Vineyard zoning of *cv* Bonarda argentine (*Vitis vinífera* L.), from Sentinel satellite images and three vegetation indexes

Zonificación de un viñedo de *cv* Bonarda argentina (*Vitis vinífera* L.) a partir de imágenes del satélite Sentinel y tres índices de vegetación

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Abstract

This study describes the results and conclusions obtained from vineyard zoning in Mendoza by using three vegetation indexes (NDVI, EVI and SAVI). Such indexes were calculated from spectral signals received by the Sentinel-2A satellite in the days close to the 2017 harvest. With this information, maps from the plot of land with the zoning given by each index were obtained. Based on the NDVI zoning, a stratified sampling was carried out. On each stratum, 14 plants were marked and the production variables total weight of grape per plant, number of grape bunchs per plant and the weight of 50 berries were measured. The results showed that NDVI and SAVI led to similar classifications in terms of vineyard zones (strata), while EVI captures high vigor levels with less sensitivity. There was a correspondence between the production variables and the strata of high, medium and low vigor. The three indexes clearly showed two different vineyard areas in terms of production. Consequently, these indexes may contribute to rationalize viticulture practices, adjusting the intensity of such practices to the characteristics and needs of each of these vineyard areas.

Keywords
precision agriculture • Sentinel 2 • zoning • vegetation indexes • grapevine • Bonarda argentina

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Resumen

El presente trabajo describe los resultados y conclusiones obtenidos en la zonificación de un viñedo de Mendoza, empleando tres índices de vegetación (NDVI, EVI y SAVI) calculados a partir de las señales espectrales captadas por Sentinel 2A, en los días próximos a la cosecha de 2017. A partir de esta información, se obtuvieron los mapas de la parcela con la zonificación dada por cada índice. En base a la zonificación dada por NDVI, se realizó un muestreo estratificado y en cada estrato se marcaron 14 plantas sobre las que se midieron las variables productivas peso total de uva, número de racimos por planta y peso de 50 bayas. Los resultados muestran que NDVI y SAVI conducen a clasificaciones similares en cuanto a zonas (estratos), mientras que sugieren que EVI capta con menos sensibilidad niveles de alto vigor. Hubo correspondencia entre los valores de las variables productivas con los estratos de alto, medio y bajo vigor. Los tres índices diferenciaron claramente dos zonas del viñedo en lo relativo a su producción, en consecuencia, los mismos podrían contribuir a racionalizar las prácticas de cultivo, adecuando su intensidad a las características y necesidades de cada una de estas zonas del viñedo.

Palabras clave

agricultura de precisión • Sentinel 2 • zonificación • índices de vegetación • vid • Bonarda argentina

Introduction

The study of the spatial variation in the vine, which has been associated to the vigor variation, tends to focus on foliar area measurement, production variables (berry weight, yield, among others) and also on variables related to the quality (polyphenol concentration and anthocyanin content of grapes, among others) (2, 7, 11).

For premium winemaking, it is essential to identify stratum of homogenous variability in a vineyard in order to contribute to wine quality and/or quantity improvement according to the needs of the winery (6).

Currently, remote sensing systems, geographic information systems and GPS receivers, allow the identification, measurement and mapping of the special variability of the grapevine. Such technologies are globally known as precision agriculture or site specific crop management (2, 14, 15) and they allow to carry out sampling plans conducted by areas or strata, to estimate the vintage precision and to perform a selective grape harvest (19).

In this context, free-to-use images given by the Sentinel-2A are currently available. Such satellite belongs to a constellation of 2 identical satellites that were launched by the European Space Agency (ESA) and they have been working since August 2015 (2A) and October 2017 (2B) in order to carry out different missions. The main goal of these satellites is to provide earth, ocean and atmosphere data. One of these missions works specifically to monitor the environment, the vegetation status and, mainly the agricultural and forestry practices, among other goals. In this way, the capacity of SPOT and Landsat missions were continued and broaden.

The optical images from the Sentinel-2 satellite may revolutionize the research on the Earth's surface since it has never been possible before to get images of such a good spatial, temporal and spectral resolution for free (13).

Different vegetation indexes could be calculated from the spectral answer of a surface received by the satellite remote sensing systems (IV). Such indexes are the product of simple relations between the reflectance in different bands of the electromagnetic spectrum, seeking to enhance the contribution of the vegetation and to mitigate the contribution of other elements such as the soil, the lighting or the atmosphere.

