APPLICATION OF REMOTE SENSING TECHNIQUES TO DISCRIMINATE BETWEEN CONVENTIONAL AND ORGANIC VINEYARDS IN THE LOIRE VALLEY, FRANCE

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Abstract

Aim: To test the use of Remote Sensing imagery and techniques to differentiate between conventional and organic vineyards.

Methods and results: Conventional and organic vineyards were identified on three satellite images acquired by the ASTER sensor of the Loire Valley. A sample of 46 conventional and 12 organic plots was used; grape varieties were Chenin Blanc (33 plots) and Cabernet Franc (25 plots). Mean reflectances were extracted from pixels inside each plot for the nine spectral bands (visible and infrared) of ASTER. A statistical discriminant analysis was performed. The vegetation index NDVI was also analysed. Results showed that all 12 organic plots, and 41 out of 46 conventional plots were correctly separated, a 91.4% success rate. Also, 23 out of 25 Cabernet, and 30 out of 33 Chenin plots were also correctly identified, also a 91.4% success rate. Regarding NDVI, there are no differences between conventional and organic vineyards within a 5% significant level. Analyses focused on the influences of chemical treatments on vineyard colors and on the effects of light reflected by inter-row spaces, suggested that both processes introduce spectral changes in conventional vineyards, mainly in short-wave infrared. Results also indicate that infrared information is essential to spectral discrimination.

Conclusion: The use of chemicals, typical to conventional viticulture, has an impact on leaf composition and cell structure, being an important factor to imprint a characteristic reflectance pattern to these vineyards; the contribution to the integrated reflectance from inter-row vegetation is probably also a differentiating factor. Both causes act synergistically to build a significant spectral difference between conventional and organic vineyards.

Significance and impact of the study: Remote Sensing techniques can be used as a first approach to vineyard monitoring, producing relevant information on viticultural methods, which can be used as early indicators of the need for field inspection or conventional laboratory analysis.

Key words: organic viticulture, remote sensing, leaf reflectance, satellite images

Résumé

Objectif : Vérifier l'utilisation de données et techniques de télédétection pour différencier les vignobles conventionnels des vignobles biologiques.

Méthodes et résultats : 58 vignobles conventionnels et biologiques ont été identifiés sur trois images satellites acquises par le capteur ASTER sur la Vallée de la Loire. Sur l'échantillon, 46 parcelles étaient en viticulture conventionnelle et 12 en viticulture biologique ; les cépages étaient le Chenin blanc (33 parcelles) et le Cabernet Franc (25 parcelles). Sur ces images, la réflectance moyenne a été calculée pour l'ensemble des pixels de chaque parcelle, pour neuf longueurs d'onde (visible et infrarouge). Une analyse statistique discriminante a été faite. L'indice de végétation NDVI a aussi été étudié. Les résultats ont montré que la totalité des 12 parcelles biologiques, et 41 des 46 parcelles conventionnelles ont été séparées correctement (taux de réussite de 91,4%). Pour la séparation des cépages, 23 parcelles de Cabernet et 30 parcelles de Chenin ont été séparées correctement, soit encore un taux de réussite de 91,4%. L'analyse statistique de NDVI a montré qu'il n'y a pas de différence significative entre les deux groupes. Les analyses de l'influence des traitements chimiques sur les couleurs de la vigne et des effets de la lumière reflétée par les espaces entre les rangs ont indiqué que ces processus ont un rôle dans l'altération spectrale des vignobles conventionnels, et que l'infrarouge est essentiel pour la séparation spectrale.

Conclusion : L'utilisation de produits chimiques, typique de la viticulture conventionnelle, a un effet sur la composition de la feuille et sur la structure de la cellule, facteur important dans la formation d'une distribution spectrale caractéristique pour ces vignobles ; néanmoins, la contribution de la réflectance intégrée en provenance de la végétation entre les rangs est aussi probablement un facteur de différence.

Signification et impact de l'étude : Les techniques de télédétection constituent une première approche pour le contrôle des vignobles, en produisant des informations pertinentes sur les méthodes de production. Ces techniques peuvent être utiles comme source d'information initiale, indiquant le besoin d'études plus détaillées au champ ou au laboratoire.

