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VITICULTURAL ZONING: A COMPARATIVE STUDY REGARDING THE ACCURACY OF DIFFERENT APPROACHES IN VINEYARDS CLIMATE SUITABILITY ASSESSMENT

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ABSTRACT. The paper presents the results of a study regarding the mesoclimate suitability assessment of three Romania's wine-growing centres (Urlaţi-Dealu Mare vineyard, Huşi-Huşi vineyard, Bucium-Iaşi vineyard), by the Huglin's heliothermal index and by a GIS based multicriteria method. The results are compared between the two types of analysis and with the macroclimate suitability map of Romania's wine regions, expressed by Huglin's heliothermal index spatial distribution. The research show that the values of Huglin's heliothermal index in Romania's wine regions varies between 2341.48 on the Danube Terraces from the southern limit of the country to lower than 1500 on the intra-mountainous wine region Transylvania. The prevailing climate class over the Romania's wine regions is IH-1 that define temperate climate. According to the assessment on Romania's macroclimate scale by Huglin's heliothermal index, the three wine-growing centers are characterized by temperate climate (IH-1), that indicate the existence of climate conditions for grapes maturation to Cabernet Sauvignon variety. The assessment on mesoclimate scale by the GIS based multicriteria method reveals a wider variability of local climate than that resulted from macroclimate and mesoclimate analysis by Huglin's heliothermal index, as follows: the climate of Urlaţi wine-growing center is suitable for quality red wines production; in Huşi wine-growing centre only 16.95% from the area has climate suitable to produce red table wines; the climate of Bucium wine-growing centre is not suitable for red wine production. Comparison with the Romania's vineyards wine production specialization confirms that the results of multicriteria GIS based evaluation reveal accurate the local climate suitability and demonstrate the need of the fine-scale assessment of vineyard climate in the viticultural zoning.

Key words: vineyard; climate; assessment; wines; Huglin's heliothermal index.

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REZUMAT. Zonarea viticulturii: studiu comparativ privind acurateţea diferitelor abordări în evaluarea favorabilităţii climatului podgoriilor. În lucrare sunt prezentate rezultatele evaluării climatului centrelor viticole Urlaţi-podgoria Dealu Mare, Huşi-podgoria Huşi, Bucium-podgoria Iaşi, prin intermediul indicelui heliotermic Huglin şi a unei metodologii multicriteriale. Rezultatele celor două tipuri de evaluare sunt comparate atât între ele, cât şi cu harta favorabilităţii macroclimatului regiunilor viticole din România, exprimată prin valori ale indicelui heliotermic Huglin. Cercetarea arată că, pe teritoriul României, valorile indicelui heliotermic Huglin variază între 2341.48 în Regiunea viticolă a Teraselor Dunării şi mai puţin de 1500 în Regiunea viticolă a Podişului Transilvaniei. Conform evaluării la scara macroclimatului, exprimată prin valorile indicelui heliotermic Huglin, cele trei centre viticole analizate dispun de condiţiile climatice necesare producţiei de vinuri roşii din soiul Cabernet Sauvignon. Evaluarea la scara mezoclimatului (scara podgoriei) prin metodologia multicriterială relevă o variaţie mult mai largă a favorabilităţii climatului local decât cea rezultată din evaluarea macroclimatului pe baza indicelui heliotermic Huglin, după cum urmează: climatul centrului viticol Urlaţi este favorabil pentru producţia de vinuri roşii de calitate; în centrul viticol Huşi numai 16.95% din suprafaţă dispune de condiţii climatice favorabile producţiei de vinuri roşii; climatul centrului viticol Bucium nu este favorabil pentru producţia de vinuri roşii. Comparaţia cu harta direcţiilor de producţie a podgoriilor din România arată că rezultatele evaluării multicriteriale sunt corecte şi demonstrează necesitatea evaluării climatului podgoriilor la scară fină în cadrul lucrărilor de zonare a viticulturii.

Cuvinte cheie: podgorie; climat; evaluare; vinuri; indicele heliotermic Huglin.

