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Vegetation index cartography as a methodology complement to *terroir* zoning for use in precision viticulture

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Abstract

Aim: Precision Viticulture (PV) is a form of vineyard management based on tools that offer winegrowers georeferenced information of each vineyard, mainly sector mapping (sub-areas) differentiated by characteristics capable of influencing vineyard usage. This provides knowledge of the variations in these sectors and PV treats each one of them in an independent and optimised manner. This allows, amongst many other possibilities, to monitor fruit ripening with the objective of performing site-specific harvest based on the characteristics of each given sector. Local variations in soil features and natural environmental factors, such as climate, lithology, geomorphology and soil, determine the units that drive or limit PV.

Methods and results: In this paper, multispectral images are used. These have been obtained between veraison and harvest in three different years in order to calculate four vegetation indexes (VI) that have been used since the end of the last century to delimit homogenous sectors in vineyards: the Normalized Difference Vegetation Index (NDVI), the Improved Soil Adjusted Vegetation Index (MSAVI), the Simple Ratio Index (SR) and the Modified Simple Ratio Index (MSR). Mapping of these VI has allowed to relate their distribution with natural environmental factors with the objective of valuing their use in the discrimination of homogenous sectors as a complement and/or alternative to traditional methodologies to *terroir* zoning. Results show that, in the area studied, the vineyards planted in alluvial soil and conglomerated zones, over dominant fine-loamy, mixed, mesic, Calcixerollic Xerochrept soil series, at elevations between 519 and 604 m, oriented east and on slopes less than 5º present higher values for all four indexes throughout the three years of study.

Conclusions: It is precisely these environmental elements (lithology, soil, elevation, orientation and slope) and many soil features that must be relatively uniform in order to make an efficient use of the studied VI.

Significance and impact of the study: The study addresses the use of VI as a companion tool to viticultural zoning, which has not been much explored at such scale level. In addition, the results obtained may lead to changes in the use of VI, which are usually used without taking into account soil and/or terrain features.

Keywords: vineyard, vegetation index, *terroir* zoning, precision viticulture, environmental factors

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Introduction

The fundamental objective of Precision Viticulture (PV) is to use detailed information about the biophysical characteristics and performance of a vineyard, at high spatial resolution, as the basis for viticultural management and decision making (Bramley, 2010). Its practical implementation is dependent on various technological developments: crop sensors and yield monitors, local and remote sensors, Global Positioning Systems (GPS), Variable-Rate Application (VRA) equipment and machinery, Geographical Information Systems (GIS) and data analysis and interpretation systems (Arno *et al.*, 2009). Therefore, PV allows maximizing yield and quality while minimizing environmental impacts and risk (Proffitt *et al.*, 2006).

Before the advent of PV, variability within vineyards was normally managed as «noise» (background level) and often went unnoticed. Therefore, the group of parameters involved in this variability could not be explained nor linked to each other (Cook and Bramley, 1998; Bramley and Hamilton, 2004).

Local variations in climate, lithology, geomorphology and soil factors determine the existence of sectors, which define the units that drive or limit PV (Gómez-Miguel, 2011). More precisely, some elements, mainly climate and soil, allow for sector discrimination based on grapevine development and grape composition, which can be explained by their influence on the water status of the plant (van Leeuwen *et al.*, 2004).

The graphic representation of the different sectors, defined by the environmental characteristics, is carried through cartography and the mapping technique provided by the use of GIS. Climate maps have been produced (Jones *et al.*, 2010), as well as lithological, geological and geomorphological maps (Morlat, 1989; Vaudour, 2010), soil maps (Morlat and Bodin, 2006), altitude, slope and orientation maps and/or a combination of various elements integrated in one unique map (Gómez-Miguel and Sotés, 1997). The completion of these maps, specially the soil map, is a complex and expensive task, but they are the basis of PV because not only do they allow the differentiation of homogenous sectors (sub-areas), they also help explain the effects of this variability in the vineyard.

When working at a regional level, medium and small scales are used (≤1:25.000/50.000), while when studying variability within or between vineyards, the used scales are larger (≥1:5.000) (Gómez-Miguel, 2011). Thus, at the field level, PV technology highlights micro-scale variability which is mainly due to variations in soil depth and physicochemical properties (Bramley and Hamilton, 2007), whereas when the area considered is larger, variability sources linked, for instance, to elevation, slope or aspect, are more likely to appear (Santesteban *et al.*, 2013).

One of the ways to discriminate the existing differences in the behaviour of plants located within the same vineyard or in different vineyards is through vegetation indexes (VI) calculated from multispectral images, used in PV since the 1990s, which allow us to identify, at different scales, different sub-areas in the vineyards. There are studies associating the Normalized Difference Vegetation Index (NDVI) with foliage density or vigour (Hall *et al.*, 2003; Johnson *et al.*, 2003), plant water status (Acevedo-Opazo *et al.*, 2008), leaf area index (LAI) (Johnson *et al.*, 2003) or grape yield and composition (Hall *et al.*, 2011), amongst others. On top of this, vine vigour could be used as surrogate indicators of vine yield and grape quality (Hall *et al.*, 2002).

Algorithms have been proposed that relate different wavelengths with leaf chlorophyll content (Steele *et al.*, 2008), leaf anthocyanin content (Steele *et al.*, 2009) or net photosynthesis (Zarco-Tejada *et al.*, 2013).

In this paper, four VI are calculated, analysed and mapped. More specifically, the distributions of NDVI (Rouse *et al.*, 1973), Improved Soil Adjusted Vegetation Index (MSAVI) (Qi *et al.*, 1994), Simple Ratio Index (SR) (Rouse *et al.*, 1973) and Modified Simple Ratio Index (MSR) (Chen, 1996) are associated with natural environmental factors. The objective is to evaluate the use of these indexes in the discrimination of homogeneous sectors (sub-areas) as a methodological complement to *terroir* zoning for use in PV.

