Chapter

Terroir Zoning: Influence on Grapevine Response (Vitis vinifera L.) at Within-vineyard and Between-Vineyard Scale

Álvaro Martínez and Vicente D. Gómez-Miguel

Abstract

Since ancient times, wines from specific regions have been valued and studies related to *terroir* focus on the elements of the environment that affect wine production. This paper presents the *terroir* variations between vineyards and within the same vineyard, as well as its influence on grape production. A soil zoning is carried out, starting from an aerial photointerpretation (FIA) and studying each soil sector based on its depth analysis (pits). This zoning of the environmental homogeneous units (EHU) is redefined with the normalized difference vegetation index (NDVI), resulting in the proposed *terroir* zoning. The temporal stability of the *terroir* zoning has been tested through the representation of the NDVI during 3 years and the response of the vineyard (yield, vegetative growth, and grape composition) during 4 years. The relationship between the EHUs, soil epipedon particularly, and the response of the vineyard is analyzed from an agglomerative hierarchical clustering (AHC) prior to a principal component analysis (PCA). There is an EHU that is shown to be more vigorous, associated with a material deposition area whose main series of soil is fine-loamy, mixed, mesic, Typic Xerofluvent. This *microterroir* produces grapes with low sugar content, high acidity, and low levels of polyphenolic compounds, including anthocyanins.

Keywords: *terroir* variability map, precision viticulture, remote sensing, soil science, vine yield, grape composition

1. Introduction

From the Sumerians to our days, including Egyptians, Phoenicians, Greeks, Romans, the Middle Ages, etc., quality wine has been linked to certain regions. This interest in the geographical origin of the wines justifies the *terroir* concept and that its use remains in the general feeling of both popular and market and scientific. The International Organization of Vine and Wine (OIV) in its Resolution VITI 333/2010 [1] collects this idea and defines the *terroir* as follows: "Vitivinicultural *terroir* is a concept which refers to an area in which collective knowledge of the interactions between the identifiable physical and biological environment and applied vitivinicultural practices develops providing distinctive characteristics for the products originating from this area."

The concept of *terroir* began to be used in the fourteenth century for some production properties of high-quality wines in Côte d'Or, Burgundy [2], being difficult to define the ideal factors that make up the *terroir* due to the interaction that exists between them [3]. This complexity of individual natural factor analysis, soil particularly, is gradually overcome with new tools for detection, management, and data analysis. In any case, although the physical and chemical interactions that affect the vineyard are not known with total accuracy, the dissemination of the *terroir* concept is fostering a better knowledge and use of geology, soil, climate, and wine culture for best wine production [2].

The first scientific studies related to the viticultural environment elements and their interactions are carried out in the last quarter of the twentieth century, being able to consider the doctoral thesis of Professor Morlat [4], one of the pioneering studies on the *terroir* zoning in the modern meaning of the term. The aforementioned work takes place in the middle area of the Loire Valley, and European countries have traditionally given more importance to the environment elements in the wine characterization, thus protecting the origin of the wines. Two examples of this tradition are the current classification of Bordeaux wines, which have been practically unchanged since its creation in 1855, and the classification of port wines that were delimited in 1758 (now that zoning has been expanded) and carried out by "Companhia Geral da Agricultura das Vinhas do Alto Douro" (a company similar to the current Regulatory Councils) at the proposal of the Marquis of Pombal.

The globalization of international wine trade has led to increased production, especially in new countries, of varietal and brand wines, and the adoption of low-input techniques, exerting significant pressure on traditional *terroir* wine producers [5]. Even so, there are many recent scientific publications on the concept of *terroir*, interrelating elements of the environment such as temperature [6], water status [7], light [8], geology [9], soil [10], etc. with the response of the vine.

To study the influence of climate in the vineyard, it is traditional to differentiate between macroclimate, mesoclimate, and microclimate depending on the scale of work. The first refers to the climate of a region and is the main limiting factor for the cultivation of the vine [11], while the mesoclimate is characteristic of a specific topographic and landscape location and affects a set of plants equally in a given geomorphological unit. Finally, the microclimate refers to the vine, surrounds to leaves and clusters and has a great influence in the biological cycle (e.g., it is of great importance in the grape ripening stage), being able to modify through the vineyard management.

Geology and geomorphology allow a synthetic approach adapted to small-scale zonings (≤ 1:50,000), explaining the behavior of the vine only indirectly [12]. The geological or geomorphological maps are useful as a first approximation to the *terroir* zoning, since very different soils can be included in the same map unit, so it is necessary to determine the types of soil [13]. For this reason, many of the approaches to viticultural zoning borrow their approach from pedological cartography, with some variants [14].