Mots clés : viticulture biologique, télédétection, réflectance, images satellite

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INTRODUCTION

Viticultural methods based on eco-friendly approaches have been in steady expansion in the last decades (Brodt et al 2009) and are presently regulated by several organizations, either governmental (EEC 1991; DPI 2010; USDA 2013 and references therein) or private (Ecocert, Qualité France, and others). These methods and their products carry denominations like "biological", "organic", or "biodynamic"; in this paper we will refer to them as "organic". Researches on wine consumers' preferences reveal a growing interest for organic products (Mollá-Bauzá et al 2005; Jonis et al 2008; Remaud et al 2008). However, the certification procedures are complex and, once a producer is certified, periodical checking is necessary to ensure continuity of compliance to regulations. There are no viticultural regions in the world where all vineyards are organic, and the spatial mixing of conventional and organic vine plots adds logistical problems to an already complex verification system.

Certification rules are strict, precise, and fundamental for granting the organic or biodynamic status, but some preliminary information can be helpful to monitoring the current situation of vineyards, either organic or else. Specifically, this paper reports how Remote Sensing techniques can be a complementary source of information, being used as an independent indicator of viticultural methods and as an early indicator of the need for field inspection.

For the purposes of this paper, we will state that the basic information from Remote Sensing is the solar radiation reflected from the terrain, and in this case, the solar spectrum is altered by the nature of reflecting objects, which can be soil, vegetation, water, and other "classes". Specific classes have quite different reflectance spectra (Swain and Davis 1978; Lillesand and Kiefer 1987), and even within a class, sub-classes carry characteristic spectra, making reliable identifications possible. This happens, for example, with vegetation reflectance spectra, and for vineyards it was demonstrated that they can be separated from other vegetation (Da Silva and Ducati 2009), while in another study, positive identifications of grape varieties were reported (Cemin and Ducati 2011).

This paper was motivated by oral reports from organic vintners in the Loire Valley, made to the first author while in field trips in the region, stating that they could see by the naked eye the color differences between their vineyards and the neighboring conventional vineyards. Presently, this paper investigates this possibility, extending the spectral range to the infrared, using Remote Sensing techniques, being focused on vineyards, either conventional or organic, in the Loire Valley.

If we accept that some viticultural practices (pruning, training systems, etc) are similar for both conventional and organic vineyards, then the differences between these systems will be due, basically, to two factors: chemical treatments and soil cover. They can act in an individual way or in a combined, synergic way. Since this study aims to assess the capability of Remote Sensing techniques to, through the use of satellite images, reveal significant spectral differences between the two methods, we have adopted the following line of action: first, we study how chemical treatments and soil cover can influence the reflectance of a typical pixel in a digital image; and then, with the perceptions gained from the first, preliminary study, we apply analytical methods on digital images to verify if vineyards from the two systems are effectively separated.

1. The light reflected from a vineyard

1.1. Light reflection by vegetation

Light reflection by vegetation is a process that takes place essentially in plant leaves. It is modulated by the wavelength involved, being dominated by leaf pigments in visible light, by cell structure at near-infrared wavelengths, and by water contained in plant tissues at mid infrared wavelengths (Swain and Davis 1978). With this knowledge, we can gain the insight that the reflecting behavior of a vine leaf can be altered, in some measure, if the plant is subjected to the treatments that are usual in conventional viticulture. If there are spectral alterations, and how much, is difficult to detect and assess, but some information can be found in the literature. For example, Tan et al (2012) report that the use of the herbicide acetochlor changes pigment content, chlorophyll fluorescence and chloroplast structure in vine leaves. In another study, Saladin et al (2003) report that the herbicide flumioxazin changes foliar chlorophyll and carotenoid contents in grapevine. These same authors also report that the herbicide flazasulfuron changes leaf color and photosynthetic pigment concentrations (Magné et al 2006). Therefore, the effects of herbicides on vine colors are quite real. The effects of fungicides on optical properties are less clear, apart from the obvious fact that, in most climates and for the majority of grape varieties, without fungicide, the plant goes sick, and in excess, it goes sick as well; both conditions induce changes in leaf color. The personal experience of the first author also tells that vines intensely treated with fungicides tend to develop thicker leaves. The effect of fertilizers on leaf reflectance was seldom reported; for N, it seems that the amount of product used, more than its origin or application method, is important to canopy volume and thickness, and this can affect the overall vineyard reflectance by blocking reflection from the soil. For K and P the matter is less clear.

From the above considerations, it is clear that the usual chemical treatments, common to conventional viticulture, are prone to induce alterations in the reflectance of grape leaves. Conversely, organic viticultural practices use few treatments, if any, and so the effects on vine leaves tend to be small. Therefore, the question is if there are systematic reflectance alterations, both in the optical and/or infrared spectral ranges, large enough to be detected, and not contaminated by other processes.