From 1974, a great number of vegetation indexes has been developed, among which the NDVI (Normalized Difference Vegetation Index) has been the most used one because of its easy way of calculation and interpretation (3). This index allows to calculate the plant vigor on a particular phenological stage. The vigor indicates the condition of the crop. In the particular case of vineyards, a strong temporal relation between this index and the leaf area index was found (10), while the relation with productivity and whit enological quality parameters (researched in a great number of studies) has been less clear (11, 12, 21).

The main problem of the NDVI index is the influence of the ground reflectance when the vegetation coverage is very poor (wide planting standards or early farming stages,) hindering the interpretation of the obtained values. Consequently, other indexes have been proposed, such as Soil Adjusted Vegetation Index (SAVI), which includes a soil-adjusted constant (L) that reduces the resulting reflectance and is able to compensate the "soil effect" in these cases (8).

Another improved vegetation index is the EVI (Enhanced Vegetation Index), which corrects distortions in the reflected light caused by clouds and aerosols that can block the satellite's view. The EVI data does not become saturated as easily as the NDVI when viewing rainforests and other areas of the Earth with large amounts of chlorophyll and it allows a better differentiation of the structural variations of the canopy (3, 9).

The purpose of the present study was to analyze and compare the zoning given by each of the three vegetation indexes abovementioned from the spectral signal of a vineyard. Such spectral signal was obtained by the remote sensing of a new satellite, better in spatial and temporal resolution in relation to other satellites that provide free-to-use images (Lansad 8).

Likewise, an attempt was made to establish whether zoning obtained agreed to the spatial variability of the production variables.

Materials and Methods

Study area

This study was carried out during the 2016-2017 production cycle in a pergola trellis system of Bonarda argentine grape cultivar, located at Chapanay division, Department of San Martín, in the East region of Mendoza province, Argentina. This area has a warm temperate climate with cold nights. During the harvest season evaluated, it was recorded an average temperature of 38.4°C maximum, 21.96°C medium and 6.18°C minimum with an average precipitation of 86.26 mm (5).

Image acquisition

Satellite images from the Sentinel-2A that were taken on the 26th of January of the year 2017 were used. Such images were taken during the veraison growing period (4). It was worked with satellite images provided by the Geological Service of the United States, whose link is: https://earthexplorer.usgs.gov/.

The bands used were the blue, red and near-infrared ones respectively with a spatial resolution of 10 m.

The obtained image of the plot of land for this study had a total of 661 pixels, each of which represents an area 10 m x 10 m.

Zoning

From the obtained image, the software QGIS2.16 (16) was used in order to calculate the vegetation indexes NDVI, EVI and SAVI.

The formulas used to calculate the NDVI, SAVI and EVI indexes are the following:

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

where:
NVDI = Normalized Difference Vegetation Index
NIR = reflectance in the near-infrared
R = reflectance in the red.

$$SAVI = \frac{NIR - R}{NIR + R + L}(1 + L) \quad (2)$$

where:
SAVI = Soil Adjusted Vegetation Index
NIR = reflectance in the near-infrared band
R = Reflectance in the red band
L = constant to adjust the vegetation-soil line to the origin, 0.5

$$EVI - 2.5\text{x}\frac{(NIR - R)}{(NIR + C1 \times R - C2 \times B + L)} \quad (3)$$

where:
EVI: Enhanced Vegetation Index
NRI = reflectance in the near-infrared band
R = reflectance in the red band
B = reflectance in the blue band; the used coefficients in the algorithm are L = 1, C1 = 6, C2 = 7.5.

Lately, an unsupervised classification was carried out. Such classification was obtained from the emerging data of the calculated pixels, based on the division of the range of values at equal intervals. From this classification, three areas (strata) associated to different levels of vigor (high, medium and low) for each calculated index arise (figure 1, page 171).

Sampling design

Taking the NDVI as a reference classification given its wide diffusion in precision viticulture (1), and taking into account that the strata produced by the preceding classification are approximately the same size, a stratified sampling was carried out, with n = 7 pixels/stratum.

The same technique was applied for the strata corresponding to the EVI and SAVI classifications.

The corresponding area of each pixel was located through a satellite navigation system (GPS +GLONASS) and, for each of them, two plants were chosen and identified.

Of a Samsung J7 phone (2016) - GPS + GLONASS + BEIDOU-, with the Mobile topographer application, which allows autonomous positioning with an error radius of 1 to 3 m, contrasted with official GPS points of the National Geographic Institute of Argentina.

