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DESIGN OF VINEYARD APPELLATION REFLECTING NATURAL TERROIR: A CASE STUDY OF MODRA, SLOVAKIA

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Design of vineyard appellation reflecting natural terroir: A case study of Modra, Slovakia

The current valid vineyard zoning in Slovakia and the other EU Member is not unified for all countries. One reason is that EU legislation relies on the Romanesque wine-labelling method based on the terroir conception which the region from where the grapes originate and in which they have been processed plays an important role. According to the Romanesque way, the borders of these regions should reflect the elements that make wines original and give them their typical character. However, the current division in Slovakia into wine-growing areas, municipalities and vineyards fields does not respect this condition. Our aim is to propose a new regionalization of vineyards in the municipality of Modra. It is based on field research of vineyards site conditions, analysis of LIDAR, meteorological and soil data in combination with geostatistical modelling at the local level. The wine-growing areas are categorised into seven homogeneous zones, which reflect the local terroir. The created zones should form the basis of an appellation to identify and protect wines produced in Modra. This paper provides a methodical procedure applicable in the regions where it is desired to form an appellation, which complies with the wine protection directives based on the geographical indication on the label.

Key words: appellation, terroir, vineyards, soil samples, digital terrain model, microclimatic measurements, municipality of Modra, Slovakia

INTRODUCTION

From the beginning of winemaking, one has been asked the same questions: "Which wine is the best?", "Where does this wine come from?", "What does the region have that it produces such a unique wine?" These questions persist as long as drinking wine and they have a rising tendency. It has been concluded that the best wines are produced in France. The reason behind it (as every Frenchman says) is its unique terroir. The concept of terroir serves as great competitive advantage in many marketing strategies, as well as the promotion and presentation of individual regions, zones, and even specific areas of vineyards on the label. This system of protection, promotion and presentation was fully established, especially in France, Italy and Spain, but the so-called Romanesque wine classification system is based on the uniqueness of the regions where grapes ripen and process. However, the appellation system in Slovakia and the entire regionalization of vineyards do not currently correspond to this kind of protection and presentation. The concept originated in France has a historical and cultural background and is currently more relevant at a scientific level. Today, its relevance is higher than in the past due to the protection of products (especially wines) based on geographical origin. There has been an increase in the number of scientific papers focused on the relationship between agricultural products and geographical environment (Rosas 2008, Sommers 2008, Jung 2014, Keller 2015, Winkler and Nicholas 2016, Karlík et al. 2018 and Ramos et al. 2018).

French perception of terroir is based on the premise that each wine is qualitatively derived from the natural environment in which the grapes ripen. The term terroir also reflects the potential of a site to express its capacities and assumptions in a context that can evoke a sense of place in humans through the creating something unique (Elaydi and McLaughlin 2012). In viticulture, the term terroir is very widespread and used primarily in the context of a combination of all natural landscape characteristics and cultural practices that together influence the taste and the wine bouquet produced in the particular part of the selected region (Renouil and de Traversay 1962). Resolution of the International Organization of Vine and Wine (OIV) OIV 333/2010 defines terroir as the concept that refers to a territory in which interactions between the inorganic and organic part of the land and applied agronomic practices create distinctive characteristics recognizing the uniqueness of products originating from those territories (OIV 2010). Thus, terroir includes soil specificities, geo-relief features, climatic conditions and biodiversity characteristics. Carey (2001) describes terroir in his work as the complex environmental factors humans cannot easily influence and modify.

Unlike of France, Slovakia does not have a strictly defined appellation system based on this concept. However, as a member of the International Organization of Vine and Wine, it has undertaken to implement legislation in the categories of designation of origin and geographical indication of the product. The reason for the current situation is the historical context. Under Act No. 313/2009 Coll. (NR SR 2009) the wine-growing region of Slovakia is divided into six wine-growing regions – Little Carpathians, Southern Slovak, Nitra, Central Slovak, Eastern Slovak and Tokaj regions All regions except Tokaj Region are further divided into 40 wine -growing districts, which fall into 702 municipalities (ÚKSUP 2020). The wine categorization was based on the traditional German labelling system, which emphasized the sugar content of the must. According to that system, we still categorize wines today, and with some exceptions, the geographical aspect is missing. The reason for introducing such wine categorizations were climatic conditions, when the sugar content in the musts was lower than today. In the past, wines were richer in acids relative to sugars but less harmonious. The Act on Viticulture and Winemaking responds to the fact that the sugar content of the must is not the only decisive factor affecting the quality of the wine. Due to legislative changes in the EP, Rada EÚ (2012), Slovakia adopted the categories "product with the designation of origin" and "product with the geographical indication" for labelling of foodstuffs. Thus, it deviated from the original German classification and moved closer to the French classification by taking at least formal consideration of the product origin.

Vineyards are an important type of agricultural land cover and create a characteristic vineyard landscape in warm climate regions in Slovakia.

In recent years, the quality of Slovak wines is rising, which is confirmed by the numerous gold medals from many prestigious competitions and successful producers place more emphasis on origin appellation and terroir (Falťan et al. 2017). On the other hand, the vineyard area is slowly decreasing (Lauko et al. 2013, Lieskovský et al. 2013 and Hanušin and Štefunková 2015). If terroir represents a strong marketing concept, Slovak wines are becoming increasingly popular globally. The legislation favours the Romanesque wine labelling according to terroir, so it is only appropriate to discuss current wine labelling. With such a labelling it will be necessary to re-regionalize the territory of Slovakia's whole wine-growing region (and its zoning) and anchor it in the law.

We aimed to create a study that could help our country in the future to find a new way of vineyards classifying to distinguish the differences and uniqueness for each region. The study provides a view of the complex topic and presents the methodical procedure for creating a picture of the wine-growing landscape. It defines the procedure by which common features of vineyards can be identified. These may be a significant determinant of the quality of the wine produced in these regions.

MATERIAL AND METHODS

Study area

The research was carried out on vineyards parcels, which belong to the Modra municipality territory according to the cadastral documentation. They have a minimum area of 250 m^2 (except terraced areas forming a more extensive unit) and are not part of the Modra urban area. Based on such defined criteria, we have identified a total of 511 vineyard areas. This cadastral area covers an area of 49.62 km^2 and is part of the district of Pezinok within the Bratislava region. Under current legislation, the wine-growing areas belong to the Little Carpathians Wine Region and to the Modra Wine District (Fig. 1). The area partially extends into the mountains of the Little Carpathians and the Danubian Lowland (Mazúr and Lukniš 1978). Although the municipality of Šenkvice still belongs to the Bratislava area of environmental burdens, the territory of Modra does not extend there (Michaeli and Boltižiar 2010). The study area is characterized by the fact that it lies the southern and south-eastern slopes of the Little Carpathians with a typical downhill flow of water and soil material. The altitude of the area in which the vineyards are located reaches values ranging from 145 to 365 m above sea level. m. The geological bedrock consists mainly of proluvial and deluvial sediments (especially granodiorite and tonalite geests), and less fluvialsediments (clay and sandy gravels, sands), on loess clays in lower parts of area (ŠGÚDŠ 2013). From the soil types in the studied area, it developed Cambisols, textured clay-sandy to sandy-clay. The lowland part dominates Pseudogley Luvisols, textured clay to clay-clay (VÚPOP 2013).