1.2. Components of reflected light: inter-row contribution

We have argued that conventional and organic vines can have different spectral behavior, for chemical reasons. That is quite possible, but since the proposition here is to apply Remote Sensing techniques to detect these differences, we have to keep in mind the fact that these viticultural methods possibly have, by their nature, another and perhaps deeper difference, arising from the fact that inter-row ground covers can be different. If we accept that conventional vineyards have their inter-row spaces paved by bare soil, due to the use of herbicides, then, in a Remote Sensing measurement, which is pixel-based, the overall reflectance of these vineyards will be, in a typical pixel, a spectral mixture of soil and vine leaves, being intrinsically different from that in a pixel imaged from a organic vineyard, which would be of vine leaves and inter-row vegetation. This counter-argument could explain an eventual spectral difference between conventional and organic vineyards, independently of the hypothesis of chemical factors. Therefore, the contribution of light reflected by the terrain between vines has to be studied.

We will start with considerations on how the total reflected light from a vineyard is built up. If a vineyard is grown in the pergola training system, the ground surface is entirely covered by vine leaves, and light reflection happens from this sole component, the vine. In these conditions, in a digital image acquired by a remote sensor (satellite, airplane) there is no spectral contamination from other features (soil, other vegetation) and the problem is quite simplified. However, in many vineyards, plants are trained in rows, and between vines there are corridors of exposed soil where other vegetation can grow. Therefore, unless the pixel size in an image is very small (at a scale of centimeters), in any pixel the reflected light is a mixture of the reflection by grape leaves, soil (if not covered), and grasses and other plant species that develop between vine rows.

What happens in the spaces between vine rows varies. In some arid regions, the soil is naturally bare, and its contribution to total reflectance can be important. However, this is not the case in the relatively humid Loire Valley. It was already said that in some conventional vineyards, inter-row soil is kept bare by the use of herbicides, but, in many cases, regardless of conventional or organic, and for environmental or practical reasons, these corridors are kept covered by low vegetation; this is the case for most of the vineyards in the Loire region, where even those labeled as "conventional" tend to adhere, in some degree, to the so-called "viticulture raisonnée". This fact was observed in our field trips. Furthermore, the use of herbicides in conventional viticulture is most often made on the soil positioned directly under the vines, for several reasons which, for the sake of brevity, will not be discussed here; therefore, if some soil is exposed, it tends to be the one which has its view blocked by the vine canopy, from the observing position of a satellite which will collect an image. Here, it is important to note that most satellites acquire data at zenithal passing and do not gather data from soil under vines. This reasoning would make the inter-row effects weaker, as discussed in more detail below.

1.3. Effects from inter-row shadowing

Even if the bare soil component in reflectance is reduced, a spectral mixture of the reflectance by vine leaves and inter-row vegetation can happen. However, the effect of shadowing has to be taken into account. This arises from the fact that vines in rows grow up to a certain height, and rows are separated by a certain distance; therefore, sunlight, if not coming from the zenith, can be prevented to illuminate the soil between rows, due to blocking by a wall of vines. It is important to note that this effect arises from a geometrical configuration and is distinct from the shadowing effect arising from clouds interposed between Sun and ground; this later phenomenon is of a different nature and will be discussed later. Both effects, by reducing the total illumination on the ground, also reduce its radiance and then its reflectance by an amount to be discussed in this paper. For the geometrical shadow effect, the proportion P of the inter-row surface that is shadowed by a continuous wall of vines is :

$$P = (h/d) * \tan z * |\sin a| \quad (1)$$

where h is the row height, d is the distance between rows, z is the Sun's zenithal distance at a given moment, and a is the lateral illumination angle at the same time, that is, a is the angle between the orientation of a given row and the solar azimuth. Here, the angle *a* modulates the shadow's length because when $a = 0°$, the row is oriented towards the Sun and the inter-row soil is entirely illuminated. In equation (1), the proportion *P* assumes values between 0 and 1, the value 1 corresponding to the whole area between vine rows being in total shadow.

To assess the importance of geometrical shadows on reflectance, we have to take into account two factors:

a) the actual values of *P* for the considered vineyards;

b) the quantitative influence of inter-row shadowing effects on the overall reflectance of a real vineyard.

Besides estimating the importance of geometrical shadow, and for a better understanding of the process, and also for the sake of completeness, we will estimate the effect of cloud shadowing on the reflectance of vegetation. In both cases, we have to keep in mind the fact that, due to diffuse and/or scattered light in Earth's atmosphere, regions in shadow are not in complete darkness, but are embedded in a non-negligible amount of radiation, either in visible or infrared wavelengths. These points will be further developed in Materials and Methods. We also want to stress the fact that this preliminary study on shadow effects will be conducted using satellite images, and thus will be based on the same tools used to study the reflectance of vineyards.

