GeoInformation in Europe, M.A. Gomarsca (ed.)
 ISBN 9789059660618

Vineyard monitoring in Portugal using multi-sensor satellite images

André R.S. Marçal & Mário Cunha
Faculdade de Ciências, Universidade do Porto, Porto, Portugal

Keywords: vineyards, vegetation indices, NDVI, Chris Proba, SPOT

ABSTRACT: In the past few years a number of examples of remote sensing data applied for viticulture have been reported in the literature. Although most cases are based on airborne data, there are some examples where satellite images have been used for mapping and monitoring vineyards, mostly in places where the vineyard areas are extensive. A practical evaluation of the applicability of satellite remote sensing data to a test site with small vineyard parcels was carried out using SPOT and Chris Proba images. The typical results possible under these conditions are presented and the main limitations are briefly discussed.

1 INTRODUCTION

Winegrowers known that grapes from different areas in the vineyard can produce different fruit characteristics, maturity, and resulting wines with different flavours, even when grape variety and vineyard management are identical (Smart 1985). Traditionally, farmers have ignored this natural variation in their fields and have applied the same treatment across the whole area. To be fair, they did not have access to tools that would let them be more sophisticated, but affordable technologies have been developed that now permit farmers to make accurate maps of this variation and then manage fields accordingly.

Remote sensing, along with other tools such as differential global positioning systems (dGPS) and geographical information systems (GIS), promotes the capacity for grape and wine producers to acquire detailed geo-referenced information about vineyard performance and can help of both grapes and wine according to expectations of vineyard performance, and desired goals in terms of yield, quality and the environment (Aho 2002).

In the past few years a number of examples of remote sensing data applied for viticulture have been reported in the literature (Hall *et al.* 2002). Although most cases are based on airborne data, there are some examples where satellite images have been used for mapping and monitoring vineyards, mostly in places where the vineyard areas are extensive. Various wine grape growers in California's Napa Valley and greater North Coast region are using digital, multispectral imagery to monitor vineyard variability for purposes such as harvest preparation, differential (or segmented) harvest, vineyard re-development and identification of problems related to irrigation, nutrient status, disease and pest infestation (Penn 1999, Carothers 2000, Aho 2002). The primary interest to growers appears to be the mapping of vigour within and across blocks (Hall *et al*. 2002, Johnson *et al*. 2003). Thus, the images currently supplied often focus on indices of plant growth such as Normalised Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI), Triangular Vegetation Index (TVI) Relative Vigour Index (RVI), Plant Cell Density Ratio (PCD or PCR), Photosynthetic Vigour Ratio (PVR), Plant Pigment Ratio (PPR) or some proprietary index based on the response in the red and near infrared regions of the electro-magnetic spectrum. Vine vigour is of interest to the grower as differences in vigour are often influenced by variable environmental conditions and can produce variability in the quality and quantity of production (Smart 1985).

The purpose of this work was to evaluate the ability of satellite remote sensing data to provide meaningful information about small vineyard parcels, such as those present in the Mediterranean countries.

2 MATERIALS AND METHODS

The use of satellite images for vineyard monitoring is somehow limited due to spatial and temporal resolution constrains. Only high spatial resolution images can be used due to the relatively small size of the vineyard parcels. However, very high resolution images are expensive and are not acquired frequently enough during the period of interest, which are mostly the spring and summer months. In this particular experiment, images from 2 satellite sensors were used: SPOT 5 – HRG (10 m pixel) and Chris Proba (17 m pixel).

2.1 *Test site*

A test site with about 40 ha of vineyards was established near Ponte da Barca, northwest Portugal (Lat. 41.8 N, Long. 8.42 W). Figure 1 shows a true-colour ortho-photograph of

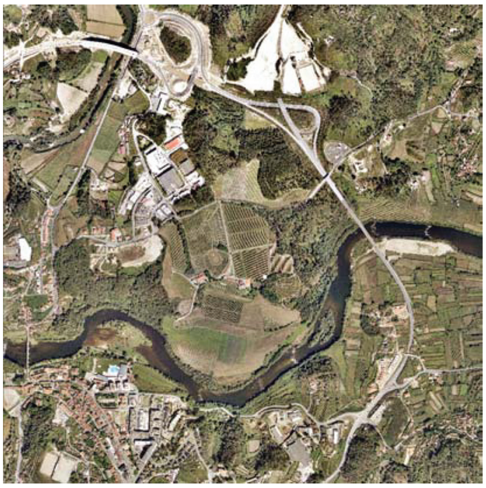

Figure 1. True colour orto-photograph of the test area.

the region, covering an area of 2.1 by 2.1 km, with a pixel size of 0.35 m. The test site is located in the centre of this image.