METHODS AND DATA

Georelief

We used data obtained using LIDAR Leica ALS 70/CM technology (the National Forestry Centre in Zvolen) for geo-relief evaluation. A digital relief model with a cell size of 1 m and a total vertical accuracy of 10 – 15 cm was used as the input of the analysis. DTM (digital terrain model) was modified in the first step with Mesh Denoise (Sun et al. 2007), which is part of the modules within the SAGA GIS software. The tool smoothed terrain inaccuracies in a DTM created from a cloud of points. The slope of the georelief and the potential global solar radiation level were expressed from the adjusted DTM. The other georelief attributes mentioned (again including slope) were derived from the aggregated DTM, to which the tool SAGA GIS package called Fill Sinks (Wang and Liu 2006) was applied in the previous step. The application of Fill Sinks generated hydrologically correct DTM. We aggregated DTM in ArcGIS 10.1 using Aggregate. The Aggregate instrument resampled the original DTM with a cell size of 1 m, wherein we obtained the new DTMs with a cell size of 10 m. As a reason for resampling the originally 1-meter DTM, it is the fact that soil modelling with very detailed DTM does not produce the most accurate results, as suggested by Gillin et al. (2015).

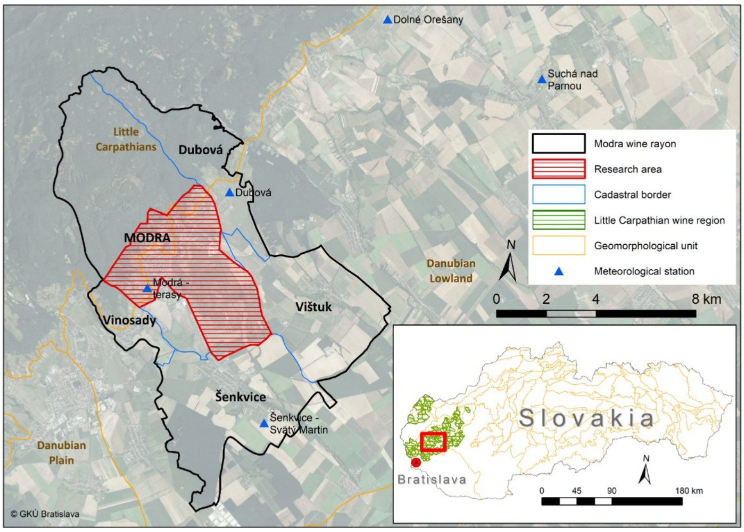

Fig.1. Location of the study area within the Little Carpathian vineyard region and Modra vineyard sub-region with a marked vineyard area of interest

Tab. 1. Selected georelief characteristics derived from DMR: in SAGA GIS interface

Georelief attribute	Brief description
Potencial global insolation	Expresses potential global insolation of the investigadet area (Hofierka a Šúri 2002).
Georelief slope	Georelief slope directly affects the possibities of vineyards cultivation, but also the calculation of other charakteristícs of georelief (e.g. potential global insolation, LS factor).
Valley depth	Expresses the vertical distance ot the area from reference point of river network in DMR (Böhner and Conrad 2012).
Southness	The coverted value of orienation of georelief in relation to the cardinal points expressed using the relation: southness = -cos (orientation). It takes value from -1 on northern slopes to 1 on southern slopes. Value converted in this way can bes used for further quantitatively oriented analyzes (Deng et al. 2007).
MRTFF (Multiresolution index of ridge top flatness)	Identifies flat and elevated forms of georelief (Gallant and Dowling 2003).
MRVBF (Multiresolution index of valley bottom flatness)	Identifies flat and low-layng areas, that have tendency to accumulate soil sediments (Gallant and Dowling 2003).
Vertical distance from watercourse network	Expresses the vertical distance between analyzed area and nearest drainage network as a reference height (Böhner and Conrad 2012)

Climate

The climate data were obtained by measuring the climate data using automated meteorological stations in our territory and its close surroundings. Over four years, meteorological stations recorded air temperatures and rainfall totals in the localities of Modra-terasy, Šenkvice – Svätý Martin and Dubová. In addition to these stations, we considered stations installed in nearby Dolné Orešany and Suchá nad Parnou as auxiliary stations.

From the measured hourly data of the air temperature and total atmospheric rainfall the following indicators were evaluated for each of the above stations:

– the sum of effective temperatures (GDD),

– cold night index (Cl),

– index of difference of the minimum night and maximum daily temperature during the vegetation period (DTR),

– average air temperature in January (T_{jan}),

– total atmospheric rainfall during the vegetation period (Z_{veg}).

In the next step, we created continuous models based on interpolating point data measured in meteorological stations. Mean values of GDD, Cl, DTR and T_{jan}, Z_{veg} were interpolated. For interpolation, we chose the cokriging method (Goovaerts 1997). Because all the climate indicators, which we needed to model spatially, correlate with altitude GDD (r = 0.56), Cl (r = 0.42), DTR (r = 0.98), T_{jan} (r = 0.42) Z_{veg} (r = 0.69), the use of cokriging together with altitude as a supporting independent variable is reasonable. The DMR was derived from the topographic map of the Slovak Republic at a scale of 1 : 10,000, using the Topo to Raster tool in ArcGIS 10.1 with a 10 m grid cell setting. The DMRs, obtained by LIDAR technology, were not available from the entire territory between meteorological stations. Cokriging was also used to assess the position of Modra vineyards regarding the probability of spring frost. The procedure for creating the Spring Frost Risk Model (RJM) was determined as follows: We considered all situations where the air temperature dropped below 0 °C in at least one of the five weather stations observed. We recorded measurements from all stations and continued iteratively until all solutions were exhausted. Subsequently, values for each of these days were interpolated using cokriging with DMR as for other climate indicators. Model Calibration in Arcgis 10.1. allows you to change the classic prediction to predict the probability of a certain value (so-called *Probability Kriging/CoKriging*).

Based on this, we have created a total of 11 spatial models with the probability that the air temperature will not exceed 0 °C during each situation. We determined the risk of spring frost during the day when at least one of the monitored stations was freezing. Subsequently, using a raster calculator, we created the final spatial model using an arithmetic average, indicating the probability of the site's susceptibility to spring frost if it freezes. Fig. 2 shows the spatial distribution of the monitored climate indicators.

Soil

Data of soil physical and chemical properties were obtained with respect to ecological demands and the nutrition of vines. The primary source of soil data was obtained directly in the field, supplemented by data from the KPP (Complex Soil

Survey) database (Skalský and Balkovič 2002). The research was realised on 51 research points.