Materials and Methods

1. Study area

The study area is located in the Council of Oyón (Álava), within the Qualified Denomination of Origin Rioja (DOCa Rioja), in north-central Spain (Figure 1). From the vineyard register (MAGRAMA, 1999) and a number of field works, 300 vineyard plots are selected, with a total area of 972.46 ha. In the region, 96.41% of vineyards are planted with the Tempranillo variety (CRDOCa Rioja, 2016) and the plots selected for this study grow this variety. All features related to vineyard management of the plots (training system, soil maintenance, fertilization, green pruning, etc.) can be considered sufficiently similar. Some common

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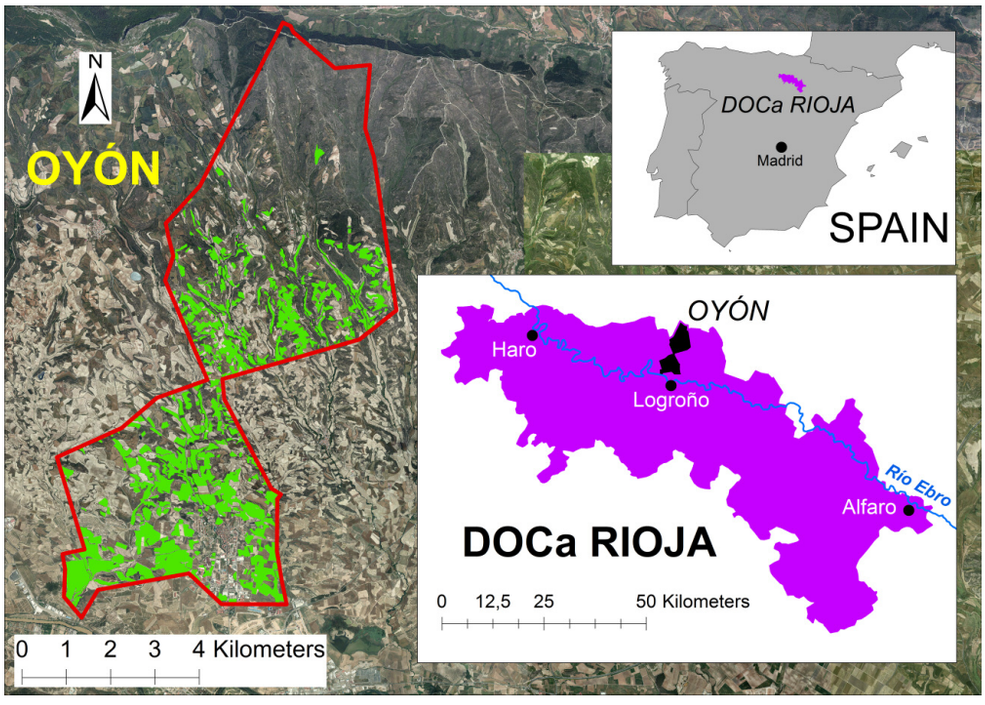

Figure 1. Distribution of the vineyard plots in the Council of Oyón within the Qualified Denomination of Origin Rioja (DOCa Rioja, Spain).

Table 1. Multicriteria Climatic Classification System (MCCS) (Tonietto and Carbonneau, 2004) of the studied years and 30-year average (Viana St., Navarra).

	2005	2010	2013	MEAN 82-13
HI	2271	2076	1987	2208
HI CLASS	HI+1	HI-1	HI-1	HI+1
CI	13.4	12.9	13.3	13.2
CI CLASS	CI+1	CI+1	CI+1	CI+1
DI	-6	40	81	47
DI CLASS	DI+1	DI+1	DI-1	DI+1

HI: Heliothermal Huglin Index, ºC; CI: Cold Night Index, ºC; DI: Dryness Index, mm.

characteristics of the vineyards are: tillage for weed control, plant density of around 2800 plants/ha, with 12 buds/plant distributed in 6 thumbs, managed in Cordon Royat. Thus, vineyard management should have no influence on VI distribution through the statistical analysis of randomly disposed elements.

In prior studies (Gómez-Miguel and Sotés, 1997; Fernández, 1999), zoning was done on the *terroir* of the DOCa Rioja and six climatic classes were identified. The area studied in this paper belongs to the fourth class, which is characterised by a Winkler Index (WI) of 1606ºC, a heliothermal Huglin Index (HI) of 2131ºC and an average annual rainfall of 430.63 mm. The analysis of climate data from the last 30 years at the nearest weather station (Viana) to the studied plots corresponded to an WI of 1702ºC, a HI of 2208ºC and an average annual rainfall of 451.6 mm. Moreover, according to the Multicriteria Climatic Classification System (MCCS) (Tonietto and Carbonneau, 2004), climate in the area is temperate warm (HI+1), with cool nights (CI+1) and moderately dry (DI+1) (Table 1), with 18.7ºC and 217 mm during the growing season (April to September). As the study area shows limited extension in space, it can be considered that most of the climate variability is induced by topographical features.

