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Agronomic classification between vineyards ('Verdejo') using NDVI and Sentinel-2 and evaluation of their wines

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Summary

A classification between three vineyards belonging to the Appellation of Origin Rueda (Castilla y León, Spain) has been established in veraison to determine the productive capacities of each vineyard and to study their impact on the grape quality. Several open-access multispectral images obtained from the SENTINEL-2A satellite in the year 2016 were used to calculate the NDVI (Normalized Difference Vegetation Index), which provides information about the vigour of the vineyards. Eleven cloud-free images were assessed and based on the NDVI, three vigour levels were established: high vigour (0.356-0.458), medium vigour (0.285-0.355) and low vigour (0.166-0.284). A level of vigour was assigned to each vineyard according to the NDVI mean values of its pixels. Significant differences were found in the pruning wood weight and yield: high, medium and low vigour values were 2438, 1895 and 1487 kg·ha^{-1} and 15984, 12990 and 10576 kg·ha^{-1}, respectively. The highest values of total acidity (6.04 g·L^{-1}) and tartaric acid (9.05 g·L^{-1}) have been obtained in low vigour, as well as the lowest values of pH (3.26), malic acid (0.42 g·L^{-1}) and potassium (1640 ppm). Finally, one wine per vigour was produced and a tasting was carried out to check if the differences between the vineyards were perceptible. According to the obtained results, the NDVI is a good indicator to classify vineyards, finding notable differences between the experimental treatments studied.

K e y w o r d s : Sentinel-2; NDVI evolution; NDVI changes; vineyard; remote sensing; *Vitis vinifera* L.

Introduction

In the next decade, forecasts point to a deceleration in food demand, due mainly to a lower world population growth and a foreseeable continuous improvement of the sector productivity (OECD/FAO 2018). Since the end of the 20th century, the vineyard world surface remains stable, with a certain downward tendency, as well as the wine production. The wine demand has grown slightly, mainly due to the increase of consumption in the United States, United Kingdom and China. In the traditional wine-producing countries the situation is diverse, with a stable consumption in Spain and Portugal, a slight decrease in France and an increase in Italy (OIV 2017), although since 2000 in Europe the consumption trend shows a decrease (OIV 2012), so exportation could be positioned as a core element in the account balances of the European wineries. In this context, it is very important for wineries to obtain competitive advantages through technological innovation that allows them to compete in the market (Fernández *et al.* 2011). In addition, there are two models worldwide: European production model, based largely on Appellations of Origin, with exhaustive quality controls, limited and highly regulated productions and the new emerging producing countries, whose production is much more liberalized (Vivas *et al.* 2013).

Therefore, it could be interesting to develop and use tools that allow not only to improve the quality of the products but also to increase efficiency, productivity and input reduction in order to make farms more competitive. To achieve this goal, the use of remote sensing technology is crucial, since it allows to obtain information quickly, accurately, objectively and non-destructively, in such a way that accurate measurements of the grapevines can be taken almost in real time (Krishna 2016).

A practical application is the calculation of the NDVI (Normalized Difference Vegetation Index), which has proved to be a useful tool for monitoring table grape quality characteristics (Anastasiou *et al.* 2018) or certain crops in the growth stage, by monitoring canopy cover (Trout *et al.* 2008). More specifically, in the vineyard it has been possible to estimate certain parameters (Johnson *et al.* 2001, Martinez-Casasnovas *et al.* 2012). The NDVI has also been related to other parameters measured in the field, such as LAI, obtaining good results (Johnson 2003).

All of these considerations lead to an increasing interest in precision agriculture, at least in the scientific and research field (Santesteban 2019) and it seems to be a promising area in which currently there is a lot of progress. For example, the use of UAV and specific cameras to obtain high-resolution images of the vineyard allow the estimation of parameters as complex as the canopy height or the Leaf Area Index (Caruso *et al.* 2017). In the Spanish agriculture is also interesting to see the increase of investment in technological innovation compared to other sectors (INE 2018). In the future, this interest is expected to spread among producers, but new methodologies have to be provided.