Soil samples were taken in the last week of May 2017 at 50 cm from a vineyard row. The depth of soil removal was chosen from a rhizosphere at a depth of approximately 50 – 70 cm (White 2009). At this depth lateral roots are located, which receive the bulk of the nutrients involved in the production of grapes, but also in its resulting characteristic properties (Fig. 3).

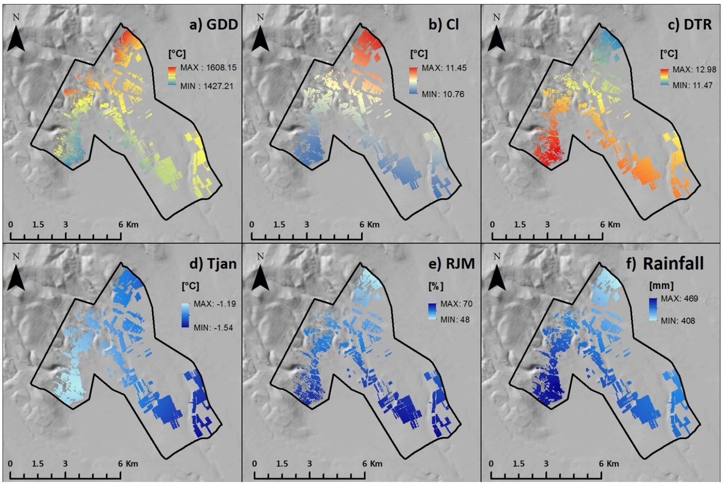

Fig. 2. Basic climate characteristics expressed for each vineyard area

(GDD – the sum of effective temperatures, CI – cold night index, DTR – index of difference of the minimum night and maximum daily temperature during the vegetation period, T_{jan} – average air temperature in January, RJM – occurrence of spring frost, Rainfall – total atmospheric rainfall during the vegetation period).

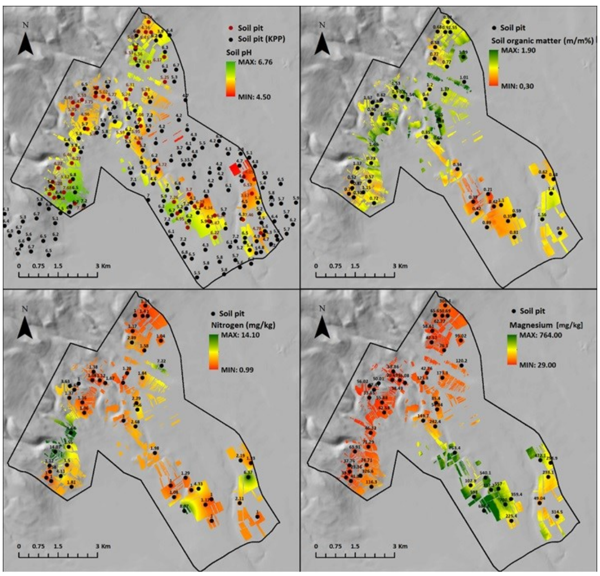

Fig. 3. Basic soil characteristics expressed for each vineyard area

The collected soil samples were subsequently analyzed in a HI-Lab laboratory in Debrecen, Hungary according to the methods shown in Tab. 2.

Tab. 2. Detailed characteristics of analytical methods used in geochemical soil analysis (HI-Lab, Debrecen)

Analyzed characteristics	Standardized method	Measuring instrument	Dispersion of measured values	Relative measurement error [%]
pH (KCl 1: 2,5) [-]	MSZ-08-0206-2:1978	WTW inolab pH7310 digitally pH-instrument	2 – 12	± 0,1
Plasticity according to Arany [K_a]	MSZ-08-0205:1978	VOS PB S40 Overhead stirrer	25 – 30 31 – 50 > 50	± 1 K_A ± 2 K_A ± 3 K_A
Content of – water-soluble salts [m/m%]	MSZ-08-0206-2:1978	WTW Cond 7110 conductometer TetraCon 325/S elektrode	0.02 – 0.2 > 0,2	± 7,5 ± 5
Content of $CaCO_3$ [m/m%]	MSZ-08-0206-2:1978 2.2.	K-10 calcimeter	0.1-5.0 > 5.0	± 7.5 ± 5
Content of organic component [m / m%]	MSZ 08-0210:1977 MSZ-08-0452: 1980	Thermo Scientific Evolution 60s UV-Visible spectrophotometer	0.1 – 0.50 0.51 – 1.5 > 1.5	± 7.5 ± 5 ± 2.5
Content of NO_2 and NO_3 soluble in KCl [mg / kg]	MSZ 20135:1999. 4.2.2. EPA 353.1:1978	Thermo Scientific Gallery Discrete Analyzer	1.0 – 10.0 > 10.0	± 7.5 ± 5
Content of magnesium soluble in KCl [mg / kg]	MSZ 20135:1999 4.2.2., 5.1. chapter	Thermo Scientific iCAP 6300 Radial View ICP-OES	0.05 – 5.0 5.01 – 200 > 200	± 7.5 ± 5 ± 2.5
Content of sulfur soluble in KCl [mg / kg]	MSZ 20135:1999 4.2.2., 5.1. chapter	Thermo Scientific iCAP 6300 Radial View ICP-OES	0.05 – 10.0 > 10.0	± 12.5 ± 7.5
Content of potassium in the form of K_2O soluble in ammonium lactate [mg / kg]	MSZ 20135:1999 4.2.1., 5.1. chapter	Thermo Scientific iCAP 6300 Radial View ICP-OES	0.3 – 50 50.1 – 200 > 200	± 7.5 ± 4 ± 2.5
Content of sodium soluble in ammonium lactate [mg / kg]	MSZ 20135:1999 4.2.1., 5.1. chapter	Thermo Scientific iCAP 6300 Radial View ICP-OES	1 – 50 51 – 200 > 200	± 7,5 ± 4 ± 2,5
Content of phosphorus (P_2O_5) soluble in ammonium lactate [mg / kg]	MSZ 20135:1999. 4.2.1., 5.1. chapter	Thermo Scientific iCAP 6300 Radial View ICP-OES	0.2 – 50.0 50.1 – 200 > 200	± 10 ± 7.5 ± 5
Content of copper soluble in EDTA [mg / kg]	MSZ 20135:1999 4.2.3., 5.1. chapter	Thermo Scientific iCAP 6300 Radial View ICP-OES	0.05 – 1.0 1.01 – 5.0 > 5.0	± 10 ± 7.5 ± 5
Content of manganese soluble in EDTA [mg / kg]	MSZ 20135:1999 4.2.3., 5.1. chapter	Thermo Scientific iCAP 6300 Radial View ICP-OES	0.02 – 20.0 20,1 – 50 > 50	± 7.5 ± 5 ± 4
Content of zinc soluble in EDTA [mg / kg]	MSZ 20135:1999 4.2.3., 5.1. chapter	Thermo Scientific iCAP 6300 Radial View ICP-OES	0.05 – 1.0 1.01 – 5.0 > 5.0	± 10 ± 7.5 ± 5

We obtained the clay content data from the KPP database used in Karlík et al. (2017), in which it was spatially modelled in the territory of Modra from 151 point data on its content beneath the topsoil.