The soil study methodology is specified in the genesis of the soil taxonomic units (STU) and the soil map (or cartographic) units (SMU) during the process of their recognition. The processing of the information generated in the different layers of information by a geographic information system (GIS) results in the quantification of the contents and the possibility of their statistical treatment [15]. This methodology has been and continues to be used as part of the *terroir* zoning of both small-scale viticultural regions (macrozoning), for example, 1:50,000 or 1:25,000, and in vineyards or sets of smaller vineyards at larger scales (microzonifications) between 1:5000 and 1:10,000.

Depending on the scale used in the zoning of the environment elements, mainly climate and soil, we will talk about macro (below 1:25,000), meso (between 1:25.000 and 1:10,000), or micro *terroir* zoning (above 1: 5000). Once the meso or micro *terroir* zoning has been carried out, the management of the vineyard is susceptible of being executed according to the environment homogeneous unit (EHU) defined by it.

The cartographic delimitation of vineyard sectors or EHUs and its individualized management is the basis of precision viticulture (PV), a vineyard management technique that relies mainly on remote sensing [16], to monitor and manage the spatial variability of the vineyard [17–19]. The images obtained by remote sensing are the basis for the creation of maps [20–23], such as the cartographic representation of the normalized difference vegetation index (NDVI) [20]; providing important information, they are very affordable, they facilitate the precision of the limits of the conventional zoning, and they are obtained more quickly than those made from the traditional zoning method [24]. These images are characterized by their temporal, spatial, and spectral resolutions and have been used in meso- and microzonifications since the end of the twentieth century [25–27].

In the present work, a methodology of NDVI integration in *terroir* zoning is proposed, redefining the cartographic limits of traditional microzoning. Once these sectors, EHU, or micro *terroirs* are defined, the behavior of the vineyard (yield, vigor, and grape composition) is related to the main factors that characterize them.

2. Material and methods

The experimental work is carried out for 4 consecutive years (2012, 2013, 2014, and 2015) in four vineyards (A, B, C, and D) located at an average distance of 2 km from each other, in the municipality of Oyón (Álava). The vineyards are protected by the DOCa Rioja, appellation of origin associated with the Ebro River, and located in the northern third of the Iberian Peninsula.

Regarding the climate of the area where the vineyards are framed, the rainfall and average annual temperature are 459 L m^{-2} and 13.7°C and during the vegetative period (April–October) are 260 L m^{-2} and 18.1°C, respectively. According to the Multicriteria System of Climatic Classification (MSCC) [28], the climate is warm temperate (HI + 1), of cool nights (CI + 1) and moderately dry (DI + 1). Although the dominant wind is from the west, another typical northwest wind (known as *cierzo*) has influence during the grape ripening.

The greater part of the vineyards of the area is grown on sandstone and lutites of Haro's facies (Middle-Upper Miocene) [29]. Some of the soils found on this geology and their associated quaternary system are [30] alfisols (e.g., Calcic Haploxeralf subgroup), entisols (e.g., Typic Xerofluvent subgroup), or inceptisols (e.g., Typic Xerocrept subgroup). For more details of the study area, see [9]. The grape cultivar is Tempranillo, grafted on 41B, and the vines are trained using a single trellis system (bilateral cordon Royat pruning), with 2976 vines/ha, and soil management is by tillage.

A zoning is carried out under viticultural criteria (variety and vine age) in the four vineyards, and in the resulting subplots, a FIA was drawn from digital orthophotographs of 0.25 meters of spectral resolution [31], discriminating sectors (A1, A2, A3 for vineyard A and analogously for the rest of the vineyards) on a scale of 1:2500, that is, on a vineyard scale. In each sector, 12 vines are marked, divided into 2 repetitions of 6 plants. Measurements of vegetative growth and yield are carried out, as well as physical-chemical analysis of the grape on each repetition. For the pedological study, a pit is made next to each of the repetitions of six vines, describing the profile and analyzing the different horizons in the laboratory. In this way, between two and three pits per hectare of vineyard are made, density suitable for very detailed soil zoning [12, 32]. The soil classification proposed by the United States Department of Agriculture has been used [30].

