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Analysis of the temporal signature of vineyards in Portugal using VEGETATION

A.R.S. Marçal, J.A. Gonçalves, H. Gonçalves & M. Cunha
Faculdade de Ciências, Universidade do Porto

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ABSTRACT: One of the most important agricultural activities in Portugal is wine production. There are several areas in continental Portugal where the majority of the land is used for vineyards. There is a potential for satellite image data to be used for the monitoring of the vineyards used for wine production, both due to the new and improved satellite sensors, and also due to the wider and easier access to data. One of the sensors that provide frequent data with reduced costs is the VEGETATION. The purpose of this work was to evaluate the usefulness of the VEGETATION NDVI data to characterise the phenology of the different wine production areas in Portugal. The CORINE Land Cover maps from 2000 were initially used to select 5 test areas with over 90% vineyard land cover. These test sites have between 18 and 93 km^2 and are located in 4 different regions: Douro (2 sites), Estremadura, Sado and Alentejo. The NDVI images from VEGETATION were used to produce temporal plots for each site, from 1988 to 2005 (36 images each year). Average temporal profiles were also produced for each region, using the 8 years of data. The differences between regions and the variability within years is discussed and compared with the wine production data available for each region.

1 INTRODUCTION

In the past few years a number of application of remote sensing data for viticulture have been reported in the literature (for example Hall *et al.* 2002; Zarco-Tejada *et al.* 2005). Although most cases are based on airborne data, there are some examples where satellite images have been used for mapping and monitoring vineyards (Johnson *et al.* 2003). The main limitations for the use of satellite remote sensing in viticulture include the low spatial resolution of the images, insufficient revisiting rates and difficulties or high costs in accessing the data.

A number of satellite sensors currently offer low spatial resolution images with a high revisiting rate (or high temporal resolution). Examples of such sensors are the MODIS, MERIS, AVHRR and SPOT VEGETATION. Although these sensors can not provide detailed information for vineyard mapping, they can be a valuable tool for monitoring, mainly for year to year comparisons on a regional scale, due to their high data acquisition rates and the wide availability of the datasets.

Wine production is one of the most important agricultural activities in Portugal. Although the vineyards in Portugal do not occupy contiguous areas as extensively as in other countries (e.g. Australia or USA), there are some regions of the country where the predominant land cover/land use is vineyards. The purpose of this work was to evaluate the usefulness of the vegetation indices produced from VEGETATION satellite images to monitor the vineyards of the main wine regions of Portugal.

1.1 *Remote sensing for vineyard monitoring*

The most common use of remote sensing for viticulture is through high resolution airborne data, used as a part of an integrated management tool for vineyards (Hall *et al.* 2002). High resolution satellite images from IKONOS sensor have also been used for the purpose of mapping vineyard leaf areas (Johnson *et al.* 2003). However, the use of satellite images for mapping and monitoring vineyards is somehow restricted due to limitations in spatial, spectral and temporal resolutions of the datasets available.

Although the use of hyper-spectral sensors allows for vegetation indices based on several or narrow bands to be used (Zarco-Tejada *et al.* 2005), most applications are based on conventional vegetation indices produced form only two bands, such as the NDVI (Johnson *et al.* 2003). The crucial aspect for the practical development of a tool for vineyard monitoring based on satellite Earth Observation data is the spatial and temporal resolution of the images, as well as the availability and cost related issues.

High spatial resolution sensors, such as IKONOS and Quickbird, can be used to produce vegetation indices, such as NDVI and LAI, at an adequate scale for vineyard monitoring (Johnson *et al.* 2003). However, these images are still infrequent and very expensive, both factors limiting the practical implementation of a satellite based monitoring system. Intermediate spatial resolution sensors, such as SPOT HRVIV and Landsat TM can partly overcome these problems, although the temporal resolution is not significantly improved and the costs might still be too high. Both these problems are solved using data from low spatial resolution sensors, such as MODIS and VEGETATION, which can provide global coverage on a daily basis, with the data distributed free of charge, or reduced costs. These are the positive aspects of these sensors, while the large pixel dimension (1×1 km) is clearly the most negative factor. It is nevertheless worth trying to evaluate the potential of these datasets for vineyard monitoring. An operational tool can be implemented in the future if the information provided by the satellite images proves to be of some use for the viticulture industry.