Next steps included the use of interpolation tools such as EBK *Regression Prediction* (EBK RP), *Empricical Bayesian Kriging* (EBK) or regularized *Spline* (hereinafter *Spline*) in ArcGIS Pro 2.0.0. We created continuous models of investigated soil characteristics from Tab. 2. Due to the negligible variability of the $CaCO_3$ content and the water-soluble salt content, these two indicators were omitted from further modelling.

As auxiliary independent variables, we tested selected georelief data given in Table 1. Independent variables were selected using the *Best Subset Selection* tool within the General Regression Models tool in Statistica 10, whereas, we used for testing only the independent variables whose Pearson correlation coefficient relative to the observed dependent variable was greater than 0.2.

In a scenario where none of the independent variables tested was selected based on the Best Subsets Selection method, we investigated whether there is a structure between the values and whether the data show some degree of spatial autocorrelation as an essential prerequisite for the application of the tool Empirical Bayesian Kriging (EBK). We used the EBK tool for interpolation if the data were spatially auto correlated. If no structure was detected in the data, we performed deterministic interpolation using a regularized Spline (Tab. 3).

Tab. 3. Interpolation methods used and their basic characteristics

Dependent variable	Interpolation method used	Independent variable (if any)	Data source dependent on variable/ number of points
Clay content in soil	EBK Regression Prediction	DMR, SAGA WI, The slope of the georelief	KPP / 151
Soil plasticity	EBK Regression Prediction	clay content in soil, SAGA WI	test pit – laboratory analysis / 51
Organic component content (SOM)	EBK Regression Prediction	clay content in soil, southern,	test pit – laboratory analysis / 51
pH	EBK	-	test pit – laboratory analysis + KPP / 51 + 151
Nitrogen content	Regularized spline	-	test pit – laboratory analysis / 51
Magnesium content	EBK Regression Prediction	clay content in soil	test pit – laboratory analysis / 51
Sulfur content	EBK Regression Prediction	MRTFF	test pit – laboratory analysis / 51
Potassium content	EBK	-	test pit – laboratory analysis / 51
Sodium content	Regularized spline	-	test pit – laboratory analysis / 51
Phosphorus content	Regularized spline	-	test pit – laboratory analysis / 51
Copper content	Regularized spline	-	test pit – laboratory analysis / 51
Manganese content	EBK Regression Prediction	vertical distance to the network of watercourses,	test pit – laboratory analysis / 51
Zinc content	EBK Regression Prediction	MRVBF, clay content in the soil	test pit – laboratory analysis / 51
Skeleton content	EBK Regression Prediction	the slope of the georelief	test pit – inventory sheets / 51

Methods

The average value of all relevant variables from the physical-geographical environment specified in the previous part of the work was expressed for each of the 511 vineyard areas. Table 4 provides a basic descriptive statistic of selected relevant physical-geographical attributes that have been included in the zoning.

Tab. 4. Basic descriptive statistics of the vineyards analysed (n = 511)

Variable	Average	Median	Minimum	Maximum	Standard deviation	Unit of measurement
Climatic data						
Cl index	11.04	11.02	10.78	11.44	0.19	[°C]
DTR	12.38	12.43	11.51	12.98	0.41	[°C]
GDD	1 512.62	1 518.20	1 428.32	1 606.46	39.12	[°C]
Tjan	-1.31	-1.31	-1.53	-1.19	0.08	[°C]
RJM	0.60	0.60	0.49	0.69	0.05	[%]
Data derived from georelief						
Potential global radiation	829.42	824.97	757.90	878.41	220.30	[kWh / m^2]
The slope of the georelief	6.11	5.68	1.68	16.52	2.83	[°]
Soil data						
Potassium content	149.79	190.89	49.85	517.80	89.57	[mg / kg]
Nitrogen content	2.79	2.23	1.14	12.27	1.77	[mg / kg]
Phosphorus content	269.95	262.52	91.87	664.29	71.60	[mg / kg]
Magnesium content	132.99	75.84	32.64	692.09	137.76	[mg / kg]
Clay content	27.15	25.25	15.95	49.08	7.76	[%]
Manganese content	44.04	44.73	15.03	86.30	15.09	[mg / kg]
Copper content	13.76	13.09	1.89	75.01	7.66	[mg / kg]
Sulfur content	3.79	2.70	1.09	32.04	1.09	[mg / kg]
Skeleton content	24.58	24.34	3.60	78.37	16.10	[%]
Zinc content	1.65	1.69	0.47	3.15	0.62	[mg / kg]
Soil pH	5.68	5.64	4.63	6.65	0.37	[-]
Soil plasticity	29.73	26.20	23.24	54.26	7.17	[k_a]
SOM	0.95	0.92	0.44	1.64	0.22	[m / m %]

Methodological work procedure can be divided into two main steps: reduction of dimensionality based on the principal components method (PCA) and creation of wine-growing zones with an emphasis on terroir using cluster analysis. A separate step at the end of the methodological procedure was to verify the accuracy of the resulting clusters (DTR – index of difference of the minimum night and maximum daily temperature during the vegetation period, GDD – the sum of effective temperatures, T_{jan} – average air temperature in January, RJM – Spring Frost Risk Model, SOM – Organic component content).

Principal component analysis

A look at the correlation matrix shows a strong correlation between some of the variables analysed (Karlík 2018). Based on the above, these data can be described by other variables standing in the background (factors/components) to reduce their high dimensionality while retaining the information contained in the new variables. There is a strong correlation between clay content in soil, magnesium content and soil plasticity. Therefore, we decided to omit soil plasticity from the analysis, which shows an almost identical correlation with other variables as clay content. The climate indicators that were modelled using DMR also correlate strongly among themselves.

For this reason, DMR was not included in the analysis. Although it directly influences the modelled soil and climate attributes, it does not directly impact the vineyard, and its inclusion in the model would be unnecessary in the inclusion of derived quantities.

Similarly, in the case of climate indicators, we have eliminated the cold-night index (Cl), which correlates very strongly with the DTR index, from the data base based on the correlation analysis. This reduced data was then standardized according to Z-score. We applied PCA to the 18 variables thus obtained, with the proviso, that we obtained the same number of uncorrelated leading components sorted in descending order of variance, which individual components can express. We determined the number of components based on a debris graph constructed from the value of Eigenvalues. The debris graph curve is declining, and the boundary that separates the optimal number of components left is at a point where its decline is visibly slowing down (Velicer and Jackson 1990).

Cluster analysis

Cluster analysis was used to create individual wine-growing zones, namely the k-means method. This method is based on splitting the data into clusters so that in-cluster similarity is as high as possible and inter-cluster similarity, differences between clusters as large as possible. The problem of the k-means method is that we do not know in advance how many clusters (vineyard zones) we need to obtain. This problem can be solved in several ways. The most commonly used way is to determine the parameter k based on internal validity indexes. In our work, we analyzed a total of six different so-called internal validity indexes, namely the Calinski -Harabash index (Calinski and Harabash 1974), the Ball / Hall index (Ball and Hall 1965), Hartigan (Hartigan 1975), WBI (Zhao et. al. 2009), Xu (Xu 1997) and R-square (Sharma 1996) to estimate the optimal value of the parameter k relative to the data analyzed.