Individual vineyard parcels were identified on the full resolution ortho-photograph, which were later degraded to 5 m resolution bitmaps. Figure 2 shows the 11 vineyard parcel bitmaps used. The size of the parcels is on average 1.00 ha (between 0.35 to 2.06 ha), which corresponds to 401 pixels of 5×5 m (140 to 822), 100 pixels of 10×10 m (35 to 205) and 35 pixels of 17×17 m (12 to 71).

2.2 *Satellite images*

The SPOT satellite archive was searched for images of the test site. Although SPOT images are available since 1986, the SPOT 5 satellite is only available since 2002. The resolution of the multi-spectral images from SPOT 1–4 is only 20 m, while for SPOT 5 it is 10 m. A total of 9 SPOT 5 multi-spectral images were selected, from 2002, 2003 and 2005. Four Chris Proba images were also made available, all from 2006. A summary of the dates and other characteristics of the image used is presented in Table 1.

The SPOT images cover a large area (60 by 60 km) with 4 spectral bands in the visible and near infrared. The Chris Proba images are 766 columns by 748 lines, with 18 bands (Mode 3). Although multiple acquisitions were made available (5 angles), only the vertical view image was used. The 18 narrow bands cover the spectral range from 438–1044 nm (visible and near infrared).

2.3 *Image pre-processing*

Both the SPOT and Chris Proba images were calibrated to radiance, using the calibration parameters provided by the data providers. The radiance values were then converted to

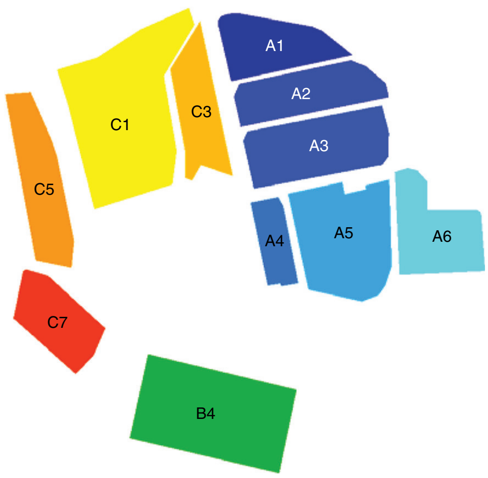

Figure 2. Vineyard parcels in the test area.

Table 1. Summary of the satellite images used (ZA-Zenith Angle).

Satellite / Sensor	ID	Date	Incidence ZA	Solar ZA
SPOT 5 – HRG 1	S1	31 July 2002	28.2	25.0
SPOT 5 – HRG 2	S2	11 September 2002	16.1	38.1
SPOT 5 – HRG 2	S3	3 May 2003	16.5	27.9
SPOT 5 – HRG 1	S4	10 July 2003	4.7	22.9
SPOT 5 – HRG 1	S5	20 August 2003	23.4	30.5
SPOT 5 – HRG 1	S6	16 September 2003	6.2	40.8
SPOT 5 – HRG 2	S7	5 June 2005	29.7	20.8
SPOT 5 – HRG 1	S8	17 June 2005	19.6	23.9
SPOT 5 – HRG 1	S9	2 September 2005	8.9	35.6
Chris Proba (Mode 3)	CP1	11 April 2006	4.66	35.0
Chris Proba (Mode 3)	CP2	28 April 2006	3.58	30.0
Chris Proba (Mode 3)	CP3	24 May 2006	6.21	23.0
Chris Proba (Mode 3)	CP4	5 September 2006	21.93	37.0

reflectance values, using the incidence and solar zenith angles for each image (Table 1), and the extraterrestrial solar irradiance for each band.

The georeferenced image used covers an area of 1.5 by 1.5 km, which is only 300 by 300 pixels of 5×5 m. Ground Control Points (GCPs) were manually identified on the satellite images, using the ortho-photograph of Figure 1 as the source for ground coordinates. Between 7 and 8 GCPs were identified on each SPOT and Chris Proba image. First order polynomial transformation functions were established for each image. The final georeferenced images were produced using bi-linear resampling.

As an illustration of the final calibrated and geometrically corrected images, Figures 3 and 4 present RGB colour composites of the images obtained from SPOT and Chris Proba data. These images are RGB colour composites of the red, near infrared and green bands. The superior spatial resolution of SPOT images is clearly noticeable from these Figures.