2 MATERIAL AND METHODS

2.1 *VEGETATION data*

The VEGETATION sensor is on board of the SPOT satellites, providing daily coverage of the entire Earth since 1998, at a spatial resolution of 1 km (SPOT 2006). The sensor acquires data in four spectral bands, ranging from 0.43 to 1.75 μm (VITO 2006).

S10 products are obtained from the compilation of daily synthesis from ten consecutive days, providing atmospherically corrected data (values corresponding to surface reflectances). The resulting surface reflectance value for each pixel corresponds to the date with maximum NDVI reflectances at the Top of the Atmosphere (TOA) for that pixel (SPOT 2006). A 10-day synthesis (S10) image is thus a result of the merging of data strips from 10 consecutive days.

The VEGETATION S10 syntheses are provided on 10 possible regions of interest. One of these pre-defined regions is ‘‘Europe’’, covering an area with latitudes between 25 N and 75 N, and longitudes between 11 W and 62 E (VITO 2006). All VEGETATION S10 syntheses of Europe were transferred from the free VEGETATION distribution site (VITO 2006). A total of 279 NDVI 10-day synthesis images were thus available, between April 1998 and December 2005. The software CROP VGT (VITO 2006) was used to crop a small section from each of these images, with the region of interest corresponding to continental Portugal (only 404 by 617 pixels). The final image set covers a period of 8 years, from 1998 to 2005, with 36 images each year. Unfortunately there is a lack of data from the first 3 months of 1998.

2.2 *Test site selection*

The CORINE Land Cover (CLC) maps from 2000 were used to select suitable test areas for each wine production region (Painho & Caetano 2005). The vector data was converted to raster files with a 100 meter grid adjusted to the VEGETATION image files, so that each VEGETATION pixel exactly matches 100 of the 100×100m pixels. A land cover class label is assigned to each 100×100 meter cell, using a majority criterion – the predominant class on the CLC2000 vector data. The classes assigned to the 100×100 meter cells are used to estimate the percentage of each land cover class in the 1×1 km pixel corresponding to the VEGETATION data.

Initially, all the 1×1 km pixels with 70% or more of its area occupied by vineyards were selected. There are a large number of pixels that verify this condition, but most are isolated pixels. As the VEGETATION images have a pixel of 1 km^2, and the 10-day synthesis are produced from several images, it is important to select only large contiguous areas, with at least 3×3 km. This process was done manually, by a visual inspection of the image of valid pixels produced with the initial selection criteria. A total of 5 test areas were obtained by this process, with between 18 and 93 pixels each. The location of these test areas is presented in figure 1, two in the Douro region (D1 and D2), one in Estremadura (E), one in Terras do Sado (S) and one in Alentejo (A).

A detailed view of the Douro 1 site is presented in Figure 1. This site has a total of 40 km^2, in two groups of contiguous pixels. The colour scale in the figure corresponds to the fraction of pixel occupied by vineyards. In the Douro 1 site there are 28 pixels with between 95 and 100% of its area occupied by vineyards (70% of the site area), 30 pixels (75% of the area) with over 90% of vineyards and 34 pixels (85% of the area) with over 85% of vineyards. The average vineyards occupancy (f) is 95.3% for this site. The same type of information is presented for the other test sites in table 1. The average vineyards occupancy is above 95% for all sites except Alentejo.

2.3 *NDVI Temporal plots*

The VEGETATION dataset for continental Portugal was used to produce temporal profiles of NDVI for each test site. As each NDVI image is obtained by merging data from 10 consecutive days, the whole site was considered as a unit, instead of using a pixel by pixel approach. This is done to prevent misregistration and other sources of errors to contaminate the temporal profiles. There is still the problem of cloud cover, as occasionally there is no valid data for a full 10-day period for the whole site. An initial