The index calculation is based on the sums of square errors between clusters (SSBs) and within clusters (SSWs), whereby the parameter k is determined based on the index used by visualizing the index values. The optimum value is considered to be either a global or a local maximum, minimum, a place where the trend of visualized values changes, depending on the monitored index. The SSW and SSB values were calculated sequentially for the k parameter ranging from $k = 2$ to $k = 50$.

The credibility of the classification of the wine-growing area into individual zones was tested on the basis of multivariate discrimination analysis (namely, the classification discrimination analysis). Classification equations for individual zones (discriminant functions) were derived using it. Subsequently, the so-called classification score was expressed for each analysed vineyard area, which was determined to belong to one of the zones.

RESULTS

From a total of 18 variables (components), we retained five based on the results of the PCA analysis. By extracting five components, we obtained a matrix of component loads that can be interpreted as correlations between the extracted components and the variables included in the PCA. Table 5 shows the loads of the extracted components, wherein the first component explains the most variability and the fifth least.

Tab. 5. Component loads of PCA method extracted components

Variable	Component 1	Component 2	Component 3	Component 4	Component 5
DTR	0.440404	**0.843049**	-0.138773	0.157080	-0.063429
GDD	**-0.523729**	**-0.711011**	0.308341	0.095329	0.222204
Tjan	-0.354467	**0.854383**	0.031462	0.141839	-0.169418
RJM	**0.727405**	**0.597311**	-0.152967	0.136442	-0.000320
Potential global glare	-0.236512	-0.084971	**0.691295**	-0.001257	0.147847
The slope of the georelief	-0.256364	0.407230	**0.545672**	0.050409	0.367902
Potassium content	-0.329372	0.349711	-0.466732	0.071495	0.299025
Nitrogen content	-0.169890	0.477639	**-0.582692**	-0.105309	0.408472
Phosphorus content	0.007182	-0.158258	-0.277174	**0.745288**	-0.044273
Magnesium content	**0.896875**	-0.139226	-0.046114	-0.061790	0.192211
Clay content	**0.861523**	-0.232823	-0.115011	-0.191415	0.166710
Manganese content	-0.407631	-0.473828	**-0.502973**	**-0.502973**	0.064624
Copper content	**-0.649775**	0.286287	-0.233868	0.150099	0.271739
Sulfur content	**0.779317**	-0.169298	-0.138873	-0.123970	0.272066
Skeleton content	-0.391738	**0.659151**	0.408637	-0.067800	0.180873
Zinc content	**-0.704249**	0.028656	-0.308840	-0.488002	0.018484
Soil pH	0.133160	**0.591599**	0.166006	**-0.592958**	-0.329030
SOM	**-0.58369**	-0.146725	-0.396261	0.178275	-0.349256

Based on the visualized values (Fig. 4), we can confirm, that the optimal number of clusters, or the vineyard zones is 7 in respect to the data. The number of clusters in each of the indexes tested was 7 as the optimal solution. (DTR – index of the difference between minimum night and maximum day temperature during the growing season, GDD – the sum of effective temperatures, T_{jan} – average air temperature in January, RJM – Spring Frost Risk Model, SOM – Organic component content).

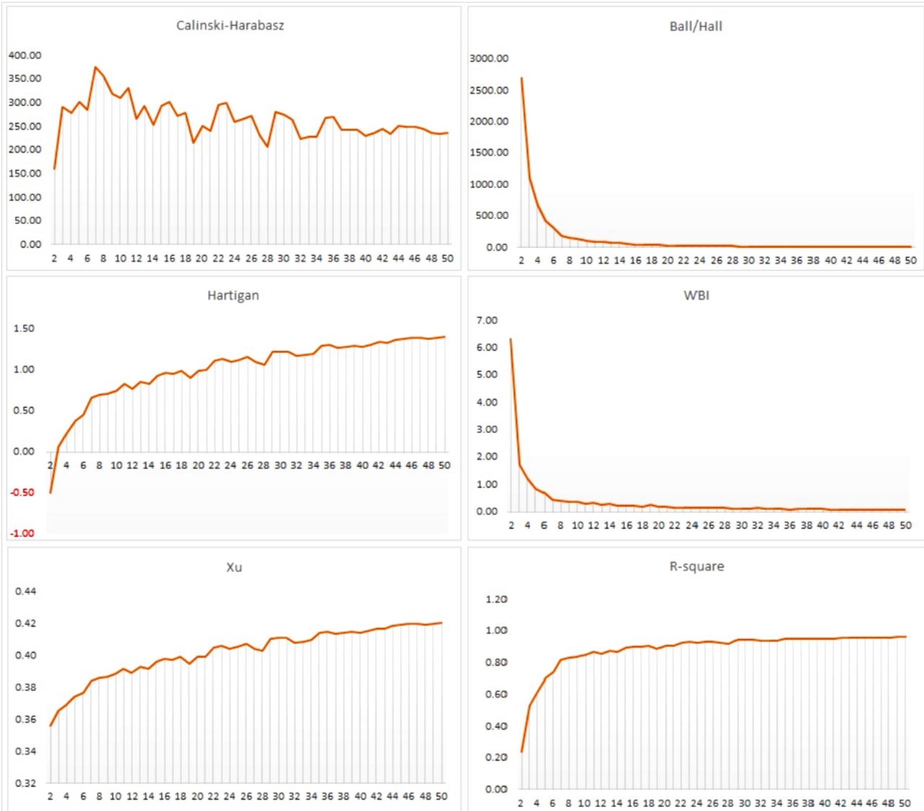

Fig. 4. Graphical representation of the values of the indices tested to estimate the parameter *k*

Multidimensional discrimination analysis reached 96.08%, while the classification of areas into zones 1, 4, 5 and 7 achieved a plausibility of up to 100%. Least accurate are the results of the vineyards inclusion in zone no. 2, where the efficiency of the classification was expressed at 87.70%, wherein 15 areas out of a total of 122 were assigned to either zone 1 (11), zone 4 (1), or zone 7 (3) in the cluster analysis.

Of the total 441.64 ha of vineyards analysed, the largest part falls into zone no. 5 with a total area of vineyards of 180.5 ha (Fig. 5). These areas sum up to 41% of the area of all analysed vineyards. The relatively high portion of this zone within the analysed areas can be justified mainly by the greater homogeneity of the terroir of this part of the land and by the size of the vineyard areas of this locality. In terms of climate characteristics, this zone is characterized by the lowest average air temperature in January (-1.41 °C) and together with zone no. 6 are slightly more prone to spring frosts (RJM).