The NDVI is defined as the difference between the radiance value in near infrared and red, divided by their sum [20]. In this work, these radiance values have been obtained from multispectral images captured by the Pléiades satellite (0.5 meters of spatial resolution) on August 25, 2014, and August 19, 2015, and by the SPOT 5 satellite (2.5 meters of spatial resolution) on August 14, 2013. The calculation and graphic representation of the NDVI are carried out pixel by pixel, with the help of the ArcGIS 10.1 software from the Environmental Systems Research Institute (ESRI). The definition of the classes (very low, low, medium, high, and very high) is done according to five quantiles, the first quantile corresponding to the very low class and the fifth quantile to the very high class.

The statistical analysis of the data was carried out through principal component analysis (PCA) and univariate ANOVA, after checking normality and homogeneity of variances of the variables. The significance of these analyses was determined for the probability levels $p < 0.05$ (*), $p < 0.01$ (**), and $p < 0.001$ (***). The means are compared by the Duncan test when there were significant differences in the analysis of variance. The SPSS program, version 15.0 (SPSS Inc. Chicago, Illinois), was used for the ANOVA analyses, and for the rest of the statistical calculations, the XLSTAT 2019.1.2 supplement was used on Microsoft Excel 2007. This complement was also used to perform an agglomerative hierarchical clustering (AHC) reducing the 28 analyzed variables of the epipedon before performing the PCA. In this case, the correlation between variables has been calculated for a significance level alpha = 0.05.

For the geostatistical study of the NDVI distribution, the normalized Moran index (NMI) is used, which measures the spatial autocorrelation allowing to evaluate if the NDVI pattern is clustered, dispersed, or random. For the calculation of this index, as well as the associated z-value, the ArcGIS 10.1 ESRI tool is used.

3. Results

Table 1 and **Figure 1** show that EHUs with high yield and high weight of pruning wood (vigorous EHUs) correspond with low probable alcohol grade, low polyphenolic content, and high acidity. These results were to be expected according to numerous previous studies by other authors [19, 33].

The AHC analysis has allowed grouping the 28 analyzed variables of the surface horizon (results not shown) into 3 homogeneous classes, represented by 1 of its variables. Thus, the fine land (FL); the alpha index (AI), which indicates the exchange capacity of the clay; and the humidity at field capacity (H33C) represent, among other variables, the silt content, the total limestone, and the pH; the content in sand, in clay, and in organic matter and the electrical conductivity and the cation exchange capacity; and the content of coarse elements, the active limestone, and the moisture content of the wilting point, respectively.

Observing the biplot graphics of the PCA (**Figure 1**) carried out for the EHUs (observations) and the characteristics of the grape studied together with the three representative variables of the epipedon, it is possible to differentiate between three groups of EHUs. The first group is formed by C1, C2, D2, and D3, which is characterized by its vigor, high yields, and higher levels of malic acid; the second group is composed of B1, B2, and D1 that could be considered as transitional; and the third group is represented by A1, A2, and A3 with a higher probable alcohol level, anthocyanin content, and total polyphenol index (TPI). Regarding the three elements of

UHM	Yield	WP	%vol	pH	M A	TPI	ANT
A1	835 abc	230 a	14.45 bc	3.95 c	2.3 abc	54.5 ef	706 cde
A2	1082 cd	407 cd	14.4 bc	3.86 ab	1.96 a	56.5 f	734 de
A3	706 a	231 a	14.76 c	4.09 d	2.92 cd	52.5 f	788 e
B1	1022 bcd	390 c	13.68 a	3.87 ab	2.01 ab	46.8 bcd	612 abc
B2	767 ab	308 b	13.86 ab	3.82 ab	2.17 ab	48.6 cd	655 bcd
C1	2342 g	559 e	13.35 a	3.9 bc	2.97 cd	43.6 abc	562 ab
C2	2439 g	584 e	13.40 a	3.87 ab	2.7 bcd	40.6 a	530 a
D1	1275 de	307 b	13.45 a	3.8 a	2.3 abc	49.9 de	673 cd
D2	1640 f	690 f	13.84 ab	3.81 a	3.09 d	43.0 ab	597 abc
D3	1506 ef	461 d	14.02 ab	3.83 ab	2.6 bcd	46.1 bcd	637 bcd
Sig.	***	***	***	***	**	***	***

Table 1.
Results (mean 2012–2015) of each UHM: yield (g), weight of pruning wood (WP, g), probable volumetric alcohol degree (%vol), pH, malic acid (MA, g/l), total polyphenol index, and anthocyanins (ANT, mg/l).