MATERIALS AND METHODS

1. Data

Information on Loire vineyards was kindly supplied by the Cellule Terroirs Viticoles of the Institut National de la Recherche Agronomique (CTV/INRA) of Angers, France. The data were a relation of vine plots with inventory information for each plot on surface, age, distance between rows and plants and, crucial for this study, viticultural method (conventional or organic) and grape variety (Cabernet Franc or Chenin Blanc). Every vineyard had an associated gmz file that allowed its visualization on Internet map servers. In addition to these vineyards, we added three plots from Coulée de Serrant, a well-known biodynamic estate where the grape variety is Chenin Blanc. The final databank had 58 vine plots: 46 in conventional viticulture and 12 in organic. Cabernet Franc was present in 25 vineyards (four organic) and Chenin Blanc in 33 (eight organic). These vine plots were located on an approximate east-west axis, about 67 km long, along the Loire River : for Chenin Blanc, they were between Chaume (east) and Saint-Martin-le-Beau (west) and for Cabernet Franc, between Mozé-sur-Louet (east) and Restigné (west).

Satellite images were acquired through the Reverb Echo service (NASA 2013), under an educational project submitted by the authors and approved by NASA. The choice was for multispectral images from ASTER (Advanced Spaceborne Thermal Emission and Reflection) sensor, which is an imager aboard Terra satellite. This was motivated by the fact that ASTER images provide reflectance data in nine wavelengths, from the visible to the short-wave infrared (Abrams et al 2002), bringing improved resources for image classification. Pixel size is 15 meters (225 m^2) at the three visible and near-infrared bands (VNIR – Visible and Near InfraRed subsystem) and 30 meters (900 m^2) for the six bands at mid infrared (SWIR – Short Wave InfraRed subsystem). More information on spectral bands is given in Table 1, along with some results. For the prime objective of this study, image dates were: 24 July 2001, 29 August 2005, and 29 April 2007; these cloudless images picture the Loire regions where the vineyards in the databank provided by INRA were.

For the preliminary study on the shadowing effects caused by cloud obscuration, an image of the Loire region with scattered clouds was acquired, dated 14 September 2005. For the analysis on effects by geometrical shadows, the Loire region is not suited, since it lacks the rugged relief necessary to produce shadows from high elevations at the time of satellite overpass, which is around 10h30 A.M. local time. The image, in this case, was of a vegetated sierra zone in Rio Grande do Sul State, Brazil, and is dated 22 April 2006. All images were of L1B level, meaning that the standard geometrical and radiometric treatments were already done by satellite management.

2. Image treatment

All ASTER images underwent a correction for atmospheric absorption, through the MODTRANS algorithm developed by Berk et al (2006). This was done simultaneously with the resampling of all six SWIR bands from their original pixel size of 30 meters to a 15-meter size, in order to match the VNIR pixel size, and thus rendering possible the atmospheric correction. The use of resampling techniques towards higher resolutions (from 30 m to 15 m) was discussed by Da Silva and Ducati (2009) and by Bombassaro and Ducati (2013). These treatments resulted in a set of images where the information, at pixel level, is the reflectance value for each one of the nine spectral bands.

3. Row orientations and shadows

The use of equation (1) supposes knowledge of *a*, the lateral illumination angle. The information on row orientation is incomplete at the original databank provided by CTV/INRA, and therefore we looked for this on an Internet map server. It turned out that actual orientations vary widely across vineyards in both viticultural methods; in fact, many plots were composed of smaller areas with several different orientations. Either in conventional or organic plots, there was a clear preference (37 plots over 58) for orientations exceeding 45º, for which sin *a* is 0.7 or higher; this indicates, in the sample, a tendency towards longer shadow lengths. Only nine parcels were oriented in such a way that inter-row spaces were almost fully illuminated at the moment of image acquisition. Applying equation (1) for a typical Loire Valley vineyard in our sample, where *h* averages 140 cm, the distance *d* between rows averages 200 cm, and the zenithal distance *z*, for the mean date and time of images, averages 38º, we have $P = 0.56 * |\sin a|$; therefore, for the majority of the study plots, *P* is 0.4 or greater, and for the whole databank we assumed that the soil between rows was 40% in shadow.