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The images for the calculation of Vegetation Indexes can be obtained from various sources, such as UAV, aircraft, satellites, proximal sensing, etc. Each one has its advantages and disadvantages. In this way, the use of UAV combined with high-resolution images has proven its usefulness due to the ability to obtain great spatial precision; however, there are certain characteristics that difficult its use, such as the lack of standard procedures to estimate vegetation indexes (Candiago *et al.* 2015). Although the satellite images have lower resolution, they have certain advantages versus other sources: on the one hand, the satellite images have a certain periodicity that does not depend on the user intervention. This periodicity depends on the revisit time of the satellite and the number of satellites in the constellation. On the other hand, the satellite is dependent on cloud level, as well as UAV, but is not restricted or adversely influenced by other weather factors that affect negatively to UAV operations such as the wind (Nex *et al.* 2014). In addition, if the farm is large or the study area is a large expanse, the satellite imagery is the best choice because it is a low-cost method compared to UAVs and ground-based robotic vehicles (Krishna 2016). Another advantage is that a large image of the entire area is obtained at the same time. More specifically, the Sentinel-2 satellites have a resolution of 10 m in the red and near-infrared bands that could be enough to monitor a vineyard, especially if we consider that we have a temporal resolution of 10 d and even of 5 d from 7/3/2017. Since then, the Sentinel-2 constellation consists of two satellites. In addition, the images are free of charge and freely accessible (ESA 2015), so if its usefulness is proved, it could be a good tool for producers, especially for those who cannot afford to pay large fees or invest in major technological developments.

In addition to the above, it should be considered that the use of UAVs or aircraft implies an initial investment, as well as having qualified personnel capable of configuring and piloting these devices and performing subsequent processing of the data obtained (Grenzdörffer *et al.* 2008). However, satellite imagery providers, whether free or not, provide a ready-to-work image. All of this increases the costs of some technologies over others and even a threshold value has been established: 5 hectares. A breakpoint is placed slightly above 5 ha, meaning that above such scale size the image taken by satellite may be more convenient (Matese *et al.* 2015).

In any case, these technologies are complementary and their combination can help in the decision-making process (Maes *et al.* 2018), so a greater use of satellite images, either individually or combined with images from other sources, will lead to a greater understanding of the vineyard and the possibility of using new technologies to monitor its parameters.

The objective of this study was to assess whether the multispectral information obtained from the satellites of the Sentinel-2 constellation were sufficient to classify three commercial vineyards already implanted and in full production, belonging to the same winemaking group and located in the same area (but separated as far as 3.5 km) and to verify whether it was possible to establish a classification based on NDVI, as well as to study their relationship with agronomic and maturity parameters. For this purpose, the NDVI was calculated to assess if it is a reliable index to estimate the vigour, defined as Pruning Wood Weight (PWW). Its relationship with the parameters in the field was studied, in order to verify its validity in the vineyard and provide winegrowers and winemakers with a decision-making tool that does not require a large amount of data, as well as being free, reliable and fast.

Material and Methods

The experiments were carried out in 2016, in A.O. Rueda, in three commercial vineyards ('Verdejo', the most widely grown cultivar in A.O. Rueda, Spain).

The annual precipitation measured at the Tordesillas weather station (Valladolid) in 2016 was 466 mm. The accumulated precipitation between 1/4/2016 and 26/9/2016 was 142 mm. The vines are trained in vertical trellis and the pruning system is Guyot. Similar handling was carried out in all the vineyards (tillage, herbicides, etc.) to ensure healthy grapevines and weed-free soil, according to the A.O. Rueda protocol and legislation in force. Main phenological stages were (Baggiolini 1952): leaves unfolded, E (5/3), flowering, I (18/6) and veraison, M (10/8). The harvest dates were 27/9/2016 and 3/10/2016. The harvest was made according to the level of SSC (Soluble Solids Content). The characteristics of the vineyards as well as types of soil (Nafría *et al.* 2013) are described in Tab. 1. The vineyards are located at a similar altitude between 713 and 755 m.a.s.l. and at less than 3.5 km between them.