INTRODUCTION

The climate is the factor that influences mostly vine, both in terms of its growth and development but also the expression of its biological production potential. The results of different studies show that climate influence is manifested by all parameters that define it as follows: radiation and insolation influence anthocyanins, sugars and malic acid content (Crippen, Morrison, 1986; Dokoozlian, 1996); temperature influences sugars, anthocyanins and malic acid content (Kliewer and Torres 1972; Buttrose *et al.,* 1971; Coombe, 1987); night temperatures influence anthocyanins and aromatics content (Tomana *et al.,* 1979); rainfalls affect grapes maturation (Tregoat *et al.,* 2002).

The suitability of climate for wine varieties is analyzed on the basis of a single climatic parameter values, often the temperature, or by reference to specific bioclimatic indices that combine the influence of two-three climatic parameters (the indices of Multicriteria Classification System, Branas index, Winkler index etc.). Since the quality of the grapes has a complex conditioning, the vineyard climate suitability assessment results are as accurate as are to be taken into consideration several climatic parameters. The multicriteria methodology used in this research (Irimia, 2012) includes the values of 10 climatic factors and bioclimatic indices representing temperature, global radiation, solar insolation,

rainfall in the growing season and the length of the growing season.

The relations vine-climate are analyzed at three different scales, respectively at microscale (of vine vicinity), at mesoscale (the vine land or vineyard scale) and at macroscale (the wine region scale). The macroclimate assessment generates very general informations regarding the vineyard climate without capturing the details revealing its local variation. The mesoclimate assessment are the most relevant because they can capture local variation of climatic factors, providing the necessary information for viticultural zoning at vineyard scale.

The viticultural zoning in Romania has been achieved in the '80s based on a number of factors representative for climate, topography and soils of vineyards from temperate-continental climate conditions (Oşlobeanu *et al.,* 1991). Climatic factors were represented individual (temperature, radiation, solar insolation), but also as bioclimatic indices representative for temperate-continental climate vineyards in Romania (real heliothermal index, bioclimatic index of Constantinescu, oenoclimatic aptitude index etc.). The indices of Multicriteria Classification System were calculated for the Romania's wine regions in 2004 (Savu, 2004); according to Huglin's heliothermal index values the climate of Romania's wine regions varies from too cold (IH-3 class) to temperate-warm (IH+1 class). At the continental level, taking into consideration the general characteristics of climate, Romania's wine regions are included in the following zones: the Transylvania Plateau in zone B; Muntenia, Oltenia, Dobrogea and Danube Terraces in the C II zone; Moldavian Hills, Crişana and Maramureş Hills in the C Ia zone [Council Regulation (EC), 479/2008].

MATERIALS AND METHODS

The assessment on macroclimate scale was performed by the analyze of Huglin's heliothermal index spatial distribution in Romanias'wine regions (Huglin, 1978). This index shows the heliothermal potential of the vineyards' climate at macroscale and offer the information regarding the wine varieties which can be cultivated (*Table 1*).

For the northern hemisphere, IH is calculated using the formula:

$$IH = \sum_{01.04}^{30.09}[(Tmj - 10) + (Txj - 10)/2] \times k$$

where:
- Tmj = mean air temperature (°C);
- Txj = maximum air temperature (°C);
- k = day length coefficient, varying from 1.02 to 1.06 between 40° and 50° latitude;
- 10 = mean temperature of air (°C), when the metabolisms processes are active.

The assessment on mesoclimate scale was realized by two different methods: first by Huglin's Heliothermal Index (IH), and second by a multicriteria GIS based methodology (Irimia, 2012).