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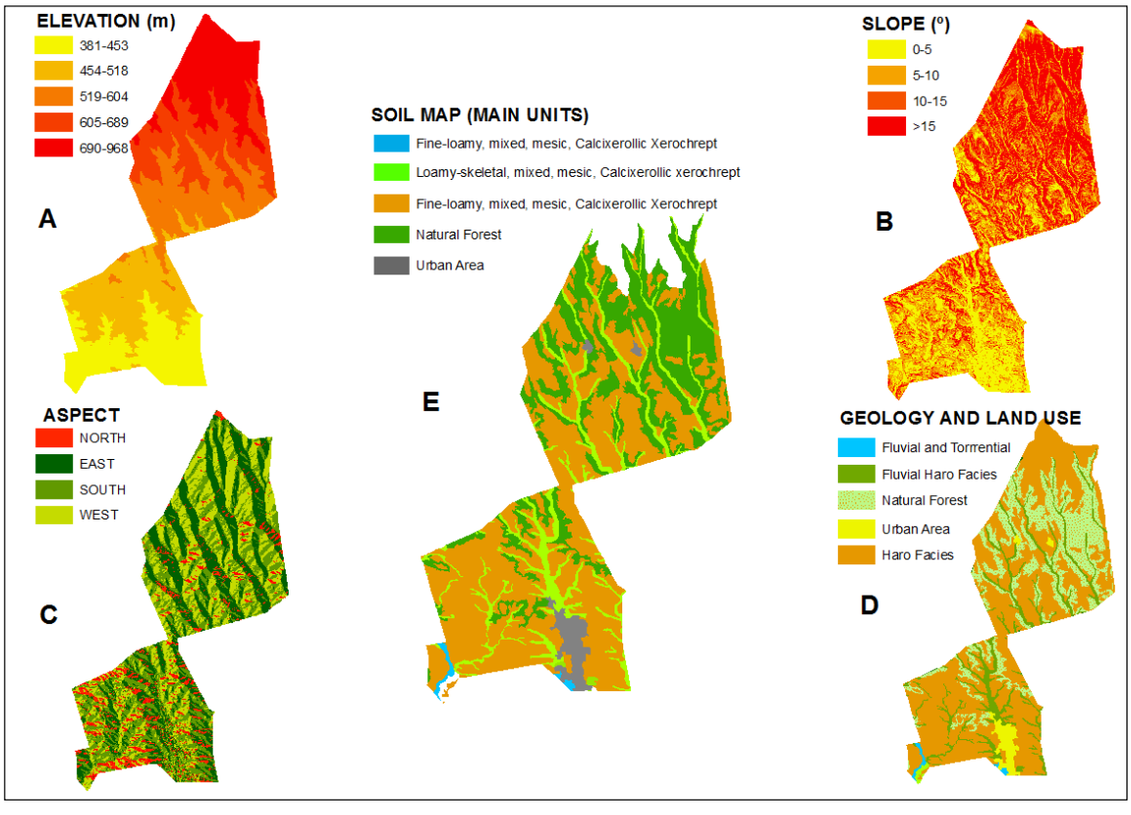

Figure 2. Elevation (A), Slope (B), Aspect (C), Geology and Land Use (D) and Soil Map (E) in Oyón.

Table 2. Epipedon soil features of Soil Map Units.

Main soil of each soil map unit	EG1	AT1	LM1	AC1	CE1	CT1	CA1	MO1	PO1	KC1	RMM	CC1	CI1
	%	%	%	%	dS/m	%	%	%	mg/kg	mg/kg	mm	meq/100g	meq/100g
Loamy-skeletal, mixed, mesic, Calcixerollic Xerochrept	15.6	50.1	33.1	16.8	0.18	15.7	6.3	0.97	6.3	109	79.9	11.2	10.5
Fine-loamy, mixed, mesic, Calcixerollic Xerochrept	2.4	23.8	51.8	24.3	0.21	29.8	7.2	1.31	6.3	229	104.3	12.7	11.1

2. Terrain and soil features

Figure 2 shows maps of the main terrain characteristics:

Elevation (Figure 2A) of Oyón is between 350 and 950 m in the north of the Council and the slope increases from south to north (Figure 2B).

Regarding geology and land use (Figure 2D), Quaternary fluvial deposits and conglomerates are found in the drainage system. These cross the municipality from north-west to south-east and their lithology corresponds to the river/torrent and slope modelling in Haro's facies. The same geographical distribution is shown by the soil map (Figure 2E).

Some epipedon soil features of the main Soil Map Units (SMU) are presented in Table 2. These characteristics are: coarse elements (EG1), sand content (AT1), silt content (LM1), clay content (AC1), electrical conductivity (CE1), total limestone (CT1), active lime (CA1), organic matter (MO1), Olsen phosphorus (PO1), potassium (KCl), cation exchange capacity (CC1) and exchangeable cation calcium (CI1). The water reserve (RMM) of the main soils is also presented.

3. Vegetation Indexes

For the comparative analysis, the above cited VI were used (Table 3). The calculation of the various VI is done from the multispectral images SPOT 5, geometrically corrected by measuring control points and block adjustment. Subsequently, pansharpening is made from the georeferenced panchromatic image (2.5 m spatial resolution) and georeferenced multispectral image (10 m spatial resolution) to obtain a fused image of 4 bands and 2.5 m spatial

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Table 3. Vegetation Indexes and the equations that define them.

Vegetation index	Equation	Reference
NDVI	$\frac{NIR - R}{NIR + R}$	(Rouse *et al.*, 1973)
MSAVI	$\frac{\left[2 * NIR + 1 - \sqrt{(2 * NIR + 1) - 8 * (NIR - R)}\right]}{2}$	(Qi *et al.*, 1994)
SR	$\frac{NIR}{R}$	(Rouse *et al.*, 1973)
MSR	$\frac{\frac{NIR}{R} - 1}{\left(\frac{NIR}{R}\right)^{0.5} + 1}$	(Chen, 1996)

resolution. The spectral region contained in each of the bands is B1 (500-590 nm, Green), B2 (610-680 nm, Red), B3 (780-890 nm, Near-Infrared) and B4 (1580-1750 nm, Medium-Infrared). Images were taken on dates close to the beginning of ripening (stage 35) and before complete ripening (stage 38) according to Eichhorn and Lorenz scale (Coombe, 1995), in particular, the 13th of August 2005, the 14th of August 2010 and the 3rd of September 2013.