Fig. 5. Wine-growing zones 1 – 7 in the cadastral area of Modra are created on the basis of cluster analysis of terroir physical-geographical properties

The probability of frost in the vineyards' zone 5 is estimated to be 65%when frost occurs in at least one of the five observed meteorological stations. In terms of georelief, the areas lie in an a territory with a slope smaller 5°, which is particularly positive in terms of accessibility and handling of the equipment in these areas. The flat georelief affects the lower level of potential solar radiation in these areas compared to the zones lying on the slopes of the Little Carpathians. This fact also affects reality, that the areas of zone no. 5 have lower sums of temperature above 10 °C in the growing season (GDD) compared to the slope positions. However, the vineyards of the most extensive zone can be distinguished more significantly from the other zones, not based on climate indicators, but on soil characteristics that are diametrically different from other vineyard locations in Modra. The soils of the fifth zone contain more clay-like fractions and are much more compact and plastic. This affects the water capacity of the soil, from which several consequences can be expected.

On the one hand, these typical deeper sandy-loamy to loamy soils slowly warm up in spring and hinder the onset of the growing season. In the dry years, due to the higher water retention capacity, these sites have created a greater water reserve for supply compared to drain loamy-sandy soils. The high proportion of clay fraction in some areas of this zone makes it difficult to cultivate. In terms of soil's chemical composition, this zone stands out from the other by the contents of two elements. The concentration of accessible magnesium is almost 10-fold compared to some zones. The content of accessible magnesium in the soil, which is bound on the clay, can be described as the main determinant. At the same time, a lower potassium content was found, which usually has in a negative relationship with magnesium (Pavloušek 2011).

The second-largest zone, no. 3 with a total vineyards area of 81.19 ha, extends from zone no. 5 to the foot of the Little Carpathians. From the climatic point of view, zone no. 3 is similar to zone no. 5, but nights in this slightly higher elevation compared to zone no. 5 are slightly warmer. This fact is reflected mainly in the lower probability of occurrence of spring frost (RJM), which is on average 56%.

Similarly, the January air temperature is on average higher than in the previous zone. The vineyards of this zone lie in the flat terrain as zone no. 5, with vineyards extending on the upper and middle alluvial cones, consisting mainly of material reallocated from the Little Carpathians. Together with zone no. 4, their vineyards have the highest content of available phosphorus in soil and with zone no. 7 again, the highest content of accessible manganese. In terms of physical properties, zone no. 3 is a transitional zone between the zones lying on the slopes of the Little Carpathians with predominantly loamy-sandy soils. Sand-loamy soils dominate, as evidenced by the second highest clay fraction content in the soil of all zones. A more acidic soil reaction characterizes the zone compared to other zones and, at the same time, a low skeletal content. The third-largest zone occupying 13% of the total area of analysed vineyards is zone no. 4, with an area of 55.93 ha. Higher laid vineyards reach higher sums of active temperatures (GDD) and, thanks to the slope positions, also higher sums of potential global radiation. These reach here (together with zones no. 6 and 7) maximum among all locations. Potential global insolation, together with higher vineyard locations, reduce the risk of spring frosts as sunlight contributes to warming the air and the higher location protects against ground frosts. For this reason, the risk of spring frost is one of the lowest in Modra (58%). In this part of Modra, the vineyards are characterized by loamy-sandy soils, whereby in this zone, the clay content of the soil is the lowest in the entire Modra. This is also reflected in the low magnesium soil content. However, the soils are much more skeletal compared to previous zones and are characterized by lower pH and the lowest plasticity. The high content of accessible phosphorus in the soil, which reaches its maximum value in the Modra vineyards, can be considered as an important feature.

The fourth-largest zone is zone no. 7, the most compact and internally homogeneous zone. Its vineyards with an area of 52.74 ha occupy a total of 12% of all analysed areas. Mesoclimate makes the zone no. 7 unique. It is largely influenced by georelief. Of all the zones, it has the highest sum of air temperatures above 10 °C per growing season, which can be taken into account when choosing varieties. Likewise, the hottest nights occur in this zone. This logically also affects the values of the DTR index, which are the lowest in the monitored territory. Vineyard areas have, for example, in comparison with zone no. 1 and no. 6 to 1 °C lower average temperature range between day and night during the growing season and compared to zones no. 1, 5 and 6, almost 15% less probability to occur in the spring months. From soil attributes, zone no. 7 can be distinguished from others mainly by a higher content of manganese and zinc in the soil. On the contrary, the lowest concentration reached phosphorus, magnesium and nitrogen.

The remaining three zones (no. 1, 2 and 6) are the smallest in terms of area, but nevertheless a high variability of their terroir can be observed. Zone no. 6 with 26.9 ha of vineyards is the third smallest zone in Modra. This zone is characterized by the coldest nights in Modra and one of the lowest temperatures above 10 °C during the growing season. On the other hand, within the zone, there are the highest differences between day and night temperature, which may suit some varieties. The soils in this zone are relatively little plastic, with the highest skeleton content within the entire wine-growing village. The elements content in the soil is below the average level in comparison with other parts of Modra. The only exception is the manganese content, which is here, on the contrary, the highest, as well as the pH level by which this zone can be characterized.

The second smallest zone no. 1, with a total vineyard of 23.15 hectares, makes approximately 5 % of the vineyards. Climatically, this zone is practically identical to zone no. 6, but due to the orientation of the vineyards more to the east, the territory has a lower level of potential global solar radiation. In terms of micro- and macro-element content in the soil, no extremely high or extremely low average values were observed for this zone.

The smallest of all identified zones is zone no. 2. It occupies 21.27 ha of vineyards. In terms of climate indicators, it can be considered average. Below-average level of potential global solar is typical, due to the south-east to east orientation of the georelief. What is typical for the zone is the highest value of available potassium in the soil. Its concentration is, for example, compared to zone no. 6, 3 times higher. Copper and nitrogen also reach the highest concentration in comparison with other zones. The manganese is also above-average in soils. Conversely, the lower concentration in this zone is characteristic for magnesium, which again is related to the content of the clay fraction in the soil.

DISCUSSION

Since the Romanesque wine classification system, which was transferred to the national level in 2009, is based on the vineyard and the location the grapes have matured (or where it has been processed), there is a need to reconsider the current zoning of vineyards. The reason is that even lower hierarchical units of the currently valid zoning of Slovakia's vineyards, created by Valachovič et al. (1986) and subsequently modified by Valachovič (1996), do not reflect terroir and are insufficient to the current state. The currently valid bonitization of wine-growing areas based on regulation (NR SR 2009) considers some components of terroir. However, it is based on data mapped at relatively non-detailed scales and, at the same time, completely abstracts from soil chemical properties. Using a point scale for categorised data can also be considered inappropriate for establishing a sharp border between individual bonitization categories. In addition, such a categorization of vineyards leads to dividing the areas into high quality and less quality, but this may not be applied in all cases. The assessment of the zone suitability also involves agronomic interventions and especially the selection of the variety because each variety (not to mention a combination with a rootstock) reacts differently to its terroir.