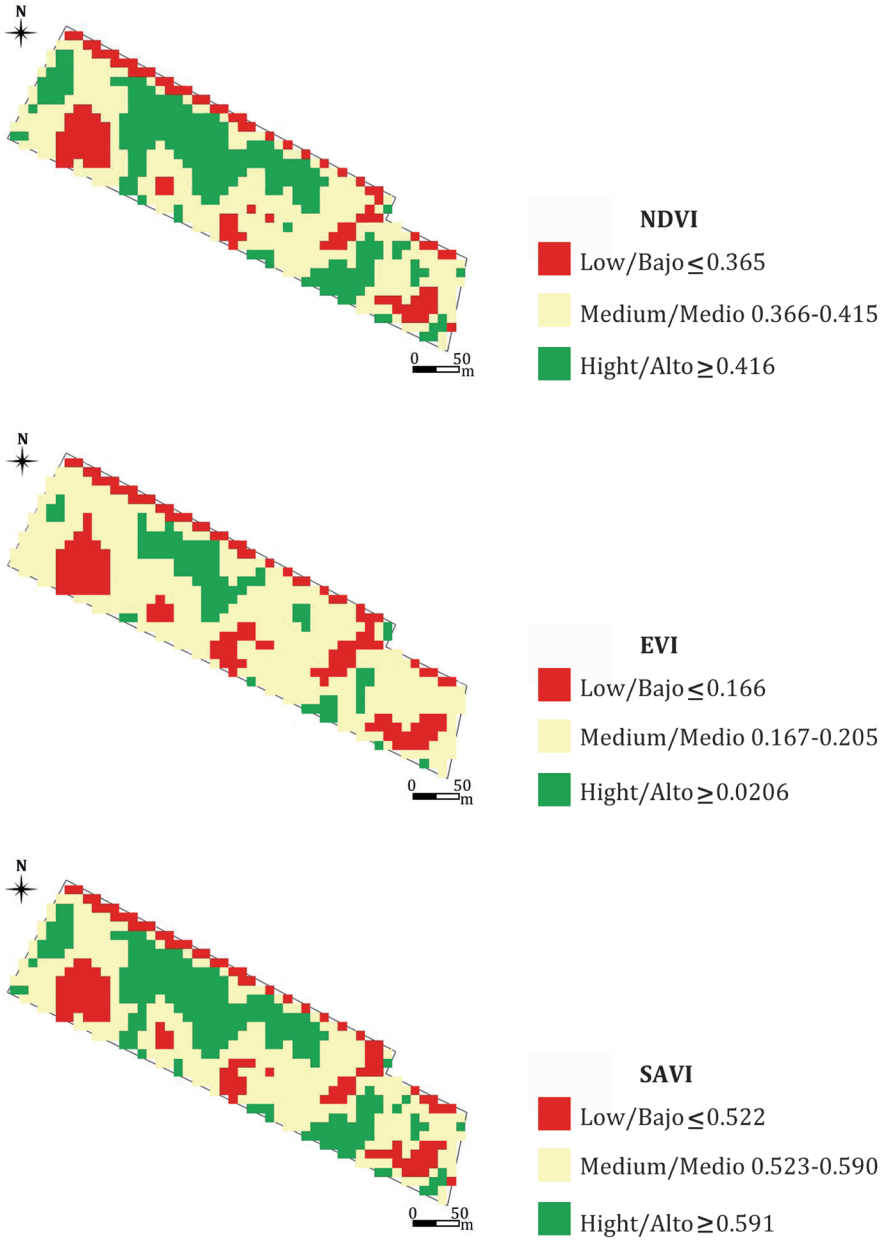

Figure 1. Maps of the studied plot with the zoning given by each vegetation index with the values of the same for each degree of vigor (stratum).

Figura 1. Mapas de la parcela estudiada con la zonificación dada por cada índice de vegetación con los valores de los mismos para cada grado de vigor (estrato).

All clusters of the plants selected as samples were harvested at the moment harvest opportunity, all the bunches of the plants sampled were collected.

The production variables evaluated were: total number of clusters, total weight of the grape and the weight of 50 berries, codified in this study as NRP, PTU and P50b respectively.

Then, a statistical description of the data sampling for each index (arranged in table form) was carried out. After that and during the inference stage, the statistical software R (17) was used to carry out a Multivariate Analysis of Variance (MANOVA) for each obtained index. In this study, the production variables obtained as response variables and, the stratum as explicative variable were included.

Two multiple comparison tests were carried out in order to determine the interaction between the strata corresponding to each index: Tukey's and Bonferroni's HSD (Honestly Significant Difference) tests with a significance level of 0.05.