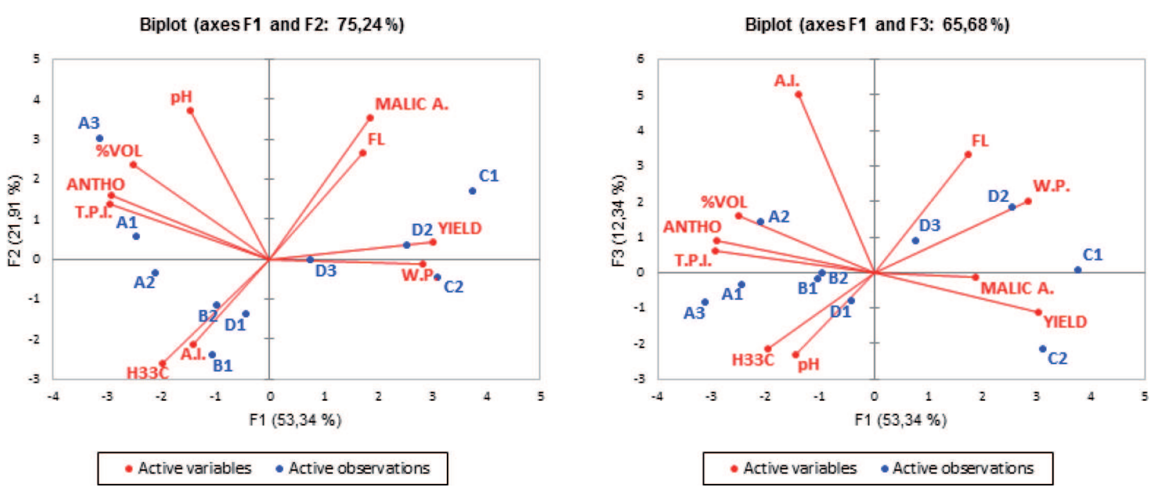

Figure 1.
Biplot graphs of observations (EHU) and variables related to the vineyard (yield, WP, %vol, pH, MA, TPI, and ANT) and to the epipedon (FL, AI, H33C). F1, F2, and F3 are the first three factors of the PCA.

the soil epipedon and its associated variables according to the AHC, it was found that there are positive correlations between the FL and the content in malic acid and between the H33c and the pH of the grape, as well as negative correlation between the H33c and malic acid (**Figure 1**).

3.1 Between-vineyard scale

Depending on the scale used in the class discrimination of the NDVI, different maps can be obtained, although the values of the distribution are constant. Thus, **Figure 2** presents the graphic representations of the four vineyards with a common classification of values, in contrast to the FIA drawn at the plot scale. On the contrary, in **Figure 3** a classification of the individualized NDVI values has been carried out for each vineyard. Comparing both figures it is observed that in **Figure 3** the NDVI distributions in each vineyard follow a pattern more similar to the FIA; in addition there are greater contrasts, something that facilitates the zoning (**Figures 2A** and **3A**). In particular, vineyards A and D present a spatial distribution