The NDVI, MSAVI and MSR values have been transformed by multiplying by 100 and adding 100, while the SR values have been multiplied by 100, which can easily be rendered with a specific colour ramp or colour map.

Figure 3 shows a map of each studied VI in the year 2010. These VI maps, along with those of the years 2005 and 2013, will be compared to main terrain and soil characteristics.

4. Data analysis

The ArcGIS 10.1 software (Environmental Systems Research Institute, ESRI) has been used for the gathering of the VI, operating with B2 (Red, R) and B3 (Near-Infrared, NIR) bands, following the equations in Table 3. This software is also used for (i) spatial auto-correlation study following the Moran´s I method (Moran, 1950; Li *et al.*, 2007), (ii) the modelling of semivariograms and calculations of their featured parameters (nugget, sill, range) and (iii) the calculations and mapping of altitude, orientation and slope from the Digital Elevation Model (DEM) with a 5 m grid spacing (IGN, 2012). Geological data are from the national geological map (IGME, 1972-2003).

Moran´s I spatial auto-correlation analysis determines if the pattern follows a scattered (Z-score<-2.58), random (-2.58<Z-score<2.58) or clustered (Z-score>2.58) distribution, with a statistical confidence level of 99% (p<0.01), where Z-scores are standard deviations of the VI spatial distributions (ArcGIS, 2017).

The Cambardella Index (Ic) is also used to define the VI distributions of different levels of spatial dependence, given their semivariogram features:

$$Ic = \frac{Co}{Co + C_1} * 100$$

where Co is the nugget variance and C_1 is the estimate of the spatial structural variance (sill). If the ratio is less than or equal to 25%, the distribution is

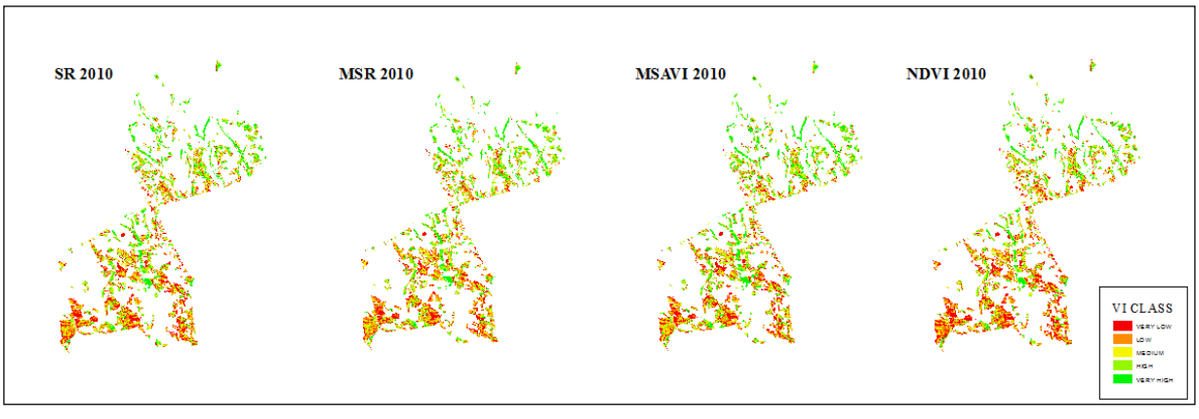

Figure 3. Distribution by classes of SR, MSR, MSAVI and NDVI for 2010 in Oyón.

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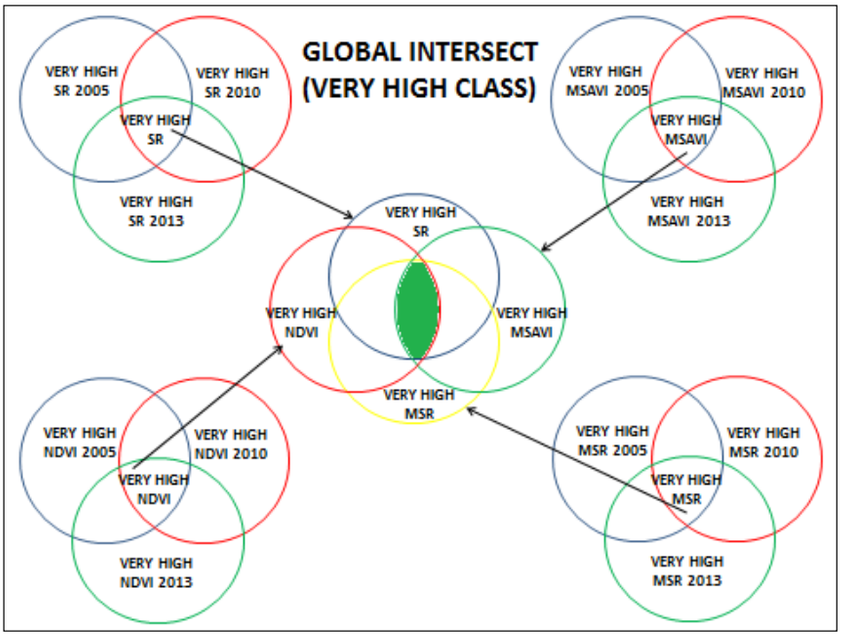

Figure 4. Schema of the methodology for the calculation of the Very High Global Intersect; the green area contains plots classified as very high for the four indexes. The calculation of the High, Medium, Low and Very Low classes is carried out in an analogous way.

considered strongly spatially dependent; if the ratio is between 25 and 75%, the distribution is considered moderately spatially dependent; and if the ratio is greater than 75%, the distribution is considered weakly spatially dependent (Cambardella *et al.*, 1994; Cambardella and Karlen, 1999).