S a t e l l i t e i m a g e r y : To perform the classification between vineyards, three levels of vigour were established based on the NDVI values calculated from the multispectral images. Free 2016 images were downloaded from the ESA's (European Space Agency) Copernicus project website. These images, obtained from the Sentinel-2A satellite, were corrected to a level-2A product with ESA's sen2cor algorithm and were filtered manually in order to obtain cloud-free products. As a Result, eleven images were assessed, evaluating each vineyard separately (Fig. 1). A level of vigour was assigned to each vineyard according to the NDVI mean values of its pixels (high, medium and low, Fig. 2). The image taken on 5/8/16 was chosen because the image was in the range of maximum mean NDVI values,

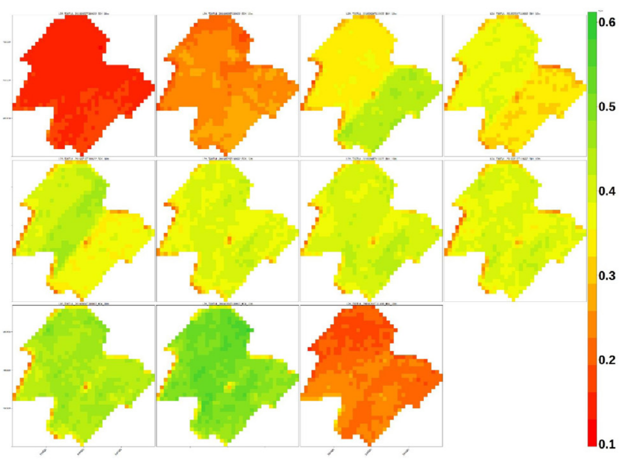

Fig. 1: Cloud-free NDVI 2016 images. High vigour vineyard.

Table 1

Characteristics of the vineyards

Vigour	Coordinates (ETRS89 UTM30N)	Type of soil (FAO, WRB)	Planting date
Low	X: 340584.8 Y: 4590813.9	Haplic Luvisol + Gleyic Luvisol	1984
Medium	X: 340858.98 Y: 4589683.83	Chromic Luvisol + Chromic Cambisol	1985
High	X: 339966.84 Y: 4593182.75	Albic Arenosol + Cambic Arenosol	2008
Vigour	Area (ha)	Orientation	row x vine spacing (m)
Low	2.14	N-S	3x3
Medium	2.25	E-W	3x3
High	25.85	NE-SW	3x1.5

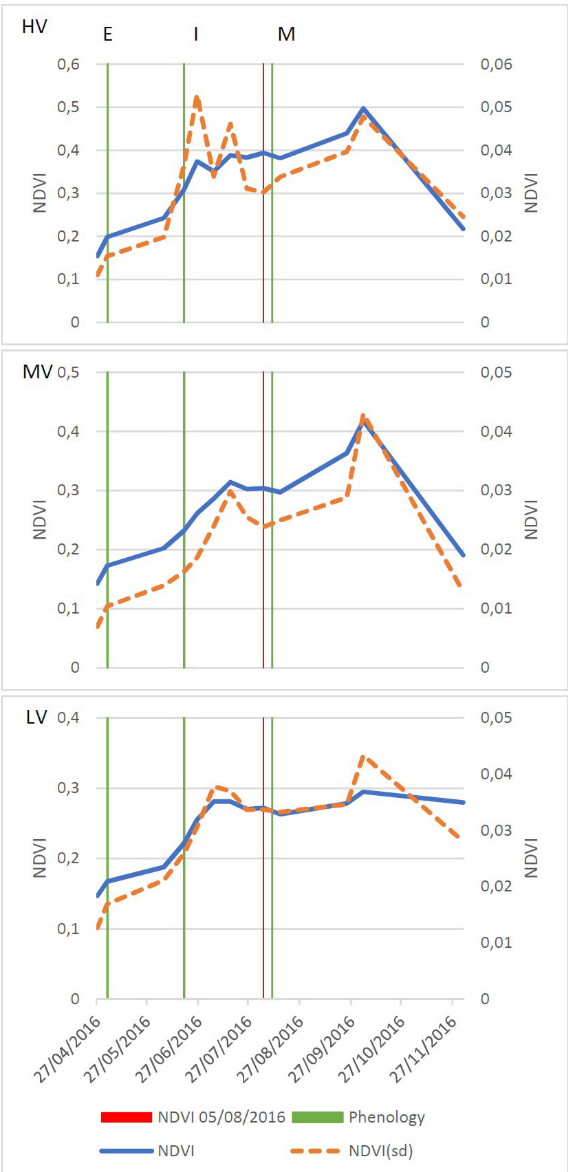

Fig. 2: NDVI evolution and standard deviation (NDVI, sd) of each vineyard. High, medium and low vigour (top to bottom).