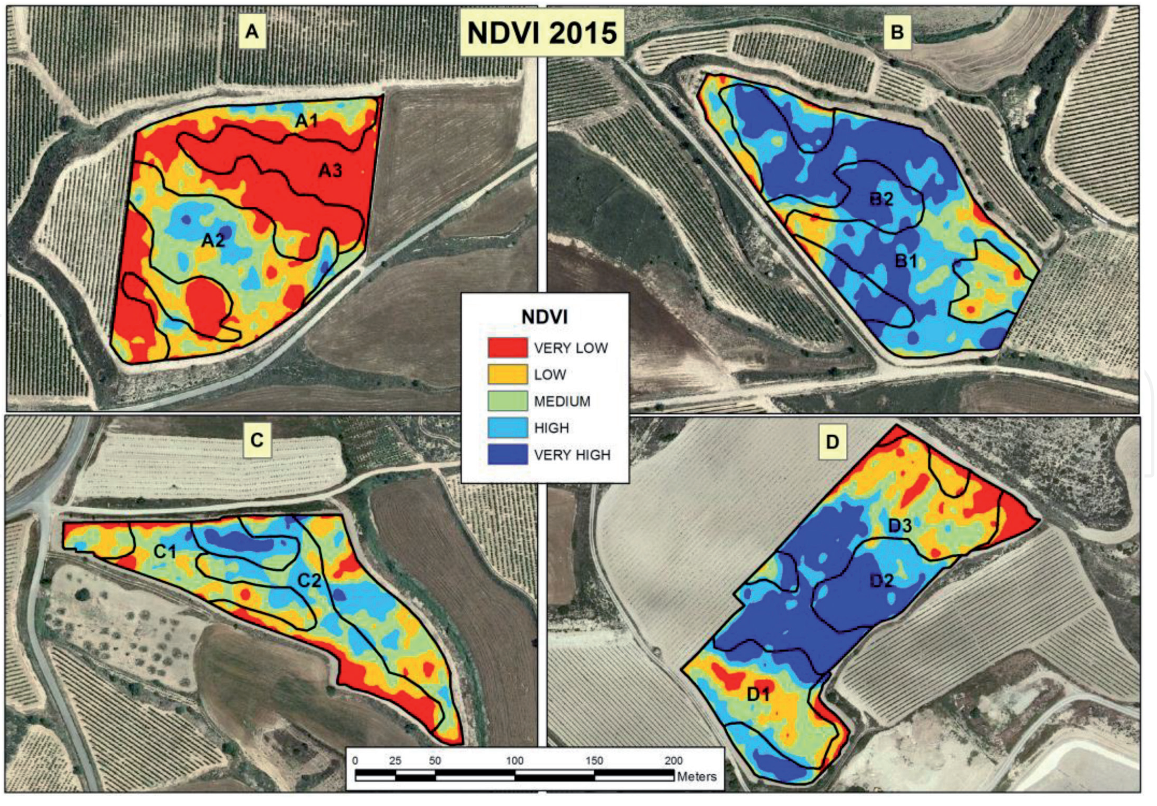

Figure 2.
Spatial distribution of NDVI from Pleiades image. A common classification is carried out for the four vineyards. The labels (A, B,C and D) represent the vineyards of the same name.