Table 1 - Huglin's Heliothermal Index classes (Tonietto and Carbonneau, 2004)

Class	Abbreviation	Interspace	Wine varieties
Very cold	IH_{-3}	≤ 1500	Only the early cultivars that can reach maturity, especially the white varieties (i.e. Muller-Thurgau, Pinot blanc, Gamay, Gewurztraminer)
Cold	IH_{-2}	> 1500 ≤ 1800	Riesling, Pinot noir, Chardonnay, Merlot, Cabernet franc
Temperate	IH_{-1}	> 1800 ≤ 2100	Cabernet-Sauvignon, Ugni Blanc, Syrah
Temperate warm	IH_{+1}	> 2100 ≤ 2400	Grenache, Mourvèdre, Carignan
Warm	IH_{+2}	> 2400 ≤ 3000	Potential which exceeds the heliothermal needs to ripen the varieties, even the late ones (with some associated risks of stress)
Very warm	IH_{+3}	> 3000	There is no heliothermal constraint for the grapes to ripen

Table 2 - Evaluation system of suitability of climatic factors and bioclimatic indices representatives for vineyards from temperate climate conditions

Climate parameters	Suitability interval	Suitability classes/ranking points			
		IV/0	III/5	II/8	I / 10
			Directions of wine production		
		Unsuitable for grape growing	White table wines, sparkling wines, wines for distillates	White quality wines and red table wines	Red and white quality wines
Average annual temperature (°C)	8.5 - 11.2	< 8.5	8.5 - 9.3	9.4-10.0	10.1-11.2
The average temperature of the warmest month (July) (°C)	18.0 - 22.0	< 18.0	18.1 - 19.0	19.8-21.0	21.1-22.0
Global radiation (kcal/cm^2/01.IV-30.IX)	80.0 - 92.0	< 80	80 - 83.9	84.0-86.9	87.0- 92
Real insolation (hours, 01.IV-30.IX)	1280 - 1610	< 1280	1280-1450	1451 -1550	1551-1610
The rainfall in the growing season (mm, 01.IV - 30.IX)	250 - 390	-	> 390	< 250	251 - 390
The sum of fractions of daily temperatures > 10°C (Σt_u°C$_{,1.04-30.09}$)*	1045 - 1675	< 1045	1045-1200	1201 -1400	1401-1675

Climate parameters	Suitability interval	Suitability classes/ranking points			
		IV/0	III/5	II/8	I / 10
			Directions of wine production		
		Unsuitable for grape growing	White table wines, sparkling wines, wines for distillates	White quality wines and red table wines	Red and white quality wines
The length of growing season (days)	160 - 210	< 160	160 - 175	176 – 190	> 190
Real heliothermal index ($IHr_{1.04\text{-}30.09}$)	1.36 - 2.66	<1.36	1.36 -1.70	1.71 - 2.20	2.21- 2.66
Bioclimatic viticultural index ($Ibcv_{1.04\text{-}30.09}$)	3.9 - 13.0	< 3.9	3.9 – 5.0	5.1 – 8.0	8.1 – 13.0
The index of oenoclimatic aptitude ($IAOe_{1.04\text{-}30.09}$)	3793 - 4600	< 3793	3793-4300	4301-4600	> 4600

Table 3 - The mesoclimate suitability according to the average of evaluation points

Suitability class	Average of evaluation points	Viticultural potential of the area
I	10	Viticultural potential for high red quality wines (HQRW)
	9	Viticultural potential for red quality wines production and secondary for white quality wines (QRW+QWW)
II	8	Viticultural potential for white quality wines production and secondary for red table wines (QWW+TRW)
	7	Viticultural potential for white quality wines (QWW)
III	6	Viticultural potential for white table wines, sparkling wines, wines for distillates and for white quality wines in very suitable years, in terms of climate (TWW+QWW)
	5	Viticultural potential for white table wines, sparkling wines and wines for distillates (TWW)
IV	0	Unsuitable for grape growing

The multicriteria methodology assess the vineyard climate according to the individual and combined suitability for wine varieties of 10 climatic factors and bioclimatic indices (Irimia and Rotaru, 2009): average annual temperature (ºC), the warmest month average temperature (July, ºC), the sum of fractions of daily temperatures > 10°C (Σ°C/1.04-30.09), global radiation (kcal/cm^2/1.04-30.09), insolation (hours/ 1.04-30.09), rainfall in the growing season (mm/1.04-30.09), the length of the growing season (days), the real heliothermal index (IHr), the bioclimatic index (Ibcv), the oenoclimatic aptitude index (IAOe). The individual suitability of the factors and indices is expressed by evaluation points assigned according to

the type of wines that they determine (*Table 2*).