4. Tracing of regions of interest (ROIs) in ASTER images

The ROIs were, for the preliminary study on shadow effects by clouds, pairs of areas on the terrain which, on the chosen image, were shadowed by a large cloud, and nearby regions, fully illuminated by sunlight. Both areas were similarly vegetated, and we selected four such pairs of ROIs. In the same way, on the ASTER image chosen for the study of geometrical shadow, we looked for areas on the western slope of mountains, still shadowed at the image acquisition time (10h30 A.M.), and for nearby areas, both uphill and downhill, fully illuminated and with similar vegetation. Polygons containing these areas were traced; the typical size of these polygons was between 60 and 300 pixels, corresponding to about one to six hectares.

The ROIs for the primary study were the vineyards themselves. Here, the tracing of the polygons containing the vine plots was more complicated, since the vineyard pictured on the gmz files had to be visualized on the ASTER image, which has 15-meter pixels, a large pixel size if compared with the images of much higher spatial resolution (about one meter) on the Internet map server over which the gmz polygon was projected. Great care was taken to do all the tracings, in order to avoid possible spectral contamination from unduly included pixels, located outside the chosen vineyard, which could include not only another vine plot, but also other spectral classes like roads or buildings. For these reasons, given that the tracings were done well inside the vineyards, as seen on the ASTER image, the typical number of pixels for vine plots was about 10 to 50 (0.2 to 1.0 hectare). This is well below the average size of the vineyards, which ranged from two to five hectares.

5. Reflectance from vineyards

From the databank provided by CTV/INRA, only 55 vineyards were suited to reflectance extraction; the other three vineyards were from the Savennières area. These were the ones already informed in Section 1 of Materials and Methods, having a suitable geometry for polygon tracing, and that could be safely identified on the ASTER images. As said, there were 46 plots in conventional viticulture and 12 following the organic method. For each one, mean values of reflectance were calculated from the pixels within the polygons, for each spectral band. Each line in the final database contained plot identification, a symbol for conventional or organic, the nine mean reflectance values, and the grape variety.

6. Quantification of shadow effects

In the study on shadow effects, mean values of reflectance were calculated for each spectral band of each polygon. For each one of the shadowed areas and their associated sunlit regions, we calculated the (reflectance illuminated)/(reflectance shadow) ratio, and then we calculated the mean ratio over all four pairs, for both situations. This was done for each spectral band, and the result was the average attenuation in reflectance due to shadowing from clouds or from geometrical shadow projection. This is shown in Table 1.

The impact of this attenuation on the theoretical reflectance of the inter-row spaces was calculated using the average value of a typical shadowed area, i.e., 40% of the soil between rows, as derived in the Section 3 of Materials and Methods. The reasoning was that in 60% of this area we have full nominal reflectance, and in 40% the reflectance is reduced by the factor calculated in this sub-section; the overall reduction in reflectance, by spectral band, follows from the weighted evaluation of these contributions. Results are also informed in Table 1.

7. Discriminant analysis

A statistical discriminant analysis was performed on the vineyard database, looking for separation between viticultural methods; three separate analyses were done: for all nine spectral bands, for the two visible bands (bands 1 and 2), and for the seven infrared bands (bands 3 to 9). Another analysis involving grape variety was also done, since it can provide additional information on the potential of the techniques presented here; in this case, only two assays were performed, one using all nine bands and another using the seven infrared bands.

8. Vegetation index

We also calculated the vegetation index NDVI (Normalized Difference Vegetation Index) for each vineyard. The NDVI (Tucker 1979) is defined as:

$$NDVI = (R_{IR} - R_{VIS})/(R_{IR} + R_{VIS}), \quad (2)$$

and is an expression of plant status or vigor, mainly derived from water availability, but also dependent of more complex factors. Here, R_{IR} is the reflectance at near infrared, which at ASTER bands is band 3 (0.760–0.860 µm), and R_{VIS} is the reflectance at red (0.630–0.690 µm). We looked for systematic effects that could exist in either conventional or organic cultures. Analysis was done through the parametric Student's t-test.

RESULTS

1. Reflectance reduction by clouds and walls

Table 1 presents how much of the reflectance is reduced by shadows, either from clouds or from geometrical projection. In both cases, reduction in reflectance is maximum in band 2, corresponding to visible red. The effect is extreme in geometrical shadows; this is understandable, since in a ground patch where direct solar light is blocked by a wall, the remaining illumination comes from diffuse light from the sky, which has few red photons, compared to those of blue wavelengths. The relative factor is about ten, in favor of the blue photons, being a result of Rayleigh scattering by gas molecules, the reason why sky is blue. So, little red light impacts the shadowed regions, and reflectance falls dramatically in band 2. This process acts also on band 1 (green/yellow), but in a lesser proportion. In cloud shadows, there are reductions in bands 1 and 2 but at a far smaller scale, since red and green photons are, in some measure, able to pass through clouds. The same physical process is still acting in band 3 (near infrared), where geometrical shadows are still the darker ones.