The average value of the four VI is also calculated for each of the 300 plots and a Principal Component Analysis (PCA) is performed relating 12 VI (3 years x 4 VI per year) with aspect, slope, elevation, RMM and the soil features presented in Table 2.

In order to graphically represent each index (Figure 3), the obtained absolute values are reclassified into five types (very high, high, medium, low, very low), each of them related to a quantile. In order to know if there is a common tendency to all indexes, each type is intersected separately, obtaining a new distribution we call Global Intersect (GI), which has the surface area included in each type for all indexes and for every year (Figure 4). Before creating this general intersection, similar interactions take place for each of the four indexes separately. All these calculations are run with the previously mentioned software.

The soil classification used throughout the text is the 1994 version of the Soil Survey Staff (1994), given that it is the one followed in the zoning tasks used for the proposed soil profiling (Gómez-Miguel and Sotés, 1997; Fernández, 1999).

Results and discussion

1. Vegetation Indexes intercomparison

Table 4 shows different statistics on the annual VI distribution. Looking at the average values achieved by these indexes, per index itself and per year of study, 2013, defined by a lower average temperature and more rainfall, presents the lowest values in all four indexes. On the contrary, 2005, the only year characterised as temperate warm, presents the highest average VI values. Intermediate values are observed in 2010.

Therefore, the highest absolute values of the four VI have been obtained when HI is greater, associated with the temperature regime during the growing season. Even though 2013 showed to be the most humid (DI=81), collecting twice the rainfall than the average series (data not shown) during the growing season (April to September) and characterised as humid, one can see that it has the lowest absolute values due to HI being the lowest in the years studied (Table 1).

According to the Ic, the spatial variability for all the indexes is reasonably dependent. On the other hand,

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Table 4. Annual index distribution descriptors.

VI	Year	Min	Max	Mean	SD	Co	C1	Ic	Z-score
NDVI	2013	76	109	90.75	5.08	35.96	14.39	71.4	93.67
MSAVI	2013	38	116	78.12	11.99	97.81	179.18	35.3	92.44
MSR	2013	100	100	99.94	0.04	34.77	19.26	64.4	111.12
SR	2013	62	123	84.06	9.06	0.014	0.009	60.9	92.72
NDVI	2010	92	125	104.40	5.50	37.89	18.45	67.3	78.83
MSAVI	2010	83	139	107.33	9.67	102.78	67.77	60.3	83.93
MSR	2010	100	100	100.05	0.07	65.74	47.21	58.2	97.06
SR	2010	86	172	110.81	13.36	0.012	0.011	53.8	77.51
NDVI	2005	98	131	111.17	5.13	21.99	15.65	58.4	75.83
MSAVI	2005	96	146	119.34	8.21	44.69	50.66	46.9	79.74
MSR	2005	100	101	100.17	0.11	106.52	81.1	56.8	108.26
SR	2005	96	193	126.65	13.81	0.009	0.006	60.0	79.42

VI: Vegetation Index; Min: minimum; Max: maximum; parameters associated with the semivariogram: Co (Nugget), C1 (Sill); Ic: Cambardella Index; Z-score: Moran´s Index critical value.

calculating the Moran´s Index and taking into account its critical value (Z-score), it is concluded that all indexes are distributed through a group pattern, which is not driven by chance (Table 4).

2. Relationship between Vegetation Indexes and soil/terrain features

There are terrain (slope) and soil (PO1) features that do not show correlation with the VI studied. Other characteristics, such as aspect and CI1, show correlation with VI in isolated years: aspect in 2005 and CI1 in 2010. All other features are correlated with all indexes and for the three years, either positively (elevation, EG1 and AT1) or negatively (the others) (Table 5).

The inverse correlation found between MO1 and RMM with the VI is remarkable. It would be interesting to carry out studies, such as the one presented here, at different scales to confirm this relationship and understand its causes.

There are works that, mainly looking for a fast and low-cost method for the identification of soil map units, (i) study the relationship between some soil features and resistivity (Andrenelli *et al.*, 2013) or between NDVI and soil apparent electric conductivity (ECa) map obtained by electromagnetic induction (Andre *et al.*, 2012; Martini *et al.*, 2013) and (ii) create remote sensing soil maps using multispectral images (Lagacherie *et al.*, 2012) or generate terrons (continuous soil-landscape units) from algorithms (Malone *et al.*, 2014).

3. VI-based zoning

Table 6 shows the surface area included in each of the five defined classes when creating the intersection of the three years of study for each of the four indexes. The common surface to the same class during all years and for all indexes (GI) is also shown in this table and Figure 5A.

Very high and very low classes are studied in greater depth than the others because they represent a larger surface area (84% of the total GI area) and because all others can be considered as transitional.

NDVI is the most discriminant index in relation to the very high class. That is, the vineyard surface area occupying the very high class in the NDVI Intersect (67.49 ha) is similar to that occupying this class in the intersection of the four indexes (GI) (61.71 ha). Therefore, the vineyards included in the very high class of the NDVI can be considered to be included in the very high class of the other calculated VI (Table 6).

In a similar manner, plots included in the very low class for the four indexes (GI) (46.77 ha) are basically defined by the plots of this class in the MSR (54.15 ha) (Table 6).

The influence of latitudinal variation (between 42º 19´29´´ N and 42º 36´34´´ N) in the distribution of classes seems remarkable, because many soil and terrain features exhibit a south-to-north gradient.