Results

In relation to the zoning given by each one of the vegetation indexes, it may be noticed on figure 1 (page 171) that the maps obtained were similar among them.

The same situation was evident when analyzing the number of classified pixels in each stratum any for three or two of them (figures 2, 3 and 4, page 173).

Regarding the information shown in the Venn diagram, it is observed that for the "high" stratum (figure 2, page 173) of the indexes, NDVI-SAVI agreed a 98% on the pixel classification, while NDVI-EVI just on the 44.5% of the cases. However, this does not modify the average calculated per stratum of the measured variables PTU and P50b as it may be observed on table 1 (page 174).

From the same diagrams, it is observed that regarding "medium" and "low" strata (figure 3 and figure 4, page 173), the percentages of coincidence between the three vegetation indexes are superior to the 85% and 98% respectively.

One of the statistical assumptions for the MANOVA was omitted from the NRP variable due to multivariate normality problems.

Both Tukey's and Bonferroni's DHS tests gave identical results in the determination of interactions between the strata corresponding to NDVI, EVI and SAVI indexes.

A summary of such tests with the average parameters and the standard deviation for each variable and each stratum is shown on table 1 (page174).

From the analysis of table 1 (page 174), it may be seen that the three vegetation indexes showed significant differences for the NRP and P50b production variables between the high and low vigor areas.

Likewise, it can be seen in the same table that NDVI and SAVI capture the same information for the measured production variables and in all the strata. Such indexes establish meaningful differences between the high and low vigor strata in the two studied variables.

However, when considering the medium vigor area in relation to the high or low vigor, the interpretation is less clear since the response differs for different variables.

In the case of the total production per plant, NDVI and SAVI detect meaningful differences between the strata of high and medium vigor and between high and low vigor. EVI just detects differences between the strata of high and low vigor.

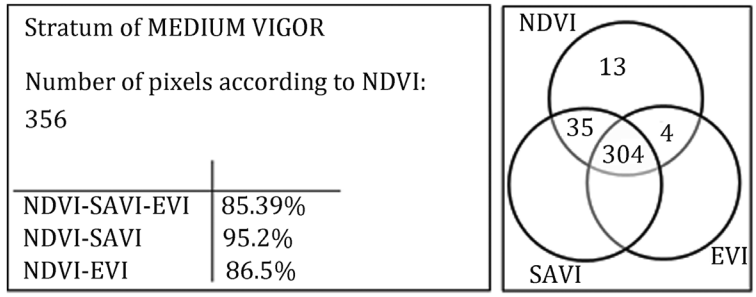

Figure 2. Venn diagrams corresponding to the distribution of pixels in the "high" stratum, according to the NDVI, EVI and SAVI indexes.

Figura 2. Diagramas de Venn correspondientes a la distribución de píxeles en el estrato "alto", según los índices NDVI, EVI y SAVI.

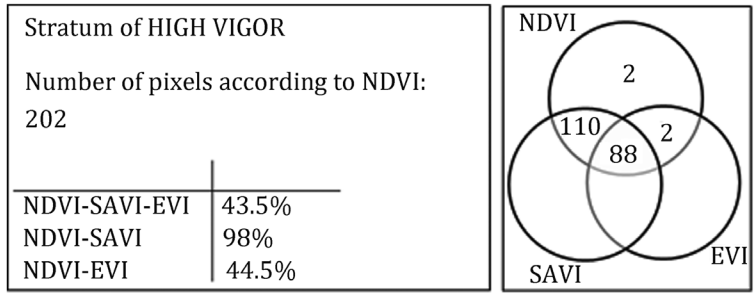

Figure 3. Venn diagrams corresponding to the distribution of pixels in the "medium" stratum, according to the NDVI, EVI and SAVI indexes.

Figura 3. Diagramas de Venn correspondientes a la distribución de píxeles en el estrato "medio", según los índices NDVI, EVI y SAVI.

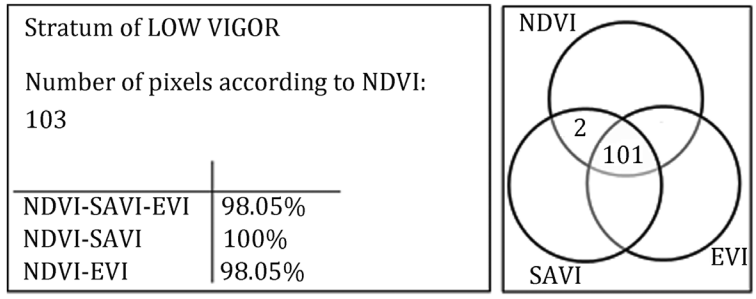

Figure 4. Venn diagrams corresponding to the distribution of pixels in the "low" stratum, according to the NDVI, EVI and SAVI indexes.