The opposite was found in the short-wave infrared (bands 4 to 9). With the possible exception of band 4, where the reduction factors for both cases are not significantly different, as suggested by their large standard deviations, the reductions in reflectance by cloud shadows are larger and statistically significant. Here, the scattering process is not caused by gas molecules, but by microscopic water droplets that form clouds, affecting longer wavelengths (Mie scattering), as those of bands 4 to 9. This perception, therefore, is consistent with the observation that reflectance reductions in ground patches obscured by geometrical shadows are smaller, since the short-wave infrared light that illuminates the soil comes only partially from direct sunlight.

2. Impact of shadows on the reflectance in vineyards

In Section 3 of Materials and Methods we derived that, in the satellite images used in this study, an average of 40% of the inter-row spaces were in shadow. From Table 1, we can see that the resulting integrated reflectance, combining illuminated and shadowed fractions of inter-row spaces, varies between 60.6% and 91.5% of the reflectance of a fully (100%) illuminated

Table 1. Basic information on ASTER images and results from analysis of shadow effects.

band	wavelength (µm)	pixel (m)	clouds	σ clouds	geometric	σ geometric	R reduced
B1	0.520–0.600	15	2 488	0.622	6 250	1 130	66.4
B2	0.630–0.690	15	3 108	0.914	67 667	58 705	60.6
B3	0.760–0.860	15	1 966	0.338	5 452	1 202	67.3
B4	1.600–1.700	30	2 885	0.457	3 092	0.714	73.3
B5	2.145–2.185	30	2 142	0.301	1 480	0.198	87.2
B6	2.185–2.225	30	2 636	0.405	1 791	0.313	82.3
B7	2.235–2.285	30	2 538	0.430	1 699	0.206	83.5
B8	2.295–2.365	30	2 515	0.435	1 638	0.258	84.4
B9	2.360–2.430	30	1 760	0.200	1 267	0.116	91.5

Column 1, ASTER band number; column 2, interval of wavelengths observed in each band; column 3, pixel size; column 4, reduction factor in reflectance due to obscuration by clouds; column 5, standard deviation of former result; column 6, reduction factor in reflectance due to obscuration by geometrical projection; column 7, standard deviation of former result; column 8, nominal reflectance relative to a fully illuminated soil (relative reflectance of 100%), if 40% of inter-row soil is shadowed.

Classification Results, all nine bands[a]

		type	Predicted Group Membership		
			1 org	2 conv	Total
Original	Count	1 org	12	0	12
		2 conv	5	41	46
	%	1 org	100.0	.0	100.0
		2 conv	10.9	89.1	100.0

a. 91.4% of original grouped cases correctly classified.

Figure 1. Discriminant analysis for viticultural method using all nine spectral bands.

Classification Results, only visible bands[a]

		type	Predicted Group Membership		
			1 org	2 conv	Total
Original	Count	1 org	8	4	12
		2 conv	14	32	46
	%	1 org	66.7	33.3	100.0
		2 conv	30.4	69.6	100.0

a. 69.0% of original grouped cases correctly classified.

Figure 2. Discriminant analysis for viticultural method using the two visible bands.

Classification Results, only infrared bands[a]

		type	Predicted Group Membership		
			1 org	2 conv	Total
Original	Count	1 org	12	0	12
		2 conv	5	41	46
	%	1 org	100.0	.0	100.0
		2 conv	10.9	89.1	100.0

a. 91.4% of original grouped cases correctly classified.

Figure 3. Discriminant analysis for viticultural method using the seven infrared bands.

Classification Results, all nine bands[a]					
		Grape variety	Predicted Group Membership		
			1 CF	2 CH	Total
Original	Count	1 CF	23	2	25
		2 CH	5	28	33
	%	1 CF	92.0	8.0	100.0
		2 CH	15.2	84.8	100.0

a. 87.9% of original grouped cases correctly classified.

Figure 4. Discriminant analysis for grape variety using all nine spectral bands.

Classification Results, only infrared bands [a]					
		Grape variety	Predicted Group Membership		
			1 CF	2 CH	Total
Original	Count	1 CF	23	2	25
		2 CH	3	30	33
	%	1 CF	92.0	8.0	100.0
		2 CH	9.1	90.9	100.0

a. 91.4% of original grouped cases correctly classified.