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Table 5. Pearson´s correlation matrix for the calculated index, terrain and soil features. Values in bold are different from zero, with an alpha significant level = 0.01.

ariables	NDVI13	NDVI10	NDVI05	MSAVI13	MSAVI10	MSAVI05	MSR13	MSR10	MSR05	SR13	SR10	SR05	ASPECT	SLOPE	ELEVATION	EG1	AT1	LM1	AC1	CE1	CT1	CA1	MO1	PO1	KC1	RMM	CC1
NDVI10	**0.795**																										
NDVI05	**0.661**	**0.782**																									
MSAVI13	**0.996**	**0.784**	**0.657**																								
MSAVI10	**0.798**	**0.997**	**0.784**	**0.791**																							
MSAVI05	**0.645**	**0.766**	**0.997**	**0.643**	**0.771**																						
MSR13	**0.954**	**0.781**	**0.634**	**0.930**	**0.774**	**0.610**																					
MSR10	**0.746**	**0.961**	**0.729**	**0.722**	**0.937**	**0.706**	**0.765**																				
MSR05	**0.680**	**0.782**	**0.952**	**0.664**	**0.773**	**0.930**	**0.684**	**0.772**																			
SR13	**0.996**	**0.797**	**0.660**	**0.985**	**0.796**	**0.641**	**0.971**	**0.761**	**0.690**																		
SR10	**0.782**	**0.994**	**0.770**	**0.766**	**0.982**	**0.751**	**0.782**	**0.984**	**0.786**	**0.789**																	
SR05	**0.675**	**0.793**	**0.994**	**0.667**	**0.791**	**0.984**	**0.659**	**0.751**	**0.975**	**0.677**	**0.786**																
ASPECT	-0.143	-0.145	**-0.172**	-0.145	-0.143	**-0.172**	**-0.162**	-0.142	-0.139	-0.139	-0.145	**-0.170**															
SLOPE	0.045	-0.031	0.105	0.059	-0.023	0.116	0.007	-0.060	0.043	0.031	-0.041	0.089	-0.078														
EVATION	**0.256**	**0.271**	**0.293**	**0.266**	**0.284**	**0.294**	**0.232**	**0.212**	**0.244**	**0.243**	**0.251**	**0.288**	0.018	**0.623**													
EG1	**0.422**	**0.502**	**0.430**	**0.407**	**0.499**	**0.420**	**0.414**	**0.469**	**0.437**	**0.431**	**0.497**	**0.437**	-0.025	**-0.229**	-0.129												
AT1	**0.424**	**0.500**	**0.431**	**0.409**	**0.497**	**0.422**	**0.415**	**0.467**	**0.438**	**0.433**	**0.495**	**0.438**	-0.024	**-0.229**	-0.128	**0.996**											
LM1	**-0.380**	**-0.467**	**-0.390**	**-0.366**	**-0.466**	**-0.381**	**-0.373**	**-0.434**	**-0.397**	**-0.389**	**-0.462**	**-0.397**	0.020	**0.223**	0.142	**-0.934**	**-0.899**										
AC1	**-0.369**	**-0.459**	**-0.379**	**-0.355**	**-0.457**	**-0.371**	**-0.365**	**-0.427**	**-0.386**	**-0.378**	**-0.454**	**-0.387**	0.026	**0.208**	0.122	**-0.914**	**-0.873**	**0.995**									
CE1	**-0.235**	**-0.320**	**-0.245**	**-0.222**	**-0.317**	**-0.238**	**-0.248**	**-0.302**	**-0.249**	**-0.245**	**-0.319**	**-0.253**	0.052	0.075	-0.019	**-0.616**	**-0.554**	**0.764**	**0.824**								
CT1	**-0.388**	**-0.470**	**-0.397**	**-0.375**	**-0.469**	**-0.389**	**-0.376**	**-0.436**	**-0.404**	**-0.396**	**-0.465**	**-0.404**	0.011	**0.243**	**0.171**	**-0.946**	**-0.919**	**0.988**	**0.968**	**0.656**							
CA1	**-0.250**	**-0.328**	**-0.261**	**-0.241**	**-0.329**	**-0.256**	**-0.243**	**-0.300**	**-0.267**	**-0.257**	**-0.322**	**-0.266**	0.003	**0.184**	**0.151**	**-0.664**	**-0.598**	**0.884**	**0.892**	**0.747**	**0.858**						
MO1	**-0.353**	**-0.444**	**-0.364**	**-0.339**	**-0.443**	**-0.356**	**-0.351**	**-0.413**	**-0.370**	**-0.363**	**-0.439**	**-0.372**	0.028	**0.195**	0.111	**-0.883**	**-0.836**	**0.985**	**0.997**	**0.861**	**0.948**	**0.907**					
PO1	0.014	-0.020	0.010	0.020	-0.016	0.014	-0.016	-0.029	0.012	0.009	-0.024	0.005	0.069	-0.130	**-0.210**	0.003	0.040	0.057	**0.151**	**0.663**	-0.091	0.031	**0.206**				
KC1	**-0.395**	**-0.484**	**-0.405**	**-0.380**	**-0.482**	**-0.395**	**-0.391**	**-0.452**	**-0.411**	**-0.405**	**-0.480**	**-0.412**	0.031	**0.210**	0.111	**-0.962**	**-0.933**	**0.986**	**0.987**	**0.794**	**0.964**	**0.809**	**0.976**	**0.160**			
RMM	**-0.343**	**-0.434**	**-0.354**	**-0.330**	**-0.432**	**-0.346**	**-0.341**	**-0.403**	**-0.360**	**-0.353**	**-0.429**	**-0.362**	0.026	**0.193**	0.112	**-0.863**	**-0.813**	**0.981**	**0.994**	**0.864**	**0.942**	**0.924**	**0.999**	**0.205**	**0.965**		
CC1	**-0.237**	**-0.322**	**-0.248**	**-0.225**	**-0.321**	**-0.242**	**-0.242**	**-0.300**	**-0.253**	**-0.246**	**-0.319**	**-0.255**	0.032	0.121	0.055	**-0.634**	**-0.562**	**0.844**	**0.887**	**0.947**	**0.763**	**0.917**	**0.920**	**0.425**	**0.822**	**0.933**	
CI1	-0.102	**-0.170**	-0.112	-0.094	**-0.170**	-0.108	-0.112	**-0.158**	-0.114	-0.108	**-0.168**	-0.117	0.029	0.043	0.005	**-0.329**	**-0.243**	**0.612**	**0.675**	**0.888**	**0.505**	**0.816**	**0.729**	**0.537**	**0.576**	**0.753**	**0.939**