and the standard deviation (NDVI sd) was the lower in that range (Fig. 2). In addition, this image is very close to veraison, which was on 10/8/16, and others authors also found that at this phenological stage the NDVI correlates better with several parameters of the vineyard (Lamb *et al.* 2004, Tagarakis *et al*. 2013). It might be worth noting that there are higher NDVI values after the harvest, probably due to a lack of soil tillage and the effect of harvesting (the vegetation spread out of the vertical trellis).

The NDVI (Normalized Difference Vegetation Index) is an index that allows quantifying the amount of vegetation of an area, as well as its health. It relates the reflected radiation in the red and Near Infrared (NIR) bands of the electromagnetic spectrum. Its mathematical equation is the following:

$$NDVI = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$

The equation adapted from the bands provided by Sentinel-2 satellites is the following:

$$NDVI = \frac{(\mathrm{B8} - \mathrm{B4})}{(\mathrm{B8} + \mathrm{B4})}$$

In the last step, the image was processed using an unsupervised classification clustering method (k-means), organizing each vineyard in a level of vigour (Fig. 3). The vineyards were associated with Low Vigour (LV), Medium Vigour (MV) and High Vigour (HV) (Fig. 3). Within each vineyard, 40 vines spread across four different blocks (10 vines per block) were tagged for assessment. For processing, QGIS software version 2.18.13 and R version 3.5.3 were used.

Wine elaboration: Three types of wine were elaborated, one from each vigour, in stainless steel tanks of 35 L. The winemaking system was traditional of white wine: grapes receival, crushed and de-stem, sulfiting by 5 g per hl, pressing and introducing in refrigeration camera for decantation. After two days, firstly the racking was carried out and secondly the sowing of yeasts *Saccharomyces cerevisiae* (ex rf. Bayanus) SB (EnartisFerm) at 16 °C for

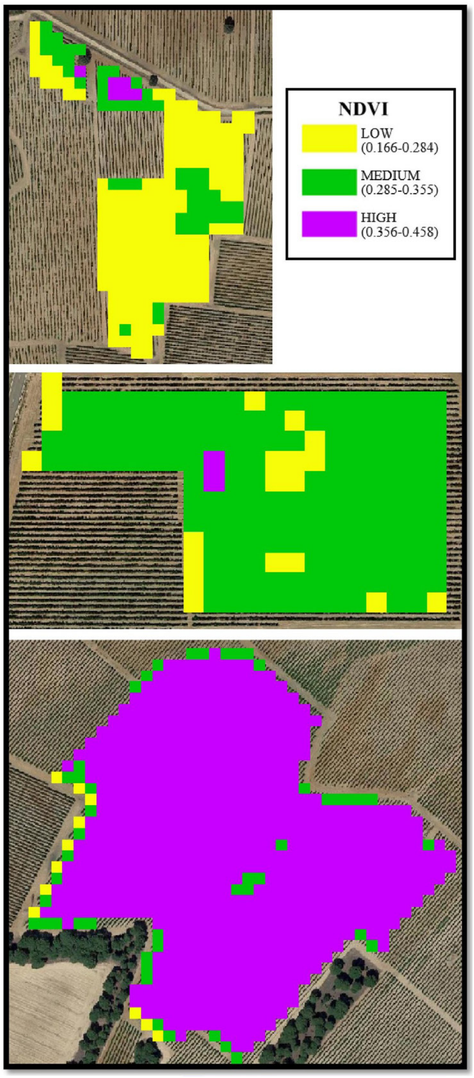

Fig. 3: NDVI classification between vineyards. 3 vigour levels: low, medium and high (top to bottom).

fermentation. Nutrients were added to the sowing and the addition was repeated at densities of 1070 and 1020 g·L^{-1}. At the end of the fermentation, a sulfitation was made and the temperature was reduced to 5 °C. Finally, the wine was decanted and kept at 6 °C until bottling.