Our article follows up on research of vineyards (Karlík 2018) and mapping wine-growing zones in the Burgenland area (Karlík et al. 2018). Compared to the previous article, the level of mapping has changed from the regional to the smallest topical dimension, where more detailed data obtained from field survey, lidar imaging and microclimate measurements were used. The influence of the georelief on the vineyard landscape structure is mainly manifested in the interaction with solar radiation, in contrast to mountain landscapes, where morphodynamic processes have a significant impact (Hreško and Boltižiar 2001). The application of cluster analysis in the identification of wine-growing zones was used in their work (Herrera-Nuñez et al. 2011, Priori et al. 2014, Moral et al. 2016, Fraga et al. 2017 and Karlík et al. 2018), which also used principal component analysis to reduce data dimensionality. Herrera-Nuñez et al. (2011), Priori et al. (2014), Moral et al. (2016) or Honorio et al. (2018) in their works they emanate from primarily the most important topoclimate indicators, but in their work, they do not use soil-substrate ratios of territory, which according to White (2009), are a key element in terroir assessment.

In contrast, Carey et al. (2009) utilize geological and soil data in addition to climate and topographic zones in earmarking wine-growing zones. Fraga et al. (2017) compared to Carey et al. (2009), also added to their work information on vine dynamics during the year, and that it is elaborated in large scales and focused to an area up to 1 km in size. In our case, each of the seven zones provides information on climate, topography and soil characteristics. For each zone, the best vine varieties can be selected based on the temperature characteristics so that the vine has optimal growth conditions (Jones and Davis 2000, Jones et al. 2009, Jones et al. 2010, Anderson et al. 2012 and Honorio et al. 2018). Based on rainfall information, it is possible to select the suitable rootstocks to improve the water status of the plant (Pavloušek 2011).

If we take into account information on climate change, thus, using the zones we create, it is possible to project the impact of climate change in the region, mainly increasing the temperature and climatic drought based on which it is possible to plan to plant in individual zones (Jones and Davis 2000, Jones 2006, Jones et al. 2012 and Fraga et al. 2016 and 2017). Furthermore other information about the terroir of the surveyed territory can be used in wine-growing practice in planning management measures to improve the quality of wine production (Pavloušek 2011 and Karlík et al. 2018).

CONCLUSION

One of the research objectives was to analyse the landscape's individual components, which impact the quality of grapevine production and can be considered the main determinants of terroir. We have shown that even in a relatively small area, the variability of individual monitored terroir components is very diverse. This confirms the merits of establishing the main objective of identifying vineyard zones reflecting their terroir. The submitted work also responds to the requirement to realize a new vineyard regionalisation in Slovakia, which would reflect the European Union strategy for the protection and labelling of agricultural products based on their locality of origin. The introduction of the terms ʻproduct with protected designation of origin' and ʻproduct with protected geographical indication' as a way of protecting, distinguishing, and highlighting the qualitative characteristics of specific products (not only wine) has come into force within the European Union at the level of individual Member States. Even though the legislative framework on wine labelling was transposed at our national level in 2009, its form remains a problem, as the protection of wines is linked to the current regionalization of vineyards. As an example serves Little Carpathian Wine Region, which includes, for example, the aeolian sands of Záhorie, the loess of the environs of Trnava and the rocks of crystalline basement of the region Little Carpathians, all of which are from these diametrically different terroirs.

In our case, we started from the need for a detailed description of the vineyard standpoints without a subsequent assessment of their quality, as the quality of the sites cannot be clearly identified if certain climate requirements to produce vines are met. Our methodology is based on field research of vineyards site conditions, analysis of LIDAR, meteorological and soil data in combination with geostatistical modelling at the local level. The wine-growing areas are categorised into seven homogeneous zones, which reflect the local terroir. As mentioned above, our work can be a helpful document and guide in mapping and getting to know the wine-growing terroir and creating a national appellation system. It will also serve as an example of large-scale research on the spatial structure of the country and its regionalization.

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NÁVRH OZNAČOVANIA VINOHRADOV REŠPEKTUJÚCI PRÍRODNÝ TERROIR: PRÍPADOVÁ ŠTÚDIA MODRA, SLOVENSKO

Súčasná platná zonácia vinohradov na Slovensku a v ostatných členských štátoch EÚ nie je jednotná pre všetky krajiny. Aj keď legislatívny rámec označovania vín bol na našej národnej úrovni transponovaný v roku 2009, problémom zostáva jeho podoba, keďže ochrana vín súvisí so súčasnou rajonizáciou vinohradov. Ako príklad slúži Malokarpatská vinohradnícka oblasť, do ktorej patria z hľadiska stanovištných podmienok rozdielne regióny, ako napríklad viate piesky Záhoria, spraše okolia Trnavy a horniny kryštalinika Malých Karpát predstavujúce diametrálne odlišný „terroir“ (spôsob opisu jedinečnosti lokality, ktorá ovplyvňuje a utvára miestne víno). Keďže románsky systém klasifikácie vín, ktorý bol prenesený na národnú úroveň v roku 2009, je založený na vinohrade a lokalite, kde hrozno dozrelo (resp. kde bolo spracované), je potrebné prehodnotiť súčasnú zonáciu vinohradov.

V článku sme analyzovali vybrané prírodné komponenty priestorovej štruktúry vinohradníckej krajiny Modry, ktoré ovplyvňujú kvalitu produkcie viniča a možno ich považovať za hlavné determinanty terroiru. Záujmové územie je lokalizované na kontakte Malých Karpát a Trnavskej pahorkatiny. Z hľadiska geologického substrátu je tvorené vo vrchnej časti najmä deluviálnymi a proluviálnymi sedimentmi z kryštalických hornín a v dolnej časti prevažne fluviálnymi štrkovými a pieskovými sedimentmi na sprašových hlinách. Na základe výsledkov detailného výskumu môžeme tvrdiť, že aj na relatívne malom území je variabilita jednotlivých sledovaných komponentov terroiru veľmi rôznorodá. To potvrdzuje opodstatnenosť stanovenia hlavného cieľa, ktorým je identifikácia vinohradníckych zón odrážajúcich ich terroir. Z metodologického hľadiska bol realizovaný terénny výskum stanovištných podmienok vinhohradov, analýza získaných dát vrátane odobraných pôdnych vzoriek s využitím prostriedkov GIS a geoštatistického modelovania rešpektujúceho veľkú mierku.