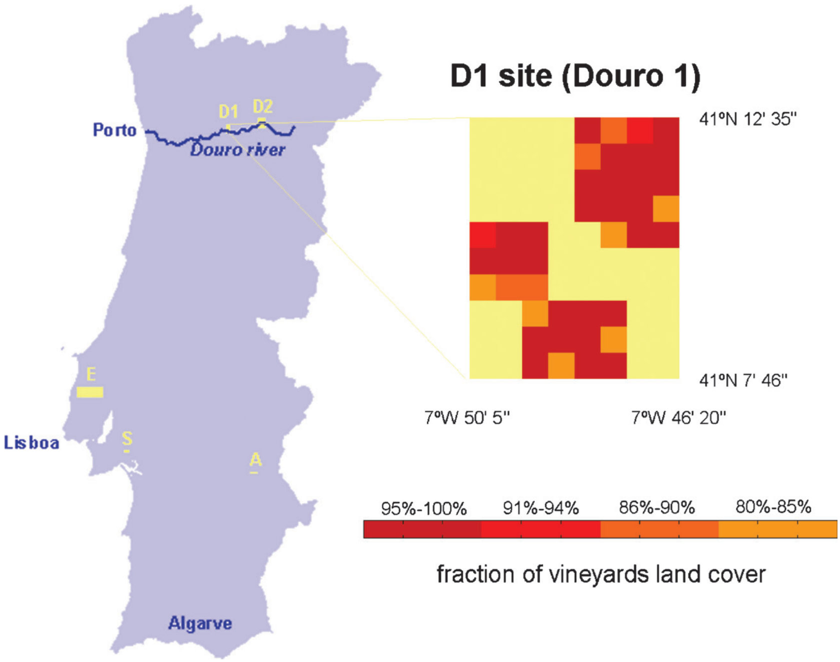

Figure 1. Location of the 5 test sites in continental Portugal, and a detail of the Douro 1 site (D1). Douro region (D1 and D2), Estremadura (E), Terras do Sado (S) and Alentejo (A).

criterion is used to select the valid observation for each image and site. Pixels with NDVI values correspondent to clouds were rejected. The average, standard deviation and 1st quartile values are computed for each image/site, using only the valid pixels.

2.4 *Wine production*

The figures for the regional production of wine are presented in Table 2, for the period 1998–2005, for the 4 regions considered in this work (IVV 2006). The vineyard areas in each of these regions are: 43000 ha for Douro, 26391 ha for Estremadura, 9052 ha for Terras do Sado and 21691 ha for Alentejo.

Table 1. Test site summary (f is the fraction of vineyard land cover in a pixel).

Site #	Site name	# Pixels	<f>	# Pixels (%) f>95%	# Pixels (%) f>90%	# Pixels (%) f>85%
1	Douro 1	40	95.3%	28 (70.0%)	30 (75.0%)	34 (85.0%)
2	Douro 2	18	97.6%	15 (83.3%)	16 (88.9%)	17 (94.4%)
3	Estremadura	93	97.9%	76 (81.7%)	82 (88.2%)	90 (96.8%)
4	Sado	34	96.4%	26 (76.5%)	29 (85.3%)	29 (85.3%)
5	Alentejo	20	91.7%	12 (60.0%)	13 (65.0%)	14 (70.0%)

Table 2. Regional wine production (in hectoliters).

Year	Douro	Estremadura	Terras do Sado	Alentejo
1998	915 430	697 778	200 474	240 829
1999	1 748 523	1 513 533	348 196	496 689
2000	1 512 891	1 305 665	329 404	434 173
2001	1 956 731	1 162 184	262 324	646 422
2002	1 412 142	1 234 546	347 621	594 135
2003	1 726 461	1 125 300	426 611	817 176
2004	1 645 627	1 294 856	373 125	825 709
2005	1 620 000	976 000	295 000	672 000

3 RESULTS

The temporal profiles of NDVI produced for each test site are presented in Figure 2. As described in Section 2.3, these plots were produced for the 1st quartile of NDVI (using only valid pixels). A frequency analysis was performed on the temporal plot of each site, with the results also presented graphically in Figure 2. There is a clear annual frequency (0.083 in the abcissa of the frequency plots) for all test sites and in some cases also a half yearly component (0.167 in the abcissa). For the Douro 1 and 2 sites the annual component is clearly dominant, by a factor of 3 to 5 over all other frequencies. In the Alentejo site there is also a dominant annual frequency, although not as strongly as for