The combined suitability of the factors and indices is expressed as the average of the evaluation points incumbent to a pixel of the map of the assessed area for the ten parameters. The average varies between 5 and 10, and is classified as shown in *Table 3*.

The spatial distribution of the 10 parameters was achieved using the digital elevation model made in raster format with pixel resolution of 30 x 30 m (Patriche *et al.,* 2011). Multiannual averages were used to accurately represent the characteristic values of factors and indices from the assessed areas.

The assessment at mesoclimate scale concern three Romanian wine-growing centres, located at different latitudes, in vineyards with different wine production directions, respectively (*Fig. 1*): Urlaţi wine-growing centre, situated at 44.98° lat. N and belonging to Dealu Mare vineyard, specialized in red quality wines; Huşi wine-growing centre, situated at 46.67°lat. N and belonging to Huşi vineyard, specialized in white quality wines; Bucium wine-growing centre, situated at 47.15° lat. N and belonging to Iaşi vineyard.

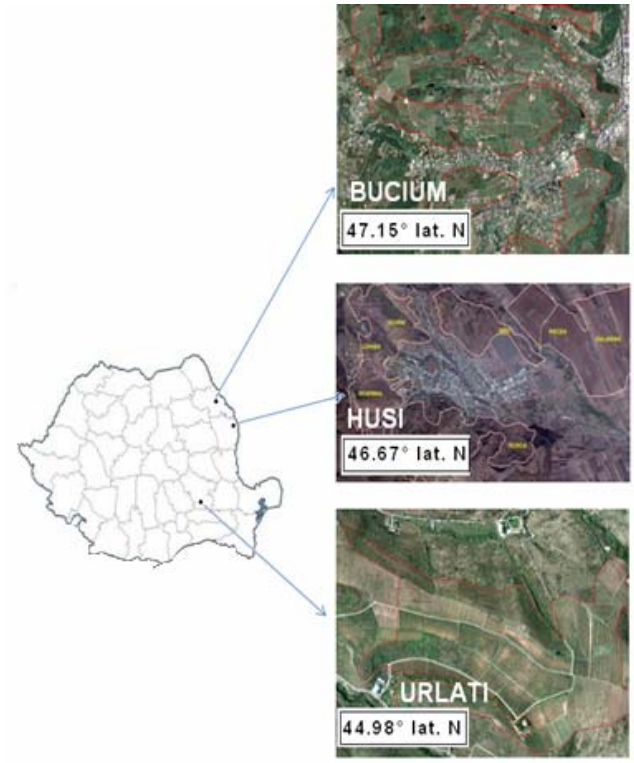


Figure 1 - Geographycal location of Urlaţi, Huşi and Bucium wine-growing centers vineyard, specialized in white quality wines and sparkling wines

RESULTS AND DISCUSSION

The assessment at macroclimate scale according to IH values. As show in the *Fig. 2*, the values of IH over the Romania's wine regions varies from maximum 2341.48, on the Danube Terraces at the southern limit of the country, to lower than 1500 in the intra-mountainous wine region Transylvania. These values reveal that Romania's viticulture is characterized by four levels of heliothermal potential, expressed by four classes of IH index, respectively: very cold climate (IH-3), cold climate (IH-2), temperate climate (IH-1) and temperate-warm climate (IH+1). The prevailing IH class over the Romanian's wine regions (Moldavia, northern half of Muntenia-Oltenia, Banat, Crişana-Maramureş, Dobrogea) is temperate climate (IH >1800≤2100). The southern limit of Moldavia, the south of Muntenia-Oltenia and the entire Danube Terraces are characterized by temperate-warm climate (IH+1, >2100≤2400); the biggest part from Transylvania and the hilly area from Moldavia are characterized by cold climate (IH-2, >1500≤1800), and small areas from the Transylvania by very cold climate (IH-3, ≤1500).