Tasting: After the wine elaboration, a consumer judging panel was established, submitting the judges to a triangular test in order to establish if the consumer was able to detect the difference between vigours, understanding that a positive result in the test implies that the differences between vigours are perceptible enough. The tests were carried out in a tasting room equipped with ten individual boxes, according to ISO 8589: 2007 and in compliance with ISO 4120: 2004 for the triangular test. To facilitate the development of the test and the decision of the consumer, two levels of vigour were chosen for comparison.

Results

Vegetative development and production: The data have been averaged per unit area in order to compare the different vineyards, since the planting density of each vineyard was different. The use of Sentinel-2 satellite images implies that the real values of NDVI are not values of specific vines, but they include both crop, spontaneous flora and soil. Therefore, it is an indicator of vigour per unit area, that is, the vigour based on the 100 m^2, which is the size of the pixel.

Although the heterogeneity of the vineyards was high (they are arranged with different orientations, planting density, soils, etc.) the used methodology for calculation of NDVI levels has been able to correctly discriminate the vigour of the vineyards, defined as Pruning Wood Weight (PWW): high, medium and low NDVI values were 2438, 1895 and 1487 kg·ha^{-1} respectively (PWW·ha^{-1}, Tab. 2). Thus, in the vineyards in which the NDVI values have been higher, the vigour has been higher, in contrast to the vineyards with lower NDVI values in which the vigour has been lower. Likewise, the high, medium and low-level values were 15984, 12990 and 10576 kg·ha^{-1}, respectively, with significant differences between levels ("Y", Tab. 2), so the NDVI has been a good indicator to estimate the yield because the higher the NDVI level, the higher the yield. These results are consistent with other author's results (ACEVEDO-OPAZO *et al.* 2008, SANTESTEBAN *et al.* 2009).

Table 2

Yield and vegetative development parameters. X·/ha, X/m^2, PWW, Pruning Wood Weight (kg·vine^{-1}); N °S, Number of Shoots per Vine; SW, Shoot Weight (g); RI, Ravaz Index; N °C, Number of Clusters/vine; GY, Grape Yield (kg·vine^{-1}); Y, Yield (kg·ha^{-1}); CW, Cluster Weight (g), BW, Berry Weight (g). Average per vigour. Levels of statistical significance (Sig.): ns, non-significant; *, $p < 0.05$; **, $p < 0.01$. Data with different letters indicate significant differences according to the LSD test

Vig.	PWW		PWW·ha^{-1}		N °S		N °S/m^2	
L	1.34	b	1487	c	32.1	a	3.57	b
M	1.71	a	1895	b	34.6	a	3.84	b
H	1.10	b	2438	a	23.9	b	5.32	a
Sig.	**		**		**		**	
Vig.	SW		SW/m^2		RI		N °C	
L	41.7		4.64	b	7.02		85.7	a
M	49.2		5.47	b	7.25		62.3	b
H	46.2		10.28	a	7.74		42.0	c
Sig.	ns		**		ns		**	
Vig.	N °C/m^2		GY		Y		CW	
L	9.53	a	9.52	b	10576	c	114	b
M	6.93	b	11.69	a	12990	b	189	a
H	9.34	a	7.19	c	15984	a	170	a
Sig.	**		**		**		**	
Vig.	CW/m^2		BW		BW/m^2			
L	12.7	c	1.25	b	0.14	c		
M	21.0	b	1.81	a	0.20	b		
H	37.8	a	2.02	a	0.45	a		
Sig.	**		**		**			

Significant differences ($p < 0.01$) were also found in the rest of the evaluated agronomic parameters, except in the I. Ravaz, which indicates that the increase in the vegetative development was proportional to the yield, without implying an imbalance in the vineyard.

Maturity parameters: The harvest time for each vineyard was established based on the accumulation of SSC (23 °Brix).Therefore, there are no significant differences in SSC or in sugars. However, there is one week difference between the harvest dates. The low vigour vineyard reached the SSC level in 27/9/2016, while the medium and high vigour vineyards reached it in 3/10/2016. In terms of maturity, significant differences were also found with $p < 0.01$ in all the parameters evaluated (Tab. 3), except for SSC and sugars since this parameter was used as an indicator of the harvest time.

