on the viticultural potential of wine growing regions.

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