Figura 4. Diagramas de Venn correspondientes a la distribución de píxeles en el estrato "bajo", según los índices NDVI, EVI y SAVI.

Table 1. Average values of productivity in each block and multiple comparison by means of Tukey's HSD test.

Tabla 1. Valores medios de productividad en cada bloque y comparación múltiple de medias por test de Tukey HSD.

		Índices de Vegetación					
		NDVI		EVI		SAVI	
Variable	Stratum	n	Average ± DS	n	Average ± DS	n	Average ± DS
PTU (kg)	High	14	12.23 ± 4.5 a	8	12.69 ± 5.3 a	14	12.16 ± 4.5 a
	Medium	14	8.20 ± 2.1 b	18	9.28 ± 3.1 ab	14	8.27 ± 2.1 b
	Low	14	6.16 ± 3.2 b	16	6.48 ± 3.1 b	14	6.16 ± 3.2 b
P50b (g)	High	14	103.2 ± 12.5 a	8	104.5 ± 12.8 a	14	101.5 ± 11.3 a
	Medium	14	92.99 ± 14.5 ab	18	96.66 ± 14.5 a	14	94.60 ±16.4 ab
	Low	14	82.78 ± 10 b	16	83.07 ± 9.7 b	14	82.78 ± 10 b

Different letters in the same column indicate meaningful differences with a p-<0.05 value.

Letras distintas en una misma columna indican diferencias significativas con un p-valor<0,05.

In the case of P50b, NDVI and SAVI just detect meaningful differences between strata of high and low vigor, while EVI detects differences between strata of medium and low vigor and between high and low vigor.

Discussion

Only NDVI and SAVI agreed on the classification on a 95% and 100% of the pixels on each stratum. This result is consistent due to the fact that in the construction of the SAVI index the same spectral bands (R and NIR) as in NDVI are added, plus a specific calibration parameter (equation 2, page 170). This result agreed with previous studies although another kinds of vegetation covers were evaluated (3, 18, 20)

Regarding the difference in the EVI classification in relation to the other indexes, just the stratum of "high" vigor coincidence may be interpreted according to its construction (equation 3, page 170). Such index is more sensitive to the near-infrared band (NIR), allowing a better differentiation of the structural variations of canopy and plant physionomy (9).

This behavior may be considered similar to the previously observed during the assessment of different vegetation covers, in which EVI showed better class distinctions in densely vegetated categories (18).

In table 1, it can be observed the correspondence between the values of the production variables and the strata of high, medium and low vigor so that the areas of the highest vigor showed the highest production values. These results are similar to the ones found by other researchers when zoning the vineyards in order to obtain areas of different grape quality (12).

The information shown in MANOVA in table 1, allows to infer that the three calculated indexes detected meaningful differences for the production variables NRP and P50b between the areas of high and low vigor. This indicates that the use of any of them allows to clearly identifying strata with dissimilar vegetation vigor.

The behavior of the indexes is less clear in relation to the differentiation between the area of high and medium vigor or between the one of low and medium vigor, which is different for each production variable under consideration. This kind of analysis was not found in the reference bibliography, reason that encourages future studies.

Conclusions

The images given by the Sentinel-2 satellite offer a good alternative for intra-parcel zoning in grapevines for winemaking production because of its spatial and temporal resolution level, as well as its easy acquisition and free availability.

Since NDVI and SAVI indexes zoned basically in the same way, in the case of a pergola trellis system, the soil effect on the reflected radiation seems to be irrelevant, therefore, NDVI index would be enough to describe the vegetative expression behavior.

The three indexes allowed to clearly differentiate two vineyard areas regarding its very different vegetative growth and yield, elements that would require a different treatment regarding farming practices.

Consequently, these indexes may contribute to rationalize the farming practices adjusting the intensity of such practices to the same characteristics and needs of each one of these vineyard areas.

For the conditions of this study and the studied variety, the descriptive information of this study would suggest that EVI would not have the same usefulness to carry out an adequate zoning. This is because it would be less sensitive to differentiate areas of high vegetation vigor than the other two indexes, which in this sense would provide a very ambiguous description of the plot of land.

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