Figure 5. Discriminant analysis for grape variety using the seven infrared bands.

soil. Reflectance is more reduced in visible light (green and red) and at near infrared.

3. Discriminant analysis

Figures 1 to 3 display the results from discriminant analysis for viticultural methods, using data from all nine ASTER bands (Fig. 1), from bands 1 and 2 (Figure 2), and from the seven infrared bands (Figure 3). Figures 4 and 5 display results for grape variety using reflectance data from all nine bands and from the seven infrared bands, respectively.

4. Vegetation index

Mean values and standard deviations of the vegetation index were calculated for both viticultural methods. For the 46 conventional plots the mean NDVI value was 0.484±0.117; for the 12 organic plots the mean NDVI value was 0.416±0.088. The standard errors of the mean values were 0.017 and 0.025, respectively. There was no significant difference between the mean values using t-test ($p = 0.065$).

DISCUSSION

Figures 1 and 3 show that reflectance data in the infrared was essential to a good discrimination between viticultural methods; in fact, data from the visible only (Figure 2) gave relatively poor results. All organic vineyards were correctly separated. There was some confusion with conventional plots, since five of them (10.9%) were classified as organic/biodynamic (four Chenin, one Cabernet).

With respect to separability of grape varieties, results were also fairly good. As for viticultural methods, data from the visible bands only added confusion. It is worthy of note, regarding this detection of spectral differences between grape varieties, that Da Silva and

Ducati (2009) had already reported that white and red grapes could be separated in ASTER images. The vector for separability, as suggested, was the fact that red varieties have the anthocyanin pigment not only in berries, but also in vacuoles within leaf cells; this introduces an intrinsic difference with respect to white varieties, which is detectable in infrared observations of the canopy.

The fact that organic vineyards where indeed identified by Remote Sensing techniques deserves some discussion. As already mentioned in the Introduction, spectral differences between conventional and organic vineyards could be traced to two main factors: chemical treatments and soil cover. Color changes caused by chemical treatments were already discussed in Section 1.1 of the Introduction, and remain as one of the possible factors leading to our results.

Influence of soil cover was approached through the possibility that conventional vineyards have bare soil; but to study the soil contribution to total reflectance we had to consider the effect of shadow. The last column of Table 1 shows that the average impact of shadow on the reflectance of inter-row spaces is higher in the visible bands; at the infrared, the effect of shadow is not very important (a reduction of about 15%), and so infrared light from the corridors do contribute to the integrated reflectance of a typical pixel. The results displayed in Figures 1 to 3 indicate that the infrared was indeed essential to differentiate between conventional and organic vineyards. Therefore, if in conventional vineyards there is bare soil between rows, this can be a relevant factor to differentiation. However, we have already argued in Section 1.2 of the Introduction that in the Loire region, field observations revealed that many conventional vineyards have grasses between rows, the same cover that is seen in organic plots.

The existence of inter-row vegetation, either only in organic vineyards or in both organic/conventional vineyards, can possibly give room for another consideration. It is well known that grasses tend to be covered by morning dew; vine leaves, which are positioned at a higher level, have less moisture and besides, this moisture dries earlier, by the action of sunlight. At the time of satellite overpass, 10h30 local, sunlight had already removed humidity on vine leaves, while at soil level there are some remaining droplets. This effect has been observed in the field. Humidity is a non-negligible infrared absorber (Kumar 1974), and in this case, reflectance from inter-row spaces tends to be reduced. This would reinforce the contribution of vine leaf reflectance to spectral separability.

With respect to the vegetation index, it seems that there are no significant differences between conventional and organic vineyards. However, this result is derived from data in visible light (red) and in the near infrared; it was shown from the discriminant analysis that differentiation between the two groups arises mainly from spectral features in the short-wave infrared.

CONCLUSIONS

The results presented are very clear on the potential of Remote Sensing techniques to differentiate conventional vineyards from organic ones. The reasons for these spectral differences seem to be shared between the impact of chemical treatments on leaf color, and corridor maintenance; possibly, the former factor is more important.

In the Introduction, we mentioned reports from vintners, stating that visual observations were enough to reveal an organic vineyard. We saw from Figures 1 to 3 that visible light performs poorly in discriminant analysis. However, we have to keep in mind that eye observations are done from the ground, with no mixing between soil and canopy reflectances. In these circumstances, and since color alterations in leaves exist also in the visible, such claims cannot be ruled out.