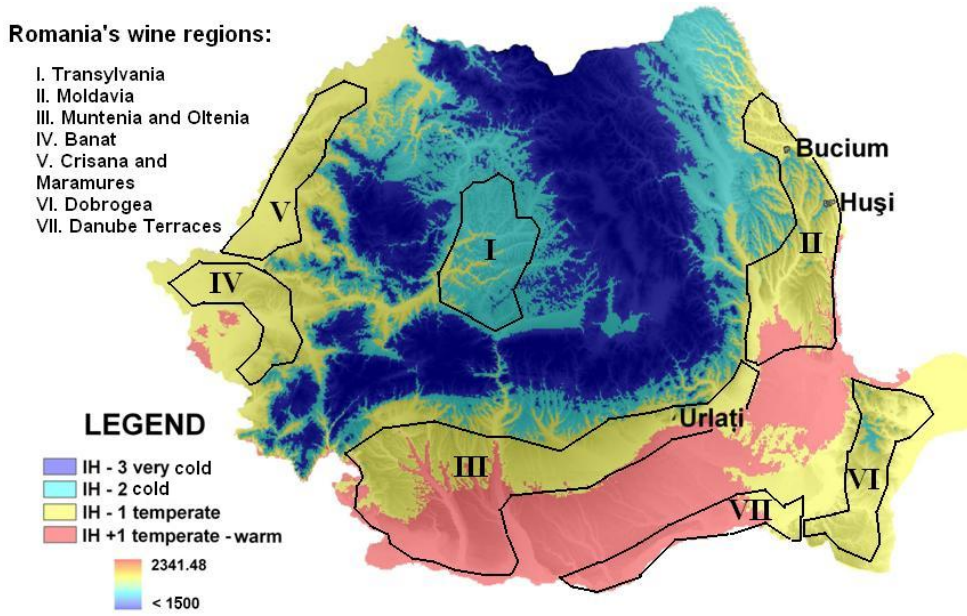


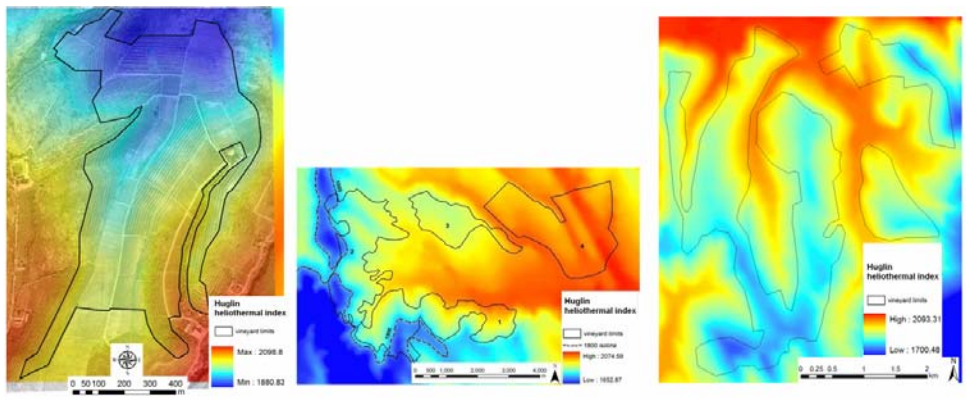
Figure 2 - The map of Huglin's Heliothermal Index spatial distribution over the Romania's wine regions

As show in the *Fig. 2*, the three analyzed wine-growing centers are situated in temperate climate area (IH-1). This type of climate has the heliothermal potential to assure the grapes maturation to late varieties as Cabernet Sauvignon (Tonietto and Carbonneau, 2004), which means that the three wine-growing centres have the heliothermal potential to produce red wines.

Using as validation criteria the traditionally established wine production directions of the three wine-growing centres, this ascertainment is confirmed only in the case of Urlaţi wine growing centre, specialized in quality red wines production; in Huşi and Bucium wine-growing centres are not produced red wines, these two centres being specialized in white wines production.