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Table 6. Surface area (ha) included in the different classes for the 3-year intersection of the indexes (NDVI Intersect, MSAVI Intersect, MSR Intersect and SR Intersect) and its general intersection (Global Intersect), elevation, geology, aspect and slope.

		Very High	High	Medium	Low	Very Low	Total
Index	Global Intersect	61.71	9.24	4.66	7.43	46.77	129.81
	NDVI Intersect	67.49	29.67	24.92	38.78	93.54	254.4
	MSAVI Intersect	89.03	34.38	26.11	28.75	79.98	258.25
	MSR Intersect	71.74	31.76	26.8	35.52	54.15	219.97
	SR Intersect	80.3	37.05	25.31	35.3	80.07	258.03
Élevation (m)	690-968	0.05	0.00	0.00	0.00	0.00	0.05
	605-689	11.75	1.50	0.50	0.40	0.90	15.05
	519-604	32.09	3.93	1.44	1.71	4.78	43.95
	454-518	11.09	2.48	1.50	2.63	19.00	36.70
	381-453	6.73	1.33	1.24	2.69	22.07	34.06
Geology	Fluvial and Torrential (Quaternary)	0.63	0.07	0.04	0.03	0.24	1.01
	Natural Forest	12.48	0.50	0.18	0.26	4.94	18.36
	Haro Facies (Quaternary)	23.88	1.72	0.59	0.55	5.24	31.98
	Haro Facies (Tertiary)	24.98	4.92	2.70	4.63	40.64	77.87
Aspect	North	3.20	0.46	0.31	0.68	5.65	10.30
	East	20.10	2.54	1.04	1.58	8.46	33.72
	South	24.11	3.90	1.86	3.32	20.82	54.01
	West	14.29	2.34	1.45	1.85	11.83	31.76
Slope (º)	0.00-5.00	29.98	3.99	1.70	2.63	15.98	54.28
	5.00-10.00	21.6	3.84	2.21	3.46	20.68	51.79
	10.00-15.00	6.87	1.08	0.55	0.94	6.00	15.44
	>15.00	3.26	0.33	0.21	0.40	4.10	8.30

The greater part of the studied vineyards is grown on sandstone and lutites of Haro's facies (Middle-Upper Miocene; Gómez-Miguel and Sotés, 1997), occupying the very low class by 52.20% and the very high class by 32.08% (Table 6 and Figure 2D). Four multi-taxa SMU have been outlined about this tertiary formation. The main series common to all is fine-loamy, mixed, mesic, Calcixerollic Xerochrept, including different secondary soil series (Gómez-Miguel and Sotés, 1997) (Figure 2E). The vineyards included in three of these SMU (44C, 45C and 47C) present a tendency towards the very low class, while in SMU 46C, vineyard surface area is similarly distributed (approximately 20 ha) in the very high and very low classes. The reason for the different behaviour of the vineyards grown over SMU 46C is probably the presence of the secondary series mesic, Calcic Haploxeralf, while SMU 44C, 45C and 47C are occupied mainly by the secondary series fine-loamy, mixed, mesic, Calcixerollic Xerochrept and fine-loamy, mixed, mesic, Lithic Xerorthent (Gómez-Miguel and Sotés, 1997).

Over fluvial of the Haro´s facies (Figure 2D) there are vineyards which show a clear tendency to a very high class (Table 6). In fact, 74.75% of the vineyards grown over alluvial materials of Haro's facies are included in the very high class. The main soil series found on this lithology are loamy-skeletal, mixed, mesic, Calcixerollic Xerochrept (Figure 2E), which also presents the greatest surface area of the very high class (Figure 5B).

Vineyard area over the fluvial modelling and the river/torrent modelling of the Quaternary is practically null, while 15% of the studied vineyards are grown in a land cover class, called Miscellaneous areas (Natural Forest; MNF), which are areas that have been cleared and grown with vineyards since the soil map was made (1997). This area tends to a very high class (68%), with 27% in the very low class (Table 5).