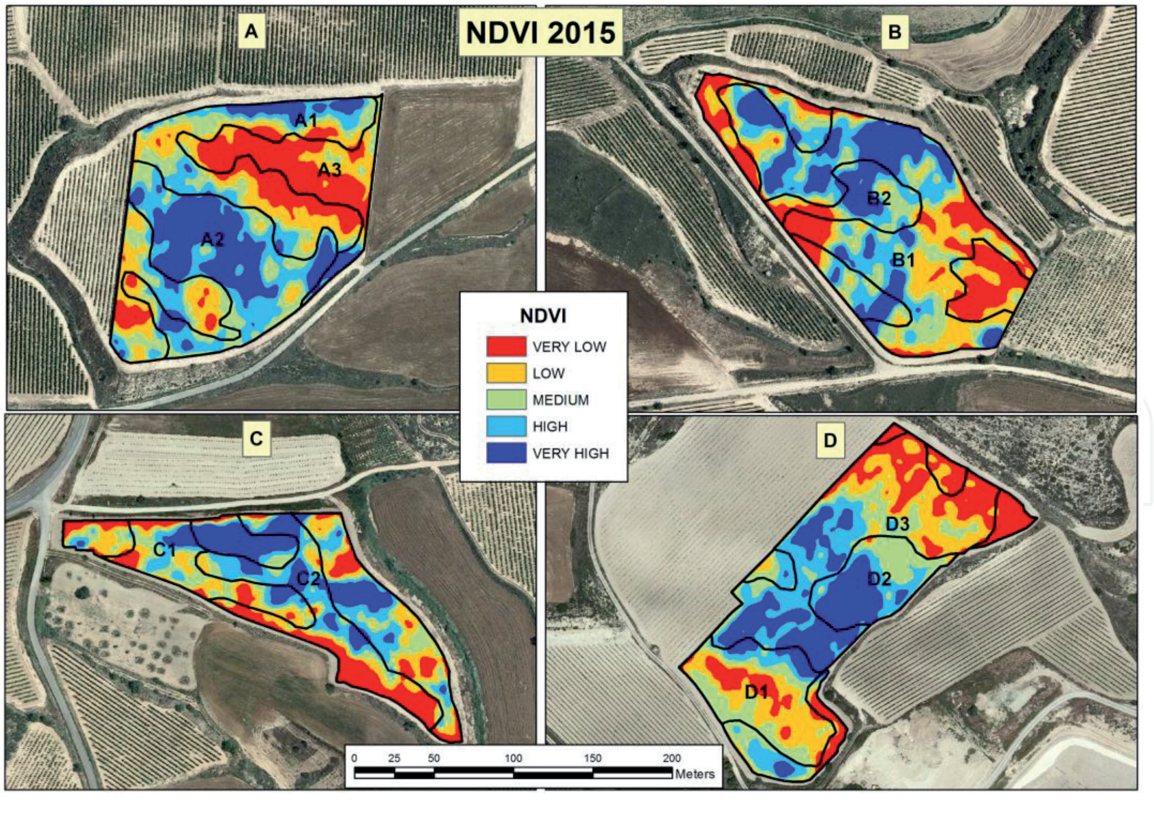

Figure 3.
Spatial distribution of NDVI from Pleiades image. A classification of the individualized NDVI values has been carried out for each vineyard. The labels (A, B,C and D) represent the vineyards of the same name.

of the NDVI similar to the FIA (**Figure 3**). However, plots B and C seem to have a more chaotic NDVI distribution in relation to the FIA, something that seems to be related to the modification of the terrain before planting. This is also the reason why plot C, which according to **Table 1** includes the most vigorous UHMs in the study, does not include more surface of the high or very high classes of the NDVI map (**Figure 3**).

Considering **Figure 2**, most of vineyard B is included, according to the NDVI, in the very high class, while the results of production and composition of the grape (**Table 1**) do not correspond to this result, agreement with previous studies [16, 19, 34]. Also sector D2 (and part of D3) is included in the very high class (**Figure 2**), but in this case this EHU is characterized by having a high yield and a high pruning weight, as well as low sugar levels, pH, IPT and anthocyanins, and the highest content in malic acid; this coincides with the aforementioned works. Again, it seems that the modification of the natural characteristics of the environment prevents the use of the NDVI as a tool for the zoning of the vineyard, at least on this scale of work.

On the contrary, sectors A1 and A3 of vineyard A are included in the very low class (**Figure 2A**). In comparison with the other sectors (**Table 1**), the vines of A1 and A3 have shown the lowest weight of pruning wood, low yields, high levels of probable alcoholic degree, pH, IPT, and total anthocyanins, as well as low levels of malic acid. The other sector of plot A (A2) has been discriminated against by the NDVI since it is not included in the very low class. Sector A2 (**Table 1**) presents higher values of production and weight of pruning wood than sectors A1 and A3. In any case, this discrimination of EHUs is better defined (in relation to the FIA) when making the classification of the vineyard scale distribution (**Figure 3A**).

3.2 Intra-vineyard scale

For the study of intra-vineyard variability, we will focus on plot D (**Figure 4**). The difference between the characteristic profiles of each EHU can be observed, appreciating, at first sight, the fluventic character of the D2B profile (**Figure 4B**) and typical of areas of deposition of material or fertile ground. A unique feature of this type of profile is that its agricultural behavior is similar to an addition of slow liberalization fertilizer, which will influence increasing soil fertility and vigor and vineyard production (**Table 1**). Specifically, this profile has a content in organic matter in the epipedon (Ap) of 2.25%, while in the Ab horizon (52–80 cm deep), there is a level of 3.6%. Regarding the NDVI, sector D2 associated with this profile (**Figure 3D**) is included mainly in the high and very high classes. This indicates, as well as the vegetative, grape composition, and pedological results, that it is a UHM that can be characterized as vigorous, in relation to the rest of the UHMs in the vineyard.

In **Figure 4D** a NDVI classification has been carried out independently in each EHU; the result obtained is not technically operational, at least in a vineyard of the size of the studied one (2 ha). In order to refine the zoning delimitation to this scale of work, we could redefine the EHUs with the help of the NDVI distribution from the classification of the vineyard (**Figure 4E**). In this way vineyard D will be zoned in three EHUs:

D1: northeast facing slope whose characteristic profile is a mesic Calcic Haploxeralf with 80 cm effective depth and with an argillic horizon (20–80 cm of depth). It is the least productive EHU of the vineyard, whose characteristics of the grape are high probable alcoholic degree, lower acidity, and high content in total polyphenols and anthocyanins (**Table 1**). Regarding the NDVI, very low, low, and medium classes appear mainly.