As a final conclusion, we can state that the techniques presently outlined can be used as a preliminary step in monitoring procedures to verify if certified vineyards are effectively abiding by the rules; in any case, field and more detailed inspections will always be decisive.

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REFERENCES

Abrams M., Hook S., Ramachandran B., 2002. *ASTER User Handbook: Advanced Spaceborne Thermal Emission and Reflection Radiometer*, version 2. NASA/Jet Propulsion Laboratory, California Institute of Technology. Available at: http://asterweb.jpl.nasa.gov/content/03_data/04_Documents/aster_user_guide_v2.pdf (accessed on August 22, 2013).

Berk A., Anderson G.P., Acharya P.K., Bernstein L.S., Muratov L., Lee J., Fox M., Adler-Golden S.M., Chetwynd J.H. Jr., Hoke M.L., Lockwood R.B., Gardner J.A., Cooley T.W., Borel C.C., Lewis P.E., Shettle E.P., 2006. MODTRAN5: 2006 Update. In: *Proc. SPIE*, **6233**, 62331F.

Bombassaro M.G., Ducati J.R., 2013. Avaliação da fiabilidade de imagens ASTER após processo de reamostragem e geração de imagem sintética. In: *Proc. XVI Simpósio Brasileiro de Sensoriamento Remoto*. São José dos Campos, Brazil: Instituto Nacional de Pesquisas Espaciais, pp. 8216-8222 (in Portuguese; abstract in English).

Brodt S., Klonsky K., Thrupp L.A., 2009. *Market Potential for Organic Crops in California: Almonds, Hay, and Winegrapes*. Giannini Foundation Information Series Report 09-1, University of California: Davis.

Cemin G., Ducati J.R., 2011. Spectral discrimination of grape varieties and a search for terroir effects using remote sensing. Journal of Wine Research, **22**(1), 57-78.

Da Silva P., Ducati J.R., 2009. Spectral features of vineyards in south Brazil from ASTER imaging. International Journal of Remote Sensing, **30**(23), 6085-6098.

DPI – Department of Environment and Primary Industries, State Government of Victoria, 2010. *Organic Viticulture: An Australian Manual*.

EEC – European Economic Community Council, 1991. Regulation (EEC) No. 2092/91 of 24 June 1991 on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs.

Jonis M., Soltz H., Schmid O., Hofmann U., Trioli G., 2008. Analysis of organic wine market needs. In: *Proc. 16th International Foundation for Organic Agriculture (IFOAM) Organic World Congress*, Modena (Italy).

Kumar R., 1974. *Radiation from Plants - Reflection and Emission: A Review*. Purdue Research Foundation: Lafayette.

Lillesand T.M., Kiefer R.W., 1987. *Remote Sensing and Image Interpretation*. 2nd ed. New York: John Wiley & Sons.

Magné C., Saladin G., Clément C., 2006. Transient effect of the herbicide flazasulfuron on carbohydrate physiology in *Vitis vinifera* L. Chemosphere, **62**(4), 650-657.

Mollá-Bauzá M.B., Martínez L.M.-C., Poveda A.M., Pérez M.R., 2005. Determination of the surplus that consumers are willing to pay for an organic wine. Spanish Journal of Agricultural Research, **3**(1), 43-51.

NASA, 2013. NASA Land Processes Distributed Active Archive Center (LP DAAC). ASTER L1B. USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota.

Remaud H., Mueller S., Chvyl P., Lockshin L., 2008. Do Australian wine consumers value organic wine? In: *Proc. 4th International Conference of the Academy of Wine Business Research*, Siena (Italy).

Saladin G., Magné C., Clément C., 2003. Impact of flumioxazin herbicide on growth and carbohydrate physiology in *Vitis vinifera* L. Plant Cell Reports, **21**(8), 821-827.

Swain P.H., Davis S.M., 1978. *Remote Sensing: The Quantitative Approach*. New York: McGraw-Hill.

Tan W., Liang T., Zhai H., 2012. Effects of acetochlor on the photosynthetic and fluorescence characteristics and chloroplast structure of grape leaves. Ying Yong Sheng Tai Xue Bao, **23**(8), 2185-2190 (in Chinese; abstract in English).

Tucker C.J., 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of the Environment, **8**(2), 127-150.

USDA – United States Department of Agriculture, 2013. *Guidelines for Labeling Wine with Organic References*. Available at: http://web.archive.org/web/20041021080518/http://www.atf.gov/alcohol/alfd/wine.pdf (accessed on August 22, 2013).