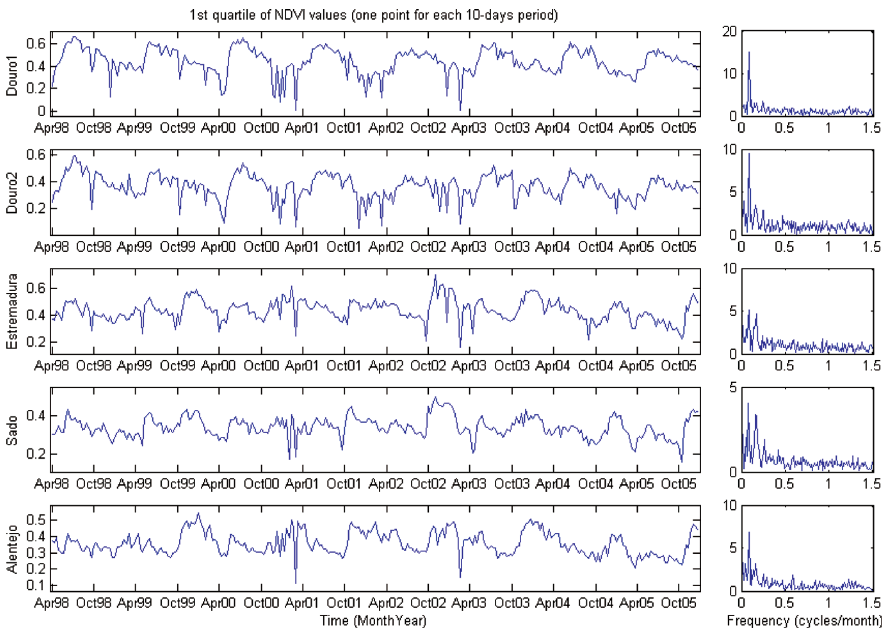

Figure 2. NDVI temporal plots (1st quartile) of the 5 test sites (left) and corresponding frequency plots (right).

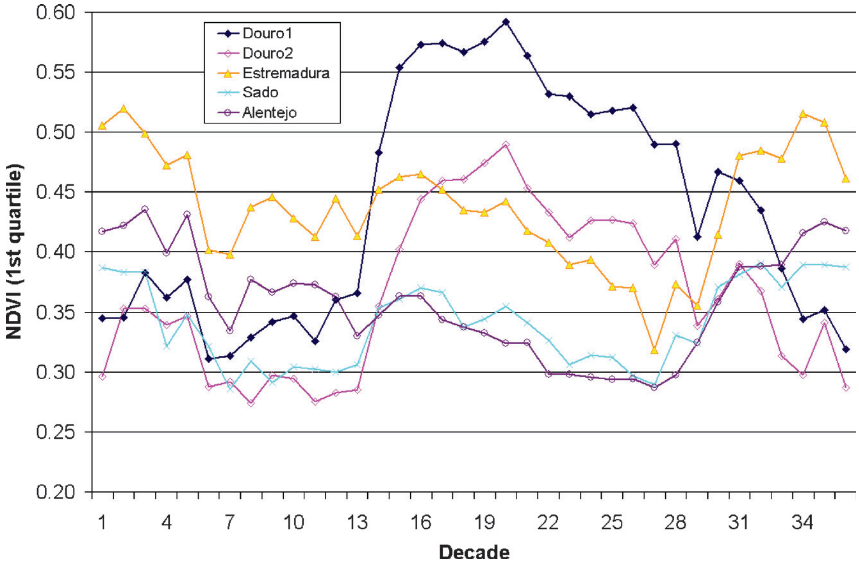

Figure 3. Average NDVI temporal plots (1st quartile) for the 5 test sites (annual average 1998–2005).

the Douro sites. For the Estremadura and Sado sites the annual and half yearly frequency components have about the same magnitude. These results could be explained by the evident continental climate influence in Douro and Alentejo with marked annual thermal contrast and high frequency of water stress in summer. Estremadura and Alentejo are relatively mild temperature, highest annual rainfall and soil water availability.

The average NDVI recorded for each decade (10 days) over the 8 years period (1998–2005) was computed for each test site. The average NDVI for the 9 decades of January to March were computed using only 7 years of data, as no data is available before April 1998. These average values were computed using the 1st quartile NDVI. The average NDVI temporal profiles are presented in figure 3 for the 5 test sites.