D2: material deposition area characterized by fine loamy, mixed, mesic, and Typic Xerofluvent with 145 cm effective depth and darker color of the epipedon. It is expected that it is the freshest sector (and most sensitive to frosts) in relation to the other two sectors of the vineyard. All these factors mean that production is the highest of the three sectors and that the grape composition is the one with the lowest

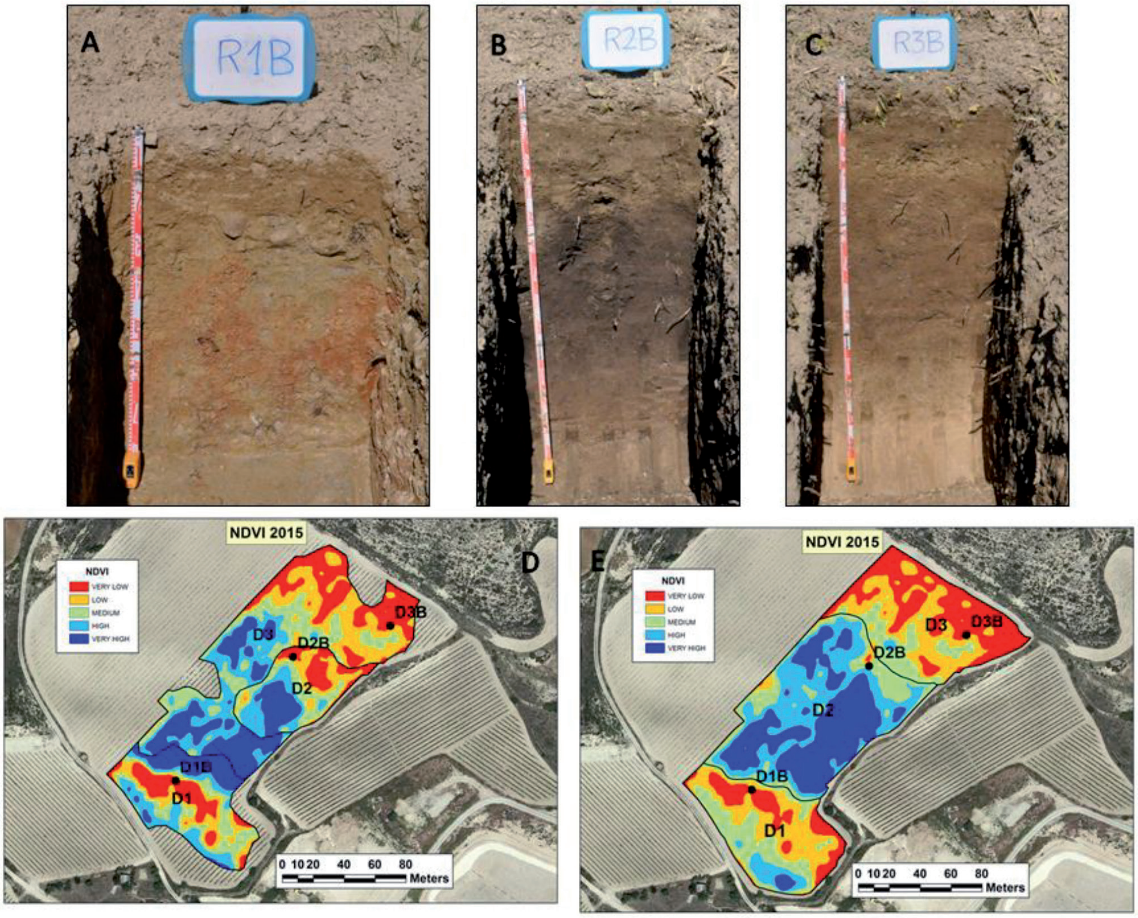

Figure 4.
Characteristic profiles of the EHUs: 4A (sector D1), 4B (sector D2), and 4C (sector D3). NDVI classification carried out independently in each EHU and location of the pits (4D). Definitive terroir *zoning redefined with the NDVI, with a single classification for the three EHUs (4E).*