The assessment at mesoclimate scale according to IH values (*Fig. 3*) reveal some differences comparing with the previous macroscale analyze. While in Urlaţi wine-growing centre, the southernmost of the three analyzed areas, the IH values (1880.80-2098.83) fall entirely in the temperate class IH-1, in the other two wine-growing centres the IH cover two climate classes, respectively *temperate* IH-1 and *cold* IH-2 classes, in contradistinction to macroscale analysis results. In Huşi wine-growing centre the IH values varies between 1652.87 and 2074.59; in Bucium the IH values varies between 1700.48 and 2093.31.

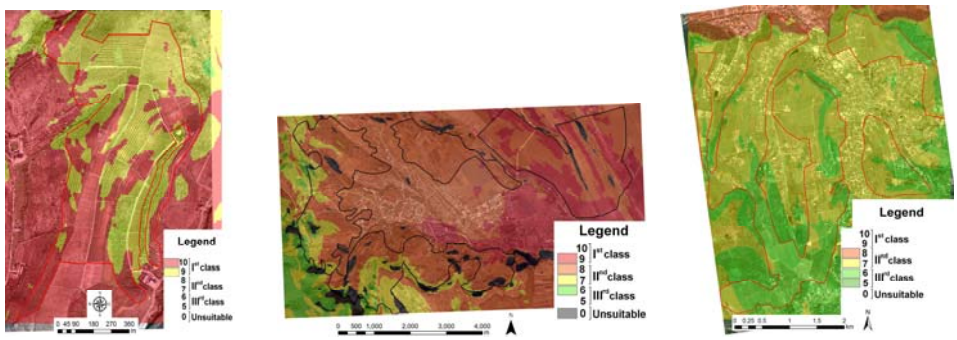
These differences shows that the climate analysis at mesoscale reveals more accurately the local variations of heliothermal potential that the macroscale analyses. The presence of cold class climate (IH-2) in Huşi and Bucium wine-growing centres explain the lack of red wines varieties from their varietal assortments.



a b C

Figure 3 - The spatial distribution of Huglin's Heliothermal Index in Urlaţi (a), Huşi (b) and Bucium (c) wine-growing centers

The assessment at mesoclimate scale according to multicriteria evaluation. The multicriteria analysis of the three wine-growing centres climate reveal a much wider local variability of climate conditions that in the two previous analysis. Summarizing the analysis results to the climate suitability maps of the three wine-growing centres (*Fig. 4*) is found that:



a B C

Figure 4 - The mesoclimate suitability in Urlaţi (a), Huşi (b) and Bucium (c) wine-growing centers

Table 4 - The structure of local climate suitability of Urlaţi, Huşi and Bucium wine-growing centers

Class / subclass		Significance	Structure of climate suitability					
			Urlaţi - 45.00°N		Huşi - 46.66°N		Bucium - 47.15°N	
			ha	%	ha	%	ha	%
Class I	10	HQRW	27.76	44.51	-	-	-	-
	9	QRW+QWW	34.60	55.48	362.74	16.95	-	-
Class II	8	QWW+TRW			1369.8	64.03	115.1	1.24
	7	QWW			262.21	12.26	616.4	66.42
Class III	6	TWW+QWW	-	-	43.47	2.03	300.0	32.33
	5	TWW	-	-	-	-	-	-
Class IV	4	UNSUITABLE	-	-	100.8	4.71	-	-
Total			**62.3**	**100**	**2139.1**	**100**	**928.0**	**100**

- on the entire area of Urlaţi wine-growing centre, the most southern one (44.98° lat. N), the climate is suitable for Cabernet Sauvignon variety grapes maturation, i.e. for quality red wines production, as macroclimate and mesoclimate assessments by IH reveals;

- in Huşi wine-growing centre, only 16.95% from the area has the climate suitability to maturate the grapes at Cabernet Sauvignon variety, i.e. to produce red table wines, that validates partially the results of macroclimate and mesoclimate assessments by IH; the difference of

78.34% is represented by climate suitability to produce white wines;

- Bucium wine-growing centre does not have the climatic suitability to produce red wines, a result in contradiction to the macroclimate assessment by IH.