Table 3

Maturity parameters. SSC, Soluble Solids Content (°Brix); Sugar (g·L^{-1}); pH; TA, Total Acidity (g of tartaric·L^{-1}); Mal. A, Malic Acid (g·L^{-1}); Tar. A, Tartaric Acid (g·L^{-1}); K, Potassium (ppm). Average per vigour. Levels of statistical significance (Sig.): ns, non-significant; *, $p < 0.05$; **, $p < 0.01$. Data with different letters indicate significant differences according to the LSD test

Vig.	SSC	Sugar	pH		TA	
L	22.6	222	3.26	c	6.04	a
M	23.1	228	3.47	b	5.35	b
H	22.8	224	3.60	a	4.80	c
Sig.	ns	ns	**		**	

Vig.	Mal. A.		Tar. A.		K	
L	0.42	b	9.05	a	1640	b
M	1.51	a	8.25	b	2088	a
H	1.45	a	7.50	c	2090	a
Sig.	**		**		**	

The highest values of total acidity (6.04 g·L^{-1}) and tartaric acid (9.05 g·L^{-1}) have been obtained in low vigour, as well as the lowest values of pH (3.26), malic acid (0.42 g·L^{-1}) and potassium (1640 ppm).The observed maturity parameters for medium vigour level were between the other two levels. Regarding malic acid levels, its differences (from 0.42 to 1.51 g·L^{-1}) may have occurred due to multiple factors, such as higher vegetative development, which usually implies greater shading of the cluster. This situation leads to a lower respiration rate and lower malic acid combustion (Hidalgo 2006).Other authors have also found a relationship between NDVI and certain maturity parameters (Martinez-Casasnovas *et al.* 2012), although agronomic parameters and NDVI are generally much more related than maturity parameters (Santesteban *et al.* 2014).

Additionally, the planting density affects both the grape production and its quality. In addition, the huge heterogeneity among the vineyards should be considered (different planting density, soils, etc.). In this work, the classification of the vineyards was made with the least possible amount of data in order to reduce costs and facilitate farmer's work. Therefore, although the vigour influences the final composition of the musts, the texture of the soil, as well as its chemical composition, is very important for the final qualitative composition of the grape (Hidalgo 2006).

Tasting: In order to facilitate the choice in the triangular test carried out by the consumer judging panel, two samples of wine were selected: high and low vigour, because the results of the production and maturity parameters were statistically significant and were the most distant from each other (Tabs 2 and 3).

The triangular test was carried out by 26 judges. Between them, 23 were able to discern which sample was different, therefore based on a binomial distribution it is observed that the difference between treatments was significant with $p < 0.001$ (Tab. 4).

Table 4

Tasting. Triangle test. Levels of statistical significance (Sig.): ns, non-significant; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$. Binomial distribution. ISO 4120:2004

Judges	Success	Sig.
26	23	***

Conclusions

The use of Sentinel-2 satellite images versus other sources were useful, because one single image covered all the vineyards at the same time, in the same atmospheric conditions (the vineyards were separated up to 3.5 km). Additionally, this procedure involves no costs (free images) and offers the possibility of consulting the images archive.

In this work, production and quality capacities have been classified 53 d before harvesting and based on a small amount of data: the satellite image. The vineyards have been classified based on NDVI: the greater the NDVI, the greater the PWW·ha^{-1}, and therefore the greater the vigour. The increase in vigour has also implied an increase in the other agronomic parameters evaluated, including the yield. It might be worth noting that in order to use this technique, proper vineyard management must be carried out (tillage, herbicides, etc.) to ensure a healthy vine crop and weed-free soil.

Regarding the tasting and maturity parameters, significant differences have also been found, although the relationship of these parameters with the NDVI is complex, since the process of grape maturation is a process in which a multitude of factors are involved and the NDVI is an index derived from the information obtained from the external surface of the crop, i.e. the canopy in its majority. For this reason, it would be desirable to incorporate additional information taken on the field to combine with the NDVI values. In this way, it is possible that more accurate results could be obtained. This observation has also been made by other authors (Borgogno-Mondino *et al.* 2017).

In conclusion, the NDVI and the applied methodology have been good tools for the estimation of the vigour levels in veraison, classifying the vineyards successfully according to the vigour, estimating three different levels of pruning weight and grape production. In any case, further research is needed to verify the reliability of this technique, including research into the correlation between soil types and vineyard.

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