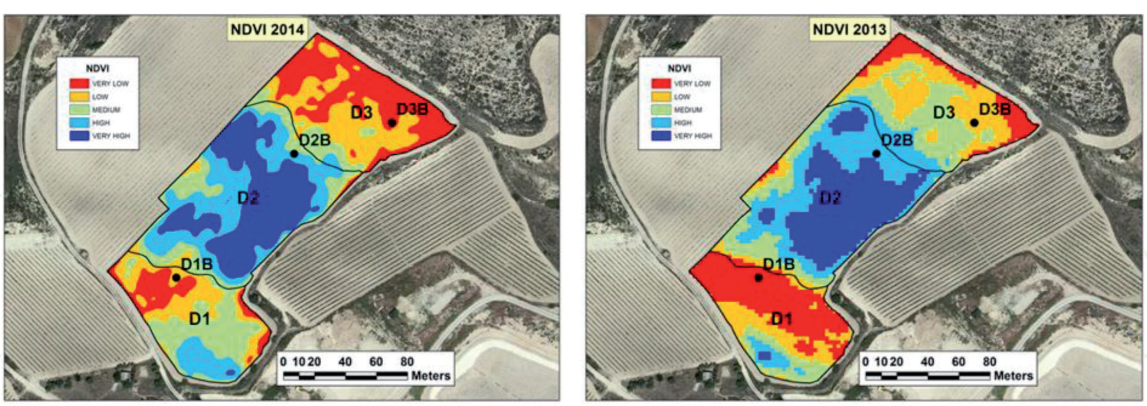

Figure 5.
Spatial distribution of the NDVI in the years 2014 (satellite Pleiades) and 2013 (satellite SPOT 5) and proposed terroir zoning.

probable alcoholic degree, the highest acidity, and the lowest content of total polyphenols and anthocyanins (**Table 1**). The very high and high classes of the NDVI are the most present in this EHU.

D3: hillside with southwest orientation, whose main soil is fine loamy, mixed, mesic, and Typic Xerothent, with an effective depth of 145 cm. It could be considered as the EHU of intermediate characteristics between the other two.

Figure 5 shows the graphic representation of the NDVI from other years (2014 and 2013), verifying the temporal stability of the zoning carried out in vineyard

D. It is noteworthy that the image of the year 2013 is of a resolution (2.5 meters) lower than the rest of the years and the distribution pattern of the NDVI is adjusted to the proposed zoning. In order to achieve a harvest as homogeneous as possible, we could recommend practices aimed at reducing vigor in D2 and increasing it in D1, always with the limitations of practical management.

The NMI calculated for the NDVI distribution has a value of 0.998 and a z-score of 397 for the years 2015 and 2014, while in 2013 the value of the NMI is 0.999 and the z-score is 77. For 3 years there is less than 1% likelihood that this clustered pattern could be a result of random chance [35]. In this type of spatial analysis, it seems that the spatial resolution of the starting image does influence, with a lower correlation with lower spatial resolution. In any case, the NDVI distributions have a grouped pattern indicating that there is a link between the NDVI distribution and the landscape or the distribution of the environment elements in space.

4. Conclusions

It has been verified that there is similarity in the distribution of the NDVI and the FIA, provided that both cartographies are made at the same scale. In vineyards grown on man-modified soils, it seems that the use of vegetation indexes, such as the NDVI, does not give the expected results, being able to conclude that there is a link between the NDVI and the characteristics of the environment, in particular with those related to the soil and landscape.

In the within-vineyard *terroir* zoning, the EHU associated to a material deposition area and characterized by the main series fine-loamy, mixed, mesic, and Typic Xerofluvent is related to the very high class of the NDVI and at the same time with vigorous properties of the vineyard: high yield, high weight of pruning wood, low probable alcohol grade, high acidity, and low levels of IPT and anthocyanin content. These results have been obtained in comparison with two EHUs associated with hillside and whose main soil series are mesic, Calcic Haploxeralf and fine-loamy, mixed, mesic Typic Xerorthent.

Regarding the NDVI, the interannual stability in the pattern has been demonstrated regardless of the resolution of the image, at least from 0.5 to 2.5 m/pixel.

Epipedon characteristics related to agronomic results have been found. Thus, it was found that there are positive correlations between the FL (and associated variables such as silt content, total limestone, and pH) and content in malic acid and between H33c (and the associated variables such as the content in coarse elements, the active limestone, and the moisture content of the wilting point) and the pH of the grape, as well as the negative correlation between the H33c and malic acid. In the future, it will be interesting to find a methodology that allows to integrate the analytical results, not only of the superficial horizon but also of all the horizons of the soil profile and the vegeto-productive results and grape composition, to be able to relate them to each other as exhaustively as possible.

The importance of the size of the vineyards to find PV applications is noteworthy. In the case of DOCa Rioja, 87% [36] of the vineyards are small (between 0.1 and 2 hectares), making the sectorization of the vineyards technically and economically unviable in order to carry out localized treatments. In any case, it is advisable to project plantations that, as far as possible, facilitate individualized management, particularly in the harvest.

Author details

Álvaro Martínez* and Vicente D. Gómez-Miguel
Universidad Politécnica de Madrid, Madrid, Spain

*Address all correspondence to: alvaro.martinezh@alumnos.upm.es

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