Almost all of the vineyards are planted between 380 and 690 m (Table 6 and Figure 2A), with the largest concentration of plants between 519 and 604 m. The vineyards included in the very high class are located in areas of greater altitude. More than 50% of this class can be found at heights between 519 and 604 m. The rest of this class is found mainly at heights

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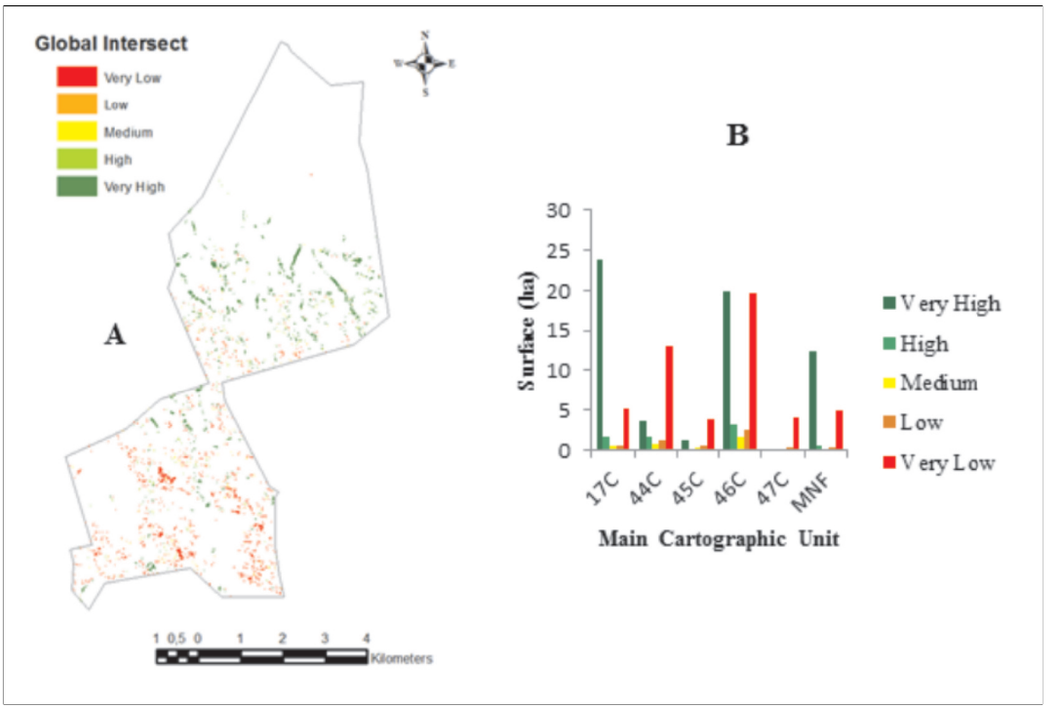

Figure 5. Global Intersect Map (A) and occupied surface (B) by GI classes included in the main mapping units: 17C (main series loamy-skeletal, mixed, mesic, Calcixerollic Xerochrept); 44C, 45C, 46C, 47C (main series fine-loamy, mixed, mesic, Calcixerollic Xerochrept); and MNF (Miscellaneous Natural Forest).

between 605-689 m and 454-518 m. On the other hand, in lower elevation areas (381-518 m), 88% of total vineyards are included in the very low class.

The spatial distribution of the very high class in the higher areas is oriented in accordance with the Quaternary coating of Haro's facies (Figure 2D), with this feature, together with the type of soil developed over this lithology, most likely accounting for the high VI values. Furthermore, altitude indirectly affects soil salinity (areas at a lower altitude have higher salinity levels), which could negatively affect the vegetative growth and the VI values.

42% of GI vineyards are oriented south and only 8% are oriented north (Table 6 and Figure 2C). The rest of the vineyards are evenly distributed, with 50% east and 50% west. Regarding the two class types of interest, 60% of the vineyards oriented east are included in the very high class, while 55% of those oriented north are included in the very low class. The south and west orientations do not show a clear trend towards either class.

82% of vineyards can be found on slopes between 0 and 10º (Table 6). Almost 50% of all the plots included in the very high class have a slope between 0 and 5º, while for those on slopes between 5 and 10º, the very low class is greater (44%).

Conclusion

In this paper, the existing relationship between the spatial distribution of VI and some natural environmental factors has been studied. The vineyards that reach the higher VI (in relative terms) are as follows:

- The vineyards planted on soil developed over alluvial deposits of gravel and conglomerates of the Quaternary cover of Haro´s facies, probably due to better fertility. This soil corresponds to fine-loamy, mixed, mesic, Calcixerollic Xerochrept as the main taxonomic unit, for which values of certain features such as thick elements, thick gravel and fine sand are high.

There are epipedon features correlated with VI during the three years with a 99% confidence level: (i) directly: coarse elements and sand content and (ii) inversely: silt content, clay content, electrical conductivity, total limestone, active limestone, organic matter, potassium and cation exchange capacity.

- The vineyards planted at higher altitude are oriented according to alluvial geology; this feature, together

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with the soil type, is probably responsible for the elevated values obtained in the VI. Furthermore, altitude indirectly affects soil salinity (areas at a lower altitude have higher salinity levels), which could negatively affect vegetative growth.

- The vineyards planted on slopes between 0 and 5º and oriented east or west, probably due to a greater capability to intercept solar radiation.

One can conclude that, in the study area, it is possible to use the VI to differentiate homogenous areas in grapevine behaviour, as long as certain elements of the physical environment are controlled and maintained homogenous in each of the sectors (sub-areas). These elements are the ones that have created variations in VI values, that is, altitude, geology, soils, slope and orientation.

If the elements mentioned in the above paragraph are maintained constant, the entities in charge of the control and protection of winegrowing could use the VI to determine the relative growth stage of the vineyards, choose strategic areas for sampling or propose selective harvesting (by sectors). That is, VI can be a useful tool, provided there is a prior zoning that includes an in-depth study of soil, terrain and climate.

Finally, the four indexes studied (NDVI, MSAVI, SR, MSR) have shown a similar spatial distribution and a high correlation between each other, possibly because the same spectral bands (Red and Near-Infrared) are operated in order to calculate them. The similarities in this behaviour lead us to think that their use for PV analysis related to vigour, water status, foliar area index and performance is the same order of magnitude as that of NDVI which, as already stated, has been used more frequently (Vaudour *et al.*, 2015).

The study has been carried out on a district but could be done over a larger area (region), provided there is a previous zoning study at the appropriate scale.

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