2.4 *NDVI computation*

The computation of NDVI from SPOT images is straightforward, once the images are properly calibrated, as there is a band corresponding to the near infrared (Band 3) and one band to the Red (Band 2). For the Chris Proba data, there are several narrow bands in the red and near infrared regions. One possible choice would be to use Chris Proba bands 7 (662 nm) and 15 (874 nm). However, a more useful approach is to simulate other satellite sensors response using the available Chris Proba narrow bands. This was done for ASTER, SPOT 4, SPOT 5, Landsat 5, Landsat 7, AVHRR and VEGETATION. The Spectral correspondence between Chris Proba and these 7 satellite sensors is presented in Table 2. The values presented correspond to the fraction of the Normalised Response Function (NRF) covered by the Chris Proba bands. Using this information, it is possible to compute SPOT simulated NDVI using Chris Proba data, as well as simulated NDVI for the other sensors based on the same Chris Proba data.

Table 2. Spectral correspondence between Chris Proba and other satellite sensors (% of NRF).

Chris Band	ASTER		SPOT 4		SPOT 5		Landsat 7		Landsat 5		Vegetation		AVHRR	
	RED	NIR	RED	NIR	RED	NIR	RED	NIR	RED	NIR	RED	NIR	RED	NIR
6	22.2		28.2		31.5		24.6		24.9		24.4		0.1	
7	46.2		37.5		38.0		42.3		39.1		32.5		61.5	
8	18.9		22.2		22.1		30.1		29.4		22.8	0.2	38.0	0.0
9	9.9		8.5		6.4		3.1		6.6		13.1	3.9	0.4	0.1
10	2.3		2.1		1.2						3.9	4.2	0.0	0.4
11	0.5		1.5		0.6						2.7	6.1		1.1
12		5.4		0.5	0.0					0.3	0.5	25.9		10.7
13		13.2		1.0		0.1		0.4		0.5	0.1	13.8		6.6
14		67.7		33.2		23.7		34.3		29.3		44.4		24.0
15		13.2		45.2		61.5		47.7		42.8		1.3		28.5
16		0.5		16.4		13.0		17.6		25.3		0.2		19.4
17				3.7		1.7				1.7				8.6
18														0.5

3 RESULTS

A sample of the results produced using the satellite data processed is presented here. The purpose of this is to illustrate the typical results that can be expected from satellite data, and to identify the potentials and limitations of Chris Proba and SPOT data for this type of vineyards.

The first result is a spectral plot of the average reflectance for the individual vineyard parcels. Figure 5 shows 5 of these plots for images CP2 (left) and CP4 (right), where the x-axis displays the Chris Proba spectral band 1–18, corresponding to 438–1044 nm. The spectral profiles of the 5 parcels are very similar for the September image, but there are considerable differences on the image from April.

The individual NDVI images, both from SPOT and Chris Proba sensors, were used to compute a number of parameters for each vineyard parcel. The minimum, maximum, average, standard deviation and median NDVI values were computed for each parcel and image. These values can be used to produce temporal plots in a variety of ways. For example, the NDVI images produced from Chris Proba data, simulated for SPOT 5 spectral response, were used to produce the parcel plots in Figure 6. The values presented are the median NDVI value for each parcel /date, but the results are very similar to those obtained using the average parcel values. The plot clearly shows differences in the temporal evolution of the NDVI values for the different parcels. These differences can also be identified in the RGB colour images of Figure 4. However, the fact that there are only 4 observations for a period of nearly 5 months is a strong limiting factor. Another illustration of the type of results possible using satellite based NDVI images is presented in Figure 7. The temporal profiles were produced using the 9 SPOT images from 3 years. In this case the NDVI values presented are the combined average in