The results of this multicriteria mesoclimate evaluation reveal correctly the wine production directions traditionally practiced in the three wine-growing centers. Comparison with the Romania's vineyards wines specialization confirms the results and explains the need of mesoscale multicriteria evaluation of vineyard climate (*Fig. 5*). As the previous research demonstrate (Irimia *et al.,* 2012), even the climate assessment results must be corrected by the influence of pedological and topografical factors, in order to obtain the accurate viticultural potential map of a vineyard.

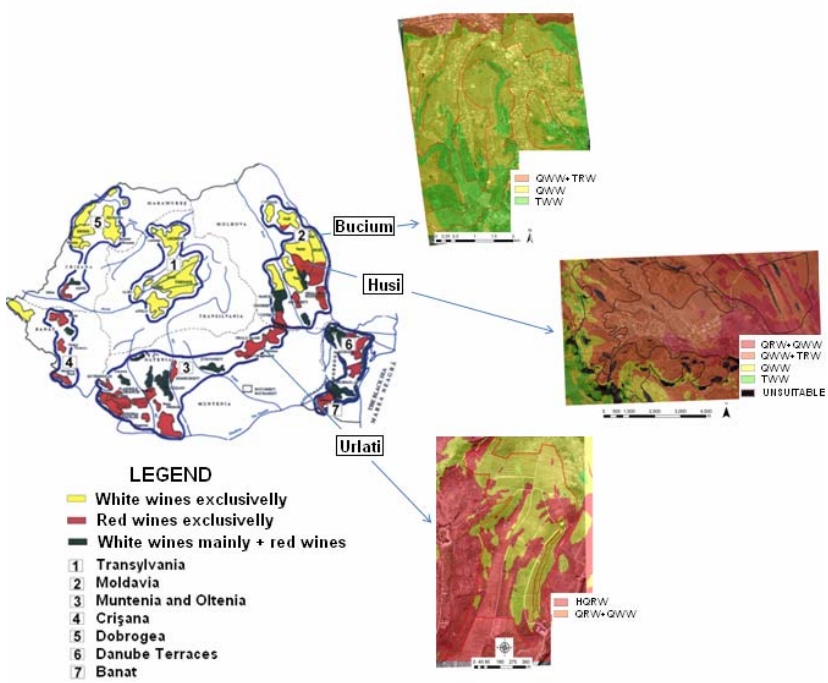


Figure 5 - The Urlaţi, Huşi and Bucium mesoclimate suitability maps, in relation with Romanias'vineyards specialization

CONCLUSIONS

The values of Huglin's Heliothermal Index in Romania's wine regions varies between 2341.48 on the southern limits of the country to lower than 1500 on the intra-mountainous wine region Transylvania. The prevailing Huglin's Heliothermal Index class over the

Romanian's wine regions is IH-1 that define temperate climate.

According to assessment on macroclimate scale by Huglin's Heliothermal Index, the Urlaţi, Huşi and Bucium wine-growing centres are characterized by temperate climate class (IH-1), that indicate the existence of heliothermal potential for grapes maturation to Cabernet Sauvignon variety.

The assessment on mesoclimate scale by Huglin's Heliothermal Index reveals temperate climate (IH-1) in Urlaţi wine-growing centre, and temperate climate (IH-1) + cold climate (IH-2) in Huşi and Bucium wine-growing centers.

The assessment on mesoclimate scale by the multicriteria method reveal a wider variability of local climate than that resulted from macroclimate analysis and mesoclimate analysis by Huglin's Heliothermal Index, as follows: the climate of Urlaţi wine-growing centre is suitable for quality red wines production; in Huşi wine-growing centre only 16.95% from the area has the climate suitable to produce red wines; the local climate of Bucium wine-growing centre is not suitable for red wines production.

The traditional established wine production directions of the three wine growing centres are: quality red wines in Urlaţi; quality white wines and white table wines in Huşi; white quality wines, white table wines and sparkling wines in Bucium wine-growing centre.

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