Georeliéf bol charakterizovaný s využitím technológie LIDAR Leica ALS 70/CM (Národné lesnícke centrum vo Zvolene) a digitálneho modelu reliéfu s veľkosťou bunky 1 m a celkovou vertikálnou presnosťou 10 – 15 cm. Klimatické údaje boli získané pomocou automatizovaných meteorologických staníc v analyzovanom území a jeho blízkom okolí. Z nameraných hodinových údajov teploty vzduchu a úhrnu atmosférických zrážok boli pre každú z uvedených staníc vyhodnotené tieto ukazovatele: suma efektívnych teplôt (GDD), index studenej noci (Cl), index rozdielu minimálnej nočnej a maximálnej dennej teploty počas vegetačného obdobia (DTR), priemerná teplota vzduchu v januári (T_{jan}) a celkové atmosférické zrážky počas vegetačného obdobia (Z_{veg}). Údaje o fyzikálnych a chemických vlastnostiach pôdy boli získané s ohľadom na ekologické nároky a výživu viniča. Hlavným zdrojom pôdnych údajov bola terénna sondáž, doplnená o údaje z databázy komplexného prieskumu pôd (Skalský a Balkovič 2002). Výskum bol realizovaný na 51 výskumných bodoch. Vzorky pôdy boli odobraté v posledný májový týždeň roku 2017 vo vzdialenosti 50 cm od riadku vinohradu. Pôdne vzorky sa odoberali v hĺbke približne 50 – 70 cm a boli následne analyzované v laboratóriu HI-Lab v Debrecíne v Maďarsku.

Štatistické analázy možno rozdeliť do dvoch hlavných krokov: redukcia množstva rozmerov na základe metódy hlavných komponentov (PCA) a vytvorenie návrhu vinohradníckych zón s dôrazom na terroir pomocou zhlukovej analýzy. Samostatným krokom na konci metodického postupu bolo overenie správnosti výsledných zhlukov. Z celkového počtu 18 premenných (komponentov) sme na základe výsledkov PCA analýzy ponechali 5. Optimálny počet klastrov v každom z testovaných indexov bol 7. Ak zoberieme do úvahy informácie o zmene klímy, tak pomocou vytvorených zón je možné modelovať vplyv klimatických zmien v regióne, najmä zvýšenie teploty vzduchu a klimatické sucho, na základe čoho sa dá plánovať výsadba pre jednotlivé zóny.

Z celkových 441,64 ha analyzovaných vinohradov najväčšia časť spadá do zóny č. 5 s celkovou výmerou vinohradov 180,5 ha. Z hľadiska klimatických charakteristík sa táto zóna vyznačuje najnižšou priemernou teplotou vzduchu v januári (-1,41 °C) a spolu so zónou č. 6 sú o niečo náchylnejšie na jarné mrazy. Pôdy piatej zóny obsahujú viac ílovitých frakcií a sú oveľa kompaktnejšie a plastickejšie. Plochý georeliéf ovplyvňuje nižšiu úroveň potenciálnej insolácie v týchto oblastiach v porovnaní so zónami ležiacimi na svahoch Malých Karpát.

Druhá najväčšia zóna, č. 3, s celkovou výmerou vinohradov 81,19 ha, siaha od zóny č. 5 na úpätie Malých Karpát. Z klimatického hľadiska je podobná zóne 5, no noci sú v tejto mierne vyššej nadmorskej výške o niečo teplejšie. Táto skutočnosť sa prejavuje najmä v nižšej pravdepodobnosti výskytu jarných mrazov. Predstavuje prechodné pásmo medzi zónami ležiacimi na svahoch Malých Karpát s prevažne hlinito-piesčitými pôdami.

Zónu č. 4, s výmerou 55,93 ha, tvoria vyššie položené vinohrady dosahujúce vyššie sumy aktívnych teplôt a vďaka sklonitým polohám aj vyššie sumy potenciálneho globálneho žiarenia, ktoré prispieva k teplejšej mikroklíme a vyššia poloha chráni pred prízemnými mrazmi. V tejto časti Modry sú vinohrady charakteristické hlinito-piesčitými pôdami, pričom v tomto pásme je obsah ílovitej pôdy najnižší v celej Modre. To sa prejavuje aj nízkym obsahom horčíka v pôde. Pôdy sú však v porovnaní s predchádzajúcimi zónami oveľa skeletnatejšie a vyznačujú sa nižším pH a najnižšou plasticitou. Za významnú vlastnosť možno považovať vysoký obsah prístupného fosforu v pôde, ktorý dosahuje maximálnu hodnotu v modranských vinohradoch.

Zóna č. 7, kde vinohrady zaberajú 52,74 ha, je najkompaktnejšia a vnútorne homogénna. Mikroklíma ovplyvnená charakterom reliéfu prispieva k jej jedinečnosti. Zo všetkých zón má najvyšší súčet teplôt vzduchu nad 10 °C za vegetačné obdobie, čo možno zohľadniť pri výbere odrôd. Rovnako najhorúcejšie noci sa vyskytujú v tejto zóne. Vinohradnícke plochy majú napríklad v porovnaní so zónou č. 1 a č. 6 až o 1 °C nižší priemerný teplotný rozsah medzi dňom a nocou počas vegetačného obdobia a v porovnaní so zónami č. 1, 5 a 6 takmer o 15 % menšiu pravdepodobnosť výskytu mrazov v jarných mesiacoch. Z pôdnych atribútov sa od ostatných odlišuje najmä vyšším obsahom mangánu a zinku v pôde. Naopak, najnižšiu koncentráciu dosiahli fosfor, horčík a dusík.

Zvyšné tri zóny sú rozlohou najmenšie, no napriek tomu možno pozorovať vysokú variabilitu ich terroiru. Zóna č. 6 s 26,9 ha vinohradov je tretia najmenšia zóna v Modre. Toto pásmo sa vyznačuje najchladnejšími nocami v Modre a jednou z najnižších teplôt počas vegetačného obdobia. Na druhej strane sú v rámci zóny najvyššie rozdiely medzi dennou a nočnou teplotou, čo môže niektorým odrodám vyhovovať. Pôdy v tejto zóne sú pomerne málo plastické, s najvyšším obsahom skeletu v rámci celej vinohradníckej obce.

Druhá najmenšia zóna č. 1 dosahuje celkovú výmeru 23,15 ha. Klimaticky je toto pásmo podobné zóne č. 6, ale vzhľadom na východnú orientáciu má nižšiu úroveň potenciálneho globálneho slnečného žiarenia. Z hľadiska obsahu živín v pôde neboli pri tejto zóne pozorované žiadne extrémne vysoké alebo extrémne nízke priemerné hodnoty.

Najmenšia zo všetkých identifikovaných zón je zóna č. 2 zaberajúca 21,27 ha. Typická je podpriemernou úrovňou potenciálnej insolácie a najvyššou hodnotou dostupného draslíka v pôde. Jeho koncentrácia je napríklad v porovnaní so zónou č. 6 trikrát vyššia. Meď a dusík tiež dosahujú najvyššiu koncentráciu v porovnaní s ostatnými zónami. Aj mangán je v pôdach nadpriemerný. Naopak, nižšia koncentrácia v tejto zóne je charakteristická pre horčík, čo opäť súvisí s obsahom ílovej frakcie v pôde.

Vzhľadom na využitie aktuálnych metodických postupov pri detailnom výskume prírodných zložiek terroiru môže byť naša práca nápomocným dokumentom a sprievodcom pri mapovaní a spoznávaní vinohradníckeho terroiru a vytváraní národného systému označovania vín na Slovensku. Poslúži tiež ako ukážka veľkomierkového výskumu priestorovej štruktúry krajiny a jej regionalizácie.

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