The average NDVI temporal plot has a very distinctive shape for the two Douro sites. They have about the same shape but the Douro 1 site has higher NDVI values throughout. This is an expected result, as the Douro 1 site is located about 50 km west of the Douro 2 site and although this is a small distance, the weather is very different on these locations. For example, the amount of rainfall in the western part of the Douro region is about 30 to 40% higher that on the eastern parts. The general shape of the Douro NDVI temporal plots are also very much what could be expected for vineyards. The NDVI has low values during the winter and early spring, with a sharp increase in late spring. The sharp decrease in NDVI value in final winter, which remains until the late spring, could by related with the weed control at the vineyard made during this period. Budbreak in early March marks the beginning of the growing season. The rate of NDVI increment is greatest early in the growing season until the end of May (that coincides with the flowering period) and then steadily decreases. The NDVI values reach a peak in July, slowly decreasing during the rest of the summer. At the beginning of October

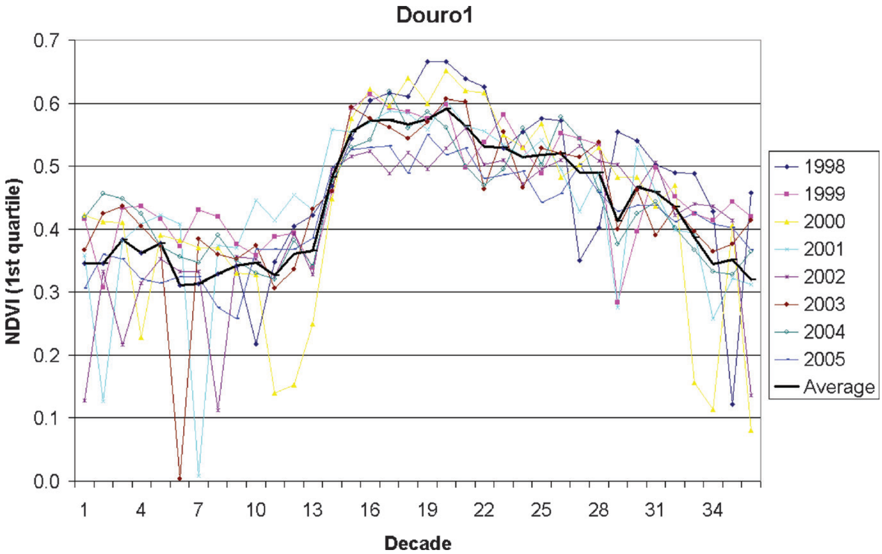

Figure 4. Annual and average NDVI temporal plots (1st quartile) for the Douro 1 site.

(vintage) there is a sharp decrease, followed by a recovery and then a slow decrease for the rest of the year.

The shape of the average NDVI temporal plot for the other 3 test sites is a lot harder to characterise. There is no clear pattern in these temporal plots. There is however a common feature for the 3 sites: a slow decrease in NDVI during the summer and an increase in the autumn. The reasons for this behaviour are not yet understood and are therefore a matter for further investigation.

The NDVI temporal plots for the Douro 1 site are presented in more detail in Figure 4. The average NDVI profile is presented together with each year profile. The figures of wine production for the Douro region, available in Table 2, show that 1998 was an extremely bad year and 2002 and 2000 were also years of low production. The best year in the 1998–2005 period was 2001, followed by 1999 and 2003. An inspection of the plots in figure 4 shows that the NDVI values in 1998 are very high during the summer, which is also the case for 2000. Another interesting feature in these plots is that the years with higher production tend to have higher NDVI values during winter and early spring than the other years, as is the case for 1999 and 2001. Unfortunately there is no data for this period for the 1998 year, which is clearly the worst in terms of wine production. A correlation analysis should be able to provide more meaningful information, but this can only be done after smoothing the temporal plots.

4 CONCLUSIONS

An experiment was carried out to evaluate the potential of VEGETATION data to characterise and monitor vineyards in Portugal. NDVI images from the VEGETATION sensor were used to produce temporal plots, from 1998 to 2005 (36 images each year), for 5 test sites located in 4 different regions: Douro (2 sites), Estremadura, Terras do Sado and Alentejo.

A frequency analysis of the NDVI temporal plots was carried out. As expected there is clearly a strong annual frequency component for all test sites, which for both Douro sites clearly dominant (by a factor of 3 to 5 over all other frequencies). For the Estremadura and Sado sites there is a half yearly component of about the same magnitude as the annual component, which at this moment is not fully understood.

The average NDVI temporal plots were also produced for each site. The Douro sites have a very distinctive shape following what could be expected for vineyards phenology. The NDVI temporal plots of the other sites have uncharacteristic shapes which can not be explained at this stage of the work. An analysis of the yearly NDVI plots for the Douro region suggests that the NDVI values at the early months of the year might be correlated with the amount of production. This is a matter for further investigation in the near future.

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