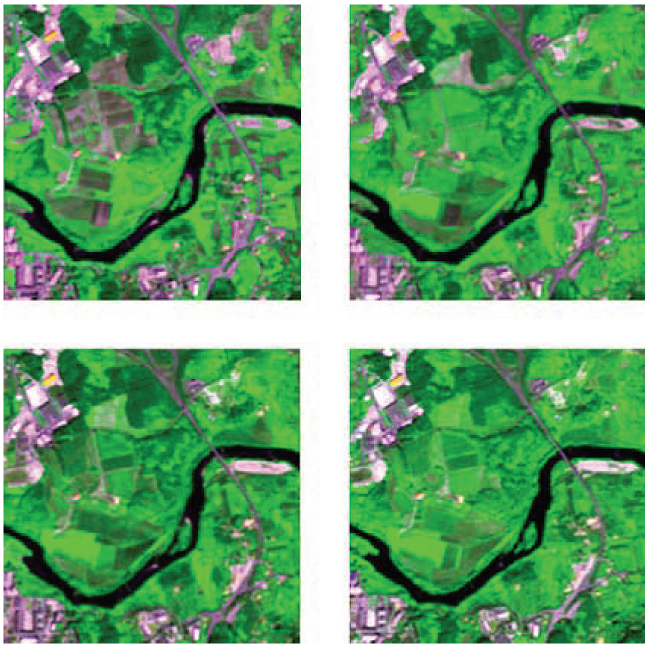

Figure 3. SPOT images S3, S4, S5, S6 (RGB 231).

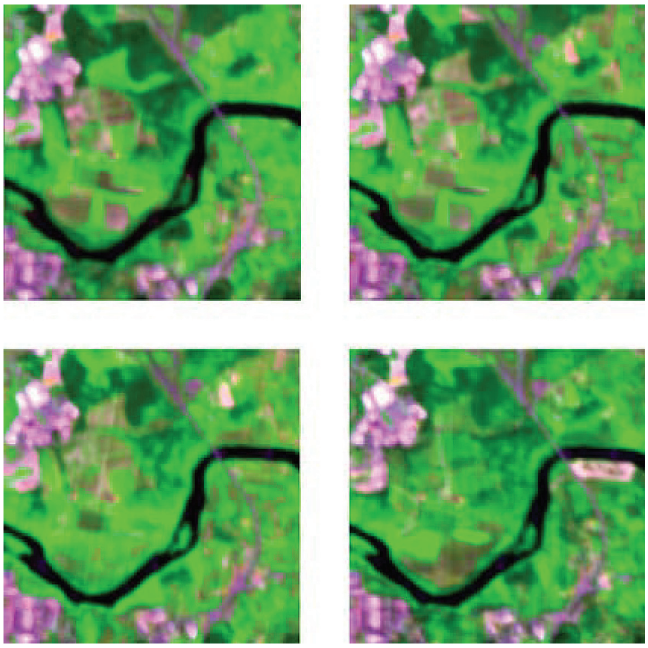

Figure 4. Chris images CP1-CP4 (RGB 7-15-1).

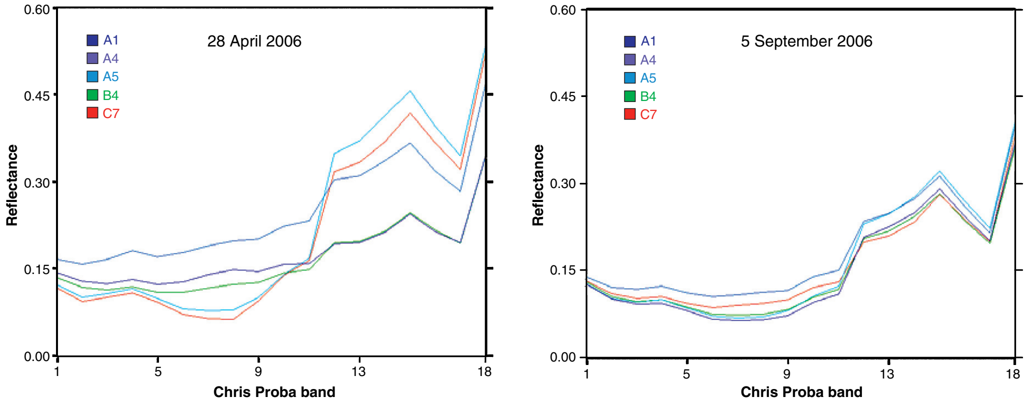

Figure 5. Spectral profiles for 5 vineyard parcels produced from Chris Proba images 2 (left) and 4 (right).

agreement with the parcels slope: flat parcels A (left) and all slope parcels C (right). Although there are noticeable differences from the various plots, the most noticeable feature is the lack of temporal resolution provided. The NDVI profiles of the 2 parcels are very similar, but the C parcels present lower values of NDVI overcoat during the final growing season.

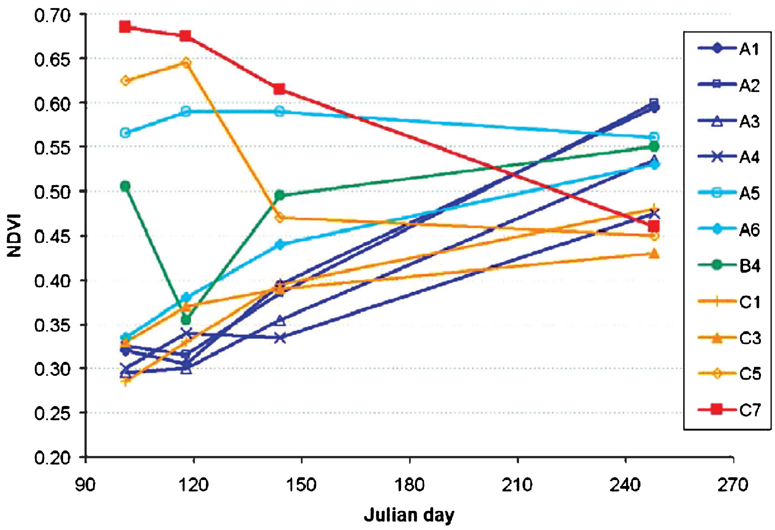

Figure 6. NDVI plots for the vineyard parcels, produced from Chris Proba data (median NDVI simulated for SPOT 5 spectral response).

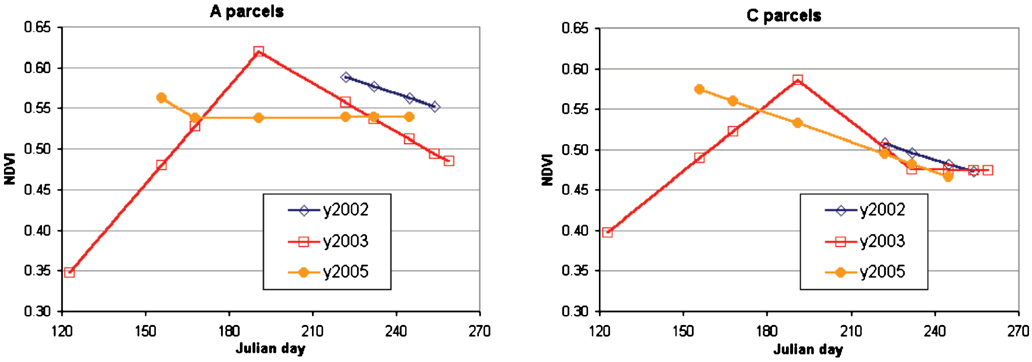

Figure 7. NDVI plots for the vineyard parcels A and C produced from SPOT data.

4 CONCLUSIONS

A practical evaluation of the applicability of satellite remote sensing images to provide mean-ingful information about small size vineyard parcels was carried out. Data from Chris Proba satel-lite sensors and SPOT 5 were used. The experiments seem to suggest that these sensors can provide useful information about vineyards, with adequate spectral and spatial resolution, but there is clearly a lack of temporal resolution. The ability to estimate and map leaf area index across vine-yard from remote sensing at regular intervals during the growing season has not yet been fully ex-ploited. Further work is required in order to relate the information extracted from the satellite im-ages with the existing field measurements of leaf area index as well as information about the impact of disease, crop quantity, fruit characteristics and wine quality. The differences in the tem-poral evolution of the NDVI values for the different parcels are an opportunity for site-specific management decisions to improve the efficacy and profitability of production.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. Teresa Mota of Comissão de Viticultura da Região dos Vinhos Verdes for her input and assistance in the test site used. The Chris Proba data was provided by the European Space Agency and the SPOT data by the OASIS programme/ CNES. This work was supported by "Centro de Investigação em Ciências Geo-Espaciais", financed by FCT, POCTI/FEDER.

REFERENCES

Aho, J.E. 2002. NASA providing new perspectives on vineyard management. *Vineyard Winery Manage* 28 (4) 74–77.

Carothers, J. 2000. Imagery technology meets vineyard management. *Practical Winery and Vineyard* May/June: 54–62.

Hall, A., Lamb, D.W., Holzapfel, B. & Louis, J. 2002. Optical remote sensing applications in viticulture - a review, *Australian Journal of Grape and Wine Research* 8, 36–47.

Johnson, L.F., Roczen, D.E., Youkhana, S.K., Nemani, R.R. & Bosch, D.F. 2003. Mapping vineyard leaf area with multispectral satellite imagery, *Computers and Electronics in Agriculture* 38, 33–44.

Penn, C. 1999. Grape growers gravitating toward space age technologies. *Wine Business Mon* 6 (2) 53–56.

Smart, R. E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. *American Journal of Enology and Viticulture* 36, 230–239.